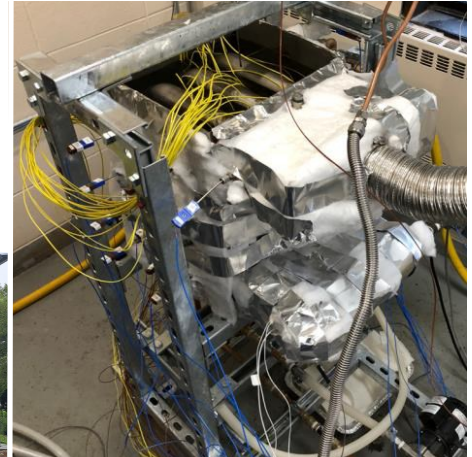
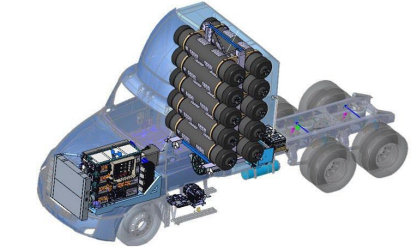
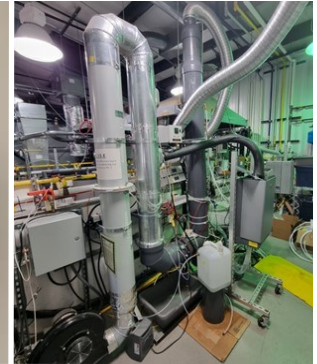
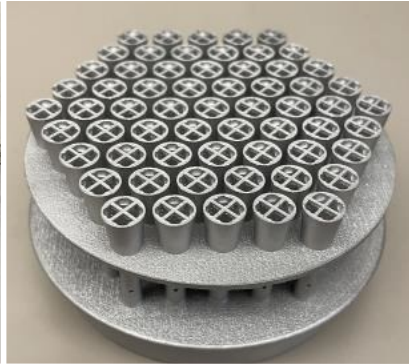
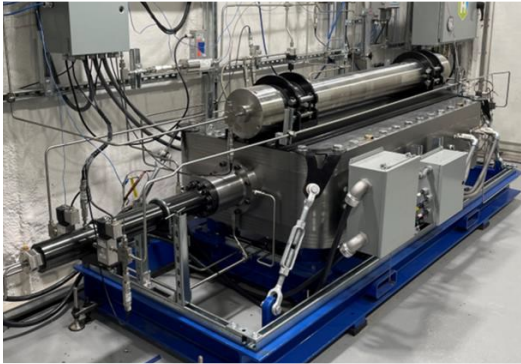




# RESEARCH PROJECT SUMMARIES 2022-2023







**Utilization Technology Development, NFP**  
**RESEARCH PROJECT SUMMARIES**  
**2022 - 2023**

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# UTD RESEARCH PROJECT SUMMARIES 2022 - 2023

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## Letter to Our Stakeholders

Twenty-one leading North American utilities that supply gaseous fuel are addressing energy use opportunities and challenges for their 37+ million customers through Utilization Technology Development, NFP (UTD), a not-for-profit applied research organization. UTD-sponsored researchers create, develop and demonstrate new products and technologies in partnership with the U.S. Department of Energy (DOE), California Energy Commission (CEC), Propane Education & Research Council (PERC), national laboratories, university researchers, entrepreneurs, leading manufacturers, utility customers, and others.

Accelerating the availability and use of higher-efficiency, gas-fired technologies and products will hasten market transformation and help ratepayers continue to enjoy affordable energy costs while leveraging the superior reliability and resiliency of the underground gas distribution system. One example is gas-fired heat pumps (GHPs) which provide efficiencies far greater than 100%. This past year saw significant developments for GHPs, including the start-up of the ANESI GHP factory production line after long-time technical development support from UTD.

This report summarizes 70+ UTD-sponsored research projects to advance innovations spanning residential, commercial, industrial, and clean transportation markets. These projects enable more integration of renewable energy (e.g. via solar thermal and PV, renewable natural gas, or hydrogen), reduce emissions, and enhance the efficiency, safety, and resiliency of end-user operations. These innovations also help UTD members strengthen their utility energy efficiency, emerging technology, and market transformation programs.

We thank the researchers, innovators, governmental funding agencies, and partners from academia, industry and elsewhere who work with us to advance applied research. UTD's efforts reduce GHG and other emissions, increase the use of renewable energy while handling supply variability, and retain affordable energy choices for consumers while addressing society's environmental challenges and need for economical, resilient, reliable energy.

### UTD Members

- > APGA Research Foundation
- > Atmos Energy Corporation
- > Dominion Energy
- > DTE Energy
- > Duke Energy
- > Enbridge Gas
- > Intermountain Gas Company
- > Louisiana R&D Committee
  - Atmos Energy Corporation
  - CenterPoint Energy, Inc.
  - Entergy Corporation
- > National Fuel Gas Distribution Corp.
- > National Grid
- > New York State Electric & Gas Corp./Rochester Gas and Electric Corp.
- > NW Natural
- > Nicor Gas
- > Oklahoma Natural Gas Company
- > Pacific Gas and Electric Company
- > Peoples Gas, a WEC Energy Group Co.
- > Southern California Gas Co., a Sempra Energy Utility
- > Southwest Gas Corporation
- > Spire Energy
- > TECO Peoples Gas

Joann Wehle  
Chair



Ron Snedic  
President







December 2023

Leading researchers, entrepreneurs, universities, governmental agencies, governmental laboratories, customers, manufacturers, and others partner with UTD as a 501(c)(6) not-for-profit organization of utilities to develop and demonstrate affordable new gas solutions for end users, and accelerate the transition to a lower-carbon future.

Development and demonstration of economical new products, systems, and technologies helps customers save money, save energy, reduce GHG emissions, integrate renewable energy (including renewable natural gas and RE-derived hydrogen), and maintain safe, reliable, resilient operation of their homes and facilities with superior environmental performance.

Please contact us if you have any questions about UTD.

**Ron Snedic** (1.847.768.0572)

**Rich Kooy** (1.847.768.0512)

UTD's 20 members serve more than 37 million natural gas customers in North America.

UTD helps utilities create exciting new products for their customers and maximize the impact of their energy-efficiency programs.

Together we're shaping the energy future with clean, efficient end-use technologies.

Visit [www.utd-co.org](http://www.utd-co.org) for more information.

## COMMERCIALIZED PRODUCTS



### **SMTI ANESI Gas-fired Absorption Heat Pump for Space Heating and/or Water Heating**

Provides AFUE-rated efficiency of 140% (~45% gas savings) with ultra-low NOx emissions of  $\leq 14$  ng/J while using zero GWP fluids, and performs reliably in extreme cold weather. Commercially introduced in 2023 after long-term technology RD&D support from UTD, including laboratory work and prototype field applications in CA, WI, IL, TN and Canada, with support from U.S. DOE, CEC and others.

#### **SMTI ANESI**

Scott Reed  
818-421-4229  
[sreed@stonemnttechnologies.com](mailto:sreed@stonemnttechnologies.com)  
[www.AnesiComfort.com](http://www.AnesiComfort.com)



### **Lochinvar XRGI MicroCHP**

Lochinvar's XRGI efficiently produces heat and 24kW of power from the same fuel source. UTD collaborated with the CEC, SoCalGas and the others to advance this engine-based micro-CHP system towards compliance with California Air Resource Board requirements. UTD is also prototyping its use for multi-family buildings or multi-unit applications.

#### **Lochinvar**

Eric Morrow  
615-318-4919  
[enmorrow@lochinvar.com](mailto:enmorrow@lochinvar.com)  
[www.lochinvar.com](http://www.lochinvar.com)



## COMMERCIALIZED PRODUCTS (continued)



### CleanO2 CarbinX™ Carbon Capture

CleanO2's revolutionary CarbinX unit captures CO<sub>2</sub> from the flue gas of boilers and furnaces to reduce GHG emissions, and turns it into a beneficial consumer product. UTD's members provided technology development expertise and support to CleanO2 since 2018 to refine early prototypes and partner with CleanO2 to identify and make product improvements.

#### CleanO2, Inc.

Jaeson Cardiff  
carbinX@cleano2.ca  
www.carbinx.com



### Yanmar 3-Pipe Engine-driven Gas Pump

Yanmar's 3-pipe, 14-ton Gas Heat Pump (GHP) with variable refrigerant flow (VRF) offers an important energy-efficiency option for the North American market by combining heat recovery with simultaneous heating and cooling. In a 2018-23 field tests, UTD validated equipment performance and produced public summaries of the results.

#### YANMAR America Corp.

Eddie Caton  
770-877-7733  
eddie\_caton@yanmar-es.com  
www.yanmar-es.com



### GRIDIRON PowerPlant™ H24 and HA65

The PowerPlant HA65 from GRIDIRON (formerly M-Trigen) provides high-efficiency microCHP with integrated cooling to homeowners, small businesses, and other users. UTD provided technical support for a notable demonstration by partnering with NYSERDA, National Grid, NJNG, and PERC to independently validate performance. UTD also supported GRIDIRON in its optimization of PowerPlant HA65 to minimize emissions, and its development of PowerPlant H24.

#### GRIDIRON

713-574-4506  
info@gridironenergy.com  
www.gridironenergy.com



### Sierra™ Engine-driven Gas Heat Pump

Sierra's (formerly NextAire™) 11-ton packaged GHP can efficiently heat and cool commercial buildings (up to 1.4 COP) while reducing electric demand. Also available are 8- and 15-ton GHPs with VRF multizone capabilities. UTD's field studies are supporting best practices for siting. UTD partnered with NYSERDA and National Fuel in a field test in NY state.

#### Blue Mountain Energy

Tom Young  
702-339-7395  
tyoung@bluemountainenergy.com  
www.bluemountainenergy.com



### Cannon Boiler Works Ultramizer®

The Ultramizer is an advanced heat-and-water recovery system for larger commercial and industrial boilers, of which there are more than 140,000 in the U.S. It increases boiler efficiency from 80% to 93% - saving customers 15% in energy while also reducing water demand.

#### Cannon Boiler Works, Inc.

Chris Giron  
724-335-8541 x414  
sales@cannonboilerworks.com  
www.cannonboilerworks.com



### U.S. Boiler K2 High Efficiency Gas Boiler

The K2 high efficiency condensing gas boiler offers 95% AFUE with 10:1 turndown, and uses a novel sheet metal burner from Europe. UTD validated its performance via laboratory tests to support potential gas utility MT incentives, and identified pathways to achieve <5 ppm NO<sub>x</sub> emissions.

#### U.S. Boiler Inc.

Craig Eshenaur  
717-239-4490  
ceshenaur@usboiler.net  
www.usboiler.net

## COMMERCIALIZED PRODUCTS (continued)

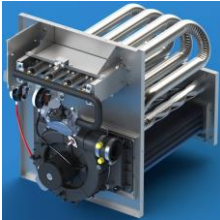


### Condensing Dedicated Outside Air System/Rooftop Unit

Condensing heating versions of Munters Dedicated Outside Air System (DOAS) and other rooftop unit (RTU) products increase heating efficiency from 80%-81% to 90%-93%. Multiple RTU manufacturers are now offering DOAS with 90+% efficiencies, facilitated by the availability of condensing duct furnace modules first developed with UTD support.

#### Munters Corporation

Larry Klekar  
210-249-3883  
larry.klekar@munters.com  
www.munters.com



### Condensing Duct Furnace Modules

High-efficiency condensing heating modules developed with UTD support are now available from Beckett Gas and other OEMs, including Heatco, and are being applied to DOAS and other products including Make-Up Air Units available from multiple manufacturers including Aeon, Daikin, and RuppAir.

#### Beckett Gas, Inc.

Joel Mohar  
440-783-7610  
jmohar@beckettcorp.com  
www.beckettgas.com



### Gas Quality Sensor

The Gas Quality Sensor (GQS) uses solid-state infrared light absorption spectroscopy to measure Btu content and composition of natural gas and bio-methane fuels. It provides faster response at much lower cost than a gas chromatograph. It was developed with UTD support and was commercially introduced by CMR Group in 2019.

#### CMR Group

Jon Stendebach  
724-452-2200  
918-407-4005  
jon.stendebach@cmr-group.com  
www.cmr-group.com



### Dettson Chinook Low-Capacity Furnace

This novel low-capacity furnace permits right-sizing for low-load buildings and aids integration with renewable energy and improved building envelopes. UTD researchers identified best application practices and provided supporting technical info.

#### Dettson

Philippe Verhas  
1-800-567-2733  
pverhas@dettson.ca  
www.dettson.com



### iFLOW and Advanced Combination Systems

UTD researchers demonstrated how a forced-air condensing tankless water heater combi system using the iFLOW can achieve 30-50% energy savings relative to best-in-class condensing furnaces and water heaters, and used a rigorous Virtual Test Home analysis to assess annualized performance.

#### iFLOW

Steve Bagshaw  
1-800-985-9227 ext 102  
steve.bagshaw@iflowhvac.com  
www.iflowhvac.com



### S.U.N. Equinox Solar-Assisted Heating System

The Equinox system is a combination solar/natural gas water heating system that uses an efficient evacuated tube design. It can be used in residential, commercial, or industrial locations and can meet 100% of domestic hot-water and space heating needs. UTD validated its energy performance in a field demonstration.

#### Solar Usage Now, LLC

Thom Blake  
260-657-5605  
tblade@solarusagenow.com  
www.solarusagenow.com



### iGEN Self-Powered Furnace

The innovative iGEN furnace generates its own electric power and contains an integrated battery, providing homeowners with continuous heating even during electricity outages. UTD supported the technical refinement of this product with laboratory testing, validation, and recommendations.

#### iGen Technologies

Michael Chatzigrigoriou  
letstalk@igentechnologies.ca  
www.igentechnologies.ca

## COMMERCIALIZED PRODUCTS (continued)



### ENERGY STAR® Fryers

Royal Range introduced the high-efficiency RHEF-75 fryer in 2019 - building on the success of the smaller-capacity, high-efficiency RHEF-45 fryer that received the National Restaurant Association's Kitchen Innovation Award and GFEN's Blue Flame Product of the Year Award. Independent testing showed 63% heavy-load cooking energy efficiency.

#### Royal Range of California

Robert Lutz  
951-360-1600  
robert@royalranges.com  
www.royalranges.com



### Low-Oil-Volume Fryers

Marketed by Frymaster as Protector® fryers, this equipment increases energy efficiency while also extending cooking-oil quality and life to provide significant customer savings. Field demonstrations completed by UTD have shown an average savings of \$4,800 per year per fryer.

#### Frymaster

800-221-4583  
www.frymaster.com



### ENERGY STAR Conveyor Oven

ENERGY STAR rated conveyor ovens from Lincoln include an advanced energy-management system to reduce energy consumption up to 38%.

#### Lincoln, a division of Manitowoc Foodservice

260-459-8200  
www.lincolnfpc.com



### ENERGY STAR Convection Oven

This unit showed improved efficiency and 40% energy savings compared to a standard oven during field testing and achieved an ENERGY STAR rating.

#### Garland

905-624-0260  
www.garland-group.com



### High-Efficiency Broiler

This broiler features infrared burners and an energy-saving hood that showed an average of 23% energy savings during field testing. It offers more efficient cooking as well as reducing heat gain to the kitchen.

#### Royal Range of California

800-769-2414  
www.royalranges.com



### ENERGY STAR Countertop Steamer

A compact, gas-fired countertop steamer for commercial foodservice offers enhanced cooking rates while providing energy savings and reduced water consumption. It was the first gas-fired boilerless steamer on the market and received an ENERGY STAR rating.

#### Market Forge Industries Inc.

617-387-4100  
866-698-3188  
custserv@mfii.com  
www.mfii.com



### High-Efficiency Broiler

The Montague Company commercialized a version of the advanced broiler technology using thermostatic broiler-temperature control and an energy-saving hood. It was recognized with a Kitchen Innovations Award in 2013.

#### Montague

800-345-1830  
www.montaguecompany.com



## COMMERCIALIZED PRODUCTS (continued)



**L9N**

### Cummins Westport 8.9L Near-Zero Emission NGV Engine

This 8.9L 320-HP NGV engine is widely used, with 50,000+ engines sold for transit, refuse-collection, and regional hauling applications since 2007. In 2016, it was advanced to become the first engine certified in North America to meet the 0.02 g/bhp-hr optional Near Zero (NZ) NO<sub>x</sub> emissions standard (i.e. 90% lower than the current EPA NO<sub>x</sub> limit of 0.2 g/bhp-hr).

#### Cummins Westport Inc.

Yemane Gessesse  
812-377-5000  
yemane.gessesse@cummins.com  
www.cumminswestport.com



**B6.7N**

### Cummins Westport 6.7L Medium-Duty NGV Engine

This 6.7L 240-HP natural gas vehicle (NGV) engine is used in school buses, shuttle buses, medium-duty trucks, and other vocational uses. It went into full commercial production in December 2016. It meets U.S. 2017 EPA GHG requirements as well as NZ NO<sub>x</sub> emissions standard of 0.02 g/bhp-hr.

#### Cummins Westport Inc.

Yemane Gessesse  
812-377-5000  
yemane.gessesse@cummins.com  
www.cumminswestport.com



**ISX12N**

### Cummins Westport 11.9L Near-Zero Emission NGV Engine

This 11.9L 400-HP NGV engine is used in large trucks, buses, and refuse vehicles. Engine sales since 2013 are approaching 10,000 units and 25,000+ engines will likely be sold in N.A. by 2020, yielding emissions reductions and \$600+ million in annual fuel sales. In Model Year 18, it became CWI's second engine certified to meet NZ NO<sub>x</sub> emissions standard of 0.02 g/bhp-hr.

#### Cummins Westport Inc.

Yemane Gessesse  
812-377-5000  
yemane.gessesse@cummins.com  
www.cumminswestport.com



### EcoZone Ribbon Burner System

UTD and SoCalGas are supporting the demonstration of Flynn Burner's advanced new EcoZone combustion system which integrates traditional ribbon burners with metal-fiber infrared burners. An installation in California at a large commercial bakery operated by a leading U.S. grocer will evaluate NO<sub>x</sub> and CO<sub>2</sub> emission reductions.

#### Flynn Burner

Travis Eddy  
518-791-7682  
travise@flynnburner.com  
www.flynnburner.com

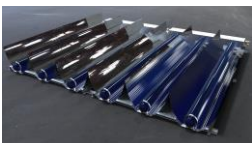


### Heat Sponge Economizer for Industrial/Commercial Boilers

In either condensing or non-condensing configurations, this heat recovery system for commercial and industrial boilers (over 140,000-unit market in U.S.) increases boiler efficiency from 80% to a range of 85%-93% (validated by UTD lab testing). It also saves customers 5%-15% in annual energy costs. UTD completed a field test in Utah to validate energy savings.

#### Boilerroom Equipment, Inc.

866-666-8977  
www.heatsponge.com



### External Concentration Parabolic Collector

This patented, non-tracking, extremely-low-profile concentrator can achieve 200°C (392°F) solar thermal energy to economically serve commercial and industrial facilities and reduce GHG emissions. It can also be integrated with natural gas as a supplemental energy source. UTD provided technical and product development support and experimental validations over a seven-year period.

#### Artic Solar Inc.

Bill Guiney  
904-513-4638  
bill@articsolar.com  
www.articsolar.com

## KEY INFORMATION & ANALYTICAL TOOLS



### CSA/ANSI Z21.40.4-23/CSA 2.94-2023 Performance Testing and Rating of Gas-Fired Air Conditioning and Heat Pump Appliances Technical Committee Support

ANSI/CSA Z21.40.4 issued in 2023 and was a major upgrade and update to the 1996 edition of this Method of Test for GHPs. Updates included: increasing what can be rated with residential seasonal efficiency metrics; enhanced calculations and test conditions to better reflect systems designed for heating operation; more optional operating points; and expanded scope to include VRF-type engine-driven systems. UTD supported participation on the Technical Task Force that updated the Standard.

Available at <https://webstore.ansi.org>



### Reliability, Cost and Environmental Impacts of Standby Generation Systems

Generac's website provides technical information related to emissions, reliability and costs of natural gas generators that was developed with UTD's support. For example, UTD researchers published a white paper that provided new data on the reliability of natural gas service and assisted in the development of a Total Cost of Ownership calculator that compares emissions and costs of natural gas vs. diesel-fueled standby generators.

Available at <https://www.gti.energy/wp-content/uploads/2019/02/Assessment-of-Natural-Gas-Electric-Distribution-Service-Reliability-SummaryReport-Jul2018.pdf> and <https://www.generac.com/Industrial/all-about/natural-gas-fuel>



### U.S. DOE Building America

Under five separate UTD projects from 2011 to 2021, UTD has developed key information and tools to support the U.S. DOE's Building America research, development, and demonstration program, which helps accelerate use of best practices by residential builders, remodelers, installers, code officials, designers, raters, teachers, and others.

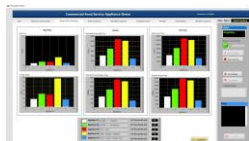
Available at <https://www.gti.energy/BuildingAmerica> and <https://basc.pnnl.gov/library>



### Commercial Foodservice (CFS) Equipment Calculator

This website provides the restaurant industry and others with information and tools to determine the economic and environmental benefits of using new, more advanced and efficient CFS equipment. The website was developed with UTD support and has been showcased at several restaurant trade shows. Further enhancements are underway in 2023.

Available at <http://cfscalc.gastechnology.org>. For more info, contact Frank Johnson; [fjohnson@gti.energy](mailto:fjohnson@gti.energy)



### Commercial Foodservice Energy Monitoring Systems (FEMS)

A real-time energy monitoring system for use in cooking demonstrations, trade shows, test kitchens, and similar venues was developed to help CFS customers better understand the GHG reduction and economic benefits of using higher-efficiency equipment.

For more info, contact Shawn Scott; [sscott@gti.energy](mailto:sscott@gti.energy)

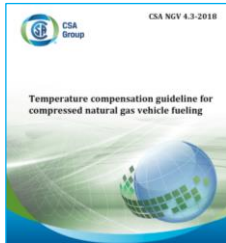


### Virtual Test Home

A Virtual Test Home (VTH) in a laboratory was developed with UTD's support. The VTH holistically analyzes equipment and system performance by assessing part-load, annualized performance for various locations. The VTH helps accelerate the adoption of advanced gas technologies (such as GHPs, combis and modulating furnaces) in the marketplace and in performance assessment tools such as U.S. DOE's *EnergyPlus*™ or other energy software.

For more info, contact Tim Kingston; [tkingston@gti.energy](mailto:tkingston@gti.energy) An overview is also available at <https://neea.org/product-council-documents/virtual-test-home>

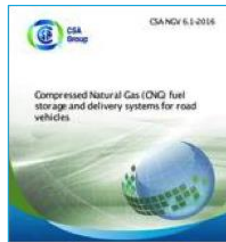
## KEY INFORMATION & ANALYTICAL TOOLS (continued)



### **CSA NGV4.3 NGV Storage and Delivery Standard Technical Committee Support**

CSA NGV4.3 was updated in 2022 and specifies requirements for temperature compensation control used to prevent compressed natural gas (CNG) dispensing systems from exceeding a safe fill level of vehicle fuel storage container(s). It contains safety performance guidelines and field evaluation methods for existing dispensing systems. UTD supported participation to lead the Technical Task Force that created the Standard in 2018 and updated it in 2022.

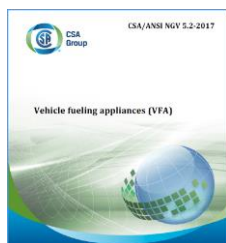
Available at [www.csagroup.org](http://www.csagroup.org)



### **CSA NGV6.1 NGV Storage and Delivery Standard Technical Committee Support**

CSA NGV6.1 was introduced in 2016 and defines the requirements for the balance of systems and equipment onboard a NGV, which is not otherwise defined by NGV1 for the receptacle or NGV2 for the storage containers. UTD supported participation on the Technical Committee.

Available at [www.csagroup.org](http://www.csagroup.org)



### **CSA NGV5.1 and NGV5.2 Fueling Appliance Standard Technical Committees Support**

CSA NGV5.1 was introduced in 2015 and updated in 2016, and provides mechanical, physical, and electrical requirements for residential fueling appliances (RFAs) that dispense natural gas for NGVs, including indoor and outdoor fueling appliances that connect to residential gas piping. A complimentary standard, NGV5.2 for vehicle fueling appliances (VFAs) in non-residential locations, has been developed and was published in late 2017. UTD supported participation on both of the Technical Committees.

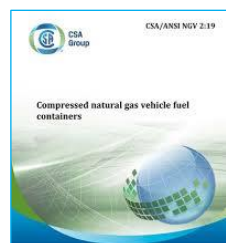
Available at [www.csagroup.org](http://www.csagroup.org)



### **CSA SPE-2.21.1:20 Best Practices for CNG Vehicle System Leak Inspection Standard Technical Committee Support**

In 2020, the first edition of CSA SPE-2.21.1 was published. It provided additional specific guidance and best practices to enhance user safety and mitigate potential leaks. Recommendations regarding in-service leak detection, inspection and repair are provided, including leak detection methods. UTD supported participation on the Technical Committee.

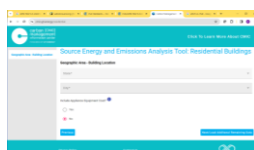
Available at [www.csagroup.org](http://www.csagroup.org)



### **CSA NGV2 CNG Vehicle Fuel Containers Standard Technical Committee Support**

The sixth edition of CSA NGV2 issued in 2019 and contains updated information and requirements for the material, design, manufacture and testing of serially-produced, refillable Type NGV 2 containers intended only for the storage of CNG for vehicle operation. The 2019 revision includes localized fire tests and conformable storage topics. UTD supported participation to lead the Technical Task Force that created the Standard.

Available at [www.csagroup.org](http://www.csagroup.org)



### **Source Energy and Emissions Analysis Tool**

The Source Energy and Emissions Analysis Tool (SEEAT) calculates source energy and greenhouse-gas emissions related to point-of-use (site) energy consumption by fuel type for each energy-consuming device in residential and commercial buildings. The methodology accounts for primary energy consumption and related emissions for the full fuel cycle.

Available at <https://cmic.gti.energy/residential> and <https://cmic.gti.energy/commercial>

## TECHNOLOGY ADVANCEMENTS



### Hydrogen-Blended Gas in Residential, Commercial and Industrial Applications

UTD is performing substantial testing on the blending of hydrogen into natural gas and the performance of blended fuels in multiple categories of equipment that are commonly used in residential, commercial and industrial applications. UTD is also developing new burner technologies that can operate on up to 100% hydrogen fuel.

*Project Managers: Multiple*



### Robur K18 Gas Heat Pump for Residential Space Heating and/or Water Heating

UTD is supporting the potential introduction into the North American market of Robur's K18 Gas Absorption Heat Pump. This 60,000 Btu/hr thermally-driven air-source heat pump will offer very high efficiency operation, with support from a long-established manufacturer. UTD is performing laboratory testing to establish detailed performance curves, which can be incorporated into energy modeling tools in order to accelerate product adoption in North America.

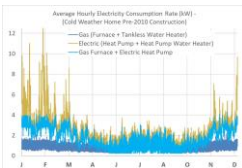
*Project Manager: Alejandro Baez Guada*



### Ultra-Low NO<sub>x</sub> Burner

This innovative firetube boiler technology has more than three years of proven successful operation at a Mission Linen Supply facility in California. It improves efficiency and achieves NO<sub>x</sub> emissions below 9 vppm, while avoiding the significant efficiency, capital cost, and/or operating cost penalties if conventional Selective Catalytic Reduction or burner enhancements such as external Flue Gas Recirculation and/or High Excess Air firing were used.

*Project Manager: David Cygan*



### Hybrid Fuel-fired and Electric-driven ResCom HVAC Systems

Researchers are evaluating emerging or commercially-available hybrid gas furnace/electric heat pump products in the North American market, in order to identify the more promising hybrid systems and develop installation and operation guides that can help end users accelerate their integration of electricity derived from renewable energy with fuel-fired equipment.

*Project Manager: Navin Kumar*



### FlexCHP High-Efficiency Ultra-Clean Power and Steam Package

This innovative CHP package allows flexible steam production while meeting stringent California emission levels without a SCR system and across the full range of firing rates — achieving NO<sub>x</sub> levels 50% below CARB limits. An installation in California operates with 84+% system efficiency and system emissions well below 9 ppm NO<sub>x</sub>. UTD has provided long-term support, including efforts to apply the technology to broader application sizes (e.g. to 400 kW / 400 BHP).

*Project Manager: David Cygan*



### Boostheat Thermal Compression Heat Pump

UTD researchers are collaborating with a European developer of a novel high-efficiency thermal compression-based heat pump technology, to help accelerate its potential introduction into North America. Leveraging global technology developments and partners can speed time to market for new technologies for end users, and help address key North American needs such as optimizing application with forced-air distribution systems, and potential integrated air conditioning capability.

*Project Manager: Alex Fridlyand*



## TECHNOLOGY ADVANCEMENTS (continued)



### Gas-Fired Warewasher

A gas-fired warewasher is being advanced in conjunction with a leading OEM. The estimated annual savings for restaurant, cafeteria, and other commercial food service operators is \$1,100-\$9,000 per warewasher (depending on size and type) while also saving energy and chemicals, when compared to electrically-heated warewashers that operate at lower temperature and thus require one-time use and environmental impact of chemicals.

*Project Manager: Shawn Scott*



### Cost-Effective Compressor/Expander for Natural Gas and Hydrogen-fueled Vehicles

With UTD cost share and U.S. DOE funding, GTI Energy and the University of Texas, Austin developed a novel approach using a linear motor compressor with only one moving piston. The technology was recently scaled up to 50 SCFM capacity with UTD funding, and gas expansion applications are also being developed. The technology has the potential to significantly enhance CNG and H2 vehicle fueling operations.

*Project Manager: Jason Stair*



### On-Demand Heat and Power System

This unique new technology has received a remarkable three rounds of funding from U.S. DOE ARPA-E, along with UTD and other co-funding support. This technology captures and stores renewable energy (or other resources, including waste heat), augments it with natural gas as needed, and delivers heat and power on-demand to commercial, industrial, and other users. The technology has been demonstrated at a pilot field installation in California.

*Project Manager: David Cygan*



### SMTI Gas-fired Absorption Heat Pump Residential Water Heater

A field test of five prototype units of this efficient residential Gas-Fired Heat Pump Water Heater was successfully completed in Southern California during 2020, with support from CEC, UTD, SoCalGas and a prospective manufacturing partner. The unit has a projected Uniform Energy Factor (UEF) of 1.20-1.30 and ultra-low NOx emissions of  $\leq 10$  ng/J. Potential commercial production is being evaluated.

*Project Manager: Paul Glanville*



### Energy Recovery Heat Exchanger

UTD researchers collaborated with CEC to demonstrate in California an advanced recuperator to increase energy efficiency at an aluminum die casting operation. Test results (independently audited) demonstrated 6-16% energy reduction. A technology transfer plan to introduce this technology from Europe to North America was developed to take next steps.

*Project Manager: David Rue*



### Customized Affordable Retrofits of Building Envelopes and Mechanicals

Researchers are advancing a new technology that can rapidly integrate highly innovative building envelope improvements with next-generation HVAC equipment retrofits to reduce GHG emissions by >50%, while providing significant operating cost savings for and minimal disruption to homeowners, residents in income-eligible housing or multi-family buildings, and others.

*Project Manager: Jason LaFleur*

## TECHNOLOGY ADVANCEMENTS (continued)

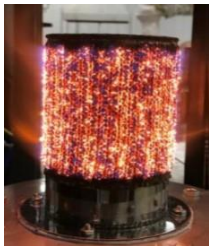
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### HeatAmp Adsorption Thermal Heat Pump

The product development effort couples a proprietary triple-state sorption technology with a novel product design integration that is expected to yield a family of cost-effective, high-efficiency, robust appliances with few moving parts. Example applications are water heating or combination water/space heating. UTD is helping HeatAmp develop its new product with laboratory testing, validation, design recommendations, and a review of applicable N.A. engineering standards.

*Project Manager: Paul Glanville*



### ThermoLift Ultra-High-Efficiency, Heating/Cooling Vuilleumier Cycle Heat Pump

Vuilleumier cycle-based heat pumps could provide a step-change efficiency improvement over vapor absorption- or compression-based cycles, achieving cooling COP > 1 and heating COP > 2. UTD is working with a leading developer to advance key system components using both computational and experimental analysis, to help achieve performance goals in alpha prototype testing funded by DOE, UTD and others.

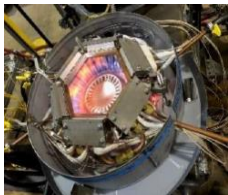
*Project Manager: Alex Fridlyand*



### Next Generation Liquid Dessiccant-based, Heat-Driven HVAC System

Liquid desiccant-based systems can efficiently remove moisture from air and reduce the amount of mechanical energy and water required by conventional HVAC technologies that de-humidify, condition, and re-humidify space air. In cooperation with NYSERDA and others, UTD is testing a novel new non-corrosive, non-toxic desiccant in a gas-driven system that offers a potential 30% increase in COP on a seasonal basis over conventional HVAC technologies.

*Project Manager: Rich Swierczyna*



### Self-Powered Water Heaters

Higher-efficiency water heaters typically require the added expense of an electrical connection and are susceptible to power outages unless a separate battery back-up system is installed. UTD researchers have assessed leading thermoelectric generator (TEG) technologies, and in 2023 are further analyzing opportunities in coordination with a major OEM to economically integrate TEGs and other technologies into a prototype water heater design.

*Project Manager: Sandeep Alavandi*



### Emerging Fuel Cells

UTD researchers are experimentally testing and evaluating several fuel cells that are entering (or exploring entry into) the North American market in order to serve residential and light commercial end users. UTD research is also working to identify and optimize the applications that can maximize the benefit of the high efficiency and reliability of these units.

*Project Manager: Tim Kingston*



### High-Efficiency Gas-Fired Thermal Vacuum Heat Pump for Food Processing

UTD partnered with CEC, SoCalGas, and others to demonstrate an innovative high-efficiency, thermal-vacuum, gas-fired heat pump technology for food drying applications at a commercial food processing company. It has the potential to be about twice as efficient as conventional processes. A prototype system at a field host site generated performance data during 2021. Other applications of this technology for agricultural applications are underway by UTD in 2023.

*Project Manager: Dave Cygan*

## TECHNOLOGY ADVANCEMENTS (continued)

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### **CNG/RNG Locomotive**

With prime funding from U.S. DOE, UTD and other entities are funding the development of a prototype locomotive that can run on fossil or renewable natural gas to serve Class I, II or III railroads in multi-engine, line-haul service, but achieve Near Zero Emissions and target 20% less fuel consumption than a diesel locomotive. UTD's project partners include Cummins Inc.

*Project Manager: Bart Sowa*



### **Distributed RNG/Biogas Production**

UTD is partnering with leading technology developers such as Chomp to increase renewable natural gas (RNG) or biogas production at end-use customer sites in order to reduce landfill requirements, reduce the transport of food waste, and meet de-carbonization goals. UTD is supporting technical advancements such as improved instrumentation and designs.

*Project Manager: Travis Pyrzynski*



### **High Efficiency Convection Oven**

In partnership with a leading OEM, UTD researchers tested design changes and innovations to achieve a 10% efficiency improvement vs. best-in-class Energy Star convection ovens. By their inherent design, these ovens constantly flow hot air out of the oven. There are an estimated 650,000-700,000 convection ovens in the US, according to a 2015 DOE study.

*Project Manager: Shawn Scott*



### **Thermal Ejector Technology to Recover Energy and Water from Hot Flue Gases**

In a field demonstration at a large industrial plant in California, UTD researchers partnered with CEC and a major manufacturer to apply a novel new thermal ejector technology which recovers useful process water from the plant's humid exhaust gas, which in turn increases energy efficiency. Discussions to install the technology at larger scale at other facilities are in progress.

*Project Manager: Lee Van Dixhorn*



### **Energy Recovery System for Brewing and Distilling Operations**

UTD researchers are testing a novel heat exchange system to recover previously-wasted energy at two micro-breweries in California, with funding from UTD and prime funding from CEC. Project goals include to recover 15-25% of heat from brew kettles, and reduce CO2 emissions by up to 25%, while maintain superior process operations.

*Project Manager: David Rue*



### **Ionic Liquid Technology for Residential and Commercial Gas Heat Pumps**

Researchers at the University of Florida and Micro Nano Technologies are partnering with UTD to design and demonstrate an early prototype of a low-cost, ultra-high-efficiency thermally-driven heat pump for residential and commercial water heating or combination water heating/space heating which employs the unique thermal properties of ionic liquids.

*Project Manager: Paul Glanville*

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## TECHNOLOGY ADVANCEMENTS (continued)



### High Efficiency Commercial Clothes Dryer

An advanced natural-gas-fired commercial clothes dryer is being created and demonstrated at laboratory scale that has the potential to save at least 50% of the energy used in the commercial clothes drying sector. It is being developed in partnership with Oak Ridge National Laboratory and others, with financial support from U.S. DOE and UTD.

*Project Manager: Dave Cygan*



### Next Generation Infrared Burner

In partnership with a leading OEM, UTD-funded researchers are testing a variety of unique metal foam materials in a laboratory to evaluate their potential performance as next-generation, high-efficiency, rapid-response, low-emission infrared burners that are directly fired with fossil or renewable natural gas. Field tests are in development.

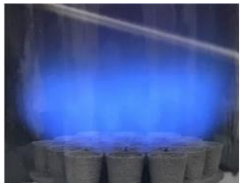
*Project Manager: Sandeep Alavandi*



### Furnace Retrofit for High-Efficiency Heating and Humidification

Tests of a patented Transport Membrane Humidifier (TMH) technology in four homes in Minnesota demonstrated a 14% increase in furnace efficiency while providing humidification without water supply. Interested licensees should contact Rich Kooy at rich.kooy@utd-co.org.

*Project Manager: Dexin Wang*



### Low NO<sub>x</sub> Energy-Efficient Advanced 3D-Printed Nozzle Burner

A novel design for next-generation retention nozzles leverages new additive manufacturing capabilities and equipment. In 2023, UTD is evaluating applications for boilers, water heating and air heating. Laboratory tests have demonstrated a robust, high-efficiency (3-6% increase), ultra-low emissions burner, with >10:1 turndown. It achieved 50%-75% reduction in NO<sub>x</sub> emissions compared to current burners, with the potential to reach <5 ppm NO<sub>x</sub>.

*Project Manager: Sandeep Alavandi*

## WORKING WITH PARTNERS TO CO-FUND UTD INITIATIVES

In 2022, each \$1.00 in new UTD funding was leveraged by \$4.8 of funding from government and industry partners for related end-use R&D. GTI Energy secured \$15.1 million from federal and state government partners and \$9.9 million from manufacturing partners and other gas industry resources (outside of UTD) for related end-use R&D. Manufacturing partners also provided significant additional in-kind co-funding.

Examples include:

- U.S. Department of Defense (DOD) funding of \$8.1 million to apply advanced energy efficiency, renewable energy, microgrid, and hybrid technologies to reduce DOD GHG emissions and energy use while increasing resiliency.
- U.S. Department of Energy (DOE) funding of \$2.3 million to develop and test novel technologies to achieve very high space heating efficiencies, and to advance hydrogen as a transportation fuel.
- California Energy Commission (CEC) funding of \$3.7 million for new projects to advance hydrogen as a low carbon fuel for transportation, industrial, and large commercial customer applications.
- New York State Energy Research and Development Authority (NYSERDA) funding of \$0.8 million to develop innovative insulation technologies to achieve deep energy building envelope retrofits.



## **Example Technical Publications/Presentations 2022-23**

developed in part with UTD's Support

Ahsan, A., "Distributed Carbon Capture for Buildings", ACEEE Hot Air & Hot Water Forums, San Diego, CA, March 7-9, 2023 <https://drive.google.com/file/d/1zsA4TkrBJptLeaVRmgy0Uzi2MQt2eHjg/view> (results in part from UTD project 1.21.C).

Air-Conditioning, Heating, and Refrigeration Institute Report No. 8030, "Role of Combustion-based Building Equipment in Decarbonization", prepared by GTI Energy, April 2023 <https://www.ahrinet.org/system/files/2023-06/AHRI%208030%20Final%20Report.pdf> (results in part from UTD projects 1.16.I, 1.19.D, 1.19.I, 1.20.H and others).

Alavandi, S., Abbasi, H., Cygan, D. and Wagner, U.; "Design and Development of Advanced 3-D Printed Burner for Process Heating Applications", American Flame Research Committee conference, Denver, CO, Sept. 25-27, 2023 (results in part from UTD project 2.20.A).

Barnes, T., and Sowa, B. "Field Demonstration of a Near-Zero, Tier 5 Compliant, Natural Gas Hybrid Line-Haul Locomotive", U.S. Department of Energy Annual Merit Review, Washington D.C., June 14, 2023 (results in part from UTD project 2.21.F).

Bhagwat, R., Schmid, M., Ahsan, A., Kumar, N., Glanville, P., "Ionic Liquid Absorption System for Dehumidification and IAQ Enhancement in Built Environment", 14<sup>th</sup> International Energy Agency Heat Pump Conference, Chicago, IL, May 15-18, 2023 (results in part from UTD project 1.20.I and 1.21.I).

Bhagwat, R., Schmid, M., Glanville, P., "Hybrid Thermally Driven Ionic Liquid Heat Pump Water Heater and Dehumidifier For Commercial Applications", 14<sup>th</sup> International Energy Agency Heat Pump Conference, Chicago, IL, May 15-18, 2023 (results in part from UTD project 1.20.I and 1.21.I).

Ekblad, M., "Commercializing a Cost-Effective Residential Retrofit Gas Heat Pump Water Heater", ACEEE Hot Air & Hot Water Forums, San Diego, CA, March 7-9, 2023 <https://drive.google.com/file/d/1J3Dv6dD8hx3JE5SSnT5E7UIDavrIXUi/view> (results in part from UTD project 1.21.A).

Fridlyand, A., Zhao, Y., Asher, W., and Glanville, P., "Burner Design Considerations for Hydrogen-blended Gas Operation", ASHRAE 2023 Winter Conference paper, *ASHRAE Transactions 2023* Vol. 129 Issue Part 1, pp. 83-91 (results in part from UTD project 1.20.H and 1.21.H).

Fridlyand, A., "Hydrogen in Buildings - Ongoing Research and Outstanding Questions", 2023 ASHRAE Winter Conference presentation, Atlanta, GA, Feb. 8, 2023 (results in part from UTD project 1.22.A and 1.22.G).

Glanville, P., Fridlyand, A., Sutherland, B., Liszka, M., Zhao, Y., Bingham, L., and Jorgensen, K., "Impact of Hydrogen/Natural Gas Blends on Partially Premixed Combustion Equipment: NO<sub>x</sub> Emission and Operational Performance", *Energies* 2022, 15, 1706. <https://doi.org/10.3390/en15051706> (results in part from UTD project 1.20.H).

Glanville, P., Fridlyand, A., Zhao, Y., (2023) "From Town Gas to Hydrogen: Historical and Modern Perspectives on Transitions Between Delivered Fuels in the Built Environment", ASHRAE 2023 Winter Conference paper, *ASHRAE Transactions 2023* Vol. 129 Issue Part 1, p. 92-102 (results in part from UTD project 1.20.H).

Glanville, P., Fridlyand, A., Zhao, Y., Sutherland, B., Jorgensen, K., and Bingham, L., "Looking Beyond the Meter - Customer-Side Impacts of Natural Gas/Hydrogen Blends in North America", 28<sup>th</sup> World Gas Conference paper, May 23-27, 2022 (results in part from UTD project 1.20.H).

Glanville, P., Kumar, N., Ahsan, A., Fridlyand, A., Ekblad, M., Hallin, I., Blackman, C., Contreras, N., "Development of a Novel Sorption-Type Heat Pump Water Heater for North American Homes", 14<sup>th</sup> International Energy Agency Heat Pump Conference, Chicago, IL, May 15-18, 2023 (results in part from UTD project 1.21.A).

Glanville, P., Zhao, Y., "Decarbonizing California's Industry with Hydrogen: Preliminary Assessment", ACEEE Summer Study on Energy Efficiency in Industry conference presentation, Detroit, MI, July 11-13, 2023 (results in part from UTD project 1.20.H and 2.23.A).

Guada, A.B., "Reducing Greenhouse Gas Emissions and Improving Energy Resilience with Integrated Energy Systems", ACEEE Hot Air & Hot Water Forums, San Diego, CA, March 7-9, 2023 <https://drive.google.com/file/d/1qVxKj7J3MwZOtB3loogPinluWXbFrpd0/view> (results in part from UTD projects 1.19.D, 1.19.I, 1.20.G and 1.20.J).

Guada, A.B. and Kingston, T., "Challenges of Integrating mCHP and SOFC Systems in Nano-Grid Environments for Thermal and Power Management Solutions in Integrated Energy Systems", ASHRAE 2023 Winter Conference paper, *ASHRAE Transactions 2023* Vol. 129 Issue Part 1, pp. 311-319 (results in part from UTD project 1.20.F).

Halliday, D., "Free-Piston Expander for Hydrogen Pre-Cooling", U.S. Department of Energy Annual Merit Review, Washington D.C., June 5-8, 2023 (results in part from UTD project 2.18.I).

Kingston, T., and Guada, A.B., "Simulated Use Performance of an Integrated Energy System for Thermal and Power Management with Micro-Combined Heat and Power in Nano-Grid Environments", ASHRAE 2023 Winter Conference paper, *ASHRAE Transactions 2023* Vol. 129 Issue Part 1, p. 536-544 (results in part from UTD project 1.20.G).

Kumar, N., "Laboratory Evaluation of a Packaged Thermal Heat Pump and Electrical Air Conditioning Unit for Space Conditioning and Hot Water", ACEEE Hot Air & Hot Water Forums, San Diego, CA, March 7-9, 2023 [https://drive.google.com/file/d/1hx8T4m36sGZxlrMUfJefoHRTh\\_Pafb8x/view](https://drive.google.com/file/d/1hx8T4m36sGZxlrMUfJefoHRTh_Pafb8x/view) (results in part from UTD project 1.18.F).

Kumar, N., Guada, A.B., Asher, W., Fridlyand, A., Glanville, P., Blaylock, M., Strong, T., "Performance of a State-of-Art Packaged Heat Pump for Residential Space Conditioning and Hot Water", 14<sup>th</sup> International Energy Agency Heat Pump Conference, Chicago, IL, May 15-18, 2023 (results in part from UTD project 1.18.H).

LaFleur, J., Goldstein, D., "Façade-Integrated Mechanical Systems", ASHRAE Decarbonization Conference presentation, Arlington, VA, Oct. 26, 2023 (results in part from UTD projects 1.22.E)

Rowley, P., Mahderekal, I., Ravi, A., Walburger, A., Genzel, N., Henderson, H., Dentz, J., Zhu, S. "Cold Climate Performance Assessment of a Natural Gas Engine-Driven Heat Pump Rooftop Design", ASHRAE 2023 Winter Conference paper, *ASHRAE Transactions 2023* Vol. 129 Issue Part 1, pp. 173-180 (results in part from UTD project 1.18.I).

Stein, J., Glanville, P., Fridlyand, A., LaFleur, J. and Mensinger Jr., M. "Translating Equipment Efficiency to Delivered Efficiency in Thermally-Driven Heat Pump Combi Systems", ASHRAE 2023 Winter Conference paper, *ASHRAE Transactions 2023*, Vol. 129 Issue Part 1, pp. 293-301 (results in part from UTD project 1.13.F and 1.16.I).

Swierczyna, R., Johnson, F., LaFleur, J., and Stein, J., "Evaluating Residential Kitchen IAQ and Hood Performance", ASHRAE 2022 Winter Conference paper, ASHRAE Transactions 2022 Vol. 128 Issue Part 1, pp. 429-436 (results in part from UTD project 1.20.K).

Zhao, Y., "Technical Considerations of Hydrogen Blending into End Use Infrastructures", AEE World Energy Conference presentation, Orlando, FL, Oct. 26, 2023 (results in part from UTD projects 1.20.H and 1.21.H).

Zhao, Y., Glanville, P., Fridlyand, A., and Sutherland, B., "Inline Hydrogen Sensor Monitoring of a Tankless Water Heater Operating Up to 30% Hydrogen Blending", ASHRAE 2023 Winter Conference paper, *ASHRAE Transactions 2023* Vol. 129 Issue Part 1, pp. 103-111 (results in part from UTD project 1.18.F and earlier UTD-funded research).

Zhao, Y., Pixler, J., Sutherland, B., Daniels, N., and Johnson, F., "Non-Powered Commercial Cooktop Burners Optimization for Efficiency Improvement/NOx Reduction and Hydrogen Blending Efforts", Western States Section Combustion Institute Fall 2023 Technical Meeting, October 16-17, 2023 (results in part from UTD projects 1.17.F and 1.21.H).

\* \* \*

Other final research reports are publicly available from the U.S. Department of Energy, California Energy Commission, Minnesota Conservation Applied Research and Development, and other governmental agencies which provided prime research funding and for which UTD provided cost share co-funding. Examples include:

Garrabrant, M. and Newland, J. of Stone Mountain Technologies Inc. "Improving Reliability, Weight and Cost of Gas-Fired Absorption Heat Pumps" U.S. Department of Energy Final Report DE-EE0008687, March 31, 2022 <https://www.osti.gov/biblio/1886933> (results in part from UTD project 1.19.E).

Sweeney, M., Glanville, P., Mort, D., Hoeschele, M., and Grant, P.. 2020. "Demonstration and Assessment of Gas Heat Pump Water Heaters in the Los Angeles Basin", California Energy Commission. Publication Number: CEC-500-2023-047 June 2023 <https://www.energy.ca.gov/sites/default/files/2023-07/CEC-500-2023-047.pdf> (results in part from UTD project 1.16.I).



# RESIDENTIAL AND LIGHT COMMERCIAL, INCLUDING mCHP





## Next-Generation Residential Gas Heat-Pump Water Heater



**A research team designed and demonstrated the first residential gas-fired heat-pump storage water heater. This project advanced this technology from laboratory prototype through multiple field demonstrations, including in California through 2020. It provides a uniform efficiency factor of  $\geq 1.2$ , to offer homeowners  $\geq 50\%$  energy savings.**

### Project Description

The industry's first residential gas heat-pump water heater (GHPWH) is near commercialization, with multiple OEM partners and a series of successful field trials advancing the design of each generation of prototypes.

In partnership with other research funding agencies, UTD co-funded a team of researchers to develop the residential/small-commercial GHPWH, reduce its costs, and improve reliability by refining a number of system components.

The initial GHPWH development initiative was funded by the U.S. Department of Energy (DOE). This UTD project effort has been a steady development led by Stone Mountain Technologies, Inc. (SMTI) along with commercial OEM partners and GTI Energy.

The first-generation GHPWH units were designed and demonstrated through laboratory testing from 2011 to 2013. Subsequently, six GHPWH units were installed and monitored in the field. Through these initial field tests, critical information was used to improve the GHPWH control strategies and future design improvements (including system sizing).

The most recent phases of this UTD project focused on supporting an additional five field demonstrations in a program sponsored by the California Energy Commission (CEC) with financial support from Southern California Gas Company (SoCalGas) in addition to UTD, and also investigating enhanced options for system diagnostics and grid interactivity.

In phase 5, the teams goal will be to reduce installation cost/barrier of condensate drain, by developing a proprietary method of neutralizing, collecting, and disposing of combustion condensate, and improving Onboard Diagnostics through Enhanced Solution Level Control (ESLC) to improve system reliability and long-term performance.

In phase 6, the team will be developing strategies to deploy the residential GHPWH as distributed energy resource (DER) for residential grid-level shed and shift events and developing methods to improve DHW capacity with supplemental gas/electric "boost" capabilities.

### Benefits / Market Implications

The motivation for developing a GHPWH is efficiency driven.

When delivered to the market, the GHPWH will be the only technology and product of its kind with a primary energy efficiency of greater than 100%. These efficiency gains are significant, with project uniform efficiency factors (UEFs) of 1.20 or greater, and consistent field results of 50% or greater energy savings over conventional water heaters, respectively.

Results from this project have the potential to reduce the cost, increase the reliability, and more than double the efficiency of the next generation of gas heat-pump water heaters for homeowners and light commercial end users.

### Technical Concept & Approach

The GHPWH units are driven by an air-source single-effect absorption heat pump, itself driven by a gas burner, capable of Coefficients of Performance (COP) of 1.4-1.9. This can yield a UEF of 1.20, more than twice the efficiency of standard gas storage water heaters, which are in, for example, 74% of California homes.



Water Heater Testing Area Test Installation Progress



*"SoCalGas RD&D continues to be impressed with the capabilities of the UTD team. They helped identify test sites, coordinate with installation partners, and share the results with the public through a webinar. This type of partnership and research project is just one way SoCalGas is working to be the cleanest, safest, and most innovative energy company in America."*

- Neil Navin  
Vice President, Clean Energy Innovations  
SoCalGas

Based upon a recent certification, the units are ultra-low-NO<sub>x</sub> compliant. The packaged GHPWH heats the 60 to 80 gallons of stored water with a nominal 10,000 Btu/hr output ammonia-water absorption heat pump, driven by a small 6,300 Btu/hr low-NO<sub>x</sub> gas burner. With such a small combustion system, the GHPWH offers retrofit installation advantages over other high-efficiency gas products.

Through the broader project funded by the CEC and cofunded by UTD and SoCalGas, the project team focused on the testing of GHPWH units and the development, use, and refinement of advanced fault detection and diagnosis. The goal was to demonstrate that the projected delivered efficiencies of 130% or greater are valid, robust, and are not achieved through a loss of user comfort. Researchers estimated the annual energy, operating cost, and emissions savings and solicited feedback from host end users and installation contractors through pre- and post-installation surveys.

## Results

Following a laboratory development program, the first prototype gas heat-pump water heater was installed in a Tennessee residence and investigated over a 10-month period. The laboratory-validated performance and preliminary field test data suggested that the 1.20 UEF target was feasible and the technology could be competitive with other available high-efficiency gas water-heating options.

In 2015, project efforts focused on transitioning the purpose-built prototype from field testing to reliability testing. Reliability testing was completed in 2016.

A report on the initial phases of the project was issued in 2017. In these phases, six GHPWH prototypes were subjected to extended reliability testing. Researchers also performed an analysis of how the GHPWH is impacted by relevant codes and standards in the U.S., Canada, Mexico, and Europe.

In 2017, seven new GHPWH units were built during Phase 4: five units for residential field demonstration; one for evaluation at SoCalGas' *Engineering Analysis Center*; and one for proprietary testing by a manufacturing partner.

In 2018, the project team monitored the performance of the five gas GHPWHs installed at the test sites, which continued through June 2019. Data continued to confirm that ~50% energy savings was achieved on a site-by-site basis and im-

proved as the ambient temperatures rise. Data was collected, aggregated, and analyzed.

Also in Phase 4, two fourth-generation GHPWH units were received from California, with one partially installed in a laboratory. Additional preparations were made to initiate standardized and non-standardized efficiency testing.

In 2020, Phase 5 involved additional laboratory testing of the GHPWH to improve onboard diagnostics and to explore innovations to ease how condensate is handled.

Phase 6 is now expanding grid-interactive capabilities and variable performance to further enhance customer's comfort and operating flexibilities. Efforts are under way to develop and demonstrate strategies to deploy the residential GHPWH as a distributed energy resource for residential grid-level shed and shift events, and develop and explore methods to improve domestic hot water capacity with supplemental gas/electric boost capabilities.

In 2021, the project team expanded its laboratory space to accommodate appliance/water-heating tests. This "Advanced Appliance Assessment" (A3) laboratory was prepared for installation and operation of GHPWH hardware. The infrastructure and instrumentation/emissions measurement capacity were completed and commissioned, with hot/chilled water circulation loops functional for water-heater testing.

For Phase 6, an agreement with SMTI to produce a next generation alpha prototype GHPWH was completed, with expectations that SMTI will deliver the updated unit in the fourth quarter of 2023. Researchers completed the Phase 6 test plans and fabricated prototypes of the additional features being developed in Phase 6.

## Status

Technical tasks under Phases 5 and 6 are advancing, including the final design and fabrication of test setups to evaluate the proof of concept of the liquid level sensor (LLS) platform and the de-condensator concept.

The project team continue to make and refine upgrades in the laboratory space, impacting both phases (phase 5 and 6) in the "Advanced Appliance Assessment", or "A3" laboratory. The ESLC and de-condensator test plans were completed and the team has begun to make progress in the fabrication and assembly of the ESLC and de-condensator test rig. The project team anticipates completing testing in the next period under Phase 5 and preparing for receipt of the SMTI prototype to close out both coincident phases.

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## Investigating Multi-Family Infrastructure Challenges



**Researchers investigated the current challenges and opportunities for the natural gas industry to better serve multi-family new construction owners, architects, and builders with advanced, efficient technologies.**

### Project Description

There is a significant opportunity for natural gas to better serve the growing multi-family new construction market; however, there are also significant barriers, many of which have been the focus of research in recent years.

Starting in 2014, in Phase 1 of this project researchers investigated national trends regarding gas and electric multi-family market shares, the economics of energy services, building codes, and installation practices.

In Phase 2, the project team provided regional multi-family market paths for advanced products that provide promising opportunities in this sector, a portfolio, and examples and discussion of successful utility initiatives.

Phase 3 recommended implementation of opportunities for specific regions or utilities, including holding utility-sponsored design-planning sessions in the form of charrettes with stakeholders within the development, design, and building communities.

The final Phase 4 effort focused on developing detailed market transformation implementation tools and action plans to optimally connect new development decision-makers with financial, marketing, and technical resources suitable for the multi-family new construction sector. Deliverables included a report with sample case studies (customizable by UTD member utilities with utility logo and program details), a review of emerging gas technologies to better serve multifamily buildings, and continuing education credit curriculum.

### Benefits / Market Implications

Pilot studies on the multi-family market identified key economic issues, code barriers, and product gaps that require investigation and resolution. Addressing these issues, gaps, and barriers will enable more multi-family end ratepayers to benefit from the lowest-cost energy option and improve energy efficiency.

This project highlighted and created resources that improve existing avenues of support for developers, utilities, and end-users to leverage natural gas as a fuel choice.

Several demonstrations showcasing innovative gas technologies are summarized in consumer-friendly case studies of successful multi-family developments.

### Technical Concept & Approach

Key earlier project tasks included:

#### •Multi-Family Market Data Collection & Analysis

Researchers used census data and other available resources to obtain a 2015 snapshot of builder and developer energy choices in the multi-family new construction market by U.S. region and by building type. The assessment included, to the extent possible, gas and electric utility rates and incentives, the availability of gas service, market trends, and code differences.

#### •Multi-Family Market Preliminary Recommendations

Researchers reviewed the analysis and developed preliminary recommendations for a path forward in each region.

#### •Technology Solutions

The project team reviewed the market data and up-to-date technical equipment and system information to recommend advanced resource-saving technology solutions.

#### •Multi-Family Stakeholder Charrette

The project team held three stakeholder charrettes in 2018 in targeted geographical regions across North America that showed the greatest need or desire for multi-family development support.



### •Development of Supporting Utility Programs

Researchers recommended utility program features and best practices that were observed to be successful.

Current research pursues:

### •Guidance for Design and Construction Professionals

Leveraging the insights from Phase 3, researchers created tangible market guidance tools tailored for design and construction professionals that could be branded by UTD member utilities.

### •Case Study Development

Three case studies were developed to showcase successful pathways to natural gas inclusion in multi-family developments.

### •Curriculum Development

The project team will develop curriculum geared towards design professionals in a one-hour presentation format.

### •Multi-Family Emerging Technologies Strategy and Needs Assessment

Investigators identified promising natural gas emerging technologies or innovation needs that can leverage the benefits of using natural gas in the multi-family market.



Early Design Charrette

## Results

The project team held interviews with key national-level players active in the multi-family market, including representatives from industry associations and gas utilities. These discussions covered past activities each of these organizations have undertaken within the multi-family market segment, current challenges, and key concerns of stakeholders. Project representatives also held discussions with many U.S. utilities and performed significant outreach to the building and development community to obtain their perspectives.

Phase 1 research reported on key trends in the housing mar-



- April Arnold  
Manager  
ONE Gas, Inc.

*"The Multifamily Infrastructure Challenges project has given us a comprehensive insight into customer concerns. We have used this insight to develop outlines and resources to help build a greater understanding of the benefits of natural gas in multifamily developments."*

ket, the use of heating fuels, and the use of electricity. The rebounding of electricity as the majority space-heating fuel can be seen in both low-rise (2-4 units) and high-rise (5+ units) buildings, while the volume of gas-heated units shows either modest or no growth. However, this trend is not reflected in water heating, where gas still plays a strong role.

In Phase 2, researchers identified the key economic and non-economic factors driving the selection of energy sources as service in new construction multi-family buildings.

In Phase 3, specific UTD members participated in stakeholder charrettes (i.e., focus group sessions) to garner feedback and dialogue with real estate developers, architects, engineers, and others involved with multi-family projects. Detailed recommendations were developed for UTD members to address economic challenges, provide technology-based solutions, and enhance their service to multi-family stakeholders, architects, builders, and others.

In Phase 4, practical tools were created to facilitate market transformation and connect utility partners with new development decision-makers, such as guidance for design and construction professionals, case studies, a "Train the Trainer" packaged curriculum, and multifamily emerging technology information snapshots. Tools and resources aimed to overcome the barriers identified in previous phases of the project and support multi-family gas end users were developed.

## Status

The project is complete. Final Reports summarized the progress completed in each phase. The Phase 4 Final Report issued in March 2023, and an informational webinar was provided to UTD members in May 2023. The tools, templates and information developed in this project provide resources for UTD members to better support multi-family developers and customers in their service territories on an on-going basis.

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## Next-Generation Advanced Residential Gas Clothes Dryer

**Researchers are investigating next-generation technologies so that a residential gas clothes dryer can economically provide gas consumers with faster drying times, while achieving 5%-15% higher efficiency than standard-efficiency gas dryers.**

### Project Description

In this project, researchers are investigating next-generation technologies – including heat recovery, indirect firing, direct venting, and advanced burners – to determine potential efficiency boosts for residential dryers. All of these techniques and technologies were shown to increase efficiencies in other areas, but scaling them to a residential dryer size, determining the additional cost to the dryer, and quantifying the efficiency increases will help dryer manufacturers determine the best path to further advance gas-fired dryers while minimizing cost increases.

UTD's guiding Technical Project Committee indicated that there is also an interest in reducing drying times if possible. This is a benefit of gas dryers for end users – the potential to increase firing rates to reduce drying times. Modulation may allow a high firing rate in the early stages and a low firing rate later to both reduce drying time and save energy.

The goal is to find a technology to achieve a 5%-15% boost over standard-efficiency gas dryers. Project deliverables include an early-stage prototype incorporating the most promising technologies, optimizing their operation in a prototype dryer, and preparing reports detailing the performance improvement provided by all of the technology options investigated.

### Benefits / Market Implications

Gas-fired dryers have not had many technological advances in recent years; however, there is potential to enhance the technology. Since about 81% of U.S. households have a clothes dryer, potential efficiency improvements in the design of gas dryers represent sizable savings to residential rate-payers.

Although electric clothes dryers represent the majority of U.S. residential dryers, a 2011 study by others indicates that it is not consumer preference for electricity that is the driving force. Although 60% of survey respondents were currently using electricity for clothes drying, only 34% stated that they actually preferred electricity. In contrast, 40% of respondents stated they currently used gas for clothes drying and 53% said they would prefer to use gas. These results indicate that the cause for gas dryer's minority market share is not due to the inherent characteristics of gas as a fuel, but is driven by other factors such as cost, availability, and other regional factors.

### Technical Concept & Approach

The project team will investigate high-efficiency dryer technology options, such as heat recovery, modulating burners, indirect firing, direct venting, and advanced burners. Researchers are also investigating the potential for technologies to reduce drying times.

The effect of each technology modification is being tested using standard methods to determine the performance improvement (efficiency, drying time, etc.) in comparison to the baseline unmodified model. The most promising technologies will be incorporated into an early prototype for demonstration.

Researchers will take the best performing technologies from Phase 2 and combine them into a prototype dryer in Phase 3. The prototype will be modified and optimized to get the best performance of the technologies working together. The prototype will be tested to determine the performance improvement of the technologies (efficiency, drying time, cloth temperature, etc.).



*New Environmental Test Chamber during Construction*

### Results

Phase 1 of this project focused in part on assembling a test station in an environmental chamber to maintain temperature and humidity to ensure accurate testing. It had become apparent during previous UTD dryer research that room temperature and humidity have a very large effect on the dryer efficiency rating. Although the test standard allows for 40%-60% relative humidity (RH) during the test, a dryer will be much



more efficient at 40% RH than at 60% RH. With that in mind, researchers decided that it was necessary to arrange the test in an environmental chamber.

Technicians completed the first modifications to the dryer. The unit was fully instrumented to allow for testing different design changes, including changes to primary aeration and air-to-fuel ratio, followed by potential heat-recovery options. Designs to recover heat from the flue were implemented and show promise for improved efficiency in testing. Overall, the heat recovery appears promising while providing a small cost added to the dryer.

Researchers attempted many different configurations for sealing the dryer to maintain stable combustion, and investigated simple heat-recovery options with many different alterations. In the end, it was determined that a novel heat-recovery set-up, along with a newly configured and sealed dryer combustion chamber, showed the most promise, with a 4% boost to the dryer efficiency while adding very little cost to the dryer.

For the study, a total of 42 temperature sensors, five gas sample points, a gas meter, and electric power meter were fitted to the dryer.

In Phase 2, researchers investigated additional heat-recovery options, modulation techniques, indirect-fired methods, direct venting, and alternate burners.

Researchers set up a new dryer in the test stand in the environmental test chamber. The project team also set up a new washer test stand to provide clothes with the needed temperature and remaining moisture content for dryer testing.

The research team developed a slightly modified test procedure to provide repeatable results that will allow comparison to technology improvements on a common basis. After this modified procedure was adapted, baseline testing was completed. Researchers also investigated the effect of firing rate on the dry time and efficiency.

It was noticed from previous dryer research that results of dryer efficiency testing according to the U.S. Department of Energy test procedure can vary based on a few factors. The current standard requires allowing the automatic moisture sensor to automatically stop the load. An issue is that the moisture sensor can create significant variability in the test results based on when it determines the load is dry. In many instances, the load is fully dry, but the dryer keeps running before the moisture sensor eventually shuts it off. Researchers need good repeatability to compare the baseline testing of a standard dryer to each technology that is being tested to improve efficiency.

The project team was able to achieve good repeatability by creating a slightly modified test procedure that measured flue RH and determined when the clothes were dry based on the flue RH.

In Phase 3, the project team developed a slightly modified test procedure to reduce variability of the results and provide repeatable results that will allow researchers to compare technology improvements on even ground. After this modified procedure was adapted, baseline testing was completed of the DOE test clothes as well as a real-world towel load baseline test. Researchers completed single-stage modulating testing at four firing rates, with results showing around a 2% boost consistently with lower firing rates. Technicians then insulated and sealed the dryer to test potential boost from better sealing and allow for implementing heat recovery. After several variations, the team was able to achieve a 5%-6% increase in efficiency with insulation and sealing as well as a 6% reduction in drying time.

The insulation and sealing also allowed for the implementation of a new heat-recovery design. An external air-to-air heat exchanger was purchased and installed on the dryers to determine the potential boost from heat recovery. Testing of the dryer in the environmental chamber demonstrated a 10%-11% boost to the efficiency of the dryer.

## Status

The team will begin to incorporate heat recovery, modulation, and insulation together to determine the maximum efficiency that can be gained through all the technologies working together.

A new environmental test chamber is being setup in the new Advanced Appliance Assessment Lab. The new chamber is close to being finished. The project team has begun to move the test setup into the chamber in order to prepare for the next round of product development and testing.

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## Gas-Fired High-Efficiency Liquid Desiccant Air Conditioning and Humidity Control

**A research team is partnering with a chemical manufacturer, two HVAC manufacturers, and others to develop and demonstrate a very-high-efficiency gas-fired liquid-desiccant-based air-conditioning and humidity-control system that uses a novel, non-corrosive, non-toxic desiccant.**



### Project Description

The goal of this project is to develop a gas-fired liquid-desiccant dedicated outdoor air system (LDDOAS) that addresses many of the critical issues now facing owners and operators of commercial HVAC systems.

The LDDOAS is designed to significantly reduce primary energy consumption, on-peak electrical demand, and water use for air conditioning in commercial buildings. The system can deeply dry a building's ventilation air without inefficient overcooling or reheating, which will enable advanced HVAC solutions (e.g., chilled beams, displacement ventilation, and other approaches) to essentially eliminate fan power for recirculating air within buildings.

In this project, a research team is partnering with a manufacturer to compare the current state-of-the-art LDDOAS technology to other advanced systems, including a concept involving a sub-atmospherically-regenerated LDDOAS system with internal water recovery and reuse capabilities.

The current Phase 2 involves demonstrating this novel technology in a laboratory to determine its potential value to end users. In Phase 2, the project team will design and experimentally evaluate a breadboard LDDOAS test rig rated at

approximately 100 CFM capacity using a novel non-corrosive, non-toxic desiccant.

Researchers are partnering with the New York State Energy Research and Development Authority (NYSERDA), a chemical manufacturer, and two HVAC industry partners in Phase 2.

### Benefits / Market Implications

New cooling designs that integrate desiccant drying and indirect evaporative cooling in compact cost-effective configurations have the potential to provide residential and commercial market end users with new high-efficiency product choices.

For a summer design day, the LDDOAS' primary energy Coefficient of Performance (COP) is 18% higher than the conventional alternative. This advantage is projected to increase to 30% when averaged over a cooling season. The effective COP for the LDDOAS is estimated to be 2.77 (where the LDDOAS is credited with energy savings for the advanced HVAC systems that it enables). The LDDOAS can also eliminate water use for air conditioning in the more humid eastern U.S.

The burden that air conditioning now imposes on electric grids



*The regenerator tower*



*The conditioner tower*

can be eased as peak loads drop by approximately 75%, from about 1.01 kW/ton-hour to 0.26 kW/ton-hour of cooling.

## Technical Concept & Approach

Desiccant-based dehumidification and air-conditioning systems can employ an open drying cycle wherein a humid gas (generally, air) comes into contact with a desiccant and is dried. The dried air continues to subsequent processes (e.g., sensible cooling), and the desiccant is regenerated by a thermal input. The desiccant loading and regenerating is performed in a cycle, allowing for continuous dehumidification.

The two major system types are liquid and solid desiccants. While solid desiccants have a larger established market presence, the liquid-based systems have gained interest in applications for active dehumidification, enhanced evaporative cooling, and indoor air quality. These liquid desiccant systems, also known as open absorption systems, have had limited market presence due primarily to the inefficiency of current regenerating components and difficulties in handling the caustic strong salt desiccant solutions.

Successful completion of Phase 2 is expected to lead into follow-on construction and field trials of alpha LDDOAS prototypes. The specific objective of Phase 2 is to prove the LDDOAS' system operation in the laboratory and determine its value to potential end users. In Phase 2, the project team will design and experimentally evaluate a breadboard LDDOAS test rig rated at approximately 100 CFM capacity (approximately 1/10th scale for small RTUs) using the novel non-corrosive, non-toxic desiccant initially evaluated and characterized in Phase 1.

## Results

In Phase 1 of this project an experimental gas-fired liquid-desiccant air-conditioning (LDAC) system was constructed. A fluid was demonstrated to operate as a desiccant over a range of process air dew points (for space conditioning) and could be regenerated at low temperatures (<200°F). The absorption/regeneration tower operated as designed (~0.5-2 lb/hr moisture movement at 50 cfm).

During regeneration, with heated liquid and cool regeneration air, 50% of the enthalpy rise in the air was latent. This result was within the expected order of magnitude.

In Phase 2, the project team initiated upgrades to a one-tower test rig. The single-tower apparatus was fully instrumented to measure temperatures, pressures, and flow across the tower to allow completion of the initial test plan. Single-tower experiments were initiated. The preconditioning system for simulating outdoor air temperature and humidity levels was completed and tested.

Liquid desiccant distribution tests in the single tower were completed. Researchers characterized the desiccant distribution in the tower by varying nozzle configurations for distrib-

uting the liquid at the top of the tower to identify the optimal nozzle to use and determine whether tower-wall effects were present.

In 2021, rigorous testing of dew-point sensors concluded that the energy imbalance was not due to instrument accuracy. One theory that emerged regarding the cause of the energy imbalance was the insufficient mixing of water vapor in the air at the exit of the tower. To ensure proper mixing of the air as it exits the tower, a reducer was constructed for the top of the tower to increase velocity and turbulence of the flow. Testing of the modified tower commenced and confirmed that insufficient mixing was causing the energy imbalance.

In 2022, data analysis was completed for regeneration and batch-conditioning tests. A new digital refractometer was purchased for measuring the refractive index of the desiccant solution. The refractometer was used in conjunction with a Karl Fischer titration, and a new correlation was generated that more accurately characterized the strength of the raw desiccant and diluted solution. Various metrics were calculated and plotted to characterize the performance of the liquid desiccant during simulated regeneration and batch-condition tests. These metrics include effectiveness, water uptake, and the difference in vapor pressure between the liquid desiccant and duct air.

The simulated regeneration tests were performed at two different desiccant dilution rates, which was controlled by setting the peristaltic pump at 30% or 50% of operating speed when injecting water into the desiccant. At greater pump-operating speeds, more water would be injected into the liquid desiccant stream before it entered the tower, making for a weaker desiccant solution. This was done to study the change in regeneration performance by the liquid desiccant at varying solution concentrations. The experimental setup was also upgraded to use gear pumps rather than diaphragm pumps to circulate the liquid desiccant, which provided better control of the flow rate.

Construction of a second packed-bed column tower allowed for simultaneous regeneration and conditioning. All major instrumentation was installed for conditioning and characterizing the air stream, including a resistance heater temperature controller, a steam humidifier, a pitot traverse array, pressure transducers, thermocouples, and humidity sensors.

## Status

The team completed the final experimental testing. Preparation of the final report is underway.

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## EnergyPlus™ Models for Advanced Gas Space-Heating Systems and Combination Systems



**In this project, researchers developed models of advanced gas space-heating and water-heating combination systems in the EnergyPlus building energy simulation engine, with an overarching objective to inform and expand energy-efficient choices for building operators, designers, and other stakeholders.**

### Project Description

EnergyPlus™ is a whole-building energy-simulation program developed with support from the U.S. Department of Energy (DOE) that engineers, facility managers, researchers, and others use to model energy consumption for heating, cooling, ventilation, lighting, and plug-and-process loads as well as water use in buildings. However, the limited capability of EnergyPlus to simulate advanced gas-heating systems makes it difficult to accurately compare these options with other HVAC alternatives.

Data indicate that current models in EnergyPlus are inadequate for estimating the dynamic efficiency of condensing furnaces, gas absorption heat pumps (GAHP), and combination systems using tankless water heaters. Having no module in EnergyPlus to estimate the performance (or, even worse, to do it incorrectly) significantly limits choices for users to consider advanced, energy efficient systems during initial screenings of HVAC options. This project helps to address these limitations in EnergyPlus and helps to provide decision makers with accurate and reliable simulation tools for advanced residential heating systems, to enable equitable comparison with competing technologies and to advance the integration of gas and renewable energy.

Specific tasks in this project included:

- Developing mathematical models and performance maps for advanced gas space- and water-heating technologies
- Performing a technical and economic potential analysis on

the above systems for the U.S. national single-family housing market, and

- Disseminating results through peer-reviewed journal publications which can support direct updates to EnergyPlus.

In Phase 1 of this project, researchers leveraged technology-performance data for furnaces and gas absorption heat pumps collected as part of other projects to develop custom modules in EnergyPlus, and then used them to estimate energy savings potentials in several climates and use cases.

In Phase 2, the project team focused on GAHP model refinement, a more expansive market analysis and further functional refinements for combined space- and water-heating systems based on tankless water heaters.

Phase 3 builds on the successes of Phases 1 and 2 by making those results publicly available through updates to EnergyPlus that are supported by peer-reviewed publications. Phase 3 has also analyzed best practices for controlling gas dedicated outdoor air systems when combined with electric variable refrigerant flow (VRF) systems.

Phase 4 focuses on including additional next-generation gas equipment models of emerging gas heat pumps (beyond initial absorption-type), and hybrid gas-electric and integrated systems into EnergyPlus. It also focuses on deploying the results from modeling advanced equipment in Phases 2 and 3 into the capabilities of the residential building rating software used to determine HERS rating index.



Daikin VRV System (L) and EC Power 25 kW mCHP (R)

### Benefits / Market Implications

Through this project, researchers developed EnergyPlus performance data and/or built-in models for advanced furnaces, gas heat pumps, and tankless water-heater combination systems to allow general users to adjust the parameters (e.g., system size, performance curves, or design features). The outcomes of these efforts were published in peer-reviewed publications, public technical reports, and presented at several industry conferences hosted by Purdue University and ASHRAE, with additional dissemination still pending.

The tools developed as part of this project will enable decision

makers to objectively evaluate the technical and economic potential of novel gas heating systems across North America.

## Technical Concept & Approach

Specific tasks for Phase 4 include:

- Deploying a Generalized Gas Heat Pump Model for EnergyPlus
- Developing and Validating Models for Electric HVAC and Power Generation Systems
- Supporting Gas System Modeling for HERS Index Rating

## Results

To achieve the project objectives, current limitations of the furnace, tankless water heater, and heat pump models were reviewed and new approaches for modeling were developed, taking advantage of part-load performance data collected on five condensing furnaces from a single manufacturer and prototype GAHP units.

In Phase 1, researchers leveraged extensive data collected in a Virtual Test Home to validate the EnergyPlus models. Using simulations of modern homes in mild and cold climates, the approach helped demonstrate how a modulating furnace could consistently save 10% on the natural gas consumption annually compared to single- and multi-stage furnaces, and an additional 2% if it is right-sized for the home.

Also, as part of Phase 1, GAHP combination system was modeled using a custom EnergyPlus script and available performance data. An analysis was then performed to compare a GAHP combination system to an electric heat pump with three different water-heater alternatives (gas, electric, and electric heat-pump water heater) with a condensing furnace and a premium water heater as the baseline. It was demonstrated that the GAHP combination systems were competitive with electric heat pump and heat-pump water-heater alternatives in mild marine climates, with respect to source energy savings and operating cost savings (\$100-\$200 per year). The GAHP combination system was the only option offering energy and operating cost savings in the colder climates.

Major accomplishments of Phase 2 included: 1) development of a whole new mathematical framework for simulating tankless-based combination units; 2) refinement of the GAHP combination model; and 3) public dissemination of the results through conference presentations and journal articles presented in 2020-2021. The major conclusion was that the GAHP is the best and most cost-effective option right now (and for the foreseeable future) for reducing CO<sub>2</sub>-equivalent



- Kevin Duell  
Lead Engineering Consultant  
NW Natural

*"Many states require energy modeling before allowing new equipment into energy codes or for incentive programs. But most engineers won't touch a new technology without knowing energy performance. With existing software, gas heat pumps aren't a built-in option. That makes this project critical for market acceptance and transformation."*

emissions in the majority of most cool- and cold-climate locations around North America.

In Phase 3, the project team developed reduced order models that can be readily integrated with simple energy-savings calculators; used models developed in Phase 2 to improve testing protocols for gas heat pumps; and partnered with an approved EnergyPlus developer to deploy a built-in model for GAHPs and other air-to-water fuel-fired heat pumps. The generalized gas heat pump model is now deployed and publicly available.

Phase 4 started in Q3 2022. EnergyPlus 23.1 was released and now includes the Gas Absorption Heat Pump model as part of the software. In Q3, the team completed validation of the ZNE models based on data collected from CA Habitat for Humanity homes. In Q4, the team completed a preliminary review of all power-generation sub-models in EnergyPlus. In 2023, the team is focusing on validating models for cold climates heat pumps, PV generators, and battery electric storage systems.

## Status

A bug was discovered in the battery model of the EnergyPlus, which was validated through troubleshooting with the development team. Phase 4 simulations will be simplified by excluding the battery simulations and picked up again in Phase 5 that started in 2023. The team is now performing case studies of different gas-electric hybrid scenarios.

The team is also preparing a summary of recommendations for improving HERS Index calculations to be included in a future publication.

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## Thermoelectric Generator for Self-Powered Water Heater



**Researchers are developing a self-powered, gas-fired tankless water heater to save ratepayers money and energy while enhancing resiliency. Hardware testing is being performed to develop the critical components and integrate the design to power a condensing tankless water heater.**

### Project Description

Many consumers are embracing tankless gas-fired water heaters for their high efficiency and compact size, including significant adoption in Europe. According to Persistence Marketing Research, tankless water heaters sales will grow at an annual rate of 5.3% from 2016 to 2024.

Currently, all gas tankless water heaters require a connection to an electrical supply to maintain operation. Unlike gas storage water heaters, tankless heaters do not hold reserve hot water that can be used during a power outage. However, advances in thermoelectric generators (TEG), low-power components, energy harvesting, and energy storage may make it possible to develop an unpowered gas-fired tankless water heater for the residential market.

In previous efforts, researchers evaluated the potential for thermoelectric concepts for water-heater integration. All of the concepts used a water-cooled TEG device for gas-to-liquid thermoelectric power generation. While difficult to implement in a gas storage water-heater design, the water-cooled TEG concept may be ideal to implement in a tankless water heater where electronics, heat exchangers, and water flow are in close proximity to each other. Components such as the spark ignitor, a gas valve, a flue damper, and energy harvest and storage circuitry may have additional application in the development of a self-powered tankless water heater.

The initial objective for this project was to validate that a

Thermoelectric Generator Heat Exchanger (TEG-HX) device can generate enough electric energy to power a tankless natural gas water heater.

In Phase 3, hardware testing was conducted to optimize the TEG-HX design to prove the concept of a self-powered natural gas-driven tankless water heater with ultra-low emissions (<5 ppm NO<sub>x</sub>) and with excess power capability. Three gas-to-water TEG-HX designs were analyzed and tested.

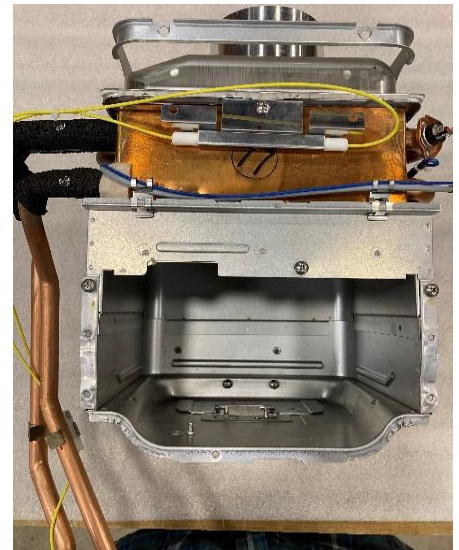
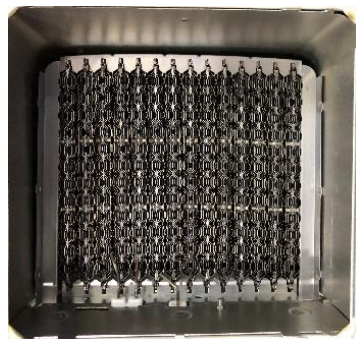
Phase 4 builds upon the hardware testing performed in prior phases to develop the critical components and integrate the design to create a complete alpha working prototype of a self-powered condensing tankless water heater.

### Benefits / Market Implications

A self-powered tankless water heater would preserve a key benefit that traditional gas storage water heaters offer – hot water availability during a power outage.

A TEG-HX-based condensing system would provide an enabling platform for higher efficiency self-powered gas appliances and serve end users with greenhouse-gas emissions reductions while still delivering hot water needed in disasters.

A TEG-HX system can also improve the efficiency of traditional storage water heaters by eliminating the energy consumed by the standing pilot light. At 400 Btu/hr, the water heater pilot



*Disassembled tankless water heater with the burner pulled out*



*"Our organization supports the development of self-powered natural gas appliances. The technology is something needed in the market today."*

- Chris Latch  
Gas & Water Manager  
City of Corinth Gas & Water Department

light in a non-powered gas storage water heater consumes about 35 therms per year, or 16% of the total energy consumption of a typical gas water heater.

The novel self-powered tankless water heater offers an identified energy savings potential of 20.9% over typical new natural-gas-driven water heaters and 73.2% over typical new electric water heaters when compared on a source-energy basis – which translates into a total of 0.4 quads savings in primary energy and a reduction of 20 Mt of CO<sub>2</sub> emissions per year in 2030.

## Technical Concept & Approach

The key to developing a self-powered tankless water heater is to generate enough energy to power a combustion air blower while harvesting and storing additional power for start-up operations.

The project began with a Phase 1 effort that characterized through technical evaluation both the power requirements and operational constraints of a tankless water heater. Capabilities were demonstrated through numerical and analytical models. Phase 2 validated this capability through technical analysis and benchtop testing. Phases 3 and 4 built upon the knowledge and technology developed in prior phases to develop the critical components and prove the concept that a TEG-HX could power a condensing tankless water heater.

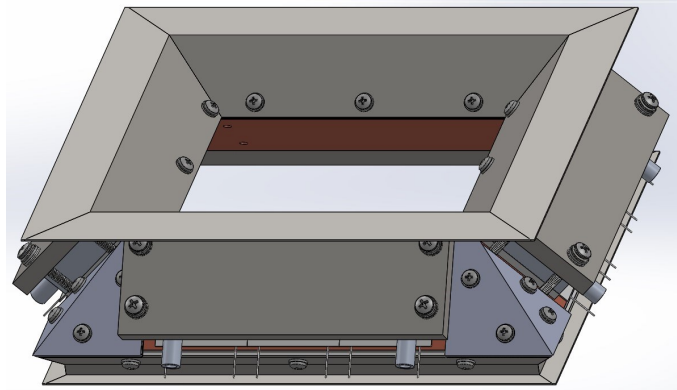
## Results

The project team analyzed and tested various TEG heat-exchanger designs and selected the most promising and most efficient design. Researchers were able to achieve more than 25 watts from a single TEG and using the new radiant burner. This showed that more than 10 TEGs can be easily installed in the water heater and provide an excess power of 200 watts – more than is needed to power the water heater.

Researchers designed and tested a TEG-HX with a new radiant burner. Based on the results of experiments and analytical predictions, it was proven that it is possible to achieve an ultra-high efficiency of the tankless water heater.

In 2020, the TEG-HX was optimized to improve performance and reduce the cost to harvest power for self-powered tankless water heater operation and produce excess power. A techno-economic analysis was completed.

In 2021, an advanced radiant burner in combination with a



*Thermoelectric generator assembly model for tankless water heater*

primary heat exchanger of the water heater was selected for testing. Researchers modified a heat pump for laboratory testing under non-standard conditions in order to confirm its improved performance. The project team developed, designed, and assembled an experimental rig for laboratory testing of the heat pump for the novel tankless water heater. Laboratory testing was initiated.

In 2022, the tankless water-heater unit with the combustion chamber was disassembled and different sections were reviewed to better understand integration approaches. The section around the combustion zone has space, and additional physical space was identified for integrating the TEGs. A solid model will be generated for the integration of the TEG assembly. Currently, three different schemes are being developed for optimized integration of the TEG and one will be chosen based on the feasibility of the approach.

In 2023, a tankless water heater unit with the combustion chamber was disassembled. Different sections of the water heater were reviewed to better understand integration approaches. Certain hardware sections were identified and were reviewed for integrating the TEG assembly. A design assembly and a solid model of the TEG with the water heater was developed.

The project team determined a path forward for integration with the tankless unit and developed models with hardware assembly identification.

## Status

The current phase of the project focuses on the development, manufacturing, and testing of an alpha prototype. Researchers will provide an analytical evaluation of the heat pump with tankless water heater and TEG integration.

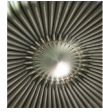
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## Combination Heating/ Cooling Vuilleumier-Cycle Heat Pump



**This project supports the development of an innovative gas-fired Vuilleumier-type heat pump to substantially increase efficiency over current gas heat pumps that operate using vapor-absorption and vapor-compression (engine-driven) cycles.**

### Project Description

This project supports the development of a gas-fired heat pump based on the Vuilleumier cycle – a closed-loop system similar in nature to the Stirling cycle – that uses a working fluid (helium) driven across several heat exchangers that interact with the environment.

The working fluid flow is driven through two linked displacers located in opposing cylindrical ends known as the “hot end” (where heat input to the cycle occurs) and the “cold end” (where heat removal from the environment occurs). Competitive with an absorption-cycle heat pump, the gas-fired Vuilleumier-cycle heat pump (GVHP) shows potential for a greater coefficient of performance (COP).

When commercialized, the GVHP would represent a step-change in efficiency over the current gas heat pumps that operate with vapor-absorption and vapor-compression (engine-driven) cycles, with a possible cooling COP of greater than 1.0 and a heating COP of greater than 2.0.

### Benefits / Market Implications

The technology developer estimates that lifetime fuel savings of a GVHP over a condensing furnace can be as high as \$9,760, with the potential for cooling-season cost savings as well. Using a benign working fluid (helium) with cost-effective design to accommodate higher working pressures (~1,450 psia), the GVHP may offer a premium gas heat-pump product with compelling emission and cost savings for gas rate-payers.

### Technical Concept & Approach

Phase 1 efforts focused on helping design, evaluate, and improve the overall performance of the GVHP hot end. The unique operating regime of the system required new burner material, air-fuel mixing, and heat-recovery methods to be assessed, with the project team’s recommendations ultimately being integrated into subsequent system prototypes.

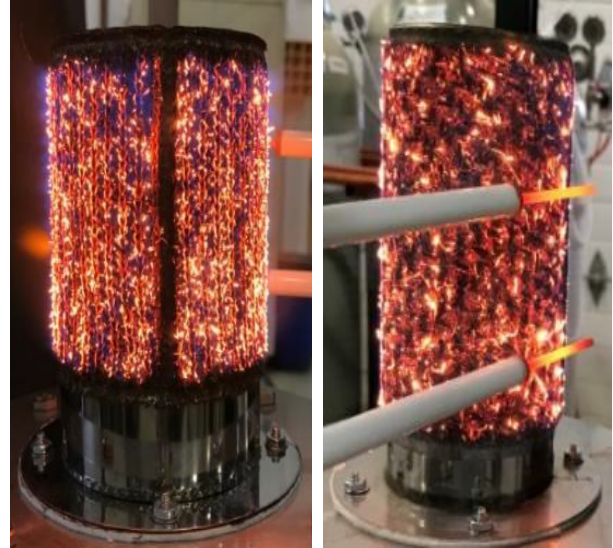


*Laboratory testing.*



"This technology represents a new class of ultra-low carbon heating and cooling appliances. ThermoLift has created a new category of heating and cooling appliances. A single unit (heating, cooling, and hot water across a wide temperature range) that supports the goals of deep de-carbonization through the highly-efficient direct use of energy. This new category of gas heat pump paves the way to use 100% renewable energy sources, including renewable natural gas derived from waste and green hydrogen derived from renewable power."

- Christopher A. Cavanagh  
Principal Program Manager - Future of Heat  
National Grid



*Initial air-preheating test setup with example burners.*

In the current Phase 2, researchers provided support on optimizing the design of the hot-end assembly and field certification of the initial prototypes. In addition, an entire pre-production prototype will be laboratory tested using standard rating procedures. This information will be used to assess the energy efficiency and technical potential of the system.

## Results

In Phase 1, the project team:

- Identified air-fuel preheat limits for a recuperator that would help the GVHP reach its performance targets
- Defined design guidelines for air-fuel mixing strategies for the GVHP
- Engaged with five burner manufacturers to find a compatible burner for the operating regime



- Validated hot-end heat-exchanger design
- Demonstrated overall hot-end efficiency consistent with initial design estimates, and
- Identified subsystems that needed redesign to reach target performance levels.

Current Phase 2 efforts include:

- Provided technical support to redesign and further optimize the combustion system and novel combustion controls
- Performed a codes-and-standards review to help with field certification of initial prototypes, and
- Testing of the full system prototype is to be completed. In preparation for whole-system testing, a comprehensive test plan for the system was prepared and the test apparatus was constructed.

## Status

The research team is currently awaiting a prototype to be provided by the technology developer to complete testing. Testing has been delayed until at least the fourth quarter of 2023.

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## Yanmar Gas Engine Heat Pump Field Studies

**Researchers evaluated the performance and economics of a Yanmar 2-pipe gas heat pump (GHP) and a Yanmar 3-pipe GHP (the first to provide simultaneous heating and cooling) in Alabama and Georgia, respectively. Researchers obtained key performance data that will enhance GHP energy models and aid facility owner/operators and designers to better evaluate efficient equipment options in order to reduce energy use and operating costs.**



### Project Description

Natural gas engine driven heat pumps (GHPs) provide high-efficiency heating and cooling while significantly reducing peak electric demand and electricity use, to save energy and reduce life-cycle costs when compared to electric heat pumps or conventional HVAC equipment.

In 2016, Yanmar America Corp. Energy Systems introduced a 14-ton GHP with a 3-pipe heat-recovery variable refrigerant flow (VRF) system, the first GHP in the U.S. market with the capability to provide simultaneous heating and cooling. This option improves the response to building loads by recovering heat from zones in cooling mode (e.g., internal loads) and redistributing it to meet heating loads in perimeter zones.

This technology provides a unique energy-efficient option, and opens up new markets where in the past electric-driven systems were the only options for simultaneous heating and cooling.

GHPs have a significant share of Japanese and European space-conditioning markets, but are relatively new to the North American market. The Yanmar product line includes 2-pipe VRF systems from 8 to 14 tons in addition to the 14-ton 3-pipe unit. As an emerging technology, GHPs face economic and market barriers, including high installation costs (which can be offset by savings in operating costs), the need for additional engine maintenance with limited service networks, and engine emissions (Primarily NO<sub>x</sub>).

For this project, researchers expanded on previous developments with GHPs in laboratory and field demonstrations to evaluate the field performance and economics of the Yanmar 3-pipe GHP. A new phase of the program involves a demonstration of Yanmar's 2-pipe GHP to compare overall performance with the Yanmar 3-pipe system in a similar warm climate.

### Benefits / Market Implications

Low gas rates and energy-resiliency concerns are key drivers for the adoption of GHPs to reduce operating costs in areas with high electric rates and demand charges or vulnerable to electrical outages.

Peak electrical demand has been growing in the commercial sector, mainly due to the high cooling requirements of commercial buildings and policies supporting electrification of homes, vehicles and facilities. GHPs offer a cost-effective and environmentally-friendly option to reduce peak electricity demand.

### Technical Concept & Approach

Specific tasks included: site selection and development of a field test plan; site monitoring and data analysis to determine the performance, environmental, and economic benefits of GHP installations in commercial buildings.

## Results

### 1. 3-Pipe Gas Engine Heat Pump Field Study:

For the demonstration, the project team selected the Lawrenceville Public Works (LPW) facility in the service territory of the Municipal Gas Authority of Georgia (MGAG). In 2016, the MGAG launched a GHP incentive program to support market transformation for GHPs. Six GHP systems provide zoned heating and cooling for the Lawrenceville facility.

One of the six GHP VRF systems at LPW was selected to be studied in the demonstration. The GHP outdoor unit and corresponding fan coils were instrumented and energy use and performance was monitored from November 2018 to October



*One of six GHPs installed at the Lawrenceville Public Works facility in Georgia.*



*"The Gas Authority recognizes the importance of market acceptance for GHP technologies, which provide energy efficient solutions for customers and reduce carbon emissions. The Gas Authority has supported the testing and installations of GHP technologies including GHP VRF applications for commercial buildings. Through our Emerging Technology Rebate Program, many of our municipal natural gas systems have supported GHP VRF installations in schools and government buildings."*

- Rodney Dill  
Vice President, Market Development & Communications  
Municipal Gas Authority of Georgia



*"Modern solutions like engine-driven gas heat pumps leverage our industry's long-standing promise and commitment to deliver affordable, reliable, efficient and resilient energy to the customers and communities we serve. At Spire, we're grateful to Pike Road Schools for partnering with UTD as a host site to better quantify energy consumption, equipment reliability and performance."*

- Steve Roberson  
Technical Analyst  
Spire Energy

2019 to evaluate its performance across the full range of ambient conditions and equipment operation.

Due to the field site's warm climate, the GHP operated in cooling mode for the majority of time, with limited runtime in heating mode. Simultaneous heating/cooling operation occurred only during mild temperatures. Based on this field site, the GHP had lower annual energy costs and reduced peak electric demand compared to equivalent all-electric VRF systems or conventional multi-zone roof top units (RTUs).

#### **Part-Load Operation:**

The GHP achieved rated efficiencies that exceeded 1.3 COPg during extended steady-state runtimes; however, overall GHP efficiency was reduced during low part-load operation. Measured seasonal efficiency was 1.18 COPg heating and 0.95 COPg cooling, excluding simultaneous operation. While it is common practice to oversize conventional HVAC equipment to ensure adequate capacity, oversizing GHP systems can impact both heating and cooling performance.

#### **Simultaneous Operation:**

Results suggest that 2-pipe VRF systems may in some cases be more cost effective than 3-pipe systems. Fan coil placement and set points may also impact performance in simultaneous operation.

#### **Economic Assessment:**

The GHP had lower annual energy costs than an equivalent multi-zone RTU or an all-electric VRF system. Savings in energy costs were driven by reductions in peak electric-



One of seven two-pipe GHPs installed at Pike Road School in Alabama.

demand and associated demand charges. Based on the measured performance at this field site, the GHP had lower life-cycle costs compared to an equivalent all-electric VRF with a simple payback of eight years based on regional energy prices. With current incentives (\$700/ton), GHPs would have an immediate payback compared to an electric 3-pipe VRF with more than \$14K savings in life-cycle costs over the 15-year life of the equipment.

## **2. 2-Pipe Gas Engine Heat Pump Field Study:**

The project team monitored an existing Yanmar 2-pipe GHP installation at a school in Pike Road, AL. Seven GHP units were installed at the school and commissioned in 2017. One GHP system was monitored from November 2022 through October 2023 to collect installed performance data with respect to part-load and ambient conditions, and to quantify the energy use and economics for a Yanmar 2-pipe GHP unit.

The GHP systems were appropriately sized for the facility cooling load and demonstrated excellent cooling performance ranging from 0.8 to 1.7 COPg, resulting in a seasonal average of 1.35 COPg. Daily average heating efficiencies exceeded 1.0 COPg on days with higher heating loads. This demonstration provided a valuable comparison to the 3-pipe GHP evaluated earlier in the project and also generated another performance dataset for the Yanmar GHP in a warm climate, with both datasets helping to advance the development of accurate engine-driven GHP models in EnergyPlus™ under UTD project 1.21.E.

## **Status**

The project is complete. During the past year, the project team collected and analyzed a full year of heating and cooling performance data of the 2-pipe VRF system. The project team issued a UTD Final Report which assesses the performance and economy of the system. This measured dataset will be incorporated in the development and validation of enhanced GHP energy models for HVAC designers and compliance-based energy simulation.

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## Advanced Nozzle Burner for Commercial Water Heaters



**Researchers are developing and demonstrating an advanced 3D-printed economical nozzle burner for commercial water heaters with high efficiency, ultra-low emissions, good turndown, superior stability, and compactness.**

### Project Description

Current commercial water-heater burner designs are not able to achieve all the technology targets of ultra-low emissions, high efficiency, good turndown, and attractive first costs. They also often have retrofit-ability limitations and are not scalable.

In Phase 1 of this project, researchers successfully developed and tested a 3D-printed burner by integrating advanced nozzle prototypes with the blower, controls, and fuel inlet of a commercial water heater. In the current Phase 2 of this project, researchers are testing a beta prototype version of this robust, smooth- and safe-operating advanced retention nozzle in a commercial water heater (~200,000 Btu/hr capacity), offering improved efficiency, turndown, emissions, stability, and compactness.

Key performance goals for Phase 2 include:

- Improve efficiency by 2%-4% for the same emissions
- Demonstrate NO<sub>x</sub> emission of <5 ppm and CO emissions of <20 ppm corrected to 3% O<sub>2</sub>, and
- Achieve turndown of 10:1.

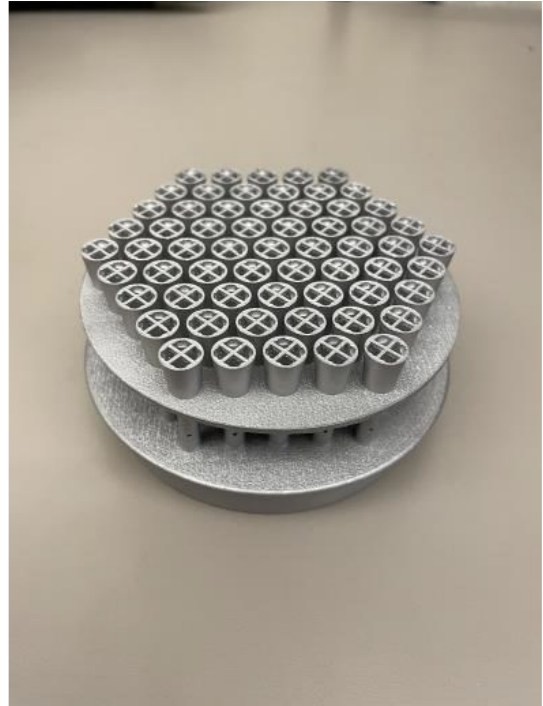
### Benefits / Market Implications

Forty-four percent of the 225,000 commercial water heater units sold annually in the U.S. are gas driven, with associated positive impacts on source-energy efficiency. Similarly, data shows that 42% of commercial buildings heat water with natural gas. Low-cost, low-emission, compact commercial gas-driven burners could further reduce source-energy use.

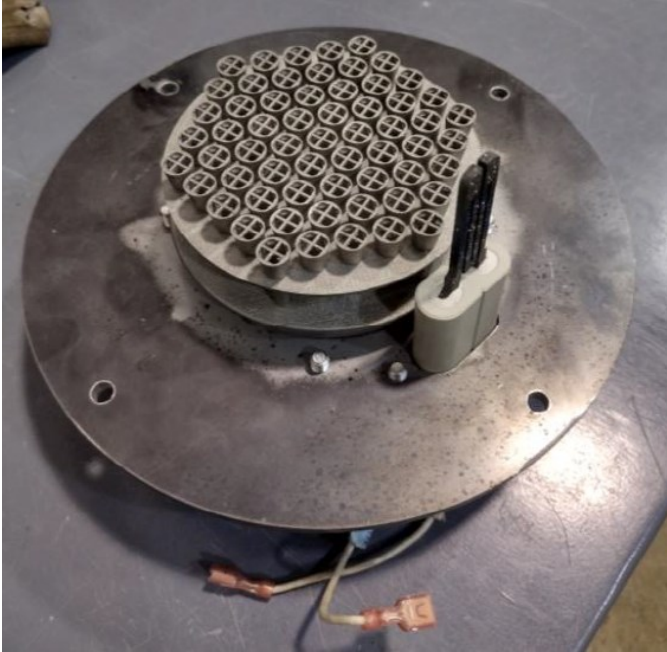
The technology to be advanced in this project can substantially reduce energy consumption in commercial buildings. Of the 40 quads used by U.S. buildings, 9% are used by the water heaters. An average 3% improvement in efficiency will lead to at least 0.12 quads of annual energy savings.

Other benefits of the advanced, patented nozzle burner technology are expected to be:

- Scalable to multiple designs and capacities
- Significant reduction in NO<sub>x</sub> emissions >75%, with turndown of 10:1 with CO emissions of <20 ppm
- Simple and robust, with potential lower first costs
- Installer- and manufacturer-focused



*3D printed hardware of the  $\beta$ -prototype design*



Test setup for 3D printed hardware -  $\beta$ -prototype design

- Reduced weight and size of the water heater; hence, lower cost and easier installation in tight locations
- Improved manufacturing ease and significantly reduced time to market
- Reduced noise (hence, more comfort), and
- Capable of integrating smart controls for smart-building applications.

## Technical Concept & Approach

In Phase 2, the project team designed and fabricated prototypes of a nozzle burner. This design considers the key features to be adapted for the prototype (e.g., flame stability within the water heater and smooth ignition). Two to three design iterations were fabricated by Oak Ridge National Laboratory.

After designing the prototypes, researchers will install the burner in a commercial water heater. The dimensions will be matched to have a drop-in design to replace the current burner. The design of the igniter may have to be modified.

The team will perform multiple ignition tests to ensure that the burner ignites reliably and smoothly at variable firing rates. This will determine the reliability and repeatability of the ignition process, even though the water heater usually operates at a constant firing rate. This will provide greater confidence in the ignition process.

After successful ignition testing, performance testing will be conducted. This will help determine the operability and turn-down characteristics of the advanced nozzle burner. The testing will be performed for different firing rates and different air-fuel ratios to evaluate the emissions and efficiency character-

istics. The firing rate will be varied to ensure operability and oxygen concentrations will be varied for evaluating emissions and efficiency performance.

## Results

Researchers designed, developed, and tested a 3D-printed advanced nozzle burner on a benchtop setup with the controls and blowers of a commercial water heater. Multiple design iterations were manufactured to improve operating characteristics and combustion performance and adapt the burner into the water heater for long-term steady and robust operation. Benchscale testing showed the burner can be adapted to a commercial water heater and is able to provide ultra-low emissions of  $<5$  ppm  $\text{NO}_x$  and  $<20$  ppm CO at 3%  $\text{O}_2$  and turndown of at least 8:1.

The novel burner was further developed to provide a drop-in retrofitable design for in-field and new water-heater installations. Design changes were made to the nozzle diameter and the number of nozzles were customized and designed to match the water heater chamber. Multiple design iterations of the advanced nozzle burner were 3D printed. A Phase 1 Final Report was issued in November 2020.

In 2021, the project team reviewed different integration methods for the burner within the water heater. The blower and the burner were and different firing rates were evaluated. The impact of the burner on upstream components such as a premixed air/fuel blower and the combustion dynamics, mixing, and emissions were evaluated.

In 2022, burner designs were further reviewed for adaptation and flame stability within the water-heater prototype. Researchers reviewed various methods for adapting the burner within the water heater. Testing showed that ignition was intermittent and the flame was not stable and, hence, further changes were made to the ignition scheme to ensure that the burner can be retrofit without any other modifications. The emissions testing showed that  $<9$  ppm emissions can be achieved.

In 2023 the  $\beta$ -prototype burner was 3D-printed and the team prepared the test setup for ignition and emissions testing of the nozzle

## Status

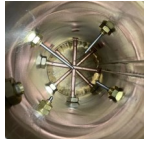
Phase 2 efforts are continuing. The project team is evaluating performance of the B-prototype nozzle for ignition and emissions.

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# Mitigating Methane Emissions from Residential and Light Commercial End-Use Equipment



**Research is being conducted to quantify the emissions and determine the conditions under which residential and light commercial end-use appliances release unburned hydrocarbons into the atmosphere, in order to identify best practices or design features to reduce methane emissions.**

## Project Description

Residential and commercial appliances are coming under increased scrutiny due to field-measured emissions of unburned hydrocarbons. However, field-derived emissions measurements are difficult to perform accurately and often lack the data resolution or flexibility to gain a full picture of emission events. This project generates laboratory measurements of methane emissions from appliances with the goal of generating greenhouse gas (GHG) emission factors, understanding the conditions leading to emissions, and identifying best practices or design features to reduce methane emissions. UTD's scientific research can help inform public dialogue on this topic.

In the first phase of this project, the team focused on assessing emissions from tankless water heaters (TWHs), which modulate directly in response to end-user loads. The high-input compact burners in TWHs frequently cycle on and off, which may increase their methane emissions.

In order to maintain outlet temperature stability while handling variable inlet water temperature and flow demands, these units ramp up and down their firing rate quickly, with 20:1 turndown ratios common for products available (which is unusual for most other gas-fired equipment). This is achieved in a number of ways. Staging multiple cassette burners is the most common method. Several burners (~16) are staged in groups, on and off, as sequenced by proportional gas valves. This allows for the highest possible turndown. Another method is use of a single ceramic "plaque" or flat woven/knitted fiber mesh, large enough and with an adequate thermal mass to permit a wide turndown ratio with a modulating gas valve. As the TWH shifts to meet the load, either rapidly staging burners on/off or modulating the single plaque/mesh burner, temporary loss of flame stability and delayed ignition can lead to temporary emission of unburned methane. While this transient effect is present with all cycling gas-fired equipment, TWHs by their nature are constantly adjusting the flame through staging or rapid and drastic modulation. Models from three different manufacturers of TWHs were tested under specific operating conditions and representative use patterns, in order to examine emissions from these various modulating methods.

Phase 2 and Phase 3 efforts expanded this project to exam-

ine furnaces, storage tank water heaters, and ranges, which have also been included in various field studies focused on residential methane emission measurements. Phase 4 builds on the work of Phases 1-3 in quantifying and identifying methane emissions in Res/Com equipment, and adds analysis of the effect of hydrogen blending.

## Benefits / Market Implications

The results from this study will support the continued improvement of residential natural gas appliances and the understanding of post-meter methane emissions. This includes standard residential gas appliances such as tankless/storage gas water heaters, furnaces, and residential ranges.

Tankless gas water heaters are currently the second most popular type of gas water-heating equipment, representing more than 10% of gas products sold in North America and more than 50% in Europe. The ability to clarify and mitigate the impact of TWHs and other gas appliances on GHG emissions will support the continued improvement of this technology for end users. Any potential restrictions that limit options to



*Furnace test bay with final modulating furnace installed for testing.*



use this type of high-efficiency device should be based on sound scientific study and consider potential product and technical advancements to minimize and mitigate potential releases.

## Technical Concept & Approach

Phase 1 focused on measuring unburned methane release from TWHs, and the results are summarized below.

A laboratory test setup from Phase 1 was adopted for Phase 2 to quantify methane emissions in furnace exhaust. In addition to steady-state testing, a control program was developed to operate the furnaces at a variety of part-load conditions to observe the impact of varying operation on emission profiles.

Researchers will use the laboratory measurements taken in Phases 1-3, supplemented with emission factors from literature where needed, to create a spreadsheet tool to estimate total residential appliance emissions based on selection of appliances in the home and adjustable operating patterns for space heating, water heating, and cooking over a range of climate zones.

In phase 4, the following tasks will be performed:

### Task 1: Literature Review and Methods Development

The team will review the current state of knowledge regarding emissions, including learnings from prior phases of this project.

### Task 2: Install and Test Res/Com Appliances

The team will install and test space heating and water heating appliances previously tested under Phases 1-3 with hydrogen blends up to 30% by volume to allow for direct comparison with emissions resulting from operation with methane/natural gas.

### Task 3: Test Industrial/Large Commercial Burners

The team will also perform benchtop tests of industrial/large commercial burners with hydrogen blends up to 50% by volume.

## Results

In Phase 1, researchers completed two tasks: 1) developing the test plan including specifications for the methane-analyzing methodology and 2) procuring and installing both a non-condensing TWH and a condensing TWH in a customized laboratory test rig. Plumbing and system controls were put in place to operate the TWH units. The project team engaged with a major university regarding the test plan as a complement to field sampling of TWHs. Input was also solicited from TWH manufacturers regarding system operation, compact burner modulation/ignition methodologies, and system controls with respect to the emission of unburned fuel.

Researchers developed methods to accurately measure the dynamic emission rate of methane from a modulating TWH and used various dynamic tests to simulate end-user behavior. Three TWHs were tested – representing a range of combustion system designs and the most popular models and manufacturers. The units were tested using steady-state, “step ramp-up”, and simulated-use patterns to establish typical methane emissions across products and combustion system designs. Through data analysis, researchers identified tankless designs, features, and operating conditions that can produce methane emissions. A list of recommendations for detection and mitigation of such conditions was developed.

Phase 1 findings showed that the tested TWHs produced measurable methane emissions through “puffing” at ignition/extinction, during modulation (depending on the burner design), during steady-state operation (depending on the burner design and firing rate), and during off periods. Both steady-state emissions and ignition/extinction emissions generally showed similar order of magnitude results as in prior field studies. Phase 1 findings were presented at the ACEEE Hot Water Forum conference on July 22, 2020, and in other venues to university researchers and other organizations.

In 2021 under Phase 2, researchers prepared the testing area and instrumentation for testing furnaces. A number of shakedown tests were performed to address issues with the methane analyzers, instrumentation, control programs, and data acquisition. Furnaces were tested in 2021-2022. Total hydrocarbon emissions data were collected for both steady-state and part-load tests to generate a full picture of the emission profile for typical furnace operation.

In 2023, furnace steady state testing (top) and part load cycling test (bottom) showing seven part-loads ranging from 40 -100% with one-hour cool down period in between each cycle. Methane spikes can be seen at ignition and extinction of the burner and is sub-atmospheric during combustion, indicating complete combustion of the gas during steady state operation.

## Status

Data analysis of all furnace testing (Task 2 Laboratory Assessment of Methane Emissions) has started. The team also reviewed additional relevant articles that were compiled on specific appliance methane emission measurements as well as end-use emission estimates.

The team has submitted an abstract to a 2024 gas industry research conference to present the findings from Phases 1 and 2. The Final Report for Phase 2 is in development.

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## Economical High-Efficiency Residential Gas Absorption Heat Pump with Integrated Cooling



**This project focuses on adding cost-effective cooling to a new low-cost gas absorption heat pump product that currently provides only heating and domestic hot water. An economical, integrated single unit that provides both air conditioning and high-efficiency heating can help more end users benefit from this exciting new product.**

### Project Description

A gas absorption heat pump (GAHP) can provide low-cost whole-house heating with significant improvements in efficiency over condensing furnaces and boilers. In addition to cost-competitive therm savings of up to 45% over conventional residential gas heating equipment, the GAHP delivers stable, comfortable temperatures without the need for auxiliary heating or backup and is projected to be ultra-low-NO<sub>x</sub> compliant with all combustion occurring outdoors. This project builds on other UTD efforts to bring to market a new heating-only, low-cost GAHP for the residential market.

One issue that might limit its adoption is that it currently does not also provide high-efficiency cooling. The economics of the heating-only GAHP (sized at nominal 80 kBtu/h output), with the aggressive equipment cost target of \$5,000, are generally suitable in cold climates and for large, single-family homes. However, the economics worsen in mixed or cooling-dominated climates, especially in the U.S. Southeast. As a result, cost-effective cooling is necessary for this product to broadly succeed and serve many ratepayers.

While GAHPs offer high efficiency and low emissions, existing GAHPs commercial products tend to be costly and have seen limited adoption in North America. The approach in this project will advance a new hybrid arrangement,

wherein the GAHP would have an electrically-driven compression cycle, and can share internal heat exchangers with the absorption heat-pump sealed system. In this project, a research team seeks to demonstrate an economical GAHP with integrated cooling that could offer a simple payback of less than three years for a hybrid system.

This project leverages co-funding from the Natural Gas Innovation Fund (NGIF) launched by the Canadian Gas Association (CGA) and moves from the development/design stage to a laboratory version of a packaged alpha prototype.

### Benefits / Market Implications

The hybrid GAHP with cooling is intended to broaden the energy and emissions savings potential of the GAHP, expanding the benefits of this technology for end users by providing applicability for mixed and cooling-dominated climates.

Of all U.S. single-family homes, 73% have central air conditioning (A/C). Early feedback from contractors and homeowners on the heating-only GAHP is that very few homeowners will permit having two large pieces of HVAC equipment outdoors. The advantage offered by operating with a chilled-water loop for A/C, using the single indoor coil, is that this is not a direct expansion system. This significantly reduces the refrigerant



*Prototype GAHP hybrid (left) and paired prototype air-handling unit (right).*

charge volume as it is only contained within the hybrid GAHP unit. In addition, many HVAC manufacturers are looking to refrigerants at higher pressures or with moderate flammability, which is challenging for conventional split A/C systems.

## Technical Concept & Approach

This project builds upon a gas-fired heat pump water heater (GHPWH) developed and supported in conjunction with UTD project 1.11.H and GAHP under 1.13.F, scaling up the same absorption heat pump technology by a four-fold factor.

Laboratory tests were conducted to estimate the hybrid unit's performance using standardized steady-state testing. In addition to standardized rating tests, an extended 24-hour simulated use test will be conducted in a virtual test home to obtain a complete mapping of performance and evaluate the impact of coincident loads. A purpose-built test-stand, water storage tank, and an environmental chamber will be used to evaluate space heating/cooling loads, domestic hot water loads, and outdoor ambient conditions.

## Results

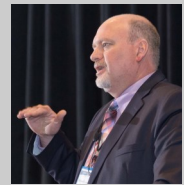
In 2020, the scope of the hybrid GAHP device was defined for the purposes of modeling. A modeling plan (assumptions, boundary conditions, etc.) was developed and simulation was executed. Researchers agreed on the operational parameters of the GAHP hybrid as it pertains to the initial building energy modeling task, using the heating GAHP modeling assumptions developed under prior efforts and absorbing modeled performance curves.

The project team ran models of single-family homes for several representative metropolitan areas, covering multiple climate zones and housing types (size, construction, occupancy) and performing annual energy assessments of hybrid GAHPs. Investigators are considering multiple baseline scenarios (all-electric, high/low efficiency, etc.). This modeling exercise will be extended to key U.S. regions, including: Chicago, Salt Lake City, Fargo, St Louis, Minneapolis, Portland, Rochester, San Francisco, Albuquerque, Atlanta, Los Angeles, and Tampa.

In 2021, the project team made upgrades and additions to the laboratory thermal heat pump test station, developed a test plan, and modified the test stand for the heating-only GAHP.

In 2022, after resolving several installation and unit issues, steady-state cooling tests and heating and dynamic tests were completed. Final results based on testing done by the team were reported to UTD members and also in a technical paper at the 14th IEA Heat Pump Conference held in May, 2023 in Chicago, IL.

*"UTD provides an invaluable contribution towards the advancement of innovative, very high-efficiency products within the gas and energy industry. Without UTD's support on numerous projects over the prior 10 years, SMTI would not have been able to prove out and de-risk our family of affordable thermally-driven heat pumps, a critical first step before investors will step in to support commercialization activities. Our Hybrid GAHP/AC heat pump model will help move gas heat pumps from a solid niche to the mainstream HVAC/water heating market."*



- Michael Garra-brant  
Founder and CEO  
Stone Mountain  
Technologies, Inc.

Key highlights from this test program included defining this alpha prototype's seasonal heating and cooling performance with an AFUE of 121.6% and an estimated SEER of 8. The seasonal cooling performance is lower than the target and is influenced by the compressor selection, this estimated SEER rating would not be acceptable by conventional standards (min. SEER = 13, soon to be increased). For heating operation, the performance degradation is mainly due to the cyclic operation of the hybrid system and the standby electric load. For this first-of-a-kind prototype, the project team have published these key results and findings in addition to modifications/improvements to meet targets. Concerning GAHP emissions, the CO emissions ranged from 11.5 to 101 ppm air-free and NOx emissions were Ultra-Low (7 to 8 ng/J), both of which are already below performance targets.

## Status

Phase 2 has been completed. A Final Report was provided to UTD members in November 2022, and the current results were publicly reported in May 2023 as summarized above. The team is now working on Phase 3 which will design, fabricate and evaluate in a laboratory a modified prototype unit which will employ using other low-GWP refrigerants with a goal to increase useful heat recovery within the operating cycle in order increase overall system efficiency.

The project team continues to partner on this project with Stone Mountain Technologies, Inc. (SMTI), the developer of the technology which has made substantial progress commercializing the heating-only GAHP unit. In July 2021, it was announced that UTD member Enbridge had invested CAN \$4,000,000 in SMTI. In November 2022, SMTI announced closing of US \$15,000,000 in Series A funding. As of October 2023, initial production runs of GAHPs from SMTI's factory were underway.

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## Gas Heat Pump RTU Cold-Climate Performance Assessment



**This project demonstrated a gas-engine-driven heat pump incorporated in a packaged rooftop unit to quantify its cold-climate performance, reductions in peak electric and peak gas demand, and environmental benefits.**

### Project Description

Gas-engine-driven heat pumps (GHPs) are an important gas cooling and heating option for commercial buildings when considering electric-demand reduction initiatives. Previous studies demonstrated that GHPs can reduce peak electric demand by 6 kW to 15 kW, compared to electric variable refrigerant flow (VRF) systems, or conventional rooftop units (RTUs), respectively.

GHPs can also reduce peak gas demand. GHPs have high heating efficiency due to the use of engine heat recovery to boost performance during the winter. This increased heating efficiency will reduce peak gas demand, generate energy savings, and reduce full-fuel-cycle greenhouse gas (GHG) emissions when compared to a baseline standard-efficiency RTUs.

Compared to electric heat pumps, GHPs have two key advantages in heating operation for cold climates. GHPs use engine heat recovery to: 1) avoid a defrosting cycle and 2) maintain heating capacity and supply temperatures during very cold ambient temperatures. Electric heat pumps require periodic defrosting at ambient temperatures below 40°F. Conventional defrosting uses reverse cycling, which results in an inherent energy penalty because it removes heat from the indoor air during the defrosting period. GHPs avoid the need for a defrosting cycle by controlling the flow of the recovered waste heat from the engine and maximizing the heat-recovery process.

A second advantage is to avoid supply temperatures which can result in the “cold blow” effect (delivery of air at less than body temperature) that compromises indoor thermal comfort. GHPs use engine heat recovery to supplement heating output in order to maintain both indoor supply temperatures and heating capacity, which can be a problem with current electric heat pumps. In cooling and moderate heating mode conditions, engine waste heat can also be directed to an optional supplemental water heater, maximizing system efficiency.

This field study quantified the performance and benefits of the packaged natural gas engine-driven heat pump rooftop unit for (PGHP) high-efficiency space conditioning for commercial buildings in cold climates. This rooftop configuration is a unique GHP design with potential for wide adoption and lower installation costs by using the same footprint as conventional packaged rooftop units. Although this model successfully demonstrated high-efficiency cooling performance and reliability in very hot climates, this field study was one of the first cold climate demonstrations of the packaged GHP. The objective of this study was to validate cold climate performance and identify any design changes needed to optimize this technology for cold-climate applications.

This project was conducted in partnership with the New York State Energy Research and Development Authority (NYSERDA) and National Fuel Gas Company, with NYSERDA providing the prime funding for this research.



Image credit: Blue Mountain Energy

*Blue Mountain Energy's packaged rooftop gas-engine-driven heat pump.*



## Benefits / Market Implications

GHPs can provide economic and resiliency benefits for commercial buildings and gas customers, such as life-cycle cost savings with favorable time-of-use rates or electric-demand charges, and infrastructure capital cost savings due to lower peak electric demands.

## Technical Concept & Approach

### • Site Selection and Baseline Monitoring

Select a site representing a potential end user for GHPs, including facilities such as offices, schools, health clubs, gymnasiums, hospitals, retail buildings, and restaurants. A small gas station and grocery store in Buffalo, NY was selected for this demonstration.

### • PGHP Installation and Demonstration Plan

Develop the demonstration plan for the selected site, and then specified, installed, and commissioned the instrumentation and data-acquisition system.

### • PGHP Performance Monitoring

Monitor the performance of the PGHP from 2020 through 2021 to determine annual energy use and costs across the full range of operating conditions.

### • Data Analysis

Analyze measured data to determine heating and cooling delivered, energy consumption, reduction in peak electric demand, GHG emission reductions, and energy cost savings relative to baseline. Estimate simple paybacks.

### • Innovative Desiccant Proof of Concept

Develop at laboratory scale an innovative 3D-printed desiccant wheel with thermo-responsive desiccants to enhance energy efficiency and thermal comfort in buildings. UTD and partners National Renewable Energy Laboratory, Blue Mountain Energy, and TCPoly will design, build, and demonstrate a proof-of-concept prototype. Separating sensible and latent cooling by using desiccants have shown up to 30% savings of primary energy. Compared to conventional desiccant systems, the proposed design has potential to reduce energy consumption by reducing the additional sensible load due to desiccant regeneration.

## Results

This field study confirmed significant peak electric-demand reductions, which may qualify for electric-demand response programs or non-wire initiatives. The measured peak demand during cooling was 4.38 kW, a significant decrease (76%) from the 18 kW summer peak demand associated with a conventional RTU using natural gas heating and electric

cooling. A comparable electric heat pump would generate 22 kW peak demand during heating operation, excluding any supplemental heating at low temperatures.

The PGHP demonstrated high cooling efficiencies with a seasonal average of 1.19 COPg (Coefficient of Performance on gas use) which aligned with rated efficiencies of 1.12-1.24 COPg reported from laboratory testing. Although the PGHP demonstrated high heating efficiencies in laboratory testing (1.4 COPg at rated conditions), the heating efficiency measured at the field site was lower than expected. Some heating-performance issues were discovered at lower ambient temperatures that will require further investigation by the product design team; this type of anomaly is not unexpected for the first cold-climate demonstration. As noted, a key objective of this study was to identify design changes needed to optimize PGHP heating performance and effectively implement this design in colder climates.

Based on regional utility pricing, the PGHP can reduce energy costs up to 44% compared to conventional and electric heat pump RTUs due to high-efficiency operation, low-cost natural gas, and reduced demand charges. Further cost reduction of the PGHP design is needed to achieve more favorable paybacks. Upstream GHG emissions for the PGHP were similar to conventional and the electric heat pump RTUs based on regional non-baseload power-generation mix; however, engine operation generated additional onsite GHG emissions, highlighting the need for an engine design that can optimize performance while minimizing emissions.

The project team analyzed the experimental NREL data on new thermo-responsive desiccant samples. A computational model was developed to optimize the geometry of the thermo-responsive desiccant channels and the desiccant wheel based on the NREL experimental data.

A conference paper which summarized the results of the rooftop GHP demonstration was presented at the 2023 ASHRAE Winter Meeting on February 5, 2023.

## Status

A public summary dated April 6, 2022 of the Final Report for Tasks 1-4 of UTD project 1.18.I is available on the Reports page of UTD's public website.

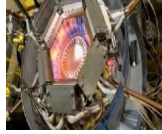
For Task 6, the project team is waiting to receive NREL's input data for the computational model. The modeled output will then be compared to the measured experimental data.

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## Integrated, Self-Powered, High-Efficiency Burner System



**Researchers are developing a grid-resilient, self-powered, fuel-flexible, high-efficiency Advanced Burner Thermoelectric Generator that can be installed in many residential and commercial building space- and water-heating systems to improve their resiliency, reliability, and efficiency.**

### Project Description

The goal of this project is to develop and demonstrate a laboratory prototype of a grid-resilient, self-powered, UTD-patent-pending, thermoelectric generator (TEG) system integrated into a commercial water heater. Initial development efforts focused on demonstrating this at a 40,000 Btu/h capacity, while current efforts are scaling up development to ~200,000 Btu/h capacity.

The integrated system consists of two key subsystems: 1) a 3D-printed high-efficiency, ultra-low-emissions, fuel-flexible, modulating burner integrated with 2) a commercially-available low-cost, high-efficiency, high-operating-temperature TEG. The project seeks to demonstrate and advance towards commercialization a design that is drop-in retrofittable, self-powered, grid-independent and with fast payback (<2 years). Specific project success goals are to:

- Effectively integrate the TEG system with the water heater to maximize the power output, electrical and controls scheme and water integration
- Demonstrate 200 hours of continuous grid-independent operation via sufficient electrical self-generation (100 We) to exceed power demands for water heating systems
- Demonstrate that the water heater can operate without any external power for a wide range of hot water demand profiles.



*Water heater with damper, data acquisition system and water load simulator for testing (left). Programmable water load simulator (right)*

- Demonstrate ability to accommodate 5-10% hydrogen blending into natural gas.
- Show how design can be a drop-in solution for a representative product application with no substantial changes to the water heater installation process
- Achieve an expression of interest or commitment from a major manufacturer to advance this prototype towards a commercial product.

Phase 2 will develop a larger-scale system and build upon the accomplishments achieved in Phase 1, which developed and demonstrated the core configuration of the TEG-integrated system.

### Benefits / Market Implications

The primary target markets are new and retrofit installations of existing water heaters in the light commercial sector. The global commercial water heater market is projected to grow from \$5.98 billion in 2021 to \$8.69 billion in 2028. The largest shares of the market are in healthcare, restaurants, institutions and offices. A self-powered commercial scale water heater technology would offer a low cost option to continue hot water production during power outages as well use in remote areas and emergency situations without the need for external power. Reliable supply of hot water is essential for many key functions in both residential and commercial sectors, including such as community warming shelters, police and fire stations, urgent care medical facilities, etc.

The technology aims to ensure safe, reliable, and resilient operation and increase integration with renewable energy (RE) sources such as hydrogen produced from RE.

### Technical Concept & Approach

In this project researchers will design, develop and test drop-in TEG burner, and develop commercial prototype designs for TEG-integrated self-powered water heater at 40,000 and ~200,000 Btu/hr capacities. The following tasks will be performed in the current phase of the project:

### Task 1: Finalize system architecture

Finalize and assess integration of the TEG with the ~200,000 Btu/hr water heater. Review the installation of the TEG and its impact on the operation, reliability, and safety. Perform a trade-off analysis to ensure optimized electricity generation from the TEG. It is important to have a drop-in design with minimum modifications to the heating system. Evaluate the TEG's operational efficiency, location with respect to the burner, and impact of modulation. Miniaturize controls. Optimize integration of the TEG and burner.

### Task 2: Integration of the TEG System with WH Controls

Design the controls and optimize the operational performance of the TEG module and integration components. Integrate the module into the water heater to ensure minimum energy usage with the water supply. Accommodate stresses to account for the TEG materials and modules with multiple interfaces being susceptible to failure during thermal cycling. Integrate the system to maximize temperature gradients and achieve maximum power output with minimal design modifications. Perform thermal and emissions characterization with and without the TEG to ensure the TEG does not impact the burner performance. Build and test the TEG module, including heat sink and cooling, with the water heater burner to characterize its operation and fine tune its arrangement and positioning.

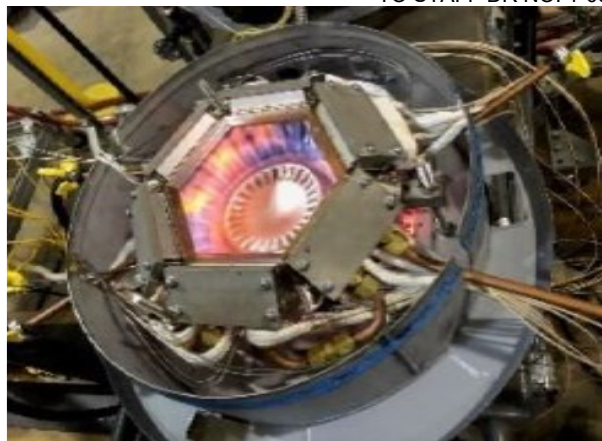
### Task 3: Integrate subsystems testing

Integrate the TEG module into the water heater and test over several days of uninterrupted operation at different water load profiles, covering from low to high water demand while ensuring continuous hot water management. Analyze test data to assess integrated system performance against KPIs. Develop designs for TEG integrated self-powered water heaters. Estimate costs of the integrated system towards a commercial prototype and the scope of its potential market.

## Results

The team performed a detailed analysis to down-select three different materials for the TEG. In addition, three different water heaters were reviewed.

In 2020, researchers performed Computational Fluid Dynamics (CFD) analysis for the fuel-flexible burner and generated a solid model, which was 3D-printed. Two water heaters were installed in the laboratory for power-consumption and thermal characteristics testing. A test rig was set up for operation with hydrogen including the appropriate interlocks and improved exhaust system. Testing and evaluation of the residential water-heater burner were performed, with temperature, emissions and electrical power demand analyzed. Different TEG integration methods and designs were evaluated. In addition, a preliminary model for hydrogen/natural-gas mixtures was developed for CFD analysis.



*TEGs assembled around burner unit*

In 2021-2, testing was performed on multiple TEG units of different power levels and physical dimensions to understand the power output. Initial CFD analysis of the burner and bench-scale setup for burner testing was completed. An analysis of an advanced 3D-printed burner was performed for hydrogen testing. Testing with the 3D burner demonstrated <5 ppm NOx emissions. Methods to improve the performance of the burner for pressure drop and air-fuel mixing were evaluated. Researchers also analyzed different single-nozzle burner designs. Further CFD modeling of the burner was completed, and key design improvements were identified and implemented. Testing results demonstrated that <5 ppm NOx emissions can be achieved for the entire firing range and with different levels of hydrogen blends with natural gas.

A Final Report which summarized Phase 1 results was provided to UTD members in October 2022.

In 2023, Phase 2 efforts were launched, and the team reviewed power demand for the larger water heater and started developing an integration design for the prototype larger-capacity TEG and water heater.

## Status

The team is currently working on the design to integrate the larger-capacity ~200,000 Btu/hr TEG burner within a water heater, and continuing to discuss and evaluate this technology development with major water heater manufacturers.

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# Sequestering Non-Condensable Gases for Enhanced Gas Absorption Heat Pump Reliability

**Researchers are developing technologies to enhance the long-term system efficiency, economy, and reliability of any absorption-type heat pump while also reducing maintenance requirements and costs. Plans are to demonstrate the technology in a prototype gas absorption heat pump.**

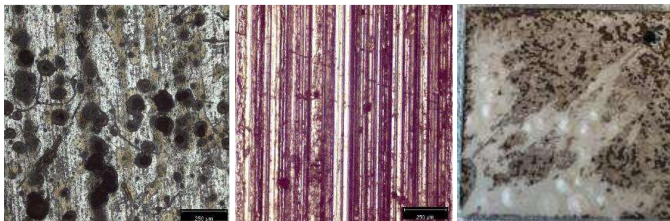


## Project Description

A significant factor that influences the cost effectiveness of high-efficiency gas absorption heat pumps (GAHP), which represent the most technologically mature option for thermal-driven heating and cooling systems, is the need for corrosion protection. The ammonia-water or strong salt absorbent/refrigerant working fluids used in absorption cycles typically create high-temperature, high-pH environments that have a tendency to form hydrogen (a non-condensable gas that degrades system efficiency), and can attack steel surfaces, promoting stress corrosion cracking and failure.

To successfully advance the use of GAHPs, it is important to minimize the impact of non-condensable gases (NCGs) on long-duration performance and reliability, and make other cost reductions. The goal of this project is to design and develop NCG isolation (NCGI) modules and provide research and development support to employ novel, low-cost aluminum heat exchangers to increase long-term system efficiency and reliability and safe operation, and reduce the cost of any GAHP. Phase 1 of this UTD project provided co-funding to a prime contract funded by the U.S. Department of Energy (DOE) with the general goal of reducing the cost and improving the reliability of residential and light commercial-sized GAHPs. Specific goals for the current Phase 2 work are:

- Develop a prototype bench-scale NCGI module, and demonstrate its operation in venting and storage modes
- Integrate several NCGIs into operating GHPs
- Demonstrate successful operation, maintaining < 5% loss in COP over simulated one-year of operation.



**(Left)** Alloy AA3003 at 100x after 60-day immersion in 28-30 wt% ammonium hydroxide solution. The micron marker is 250  $\mu\text{m}$   
**(Middle)** Alloy AA6061 Sample 1 at 100x after 60-day immersion in 28-30 wt% ammonium hydroxide. The micron marker is 250  $\mu\text{m}$   
**(Right)** Alloy AA5052 Sample 2 after 60-day immersion in 28-30 wt% ammonium hydroxide

Ref: Garrabrant, M., Newland, J., Glanville, P., Spicer, K., and Frankel, G. (2022) Improving Reliability, Weight and Cost of Gas-Fired Absorption Heat Pumps. United States: N. p., doi:10.2172/1886933

## Benefits / Market Implications

High-efficiency GAHPs are strategically important to achieve energy efficiency and decarbonization goals. This project seeks to ensure optimum long-term performance, economy, and reliability of these new product categories for end users.

The efficiency of GAHPs that use ammonia-water or strong salt absorbent/refrigerant working fluids can slightly decline over time as NCGs are created within the system. An economical and effective NCGI module will increase the long-term efficiency of GAHPs while simultaneously enhancing their reliability and reducing periodic maintenance expense.

Current GAHP heat exchangers use carbon in part because steel tube/aluminum fin evaporator copper coils are not compatible with ammonia-water solutions. As such, the evaporator coils of GAHP systems are the heaviest and most expensive part of the system. By shifting to an aluminum evaporator (provided that corrosion issues are within control), the GAHP may be significantly lighter and less expensive. The evaporator coil in a standard 80 kBtu/h GHP weighs about 150 pounds; however, an all-aluminum coil could weigh just 25 pounds and might save perhaps \$375.

## Technical Concept & Approach

Both building on experience with gas absorption heat pumps (GAHPs) and their corrosion control and leveraging technol-



Laboratory setup assembly.





*"Succeeding today's gas furnace and water heater are highly-efficient gas heat pumps (GHPs) — the future for space- and hot-water heating. However, to gain customer acceptance, GHPs must be highly reliable, similar to a gas furnace with extremely low maintenance. One of the critical issues for long-term reliability of absorption GHPs is the removal of non-condensable gases. We're very pleased that this UTD-funded technology development, in partnership with U.S. DOE, will further enhance GHP reliability."*

- Aqeel Zaidi  
Manager, Technology Development  
Enbridge Gas Inc.

ogy developments in chemical processing, the team will develop and demonstrate solutions to handle NCGs through isolation, storage, or both. The current project phase will perform the following tasks:

#### **Task 1. Non-condensable Gas Isolation Analysis and Final Design**

- Aggregate findings from 25+ GAHP field demonstrations and long-term laboratory testing to further characterize NCG development and the impact/benefits of removal/isolation.
- Finalize the design NCGI module specification, compatible with GAHP units from Robur, SMTI, Vicot and other leading OEMs.
- Finalize the selection and preparation for the H<sub>2</sub>-selective membranes using a membrane system developed for nuclear fuel applications, building on prior literature survey and bench-scale data collection during Phase 1.

#### **Task 2. Bench-Testing of NCGI**

- Perform bench testing on multiple versions of the NCGI module, using a modified NH<sub>3</sub>/H<sub>2</sub>O Corrosion Test Station at GTI to provide a simulated environment for each module.
- The NCGI module will be in communication with an NH<sub>3</sub>/H<sub>2</sub>O mixture at representative conditions (concentration, temperature, pressure), while a controlled amount of H<sub>2</sub> will be fed into the volume to come into contact with the NCGI module to quantify H<sub>2</sub> selectivity, transfer rates, and need for module thermal management

#### **Task 3. In-situ GAHP Evaluation of NCGI Prototype**

Two evaluations will be performed to frame control options:

- A GAHP will be operate for an extended period of time on an automated test stand for 30 days of accelerated opera-

tion exposed to the NCGI module, then the NCGI module is deactivated/removed and the AHP performs a second 30 day period of operation comparing the performance and operating pressures.

- After the 30 day period without NCGI activation, the NCGI will be activated and exposed to the AHP suddenly, with several repeated on/off cycles of the NCGI module to understand the dynamics of intermittent module activation and the short-term impact on GAHP performance.

## **Results**

In 2020 through 2021, the project team completed rounds of corrosion testing with the alloy samples using a custom-built corrosion test stand. In parallel, university researchers initiated atmospheric pressure testing. Testing included bare metal (baseline) and various coatings – in total, 96 alloy and 16 low-carbon steel samples. The project team reviewed the results and shifted towards the next set of alloys for testing. Tests were completed in 2022 and a Phase 1 Final Report was issued. This last round of testing included an evaluation of a range of corrosion-protection solutions for proprietary aluminum alloy coupons from a third party and several baseline coupons. Each coupon test was at two ammonia concentrations, mid (50%-75%) and high (90%-95%), and the coupons were tested in pairs with duplicates for each run – in total 64 test points for this project.

In current Phase 2 efforts, the project team has performed preliminary analysis using corrosion simulation software to evaluate the corrosion mitigation capabilities of degassed water against normal water when mixed with 10% NH<sub>3</sub> solution. Unlike as learnt from previous literature, the use of degassed water did not have a significant impact over corrosion mitigation of carbon steel. The dissolved gases in the normal water are helping to reach the safe pH levels where passivation of carbon steel is possible. To better understand this, the project team has decided to perform a few preliminary tests to evaluate the validation of the results obtained from the software.

## **Status**

The project team is making improvements to the testing apparatus, including the pressure test vessels. The project team is also in communication with commercial membrane manufacturing partner, and will identify and purchase 2-3 hydrogen getters after the preliminary tests are completed.

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## Yanmar Three-Pipe Gas Heat Pump Cold Climate Case Study



Researchers evaluated the performance and economics of the Yanmar three-pipe natural gas-engine-driven heat pump (GHP) in a cold climate. The GHP performance curves developed in this project can help refine GHP models in EnergyPlus™ to better support designers, end-users, and others in decision-making and shaping energy efficiency programs and incentives.

### Project Description

Natural gas engine-driven heat pumps (GHPs) provide high-efficiency space heating and cooling using an advanced natural gas engine in place of an electric motor. GHP engines have a demonstrated long life and extended maintenance intervals of about 10,000 hours.

GHP heating output is supplemented by heat recovered from the engine cooling jacket and exhaust, similar to a combined heat-and-power system, increasing overall system efficiency. In contrast, electric-driven heat pumps typically require back-up heating to supplement the heat pump output at low outdoor temperatures.

GHPs combine high-efficiency heating and cooling (1.0-1.4 coefficient of performance – COP<sub>g</sub> – at rated conditions) to significantly reduce peak electric demand and electricity use with potential savings in operating and lifecycle costs, as compared to electric variable refrigerant flow (VRF) heat pumps or conventional HVAC equipment.

GHPs have a significant share of the Japanese and European space-conditioning markets, and became available in the U.S. in 2016. Yanmar offers a range of GHP VRF (GVRF) systems, from 8 to 14 tons. While most of these products are two-pipe systems that can operate either in cooling or heating mode, Yanmar's 14-ton GHP has a three-pipe heat-recovery VRF system that can simultaneously provide heating and cooling.



Seven installed GHPs at the host site in Dover, DE.

Multiple prior field demonstrations reported significant reductions in electric usage, demand charges, and water use, generating cost savings that more than offset the initial cost premium of GHPs. According to one manufacturer, GHPs reduced operating costs by up to 30% and electricity usage by up to 80% compared to electric heat pumps. UTD project 1.19.F evaluated the performance and economics of Yanmar's three-pipe GHP in a cold climate (Delaware) and built upon a prior field evaluation of the three-pipe GHP in a warm climate (Georgia) in recently-completed UTD project 1.17.G, which reduced peak electric demand by 8 kW (98%) in heating and 10 kW (96%) in cooling as compared to an electric three-pipe VRF, and reduced peak electric demand by 11 kW (96%) in cooling as compared to an electric multi-zone rooftop unit with electric cooling.

### Benefits / Market Implications

End users in facilities and markets such as these can benefit from this technology:

- Multi-zoned commercial buildings, such as office buildings, retail, schools, hotels, health clubs, nursing homes, and mid/high-rise multifamily residences
- Facilities that benefit from life-cycle savings, such as commercial offices, government facilities, factories, schools, and other owner-occupied buildings, and
- Electric-grid-constrained markets or regions with relatively high electricity prices and/or high demand charges.

This demonstration will help end users assess the value of gas engine-driven heat pumps while supporting ongoing efforts to refine cold climate performance data in EnergyPlus™ and other modeling software, including through UTD project 1.21.E.

### Technical Concept & Approach

The project team identified an existing Yanmar three-pipe GHP installation in Delaware as a demonstration site. Using measured performance data, researchers determined net

energy savings and economics based on natural gas consumption, electricity use, and electric demand. Specific project tasks included: site selection and development of a field test plan; site monitoring and data analysis.

Key performance objectives are to: 1) achieve acceptable efficient heating and cooling performance, 2) demonstrate efficient part-load performance, and 3) demonstrate capacity and efficiency under cold ambient conditions.

## Results

For the demonstration, the project team selected a multi-story, multi-zone office building located in ASHRAE climate zone 4A. Seven GHP systems provide zoned heating and cooling to the entire facility. Ventilation air was delivered to each zone from an Energy Recovery Ventilator (ERV) unit, which conditioned outside air to space neutral conditions. One of the seven GHP systems was selected to be studied in this demonstration. The selected GHP was a 3-pipe, 14-ton GVRF system with ten indoor Fan Coil Units (FCUs) that supplied zoned heating and cooling to office spaces. The tempered outside air was ducted into the indoor FCU before being supplied into the conditioned space. All of the 10 indoor FCUs associated with GHP-3 were ducted, which allowed for accurate measurement of return and supply air. The GHP outdoor unit and corresponding FCUs were instrumented to monitor energy use and performance. The GHP system was monitored from December 2021 to April 2023 to evaluate its performance across the full range of ambient conditions and equipment operation.

Due to the field site's cold climate, the GHP operated in either heating mode or simultaneous heating/cooling mode for a majority of the time. Cooling operation was extremely limited and only occurred sporadically during the summer.

### Part-Load Operation:

The GHP was sized for peak heating loads and predominantly operated in the 25% to 50% part-load ratio range, while ramping up to 60% on very cold days. This sizing strategy is common practice for sizing HVAC equipment and the resulting operation, especially at extremely low part-loads (below 30%) impacted both heating and cooling performance.

The performance data of the GHP was broken down into hourly steady-state values (i.e., when the outdoor unit ran for the entirety of the hour). This eliminated cycling and other ramp-up and ramp-down inefficiencies of the GHP system. The GHP achieved rated heating efficiencies up to 2.0 COPg during extended steady-state runtimes. Steady state efficiencies on days with below-freezing temperatures ranged from 1.0 to 1.32, which were in line with the rated efficiencies. This highlighted that the GHP did not show any drop in performance or capacity during cold ambient days. Measured seasonal efficiency was 1.2 COPg for heating and 0.72 COPg for cooling, excluding simultaneous operation. Unfortunately,



- Shane Breakie  
VP of Sustainability and Growth  
Chesapeake Utilities Corporation

*"Chesapeake Utilities integrated 7 state-of-the-art Natural Gas Heat Pump (GHP) units during the construction of our Corporate site in Dover, DE, more than 5 years ago. Since then, we've not only experienced substantial savings and heightened comfort levels but have also successfully transformed our site into a showcase for the community, highlighting the efficiency of this advanced HVAC technology."*

reduced efficiencies were seen for cooling due to ERV commissioning issues at the site. The ERV supplied ventilation air at very low temperatures leading to artificial calls for heating even when the outdoor temperatures were high.

### Simultaneous Operation:

The GHP system exhibited significant runtime in simultaneous heating and cooling mode. Researchers believe that this was due to a combination of fan coil placement, zonal thermostat set points and ERV supply air temperatures. Daily performance for simultaneous operation ranged from 0.36 to 1.84 COPg.

Comparisons were made between the 3-pipe GHP performance datapoints generated in this project to the results of prior part-load performance curve data by others for the same 2-pipe GHP unit. The project team noted good correlation between the two datasets making it a great candidate to generate a refined performance curve fit for EnergyPlus. The agreement between these datasets also suggested that the performance of a 2-pipe VRF system in heating or cooling operation can be equated to the same 3-pipe VRF system in pure heating or cooling operation.

## Status

This project is complete and a UTD final project report is being reviewed and finalized. This demonstration and analysis generated a crucial performance dataset for the Yanmar GHP in a cold climate to support the development of refined GHP models in EnergyPlus in coordination with efforts underway in UTD project 1.21.E, and to support designers, end-users and others in their selections of energy efficient options. Results of this research will be disseminated at the 2024 ASHRAE Winter Conference as a conference paper presentation.

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## Robur and SMTI Low-Capacity Gas Absorption Heat Pump Laboratory Evaluation

**This project evaluated the performance of new low-capacity gas-fired absorption heat pumps, specifically the Robur K18 (60 MBH) and SMTI 40K (40 MBH) units, since they may soon enter the North American market. Best operating practices were identified to apply these highly-efficient units in high-performance residential**



### Project Description

Cost-effective, right-sized, and properly-installed Thermal Heat Pumps (THPs) will be a crucial linchpin for society and end users to meet aggressive energy-efficiency goals. However, an impediment is that most low-load, new-construction residential HVAC systems installed are vastly oversized, often installed with oversizing factors greater than 1.4 dictated by the Air Conditioning Contractors of America (ACCA). Significant improvements in building envelopes (per 2006 and later codes) have also reduced thermal loads, regardless of climate. Many existing homes now would only require low-capacity heating systems, typically under 60 MBH of heating output (MBH = 1,000 Btu/hr).

Low-capacity heating systems are broadly classified as those with a nominal output of less than 60 MBH or lower. These systems typically apply to new construction, with envelopes built to modern codes or retrofits where envelope improvements and other measures are employed. Focus on this low-capacity product category is also essential for the

emerging suite of highly-efficient THPs because they will be more expensive than furnaces on a per-MBH basis.

Robur Corporation is one of the most mature manufacturers of light-commercial-sized absorption-based gas heat pumps (GAHPs), with products available in Europe for 15+ years and the U.S. for 10+ years. Robur sells GAHPs direct to consumers through a distribution network. The company has discussed bringing its low-capacity (60 MBH) residential-scale K18 units from Europe to North America. However, greater granularity is needed to develop seasonal performance metrics and identify best practices to optimize its application for the North American market, which predominantly uses forced-air distribution.

In several phases of efforts with the U.S. Department of Energy, the California Energy Commission, and UTD, researchers also provided substantial technical and project support to Stone Mountain Technologies, Inc. (SMTI), to bring a residential-scale ANESI GAHP to market based on the single-effect vapor-absorption cycle. This effort included installing prototypes at eight residential field test sites, with future placements and adding a vapor compression system for cooling in parallel – all focusing on the retrofit size category of 80 MBH nominal.

GAHP systems are very suitable for cold climates due to specific design features and using NH<sub>3</sub> as an efficient refrigerant. Seasonal efficiencies of up to 140% are feasible. These GAHP systems are generally geared towards the retrofit market, replacing furnaces and, to a lesser extent, boilers – including water heaters when deployed as a combination system. Considerable resources have been applied to develop standard-sized GAHPs for light commercial/large residential applications; these efforts include the design and demonstration of SMTI 80 MBH systems and the deployment of commercially available Robur GAHP-A units. A portion of this UTD project seeks to apply and prove out findings and strategies regarding an emerging prototype ANESI GAHP that is half the size – rated at 40 MBH.

In summary, the objective of this project was to evaluate and optimize the performance of low-capacity GAHPs, specifically the Robur K18 (60 MBH) and SMTI 40K (40 MBH) units, when applied to residential combination space/water heating systems (forced-air heating) to fill out the product portfolio and target low-load, new-construction applications. How the



*A prototype North American Robur K18 GAHP installed inside a laboratory environmental test chamber*





SMTI 40K Hybrid GAHP system installation in HVAC laboratory. (left) The installation of the GAHP in a environmental chamber; (right)

GAHPs perform in, addition to how system parameters are optimally controlled (system modulation, space vs. water heating modes, air handler operation, etc.) was determined in this experimental effort. For GAHP combination systems, a reduction in oversizing factor is recommended relative to ACCA guidelines for gas-fired furnaces.

## Benefits / Market Implications

The primary target markets impacted are as follows:

**Equipment Type:** Air-to-water gas-fired heat pumps, absorption-type (space heat: forced-air or hydronic; water heat: DHW via indirect tank)

**Application:** Residential low-capacity homes and low-rise multifamily

**Climate:** Heating dominant, but all apply.

The anticipated benefits to ratepayers of developing system-integration strategies to optimize low-capacity GAHP operation in high-performance homes include:

**Efficiency:** Reduction in gas consumption for space/water heating by 40% or greater, with nominal incremental electricity consumption

**Emissions:** Reduction in greenhouse gas emissions by 40% or greater while broadly deploying ultra-low-NO<sub>x</sub> solutions, and

**Health and Safety:** Elimination of indoor air quality and venting concerns with combustion outdoors and the broad utilization of natural refrigerants rather than ozone-depleting or high-GWP refrigerants.

## Technical Concept & Approach

In this effort, the project team performed a laboratory-based experimental investigation of two low-capacity GAHP systems, with the goals of 1) developing high-resolution performance curves to estimate seasonal performance and develop high-resolution simulation tools and 2) optimizing GAHP performance as a combination system by developing control strategies with off-the-shelf air-handling units and storage tanks, and 3) evaluating GAHP reliability during an extended operation test in an outdoor environment. Comparative performance and opportunities for further product development were highlighted with the GAHP OEM partners.

Through 24-hour simulated-use testing, the researchers strove to optimize the interaction between GAHP and system components (e.g., indirect tank, air handler) to improve daily efficiency to be within 10% of seasonal ratings.

## Results

The project team evaluated the SMTI 40K hybrid and Robur K18 GAHPs in a laboratory per the revised ANSI Z21.40.4 method of testing. Test results demonstrated that both technologies can operate within a seasonal AFUE of 120% relative to the U.S. national average climate zone while operating within ultra-low-NO<sub>x</sub> and South Coast Air Quality Management District (SCAQMD) emissions limits.

The alpha prototype SMTI 40K hybrid GAHP system was also evaluated with a prototype advanced air handler unit (AHU) in a Virtual Test Home (VTH) in the laboratory. The testing program optimized controls and right-sizing for the subsequent production-version AHU.

## Status

Evaluations of the SMTI 40K hybrid and Robur K18 GAHPs have been completed, and the results were very promising. A Final Report was issued to UTD members in March 2023, and overall results were shared with the GAHP OEM partners to help them improve their final product designs, including recommended firmware upgrades. As UTD members and other North American gas utilities support roll-out and deployment of GAHPs, and residential building envelopes continue to improve, the findings of this UTD project will help ensure successful and efficient field deployments of very-high-efficiency, low-capacity GAHPs.

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## BOOSTHEAT Thermal-Compression-Based Gas Heat Pump



**Researchers are supporting the development of a high-efficiency thermal-compression-based heat pump product for North America with 1) high-modulation ratio, 2) integration with forced-air distribution, and 3) optional cost-effective cooling. If successful and deployed widely, environmental and ratepayer benefits will be significant.**

### Project Description

This project addresses the need for cost-effective thermal heat pumps (THPs) that provide next-generation performance of high efficiency, self-power capability, and both high-temperature heat and low-temperature chilling.

Researchers are investigating THPs that use natural refrigerants, but with higher operating efficiencies. One of the primary players in this field is the French company BOOSTHEAT. Through this project, researchers are extending their partnership with BOOSTHEAT (that began with a third-party evaluations of the BH.20 heat-pump boiler) with a product-development program in advance of a North American introduction.

To date, the BH.20 demonstrated a Coefficient of Performance (COP) for gas of 1.90 (low-temperature heating) and 1.63 (high-temperature heating) in third-party testing in Europe, and is capable of delivering heat at temperatures above 150°F. However, as initial testing showed, the BH.20 was very much optimized for the European residential hydronic heating market and, specifically, the low-temperature emitter market. As a result, a direct translation of the BH.20 to North America, with a wider operating envelope of ambient conditions and the requirements of forced-air heat distribution, will not leverage the full potential of this exciting THP.

BOOSTHEAT's core technology is the thermal compressor itself. The balance of the BH.20 is comprised of the common components of a trans-critical CO<sub>2</sub> heat pump (evaporator, gas cooler/condenser, and expansion valve). In this vein, BOOSTHEAT's core technology is not unlike the vapor-absorption and vapor-compression gas heat pumps that use these common components as their core technologies. BOOSTHEAT's thermal compressor is essentially a gamma-type Stirling engine with the power cylinder/piston replaced by inlet/exhaust ports.

An initial evaluation of the BH.20 in 2019 revealed several opportunities to improve performance in North America, which, by and large, were the result of design decisions for the European market and hardware issues in a pre-commercial prototype.

The goal of this project is to help develop a North American THP and investigate other applications for the Thermal Compressor with a focus on 1) high-modulation ratio, 2) integration with forced-air distribution, and 3) optionally adding cost-effective cooling. BOOSTHEAT has partnered with UTD on this project to help pave the way for a North American product. This UTD project will help BOOSTHEAT address key product development needs.

### Benefits / Market Implications

Thermal compression-type THPs may offer a 20% or greater improvement in energy/emission reductions versus best-in-class conventional sorption and vapor compression-type THPs.

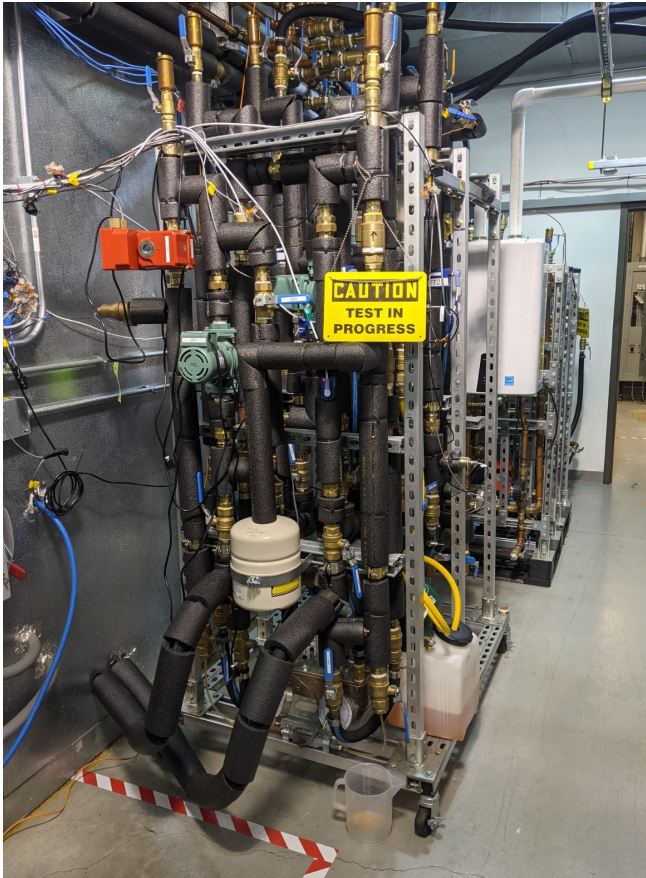
The primary target application markets are:

- **Equipment Type:** Water-to-water gas-fired heat pumps with outdoor heat exchanger (effectively air-to-water)
- **Application:** Residential homes and low-rise multifamily
- **Climate:** Heating dominant, but all climates apply.

Benefits include:

- **Efficiency:** Targeted reductions in gas consumption for space/water heating by 60% or greater, with nominal incremental electricity consumption
- **Emissions:** Expected 60% or greater reduction in greenhouse gas emissions while broadly deploying ultra-low-NO<sub>x</sub> solutions and utilizing natural refrigerants, and

If the project is successful, the BOOSTHEAT THP will be better positioned for the North American market and will lead into well-crafted pilot projects. If deployed widely in ratepayer homes, broad ratepayer and environmental benefits can accrue.



Completed laboratory test stand.

## Technical Concept & Approach

The project work is broken into two major tasks:

### Task 1: Design Improvements to TC-THP

- Install and evaluate performance of an existing 2nd generation GHP with controls modifications designed to reduce cycling losses, improve capacity/efficiency loss with colder ambient/warmer loop temperatures, improve performance when coupled with external AHUs and ISTs, reduce backup boiler operation, and combustion system tuning to meet 14 ng/J NOx emissions
- Develop a comprehensive performance assessment, with steady state, cycling, and simulated use testing protocol originally applied to unmodified *BH.20* baseline and summarize results in Experimental Test Report
- Characterize the thermal compressor to assess its potential use for HVAC/DHW-type applications by testing DHW-only / commercial DHW application, assessing suitability/attractiveness for hybrid-heating application (supplementing a boiler for instance), and assessing suitability/attractiveness for space cooling / chilling application and heat recovery-type applications

### Task 2: Technoeconomic Assessment of thermal compressor

- Perform a technoeconomic assessment of the thermal compressor (2nd gen.) vs. alternative THP technologies and electric HP technologies.
- Consider potential commercialization partners in North America for Boostheat's thermal compression technology, and as appropriate provide relevant information or contacts to Boostheat.

## Results

Boostheat was recently purchased by a holding company, and as a result their commercialization plans have changed. Boostheat has indicated that they will focus on developing its core technology, the thermal compressor, and will explore licensing and supplier agreements where its thermal compressor could be packaged into a gas heat pump product by others. The new commercialization plans at Boostheat required a pivot for this UTD project, as the system that can be tested is no longer representative of a final commercial product.

## Status

In Q1 of 2023, the team prepared a revised scope of work for this project. The revised scope of work will test the existing TC-THP prototype from Boostheat under heating, cooling, and water heater applications for both commercial and residential applications. The scope revisions were accepted and the team is working on securing the TC-THP for testing as well as revising the original test plan.

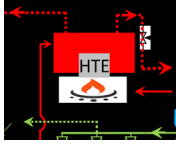
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## Gas-Fired Binary-Fluid Ejector Heat Pump Water Heater



Research is being conducted to develop and demonstrate a prototype gas-fired binary-fluid ejector heat pump water heater that provides 12,000 Btu/hr (3.5 kW) capacity, achieves a UEF (Uniform Energy Factor) of 1.4 or better, and shows an attractive value proposition for gas consumers.

### Project Description

This project involves modeling, designing, building, and testing a prototype of a gas-fired ejector heat-pump water heater (GFEHP). This first-of-a-kind heat pump uses a novel cycle that combines a binary-fluid ejector and sorption subsystem into one high-efficiency cycle. The technology integrates several components that are thermally and hydraulically coupled. The overall objective is to develop and demonstrate GFEHP technology at 12,000 Btu/hr (3.5 kW) capacity in the laboratory and achieve a gas Coefficient of Performance (COP) of 2.0 (equating to a UEF > 1.4). This project is taking a ground-up approach for designing and building the novel GFEHP prototype, starting with system specification, modeling, and breadboard prototyping, then culminating in a full system prototype construction and testing.

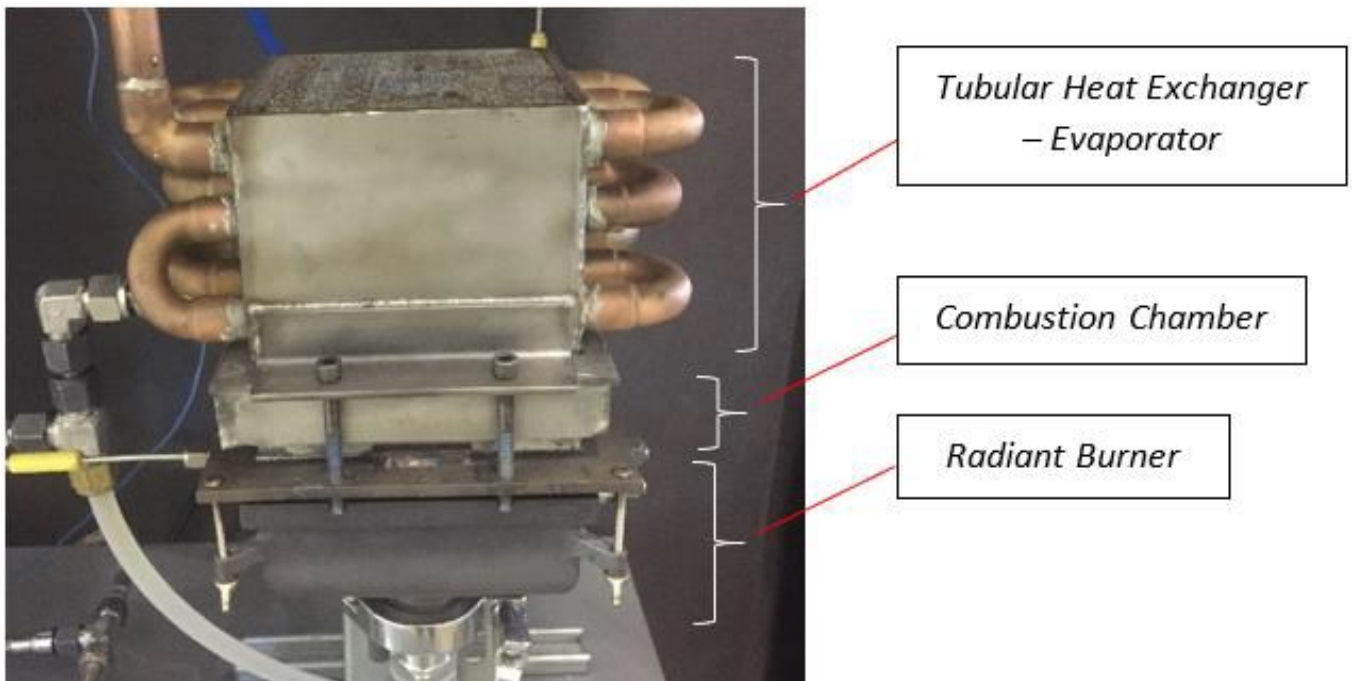
The project is a collaboration among UTD, the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory, the University of Missouri (MU), and ThermAvant Technologies. UTD's funding is being leveraged by approximately \$1.9 million in prime funding provided by the DOE.

### Benefits / Market Implications

The primary target markets impacted by GFEHP will be residential, multifamily, and light commercial water heating.

The GFEHP has a target gas COP of 2, which translates into an energy factor (EF) of at least 1.4 if the burner is non-condensing and its storage tank is not well insulated. With a well-insulated tank and condensing burner, the GFEHP can have an EF of 1.8. State-of-the-art gas-fired water heaters have a thermal efficiency of 0.98, which translates to a <1 EF.

The GFEHP is expected to be twice as efficient as the state-of-the-art product on a primary energy basis (e.g., tankless water heaters and electric heat pump water heaters). Compared with an electrically-driven vapor compression heat pump water heater, the GFEHP replaces the compressor and the expansion valve with an ejector, additional heat exchangers, and an oscillating heat pipe. A cost comparison indicates that it is possible to meet cost targets of \$4,000.



*The laboratory-scale heat-transfer system was designed, fabricated, assembled, and tested.*





- Steve Roberson  
Technical Analyst  
Spire Energy

*"Innovative next-generation technical solutions like the gas-fired binary-fluid ejector heat pump water heater can double the efficiency of standard water heaters while greatly reducing related emissions. UTD's partnering with the U.S. DOE, MU, ORNL, and ThermAvant brings a strong team to deliver significant efficiency gains from this exciting technology, while ensuring cost-effective solutions for the customers we serve!"*

Water heating is a source of significant primary energy consumption in U.S. (second in buildings only to space heating). There are approximately 60 million minimum-efficiency gas water heaters in U.S. homes ( $EF < 0.67$ ), responsible for 2.86 quads of primary energy consumption and an annual consumer expenditure of around \$32.6 billion. As improving building envelopes reduce space-heating loads and more high-efficiency warm-air furnaces are installed, water heating represents a growing proportion of the residential gas load. The GFEHP technology will provide high efficiency as a retrofit option to all existing gas water heaters and the 9.1 million homes that currently do not use natural gas in water heating but have gas availability. As new houses become more efficient, innovative gas solutions such as GFEHP water heating can provide low-cost, high-efficiency heating options.

## Technical Concept & Approach

Specific tasks for this project include:

- **Identify System Architecture and Product Specifications**

The project team will develop a conceptual design of the GFEHP. Thermodynamic modeling will be used to ensure that the targeted thermal efficiency metrics are feasible. The project team will develop a system architecture that specifies the required components, their efficiency target levels, and how they are integrated.

- **Design, Manufacture, and Test of the Combustion System**

The project team will develop an ultra-low- $NO_x$ , high-efficiency, low-cost manufactured burner that will be used in the prototype system.

- **Assemble the Prototype Combustion System, Characterize its Performance, and Validate the Model**

In this task, combustion sub-systems will be integrated with other required components to form a breadboard prototype

of the proposed GFEHP. The breadboard will provide valuable information on the characteristics of the GFEHP as a system.

- **Support the Design of an Alpha Prototype**

The validated system model and information gained from the breadboard evaluation will be used to design an alpha prototype of the GFEHP.

- **Techno-Economic Study**

The goal of this task is to support commercialization by assessing the value proposition and the potential of a GFEHP water heater. To do so, the first cost at maturity of the GFEHP (based on the alpha design) will be estimated.

## Results

In 2020, the project team provided guidance on burner design. Researchers recommended a radiant-type burner, which is the only technology to achieve ultra-low- $NO_x$  emissions without sacrificing efficiency. Other off-the-shelf and prototype burners considered included a metal fiber mesh burner, a permeable metal matrix burner, and volumetric and flat-metal foam burners. Investigators also analyzed the option of using a thermoelectric generator (TEG) in combination with a radiant burner for self-powering of some components of GFEHP.

A report titled *Product Characterization Criteria Brief* was compiled that summarized the applicable efficiency standards and emission requirements for commercialized and pre-commercial gas and electric water heaters. Recommendations related to target cost and physical characteristics of the GFEHP water heater were provided.

In 2021-2022, the project team modified the existing design and test stand to test the system at conditions closer to what would be seen in the full prototype system. A preliminary engineering design of the laboratory prototype combustion and heat exchanger system for the GFEHP was completed.

In 2022-2023, the team designed, built, and tested a breadboard prototype with the anticipation of building and testing an alpha prototype in early 2024.

## Status

The team is currently working on finalizing the alpha prototype design.

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# Emerging Residential/Commercial Fuel Cells Laboratory Evaluation



**Researchers evaluated the merits of residential/commercial-scale fuel-cell systems less than 50 kW and prioritized them in terms of North American market fit and readiness. This will help increase highly-efficient, environmentally-responsible options for natural gas and propane end users in the residential/commercial sector.**

## Project Description

The micro-CHP (Combined Heat and Power) market in North America has seen a very significant uptick in new products or product positioning. Contributing to the market interest are diverging gas and electricity energy rates, the growing demand for power and energy resilience, and major federal programs and private entities that made advancements in fuel-cell technologies.

The goal of this project was to evaluate the merits of residential/commercial-scale fuel-cell systems less than 50 kW and prioritize them in terms of North American market fit and readiness. Systems were selected for further evaluation in the laboratory to characterize power/thermal capacities, efficiencies, and qualities, as well as modulation and cycling capabilities. Laboratory research on these fuel-cell systems focuses on achieving high electrical efficiencies and near-zero emissions. This research will help increase highly-efficient, environmentally-responsible options for natural gas and propane end users in the residential-commercial sector.

UTD partnered with the Propane Education and Research Council (PERC) on this research, with PERC providing co-funding to UTD.

Fuel cells can also generate electricity with a hydrogen-rich fuel source, and when pure hydrogen is used, the only by-product is heat and water, thus yielding zero emissions. While most hydrogen is produced from fossil fuels, specifically natural gas, electricity from the grid or from renewable sources also produce hydrogen. As hydrogen blending becomes more prevalent, fuel cells could be an important technology to serve hydrogen-rich on-site power applications.

Historically, the biggest challenges for fuel cell technologies are their high costs relative to other mCHP technologies, fuel-cell stack degradation, and inabilities to modulate or cycle on and off quickly and frequently. These were the prime factors in evaluating and prioritizing fuel cell types that are best positioned for the North American market.

## Technical Concept & Approach

Researchers conducted a fuel-cell market landscape assessment. Based on market fit and feasibility, two fuel-cell systems were selected for evaluation. Investigators conducted those evaluations in a fuel cell laboratory designed for tests such as

## Benefits / Market Implications

The primary likely end-user applications are:

- Residential and light-commercial applications, especially in areas where net-metering is allowed and in support of Zero Net Energy homes, Zero Energy Ready Homes, and High-Performance Building initiatives/sectors, and
- The California micro-CHP (mCHP) market, with this research supporting possible distributed-generation certification by the California Air Resources Board.

Fuel cells can offer key potential advantages in mCHP applications. The economics of fuel cells are less dependent on the effective use of recovered thermal energy than other mCHP prime movers, such as reciprocating engines, because they have higher electrical efficiencies. They produce more power than thermal energy (high power-to-heat ratio), displacing electricity, which is at least three times more expensive on an equivalent energy basis than natural gas.



*AISIN SOFCs installation at research laboratory*



*"Accelerating the availability of small-scale fuel cells will help more of our residential and light commercial customers generate reliable, resilient, low-emission on-site power and thermal energy that can dovetail with variable renewable energy. This UTD research helps speed the transition to clean hydrogen, electrify buildings and helps us reach our decarbonization goals."*

- Neil Navin  
Vice President, Clean Energy Innovations  
SoCalGas

those defined by ASHRAE Standard 204-2020 *Method of Test for Rating Micro Combined Heat-and-Power Devices*. Additionally, the laboratory is equipped with emission analyzers for developing baseline emission rates produced by the mCHP systems.

Specific project tasks included:

- **Fuel Cell Market Landscape Evaluation**

Researchers evaluated the merits of residential/commercial-scale fuel-cell systems less than 50kW and developed a prioritized list of at least 10 fuel-cell systems.

- **Procure Fuel Cell System and Develop Test Plans**

Through UTD research project 1.13.D, UTD assisted the consensus development of ASHRAE Standards Committee SPC204. Through SPC204, a formalized Method of Testing was released to the public and will be used as a guide for formulating a rigorous test plan with the fuel-cell manufacturer. The systems are being evaluated on- and off-grid as CHP and distributed-generation devices. The main objective of the evaluations was to assess the performance and endurance of the fuel-cell units as well as their ability to load follow and rapidly cycle on and off operating on pipeline-quality natural gas for validation of the pre-production prototypes.

- **Fuel Cell Test setup, Installation and Testing**

Test plans were implemented for both fuel cells. The systems were evaluated on a two-week test schedule conducted 18 times across nine months and included polarization mapping, part-load performance, stack durability, stack power cycling, long-term emissions, and stack deep cycling.

- **Data Analysis, Reduction, and Reporting**

The project team post-processed test data to determine maximum steady-state power and thermal capacities, and assessed transient performance of the system at various loads and conditions. This helped characterize the potential performance of the systems for residential and commercial applications.

The key deliverable for this project was a report that documented the current fuel-cell market landscape for propane

and natural gas, and the performance of selected natural-gas fuel-cell systems.

## Results

In 2020, researchers completed a micro-CHP fuel-cell market landscape assessment with 16 fuel-cell systems based on technologies identified for residential/commercial CHP applications. These systems were evaluated based on electrical efficiencies, prior interactions with respective manufacturers, successful field demonstrations, and North American market fit. Seven systems were selected for potential further evaluation in the laboratory. Further evaluation was conducted on two systems.

One system is designed to integrate with a boiler as a traditional CHP system where heat is recovered for preheating a small boiler or incoming cold water. It is also designed to operate on or off grid. Results indicate Full load LHV electrical efficiency was about 51% and total LHV efficiency was about 100% or in terms of HHV efficiency, about 90%.

A second system is designed to integrate with photovoltaic panels and battery storage, providing a combination of renewable and fuel-fired electricity on or off grid. This system ultimately could not be evaluated due to high (20 psi) fuel input pressure requirement, which is inadequate for residential buildings per the National Fuel Gas Code (NFPA) 54; and the need for external devices to regulate voltage and control the fuel cell stack power generation functions. The manufacturer has subsequently informed UTD of their progress operating their SOFC on natural gas and hydrogen blends, including in-house testing on low pressure natural gas and anticipated certification.

## Status

A review of the market for residential- and light commercial-scale fuel cells and subsequent testing and analysis of promising systems has been completed. A final report has been issued to UTD members, and a webinar which summarized results was given to members in September 2023.

UTD recommends evaluating the second manufacturer's next generation SOFC in the laboratory to confirm performance claims, verify its durability, and understand its responses to operating in a nanogrid environment. Additionally, to advance these technologies from stage 4 to 5, UTD recommends developing next phase projects for beta prototype laboratory evaluations.

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# High-Efficiency Combination System Integrating PV and Self-Power



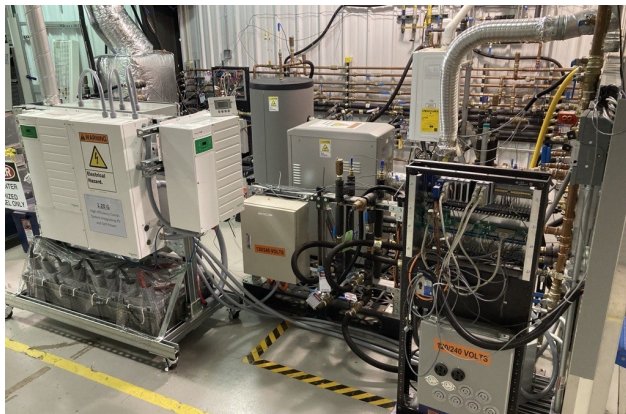
**Researchers are demonstrating hybrid residential combined HVAC and water-heating systems that use novel controls to integrate gas/electric systems with micro-combined heat and power, energy storage, and renewable energy in order to increase resilience and reduce operating costs and greenhouse gas emissions by up to 50%.**

## Project Description

Integrated energy systems (IES) are an emerging approach to provide high-efficiency, self-powered HVAC and water heating by integrating fuel-fired and electrically-powered equipment with distributed energy resources and energy storage. This project is developing and demonstrating hybrid residential HVAC and water heating systems in a laboratory that use off-the-shelf appliances and novel controls to integrate gas/electric systems with micro-CHP (mCHP), energy storage, and renewable energy in order to reduce operating costs and GHG emissions by up to 50% and achieve COPs up to 1.5 while retaining superior resiliency. The initial efforts of this project demonstrated that the integration of a residential scale mCHP system with a tankless combi and an electrically-driven air source heat pump (ASHP) could achieve highly-efficient, self-powered HVAC and water heating. The goals for current project efforts include:

- Develop an ad hoc retrofit solution to replace an AC system with an electric ASHP that is easily integrated with a fuel-fired furnace (existing or new) to achieve COP>1.0.
- Develop an mCHP retrofit solution with an existing furnace and ASHP to achieve self-powered fuel-fired space heating with COP>1.0.
- Integrate a ~5kW mCHP with an air-to-water combi heat pump to achieve self-powered fuel-fired HVAC and water heating with COP>1.5.

UTD is partnering with the Propane Education and Research Council (PERC), which provided co-funding to this project.



*Laboratory facility used to demonstrate and test novel integrated energy systems.*

## Benefits / Market Implications

The target markets to be impacted include, for example:

- Single-family and multifamily residential markets (retrofit or new, including affordable housing markets) where NG/LPG-fueled furnaces and/or ASHPs are used.
- Small commercial applications with moderate HVAC and water heating loads.

Benefits of this project include reducing GHG emissions by: increasing integration of PV renewable energy; using significantly more efficient NG/LPG-fueled equipment; increasing HVAC system operational resiliency for ratepayers through on-site power generation/nanogrids; and the opportunity to rapidly implement the innovations since they integrate and control off-the-shelf appliances in novel ways.

## Technical Concept & Approach

Continuing to move from research implementation to technology development, UTD will conduct this project in the laboratory and use Virtual Test Home (VTH) methods for simulated-use evaluations.

The current phase of work will complete the following tasks:

### Task 1 – Prepare Overall Test Plan and Procure all Equipment

The team will procure equipment for the ad hoc system, mCHP retrofit and air source heat pump. The Project Test Plan for this project will be developed in order to answer the following research questions:

1. Can an ad hoc retrofit solution to replace an AC system with an electric air-source heat pump (ASHP) be easily integrated with a fuel-fired furnace to achieve COP>1.0.?
2. Can a fuel-fired mCHP retrofit solution with an existing furnace and ASHP achieve self-powered fuel-fired space heating with COP>1.0?
3. Can a fuel-fired ~5kW mCHP be integrated with an air source heat pump to achieve self-powered fuel-fired HVAC



and water heating with COP>1.5?

## Task 2 – Develop Cloud-based Smart Fuel Switching Control

BKR Energy has developed an innovative cloud-based smart fuel switching controller that uses data on weather, energy rates, and emissions factors to make fuel switching decisions. Working with BKR Energy, the team will develop control strategies to help answer and achieve the research questions above.

## Task 3 – Implement hardware-in-the-loop test protocol

The team will continue to implement hardware-in-the-loop test protocols inside the laboratory. EnergyPlus™ modeling will be implemented to co-simulate building models and hardware interface capabilities. This functionality will enable co-simulation of a building model as the hardware operates, permitting “real-time” interaction between the building model and HVAC system.

## Task 4 – Design and Build Residential Hybrid and mCHP IES

The team will design, build and test the ad hoc retrofit solution, an additional mCHP retrofit solution, and an integrated 5kW mCHP with an ASHP system. VTH data will be reduced to 24-hour load versus efficiency profiles. As with all VTH data sets, they will be used to develop performance curves that can be used in building energy modeling software to predict energy, GHG, and cost savings from the various IES systems.

## Results

In Phase 1 a residential nanogrid testbed was built and a prototype system achieved key performance markers such as: self-powered HVAC water heating on- and off-grid for superior resiliency for ratepayers; annual hybrid space-heating efficiencies >100%; predicted annual GHG reductions based on IES performance of >30% in cold climates; and annual operating cost savings of >40% in several regions.

The performance of the prototype matched best-in-class advanced combi system performance. More importantly, the prototype has led to development of a full IES where an electric heat pump and onsite power are already installed and the control logic developed for integration.

The VTH performance-based modeling efforts determined that significant energy, cost, and emissions-related savings are possible with the hybrid self-powered system when compared to a traditional 90%-efficient furnace, 0.62 EF water heater, and 15 SEER HSPF air conditioner. Modeled estimates for seven different climates were developed.



*Enginuity E-ONE Micro-CHP System (image credit: Enginuity)*

Additional findings indicated that specific IES designs (particularly with integrated PV) can achieve self-powered space heating/cooling and water heating at annual COP >1.5 on a source energy basis with 30-50% lower operating costs and similar GHG emissions reductions than with separate code-compliant equipment in various climates.

Researchers also determined the nanogrid system can operate entirely off grid and power the HVAC and water heating loads but with substantial battery storage, thus demonstrating resiliency.

To communicate these important findings and concepts to building HVAC design professionals, results from this project were presented at the ASHRAE 2022 Winter Conference in Las Vegas, NV in January 2022 and the World Gas Conference 2022 in Daegu, Korea in May 2022. Additionally, a paper was presented at the Purdue 2022 Refrigeration & Air Conditioning conference in West Lafayette, IN in July 2022. Two papers resulting from this research were also presented at the ASHRAE 2023 Winter Conference in Atlanta, GA in February 2023.

## Status

In 2023 the project team: formalized a Project Test Plan with Enginuity; secured an Enginuity E-ONE mCHP system along with automated electric and thermal load banks in order to perform simulated use testing of E-ONE; and completed modeling of nanogrid systems to understand control options and quantify cost/GHG benefits. The team will install the E-ONE in a nanogrid testbed and begin simulated use lab evaluations.

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# Hydrogen-Blended Gas in Residential/Commercial Combustion Equipment



**This project is adapting and demonstrating solutions to use hydrogen blends in residential and commercial combustion equipment. Researchers will demonstrate multiple solutions in a controlled laboratory environment and leverage findings from other researchers globally.**

## Project Description

A number of researchers worldwide are investigating the impacts of hydrogen blending in fossil or renewable natural gas on end-use equipment safety and performance. While hydrogen as a fuel presents a number of challenges to existing combustion equipment, an emerging consensus suggests that low blends (e.g., <20% by volume) are suitable for existing equipment.

Technology demonstrations are under way in Europe, where natural gas is predominantly used for heating. However, renewable energy production is high, primarily since imported natural gas prices are high, and environmental requirements are strict. Through these efforts, several products are undergoing development and demonstration, from domestic boilers to cooking ranges and their associated combustion components, that can safely and efficiently utilize up to 100% hydrogen fuels.

Under Phase 1, this project seeks to build on these European efforts through extended technology transfer, while developing an R&D roadmap for hydrogen-blend-compatible equipment in North America, with an initial focus on >50% hydrogen blending by volume.

The concurrent Phases 2 and 3 of this project seeks to support the potential deployment of up to 30% hydrogen-blended gas in North American buildings by assessing the performance, emission, safety, and qualitative impacts of hydrogen blending on widely-used residential gas-heating appliances. Phase 2 focuses on high load gas appliances

such as furnaces and water heaters, while Phase 3 focuses on widely-used but low-load peripheral gas appliances such as gas lights, space heaters, and indoor fireplaces.

## Benefits / Market Implications

This project initiated a significant technology-transfer and research effort with several leading global technologists to demonstrate high-hydrogen-compatible equipment and lay out a path for wider utilization of hydrogen in North America. Subsequent phases of the project are aiming to assess the compatibility of existing appliances with hydrogen blends to quantify net benefits of hydrogen blending at different levels. If successful, broad ratepayer benefits are anticipated to include:

- **Emissions:** Up to 100% reduction in the onsite carbon emissions associated from natural gas consumption, and
- **Health and Safety:** Reduction or elimination of carbon-based emissions, including carbon monoxide and trace contaminants.

## Technical Concept & Approach

Specific tasks for Phase 1 include:

### • Test Planning and Equipment Procurement

The project team will design, develop, and fabricate a high-hydrogen blending system, including installation and calibration of necessary safety sensors and equipment in consultation with European partners with equivalent test stations.

### • Experimental Evaluation of High-Hydrogen-Compatible Equipment

Researchers will install and evaluate the performance, efficiency, and emissions from five or more components. For combustion components, investigators will evaluate the potential for reduced NO<sub>x</sub> emissions. Through the demonstration of high-hydrogen-compatible equipment, the project team will additionally evaluate the efficacy of components, including gas valves and meters.



Table-top hearth hydrogen-blending test setup



"Clean hydrogen will be key to helping consumers take advantage of the reliability and resilience of the gas system, while aiding us in reaching our decarbonization goals. This project will help assess the compatibility of existing appliances with blended gas and demonstrate the next generation of hydrogen-ready equipment"

- Neil Navin  
Vice President, Clean Energy Innovations  
SoCalGas

## • Roadmapping and Outreach

The project team will prepare and issue a *R&D Roadmap for North American Residential/Commercial Equipment Compatible with Up to 100% Hydrogen Content Fuels*. One or more outreach events will be held, targeting interested manufacturers, utilities, regulators, and advocates.

Specific tasks for Phase 2 include:

## • Testing of Standard Gas Appliances Under Rating and Adverse Operating Conditions

Working with appliance manufacturing partners, researchers will perform standard rating and simulated-use tests with several typical furnaces and condensing water heaters in "as-shipped" condition to quantify any changes in efficiency and emissions of criteria pollutants for existing appliances when operating on hydrogen blends up to 30%. Additional tests will focus on adjusted appliance tests as well as operating under adverse operating conditions to determine if the use of hydrogen will cause existing appliance to lose compliance with ANSI standards.

Specific tasks for Phase 3 include:

## • Qualitative Impacts of Hydrogen Blending on Aesthetic Burners

The team will build a test apparatus for evaluating the qualitative and aesthetic output of fireplaces, radiant space heaters, and gas lights based on changes to flame size, shape, color, luminosity, and radiant output. When possible, small modifications will be considered to improve any of the qualitative features.

## Results

In 2020, researchers coordinated with manufacturers of key hydrogen-capable components and combustion systems.



Hearth testing with Natural Gas (left) and a 30% H2 blend (right)



H2 Source and Mixer Undergoing Installation

Within this group, several appliance manufacturers discussed approaches to operating with hydrogen blends, up to 60% in most cases and 100% in some cases. Hydrogen-compatible flow sensors were acquired and project representatives developed a hydrogen/natural gas automated mixing station.

In 2021, the project team developed a comprehensive review of hydrogen demonstrations in Europe and Asia that included end-use customers, including materials from the EU-based *THyGA* project, adapting some of the timely findings for a February UTD member webinar. Additionally, researchers actively coordinated with other North American hydrogen studies and testing efforts.

In 2022, test stands were built and/or modified for standardized testing of furnaces and water heaters. As part of the R&D roadmapping and outreach efforts under this project, the team prepared a summary paper for the *World Gas Conference* held in May 2022. Researchers demonstrated that methane emissions decrease with added hydrogen. The response to results was very positive, in particular with high interest from organizations in Latin America.

In 2023 the team completed commissioning the test stand for Phases 2 and 3, and as of the beginning of Q3, had initiated initial tests with hydrogen blends in a hearth and gas furnaces. Results to date for this project were presented at a seminar at ASHRAE's Winter Conference in February 2023

## Status

For Phase 2, rating and simulated use tests are ongoing with the first round of gas furnace tests complete.

For Phase 3 combustion performance and hydrogen compatibility is ongoing and qualitative impact tests will be performed in parallel to compatibility tests. The fireplace test stand facilitates both.

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# Membrane-Based Ionic Liquid Absorption Heat Pump for Commercial HVAC



**This project developed an innovative thermally-driven cooling technology for commercial HVAC applications. The technology will be demonstrated in a prototype ultra-high-efficiency dedicated outdoor air system. At the core of the equipment is a novel, scalable absorption system centered on a compact membrane-based heat and mass exchanger for retrofit HVAC equipment.**

## Project Description

Commercial building owners often use natural gas in buildings with forced-air-type HVAC equipment (e.g., rooftop units, or RTUs) as the primary means of heating and cooling. The U.S. Department of Energy's Advanced RTU Campaign estimates that more than 60% of commercial building area is conditioned by RTUs.

For RTUs to process outside air to remove moisture, vapor compression systems must overcool air to saturation conditions. This is a thermodynamically-inefficient process, particularly in dedicated outdoor air system (DOAS) applications in which cooled air is often reheated. The ability to directly remove moisture from air, without cooling it, would enable more efficient HVAC systems capable of separate sensible and latent cooling in locations where latent load constitutes the majority of the ventilation load.

For this project, a research team developed a prototype novel highly-efficient gas-fired absorption cycle which combines dehumidification and heat-pump functions. The system can use ventilation or indoor humidity load for water and/or space heating. Specifically, the system is enabled by:

1. An absorption cycle that allows combined dehumidification and heating
2. Non-crystallizing ionic liquids that allow double-effecting the cycle and operating at elevated temperatures (~160°C) without costly materials
3. Compact membrane-based absorber which contains ionic liquids and directly cooling to provide a high system coefficient of performance, and
4. Novel, highly-integrated, double-effect desorber condenser designed to reduce size, weight, and cost.

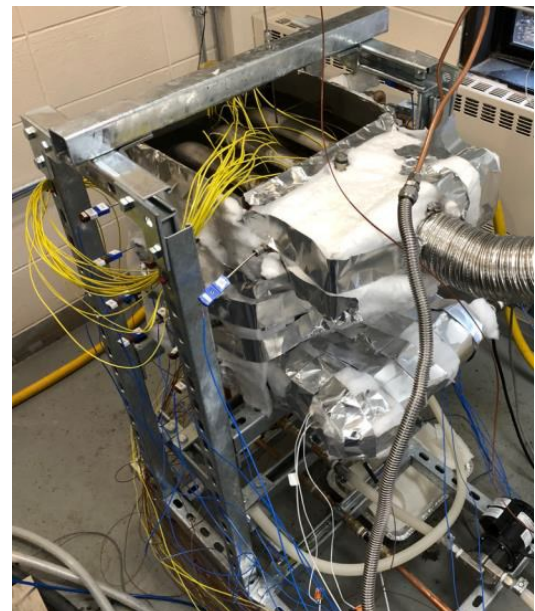
The goal was to develop an innovative thermally-driven cooling technology for commercial HVAC and demonstrate it in a prototype ultra-high-efficiency DOAS RTU. This technology is centered on a compact membrane-based heat and mass exchanger with no desiccant entrainment. The compact size permits easy retrofit into existing building infrastructures. Regeneration of the system is driven by efficient heating (natural gas, propane, waste heat, solar, etc.).

The U.S. Department of Energy (DOE) provided prime funding to the University of Florida (UF) for this technology development effort. UTD partnered with the UF, DOE, and participating OEMs by providing technology innovation support as well as co-funding to DOE.

## Benefits / Market Implications

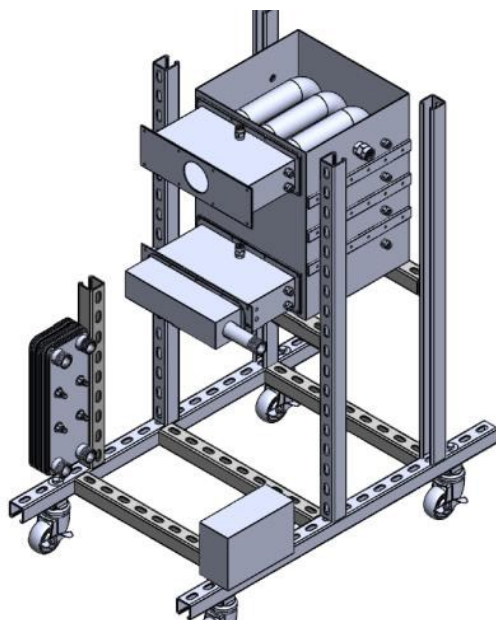
End users who can benefit from this technology include those that: 1) use DOAS for dehumidification combined with building zones reheating and/or hot-water supply; 2) handle indoor humidity in tight buildings combined with ventilation air and/or space heating in winter; and 3) handle humidity in indoor pools combined with pool water and/or space heating.

If successful in developing this advanced technology, the project team projects several benefits, including an increase in heat pump energy efficiency, a reduction in peak electrical power consumption, and an increase in the energy efficiency of liquid-desiccant-based latent cooling cycles. Estimates indicate a potential 85% reduction in operating costs.



*System desorber testing implementation*





*System desorber design*

## Technical Concept & Approach

### • Proof-of-Concept System Integration and Testing

Experts provided commercial HVAC advice to the team during the initial product definition, competitive assessment, and determination of operating conditions. Additionally, researchers performed a codes-and-standards analysis to identify any possible non-technical barriers to DOAS RTU system design and deployment. Researchers evaluated the technical feasibility and comparative performance of options for direct and indirect-fired (steam/oil) desorbers. The team designed and fabricated simulators for the desorber(s) to evaluate multiple combustion system design options and performance.

### • System Integration and Testing

An experimental test plan was developed, and the team constructed a simulator test rig, procured cost-effective options for the combustion system (burner, gas valve/controls, ignition system, blower/inducer), and planned shakedown testing. Investigators compared the performance of each system combination in support of meeting performance and emission targets, and made initial recommendations to the project team.

### • System Test

With the prototype installed in the laboratory, researchers performed a shakedown to assure the RTU, instrumentation, and controls are all functioning correctly. The ability of the test rig to create and sustain the desired environmental conditions was also verified.

## Results

In 2020, researchers performed initial modeling and analysis to provide insight into fuel/air side impacts on the hot-side components and completed design activities. Simulation using ionic liquid thermophysical properties indicated that a direct-fired desorber/condenser is feasible and worth experimental investigation. The simulations were based on input geometry and heat-transfer parameters, as well as past experience with direct-fired heat exchangers. The overall heat-transfer efficiency from the flue gas to the ionic liquid solution appeared to be very high for all scenarios considered based on results from the simulations. Calculations from first principles yielded maximum potential heat transfer efficiencies in the range 75%-81%.

The codes-and-standards analysis did not identify any possible non-technical barriers to DOAS RTU system design and deployment that could not be addressed.

In 2021, a study was completed regarding the impact of direct firing the desorber, concerning capacity, hot spots (material reliability), and other factors. The project team performed open-air testing of the burners and validated the functionality of the burner ignition and operational controls.

In 2022-23 full desorber tests were completed, demonstrating that a direct-fired design is technically feasible and meets emissions requirements (e.g. Ultra Low NOx), with recommendations for subsequent prototype optimization. The project team publicly reported results of UTD 1.20.I in this DOE project in a technical paper presented at the IEA Heat Pump Conference held in May 2023 in Chicago.

## Status

Due to a delay in the readiness of the 1,000 CFM prototype to be provided by other team members, a final report for UTD 1.20.I was issued to UTD members in August 2023 to summarize the results to date. The project team will continue the important work to assemble and test the 1,000 CFM prototype under the overall DOE-funded project, with subsequent reporting to be provided to UTD members. Those findings will also support related efforts in UTD 1.21.I.

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## Integrated mCHP System for Multi-Family Buildings

**A project team is cleverly integrating an mCHP unit with best-in-class electric heat pumps, thermal storage, PV and other commercially-available equipment to serve a simulated multi-family application scenario. This advanced system provides annual gas efficiencies greater than 130% for heating, cooling, and hot-water loads, while increasing resiliency and using more Renewable Energy. Gas customers can immediately benefit.**



### Project Description

This project is demonstrating and optimizing the integration of a near-zero emission (NZE) micro-combined heat-and-power (mCHP) unit coupled with best-in-class electric heat pumps in a multi-family application scenario. By integrating this commercially-available equipment with thermal storage, PV and smart management capabilities, the system can operate as an advanced integrated system to achieve annual gas efficiencies greater than 130% for heating, cooling, and hot-water loads, while providing the high resiliency of on-site power generation, and substantially reducing operating costs and greenhouse gas emissions in cold climate zones.

Specific project objectives are to:

- Integrate communications functions with variable-speed compressor electric heat pump operation and an mCHP system power lead-mode for space heating and cooling.
- Right size thermal storage and manage hot-water production for the mCHP system
- Characterize space and water-heating and space-cooling part-load performance.
- Communicate results to facilitate market transformation.

UTD is partnering on this project with the U.S. Department of Energy (DOE), in which part of this UTD project is supporting a DOE-funded Connected Communities research program that expands DOE's network of grid-interactive, efficient building communities nationwide and enables them to interact with the electrical grid to optimize their energy consumption, which will reduce their carbon emissions and energy costs. UTD is also partnering on this project with the Propane Education and Research Council (PERC), which provided co-funding to UTD.

### Benefits / Market Implications

Optimization of an mCHP unit integrated with cold-climate air source heat pumps (ccASHPs), thermal storage management and PV will help increase low-cost, reliable energy solutions for consumers. Applications beyond multi-family housing include multi-unit buildings, low-rise suburban office

buildings, smaller strip malls/plazas, distributed thermal microgrids, etc.

NZE buildings are often perceived as feasible only with all-electric HVAC and domestic hot water provided by electric heat pumps powered by on-site PV power generation. However, advanced mCHP integrated systems can provide similar or lower emissions at lower operating costs with superior energy resiliency while directly integrating PV energy. A reliable and



*The mCHP integrated system indoor installation.*

efficient mCHP system, when cleverly integrated with best-in-class heat pump heating/cooling, can provide numerous benefits. In addition to meeting thermal demands, mCHP can be leveraged to provide clean backup energy to power EV charging stations when PV power is insufficient. Demonstrating its feasibility can inform consumers, homebuilders, manufacturers, and other stakeholders about the benefits for end users and the environment of integrated energy systems.

### Technical Concept & Approach

Under Phase 1, this project team will develop a test plan and subsequently build a microgrid testbed to represent a 4-townhome multi-family building. This microgrid testbed will include the Lochinvar 24 kW mCHP with four 3-ton best-in-class electric heat pumps.

This microgrid will be evaluated using a Virtual Test Home (VTH) load-based evaluation methodology to optimize microgrid integration and control strategies. The microgrid performance will be characterized for building energy modeling to



*The mCHP integrated system outdoor installation.*

develop sizing guidelines for multi-family building sizing and location, including utility operating costs and region of transmission marginal operating emission rates (MOER). Researchers will quantify the microgrid's MOER and operating cost reduction relative to commercially available all-gas and all-electric baselines. Results will be communicated to industry stakeholders, including building design professionals and hybrid residential HVAC solution manufacturers.

Under Phase 2, this project team will install a PV array and EV charging stations in the microgrid and develop integration strategies to cascade power prioritization, starting with solar, on-site cogeneration, and lastly the grid. An automated load bank will simulate realistic EV charging station loads and capture the effects on the microgrid performance. The project team will also develop performance curves, evaluate microgrid performance with EV charging stations and PV in multiple climate zones, and develop design guidelines.

## Results

During Phase 1, the project team developed a test plan and microgrid testbed design, integrated microgrid components, and evaluated its performance over the 2023 heating season in Chicago, IL. The test plan encompassed the microgrid testbed design and component selection. The Lochinvar 24 kW mCHP and four 3-ton ccASHPs were selected for this microgrid. Hydronic integration strategies were developed to leverage on-site cogeneration to prioritize water heating loads while supplementing space heating loads with the ccASHP's heating output. Power integration strategies were also considered to modulate the mCHP as a function of the ccASHP's power demand. The mCHP heat production was designed to be distributed to individual dwellers' indirect tanks and hot-water coils for water and space heating.

To evaluate the microgrid performance, a hybrid approach to couple actual weather conditions with simulated loads was implemented using the VTH test rig and building energy mod-

eling. The simulated loads were crafted to optimize performance via simplified energy modeling. This simplified modeling showed that four-unit townhouse homes with peak heating loads of 60 MBH at design conditions were needed to maximize microgrid performance.

Results indicate that this microgrid can operate at COPs between 1 and 1.8 across the heating season. The resulting carbon footprint rate of the microgrid was an average of 300 lbm/MWh, which is 25% of the national average MOER of the current electric grid and approaches many 2050 emission targets! This project demonstrated that advanced mCHP technologies integrated with best-in-class electric ccASHPs can: operate with only 14% of the net power requirements; reduce electric loads by 27%; reduce installation costs by 43%; and reduce greenhouse gas (GHG) emissions by 47% of fully-electrified multifamily building HVAC&WH systems.

During Phase 2, the project team designed and implemented power integration strategies for PV and EV charging stations. The PV array was sized for 13 kW, and two dual-pole 40 Amp level 2 charging stations were selected. The project team has disseminated the microgrid performance over the 2023 cooling season and is collecting data for the 2023/2024 heating season.

The cooling season evaluation results indicated that the microgrid provides space cooling and water heating with only 13% grid power and efficiencies between 3.0 and 6.0. The microgrid power requirements were heavily managed by solar power generation, with 42% of the net power consumption. Cogeneration, supporting peak cooling power requirements, contributed 14% of the microgrid power requirement while managing all water heating loads. These project results will support analysis within a Connected Communities project awarded by DOE to the Electric Power Research Institute (EPRI).

## Status

Phase 1 of this project is complete. A Phase 1 final report was issued to UTD members in July 2023. Phase 1 results were also published in technical paper #AT-23-C062 presented to HVAC system design professionals at the ASHRAE 2022 Winter Conference held in Las Vegas, NV to help accelerate market adoption and transformation.

Efforts currently underway during Phase 2 are to: continue to collect performance data for the 2023/2024 heating season; engage modeling tasks to estimate performance across multiple climate zones in the U.S.; and develop design guidelines as part of the deliverables, which includes a report and another conference paper.

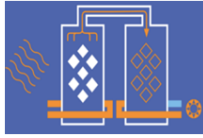
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## HeatAmp Adsorption Thermal Heat Pump



Researchers are advancing the development of an innovative, high-efficiency, and robust gas-fired thermal heat pump technology by optimizing, designing, building, and testing a cost-effective alpha prototype burner/boiler and combustion system and integrating it into a complete alpha prototype water heater.

### Project Description

The technology being developed in this project is based on a proprietary chemisorption sorption system from HeatAmp Sweden AB. The technology is coupled with a novel system integration that is expected to result in a cost-effective, robust, and scalable appliance design with few moving parts.

The Chemisorption unit is compact and efficient and without the corrosion management or sealing requirements of standard absorption machines.

The driving force of the technology is a compact gas-fired heater desorbing the refrigerant, with an efficient integrated backup boiler and a fuel-flexible combustion system projected to be compatible with renewable natural gas and/or hydrogen. Desorbed refrigerant heats the buffer tank, then the refrigerant flows to a receiver/evaporator.

The primary target use is for domestic hot water applications, with options for combined space/water heating or pool-heating.

HeatAmp's cost-effective thermal heat pump (THP) technology has potential for market transformation by virtue of its high efficiency (projected >33% energy/emission savings vs. standard fuel-fired equipment) and the opportunity for increased reliability and operating life relative to other sorption-type heat -pump technologies. Additionally, the scale-up of core sorption heating technology can drive innovative applications in other product categories (e.g., commercial HVAC).

In summary the goal of this project is to advance the development of this cost-competitive, THP technology by optimizing a cost-effective alpha prototype burner/boiler assembly and then evaluating the technology in a alpha prototype of a complete integrated water heater. UTD is partnering with the Northwest Energy Efficiency Alliance (NEEA), which provided co-funding to this UTD project.

### Benefits / Market Implications

As a competitive addition to the residential-scale THP portfolio, this technology has several potential advantages. The appliance uses a natural refrigerant with zero ozone depletion and zero global warming potential, suitable for all climate zones. Additionally, the sorption components are integrated into the tank, reducing thermal losses and safely isolating the

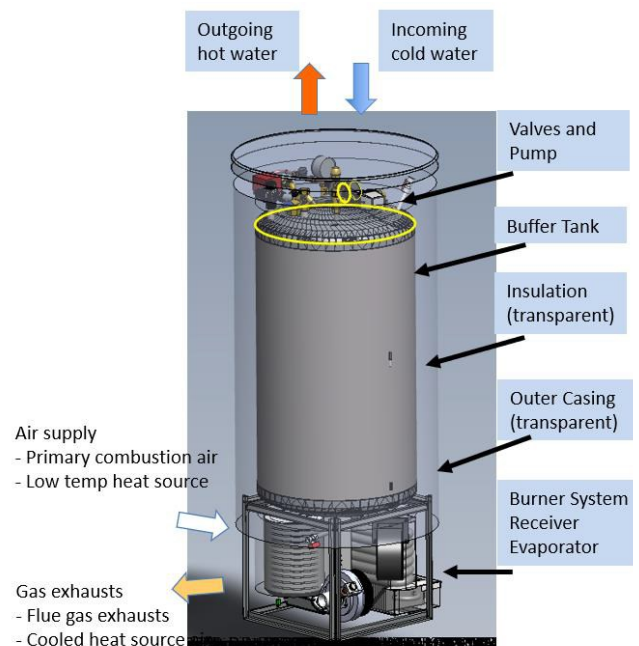
refrigerant charge.

The projected 2030 US residential fuel-fired heating market size is 2.7 Quads/year per DOE's BTO Market Calculator. With a target COP<sub>gas</sub> of 1.30, this chemisorption heat pump and similarly-efficient products have the potential to reduce US 2030 energy consumption by approximately 830 TBtu/year.

### Technical Concept & Approach

With first-cost sensitivity of residential appliances being a major barrier, emphasis is being placed on balancing cost vs. performance in components and in developing a simple overall system. Attention is also being paid to ensuring installer comfort with the new technology, including actual vs. perceived safety implications.

Researchers are developing design/specification recommendations for an alpha burner/boiler, including the combustion system (burner, blower, fuel/air mixing, combustion controls) and boiler module (combustion chamber, heat exchangers, venting/flue, overall burner/boiler controls).



Alpha prototype (XBTI-10) CAD rendering





- Magnus Ekblad  
CEO  
HeatAmp Sweden AB

*"Gas-driven Heat Pumps with energy efficiencies over 100% will be key for residential users to reduce energy costs and GHG emissions, but also to meet future energy standards. By maintaining heating appliance capacity we ensure the same end-user experience as for current products. UTD has provided and continues to provide valuable technical support for important developments of HeatAmp's technology including 3rd party support from GTI Energy to accelerate the steps needed to commercialize the technology."*

The system will be fabricated and evaluated using bench-scale testing and a simulated load test rig. Performance/emissions/safety testing will be performed (steady state, ramp up/down, etc.), results reviewed, and recommendations for optimized burner/boiler developed.

A final optimized burner/boiler system will then be evaluated within the alpha prototype THP unit. Performance will be analyzed and estimates of manufacturing costs will be generated.

Researchers will compare performance of the THP system to baseline and emerging technologies, as both water heater and whole-house heating systems, using extrapolative modeling to establish the North American technical potential.

In summary, the technical goals are:

- Design and demonstrate a burner/boiler system for the THP capable of >93% effectiveness (>83% fuel to steam), with NOx emissions of 14 ng/J or lower, and successful operation with up to 30% blended hydrogen; and
- Design an advanced sorption-type THP capable of achieving a projected >1.2 UEF (or equivalent) and demonstrating > 1,000 hours of operation in a laboratory test program.

## Results

In 2021, the project team held several project meetings to outline the project goals/tasks, finalize the scope of work, and define the partnership. The research team prepared a simplified dynamic modeling of the heat pump water heating design to assess its ability to meet standard and extreme hot-water demands.

After an extensive design process involving HeatAmp and the project team, the burner/boiler testing in the lab indicated that an operating efficiency of up to 96% was feasible, though not at full-fire. The project team has identified design modifications necessary to reach this target at full-fire, which will be explored in Phase 2. NOx emissions ranged from 3 to 15 ng/J, with modifications identified to assure the 14 ng/J target is met



*The "Alpha" Prototype Set-up for laboratory evaluation at full-fire.*

A calibrated simulation tool was developed and used to estimate performance against the standard simulated use test pattern, leading to recommendations for the full "alpha" prototype design and controls strategy.

Burner/boiler system testing completed in 2022-2023 met the targets of 10 kW-13.5 kW firing rate with  $\lambda = 1.7$ , although the team encountered system challenges with flame stability under certain conditions. The project team presented a technical paper at the 14th IEA Heat Pump Conference in May 2023 which summarized this project's technical progress to date.

## Status

Design and safety documentation for "Alpha" prototype has been completed and a second "Alpha" prototype has been manufactured and is undergoing testing.

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## RESIDENTIAL AND LIGHT COMMERCIAL, INCLUDING mCHP

PROJECT NO. 1.21.B  
SUMMARY REPORT

# Technical Support for Residential & Light Commercial Gas Equipment Testing, Performance, and Safety

This project provides support to technical committees that develop, refine, or update codes and standards to improve safety for natural gas end users and increase the energy efficiency, reliability, and resiliency of gas equipment and integrated systems.

## Project Description

Advanced technologies are often developed to address problems with existing alternatives in the market; however, new technologies are typically evaluated using existing criteria, which may misrepresent performance and necessitate costly engineering redesign that delays market introduction. In many cases, advanced technologies will not be included in codes and standards unless they are updated. When existing technologies advance from lower- to higher-performance levels, there is often a gap in test protocols and rating procedures to capture the full benefit of the advancement. This project helps address that gap.

Through this project, researchers provide technical support to industry groups and professional societies that develop codes and standards by consensus in open technical sessions. Researchers provide analytical test results, laboratory test results, and field test data to develop and improve test methods to more accurately reflect real-world conditions.

This project builds upon past UTD projects to provide technical information to advance codes and standards such as:

- ANSI/ASHRAE Standard 146-2020 *Method of Test (MOT) for Rating Pool Heaters*
- ANSI/ASHRAE Standard 118.1 *MOT for Rating Commercial Gas, Electric, and Oil Service Water Heating Equipment*
- ANSI/ASHRAE Standard 204P *MOT for Rating Micro-Combined-Heat-and-Power Devices*
- ASHRAE MOT for water heaters, gas-fired heat pumps, furnaces, boilers, combis, and micro-combined heat and power systems (micro-CHP)
- NFPA 54 and ANSI Z223.1 safety requirements for fuel gas piping systems in homes and other buildings
- ASHRAE forums, seminars, and research projects, and
- Mixed-fuel net zero emissions publications and seminars.

## Benefits / Market Implications

This project provides information to improve safety for end users and accelerate the use of new advanced gas technologies for space conditioning, water heating, and micro-combined heat and power (mCHP).

These advanced gas technologies can help utilities meet the goals of energy-efficiency programs while reducing individual ratepayer costs. Other important benefits include:

- Expanding customers' competitive choices of product offerings that can save energy and costs
- Ensuring safe and reliable operation of gas appliances
- Developing accurate and consistent equipment ratings for consumers to compare cost, efficiency, and the environmental impact of available products and fuel choices, and
- Expanding choices of product offerings that support ZNE initiatives.



Target markets impacted by this project include current equipment such as furnaces, water heaters and mCHP, as well as new cost effective, high efficiency, gas-fired technologies for all residential and commercial space-conditioning markets, such as gas-fired heat pumps.

## Technical Concept & Approach

The project team continues to support the development and consensus review of water-heating and combination system energy codes, as well as methods used to model the performance of new technologies. Examples include:

- The working group for SPC 124 *MOT for Rating Combination Space-Heating and Water-Heating Appliances* is developing a test setup and methodology for testing integrated combination-system packages. The project team was asked to help develop a potential new approach and test protocol based on laboratory evaluations conducted with a Virtual Test Home.
- Project representatives review standards and MOT for space-conditioning equipment, building energy codes, and appliances to identify the testing needed to support appropriate codes for new advanced gas technologies. This task also includes technical support for the consensus updates for ASHRAE 40 and ANSI test methods to reflect recent developments in gas heat pumps.
- A project representative serves as a voting member on ASHRAE technical committees.

## Results

Project team members have supported technical discussions on various committees, such as:

- ASHRAE Technical Committee 4.3, *Ventilation Requirements and Infiltration*
- ASHRAE Technical Committee 5.10, *Kitchen Ventilation*
- ASHRAE Technical Committee 6.1, *Hydronic & Steam Heating Equipment and Systems*
- ASHRAE Technical Committee 6.3, *Residential & Light Commercial Forced Air Heating and Cooling Systems*
- ASHRAE Technical Committee 6.9, *Thermal Storage*
- ASHRAE Technical Committee 6.6, *Service Water Heating Systems*
- ASHRAE Technical Committee 6.10, *Fuels and Combustion*
- ASHRAE Technical Committee 8.03, *Absorption and Heat Operated Machines*

- ASHRAE Standards Project Committee 40, *Methods of Testing for Rating Heat-Operated Unitary Air-Conditioning and Heat-Pump Equipment*
- ASHRAE Standing Standards Project Committee 41, *Standard Methods for Measurement*
- ASHRAE Standards Project Committee 118.1, *Method of Testing for Rating Commercial Gas, Electric and Oil Service Water Heating Equipment*
- ASHRAE Standards Project Committee 124, *Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances*
- ASHRAE Standards Project Committee 154, *Ventilation for Commercial Cooking Operations*
- ASHRAE Standards Project Committee 155p, *SPC 155P Method of Testing for Rating Commercial Space Heating Boiler Systems*
- ASHRAE SSPC 154, *Ventilation for Commercial Cooking Operations*
- Proposed New Standard, Z21.85 - *Alternative Connection Means for Use in Gas Appliances*
- Proposed New Standard, Z23550 - *Safety and control devices for gas and/or oil burners and appliances*
- *Meeting of the Z21/Z83 Technical Committee and, CSA Gas Appliances & Related Accessories Technical Committee Joint Meeting*
- Proposed New Standard, Z23551-4 - *Safety and control devices for gas burners and gas-burning appliances*
- ANSI Z21.40:23/CGA 2.94:23 DRAFT STANDARD, *Performance Testing And Rating Of Gas-Fired, Air Conditioning And Heat Pump Appliances*
- New Edition - ANSI Z21.20-2014 - CAN/CSA C22.2 No. 60730-2-5-14 - *Automatic electrical controls for household and similar use control systems*, and
- NFPA 54/ANSI Z223.1, *The National Fuel Gas Code*.

## Status

Representatives participate in relevant technical committees and prepare conference papers and presentations of value to the HVAC and built environments community.

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## CleanO2 CarbinX™ Carbon Capture



**Research is further advancing the performance and applicability of CleanO2's CarbinX distributed carbon capture device by extending operation to higher-efficiency condensing appliances. This builds on prior product development research support including to validate claims of avoided CO2 emissions, and average cost savings and energy savings.**

### Project Description

This project is advancing the performance of CleanO2's CarbinX™ latest carbon capture device by validating carbon capture and heat-recovery rates in a laboratory test stand, and identifying potential areas for further technical refinement.

This project builds on efforts since 2018 by the research team partnering with CleanO2 under additional separate funding provided by UTD members. The prior research on an earlier prototype identified potential areas for product improvement, such as: addressing the possibility of moisture accumulating in the reaction chamber; optimizing the reaction chamber to maximize carbon capture; adding sensors to indicate progress or completion of reaction process; and easing the process to load the caustic potash and extract the pearl ash.

CleanO2's newest system addresses these areas by: adding moisture sensors and controls to alternate flue-gas and fresh-air intake; using multiple batch reactors in place of one large reaction chamber to improve the carbon capture rate; adding wireless communication to notify the building owner of the reaction progress; and incorporating other improvements.

Current efforts focus on advancing CleanO2's next-gen commercial carbon capture unit (CarbinX v. 4) to apply to higher-efficiency condensing appliances. The team seeks to demonstrate in a laboratory setting carbon capture efficiency  $\geq 50\%$  and payback period  $\leq 5$  years. This will enable condensing boilers, water heaters, or other condensing appliances, to provide high-efficiency and low-carbon operation to residential and commercial building operators.



Experimental test stand with carbon capture unit (left), water-heater simulator (middle), and recirculation loop (right).

### Benefits / Market Implications

Implementing distributed carbon capture technology will reduce greenhouse gas (GHG) emissions in the residential and light commercial/industrial markets while retaining customer choice options to use gas in zero net energy buildings. The team is targeting a 50% reduction in GHG emissions compared with the 20% which has already been demonstrated. An eventual goal may be to reach 100% GHG emissions reduction for future technology beyond the next-gen unit.

This product will save consumers money through fuel savings and pearl ash rebates with an estimated payback period of 4.8 to 7.5 years. The project has a specific goal of a 5 year payback period without a carbon levy, although the technology may also reduce carbon levies owed by customers in jurisdictions that have a carbon-pricing program.

The primary target markets impacted will be:

- Residential and commercial buildings (e.g. multifamily, assisted living, hotels, schools, offices, shopping malls)
- Commercial boilers >250 MBH and <1,500 MBH

### Technical Concept & Approach

The current efforts will study and investigate different technologies for improving the carbon capture efficiency and waste heat recovery effectiveness of CleanO2's CarbinX v. 4 prototype. Scaling of the carbon capture unit for larger fuel-



Interior of reaction chamber after operating unit for a few hours with ~25 kg of caustic potash





*"UTD and its utility members have been essential partners in advancing our carbon capture technology. Their support has helped us to develop a cleaner, more sustainable energy future. We are grateful to their partnership and look forward to continued success in carbon capture and utilization with our disruptive technology along with help from our partners at GTI Energy."*

- Jaeson Cardiff  
Chief Executive Officer  
CleanO2 Carbon Capture Technologies Inc.

fired appliances will also be addressed. The following tasks will be performed:

### **Task 1: Design Optimization of Carbon Capture Reaction Chamber**

- Develop a numerical model of CleanO2's cartridge-style reactors for CarbinX v. 4 using design and performance data provided by CleanO2
- Use CFD to optimize reactor design for improved flue gas flow path and carbon capture efficiency

### **Task 2: Design Optimization of Waste Heat Recovery System**

- Perform modeling of hot water demand for standard installation sites of CleanO2's technology and determine baseline waste heat recovery of current CarbinX storage tank configuration
- Investigate different tank designs and configurations to optimize waste heat recovery while minimizing the CarbinX footprint

### **Task 3: Advanced Simulated Use Testing of CleanO2's Latest CarbinX Prototype**

- Complete baseline testing of CleanO2's CarbinX v. 4 to assess carbon capture efficiency and waste heat recovery using standard draw profiles, such as DOE's Uniform Test Method for Measuring the Energy Consumption of Water Heaters. All testing will be completed with a 500 MBH condensing commercial water heater
- Perform multiple tests at various water heater turndown ratios to determine effect on carbon capture and waste heat recovery performance and extrapolate findings to firing rates >500 MBH
- Test the CarbinX with both natural gas and propane combustion and determine any changes to carbon capture rate and waste heat recovery effectiveness and possible implications on payback period

- In coordination with CleanO2, the project team will modify CleanO2's prototype based on findings from Task 1 and Task 2 in order to evaluate potential additional improvements to carbon capture efficiency and waste heat recovery following the same draw profiles as for baseline testing.

## **Results**

This project builds upon prior efforts by the research team with CleanO2 to support the technology development since 2018. As one outcome, CleanO2 plans to develop and ship a moisture-knockout module that will allow for compatibility for the current system with higher-efficiency condensing appliances.

Major upgrades were made to an experimental test stand to improve functionality and safety. Most of the changes were made to the recirculation/heat rejection loop, which now allows for more efficient charging and evacuation of air. New temperature-limit controllers were installed on the water-heater simulator and flue-gas venting to cut off gas supply to the burner if temperatures exceed a specified threshold. Multiple shakedown tests were performed with the water-heater simulator to test for performance stability.

Final tuning of the CarbinX unit, water heater simulator, and heat rejection loops was completed to confirm stable operation of the burner with the activation of the CarbinX inducer. One week of continuous operation of the CarbinX unit has been completed while collecting carbon capture data.

## **Status**

The team is finalizing the commissioning process and will soon begin advanced testing, operation, and further optimization of the CarbinX v. 4 prototype unit.

CleanO2 has commercialized earlier versions of its CarbinX unit; more information is available via its website <https://www.carbinx.com>. The output of the CarbinX units are sold for example through the website <https://cleano2.ca>.

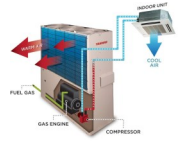
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## Gas Engine Heat Pump Modeling, Testing, and Implementation

**This project is refining gas-engine-driven heat pump performance models based on actual field data for variable refrigerant flow systems operating across a range of conditions. These efforts will optimize benefits for end users through more advanced techno-economic assessments, performance validations and enhanced energy models for system designs as well as compliance-based energy simulations.**



### Project Description

The performance of all air-source heat pumps – including electric- and gas-engine-driven – varies significantly with ambient temperatures. In addition, the complexity and customized design of variable refrigerant flow (VRF) systems make it costly to accurately measure real-time performance and efficiency. As a result, energy savings are often calculated using simplified energy modeling based on steady-state laboratory data obtained under controlled conditions, rather than actual installed performance.

EnergyPlus™ gas-engine heat pump (GEHP) models were typically based on published electric VRF models adapted to GEHP manufacturer performance data and a limited number of measured datasets. Manufacturers' performance data is typically only available for part-load operation at 60% and above; however, researchers know from previous demonstrations that GEHPs typically operate at much lower part-loads. Furthermore, the measured field data used for the model was from a single installation, corresponding to a limited range of operating conditions.

In summary, a more complete dataset of GEHP measured

performance data is required to enhance EnergyPlus models and improve their accuracy to better predict energy savings, greenhouse-gas (GHG) reduction, and economic benefits for facility owner/operators, designers, and others.

Recently, a number of GEHP equipment options were also introduced to expand the applications for GEHP and/or VRF systems. This project investigates options such as:

- An AHU Integration Kit that incorporates an expansion valve and controller enabling the VRF system to integrate a non-VRF air handling unit (AHU) in addition to, or in lieu of, multiple VRF AHUs
- The Yanmar Hydrobox and Blue Mountain Energy (BME) Sierra AWS System that transfers heating or cooling from the heat pump VRF system to a facility's hydronic heating and cooling system

This project is being done in collaboration with National Research Council Canada (NRCC) and will validate performance for VRF systems across a range of conditions with the goal to support end users with superior analysis tools and information through:

- Enhanced GEHP energy models using measured performance data
- Validation of new methods for testing for new GEHP performance metrics
- Techno-economic assessments to assess best use of new GEHP equipment options.

### Benefits / Market Implications

GEHPs are increasingly cost-competitive with electric VRF systems; recent pricing reduced the incremental cost to \$500-\$1,000/ton. Equipment options are expected to expand potential applications to include both hydronic or forced-air installations.

This project provides benefits for ratepayers, society, and the environment such as:

- Expanded options for reducing both gas consumption and electric demand response (approximately 10kW reduction in peak electric demand per unit)



*Example of a Yanmar Gas Engine Heat Pump being analyzed, with a gas meter to monitor gas consumption*

- Targeted 20%-40% savings in energy costs, along with lower life cycle costs
- Reduced GHG emissions via high performance end-use gas equipment that is more affordable and more efficient
- Reduced GHG emissions via high performance compared to conventional HVAC system.
- Improved comfort in multi-zone facilities compared to conventional HVAC system.

Examples of end-users that can benefit include:

- Multi-zone commercial buildings (offices, schools, retail, etc.)
- Markets with electric constraints and/or high demand charges
- Both new or retrofit installations.

This project will also support commercial building designers and owners/operators who use EnergyPlus software.

## Technical Concept & Approach

This project will develop enhanced energy models as well as validate new test standards for GEHPs.

Researchers will enhance existing EnergyPlus models. The project team will seek to publish these GEHP models and disseminate them widely. This task includes collaboration with NRCC to share data, validate performance curves, and approve GEHP models for use in compliance-based energy simulation.

The research team will work with manufacturers and testing agencies to validate new GEHP methods of test and compare these ratings to the measured seasonal performance observed in the field. This effort will provide valuable feedback and insight on how well the new performance standard matches seasonal performance, with the long-term goal that comparable GEHP performance ratings can be directly compared to other HVAC technologies, such as electric heat pumps VRF systems.

Technical feasibility and economic assessments will be performed on GEHP options (AHU Integration Kit, Hydro-Box) to determine the potential energy savings of these options, the economic benefit and payback, limitations in performance, and the range of potential applications. This assessment will identify the most promising technologies and application options that warrant further investigation or demonstration. A preliminary technology assessment of current GEHP ancillary products will determine the energy or economic benefits of these options and configurations and estimate the potential market for these applications.

## Results

For Phase 1, the project team is developing GEHP performance curves based on four GEHP field datasets in both warm and cold climates. The team is sharing data and collaborating with NRCC staff to develop and validate these heating and cooling performance curves with respect to outdoor ambient temperatures and part load operation. In addition, NRCC is also supporting this effort by monitoring an 8-ton Yanmar GEHP VRF unit installed at their test facility and has commenced data collection.

For Phase 2, the team is monitoring a Yanmar GEHP with an AHU Integration Kit installed at the Middletown Recreation and Community Center in Middletown, CT, to validate performance, best practices, and economic benefits. A successful demonstration of the AHU Integration Kit will support a high-efficiency and cost-effective role for natural gas in space conditioning for commercial buildings.

## Status

For Phase 1, the team is working to refine hourly performance curves for the Yanmar GEHP VRF system using four completed field datasets. This series of heating performance curves will be presented at the ASHRAE Winter Meeting in January 2024. The team continues to collaborate with NRCC and Yanmar to enhance GEHP energy models. An updated version of the CSA/ANSI Z21.40:23/CSA 2.94:23 Performance testing and rating of gas-fired air-conditioning and heat pump appliances standard was recently approved and the team will reach out to VRF manufacturers to obtain any available laboratory test data using this updated standard. Additionally, development of the techno-economic assessment of Yanmar's AHU Integration Kit and Hydrobox designs continues.

For Phase 2, the team continues monitoring the system performance of the GEHP and AHU Integration Kit field site in Middletown, CT since April 2023. Based on preliminary results, the system performance approached the rated GEHP cooling efficiency of 1.0 COPg during design day temperatures of 95°F. Higher cooling efficiencies were observed during periods with greater part loads and more steady state operation. The team will continue to track the system performance during the upcoming heating season.

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## Commercial Heat Pump Water Heater Field Performance Comparison



**Researchers will directly compare the performance of commercial fuel-fired and electric-driven heat pump water heater technologies in both a commercial installation and a laboratory using established ASHRAE testing standards to provide end users with validated cost- and energy-savings analyses of each technology and aid customer choice.**

### Project Description

Commercial water heating end users are seeking higher-efficiency equipment options. Both fuel-fired and electric-driven heat pump water heaters promise efficiencies well above 100%, leading to energy and fuel-cost savings and reduced greenhouse gas (GHG) emissions. In recent years, Stone Mountain Technology, Inc. (SMTI) developed and introduced a gas-fired absorption heat pump water heater (GHPWH). Past projects funded in part by the U.S. Department of Energy (DOE), California Energy Commission (CEC), UTD and others have played important roles in advancing SMTI's product development.

Due to differences in the respective technologies, the standard measure of heat-pump performance – Coefficient of Performance (COP) – does not provide a sufficient metric to compare gas and electric heat pumps. While COP is a good measure when comparing traditional technology of the same fuel, it does not provide a useful comparison when evaluating cost savings or GHG emission performance between electric and gas heat pumps.

The U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) through EERE's Building Technologies Office provided prime funding for a public sector hot-water "proving ground" demonstration of SMTI's 80 kBtu/hr system at a field site. SMTI's commercial GHPWH and a comparable commercial electric heat pump water heater will be tested using the ASHRAE 118.1 hot-water testing standard for comparable performance testing. This will provide real-world operating data to assess energy and cost-saving potential in order to provide end users with additional scientific data to compare these two technologies, to help inform customer choice with comprehensive data. The field test data will be augmented by laboratory tests.

The Tennessee Department of Environment and Conservation (TDEC) is leading the DOE-funded project, through TDEC's Office of Energy Programs. UTD is partnering with DOE, TDEC, the National Association of State Energy Officials (NASEO), the Tennessee Advanced Energy Business Council (TAEBC), and SMTI by providing co-funding to DOE's prime funding. The Propane Education and Research Council (PERC) is also partnering in this project, by providing co-funding to UTD project 1.21.F.

### Benefits / Market Implications

Key benefits that GHPWHs provide customers are to reduce operating costs and energy consumption. Cost savings occur from reduced peak electric demand costs, low gas prices relative to electricity on a per-therm equivalent basis, and overall reductions in energy use. Prior research has shown that total natural gas savings and GHG emission reductions of 16% to 26% (with the potential of up to 53% savings is achievable if the gas heat pump is right-sized) versus conventional water heating technologies. Similar fuel savings are anticipated when fired with propane.

Other important benefits that GHPWHs provide include better cold-weather performance, with ability to operate to -40° F, as well as the resiliency and reliability of the underground



SMTI gas heat pump. (Source: SMTI)



gas delivery system. Propane-fired versions provide options for areas not served by gas distribution infrastructure. Gas heat pumps maintain high efficiency, compared to electric heat pumps, even when ambient temperatures decrease.

New GHPWH product and technologies provide gas utilities and propane distributors with more high-efficiency options to include in their energy-efficiency incentive programs.

GHPWHs can also be beneficial for end users in areas where the electric supply may be constrained, and upgrades to the electric distribution grid may not be feasible within the end-users' timeframe.

The scientific data that evaluates the impact of deploying various types of heat pump water heaters may also aid public dialogue regarding energy efficiency and energy source options.

Examples of gas customers that can benefit include:

- Commercial water heating with a high hot-water use (>1,500 gallons per day)
- Multi-family housing
- Restaurants
- Hotels
- Assisted-living facilities, and
- Health and fitness centers.

## Technical Concept & Approach

The project will provide measurement and verification (M&V) support for the DOE-funded field demonstration project. The same models of both the SMTI gas-fired heat pump water heater and a commercially available electric-driven heat pump water heater will also be tested in a laboratory, to provide end users with an additional direct performance comparison.

The research team will:

- Develop an M&V plan and specify instrumentation for baseline and field demonstration of one SMTI 80 kBtu/hr GPWH
- Develop an interface for baseline and demonstration data to provide near real-time access to collected data and analysis
- Collect, monitor, and analyze baseline and demonstration data
- Prepare interim and final field test data analysis report for inclusion in DOE reports
- Assist in report development and disseminating results

- Install and test the SMTI gas pump water heater following ASHRAE 118.1 standard test for water heating with natural gas
- Install and test a commercial electric heat pump water heater following the ASHRAE standard test for water heating, and
- Provide energy and cost-saving analysis based on testing compared to traditional technology.

## Results

The host site that was initially planned for this project ultimately declined from participating in this field study, which resulted in a project delay. A new host site, Kings University in Bristol, TN was identified and onboarded. An engineering analysis was performed to validate the applicability of installing the heat pump, and a measurement and verification plan has been developed.

## Status

The project team is developing the engineering design, procuring M&V equipment, and planning for installation in December 2023. SMTI's heat pump is scheduled to be installed and commissioned at the host site by February 15, 2024. The heat pump will be installed in parallel to the existing service hot water system providing the opportunity to collect baseline and retrofit data.

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## Ionic Liquid Absorption Heat Pump for Commercial Water Heating

**Researchers are designing and demonstrating in a laboratory environment an early prototype of a low-cost, ultra-high-efficiency gas-fired commercial heat pump water heater with a novel semi-open absorption cycle that uses a benign ionic liquid and provides integrated latent cooling to further maximize efficiency.**



### Project Description

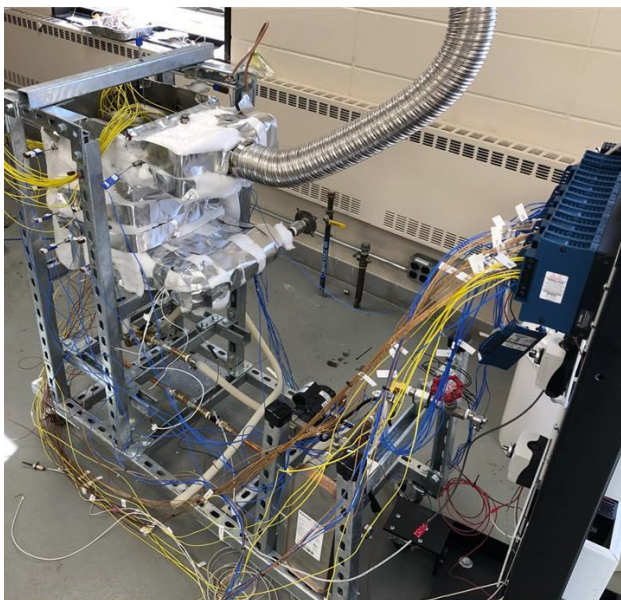
In the water-heating industry, significant attention has been given over the past decade to the development of high-efficiency water heaters for residential buildings. Much of this attention has concerned the tankless water heater, electric heat pump water heaters, and even the development of gas-fired heat pump water heaters (GHPWHs). However, hot water in commercial buildings has not received similar levels of attention, where despite greater numbers of residential water heaters sold per year (with approximately 36 times as many residential storage water heaters sold as commercial storage water heaters), commercial buildings can consume 10 to 100 times the hot water as a typical home. Prior research efforts in UTD project 1.16.I demonstrated the potential for high-efficiency GHPWHs using an ammonia/water closed absorption system, which has performance advantages but also some challenges by using ammonia.

UTD project 1.21.I advances a different technology for commercial hot-water applications – a novel semi-open absorption cycle (SOA-GHPWH) that uses a benign ionic liquid and which provides integrated latent cooling to further maximize efficiency. UTD is partnering with the University of Florida (UF), their partner Micro Nano Technologies, and with poten-

tial support from a leading commercial water heater OEM. All experimental work will be conducted with natural-gas-fired regeneration; however, findings should be directly relevant to propane-fired regeneration as well. The Propane Education and Research Council (PERC) is providing co-funding to this UTD project.

The heat pump design being developed in 1.21.I has several potential advantages over the closed ammonia/water GHPWH. First, the system operates at the atmospheric pressure, thus the lack of up to ~400 psig pressure allows simpler designs and low-cost components – with only small hydrostatic pressures and thin heat-transfer walls, enabling inexpensive low-thermal-resistance materials such as polymers to be used. Second, an inexpensive non-hermetic plastic solution pump is used.

In summary, the objective for this project is to design and demonstrate in a laboratory environment an alpha working prototype of an SOA-GHPWH targeted for commercial water heating applications. The project team will leverage the unique benefits of the GHPWH design, including a) environmentally-benign and safe working fluids, b) supplemental latent cooling via dehumidification, and c) the potential for long-term reliability and avoidance of costly corrosion-resistant materials and approaches. Research work in project 1.21.I is being coordinated with the work in project 1.20.I, which is applying this technology to rooftop units.

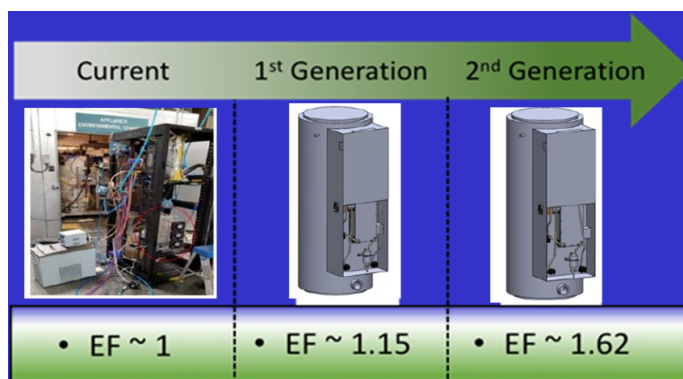


*Desorber Test Stand With Safety Improvements and Insulation*

### Benefits / Market Implications

The benefits that GHPWHs provide customers are primarily higher resiliency and efficiency, and reduced operating cost due to: reduced peak electric demand costs and total energy consumption; the resiliency of gaseous-fuel vs. electric-driven energy delivery; superior cold-weather performance; and lower purchased energy costs on a per-therm equivalent basis. The development of an SOA-GHPWH can provide another robust and attractively-priced fuel-fired GHPWH option for commercial end users.

The current product focus is a 145 kBtu/hr output system with a 100 gallons storage tank and a firing rate of 90 kBtu/hr, which allows this product to have the highest hot-water output in the market while only using a one-half-inch



Conceptual rendering. Source: University of Florida

gas connection. The project team's simulations suggest that this GHPWH will have a recovery rate of 220 gallons per hour at 70°F rise. For a system installation with integrated controls, including a conventional water heater in series to support peak demand, the projected economics are very attractive.

For a 5,000 gallon-a-day hot-water demand – typical for full-size restaurants or mid-size hotel, dormitory, or multifamily buildings – the SOA-GHPWH system is projected to reduce natural gas consumption by 5,655 therms (42%), with associated annual operating cost savings of \$6,390 (\$1.13/therm assumed). The projected cost of the GHPWH system in this example, including the peak demand conventional water heater is \$11,950. Thus, the simple payback period is estimated to be 1.9 years. Note that this estimate is conservative with respect to the project, as the GHPWH operation will be more efficient in hot/humid climates and the economic benefit of supplemental dehumidification, reducing overall site HVAC operating costs, will further improve the value proposition.

## Technical Concept & Approach

A research team will develop a final design for the SOA heat pump module, including the desorber/condenser, conditioning equipment, combustion system, and other components. The module will then be fabricated and tested.

Researchers will perform a battery of steady-state tests, varying stored water and ambient air dry bulb/dew point temperatures for performance mapping. Ultra-low NO<sub>x</sub> performance will be demonstrated with simulated thermal loads. Cycling tests will be performed using extended draw sequences, varying the magnitude and clustering of hot-water draws per prior field observations. An optimized control strategy will be identified per cycling tests.

The project team will develop a final alpha SOA-GHPWH testing report, with improvements identified for design, integration, and controls based on test data and simplified simulation of GHPWH dynamics.

A manufactured cost estimate of the heat pump module will be developed and researchers will identify areas for cost reduction in subsequent efforts.

## Results

In 2021, the project team continued to refine the product definition and consider codes/standards implications and controls specification options. In addition to defining the concept for the target application, the effort leveraged a parallel commercial HVAC effort using a hospital application to consider deep-dehumidification applications (defined as a separate sensible/latent air-conditioning version) and a compressor-less HVAC version.

The team finalized the design of the desorber, which included shifting the type of overall heat exchanger (HX) design. In addition to these desorber design exercises, the team continued to solicit and evaluate custom premix burner options in open-air testing from multiple burner manufacturing partners.

Final simulations of the desorber design were performed to screen for potential hot spots and other issues. A package of drawings was prepared, bids were secured from local fabricators, and a fabricator was selected.

The desorber setup and testing were completed (with a water boil test and using peanut oil to simulate ionic liquid). These tests yielded results that were used to calibrate parallel computational fluid dynamics (CFD) modeling and a general analytical approach to heat transfer estimated. Results from peanut oil were analyzed and extended to the ionic liquid. Finally, a Multiphysics CFD simulation was performed, where gas phase (flue gases) and shell-side fluid (peanut oil / ionic liquid) were combined for the first time.

Using the data collected, the local heat transfer coefficients were estimated using standard non-dimensional analysis yielding an estimated Nusselt number of 46.3 and HTC of 315 W/m<sup>2</sup>K, within a 5% error from experimental results.

Progress and results to date from this project were communicated in technical papers that were delivered at the 14th International Energy Agency (IEA) Heat Pump Conference held in May 2023 in Chicago, IL, USA.

## Status

The research team completed testing of the desorber, and is preparing to report full desorber test results to UF and other project sponsors. The team will support subsequent analysis and testing on UF's side with updated desorber designs.

The team will also be working to develop a test plan and test rig design to test the 1,000 CFM prototype with UF.

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## Hydrogen Blending End-Use Performance and Safety Field Demonstration



**Gas utility personnel and energy researchers are partnering to demonstrate the safety, technical, and performance implications of blending hydrogen into natural gas when used in fuel-fired equipment such as HVAC, water heating, cooking, and hearth products.**

### Project Description

Blending hydrogen into natural gas for use by existing gas appliances has the potential to reduce NO<sub>x</sub> and CO emissions into the home while also reducing carbon emissions (depending on the source of the hydrogen). This project seeks to demonstrate the safety and efficacy of a hydrogen/natural gas blend for a variety of end use products including HVAC, water heating, cooking, and hearth products. This project will test multiple retrofit and mitigation strategies. Efficacy will be measured by:

- End user safety and performance
- Estimates of decarbonizations potential
- Reductions of NO<sub>x</sub> and CO emissions

The results of this analysis will be packaged into best practices for field service technicians during utility blending programs. Outreach will be provided to builders, equipment manufacturers, and code authorities. Best practices will be issued for equipment commissioning for field installers/technicians during utility blending pilots. A methodology to estimate customer decarbonization potential in utility territories will be developed and implemented. Findings will be showcased with trade allies, builders, policy/standards, and other stakeholders.

### Benefits / Market Implications

Hydrogen blending into gas grids for use in buildings and industry has distinct benefits:

- It can provide a significant decarbonization/energy storage “win” in the near-term
- This scale up of hydrogen demand further stimulates scale up of hydrogen supply and distribution technologies
- Low concentration hydrogen blending can be a stepping stone towards 100% hydrogen distribution, which can contribute to net zero emissions by 2050.

Hydrogen blending research is being conducted worldwide.

Many utilities have recognized the benefit of adopting hydrogen into natural gas pipeline and, with significant efforts on their parts, have initiated hydrogen blending in the field. While other countries have embarked on hydrogen/natural gas blending pilots, such as in the UK, Germany, or the Netherlands, this is only recently happening in the US and Canada, leading governments and stakeholders to drive the development of safety/performance standards for gas-fired appliances, including the identification of suitable hydrogen limits on existing equipment.

This UTD demonstration project can, via outreach and expanding the dataset of operating existing/standard end use equipment on hydrogen blends, catalyze similar developments in the US/Canada while serving to address research gaps and develop best practices for in-field equipment commissioning in blending pilots.



*Appliance Samples*

### Technical Concept and Approach

This effort will focus on assessing the impacts on common, building-owned end-use equipment that are lightly maintained (i.e., in residential or light commercial building applications). Broadly, this project concerns fuel-fired equipment that are inside of the scope of the EnergyStar® program specifications for residential and commercial-sized equipment. Physical testing will focus largely on residential-type equipment (see below), however decarbonization modeling,



best practices development, and outreach will concern the full range of building-owned end use equipment.

This project will focus on existing equipment and addressing technical gaps in product development, field servicing, utility training, and stakeholder education, in order to: expand this emerging dataset for a wide range of equipment types at a controlled demonstration for short-term and long-term effects; support the momentum behind utility blending pilots with development of best practices and mitigation techniques; and engage a growing group of multiple stakeholders through in-person and media pathways (OEMs, builders/contractors, utilities, codes/standards bodies).

The hydrogen blending test site will occur at a utility-owned demonstration site located in the greater Las Vegas region.

Under this project, a proposed solar panel-coupled Polymer Exchange Membrane (PEM) electrolyzer with the hydrogen generation capacity of 2 kg/day is going to be adopted to generate and blend hydrogen into the natural gas system onsite. The field testing at the Southwest Gas demonstration site will select 30 representative appliances from the market to conduct hydrogen blending research.



*Simulated Neighborhood at Demo Site*

Equipment test rigs will identified for this project include:

- Four automated test stands will operate and collect long-term and short-term data from: central warm-air furnaces, wall furnaces, storage-type water heaters, and decorative gas appliances
- Four manual test stands will operate and collect short-term data only from: indoor cooking appliances, dryer/indoor hearth products, space heaters, and outdoor cooking/patio heating appliances

## Results

The Blended Hydrogen Field Demonstration Plan was complete and socialized with Southwest Gas (host) and UNLV (partner). This plan would involve both short term (manually-operated) and long term (automated) testing of residential-type equipment with hydrogen blends.

The project team developed safety documentation in preparation for testing, including:

- Job Safety Analyses – Safety documentation for eight test stands, which included process & instrumentation diagrams (P&IDs). These were separately prepared and submitted for automated testing (unattended) and manual testing (attended).
- Manual Testing Protocols – in addition to the *Blended Hydrogen Field Demonstration Plan* which was previously developed and submitted, these protocols spell out how each manual (attended) test will be performed.

With the test rigs largely designed, the team has prepared ‘bills of materials’ for each rig and has identified prospective models for each of the 30 appliances to be tested. Once aforementioned documentation and agreements are complete, these will be acted upon with procurement in the next reporting period.

## Status

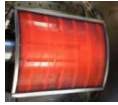
The team is moving towards fabrication and deployment of test rigs with plans to initiate testing in early 2024. The project team has also coordinated with partner UNLV on test support and the installation/operation of the 2.2 kg/day hydrogen electrolyzer.

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## Fuel-flexible Ultra-Low NO<sub>x</sub> Catalytic Burners for ResCom Appliances



Researchers are developing, testing and demonstrating catalytic gas burners to use a blend of hydrogen and natural gas with up to 50% hydrogen, while achieving low NO<sub>x</sub> emissions. These advanced burners will enhance the safe, economical operation for end users and reduce GHG emissions by using fuels that contain more hydrogen.

### Project Description

This project is developing and demonstrating fuel-flexible hydrogen-natural gas low-cost catalytic combustion gas burners for residential and light commercial applications that can accommodate up to 50% hydrogen while achieving NO<sub>x</sub> emissions superior to the current state of the art. Specific goals for this project are to demonstrate stable operation while accommodating fuel flexibility of at least 0-50% hydrogen, demonstrate at least sub 10 ppm @ 3% O<sub>2</sub> NO<sub>x</sub> emissions, and quantify performance of the burner operating on different fuel blends.



*Improved Catalytic Burners can provide Fuel-flexible Operation*

### Benefits / Market Implications

The primary target markets impacted will be residential gas water heating and furnace markets (over 61 million households in the US and Canada) and other domestic heaters with heating loads of less than 40,000 BTU/hr (outdoor heaters, etc.). Secondary target markets may include food service combustion equipment, including range top burners and ovens, and light industry heating devices.

Project success will have multiple benefits including:

**Saving consumers money:** Hydrogen-natural gas burners would expand customer's competitive choices of product offerings (including fuel options from natural gas to H<sub>2</sub> blends).

**Expanding fuel flexibility of domestic combustion appliances:** Ensuring safe, reliable, and resilient operation of end

user's equipment and energy delivery systems allows fuel flexible gas burners to come to market.

#### Achieving superior environmental performance:

- Reduction in GHG emissions beyond current Ultra-Low NO<sub>x</sub> domestic devices, including storage water heaters and furnaces, by adopting hydrogen in the pipeline natural gas.
- Reduction of NO<sub>x</sub> emissions under 10 ppm @3% O<sub>2</sub>, which meets SCAQMD's Rule 1121.
- Expansion of choices of product offerings that support Zero Net Energy (ZNE) buildings.
- Provide scientific data to assess IAQ impacts of adopting catalytic burners in domestic appliances.
- Expand the integration of natural gas with hydrogen/power-to-gas in domestic, commercial, and light industry applications.

Combustion applications are the major appliance types for domestic water and air heating. For example, 32% of the domestic natural gas in California is used for space heating and 59% for water heating. Currently, more than 80% of space heating appliances and more than 90% of water heaters in California are fueled with natural gas.

As decarbonization efforts across North America and Canada, adopting H<sub>2</sub>-tolerant burners with Ultra-Low NO<sub>x</sub> performance is of great interest to both gas consumers and utilities.

Adapting natural gas/propane catalytic burners to natural gas/hydrogen mixtures will assist energy transition to renewable hydrogen in residential and light commercial applications. A fuel flexible burner (up to at least 50% H<sub>2</sub>) which can accommodate varying fuel blends will aid the industry transition as the amount of hydrogen that can be manufactured and injected varies. Over 61 million households in the US and Canada would likely benefit from this alternative option of fuel flexible Ultra-Low NO<sub>x</sub> device. This project may also help launch a key new product supplier and thus expand consumer choices for Ultra-Low NO<sub>x</sub> combustion

appliances. The research is also expected to help gas utilities achieve their Scope 3 GHG reduction goals, while manufacturers and consumers meet strict NOx emission regulations (e.g., SCAQMD Rule 1121).

## Technical Concept & Approach

This project is broken down into three sequential tasks.

### Task 1: Investigate Prototype Burner H2 Tolerance levels

Conduct tests on at least five current off-the-shelf catalytic burners on various H2 blending levels to identify the tolerance levels of existing natural gas catalytic burners and examine combustion performance (NOx, CO, THC emissions, efficiency, etc.).

### Task 2: Optimize and Manufacture Prototype Burner

Down-select 2-3 of the most promising tested burners and work with manufacturers to evaluate potential burner re-design or optimization to better accommodate H2. Manufacture and test the fuel-flexible burners (up to 50% H2) to meet the sub 10 ppm @ 3% O2 NOx target.

### Task 3: Adjust and Test the Prototype Burner in Simulated Appliances

Install one or more optimized burners into a storage water heater and a room furnace. Evaluate the appliance performance and conduct further optimization if necessary.



*Example Catalytic Burner (Image Credit: Alzeta Corp.)*



*Example Catalytic Burner*

## Results

A literature review report of available burners was developed, and updates are being finalized. The review builds on previous studies and other research underway on catalytic burners. The project team has contacted multiple burner manufacturers to secure burners to conduct testing. Three catalytic burners have already been secured to conduct the Task 1 testing on various fuel blends.

## Status

The project team is setting up the testing space in an industrial laboratory in order to conduct individual burner testing.

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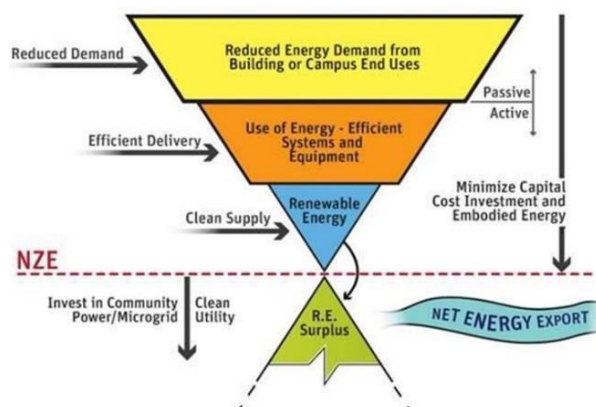
# Deep Energy Customized Affordable Retrofits of Building Envelopes and Mechanicals



**Researchers are advancing technologies that can rapidly integrate highly innovative building envelope improvements with next-generation HVAC equipment retrofits to reduce GHG emissions by  $\geq 50\%$ , while providing significant operating cost savings for homeowners, multi-family residences, income-eligible housing, and others.**

## Project Description

While much greater use of renewable natural gas, hydrogen generated from renewable energy, and other initiatives are key methods to support decarbonization efforts, whole-building decarbonization approaches will be most impactful if they first reduce energy demand through improved passive building envelope measures, especially when coupled with very-high-efficiency next-generation mechanical systems to efficiently use and deliver energy through the building. The image below illustrates one recommended priority of efforts to decarbonize buildings.



*Decarbonizing buildings for net zero energy (NZE) Source: Affiliated Engineers, Inc.*

The goal of this project is to advance the development and rapid deployment of innovative residential building envelope improvements coupled with directly-integrated next generation, high-efficiency space conditioning equipment to reduce energy use. Improvements will be developed and demonstrated in the laboratory and in field installations using multiple innovative methods. UTD is partnering with a number of entities, including providing co-funding to prime-funded contracts from the New York State Energy Research and Development Authority (NYSERDA) and the State of Illinois Environmental Protection Agency (EPA).

## Benefits / Market Implications

Successful commercialization and deployment of the technologies being developed in this UTD "DECARB-EM" project will have a transformative impact on residential energy use. Customers will realize significant cost savings by reducing

energy use, while GHG emissions will also be significantly reduced.

The primary target markets impacted will be buildings such as: single-family residences, or low-rise multifamily (e.g. 3 floors), or mid/high-rise multifamily residences (e.g. >3 floors), or income-eligible affordable housing; located in cold climate applications (generally U.S. climate zones Zone 4 and above); using either hydronic and forced air HVAC, and; primarily built more than 20 years ago (since this is the largest building stock by far).

The target is to achieve a 50% reduction in GHG emissions, with significant operating cost savings through reduced loads, higher part-load efficiencies with next generation gas technologies. This project will also expand customer's competitive choices of product offerings (including fuel options for decarbonization) while also addressing indoor air quality concerns by integrating mechanical ventilation into retrofits.

## Technical Concept & Approach

First, laboratory testing will validate a novel distribution system for all heating, ventilation, and cooling designed for an exterior envelope retrofit panel being introduced by Hydronic Shell Technologies (HST). This technology provides ideal distribution for an air-to-water heat pump such as many gas-fired heat pump (GHP) systems, while addressing indoor air quality concerns by providing mechanical ventilation as part of exterior insulated panel retrofits.

Second, the NYSERDA-prime-funded effort will develop a process roadmap to streamline high performance retrofit panels, minimizing on-site disruption for any deep energy retrofits. Performing retrofits in an exterior-only manner that minimizes occupant disruption and eliminates relocation is critical for mass adoption. This UTD project will support that by maximizing offsite construction with digital support tools so that deep energy retrofits can be completed in days instead of weeks, at a more affordable cost. Monitored performance in the NYSERDA project and related efforts at other projects will demonstrate integrated improvements and provide validation.

Third, design guidance will be developed to provide gas-focused solutions that incorporate building envelope and mechanical technologies to deliver deep decarbonization objectives.





Point cloud image result from lidar scan of multi-family building

The following tasks will be performed to achieve the research objectives:

### Task 1: Hydronic Shell Laboratory and Technoeconomic Analysis

Perform validation tests of heat transfer for the hydronic shell mechanical distribution system (hydrobox and radiant convectors only), and the system's ability to meet various loads and maintain comfort setpoints in the laboratory using environmental chambers. This will inform GHP design applications for building retrofits.

### Task 2: Multifamily Deep Retrofit Mechanical Packages

Identify centralized packages of mechanical system retrofits leveraging fuel-fired equipment such as GHPs and install one in conjunction with deep energy retrofits, and measure performance in a baseline year, post envelope year, and mechanical year. This will occur on a multifamily project with NYSERDA funding.

### Task 3: Single-Family Deep Retrofit Mechanical Packages

Identify single family mechanical system retrofits to deploy fuel-fired equipment such as an advanced combi, hybrid system, or GHPs in deep energy retrofits, and measure performance in a baseline year, post envelope year, and mechanical year. This will occur on a single-family project with IL EPA funding.



Hydronic Shell envelope/mechanical panel

*"UTD provided funding to build and test HST's first prototype panel at GTI Energy, validating our concept at a stage where our technology was too early even for most government grants. It's opened doors to new sources of funding and success in several prize competitions, totaling over \$400,000 since testing at GTI began. We're now on a clear path to commercialization that's been enabled and accelerated by UTD's support."*



– David Goldstein,  
Founder and  
CEO, Hydronic Shell  
Technologies (HST)

### Task 4: Scaling Customized Retrofit Processes

Using findings from prior tasks and co-funded work from NYSERDA and others, develop improvements and identify ways to expedite customization timelines and minimize costs for deep energy retrofits in subsequent field tests which can demonstrate and optimize installation efficiency.

## Results

Preliminary modeling on an existing 100-unit building in NY has shown over 70% GHG reductions when the hydronic shell is combined with gas heat pump technology. Results of UTD project 1.22.E were used by HST in its application and successful award in November 2023 to receive a \$3 million grant from the Housing Affordability Breakthrough Challenge.

## Status

In the current project period, the first stage of evaluation of the Hydrobox system was completed. Installation was completed of all system hardware components in an environmental chamber, along with a hydronic loop, testing and data collection equipment, and controls programming. Data recording has begun. Modeling was done to determine a way to construct a simulated "interior wall" to represent the existing building wall within the HST installation in the environmental chamber. The interior wall will be built and installed after initial heating data collection of the Hydrobox unit and radiant emitters. The team completed shakedown tests for chamber testing and started data collection and submitted abstract proposals to ResNet, ASHRAE, and PhiusCon.

The team also completed lidar scanning of a multi-family building façade for Task 2 as well as installed a tankless water heater that will be the base of a hybrid advanced combi in the single-family home for Task 3 including instrumentation for temperature and water consumption recording.

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## Safe Use of Hydrogen in Buildings



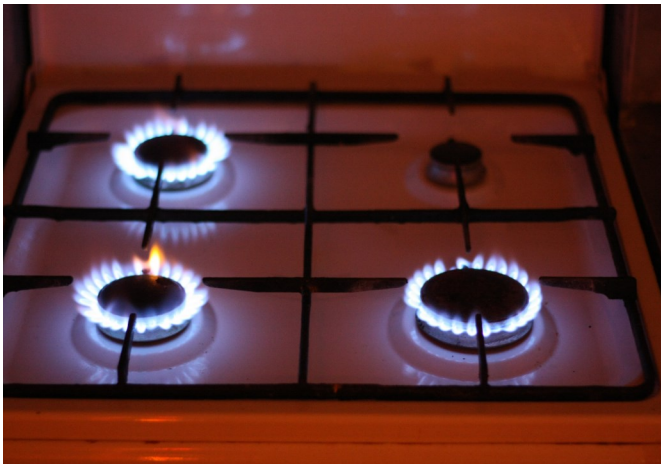
**This project aims to address barriers for safe use of higher hydrogen blends (>30%) in residential and light commercial appliances such as hydrogen's potential propensity (in blends with natural gas) of leaking from existing building gas distribution systems and appliance gas handling subsystems, and potential detonation risks.**

### Project Description

Hydrogen, as a decarbonization means, offers only limited opportunity for GHG emissions reductions at low blends (e.g., up to 12% GHG emission reduction with 30% H<sub>2</sub>). The carbon reduction potential of hydrogen is reduced further if it is not generated from clean energy sources, if the appliance efficiency is reduced, or if its leak rate is significant in the existing gas infrastructure.

There are ongoing efforts in the industry and the academia to quantify preferential hydrogen leakage. Even if hydrogen blends up to 20-30% are permitted in buildings (currently it is not under NFPA 54), to achieve decarbonization goals of greater than 7-12% on the fuel side, higher concentrations of H<sub>2</sub> will be needed. It is well understood that 100% H<sub>2</sub> appliances and gas distribution systems need special design considerations and that appliances operating with low blends likely do not need many changes. However, the transition from where no changes are necessary to where significant changes are necessary is not well defined.

This project seeks to enable broad deployment of hydrogen-blended gas by proactively addressing consumer and regulator concerns about its safe use in buildings. To help achieve this, this project will characterize the propensity of hydrogen (in blends with natural gas) to preferentially leak from existing building gas distribution systems and appliance gas han-



*A gas range is one appliance that has been shown to be susceptible to flashback and theoretical studies have raised a concern about detonation risk with blends above 45% H<sub>2</sub> by volume*

dling subsystems. Additionally, this project aims to address barriers for safe use of higher hydrogen blends (>30%) in Res/Com appliances.

### Benefits / Market Implications

This project will respond to growing interest and concerns about the use of hydrogen in buildings. With codes and standards revision efforts increasing to enable the safe use of hydrogen in buildings (e.g., CSA formed a committee to enable 100% hydrogen use in appliances), this project will provide timely information to help shape how hydrogen's use will be enabled or restricted in the near future.

The primary target markets impacted will be:

- Those served by low-pressure gas distribution systems (5 in wc – 2 psig), including low-rise residential, multi-family, and small commercial buildings.
- Appliances utilizing premixed combustion systems including gas heat pumps, mCHPs, tankless water heaters, condensing boilers, and ultralow NO<sub>x</sub> equipment.
- Hydronic and forced air installations.
- Gas-grid supply-constrained markets

Secondary target markets may include large commercial and industrial buildings served by high-pressure gas supply (>5 psig) and large commercial and industrial premix burners.

The development, distribution, and utilization of "Green" and "Blue" hydrogen, produced from clean power-to-gas and methane reformation with carbon capture schemes, respectively, is an important strategic area for society to meet ambitious long-term decarbonization goals.

To that end, society must look beyond small-scale hydrogen blending demonstrations (typically limited to 5-10% H<sub>2</sub>). However, the use of higher concentrations of hydrogen inside existing buildings and appliances comes with additional questions and concerns. To permit even up to 20% of hydrogen in buildings would require building code revisions (e.g.,

NFPA 54 – National Fuel Gas Code), and none of the current appliance standards under ANSI Z21 series consider hydrogen specific requirements. This project addresses some of the current knowledge gaps about hydrogen leakage from building gas distribution systems, appliances, as well as potential new requirements in appliance standards for certification for hydrogen operation.

## Technical Concept & Approach

The project will investigate the propensity of hydrogen to preferentially leak from blended gas in low-pressure gas distribution systems and appliance gas line connections. Going beyond the distribution system, the study will investigate the potential and risks for leaks inside the appliances, which could pose special risk due to being enclosed and potentially exposed to high temperatures and sparks. In a parallel task, the project team will investigate increasing detonation risks as the level of hydrogen blend increases for use with Res/Com combustion systems.

This project is broken into two tasks:

### **Task 1: Res/Com Gas Line and Appliance Leakage Assessment**

Develop a test plan and an experimental test rig to quantitatively assess the propensity of hydrogen to preferentially leak from building gas lines and appliances. Develop an interim summary of the findings and recommendations on the leak risks and mitigation strategies.

### **Task 2: Detonation Risk Assessment for Hydrogen-blended Gas**

Develop an assessment of detonation risks with increasing hydrogen use in appliances, to be disseminated publicly through peer-reviewed publications.

## Results

The research team completed a preliminary literature review on hydrogen-methane-air detonation characteristics with a focus on conditions relevant to the process industry, and conducted a literature review on hydrogen/natural gas mixture leakage research. The team also scouted a location for leakage testing, instrumentation and data acquisition equipment, and sensor products for testing. A test plan for Task 1 has also been completed.

## Status

In preparation for testing later in 2023, the team is constructing the test apparatus for preferential leakage testing.

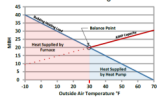
The team has also completed a preliminary literature review on detonation risks with hydrogen-natural gas blends. The team will compile some of the findings with a spreadsheet-based calculator to predict appliance operating conditions under which the risk of detonation increases.

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# Hybrid Fuel-fired and Electric-driven Residential/Commercial HVAC Systems



Researchers are studying emerging or commercially-available hybrid gas furnace/electric heat pump products in the North American market, in order to evaluate promising hybrid systems and develop installation and operation guides that can help end users accelerate their integration of electricity derived from renewable energy with fuel-fired equipment.

## Project Description

This project seeks to characterize the performance of hybrid gas furnace/electric heat pump products and quantify potential energy, operating cost, GHG savings, fuel versus electric space heating contributions, and potential user comfort issues in all seven Building America climate zones. This project will be done in three steps: 1) Conduct a thorough market assessment of emerging or commercially ready hybrid gas furnace/electric heat pump products in the North American market. 2) Select and evaluate three promising hybrid systems. 3) Develop and publish design, installation, and operational guidelines for clean, efficient, and cost-effective use of hybrid forced air heating systems in various climates.

UTD is partnering on this project with the Northwest Energy Efficiency Alliance (NEEA) and the Propane Education and Research Council (PERC), with both entities co-funding this UTD project.

## Benefits / Market Implications

Hybrid fuel-fired and electric heat pump systems apply to residential and commercial applications, but the primary target markets impacted by this project will be single-family and multifamily residential new construction and retrofits.

Previous UTD research characterizing the full performance spectrum of fuel-fired residential space heating systems as well as cold-climate and non-cold-climate electric-driven air source heat pump (ASHPs) indicates these systems, if properly integrated and controlled, can generate energy, cost, and GHG savings by 15% to 30%. More importantly, these savings can be realized now, with off-the-shelf equipment that gives customers choices in the fuels they use to heat their homes in a cost-effective, resilient, and environmentally responsible manner.

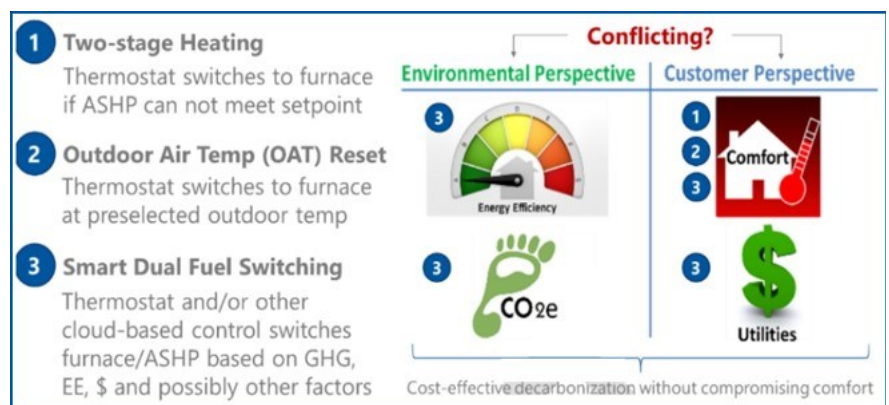
Driven by ambitious goals to decarbonize the power generation systems, electrification is an emerging trend to switch end-use equipment from non-electric to electric sources of energy. Such societal shifts toward decarbonization coupled with tech-

nological advancements and rapid R&D investments have contributed to an expanding North American electric ASHP market, one that may result in dramatic increases in building electric loads. Those loads, combined with the effects of a nascent electric vehicle market, may strain the North American power grid. For example, the 2021 Electrification Futures Study report published by the National Renewable Energy Laboratory (NREL) shows an extraordinary need for new installed power capacity in the U.S. given medium and high electrification load growth scenarios. In this report, new power capacity is predicted to be more than doubled by 2050; to primarily be met using intermittent PV and wind energy resources with very little storage capacity.

By employing hybrid systems, end users can maximize use of electricity derived from renewable energy while also leveraging the very large underground gas storage capacity in N.A. for peak day energy needs. Hybrid systems also permit end users operational flexibility and enhance operational resiliency.

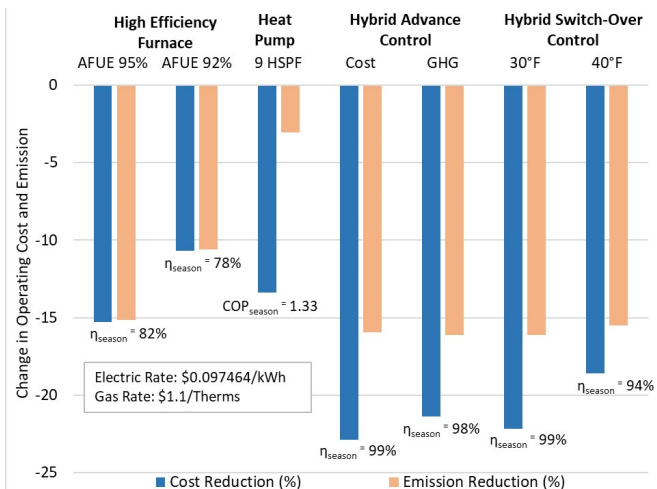
## Technical Concept & Approach

The project team will conduct a thorough market assessment of emerging or commercially ready hybrid furnace-heat pump products in the North American market. Some major manufacturers such as Carrier, Daikin, Lennox and Rheem have developed packaged products that include a furnace, ASHP, A-coil and thermostat. However, hybrid systems can also be mix-and-match using a smart thermostat. Moreover, hybrid systems can integrate a cold-climate or non-cold-climate ASHP.



The hybrid control modes





Modeling result of 9 HSPF and 95% AFUE hybrid system compared with 80% AFUE furnace at Rochester, MN

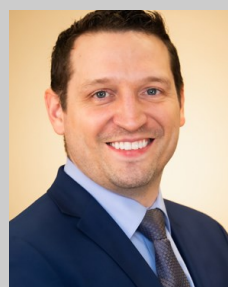
The team will segment emerging and available hybrid products by these various categories. The team will then select three hybrid systems to evaluate in a laboratory. Laboratory research will focus on characterizing the hybrid systems' performance across a range of operating conditions using a lab-based Virtual Test Home methodology. Those performance characterizations will be built into energy modeling software to quantify potential energy, operating cost, and GHG savings. The models will also be used to understand and quantify fuel versus electric space heating contributions. The models will be configured in seven Building America climate zones and consider both natural gas and propane. Finally, the team will work to publish hybrid design, installation, and operating guidelines and disseminate the research material. The project is broken up into three tasks:

### Task 1: Market Landscape

Conduct a thorough market assessment of emerging or commercially ready hybrid furnace-heat pump products in the North American market.

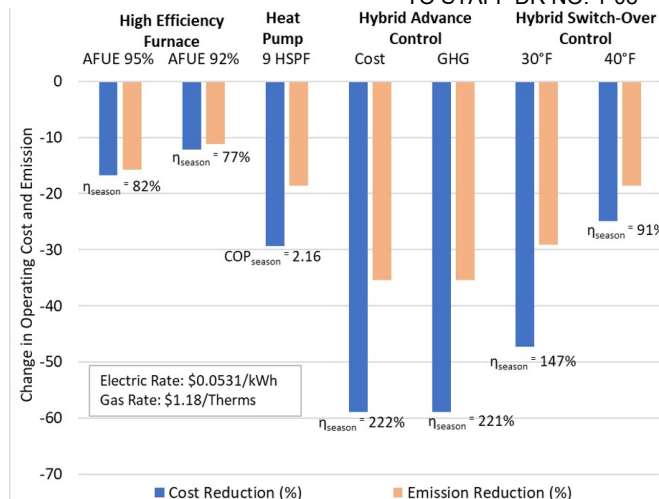
### Task 2: Laboratory Evaluations

Select one single-manufacturer hybrid system with a non-cold-climate ASHP, one single-manufacturer hybrid system with a cold-climate ASHP, and one mix-and-match hybrid system



*"The annual GHG emissions, operating costs, and source energy consumption of hybrid heating systems will depend on the local climate, regional electric grid fuel mix, system control logic, peak demand periods, and other factors. This project will help the design and contractor community to manufacture and install economical, effective hybrid systems, while enhancing real-time control options for customers to reduce overall GHG emissions, operating costs, or source energy use."*

- Thomas Manjarres  
Technical Lead – Energy Efficiency Programs  
Peoples Gas and North Shore Gas



Modeling result of 9 HSPF and 95% AFUE hybrid system compared with 80% AFUE furnace at Seattle, WA

(i.e. different component OEMs) with a cold-climate ASHP and a third-party smart thermostat. With the selected systems, perform laboratory evaluations and performance characterizations using a Virtual Test Home methodology and develop Energy Plus™ modules specific to the hybrid systems. Then model those systems for energy, operating cost, GHG and other parametric quantifications relative to local code-compliant equipment as well as equipment associated with electrification strategies.

### Task 3: Design Guidelines

Based on the market landscape and laboratory research, the team will develop design guidelines for designing, installing, and operating hybrid systems efficiently and cost effectively.

## Results

A market landscape of emerging or commercially ready hybrid gas furnace/electric heat pump products in the N.A. market has been created. A hybrid system has been identified and ordered. Testing infrastructure has been designed.

## Status

The project team has finalized a market landscape, and is currently addressing comments and suggestions received from the project sponsors on it. The team has designed and built a thermostat environmental emulator for hybrid load-based testing. The team has obtained a representative hybrid system, built the testing infrastructure, developed a test plan, and will evaluate the hybrid system in the heating season of 2023/2024.

### For more information:

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## Emerging Distributed Methane Pyrolysis Technologies



Researchers are surveying emerging methane pyrolysis technologies to produce hydrogen (“turquoise” hydrogen), which allows siting hydrogen generation close to the point of use and potentially very cost-effectively for gas end users to decarbonize their operations.

### Project Description

This project is classifying a range of emerging distributed methane pyrolysis solutions as good/better/best fit for gas ratepayers and consumers to decarbonize their operations, by combining application/process modeling with end user demand modeling and technology assessments. The research team initially conducted primary research via direct outreach to the leading technology developers in this space in order to create a landscape survey of options for distributed methane pyrolysis technologies. The survey included a techno-economic assessment (TEA) over a range of applications, with treatment of the underlying conversion process, hydrogen end uses, and handling of carbon outputs. Current efforts are expanding this analysis with additional direct outreach and refinement of the TEA.

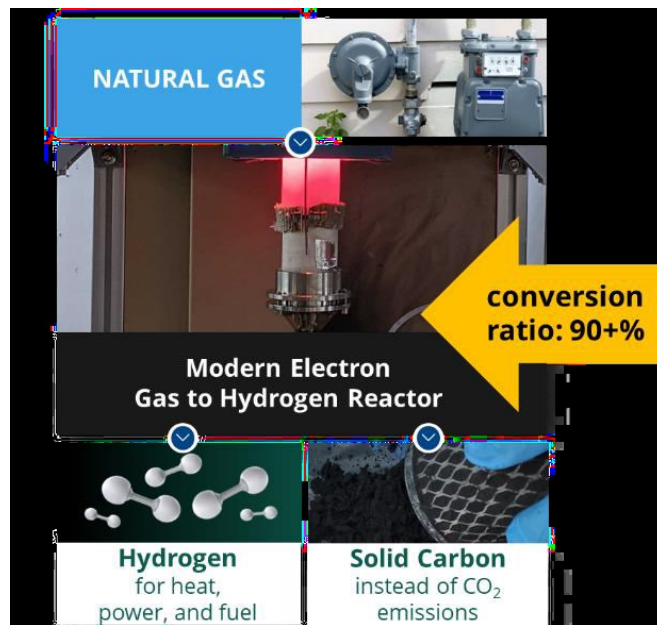
With decarbonization pressures on utilities, their customers and society - - coupled with a wave of investments in technologies for hydrogen production, distribution, and use - - it is important to understand the advantages and disadvantages of different approaches for ratepayers to decarbonize their fuels. This need is further accelerated by incentives, such as the tax credits in the U.S. *Inflation Reduction Act (IRA)*, which provide significant tax credits for investments and production of low carbon hydrogen.

Different approaches to distributed methane pyrolysis will have a range of benefits depending on, among other aspects: the scale of their production (10 vs. 100 kg/day) and capacity factors, the ease of carbon utilization/disposal, process efficiency and emissions, and the avoided infrastructure modifications to reach the same overall decarbonization. This project directly addresses UTD goals to reduce GHG emissions while simultaneously accelerating the transition for hydrogen and also leveraging the existing natural gas delivery infrastructure.

Full decarbonization of utility customers, mitigating downstream GHG emissions, is primarily achieved through substitution of delivered natural gas with non-fossil gases, bio-methane (RNG), hydrogen, and blends thereof. For instance, in a decarbonization pathways study for natural gas utilities which issued in February 2022, the American Gas Association (AGA) pointed to 59% of total decarbonization by 2050 in one scenario coming from renewable and low carbon gases.

The majority of hydrogen produced today is “gray”, that is steam reformation of natural gas resulting in direct emissions of CO<sub>2</sub>. Some major emerging pathways are “blue” hydrogen, “gray” hydrogen with the addition of carbon capture and sequestration, and “green” hydrogen, hydrogen produced via electrolysis powered by renewable electricity. This research project focuses on “turquoise” hydrogen, a blend of blue and green, which is driven by methane pyrolysis.

Turquoise hydrogen has the distinct advantages over green and blue pathways by a) using a much lower cost feedstock (methane vs. water & electricity) and b) providing an ease of carbon capture via solid carbon, which is approximately 1,000 times denser than atmospheric CO<sub>2</sub>, sequestering



Methane Pyrolysis Concept (Source: Modern Hydrogen)

### Benefits / Market Implications

The primary target markets are to be determined but are likely to be quite cross-cutting. Initial applications could be commercial or industrial processes or boilers, where produced solid carbon may be readily collected.



*"Low carbon hydrogen will play an important role in reducing the GHG emissions through deployment in heating, industrial and transportation applications to achieve a sustainable clean energy future. Methane pyrolysis offers a unique opportunity to produce hydrogen by using natural gas as a low-cost feedstock and leveraging existing natural gas distribution infrastructure. We're very pleased to support this project to help increase the awareness of this innovative hydrogen production technology, that could lead to scaling up of this technology."*

- Aqeel Zaidi  
Manager, Technology Development  
Enbridge Gas Inc.

nearly 4,000 times as much carbon. For these reasons, turquoise hydrogen production can be physically closer to the point of natural gas use and can leverage existing gas distribution infrastructure. This has the potential to avoid much of the infrastructure mitigations to accommodate hydrogen-based fuels by utilities, by using methane as a valuable feedstock or providing relative ease of carbon sequestration.

With these advantages in mind, there are a) estimates that turquoise hydrogen will provide more environmental benefits at a lower cost than green or blue pathways and b) that the captured carbon may provide useful revenue streams. This project explores this potential with a techno-economic assessment, while grounding the analysis in technologies currently under development and with considerations of a range of use cases.

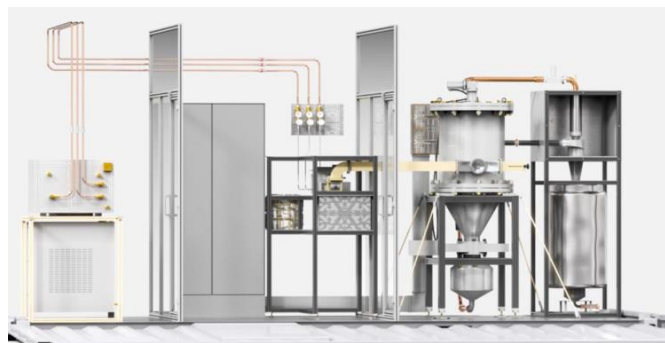
## Technical Concept & Approach

The project team initially began application/process modeling by defining the approach up through developing a final system modeling plan, to couple with end user demand modeling and identified a range of distributed methane pyrolysis solutions (good/better/best).

This project performed a) a thorough modeling assessment of methane pyrolysis options with application considerations, b) provided analytical feedback to UTD members and select methane pyrolysis partners, c) provided a summary of R&D gaps for methane pyrolysis solutions – conversion technology and carbon handling, and d) a pre-feasibility analysis for a prospective demonstration. This was focused on the five or more application scenarios (e.g. boiler for space heating or industrial drying process) and five or more carbon output scenarios (e.g. disposal to soil, or as feedstock) identified in Phase 1, as reported in Q3-23.

Phase 1 results of this analysis will be used to refine the TEA

to update assumptions based on both modeling results and any new information gathered. The project team will also collect data and information from industry scale-up efforts, as experimental and pilot-scale efforts are underway in a range of applications, providing this summary along with modeling results and recommended next steps.



Rendering of the Levidian LOOP Skid – Microwave-Assisted Pyrolysis with Graphene Outputs (Source: Levidian)

## Results

The team held information interviews with leading methane pyrolysis technology developers such as Levidian (UK), Molten Industries (US), Modern Hydrogen (US), H Quest (US), and Hago Energetics (US). These developers cover a wide range of pathways ranging from high-temperature thermal conversion (Modern Hydrogen) to use of biogenic catalysts (Hago Energetics), additional level of maturity varies where some are at the bench/lab-scale (Molten) while others have one or more demonstrations active with partners (Levidian).

## Status

The project team completed its initial outreach and engagement with pyrolysis technology developers. Informational interviews were held with Levidian (UK), Molten Industries (US), Modern Hydrogen (US), H Quest (US), Ekona Power (US), Hago Energetics (US) and others. A Final Report for Phase 1 issued in August 2023, and an informational webinar was provided to UTD members in September 2023. Current activities underway in Phase 2 are to perform additional direct outreach to methane pyrolysis technology developers, and further refine the TEA, in order to identify superior opportunities to advance these technologies in end use applications.

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## Triathlon™ 2030 Five-ton Cold Climate Gas Heat Pump



**Researchers assisted in developing the prototype design of a new five-ton natural gas engine-driven cold-climate gas heat pump (GHP), which could provide high-efficiency water heating, space conditioning, power generation, and off-grid operation in one unit.**

### Project Description

Over the last 20 years, there have been several advances in gas-engine heat pump (GHP) design and components, including controls, condensing coils, refrigerants, motors, and fans. This combination of new developments with a proven, high-reliability/low-emission engine provides a low-risk path to developing a high-performance, low-cost heat-pump design.

This effort built on prior five-ton GHP designs first developed in 1995 that used off-the-shelf components, leaving much room for incremental improvement. The most recent design was built and tested in 2015 and optimized for the hot, dry climate of the southwestern U.S. (e.g., Nevada and Arizona). The project achieved its goals for combined water heating, space conditioning, power generation, and off-grid operation: 1.2 cooling Coefficient of Performance (COP); 1.5 heating COP; 80% primary energy savings for water heating; and a five-year payback based on \$8,000 product cost and at 1,000 units/year production volume.

The objective for this current project was to assist in developing and testing a new five-ton natural gas-engine-driven cold-climate heat pump prototype. By providing technical

support, UTD researchers supported the efforts of a project sponsored by the New York State Energy and Research Development Authority (NYSERDA) led by Syracuse Center of Excellence at Syracuse University.

Targets of the NYSERDA NextGen HVAC Challenge include lowering energy source consumption compared to current baseline technology, lowering greenhouse-gas emission levels compared to current baseline technology, providing clear peak-demand reduction compared to current baseline technology, and achieving average annual COP >2.0 with emphasis on cold-climate heating capacity and efficiency, with initial product cost targets of <\$5,000 per unit based on a production volume of 500 units/year.

### Benefits / Market Implications

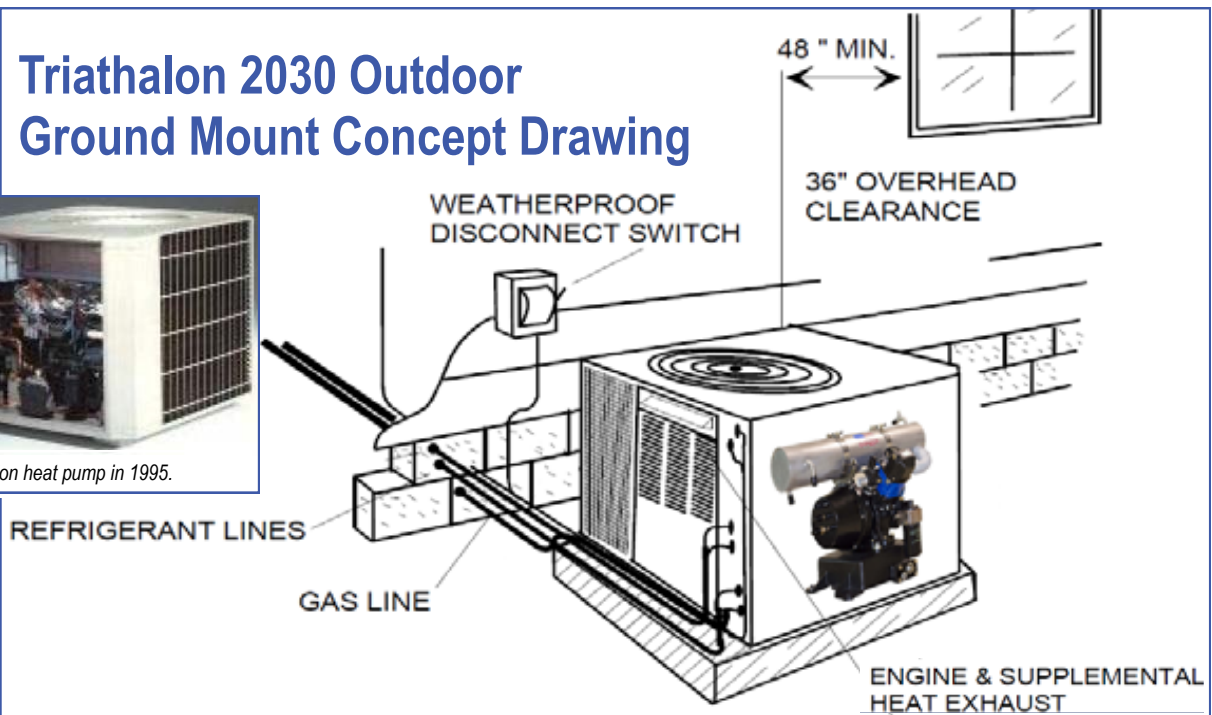
This GHP can provide the following benefits:

- Achieve high heating efficiency and the ability to operate at significantly lower outside temperatures than electric heat pumps

### Triathlon 2030 Outdoor Ground Mount Concept Drawing



Triathlon heat pump in 1995.







- James C. Green  
President & CEO  
Axiom Energy Group

*"A new five-ton natural-gas-engine-driven cold-climate heat pump prototype can meet New York State Energy and Research Development Authority (NYSERDA) NextGen HVAC Challenge as a cost-effective and energy-resilient option to reduce greenhouse-gas emission levels and reduce peak electric demand when compared to current baseline technology. We thank NYSERDA and UTD for supporting the development of this innovative technology, which when commercialized could serve many homes and small businesses across North America."*

- Expand customers' competitive choices of product offerings and fuel options
- Reduce electrical energy and peak demand for end users
- Improve the use and resilience of the power grid
- Defer investments to increase grid capacity, and
- Avoid rate increases associated with capital projects to increase power grid capacity.

## Technical Concept & Approach

This UTD project provided cost share for the Feasibility Stage which included the development of a prototype design and to model its performance, reliability, serviceability, and cost targets. The Triathlon 2030 design goal focused on space heating and cooling applied to small commercial building load profiles, such as offices, lodging, restaurants, fitness centers, health care, box retail, strip malls, light commercial, and educational facilities.

The Triathlon 2030 was designed to be a reliable, drop-in replacement with a similar footprint to conventional five-ton rooftop units. The major technical design challenge was to redesign and improve engine heat recovery for cold-climate operation. The multifunction power-generation and water-heating capability incorporated in the GHP design will be eliminated to reduce both manufactured and installed cost.

Following the successful proof of concept, NYSERDA had a Go/No-Go option to fund the prototype breadboard development for laboratory testing. Potential follow-on efforts included the prototype development and commercialization, followed by demonstration of four commercialized units. The NYSERDA-funded project team developed energy and economic system models to forecast simple payback, life-cycle costs, utility avoided cost value, source energy savings, and reduced greenhouse gas emissions. The project team also analyzed the New York State Value Proposition to meet NYSERDA goals.

A follow-on modeling study evaluated the impact of eight hybrid gas/electric configurations integrating an electric cold

climate air source heat pump (ccASHP) with various forms of gas-fired auxiliary or supplemental heating. The supplemental heating methods included electric resistance heating, a gas furnace, or a compact combined heat and power (CHP) unit.

## Results

In Phase 1, the project team developed the modeling approach for the preliminary energy and economic assessment of the five-ton Triathlon 2030 GHP design. Three building types (small office, strip mall, and full-service restaurant) were selected to represent the best applications for a light-commercial five-ton GHP split system. Actual weather data was used for three locations (New York City, Buffalo, and Binghamton). Detailed electric and gas utility rates for each location were updated.

Researchers created Energy Plus™ models to compare energy costs and full-fuel-cycle greenhouse gas emissions between the GHP prototype design and conventional equipment, while considering the current and future power-generation mix and natural gas supply.

Based on modeled results, the Triathlon 2030 GHP concept design met the NYSERDA NextGen HVAC Challenge targets in some cases. As expected, it consistently reduced peak electric demand compared to baseline technologies. In high heating load applications, the GHP high heating efficiency reduced annual source energy consumption along with GHG emissions, but did not reduce GHG emissions at some target NYS applications. With the current configuration, excluding water heating or power generation options, the design was unable to exceed an annual COP >2.0. Without utility incentives, the design will not be able to achieve the three-year payback target.

Of the follow-on models which the team developed for a hybrid heat pump design, the addition of a CHP unit resulted in only slight changes in energy costs or GHG emissions. A hybrid ccASHP/CHP design would not be cost-effective based on energy savings alone, and would require utility incentives for economic viability, as well as the availability of the utility natural gas.

## Status

The project is complete and a final report has been issued to UTD members. Further development of this heat pump may occur as additional funding sources are identified.

## For more information:

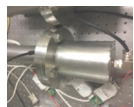
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# LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP





## Field Evaluation of Gas-Quality Sensor



**Field evaluations were conducted to demonstrate a new, reliable, low-cost gas-quality sensor that can detect changes in gas quality (heating value, hydrocarbon, and CO<sub>2</sub> concentrations) in real time and provide valuable data to operators and end users.**

### Project Description

Natural gas is priced by total energy delivered (in Btus or therms). However, Btu content cannot be easily measured, so a common practice is to measure the volumetric flow rate at the point of use, and to determine total energy used by multiplying this number by the average energy content (Btu per standard cubic foot) measured at a central location. While this approach is economical and recognized as sufficiently accurate for billing residential, commercial, and most industrial customers, there are industrial combustion processes (e.g., processes for glass and fertilizer production) and power-generation equipment (e.g., dry low-NO<sub>x</sub> gas turbines and lean-burn internal combustion engines) that have stricter limits on gas quality and composition.

Some large-volume end-user applications have in-line equipment to continuously monitor gas quality to obtain measurements that can be readily converted to heating value, methane number, or Wobbe Index. The introduction of shale gas and upgraded biogas from anaerobic digesters into the gas-transmission network is increasing the importance of more accurately and more regularly measuring the heating value of the gas for many of these large-volume customers.

The most common equipment used today for continuously measuring natural gas heating value is the gas chromatograph (GC). Although GCs provide accurate Btu values based on direct measurements and compositional data, they have several drawbacks, including:

- Long response times (often four minutes or more)
- High capital costs (in excess of \$20,000), and
- Regular calibration required (a recurring operating cost).

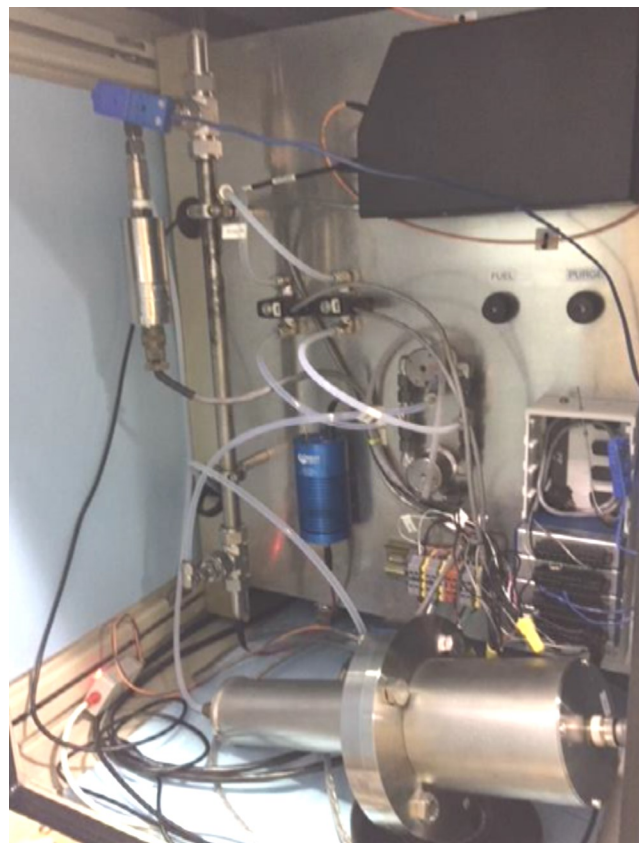
To address the issue, researchers developed and extensively tested in a laboratory a heating-value sensor on natural gas, biogas, and producer gas. The sensor is significantly lower in cost than gas chromatographs and will address other limitations of the GC.

The objective of this project is to continue to develop and demonstrate in actual field-operating conditions a practical, reliable, and low-cost gas-quality sensor (GQS) that can detect changes in gas quality (e.g., heating value, hydrocarbons, and carbon-dioxide concentrations) in real time and provide this data to natural gas pipeline operators, local distribution companies, and end users of natural gas.

The technology development that was advanced in laboratory testing and field demonstrations in this project supported the commercial introduction of the NIRIS NG GQS sensor by licensee CMR Group in 2019. The most recent phase of this project is exploring if the GQS can also measure hydrogen content in natural gas.

### Benefits / Market Implications

Gas distribution companies and large-volume gas consumers that are sensitive to variations in gas quality will benefit from the faster, lower-cost new Btu sensor. Industrial customers can operate equipment more efficiently with lower emissions when real-time fuel heating-value data are available. Operators of natural-gas-fueled turbines and internal combustion engines can have enhanced control of equipment performance and protection.



*The GQS in laboratory testing prior to the shipment to the field-test site.*



Specific advantages of the GQS include:

- The sensor needs to be calibrated just once for the application
- Simple to use; no special training is needed
- Measurements can be taken at high gas pressures
- Measurements can be taken continuously, allowing trending and controls operation, and
- In-line configurations are possible.

## Technical Concept & Approach

The GQS uses the infrared light-absorption properties of hydrocarbon gases to measure the Btu content and composition of a natural gas mixture. It has been shown that this sensor technology can be used to measure the air/fuel ratio in air/hydrocarbon gas mixtures delivered to combustion equipment. The accuracy of heating-value measurements made by this new instrument can closely match those of a GC, but at a much lower cost.

Technicians prepared, calibrated, and installed a GQS prototype at a utility site in Tulsa, OK, to monitor the heating value and composition of natural gas for 12 months.

GQS measurements were conducted side-by-side with a gas chromatograph to verify accuracy of the GQS measurements. The gas-quality data can be provided to the pipeline operators and/or end users in real time.

The project team will provide support to the licensee of the GQS technology as production gas-quality sensors move through customer testing and will assess the capability of the GQS to also measure hydrogen content.

## Results

Early project activities involved modifying software so that a new spectrometer could be integrated with the concentration determining algorithms. The new spectrometer was capable of reading high wavelength data and therefore was expected to be able to collect carbon dioxide data directly. Software was modified to collect and process this data.

Changes were needed to meet the requirements established by the demonstration site. The project team used a mobile hot spot to collect and transmit data during the demonstration period. Communications with the computer were carried out through an Ethernet cable using the available port on the enclosure.

An experimental apparatus was used to calibrate and test the GQS after upgrades and modifications. In 2017, testing of beta

prototypes was performed using 12 gas mixtures with compositions covering the range of anticipated real-world biogas and natural gas. Calibration testing of 10 new prototype sensors from CMR was conducted in 2019.

GQS developments also included:

- The new spectrometer can read high wavelength data and, therefore, collect carbon dioxide data directly. Software was modified to collect and process this data.
- Details of the dimensions, utility requirements, and other aspects of the enclosure (inlet and outlet ports, temperature range, etc.) to hold the GQS for demonstration testing were made.
- The team completed assembling the GQS inside the enclosure. Two sensors were installed. One sensor followed a prototype design using a spectrometer and the other sensor is a commercial prototype built by the commercializing partner and using an interferometer.
- All sensors were installed in enclosures and prepared for testing per safety requirements of the host site.

The project team transferred several beta prototype sensors back to CMR. One sensor was transferred to a U.S. engine company for validation testing. Two sensors were returned to CMR in France so they could be sent to companies carrying out validation testing in real-world conditions.

Data from a demonstration test in Tulsa was retrieved, processed, and shared with CMR. The data showed more scatter than anticipated, which appeared to be a result of temperature variations during the demonstration period. Efforts were made to apply a temperature correction.

## Status

Final Reports for Phases 1 and 2 of this project were issued to UTD members in 2021 and 2023.

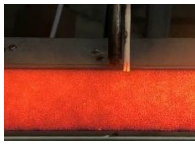
Phase 3 efforts to investigate adding more capabilities to the GQS are currently underway. CMR will provide the latest version of its GQS unit to the project team for additional testing, including when measuring hydrogen content in gas streams. The project team is currently awaiting this delivery.

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## Next Generation Infrared Burner



Researchers are designing, building, and testing prototype high-performance, low-emission gas-fired infrared burners that use an advanced metal foam material to offer end users new high-efficiency products. The project team is collaborating with material and burner manufacturers. Field testing at a host site and durability testing at a laboratory is in progress.

### Project Description

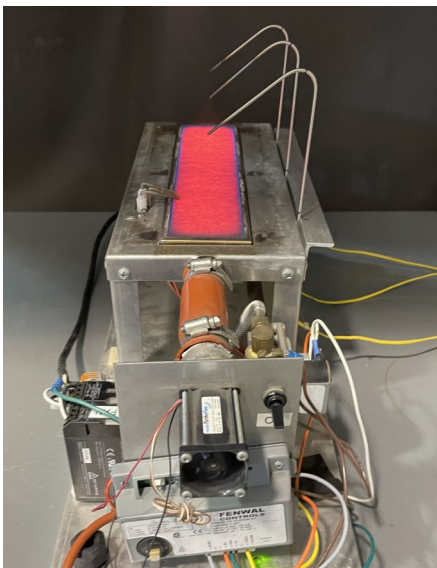
Using gas-fired infrared (IR) heaters instead of electric-driven IR heaters can significantly reduce both source-energy emissions and end users' operating costs. The goal of this project is to build on earlier developments to advance a gas-fired IR burner for commercial and industrial use.

Unlike conduction or convection, IR heating transfers heat through electromagnetic radiation (light). As IR light is absorbed by the load material, its surface is heated. This surface-heating phenomenon can be highly efficient by avoiding the unnecessary thermal load of heating surrounding air.

In this project, researchers investigated advanced metal foam IR burners, with better material properties. In the current phase of the project, the research team will design, build, and test in the field a prototype next-generation, high-response, higher-efficiency IR burner.

### Benefits / Market Implications

Currently, nearly 75% of the IR-heater market in commercial and industrial applications is occupied by electric units. Development of an advanced gas-fired IR burner that can meet market specifications will increase customer choice and save energy on a source basis in most locales.



Laboratory testing.

### Technical Concept & Approach

Specific tasks included:

- **Burner Design**

The project team designed a laboratory-sized 35,000 Btu/hr burner with sensors, control, and valves with advanced material. This unit has broad flexibility and is well instrumented so a wide range of parametric tests can be conducted and data used to optimize design and operating conditions.

- **Laboratory Testing**

A range of IR burner tests were conducted to demonstrate safe and stable operation, collect valuable data for burner optimization, and investigate the effect of all independent variables on the performance of the advance IR burner.

- **Field Test**

Initial prototypes of a commercially-made product will be tested at a host site.

### Results

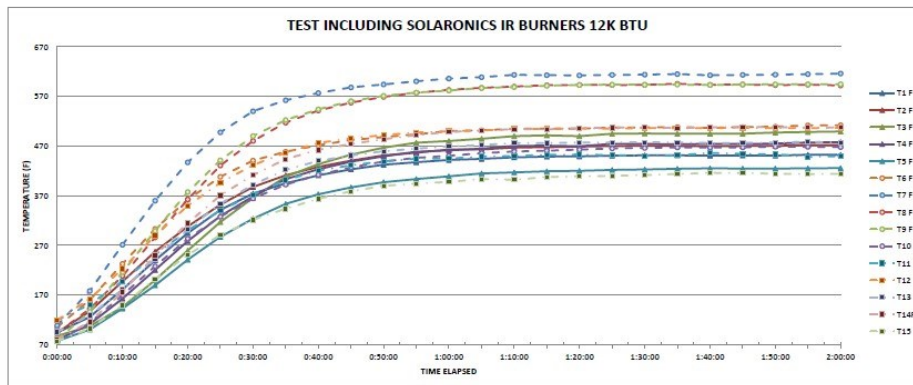
Researchers selected and tested multiple commercial IR burners to evaluate operational and emissions performance. Different materials and original equipment manufacturers (OEMs) were chosen for the testing to provide a spectrum of performance data. The key performance indicators for the burner testing were to successfully achieve target goals for



turndown, emissions, start-up and shutdown characteristics, and temperature uniformity.

Testing showed the advantages and key limitations of these burners. The high-throughput burners could provide high output; however, these led to high emissions and potential material degradation. Burner materials such as ceramics led to cracking due to thermal cycling and were difficult to form into different shapes. Other materials such as metal fibers lead to non-uniform mixing, non-uniform temperature profiles, and loss of fiber material due to high-temperature zones.

Metal foam materials testing showed promise in certain aspects, such as adapting to different shapes and layouts, more robust design, and improved thermal cycling characteristics. This material showed the potential to replace a majority of the materials and be able to provide a long-term solution to gas-fired IR.



Emissions and performance testing showed that the non-uniform mixing and high local temperatures led to increased NO<sub>x</sub> emissions (>20 ppm @ 3% O<sub>2</sub>). In addition, the start-up time for a gas-fired IR was high (>7 seconds) with burner material choice making a significant impact.

In 2019, emissions and temperature measurement testing were conducted at different axial locations from the burner surface. A report was issued in July 2019 that summarizes the differences in burner configurations tested.

In 2020, researchers teamed with a burner manufacturer and an advanced material manufacturer to resolve key issues to move the technology to the market. Emissions and temperature-measurement testing were performed at different axial



Burner assembly with multiple IR burners designed for host site.

*"This project is evaluating advanced materials for improved performance, increase efficiency, and durability. It is critical to evaluate these materials."*

- Tom Martelle  
Chief Engineer  
Solaronics, Inc.



and longitudinal locations from the burner surface. Test hardware was fabricated to reduce air entrainment and provide more data for comparison with previous data.

In 2021, the project team conducted performance mapping of the burner at different axial and radial locations. Testing showed that emissions were below 20 ppm for NO<sub>x</sub> and CO dropped below 10 ppm, both corrected to 3% oxygen, from about six inches from the surface of the burner. In addition, improvements to the uniformity of the temperature and the oxygen concentration at a given plane (nine inches from surface of burner) were sought. A host site for a demonstration was identified and design criteria for testing was evaluated. A set of prototype burners was fabricated, assembled, and tested at a host site.

In 2022, heat-flux measurements were performed for the different conditions and were compared with the performance of traditional IR burners. The measurements showed this IR burner was in the similar range (8 to 10 Btu/ft<sup>2</sup>-s) compared to other industrial burner systems in terms of heat released.

In 2023, Solaronics and one of its customers are testing a pre-production version of the new burner at a host site in California and have collected preliminary test results. Simultaneously, durability testing at an industrial laboratory is in progress for multiple hundreds of hours to further evaluate the market-readiness of the material and burner unit. The project team is also setting up laboratory tests to fire hydrogen and has ordered instrumentation and controls to support that effort.

## Status

The final report for Phase 2 was released to UTD members.

The project team is continuing to test pre-production versions of the burner made by Solaronics and is separately working to setup laboratory tests to assess how the burner operates when using hydrogen-enriched natural gas.

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**LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP**

## Recovery of Water from Humid Exhaust Gas to Save Water and Energy



**In a field demonstration at a large industrial facility in California, researchers applied a novel new thermal ejector technology using heat pipes to recover useful process water from humid exhaust gas, which in turn can increase overall efficiency.**

### Project Description

Industries that use large volumes of water to cool natural-gas-fired furnaces could save energy and money if water from hot exhaust gases can be economically recovered and returned to the plant for cooling and other uses. For this project, a research team demonstrated an innovative self-regulated ejector cooling system that generates colder water at a manufacturing plant, which, in turn, can increase overall efficiency.

This effort was conducted in collaboration with the California Energy Commission (CEC) and a leading U.S. drywall manufacturer. UTD provided co-funding to the prime funding provided by CEC.

The thermal ejector technology using heat pipes demonstrated is the first practical technology that can recover room-temperature water that can immediately be returned to a plant and used for process cooling.

### Benefits / Market Implications

Operators of drying, curing, commercial cooking, and other agricultural and industrial processes with humid exhaust gases are strongly positioned to realize large benefits from this thermal ejector technology. This technology offers the opportunity to reduce the huge water demand at power plants. Overall, freshwater savings are estimated at one billion gallons per year in California if deployed for example on 50% of applicable industrial and commercial furnaces. Some sites can also save significant amounts of natural gas when warm water produced by a unit displaces ambient temperature waster supplies. Carbon dioxide emissions would also decrease at sites where recovered warm water reduces natural gas demand.

### Technical Concept & Approach

For this project, a demonstration of thermal ejector technology with heat pipes was conducted at a major industrial host site in California. The project team attached a demonstration-scale unit to the humid exhaust gas of equipment at the manufacturing facility and recovered water from a portion of that exhaust gas. The demonstration system is based on the laboratory-tested prototype but has production capacity of 700 lb of water per hour (~82 gallons/hour).

Using the remaining thermal energy in the humid exhaust gas from the facility's drying kiln helps to conserve water and enable the plant to receive an added benefit from the same natural gas already being burned in the kiln, thereby also conserving natural gas.

Project work began with modeling and design of the demonstration unit. The unit was designed to recover water from 1 to 2% of the kiln exhaust gas. After modeling and design calculations, a skid-mounted system was designed.

Demonstration testing was carried out over a period of six months. A full set of performance data was collected. The project team developed a technology transfer strategy, including a product-readiness plan.



*California host site facility.*



## Results

The host site provided exhaust gas data for a furnace similar to the one to be used for the demonstration. This data confirmed the anticipated range of exhaust-gas compositions, including water content, to be expected. Additional research focused on modifying and simplifying the demonstration system design. The final system design has one quarter the footprint of the first system design and is much more conducive for further scale-up. In the final system design, no external water is required and the power demand was greatly reduced. Components are reasonable in size because there are no gas-to-gas heat exchangers in the system. In the final design, power demand was also greatly reduced.

The water content in the 256°F exhaust gas is 43 volume percent (32 weight percent). While the project goal was to demonstrate nominal water recovery of 100 gallons per hour, the amount of water recovered depends on ambient air temperature which changes from day to night and around the year. Measured results averaged 82 gal/h of water recovered. Review of historical weather data showed that although temperature can reach 117°F on summer days, the average year-round temperature is 73°F. This data was used to design a demonstration unit producing 82 gallons per hour of water at 73°F. Water recovery will be lower at higher ambient air temperatures.

A refrigerant recirculates in closed heat pipes to cool the flue gas and to carry the heat up to an upper chamber where it condenses and returns to the lower chamber to recover more heat. Ambient air moved by low-pressure-drop fans is used to extract heat from the refrigerant into the environment. The external power needed is for two water pumps, two ambient air fans, the flue gas blower, valves, and controls.

In 2021, the skid framework and electrical boxes were completed and all components were installed on the skid frame. Wiring and sensors were installed and checked for proper installation and accuracy. The skid was finished, moved to the host site, and connected to the exhaust duct with mechanical and electrical connections. Startup in fully-automated operation was initiated in April 2021.

Automated operation and data collection worked well through the demonstration period. Results confirmed an average water-recovery rate of 83 gallons per hour.

An analysis was made of the full cost of designing and building the demonstration unit used to collect an average of 80+ gallons of water per hour. The total cost of labor and materials was \$566,000. A review of this found that careful planning, purchase of low-cost components, and less engineering for the next system of the same size would lead to a cost of \$266,000. Over a five-year period, a system of this size would be expected to recover approximately 2.5 million gallons of water. Therefore, the capital cost would be \$100 per 1,000 gallons of water. Natural gas savings would lower this to a net cost of \$80 per 1,000 gallons of recovered water. Current water costs in the U.S. range from \$6 to \$20 per 1,000 gallons and are expected to double in the next decade to an average

of \$30 per 1,000 gallons. This analysis provides guidance on what is needed to lower the cost of the technology.

On an energy basis, the recovery of water at temperatures below 60°F is more than break even. That confirms that lowering the capital cost is key to commercial success. The most expensive component is the heat exchangers.

## Status

Both UTD projects are complete. Final reports for UTD projects 2.17.A and 2.20.D were issued to UTD members in May 2023 and July 2023, respectively. A draft Final Report was also submitted to CEC, and CEC will publish the Final Report after it completes its review.

Next steps to promote large-scale commercialization of the technology are being evaluated, and interested end users can contact UTD directly. Results of modeling performed under UTD 2.20.D indicated that a scale-up of the field demonstration unit by at least 10:1 in capacity will likely be needed for the technology to be economically attractive for commercial-scale applications in one key industry application evaluated.



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LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

## High-Efficiency Thermo-Vacuum Commercial Clothes Dryer



**Researchers are developing and demonstrating at laboratory scale an advanced prototype gas-fired commercial clothes dryer. The technology has the potential to save at least 50% of the energy used in the commercial laundry sector, while also reducing drying time and water consumption.**

### Project Description

The most common commercial clothes-drying method uses a combination of electrically-driven centrifuge coupled with moisture evaporation by heated air. Research suggests that integrating a thermal-driven ejector vacuum system into a commercial dryer can provide significant performance improvements along with substantial fuel savings and reduced water consumption.

The goals of this project are to develop an advanced clothes dryer concept and demonstrate the technical and economic benefits of an innovative ejector-based technology that can minimize heat losses and accelerate the drying process due to the simultaneous thermal and vacuum effect on moisture removal from the capillary fibers of the laundry being dried.

UTD is partnering with the U.S. Department of Energy (DOE) on this technology development by providing co-funding to a major prime contract award from DOE.

### Benefits / Market Implications

The technology being developed in this project is expected to have the potential to save at least 50% of the energy used

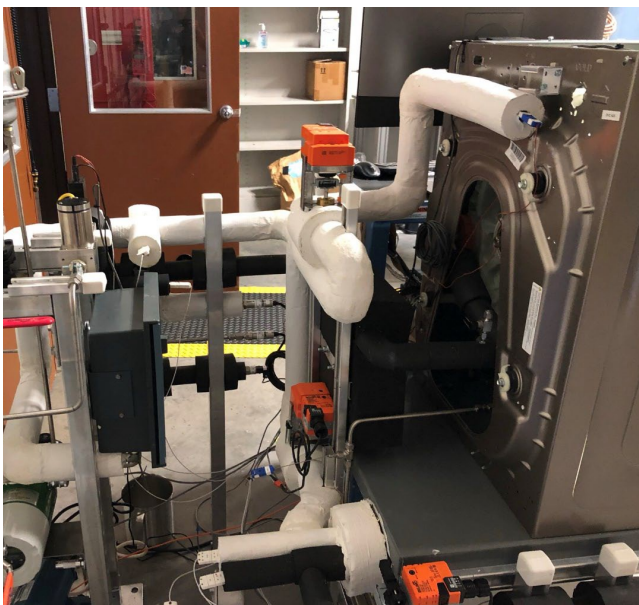
for commercial clothes drying, due to its unique approach to integrate heating and vacuum for moisture removal.

For example, using one thermo-vacuum dryer to produce 50 pounds of dry laundry would save approximately \$8,000 per year. The annual savings from the use of new drying technology across the U.S. has a potential to reach over \$2.5 billion.

Preliminary estimated benefits of the high-efficiency thermo-vacuum clothes-drying technology are:

- Drying time reduced up to 75%
- Higher Combined Energy Factor (CEF): 5-6 (estimated) versus 3-4 (ENERGY STAR, conventional)
- \$6K-8K annual savings (payback period under two years), and
- At least 20% reduction in water consumption.

The primary target markets impacted will be commercial laundry markets, including on-premise laundries, multi-family housing, dry cleaners, industrial, and coin-operated facilities. Special focus is made on “cleanroom” applications, including healthcare and electronic manufacturing.



*Photos illustrate the technology prototype infrastructure laboratory testing facilities.  
The modified commercial dryer was tested for drying performance evaluation and comparison with state-of-the-art technology.*



## Technical Concept & Approach

The main element of the thermo-vacuum drying system is an ejector, which simultaneously provides a dynamic vacuum and removes moisture from the drying chamber. The operation relies on the heat circulating mostly in a closed cycle between the steam source, the vacuum ejector, and the drying chamber. This leads to continuous heat recuperation, which makes the process highly energy efficient.

This technology should not require replacing existing laundry equipment completely; it can be used to upgrade existing dryers to a higher performance level. In addition, this technology may allow combining both washing and drying processes in new installations. This will simplify the system design, reduce the cost of the drying process, and, therefore, reduce the operational footprint.

In Phase 1 of this project, researchers performed a commercial market review along with a preliminary cost/benefit analysis and estimated a simple payback period.

In Phase 2, UTD is providing co-funding to a large prime contract funded by the U.S. DOE to: characterize a refined concept and experimentally define the drying curves for three test fabric types; specify key components of the prototype to be tested; develop a test plan and matrix; and identify applicable measurement and verification protocols.

## Results

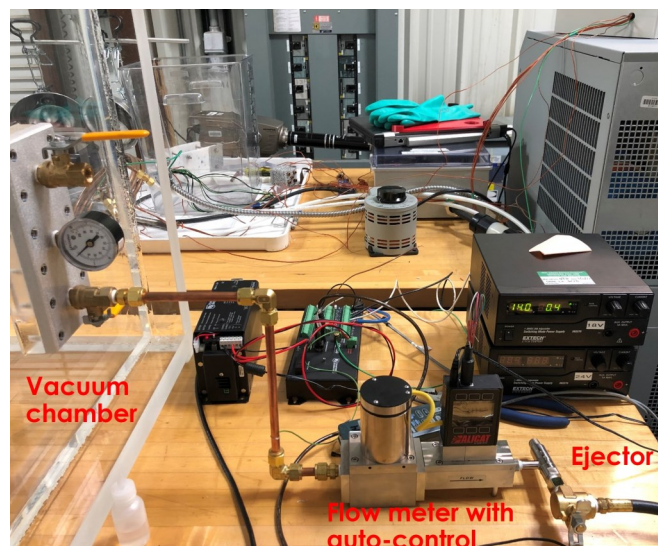
In Phase 1, researchers conducted a bench-scale evaluation of the technology concept and proved its feasibility. A bench-scale system was then constructed by modifying a commercially-available residential clothes dryer with an integrated heat exchanger and steam-driven ejector. Preliminary testing was completed with encouraging results that indicate a possibility of either reduced drying time or increased throughput.

A thermodynamic analysis of the thermal vacuum drying cycle showed that the overall efficiency increases by at least a factor of two. The heat transfer coefficient from condensing steam to the wet laundry through the wall of the perforated rotating drum decreases as drying progresses, but this does not adversely affect the heat and mass transfer process due to a sharp decrease in the heat and mass flow of steam at the final stage of drying.

Bench-scale experimentation for drying of selected fabric samples was conducted. These drying curves serve as a basis for designing prototype units, and help inform the development of refined drying curves.

Commercial product lines were assessed and evaluated, and major equipment OEMs were contacted.

The integrated drying concept was characterized to establish the baseline performance. A benchmark unit for the laboratory-scale testing was defined and specification of key compo-



*Benchscale testing.*

nents is in progress.

In 2020, the numerical model of the thermo-vacuum drying process was refined and verified with the initial bench-scale experimental data. The feasibility study and bench-scale evaluation demonstrated the superior performance of the technology and provided promising results for moving the technology forward.

A paper entitled *Thermodynamic Analysis of Thermo-vacuum Clothes Drying Operation* that includes the methodology, model description, and process energy analysis was presented at the 18th International Refrigeration and Air Conditioning Conference in May 2021.

In 2021-22, promising discussions occurred with major equipment manufacturers, which demonstrated significant market interest. In addition, the U.S. Patent Office issued a patent (11,261,560) for the technology in March 2022.

## Status

DOE's agency representative has determined that no additional DOE funds will be provided to this project due to limited federal funding availability as well as greater interest in a competing clothes drying approach. The team submitted a Final Report in November 2023 for work completed under Phase 2, and will seek alternative next steps to advance the development and availability of this energy-efficient technology.

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## LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

# Capstone C200S Micro-Turbine Laboratory Evaluation



**The objective of this project is to evaluate and characterize the performance of the Capstone C200S 200kW Signature Series micro-turbine in order to scale-up the novel, highly-efficient FlexCHP technology to benefit a large number of universities, hospitals, manufacturers, and other end users.**

## Project Description

To succeed in today's marketplace, combined heat-and-power (CHP) systems must achieve high efficiency and low emissions in a cost-competitive package that is capable of broad deployment throughout existing market segments. The FlexCHP technology developed with support from UTD satisfies these needs for those installations that need 65 kW demand and 80 boiler-horsepower (BHP). The technology can benefit commercial and industrial steam-generation markets because of its ability to achieve high steam-production rates and efficiencies that are unmatched by any other competing turbine-based CHP approach.

The FlexCHP technology uses exhaust from a turbine generator as an oxidant for downstream combustion with supplemental natural gas to generate steam in a firetube boiler. While some competing CHP technologies recover heat from the high-temperature turbine exhaust (~600°F) by delivering the exhaust through a Heat Recovery Steam Generator (HRSG), this approach fails to maximize the quantity of recoverable heat because the exhaust excess oxygen levels are not reduced. The FlexCHP maximizes efficiency by reducing the exhaust oxygen levels from 17.7% in the turbine exhaust to 3% in the boiler stack through supplemental combustion. In comparison to simply delivering the turbine exhaust through a HRSG, the FlexCHP technology provides an efficiency gain of more than 30 percentage points (~60% increase).

FlexCHP is the only CHP technology that demonstrated high steam output and efficiencies of 84% without post combustion clean-up (e.g., selective catalytic reduction or other expensive after-treatment). Further, it is the only technology capable of attaining compliance with air-quality regulations in key non-attainment regions.

While the FlexCHP systems has been successfully developed and field demonstrated at a capacity of 80 BHP and 65 kW electricity (integration with a Capstone C65 micro-turbine), the economics of the technology favors larger-capacity installations, and thus there is need to develop and demonstrate a scaled-up version. The development of an integrated turbine/burner/boiler product that offers the additional advantage of grid-independence for reliable operation will advance the adoption of CHP solutions if the development team is able to

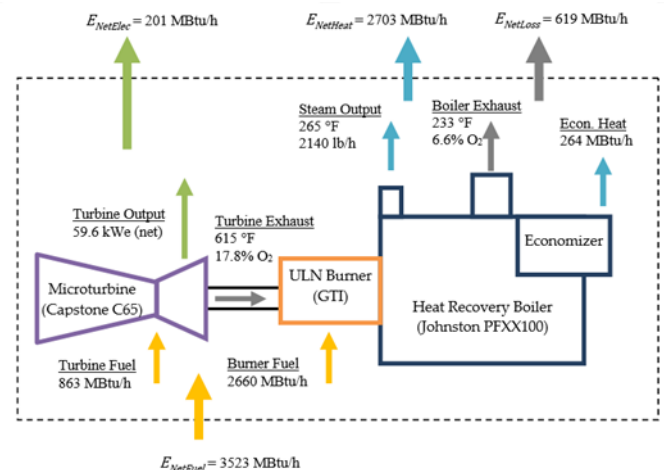
transition from 65 kW to larger units.

The potential customer base for the larger Capstone C200S far exceeds that of the C65, and customers with even higher load demands can be satisfied by coupling multiple C200S units to achieve the required output. The objective for this project is to evaluate and characterize the performance of the Capstone C200S 200kW Signature Series micro-turbine in order to scale-up the novel, highly-efficient FlexCHP technology to benefit a large number of universities, hospitals, manufacturers, and other end users.

## Benefits / Market Implications

Successful commercialization and deployment of the FlexCHP technology will have a transformative impact on commercial and industrial steam markets. Rather than purchasing a standard boiler with a conventional burner, end users will have the option of investing in a FlexCHP unit to generate on-demand steam and electricity. Customers will realize significant cost savings through reductions in electricity purchased from the grid. Ultimately, greenhouse-gas and criteria pollutant emissions will be significantly reduced.

For steam boiler customers for whom the price differential between electricity and natural gas rates exceeds a ratio of



FlexCHP system flows





*"The FlexCHP system is exactly the type of innovation that Capstone Green Energy is interested in pursuing as part of our energy solutions portfolio. The product will enable customers to maximize the returns on their investments, while also utilizing clean energy."*

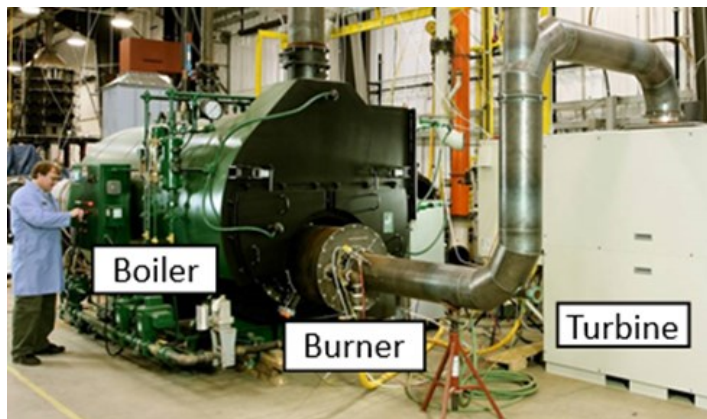
- Don Ayers  
Vice President, Technology  
Capstone Green Energy Corporation

three years by purchasing a FlexCHP unit, with significant long-term benefit (assuming operation five days a week, 48 weeks per year). For customers paying electricity rates that are six times that of their gas rates (as is the case in key California and the Northeast), customers can achieve payback in less than 1.5 years. As the FlexCHP is deployed more widely and equipment prices are reduced, the economic benefits of the technology will increase further.

As an example, consider a customer with a steam demand of 200 BHP and electricity load of 200 kWe. This customer could install a standard 200 BHP boiler that consumes gas at a rate of 8.5 million Btu/h and purchase electricity from the grid. Alternatively, the customer could install a FlexCHP rated at 200 BHP/200 kWe to generate the required quantity of steam and self-generate 200 kWe of electricity, consuming gas at a rate of 9.3 million Btu/h. If the customer rates for electricity are four times that of their rates for natural gas, on a per-unit-energy basis, the customer could reduce its energy costs by 18% annually by installing a FlexCHP unit. At the same time, greenhouse gas emissions would be reduced by more than 16% based on a source energy analysis of a representative installation site. In addition, the resiliency of electricity supplied to a facility can often be increased.

In 2021, Capstone was rebranded as Capstone Green Energy Corporation and focuses on four key business segments which will align well with increased CHP applications, including the FlexCHP technology.

- Through its Energy as a Service business, it offers rental solutions for its micro-turbine energy systems and battery storage systems as well as aftermarket parts and comprehensive service contracts.
- Energy Conversion Products are driven by the company's industry-leading, highly efficient, low-emission, resilient micro-turbine energy systems offering scalable solutions in addition to a broad range of customer-tailored solutions.
- The Energy Storage Products segment designs and installs micro-grid storage systems, creating customized solutions using a combination of battery technologies and monitoring software.
- Through Hydrogen Energy Solutions, Capstone Green Energy offers customers a variety of hydrogen products, including the company's micro-turbine energy systems.



FlexCHP-65 components

## Technical Concept & Approach

Activities in this project fit within a broader research program to develop and demonstrate an advanced FlexCHP technology at larger capacities which is 1) capable of operating on both turbine exhaust gas and air and 2) is packaged as a fully-integrated commercial product across load scales for deployment by the manufacturing partner.

Project efforts focus on logistics, procurement, installation, and testing of the C200S micro-turbine. A test plan was developed to characterize system performance across a broad operating range, and data will be compared to the manufacturer's claims. This will provide insight and knowledge for determining the optimal burner configuration to be used for scaling the technology to larger capacities.

## Results

The C200S microturbine was characterized for ambient temperature during measurements, turbine electrical power output; turbine fuel input, and other factors. Flex CHP technology was tested on Simulated Turbine Exhaust Gas (STEG) designed to be representative of C200S microturbine output. Performance was comparable to previous smaller scale tests. The burner was capable of adding significant thermal energy to the STEG while contributing little additional NOx emissions at the stack.

## Status

Testing of the scaled up Flex CHP technology on STEG which is representative of the Capstone C200S 200 kW Signature Series microturbine has been completed. The Final Report was issued to UTD members in March 2023. The unit is ready for a larger demonstration project to evaluate the benefits of integrated CHP at an end-user site.

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**LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP**

## Low-Emissions Efficient Burner for Ovens and Dryers – Field Evaluation

**This project is validating the performance of a novel burner both in a laboratory and at an end-user host site. The goal is to advance the commercial introduction of a new burner that will reduce emissions, energy use, and operating and capital expenses for the many end users who use hot air in their process operations.**



### Project Description

Emissions from packaged burners can be impacted by cross-flow or end-flow process air and low-turn-down conditions. A new burner with 9 ppm NO<sub>x</sub> emissions and < 50 ppm CO emissions would be innovative in this industry.

In this project, researchers and manufacturers are advancing and refining a new burner that offers these improvements. It uses 3D printing to manufacture the complete burner assembly as a single-step operation which reduces labor and tooling costs, and to fabricate internal geometries which cannot be achieved via conventional subtractive manufacturing. In addition, there is no need to braze the different nozzles together for further assembly. This innovative approach can simultaneously reduce emissions and equipment costs, and introduce another product in this market to expand ratepayer's choices and options.

The goal of this project is to combine a novel burner technology previously developed with UTD's support with other product design improvements into a 3 MMBtu/hr burner-assembly system to heat process air. Researchers will validate the performance of the burner assembly first in the laboratory and then at an end-user's field host site. In addition to the burner assembly, a cross-flow air-duct assembly provides heated air for simulating process-heating applications. The temperature is controlled by the burner firing rate. In addition, researchers will fabricate, and test the burner for air-heating applications (such as ovens and dryers) using up to

50% hydrogen blends with natural gas. The project team is partnering with a manufacturer of process heaters as it advances this new technology to market.

### Benefits / Market Implications

Leading customer application segments for an improved process heater include automotive manufacturing applications, environmental applications, and food-drying applications such as milk-flash dryers. The technology has the potential to reduce NO<sub>x</sub> emissions by >80%, CO emissions from 300 ppm to 50 ppm, and blower requirements by 30%, while also increasing efficiency by 4%.

The commercial introduction of a more energy-efficient, low-emission burner that will bring increased competition into this market segment, thereby saving energy and reducing operating costs and potential capital costs for consumers.

### Technical Concept & Approach

This project will test the direct and indirect process heating applications with a focus on the burner performance and progress from a laboratory to a host site.

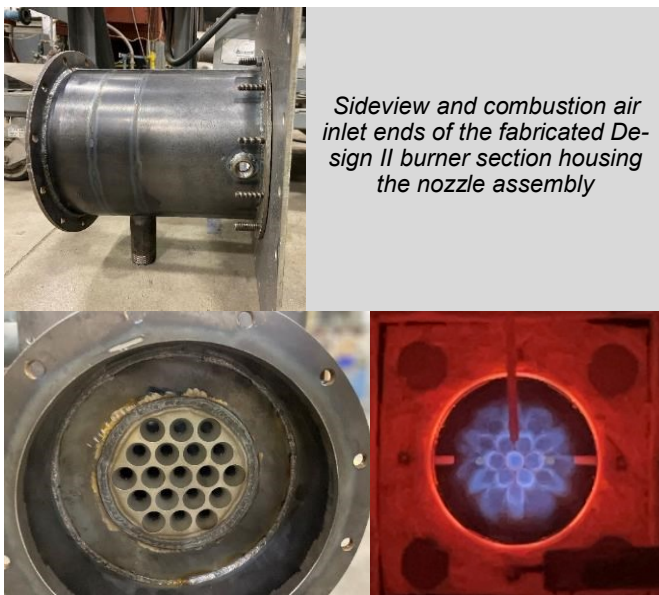
Specific tasks will include:

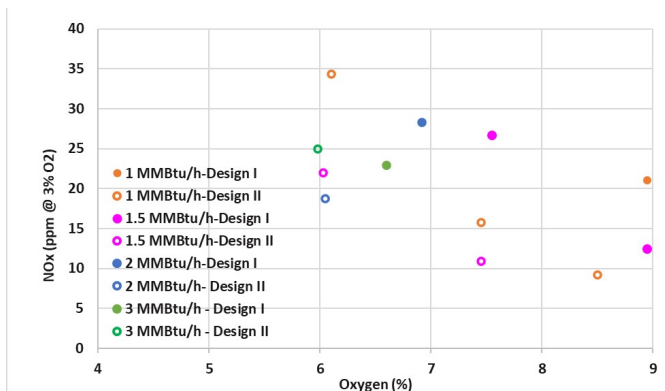
- **Integrate burner assembly at laboratory**

Researchers will integrate the burner and the cross-flow air duct. Two blowers are to be installed, one for the burner and the other for the cross-flow air. The fuel and the controls will be linked. Shakedown testing of the complete test setup will be performed for smooth and safe operation. In addition, process parameters and the parasitic loads (e.g., blower, controls) will be discussed with host-site representatives.

- **Evaluate burner performance at laboratory**

The project team will test the assembled burner to evaluate its performance for key parameters (emissions, turn-down, reliable and smooth ignition, and blower-power requirements). After performing shakedown testing of the burner, multiple ignition tests will be performed to ensure the burner ignites reliably and smoothly at variable firing





*NOx emissions at the furnace exit at different firing rates for Design I and II burners*

rates. After successful ignition testing, the test assembly with the burner will be evaluated for performance and refined.

- **Design and integrate burner assembly at the host site**

The project team will integrate the burner in a simulated environment process-heating environment similar to the host site. Researchers will generate designs and drawings necessary to adapt the assembly into the host site process. The hardware will take into account the host site equipment, so that minimum modifications will be required when installed at the host site.

- **Evaluate prototype-burner performance at different operating and process conditions**

Ignition testing will be conducted to ensure that the burner ignites reliably and smoothly. Different process conditions will be tested to ensure all the parameters are covered. The project will further demonstrate and validate burner performance in a laboratory setting, as an important step to help establish a commercialization partner.

- **Develop burner design to burn natural gas/hydrogen (NG-H2) blends**

Researchers will perform design modifications to the improved NG air-heater burner to enable operation with NG-H2 blends up to 50% H2 to provide greenhouse gas reductions compared to NG alone, while maintaining or improving NO<sub>x</sub> and CO emissions, flame stability, and short flame lengths with no adverse impacts on controls, safety, and burner costs.

- **Evaluate NG-H2 burner performance**

The NG-H2 burner will be tested over the range of 0 to 50% H2 in the fuel in a laboratory. The key parameters will be emissions, turndown, reliable and smooth ignition, blower power requirements, and safety (overheating of burner components, flashback, lift-off etc.).

- **Data analysis and performance assessment**

Test data will be analyzed from both NG and NG-H2 firing



*Simulated test rig for air-heating applications.*

and to compare ease of ignition, NO<sub>x</sub> and CO emissions, and operating range of flame stability for NG and NG-H2 firing.

## Results

A first prototype burner was designed and tested in 2021 to evaluate performance that resulted in lower emissions and good performance in a certain firing range from 1 to 2 MMBtu/hr; however, further improvements were required to achieve the desired for the complete firing range from 1 to 3 MMBtu/hr.

In 2022 and 2023, an improved second prototype burner design was fabricated based on further computational fluid dynamics analysis and when tested on natural gas it demonstrated: operation at up to 6:1 turndown; very low CO emissions of below 10 ppm over the entire range of firing rates; robust ignition and stable flames; and superior NO<sub>x</sub> performance. Performance testing of both prototype designs were completed with < 9 ppm NO<sub>x</sub> (corr. to 3% O<sub>2</sub>) and < 10 ppm CO (corr. to 3% O<sub>2</sub>) emissions were achieved.

## Status

Phase 1 results were summarized in a Final Report to UTD Members that was issued in August 2023. In addition, the project results were publicly communicated in a presentation provided to the American Flame Research Committee in Denver, CO in September 2023.

Discussions with a host site to demonstrate its performance at its location on natural gas are in progress. Separately, additional laboratory testing, evaluation and optimization of the burner to operate using up to 50% hydrogen blended into natural gas remains in progress.

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## Sub-Dew-Point Cooling Technology



**Researchers demonstrated at laboratory scale a cost-effective and reliable technology to provide deep cooling of water or air to increase the efficiency, lower the cost, and enhance the performance flexibility of residential and commercial appliances as well as industrial systems.**

### Project Description

Conventional cooling towers typically utilize evaporative heat exchange. In this context, modern cooling towers are close to maximum efficiency by often achieving cooled-water temperatures of 5°F to 7°F above ambient wet-bulb temperature. Advanced cooling techniques with higher efficiencies are being developed; but they require complex retrofits, high energy costs, or a full replacement of the cooling tower with a new unit.

In this project, a research team will demonstrate and characterize the performance of an innovative sub-dew-point cooling-enhancement technology. No drastic modifications will be required to the existing cooling system designs and no new materials must be developed or obtained. Technology enhancements can use commercial off-the-shelf hardware that is packaged as a Pressure Dehumidification System (PDHS) and installed as add-ons or economically integrated with new equipment. These features and flexible application lower the technical risk.

The technology can be driven by natural gas combustion or available waste heat or potentially solar thermal energy to further improve cooling performance and energy efficiency.

The novel sub-dew-point cooling technology (SDPCT) will provide the following advantages:

- Low-cost flexible cooling for residential, and commercial, and industrial applications
- Off-the-shelf components
- High-performance efficiency
- Lower carbon footprint (compared to electrically-powered equipment on a source energy basis)
- High cooling performance due to employing an advanced high-efficiency refrigeration cycle, and
- Further integration of natural gas with renewable natural gas, solar energy, ground-source heat pumps, hydrogen/power-to-gas, or other renewable energy sources.

UTD is partnering with the U.S. Department of Energy (DOE), a leading global heat transfer equipment manufacturer, and university researchers, by providing co-funding to a prime contract from DOE via this project.



*Overall view of the PDHS prototype installed and tested in the laboratory.*



## Benefits / Market Implications

The primary markets that can benefit will include:

- Residential/commercial appliances such as chillers, HVAC, power generators, etc.
- Industrial cooling systems and power plants
- Hospitals, nursing homes, and other life-safety-critical institutions, and
- Distributed power-generation systems.

The modular chiller market (air- and water-cooled) in residential, commercial, and industrial applications in North America is projected to grow from \$0.65 billion in 2019 to \$0.83 billion in 2024. The natural-gas-assisted SDPCT can potentially replace most of the conventional vapor-compression chillers. Using natural gas in SDPCT could allow for a reduction in cooling costs by 20%-40%. This effort can fill a key technology/program gap for energy efficiency gas utility programs. The SDPCT will also lower electricity consumption and water use in residential and commercial appliances.

## Technical Concept & Approach

This project demonstrated and validated the SDPCT performance in a laboratory setting as an important step to advance the technology development.

The project consisted of several tasks structured over a 36-month period, including:

- Concept refinement and performance characterization
- Components design and manufacturing review
- Engineering, purchasing, and fabrication of the prototype
- Assembly, installation, and test plan development
- Data collection and processing, and
- Performance analysis, scale-up design recommendations, and techno-economic assessment.

Deliverables included performance validation of the sub-dew-point cooling system with a capacity of 100 kW (design and performance characteristics).

## Results

In 2020, the new SDPCT layout – with a reliable and efficient dehumidification technique based on near-atmospheric pressure regulation – was simulated and evaluated. Initial, boundary, and operational conditions for the pressure dehumidifying system were specified. Nominal SDPCT component boundary conditions in terms of pressures, temperatures, volume, and mass flow rates that support the SDPCT con-



*"The sub-dew-point cooling technology is a very exciting and promising technology! I'm pleased to have contributed my expertise in heat-transfer numerical modeling of its key components. It's really great to see government, universities, manufacturers, utilities, and other researchers partnering together through DOE's and UTD's financial support to accelerate the commercial availability of new energy-efficient technologies for homeowners, businesses, campuses, and industry!"*

Sumanta Acharya  
Department Chair  
Professor of Mechanical and Aerospace Engineering  
Illinois Institute of Technology

ceptual design were defined.

The overall SDPCT concept was refined based upon numerical simulations of heat-transfer processes and smart fluid flow arrangements. These simulations were conducted to optimize heat and mass-exchange systems and the overall pressure-dehumidifying system.

In 2021, key individual components and advanced techniques were specified. Preliminary design calculations for the follow-on detailed engineering and fabrication of the PDHS prototype were performed. Concept refinement and performance characterization were completed.

In 2022, the PDHS prototype was fully assembled and installed. Testing was performed in the range of three representative climate zones – Baltimore, Chicago, and Dallas.

From the results of the experiments, estimated water savings in the cooling tower exceeded 20%. The reduction in make-up water results in water cost savings of 47.1-59.6 \$/MWh. Compared to a baseline conventional power plant design net output increases by about 0.3% for the option without condenser upgrade and about 1% for the case with condenser upgrade at 95°F/35°C ambient.

## Status

Testing of the PDHS at laboratory-scale in the controlled environment at an industrial laboratory has been completed. A Final Report for project 2.20.B was issued to UTD members in April 2023. Additional summaries of the results will be available in the Final Report to DOE, as prime funder of this research. Discussions about next steps to advance the technology continue with project partners.

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**LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP**

## High-Efficiency, Low-Emission Commercial Baking Oven Field Demonstration



**A field demonstration is being conducted to validate at least 10% CO<sub>2</sub> emission reduction and 25% NO<sub>x</sub> emission reduction in commercial baking settings by applying advanced ribbon burners coupled with optimized combustion controls technology.**

### Project Description

The gas-fired ribbon burner is a mature, low-cost technology that is widely applied in many industries, such as baking, drying, and surface-treatment applications.

The objective of this project is to demonstrate at least a 25% NO<sub>x</sub> emission reduction by optimizing the combustion process in a multi-zoned commercial wholesale baking oven within the environmental jurisdiction of California's South Coast Air Quality Management District (SCAQMD). Carbon dioxide emissions are also anticipated to be reduced by 10% through combustion system optimization.

The project team is demonstrating the performance of a combustion system with advanced ribbon burners and a control system that uses an Integrated Flame Plasma Analyzer to continuously analyze and monitor the air/gas mixture being delivered to the burner to optimize the flame chemistry in each zone of the oven (called an Ecozone). This signal is used as input to operate a gas flow valve to maintain optimal flame chemistry. This ensures that the preset optimum air/fuel ratio is constantly maintained regardless of changes in temperature, humidity, or gas composition.

The advanced ribbon burner configuration to be demonstrated in this project successfully integrates both traditional ribbon and metal-fiber infrared options. Combustion performance is achieved with a simple changeover between infrared and blue-flame ribbon modes. The approach theoretically provides the means to minimize NO<sub>x</sub> and CO<sub>2</sub> emissions while operating the burners at the most efficient firing rate possible at every moment of the baking process.

Testing and performance data will be collected over a wide range of operating conditions at a large commercial bakery operated by a leading U.S. grocery retailer to prove the anticipated energy savings and environmental benefits. Testing is being coordinated with a leading burner manufacturer and an independent measurement and verification contractor.

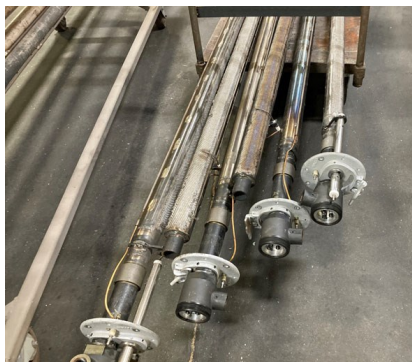
UTD is partnering with SCAQMD and SoCalGas in this effort by providing co-funding to SCAQMD's prime funding.

### Benefits / Market Implications

There are more than 3,000 commercial and wholesale bakeries in the U.S., and the U.S. baking industry consumes more than \$870 million of energy annually. Additionally, the baking industry in many air-management districts is subject to strict NO<sub>x</sub> emissions limits. Offering a technology that promises both energy and emissions reductions is an attractive prospect for the baking industry for financial, environmental, and social reasons.

End users that will benefit include wholesale bakeries using direct-fired ovens and other users, such as for flame treatment, gas-fired drying, process heating, and other industries using ribbon burners and zonal control systems for process heat.

Wholesale bakeries are very energy-intense operations. Energy efficiency is typically low, but upgrades to improve the energy efficiency of bakery systems are often unlikely to occur if they require costly downtime and significant capital investment. The technology being investigated in this project can be implemented without significant change or modifica-



*Combi-burners, zone 5 replacement and interior re-firing*

tion to the oven, the products, or the exhaust hardware. The burner fits in standard oven sleeves and burner plates.

The optimized combustion process demonstration in this project is expected to reduce natural gas consumption by 10%. Additionally, the innovative burners are expected to reduce combustion system NO<sub>x</sub> emissions by at least 25%, helping bakeries continue to meet and exceed stringent emissions requirements.

For a bakery that uses 18 MMCF of natural gas each year (such as the host site for this project), this represents almost \$7,500 savings in energy costs and 157 pounds of NO<sub>x</sub> reductions for the facility.

## Technical Concept & Approach

Specific project tasks include:

- Host site performance historical assessment and baseline testing data analysis
- Engineering, fabrication, and purchasing of the demonstration system components
- System assembly and installation
- Startup and shakedown
- Data collection and performance monitoring
- Data processing and analysis, and
- Project management, administration, and scheduled reporting.

Deliverables include a presentation of demonstration results and comparative techno-economic analysis for wholesale baking.

## Results

Baseline performance testing of the existing baking oven combustion system at the host site was conducted to establish a benchmark for the follow-on performance comparison and techno-economic analysis. Combustion emissions (including NO<sub>x</sub> and volatile organic compounds) were evaluated by the project team and verified by an independent contractor.

Engineering of the new demonstration combustion system was completed. Components of the demonstration combustion system were then fabricated, delivered, and installed at the host site location, followed by system startup and shakedown. Based on technical issues identified during the system shakedown period, the OEM modified aspects of the burner and then performed laboratory testing.



*"We at Flynn feel that utilizing Ecozone technology will be a significant step forward to the real-time control of limiting NO<sub>x</sub> emissions from ribbon burners, once deemed a near impossibility. Years of research and development of our sister product line in surface treatment has fueled the continuous technological improvements today. We thank SCAQMD, UTD, and the field host site for their support."*

- Travis Eddy  
Vice President - Sales  
Flynn Burner Corporation

Two replacement burners were shipped to site for functional testing in the oven. The burners were installed in April 2023, lit, and tuned. Based on this, the remaining burners were modified and prepared for shipment for final testing. Multiple unrelated factors have delayed testing. 1) The test site experienced an additional issue related to the carriage mechanism. 2) There has been high production demand for bread, limiting access for testing, and 3) There was uncertainty how the new SCAQMD ruling for commercial ovens (Rule 1153.1, published 8/4/23) affects testing and the plant's permit.

## Status

The oven carriage issues have been addressed and are no longer a limiting factor. High production demand continues, so installation and testing will need to be coordinated with the plant to minimize impact on production. We are coordinating test and permit requirements with SCAQMD so testing can proceed in 2024.

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## Energy Source Options for Industrial and Large Commercial Gas Users

**Information is being developed to help end users identify the best opportunities for decarbonization by changing energy sources, using renewable natural gas blends, and/or making efficiency improvements in industrial and large commercial market sectors.**



### Project Description

This project supports industrial and large commercial end users as they seek to reduce greenhouse gas (GHG) emissions by providing comprehensive new analytical resources. Researchers developed and validated a spreadsheet tool to analyze the economic and environmental impact of fuel-substitution options with related strategies. The tool is comprised of a number of interactive worksheets that allow the user to examine several potential scenarios for carbon-emissions mitigation on both an economic and environmental basis – including changing energy sources, using renewable natural gas blends, and making efficiency upgrades. The initial version of the tool focuses on boilers used for process and/or space heating – one of the largest end-use applications in multiple industries.

The tool will assist industrial and large commercial end users in understanding the tradeoffs for different carbon-mitigation scenarios, accounting for annual energy costs, equipment costs, infrastructure costs, full-fuel-cycle GHG emissions, and the total life-cycle costs associated with GHG-emissions reduction. The tool incorporates baseline natural gas consumption as provided by the end user. The tool can perform qualitative and quantitative evaluations of the carbon-mitigation alternatives and help end users prioritize options that provide the best economics and the most cost-effective reduction in GHG emissions.

The tool allows users to calculate impacts on an individual customer level and could be used to aggregate customer data based on industry SIC code. The carbon-mitigation op-

tions evaluated were:

1. Displacing a percentage of the baseline natural gas technology with a commercially-available electric version (e.g., replacing a certain percentage of existing natural gas boilers with electric boilers)
2. Incorporating a percentage of renewable natural gas in the gas supply, and
3. Replacing a percentage of baseline gas equipment with higher-efficiency gas-fired equipment.

The effect of a carbon tax is also included in the analysis, as well as an option to purchase carbon offsets as part of total mitigation measures and scenario options analysis.

### Benefits / Market Implications

According to the U.S. Energy Information Administration, the energy use of the industrial sector is projected to grow nearly twice as fast as that of other end-use sectors through 2050. Industrial applications account for the second-largest share (35%) of energy consumption in the U.S. (26.3 quads in 2019) behind only transportation. Twelve percent of that (3.2 quads) is from electricity while 40 percent (10.5 quads) is from natural gas. Natural gas provides well over 50% of the energy consumption in specific industries. Solutions are needed to bring down the carbon intensity of the industrial sector as governments set economy-wide decarbonization targets. Decarbonization pathways need to be weighed carefully – trying to apply a one-size-fits-all approach could lead to increased costs, reduction in manufacturing productivity or quality, and even increased GHG or CO<sub>2</sub> emissions.

This project provides end users and local utilities with insights regarding their decarbonization options such as for:

- Industrial and commercial process-heating boilers
- Water heaters for hospitals, nursing homes, and other life safety-critical institutions
- Food processing facilities (vegetables, grains, etc.), and
- Process facilities with steam demands.



*Example of an industrial boiler installation. Image Credit: Hurst Boiler and Welding Inc.*



Commercial and Industrial Boilers			
Industrial	SIC#35 Industrial Machinery & Equipment		
		Average Capacity	Annual Gas Use
	#Unit	(MBH)	(MMBtu)
Natural Gas Baseline	4	30,000	841,000
Fuel Options			
	Input Mix (%)	Input Efficiency (%)	
Natural Gas Baseline		82	
Replace with Electric Boilers	10.00	98	
Renewable Natural Gas Blend	16.00		
Replace with High-eff Gas Boilers	20.00	93	
Purchased Carbon Offsets for	0.00	(% Industry Baseline CO2eq	

Energy Source Options Boiler Energy Screen

Options for reducing emissions in the industrial sector include improved energy efficiency, deploying new manufacturing techniques, switching to lower-emitting fuels, and integrating combined heat and power or carbon capture and storage.

## Technical Concept & Approach

Project deliverables will include an industrial and large commercial market assessment tool with a techno-economic analysis of available technical alternatives and energy resource options. This assessment can support roadmap analyses for greater decarbonization in challenging industrial and large commercial end-use sectors. Co-funding support for some phases of this UTD project was also provided by Energy Solutions Center, Inc.

## Results

In 2020, a Microsoft Excel spreadsheet tool was developed and initial analysis was performed for specific UTD members who provided industrial boiler data. This allowed for an investigation of the tradeoffs between equipment costs, customer electric electricity infrastructure costs, CO<sub>2</sub> emissions avoided (or added), and the costs associated with CO<sub>2</sub> emissions reduction their service territories.

In 2021, a database of industrial energy consumption data was analyzed for key end-use applications, and was used to prioritize the industrial technologies based on geographical locations that were linked to individual funders' service territories. The total industry consumption was analyzed for nine different census regions. A database of 77,000 data points was used to categorize the energy use for each of the nine census regions based on five selected subsectors (i.e., food processing, process heating, space heating, etc.). Each of the five selected subsectors was then divided into 18 key

technologies to better understand the overall spectrum of end uses and to identify the technology consuming the highest amount of energy under each of the key subsectors, with a geographical indicator.

Researchers performed a market assessment and techno-economic analysis of possible energy source options and electrification scenarios for a spectrum of industrial and large commercial subsectors and end-use applications.

In 2022, the spreadsheet-based tool was transitioned to an online platform. Several GHG reduction pathways for process -heating segments were identified and evaluated on a preliminary basis, including net-zero carbon alternative fuels, renewable energy options, energy efficiency improvements (waste-heat recovery), electrification, hybrid energy sources, and system optimization and control. For Phase 2, the team focused on expanding this tool to include boilers.

In 2023 the team started working to expand the tool to include furnaces and ovens as part of Phase 3.

## Status

Phase 1 and Phase 2 of the project have been completed. The Phase 2 final report was released in March of 2023. The team has started software development and is working to identify end-user sectors of furnaces and ovens to include in the tool.

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**LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP**

## High-Hydrogen Burner for Commercial and Industrial Applications



**Researchers are designing, fabricating, and testing an advanced fuel-flexible, high-hydrogen/renewable natural gas burner for commercial- and industrial-scale furnaces. Input from two national laboratories and from representative end users will help ensure that the final prototype burner meets performance requirements.**

### Project Description

Hydrogen gas ( $H_2$ ) is being pursued as a sustainable energy carrier and the blending of  $H_2$  into the existing natural gas pipelines as a means of increasing the output of renewable energy systems by converting photovoltaic energy to  $H_2$ . Demonstrations of relatively low concentrations of  $H_2$  (less than 5%-15% by volume) are under way across the world. Natural gas blended with renewable hydrogen can provide a stable, low-emissions, energy-efficient long-term solution.

Greater reductions in greenhouse gas emissions will occur when higher concentrations (50+% hydrogen) can be used. There is wide agreement that the industrial and large commercial sector is particularly challenging to electrify, and certain industries may significantly benefit from using gas with high-hydrogen content (up to 100% hydrogen). But researchers note that there are significant differences while operating  $H_2$  as compared to pure natural gas. The addition of  $H_2$  increases the flame speed significantly, which can increase the risk of flashback (flame propagating into the upstream mixing region). As the  $H_2$  addition increases, the flame speed also increases, leading to impact on the combustion systems. And in order to match the heating value, the volume of  $H_2$  required is nearly three times that of natural gas. Current commercial burners cannot operate stably with high  $H_2$  due to fluctuation in composition and combustion characteristics.

In earlier UTD-funded efforts, researchers successfully developed and bench-scale-tested a new 3D-printed burner design capable of operating efficiently and robustly. This project will demonstrate a scaled-up burner in a laboratory with high hydrogen (up to 60%) to evaluate the technology with Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), and two leading large gas users.

The innovative 3D-printed burner design is anticipated to provide greater fuel flexibility with high turndown and ultra-low emissions. This design has the potential to enable the use of fuel gas containing high hydrogen without extensive modifications. Example potential applications include process reheaters, heat-treating furnaces, and mini-mills that currently use large amounts of natural gas.

Testing demonstrated stable and robust performance that provides superior air/fuel mixing, uniform cross-sectional flame temperature profile, and over 6:1 turndown. The burner is fuel flexible, allowing the use of a wide variety of conventional and recycled combustible gases, including hydrogen. With the inherent internal recirculation of cooled products, the design reduces  $NO_x$  emissions to <5 ppm and minimizes cross-sectional temperature and velocity gradients at the burner exit. The burner design ensures a robust flame and eliminates potential for flashback and flame propagation into the air-fuel inlet region.



*Installed  $H_2$  flow meter for testing with higher  $H_2$  and all parts ordered for assembly*

In this project, a research team will design, develop, and test the advanced fuel-flexible burner in a laboratory environment furnace to evaluate and compare the burner performance with corresponding state-of-the-art natural gas burners.

## Benefits / Market Implications

Blending of hydrogen into natural gas can present some challenges to various end-use applications in terms of efficiency, process control, or pollutant emissions. A burner capable of handling variable and high H<sub>2</sub> gas concentrations can provide a long-term and sustainable solution.

Adoption of high-hydrogen gas concentrations may first occur in selected single-site users or clusters of large-demand end users, with industrial users being prime candidates since fewer, larger burners need to be changed out.

## Technical Concept & Approach

The following tasks will be performed in the current project:

- **Design and Develop a High Hydrogen Burner**

A research team will design and develop a high-hydrogen burner by modifying and adapting the natural gas design. The project team will use Computational Fluid Dynamics (CFD) and chemical kinetics (with ANL) to adapt and modify the design by evaluating mixing and flame characteristics with H<sub>2</sub>.

- **Setup a Test Rig and Perform Burner Testing with Natural Gas**

A laboratory test rig will be developed to operate with natural gas and installed with the required flow controllers and instrumentation. Researchers will test a natural-gas-fired burner to evaluate its performance for various key parameters as a baseline for comparison with H<sub>2</sub>. After performing shakedown testing of the burner, performance testing will be conducted. The key parameters will be emissions, turndown, blower power requirements, and heat-transfer characteristics. This will help determine the operability and turndown characteristics of the natural gas burner. The testing will be performed for different firing rates and different air/fuel ratios to evaluate the emissions and efficiency characteristics.

- **Fabricate and Install Burner for Hydrogen**

The project team will generate burner and assembly-design drawings to install the burner assembly into a laboratory furnace. The components for the burner and its assembly will be fabricated with ORNL.



*Air-fuel skid assembly for H2 operation*

- **Evaluate Prototype Burner Performance**

Ignition testing will be performed to ensure that the burner ignites reliably, repeatedly, and smoothly. The different process conditions will be tested to ensure all the parameters are covered.

The target outcome is to provide a laboratory-proven prototype burner assembly that is ready to be field tested at two industrial user host sites in California. Actual field testing of the prototype will be separately funded/authorized.

## Results

In 2021, the project team evaluated the testing apparatus and instrumentation required to perform hydrogen testing. A flow meter, controls and other equipment for high-hydrogen testing were ordered.

In 2022, the flow meter was installed in the air/fuel train set-up. Flow meter shakedown testing was performed to ensure safe and reliable operation. Design changes to the burner were reviewed using CFD analyses.

In 2023, assembly of the air-fuel skid for H<sub>2</sub> operation was completed. Job Safety Analysis (JSA) and Standard Operating Procedure (SOP) were updated to perform H<sub>2</sub> testing and to ensure smooth and safe operation with hydrogen.

## Status

The team is currently testing with NG-H<sub>2</sub> blends is in progress for ignition, operability and performance up to 3 MMBtu/h firing capacity.

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## Field Demonstration of Energy Recovery from Brewing/Distilling Operation

**This project is validating an innovative waste-heat-recovery technology at two micro-breweries. The process will economically recover heat from brew kettles and re-use it for water heating in order to save energy and reduce CO<sub>2</sub> emissions by up to 25%.**

### Project Description

This project is developing and demonstrating a Waste Heat Effective Transfer (WHET) energy recovery technology in brewing/distilling operations to validate the technology as a robust and reliable operation where waste heat is available and water heating is needed.

The innovative WHET technology combines commercially-available technologies into a simple, reliable, compact, and inexpensive system to economically recover and reuse low-level waste heat. Previous waste-heat-recovery systems have been large, complex, and often too expensive to be deployed because payback times from natural gas savings were too long. WHET systems can operate efficiently and economically at virtually any scale in any industrial setting where waste heat is available and there is a need for hot water or heated water entering a boiler.

The WHET process is designed to be inexpensive, easy to install, and nearly invisible to the plant operator. Simple pay-back periods are expected to be under five years.

The process consists of several key components:

1. A heat-exchange module made with fluted, flared, or spiraled copper tubing (to yield enhanced heat transfer rates) is installed in the flue containing low-temperature

(under 400°F) exhaust gas. This commercially-available tubing provides excellent heat transfer in minimum space and with minimum pressure drop.

2. The flow rate of water through the tubing is controlled by temperature of the exhaust gas and water before and after the heat exchanger. The controller logic is critical because many processes are carried out batch-wise, and the water flow rate must be regulated to avoid extracting too much heat from the exhaust gas and producing problems with condensation in the flue. A flow control loop with valves is used to mix the heated WHET product water with plant water in a water heater or a working process needing heated water. The controller balances available waste heat with facility hot water needs.

Researchers will validate the WHET technology at two micro-breweries. The WHET process will economically recover heat from brew kettles and use that heat for water heating. This approach will provide sufficient operational flexibility to match variations in facility operating load. The goal is to achieve a 15% to 25% recovery of heat from the brew kettles, or 60% of the available waste heat in exhaust gases. A second goal is to reduce CO<sub>2</sub> emissions by up to 25%.

UTD is partnering with the California Energy Commission (CEC) in this project by providing co-funding to a prime contract funded by CEC.



*Installation of the heat exchanger in the boiler room (left) and the tank (right) in one of the micro-breweries*



## Benefits / Market Implications

The current project focuses on demonstrations in breweries and distilleries, a growing market need. In California alone there are now nearly 1,000 brewery license holders and nearly 100 distillery license holders.

The need to heat water, brew, and distill leads to a large energy footprint for brewing and distilling. Energy costs and potential savings are high, although savings as a fraction of total cost are low because the cost of high-quality grains and other raw materials is high. While the percentage of total operating cost savings is low (estimated 25% savings in the 2%-4% of total operating costs related to energy), the total energy saved for brewing and distilling can be large.

The WHET technology also holds the promise of achieving superior environmental performance, including a 25% reduction in greenhouse gas and NO<sub>x</sub> emissions. The technology recovers low-level waste heat and uses it to reduce the natural gas needed for water heating. The approach is practical, flexible, and less expensive than other approaches.

The primary target markets impacted will be: 1) breweries, 2) distilleries, 3) commercial cooking facilities, and 4) laundry facilities. Secondary target markets may include industrial processes using hot water, boiler applications in which pre-heated boiler feed water saves energy, and chemical processes requiring hot water.

## Technical Concept & Approach

Perform the following tasks:

- **WHET System Design and Fabrication**

Individually design WHET systems for the two brewery demonstration sites to match their batch operating practices. Fabricate heat exchangers from extended-surface copper components. Assemble the WHET systems in California and install them at the demonstration sites.

- **WHET Demonstration Installation and Baseline Testing**

Install the WHET systems at the two micro-breweries. Collect baseline data to determine waste heat available from the brew kettles and the quantity and conditions of hot water used during the brewing cycle. The data provides a baseline to determine energy savings achieved with the WHET system.

- **WHET Demonstration Long-Term Testing**

Perform at least 12 months of WHET demonstration testing at both breweries. Parametric tests will be carried out to optimize WHET energy savings. Operate the WHET system at optimized conditions for a long period of time.

Gather data on temperatures, flue gas volume, water temperatures, and water flow rates. Monitor energy requirements for hot-water heating to determine WHET system energy savings.

- **Performance Monitoring and Evaluation**

Analyze all collected data, conduct all analyses, and report results to sponsors.

## Results

In 2021, the project team focused on obtaining equipment and components, selecting and then working with the installer, and planning for the first installation. One of the originally-planned brewery sites announced that they were closing. The project team then secured a new, second demonstration location while moving forward with setting up the first demonstration in Sacramento, CA.

In 2022, the project team organized the first installation of the WHET system. This included securing delivery of the water storage tanks, controls components, and other parts. Other activities included locating and negotiating with a reputable installer and finalizing plans for installation. The first system is now in place and is undergoing shakedown testing while brewery baseline data is being collected. Preparations are under way to install the second system.

In 2023, the second demonstration site was forced to close. The team found a replacement demonstration site. The team worked with local contractors and completed the installation process for the second installation during the third quarter of 2023. Baseline testing has been completed at the second site and both sites are now in demonstration mode. The project team will be monitoring the performance of the demonstration systems for a minimum of 12 months.

## Status

The team is focused on completing demonstration testing and processing the resulting data.

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## Zero-Emission Processes with Carbon Recovery

**Researchers are advancing the development of a new synthetic air-combustion process that simultaneously improves industrial boiler or furnace efficiency when using natural gas – while also lowering CO<sub>2</sub> emissions and providing a means to capture or convert CO<sub>2</sub> to valuable products.**

### Project Description

Synthetic air combustion (SAC) is a form of oxygen-fired combustion that offers the benefits of lower fuel demand and decreased emissions. Oxygen firing, however, produces a much higher flame temperature than air firing and requires complete rebuilds of equipment and using a new refractory – all of which is costly.

The goal of this specific project is to advance the development of a new SAC process that simultaneously improves industrial boiler or furnace efficiency when using natural gas, while also lowering CO<sub>2</sub> emissions and providing a means to capture or convert CO<sub>2</sub> to valuable products. Laboratory tests will be conducted at industrial conditions. Testing will help compare calculated and experimental results when using SAC to typical air-fired combustion.

This UTD project builds upon an earlier-stage R&D project to explore potential benefits of SAC, which began in 2020 and was funded by UTD members.

### Benefits / Market Implications

This project will help utilities and their customers address methane-emission and greenhouse-gas-reduction goals or pending legislation related to emissions of CO<sub>2</sub>

SAC can be applied to a very wide range of industrial processes. While some processes will benefit more than others from adoption of SAC, the technology can reach all industrial sectors across the country.

SAC is compatible with a wide range of fuels, making the use of renewable natural gas (RNG), biomethane, and hydrogen-enriched natural gas.

SAC offers natural gas end users a path toward a lower-carbon world. Important benefits of SAC are the ability maintain the existing industrial furnace and boiler infrastructure and to achieve real cost savings that make SAC a practical way to operate in a reduced carbon world:

Benefits to end users and the environment are targeted to include:

- Reduction of CO<sub>2</sub> emission by >8%. When add-on technologies such as reforming or bi-reforming are included, SAC provides the enabling technology to provide 100% elimina-

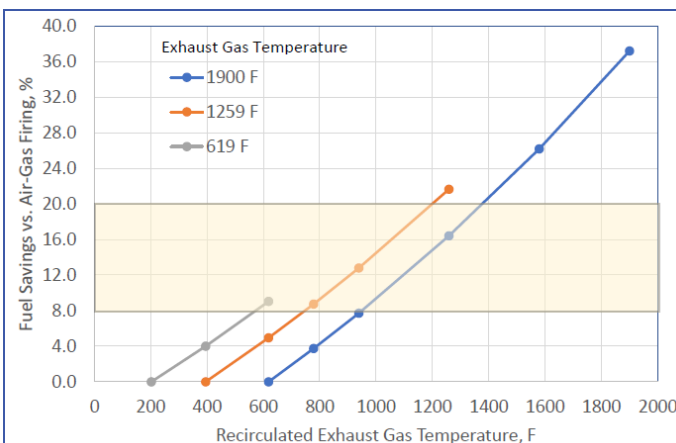
tion of CO<sub>2</sub> emissions

- Reduction of natural gas consumption by >8%
- Near elimination of NO<sub>x</sub> emissions
- CO<sub>2</sub> can more easily be converted into a number of valuable chemicals, or recovered and sequestered
- Improving product throughput and quality through greater combustion control (targeted 10% increase in furnace throughput with higher product quality)
- Retaining customer choice for gaseous fuels, including RNG, biogas, natural gas, and blended fuels, and
- Higher flame stability.

The primary target markets impacted will be:

- Industrial furnaces
- Process heaters, and
- Stationary boilers.

Secondary target markets include a wide range of industrial processes that generate hot exhaust gases.



*The figure above shows the results of mass and energy balances illustrating fuel savings provided by the SAC process as a function of exhaust-gas temperature and recirculated exhaust-gas temperature. Within the range of most industrial process operations and the range of currently practical gas recirculation temperatures (up to 1,200°F), calculations show natural gas savings of 8% to 20% can be realized.*

## Technical Concept & Approach

This project takes a deeper look at SAC by examining the practical aspects of the technology, the economics and environmental benefits, and the linkage to renewable sources of oxygen. Researchers are conducting laboratory SAC tests with heated synthetic air containing a simulated flue gas of carbon dioxide and steam.

Specific activities include:

### **Modeling of Industrial Combustion Processes Focusing on SAC**

The project team will carry out combustion and thermal modeling of common industrial-combustion processes with air and synthetic air at a range of conditions. The results will be used to determine the economic and emissions benefits of the SAC process. The effort will also evaluate SAC in combination with renewable oxygen production and carbon capture or carbon conversion to products technologies.

### **Synthetic Air-Combustion Testing**

A series of tests will be carried out on a laboratory furnace. Synthetic air containing oxygen, CO<sub>2</sub>, and steam will be provided to the burner at a range of temperatures simulating recirculated flue gas. Data will be collected on temperatures, efficiency, flame properties, and emissions. Results will be compared with results when firing the same burner under air and ambient synthetic air conditions.

### **Data Processing and Modeling of SAC Efficiency and Emissions**

Comparisons of flame properties, combustion stability, efficiency, and emissions will be made between tests with the industrial burner when fired with air, ambient synthetic air containing oxygen and CO<sub>2</sub>, and heated synthetic air containing CO<sub>2</sub> and steam.

## Results

The team first conducted synthetic air combustion tests using synthetic air containing oxygen and carbon dioxide at ambient temperature. Results confirmed that burners run well on synthetic air. With CO<sub>2</sub> alone, NO<sub>x</sub> is low, but CO is high under certain firing conditions.

In an effort to reduce CO, the team tested a preheated synthetic air containing steam and CO<sub>2</sub> at elevated temperatures. Testing found that the burner was stable when firing with synthetic air and heat release was similar to firing with air and natural gas. NO<sub>x</sub> emissions dropped to near zero. CO levels were significantly lower than when firing with synthetic air containing only CO<sub>2</sub>, but CO levels were still well above the levels obtained with air firing. The CO level could be lowered to the same levels as obtained with air firing by increasing the oxygen to natural gas ratio from 2.07 to 2.20.

The team calculated conditions for the parametric synthetic air combustion tests with synthetic air containing oxygen, steam, and CO<sub>2</sub>. The results indicate a small amount of CO<sub>2</sub> dissociation is occurring in flames, and the CO is elevated because a large fraction of the inlet gas to the burner is CO<sub>2</sub> when firing with synthetic air. To avoid the need to use high levels of excess oxygen, burners may need to be designed to change mixing patterns so CO<sub>2</sub> dissociation is avoided.

Several possible paths were identified to incorporate CO<sub>2</sub> capture. The major routes include:

### **Membrane separation of CO<sub>2</sub> from other exhaust gas components followed by compression**

A large number of membranes including size exclusion, thermophilic, and graphene oxide membranes are under development by many organizations. This path may prove to be an attractive route for CO<sub>2</sub> separation from SAC exhaust gases.

### **Sorbent recovery of CO<sub>2</sub>, removal of water, and compression**

Solvent recovery of CO<sub>2</sub> from exhaust gas using amines and other chemicals is the most studied and most mature approach. This approach is fairly complex. The project team will evaluate this approach, although other approaches appear more promising.

### **Cryogenic recovery of CO<sub>2</sub> as dry ice followed by compression**

Thermodynamic calculations have shown the cryogenic path is too energy-intensive to be attractive.

### **Removal of particulates, NO<sub>x</sub>, and SO<sub>2</sub>, followed by catalytic removal of oxygen from the exhaust gas and then followed by compression of CO<sub>2</sub> with integrated H<sub>2</sub>O removal.**

A potentially attractive path is to start with removal of the trace components using traditional gas processing technologies. Then the oxygen must be removed, and this can be accomplished using thermal oxidation. This path is attractive because no membranes or sorbents are required.

## Status

The team is working to define the form and extent of layouts, mass and energy balances, and economics to be used to compare CO<sub>2</sub> capture approaches before beginning detailed analyses for the selected CO<sub>2</sub> capture approaches.

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## High-Efficiency Crop-Drying Process



**Researchers are developing a high-efficiency, low-labor crop-drying process that can be retrofitted into existing farm operations to save energy and improve product quality. The project team identified two crops of higher market value, prepared a preliminary design, and is advancing product development.**

### Project Description

Sun drying is the simplest and least expensive method of crop drying, but it is almost impossible to manage the drying conditions and control the quality of the dried product during the drying process.

The agriculture industry has employed a number of drying methods and techniques to improve crop drying in order to reduce spoilage, increase the marketability of product quality, and to get to the market as fast as possible.

The Thermo-Vacuum Drying (TVD) process that was developed and initially demonstrated in previous UTD project 2.17.B can improve operating efficiency and product quality and reduce greenhouse gas emissions to contribute to decarbonization targets. This technology was applied to rotary drying in bulk food drying operations in that UTD project and may have application in a wide spectrum of crop drying at low temperature to preserve quality and prevent spoilage.

TVD is an ejector-based technology that uses a motive force to create a dynamic vacuum to remove moisture from the product being dried. The removed moisture is then condensed and captured for reuse. That motive force can be pressurized air or steam. One of the key challenges was to remove moisture evaporated from the drying air at sub-atmospheric pressure with cost-effective dehumidification techniques.

The objective of this UTD project is to advance the development of the TVD process so that it can be retrofitted into existing farm operations. In addition, the project outcome may help secure follow-on external funding from governmental agencies for subsequent larger-scale field demonstrations.

### Benefits / Market Implications

Development of advanced low-temperature crop-drying methods can reduce primary energy consumption by 10% to 15%, increase the drying rate (resulting in a reduced drying time by 25% or more), and improve product quality.

This technology can be applied to a variety of markets, including:

#### Traditional Markets – Fruits, Herbs, and Nuts

- Dried fruit was a \$9.8 billion market in 2018, dominated by grapes, dates, prunes, apricots, cranberries, and figs.
- Fruit drying has two main forms of product: semi-moist (20% to 25% moisture content) and dried fruits (15% to 20% moisture content).
- Dried herbs was a \$4.1 billion market in 2018 and is expected to grow to \$6.1B by 2026.
- Nuts are a \$37.5 billion (2018) worldwide market.

#### Emerging Market – Large-Scale Biomass Gasification

- Utility-scale production of renewable gas from woody or leafy biomass and other biomass feedstocks is being considered. Efficient, economical methods to remove moisture from this feedstock at large scale will be an important need as new sources of large-scale renewable gas are considered. Relevant context includes major project development announcements during 2023 by SunGas Renewables and similar entities.



*Thermo-Vacuum Dryer of 100 tons per day capacity in previous UTD project 2.17.B.*



## Technical Concept & Approach

The project team is comprised of a primary technology developer, an ejector system designer, and a marketing and technical support expert.

Tasks were performed over a nine-month term, including:

- **Crop Selection and Characterization**

The project team identified, characterized, and selected two high-value crop-drying markets to evaluate. Crop-drying specifications were developed. Researchers characterized the performance of current drying methods and techniques (including typical equipment in use) and analyzed the opportunity for a TVD process.

Tasks performed over a nine-month term included:

- **Crop Selection and Characterization**

The project team identified, characterized, and selected two high-value crop-drying markets to evaluate. Crop-drying specifications were developed. Researchers characterized the performance of current drying methods and techniques (including typical equipment in use) and analyzed the opportunity for a TVD process.

- **Commercialization Scale-Up Planning**

The project team selected and analyzed the most-promising solutions and developed a preliminary design for high-efficiency drying of the selected crops. A preliminary economic analysis of most feasible and workable designs was also conducted.

## Results

Two high-value crop types were identified and prioritized for further evaluation – tree nuts (almonds, walnuts, and pistachios) and field crops (alfalfa and hemp).

**Almonds** - This is a \$5.5 billion market with 78% of the world's supply grown almost entirely in the state of California. Current on-ground harvesting relies on sun and air drying; however, insect infestation, microbial infection, and dust generation is moving the industry to consider off-ground harvesting methods.

**Walnuts** - U.S. production is valued at \$1.3 billion. Walnuts require drying within 48 hours of harvest to stabilize product quality, shelf life, and increase prices paid by packagers. Because most walnuts are harvested in an 8-10-week window, walnut hullers have an immediate need to accelerate current batch-drying times and dry at lower temperatures to preserve product quality.

**Pistachios** - U.S. production is valued at \$1.9 billion. Pistachio huller needs include accelerating the drying process, drying at lower temperatures, eliminating the need for silo drying, and developing an added-value market in cattle feed



*Thermo-Vacuum Dryer of 100 tons per day capacity in previous UTD project 2.17.B*

from dried green waste (hulls).

**Alfalfa** - Alfalfa is the fourth most widely grown crop in the U.S., with an estimated annual value of \$11.7 billion dollars. The primary benefits of dehydrated alfalfa pellets as a high nutritional, low-cost feed supplement include ease of storage and handling. This has led to increased demand among beef, dairy, and pork producers domestically and internationally.

**Hemp** – The current value of the hemp market is \$824 million (2022). Cost-effective and efficient drying technology has the potential to significantly improve drying time at lower temperature to improve product quality and increase oil output.

Other drying opportunities exist for co-products of existing crops. These include dried distiller grains (DDG) and brewers spent grains (BSG). Based on the project findings, the project team drafted a TVD design layout for a follow-on technology prototype demonstration.

## Status

Product development efforts are currently in progress.

The timing to fabricate the prototype equipment and select the final site for the technology demonstration will depend on when a primary supplier to the project provides key contract deliverables.

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## LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

# Ribbon Burner Performance With Hydrogen-Blended Gases



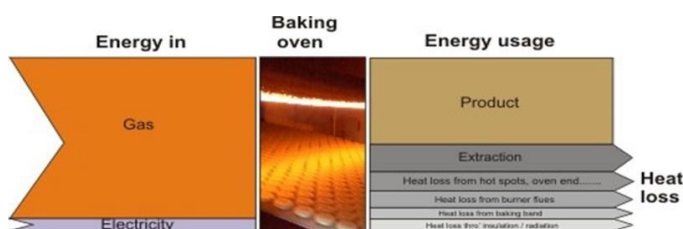
Researchers are evaluating the performance of traditional ribbon burners when operating with hydrogen and hydrogen-natural gas blends, with hydrogen content in the gaseous fuel from 0% to 100%. This research supports decarbonization efforts by end users in the baking, heat treating, and similar industries.

## Project Description

The goal of this project is to evaluate the performance of traditional ribbon burners when operating with hydrogen and hydrogen-natural gas blends in the range of hydrogen content in the gaseous fuel from 0% (natural gas only) to 100% (hydrogen only), in order to prove technical feasibility and identify the optimal performance along with possible design gaps. The data and correlations obtained will serve the project team as a basis for developing innovative decarbonization concepts and hardware that will integrate green hydrogen production (zero carbon).



*Pita bread baking oven interior*



*Energy input/output of traditional ribbon burners*

## Benefits / Market Implications

Deep-decarbonization policies are being expanding across the continent. That's why low-carbon, carbon neutral or zero-carbon solutions are of industry's great interest.

The primary target market is industrial wholesale baking. The baking industry is a huge business. It is projected that the revenue of bread and bakery product manufacturing in California will be approximately \$5.82B by 2024. Government regulations continue to challenge the industry. The Environmental Protection Agency, the Food and Drug Administration, SCAQMD, and other entities oversee the operations of bakeries and issue new rules and regulations.

In addition, if many customers demand "climate-smart bread," then bakeries would have to prove that their bread production uses less energy than the average loaf and emit less harmful emissions. The current carbon footprint of the average wholesale bakery results in a range of 977-1,244 g CO<sub>2</sub> eq. per loaf of bread.

Some of the baking applications, such as a pita bread production for example, are very hard to be electrified because it requires a flame presence, so fuel substitution is a likely viable option for pita bread baking.

Potential secondary target markets for further consideration include surface treatment and material thermoforming

Ribbon burners are widely employed across wholesale baking industry and estimated to produce over 39,000 tons a year of NO<sub>x</sub> annually in the United States. Specific burner type and firing rate depend on the product baked (bread, crackers, tortilla, bagels, etc.). Implementation of the appropriate fuel-switching technology may significantly reduce carbon footprint as well as improve energy efficiency of the operations.

## Technical Concept & Approach

Ribbon burner performance will be evaluated based on a test matrix including fuel consumption, combustion emissions, temperature profile, and flame characteristics. Operation of the burners (flame shape and color, combustion and ignition stability) will be observed in the range of the hydrogen natural gas blends of 0-100%.

The project is broken down into 3 major tasks:

### Task 1: Lab-Scale Test Rig and Fuel Supply Setup

Construct a test facility to analyze the selected ribbon burners' performance in a controlled environment. This includes:

- Select type and size of the ribbon burners to be evaluated.
- Assemble the components of the ribbon burner combustion system along with the control, measurement, appropriate ignition, and flame safety
- Setup a gas blending system or purchase the required hydrogen-natural gas mixture
- Develop safe operating procedure for test firings
- Startup and shakedown of the test rig (ready for data collection)

### **Task 2: Test Matrix Development and Performance Data Collection**

Collect the data of the selected burners in the range of the hydrogen-natural gas blends of 0-100%. This includes:

- Develop test matrix and select appropriate measurement protocols
- Collect the performance data (fuel consumption, combustion emissions, temperature profile, flame characteristics)
- Observe the burners' operation (flame shape and color, combustion and ignition stability)
- Reduce the raw data for the follow-on analysis and representation



*Exterior of an industrial demonstration oven*

### **Task 3: Data Analysis and Final Reporting**

Analyze all project findings and report them to project funders. The work effort includes:

- Performance data on ribbon burner heat release and emissions in a range of tested hydrogen content
- Recommendations for H<sub>2</sub>-retrofit in industrial bakery settings and for a follow-on demonstration.



*Ribbon burner test setup in laboratory*

## **Results**

The type and size of the ribbon burners were selected to evaluate the performance of burners with a mixture of hydrogen and natural gas. A test rig was set up to analyze the selected ribbon burners' performance evaluation. Ribbon burners were tested with mixtures of 0-100% hydrogen and natural gas.

Performance data (fuel consumption, combustion emissions, temperature profile, and flame characteristics) were collected for selected ribbon burners (Task 2). The analysis of experimental data on the tested ribbon burner in the range of the tested hydrogen content was carried out (Task 3).

Selected burners with different geometries have been successfully demonstrated to operate stable, without flashback at fuel hydrogen content up to 95% by volume. With 100% hydrogen, flashback and/or false triggering of the flame sensor is observed.

## **Status**

Based on test results and discussions with a leading manufacturer of ribbon burners, the ribbon burner geometry was modified to burn hydrogen. Prototypes of the modified burners were manufactured and shipped to the team for testing. Further testing and development continues in an industrial research laboratory.

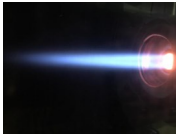
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## High Performance Adjustable Port Burner



**Researchers demonstrated that an innovative prototype adjustable port burner can provide superior ability to operate on varying mixtures of Hydrogen Enriched Natural Gas (HENG) safely and reliably with minimal emissions ( $O_2$ ,  $CO_2$ ,  $CO$ ,  $NO_x$ ).**

### Project Description

Conventional fixed port burners are constrained by being limited in the variation of fuel or oxidant flowing through the burner because of the need to stay within the required velocity limits to maintain stable combustion and performance. This project demonstrated that a prototype version of an innovative adjustable port burner technology could provide superior ability to operate on variable mixtures of Hydrogen Enriched Natural Gas (HENG) safely and reliably with minimal emissions ( $O_2$ ,  $CO_2$ ,  $CO$ ,  $NO_x$ ) compared to current conventional fixed port burners.

### Benefits / Market Implications

Operating fixed-port burners on HENG or other low carbon fuels can present some real challenges in real world use applications in terms of combustion stability, resiliency, efficiency, and process control. There is a need for new technical solutions and there are significant differences in operational requirements for the present designs of fixed-port burners to operate effectively with HENG natural gas mixtures or alternative low carbon fuels. The combustion characteristics of HENG will change significantly as more hydrogen is added to the supply fuel; for example, increased amounts of hydrogen can increase the flame propagation speed by about 5 times. An innovative new adjustable port technology can benefit consumers and ratepayers by: expanding competitive choices when operating on future low carbon fuel alternatives; pre-

venting product obsolescence by being adaptable to changes in gas supply compositions including HENG mixtures; and allowing flexible operation on multiple fuels and lower carbon mixtures while retaining superior performance and operational reliability. This is expected to accelerate the reduction in greenhouse gas (GHG) emissions when low carbon fuel sources are used.

The primary target markets impacted will be commercial/industrial gas-fired equipment in capacity ranges of >0.5 MBH and <15 MBH such as water and firetube boilers, furnaces and kilns, and ovens. Secondary target markets include mCHP, DG and other end use products that can benefit from a fuel flexible high-performance burner.

In the U.S., the American Boiler Manufacturers Association (ABMA) reported sales of 4,000-5,000 boilers per year since 1992 in the <10 MMBtu/hr market segment with an average unit size of 3.5 MMBtu/hr. Boilers in this segment of the boiler inventory are mostly found in the food, chemical and other industries and at education and health care facilities. A 2005 analysis by Energy and Environmental Analysis, Inc. (EEA) for the U.S. Department of Energy estimated that the commercial boiler inventory includes 120,000 units with an aggregate capacity of 1.1 million MMBtu/hr and consume approximately 1,630 TBtu/year, which is 28 percent of all energy inputs in the sector. Commercial boilers at U.S. office buildings, health care facilities and educational establishments account for more than half of commercial boiler units and capacity.

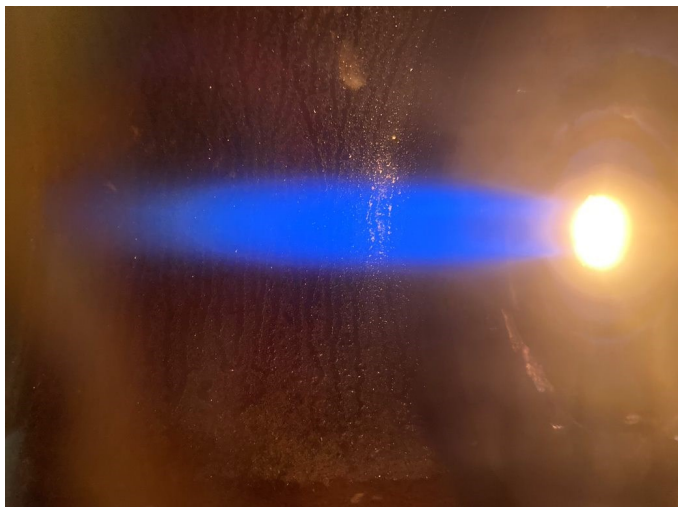


Laboratory Burner Testing



Burner Test controls





*40% Hydrogen by volume at 90 kBTu/hr*

## Technical Concept & Approach

This project built upon earlier bench-scale testing of a conceptual prototype adjustable port burner by evaluating and demonstrating the burner performance fueled by HENG with increasing hydrogen content. The work focused on refining the operation of prototype adjustable port burner and demonstrating the active port concept with lower carbon fuel mixtures. The effort advanced the technology from Stage 3 – Research Implementation to Stage 4 – Technology Development.

The following tasks were performed in the project:

### Task 1: Test Planning and Preparation

A test plan was developed to evaluate the performance of the prototype adjustable port burner which included a testing matrix and the parameter measurements consistent with typical laboratory burner evaluations. Testing in a single burner nozzle test station was planned.

This testing station facilitated direct testing of burners by recreating the heat transfer and flue gas flow conditions of a typical burner application while allowing for in-situ measurements that would not be possible if installed in a typical equipment configuration. The station featured a twelve-inch water-cooled firing chamber with quartz glass observation windows along one side for flame observation. Multiple ports were available for insertion of instrumentation and gas analysis probes. The single nozzle test station was modified as necessary to operate the burner on HENG with mixtures with up to 100% hydrogen.

### Task 2: Burner Performance Testing

Based upon the test matrix developed in Task 1, the adjustable port burner technology was evaluated with a range of

HENG (blending of hydrogen in natural gas from 0-100% by volume). The burner was tested for combustion emissions ( $O_2$ ,  $CO_2$ ,  $CO$ ,  $NO_x$ ) and flame appearance. Ignition testing was performed to ensure the burner ignited reliably, repeatedly, and efficiently. Incorporation of modular design components that were easily replaceable and/or modifiable during the project was a primary consideration during this task.

## Results

This testing confirmed that the adjustable port burner technology provides superior capability for a premixed burner to operate on Hydrogen Enriched Natural Gas (HENG) with higher hydrogen content more safely and reliably than conventionally-designed fixed port burners. The burner provided stable ignition and fuel combustion while operating with changing HENG composition (0 to 80% hydrogen blending), firing rate (30 to 90 kBTu/hr), excess air flow rate adjustments (20 to 35%), and exit port size adjustments made during burner operation. The burner was able to maintain low  $NO_x$  emission levels throughout the testing matrix. Automated burner operating controls were developed and they demonstrated how a burner with adjustable port technology can easily be incorporated using a standard industrial programmable logic controller (PLC) and Human Machine Interface (HMI). These controls were used throughout the testing to control the burner firing rate, fuel blend composition, excess air, and port size or exit port pressure control.

## Status

A Final Report which describes the work performed, results, conclusions, and recommendations was issued in August 2023. Opportunities for next-step funding and efforts to advance the development of this innovative technology to a larger scale, including exploratory discussions with potential commercialization partners and seeking governmental or other research and demonstration grants, are being sought.

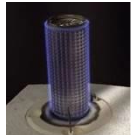
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## LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

# Mitigating Methane Emissions From Large Commercial and Industrial End Use Equipment



**Researchers quantified methane emissions from large commercial and industrial end use natural gas burners (focusing on startup and shutdown) and in partnership with burner manufacturers identified and tested some broadly applicable methods to mitigate these emissions, with a goal of reduce methane emissions by >50% during transient operations.**

## Project Description

The goal of this project was to identify and demonstrate broadly applicable methods to mitigate emissions from large commercial and industrial end natural gas burners, after first quantifying the methane emissions. Different widely-used burner types were evaluated, including high velocity, baffle and premixed burners with various ignition systems.

Earlier UTD efforts under UTD project 1.18.F tested methane emissions from three residential and small commercial burners which ranged from 180 KBtu/h to 1 MMBtu/h in capacity (each with a different burner design) and identified opportunities to mitigate those emissions. Testing showed that methane emissions during start-up were affected by the air-fuel ratio and overall burner designs, and that higher emissions were seen with higher excess O<sub>2</sub> in the mixture. Those results have been published.

UTD project 2.22.E extends those earlier efforts to larger commercial and industrial burners, by testing three types of burners rated from 1.0 to 3.2 MMBtu/h that cover a broad range of applications - from ovens and furnaces to boilers which are commercially available in capacities of 0.150 to 20 MMBtu/h.

Key Performance Indicators (KPI) for project success were to:

- Quantify methane emissions from three widely used large commercial and industrial burners representing a broad cross-section of applications. The burners will be selected

in consultation with leading manufacturers.

- Quantify impacts of changing fuel-air mixing, ignitor positioning, lag time between air and fuel input and fuel ramp up.
- Develop methods for each of the burners to lower methane emissions during start-up and shutdown.
- Reduce methane emissions by >50% during transient operation.
- Engage burner manufacturers towards demonstrating transient methane emissions reduction in the field.

## Benefits / Market Implications

Natural gas is considered a cleaner fuel alternative to coal, producing roughly 56% the amount of CO<sub>2</sub> per unit of energy as coal. Despite the environmental benefits of natural gas as an low carbon fuel source, the primary constituent of natural gas is methane (CH<sub>4</sub>), a relatively short-lived GHG that has 28- 34 and 84-86 times the cumulative radiative forcing (ability to trap heat) of CO<sub>2</sub> on a mass basis over 100 years and 20 years, respectively. Recent studies indicate that CH<sub>4</sub> leakage into the atmosphere may negate some of the fuel's advantages, therefore, identifying significant sources of CH<sub>4</sub> emissions is imperative for effective development of methods to control emissions of GHGs.



*Equipment tested – Large commercial/industrial furnace (left), commercial water heater (center) and modulating boiler (right)*

Thus natural gas producers and distributors are under pressure to identify, quantify and reduce or eliminate the emission of methane, a greenhouse gas (GHG) with significantly greater warming potential than carbon dioxide (CO<sub>2</sub>). While upstream origination and distribution have been a primary focus to date, post-meter emissions are beginning to be a focus area as well. Therefore this project provides measured data on methane emissions from large commercial and industrial burners, and identifies opportunities to mitigate these end use emissions.

## Technical Concept & Approach

This project will develop and demonstrate methods to mitigate methane emissions from large commercial and industrial burners. The effort will advance the technology from Stage 3 – Research Implementation to Stage 4 – Technology Development.

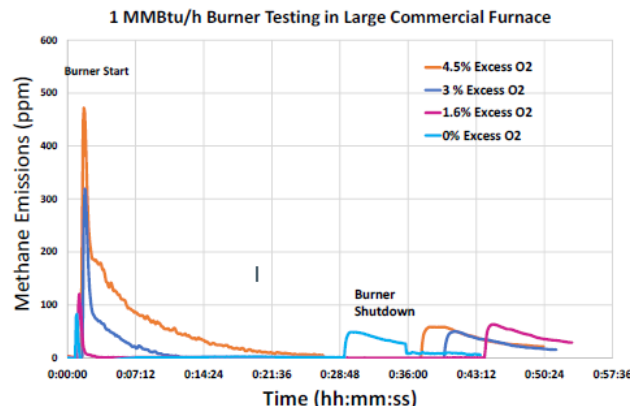
The project is broken down into the following tasks:

### Task 1: Select commercially available burners

The team down-selected and acquired 3 different widely used large commercial-industrial burners to broadly cover fuel-air mixing types (high velocity, baffle and premixed burners) and ignition systems (spark and pilot).

### Task 2: Setup test rig for burner testing

The team setup a test rig to operate with natural gas and installed the required flow controllers and instrumentation. The system allowed testing of the selected burners. The system was instrumented to measure air and gas flow rates, and combustion emissions. Testing was performed for a range of firing



Methane emissions in a large commercial furnace firing at 1 MMBtu/h at different air-fuel ratios

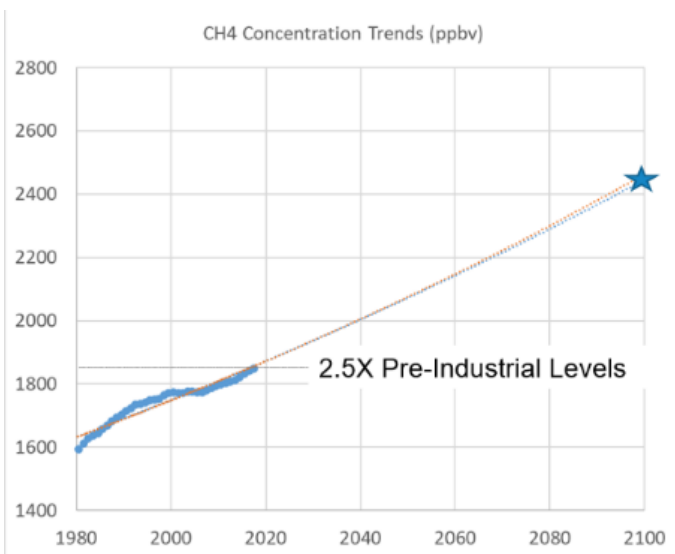
rates, air-fuel ratios, ignitor types, and lag and ramping times.

### Task 3: Perform multiple burner testing

Baseline testing of the burners for methane emissions was performed to collect data and perform analysis based on the way these burners operate. This provides a clear understanding of the start-up, shutdown and steady state emissions and operational challenges related to methane emissions.

### Task 4: Burner modification and testing to reduce or eliminate methane emissions

The team, in discussion with burner manufacturers, evaluated impacts of ignition, air-fuel mixing and injection timing and ramping changes to identify techniques for lowering the transient methane emissions, while maintaining burner performance. The testing provided experimental data for performance improvements that can reduce methane emissions.



Increase in total methane emissions over time

## Status and Results

Testing has concluded and the project is complete. A Final Report was submitted to UTD members in December 2023. Results from this project are scheduled to be presented in May 2024 at the International Gas Research Conference 2024, a major gas industry research conference.

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## LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

# Tecogen Hybrid Gas/Electric Chiller Laboratory Evaluation



**Researchers will validate a promising emerging high-efficiency hybrid (natural gas/electric) chiller technology. The new product will increase operational resiliency for end users, expand integration of gas and electricity, and provide facility owner/operators with increased demand side management of their gas and electricity consumption.**

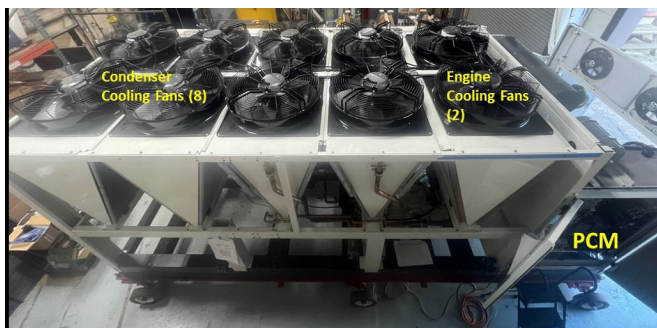
## Project Description

The goal of this project is to validate an emerging high-efficiency hybrid (natural gas/electric) chiller technology being developed by Tecogen in order to support its market entry and successful commercialization. The new product line will provide 200-400 tons and represents a new option for end users to increase operational resiliency, provide more integration of gas with electricity, allow demand control of both electricity and gas consumption, align with microgrid developments, and build on Tecogen's proprietary power electronics / inverter / generator / engine system which is proven in their InVerde e+ combined heat and power (CHP) product.

The approach incorporates the proven integrated InVerde high voltage DC (600V) power electronics. Packaging will likely be a single-skid mounted unit that is significantly smaller than Tecogen's existing Tecochill RT product line. The packaging approach aligns with current market trends and supports resilience, sustainability, and ease of retrofit. The entire chiller is within the power scope and can power ancillary devices during a blackout. A utility electrical interconnection barrier is not required.

Key Performance Indicators of success for the research project will be to:

- Demonstrate capacity and measure efficiency from low load to 200 ton rating
- Demonstrate ability to power ancillary devices during blackout (pumps, etc.)
- Confirm heat recovery operation and capacity



Hybrid chiller prototype construction cell

- Support optimization of the control system to consider pre-programmed grid carbon intensity (gCO<sub>2</sub>/kWh), incorporate real-time utilization of heat recovery, and ability to dynamically shift percentage of one power input verses the other to provide the lowest GHG profile.

## Benefits / Market Implications

Rapidly-escalating electricity prices and a focus on grid resilience has caused some facility owners to investigate alternative cooling systems such as gas-fired absorption chillers, gas-fueled engine driven chillers, and hybrid systems. Hybrid chillers can be optimized to provide the most economical or lowest carbon intensity cooling, often depending on the time of day used (e.g. during on-peak or off-peak electric periods) or when loads are light.

The primary target markets to benefit from this technology will probably be large commercial, industrial and other applications that need 200-400 tons or more of cooling with a high degree of resiliency and energy source flexibility in gas-grid supply-constrained markets or electric-grid supply-constrained markets with high electrical energy and demand charges. This may include:

- Hospitals, nursing homes, and other life-safety-critical institutions
- Food processing facilities and high-value manufacturing operations for which reliable temperature control is needed to avoid spoilage/lost production during electrical outage
- Mid-size colleges and universities; high schools
- Large multi-family residences
- Governmental or other mission-critical facilities
- Corporate or other small/mid-sized data centers

Tecogen's planned new product offers a hybrid gas/electric chiller to serve the very large market of end-users that need 200-400+ tons with key advantages:

- This product is a compact, integrated unit with built-in controls to allow easy fuel-switching, resiliency, and time-of-day





*Tecogen InVerde e+ CHP (source Tecogen)*

controls, which can optimize operation for maximum GHG reductions, minimum costs, or other factors selected by end user.

- It incorporates heat recovery for high efficiency CHP when in the operational mode fueled by gas and its two power sources offer extra resiliency, such as during grid outages.
- It meets the strictest ultra-low emissions standards, including being SCAQMD compliant.
- It allows consumers to avoid electric demand charges and peak "time-of-day" rates and it can provide power to some ancillary devices during a blackout or even operate without a utility electrical interconnection.

## Technical Concept & Approach

The project will validate the performance of Tecogen's hybrid gas/electric chiller over an 9-month period.

The project is broken into the following tasks:

### Task 1: Evaluation agreement

The specifications of the hybrid chiller to be tested, evaluation approach, ownership of data etc. will be developed in an evaluation agreement.

### Task 2: Test planning

The project team will develop a detailed plan for evaluating the performance of the gas/electric hybrid chiller over a range of

turndown ratios and operating scenarios. The plan will describe the conceptual retrofit scheme, evaluation test matrix, schedule, duration, measurements to be made and intended outcomes that are consistent with laboratory evaluation.

### Task 3: Installation and testing

The team will prepare a site in a laboratory for the hybrid chiller, secure the unit and initiate testing per the test matrix developed in Task 2, and analyze the test results.

## Results

Tecogen has worked to complete fabrication of the test unit. Per Tecogen, work was conducted in the following areas. A Power Control Module was installed into Tecogen's electronics laboratory and successfully tested with power first applied to the engine/generator side and then to the utility side. The load was limited to about 80 kW, about 2/3 of the full rating and utilized a load bank. Testing was able to complete the initial draft of software relating to the Power Control Module control, although fine tuning of the control parameters will be necessary when chiller testing is initiated. An outdoor test loop was prepared for chiller testing with the main efforts applied to the chilled water piping.

## Status

Tecogen has worked to complete fabrication of the test unit. A detailed project agreement with Tecogen is being prepared.

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## FOOD PREPARATION AND SERVICE





## Commercial Foodservice Equipment Demonstrations



Through restaurant and commercial-cooking field demonstrations, researchers are gathering valuable data and refining a performance comparison tool to quantify the operating savings and efficiency benefits for end users of gas-fired commercial foodservice equipment in real-world situations.

### Project Description

Researchers and gas-industry representatives are conducting demonstrations of gas-fired commercial foodservice (CFS) equipment to quantify the benefits of the equipment in real-world situations. Demonstrations are designed to address the reluctance of some CFS operators to replace existing equipment with newer high-efficiency models because of concerns about higher costs or uncertainty that the new equipment will be able to prepare the food as expected. Chain restaurants – which represent about 50% of the CFS industry – are recognizing the long-term cost benefits of newer equipment; however, this information is not generally available to the rest of the industry.

In UTD-supported CFS demonstrations, technicians test selected equipment in the laboratory and/or at commercial demonstration sites and document performance. Testing is being conducted with some of the industry's most recent market introductions, including a steam kettle, range, conveyor oven, convection oven, boiler-less steamer, low-oil-volume fryer, and griddle. Any other appliance of particular interest could be targeted for laboratory performance testing or field demonstrations.

Demonstration activities are focused in two areas: 1) long-term demonstrations in restaurants; and 2) single-day demonstrations at test kitchens and trade shows showing how well new high-efficiency equipment performs when compared to traditional equipment, including the development of software and associated data collection to visually demonstrate equipment performance results.



Griddle testing at Piedmont Tech Center.

### Benefits / Market Implications

Verifying the performance of a CFS technology in the laboratory or the field will demonstrate the advantages of specific technologies and provide valuable performance information for end users, utilities (to aid the development and refinement of their energy efficiency incentive programs), manufacturers and others with the ability to quickly evaluate appliances (whether gas-fired or electric-driven), and understand the true efficiency and cooking performance of the appliance.

### Technical Concept & Approach

The appliance performance and feedback from the test sites will be incorporated into reports detailing the benefits and performance of the systems. In addition, a system to provide comparative real-time energy consumption and product performance of various CFS equipment will be developed.

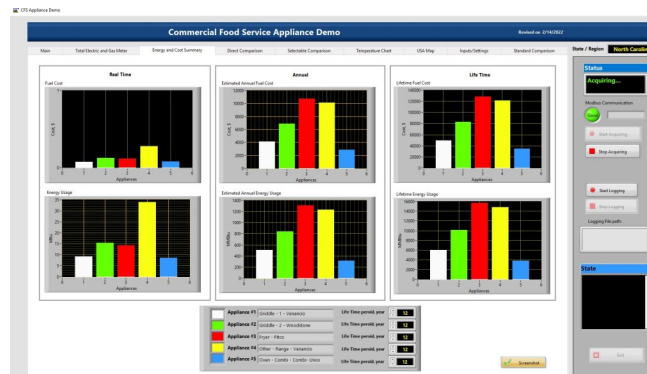
Opportunities for demonstrations are being identified at other utilities and end-user host sites as additional project funding is provided. The time and cost varies based on the appliance and scope of the tests.

### Results

Whole-kitchen assessments (WKA) were conducted at:

- A 120-seat restaurant that serves a wide variety of dishes and is especially known for its extensive dessert menu of pies. **Findings:** Replacing the existing fryers, convection ovens, and griddle with energy-efficient models would save 2,597 therms (\$1,346) per year of energy usage. Assuming an operational life of 12 years, the total savings is 31,164 therms and \$16,152.
- A full-service caterer. **Findings:** Replacing the existing convection oven, combination oven, and griddle with energy-efficient models would save 668 therms (\$349) per year of energy. Assuming an operational life of 12 years, the total savings is 8,016 therms and \$4,188.
- Two counter restaurants with menus that focus on hot dogs, burgers, sausages, and French fries. **Findings:**





One tab of the FEMS Tool

Replacing the existing fryers and griddle with energy-efficient models would save 2,721 therms (\$2,535 per year) of energy. Assuming an operational life of 12 years for both appliance types, the total savings is 32,652 therms and \$30,420.

Overall, the WKAs showed the potential savings of 109,000 therms and \$85,716 over a 12-year appliance lifespan if the standard equipment used in just these four locations were replaced with existing energy efficient options.

A fryer comparison demonstration was initiated at a casino. The demonstration compared three different models from different manufacturers. Three baseline fryers were monitored. After about a month of monitoring, the baseline fryers were replaced with ENERGY STAR equivalents from three different manufacturers.

In 2018, a cooking demonstration was conducted in Tulsa, OK, where the energy usage for four fryers were compared with each other and with standard gas and electric units. Annual energy cost savings for the highest-efficiency fryer tested was \$540 per year when compared with a standard gas fryer and \$785 per year when compared with an electric fryer. Data collected during the demonstration showed that a CFS facility could achieve significant operational savings by using energy-efficient natural gas-fired equipment compared with standard gas-fired and electric equipment. Based on these results, UTD members directed the project team to further design and develop a Foodservice Energy Monitoring System (FEMS) under subsequent phases of this project that could be used at trade shows, test kitchens, and similar venues.

In 2019, a new demonstration site was identified and evaluated for replacing an electric fryer with an energy-efficient gas unit. The entire menu is prepared in the kitchen equipped with an electric fryer, oven, and rangetop. Advancements were also made to the FEMS system.

In 2020, researchers also began working on a unique opportunity on a larger rack-oven monitoring project. Data from rack ovens in California and the Midwest was analyzed to determine potential energy savings of efficient models. Efficient gas ovens should have a much lower source-energy use and significant cost savings that can be proven through this project.

Unfortunately progress under this UTD project was impacted during 2020-22 due to Covid-19 and its dramatic impact on the CFS industry, including at some field test sites planned for this project.

In 2021, the project team completed work with Duke Energy's Piedmont Natural Gas subsidiary to install and test a FEMS data collection and visualization system in Piedmont's new test kitchen. The system monitors, records, and displays data on the performance of various appliances being cooked on at the same time and how they compare to each other. Researchers also continued to monitor the baseline fryer in Detroit and a Royal range high-production fryer in Tulsa; analysis of the data found a 50% reduction in gas use with the new Royal range fryer.

In 2022-23, a high-efficiency fryer was delivered to a restaurant in Detroit in coordination with UTD project 1.14.C, but the opening of the restaurant has been delayed due to facility renovations as well as unavailability of some other equipment. In addition, the FEMS system was upgraded to be able to print a pdf report of the results of live testing; this report can be instantly printed for end users to take with them and help make informed equipment purchase decisions.

## Status

Researchers are closing out two fryer demonstration field demos as well as the rack oven analysis. The timing of this will depend on the status of the ability to gain data from the high efficiency fryer installed in the Detroit restaurant.

The FEMS software is available for equipment distributors or other test kitchens that want to show live cooking performance of equipment and help end users assess and implement energy conservation and operating cost saving options.

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## Demonstration of High-Production Fryers

**Commercially-available high-production, high-efficiency fryers are being evaluated in a test kitchen and in operating restaurants to compare their performance to alternative gas and electric models in order to support decision making by end users.**



### Project Description

High-energy-density electric-powered fryer models are capable of delivering more heat in a given amount of frying space than gas-fired fryers on the market. However, today's advanced gas heat-exchanger designs can transfer more heat from a burner in a given frying space than electric models, allowing gas models to better serve end users who need high-production capacity.

To demonstrate current technology, in this project a research team is testing and evaluating two high-production fryers at test kitchens, followed by demonstrations at field sites.

Sites within the sponsors' territories are chosen to demonstrate the efficiency, cost, and production benefits of commercially available gas fryers.



*Detroit baseline fryer.*

### Benefits / Market Implications

High-performance gas-fired fryers are often used in commercial kitchens. Generally, gas-fired models will save end users money and reduce emissions (on a source-energy basis) versus their electric counterparts. Producing high-production models that cook well and deliver even greater cost savings will further serve end users in the fryer market.

### Technical Concept & Approach

Leading high-production gas fryers are being compared to standard electric and gas fryers. Sites are being sought to document the energy efficiency and performance advantages of high-production fryers and include baseline monitoring of previous fryers to demonstrate the potential cost and energy savings. Sites with both legacy electric and gas fryers are being sought to assess the benefits over older-generation models.

Site surveys will also obtain direct feedback from users on the performance advantages of the new system.

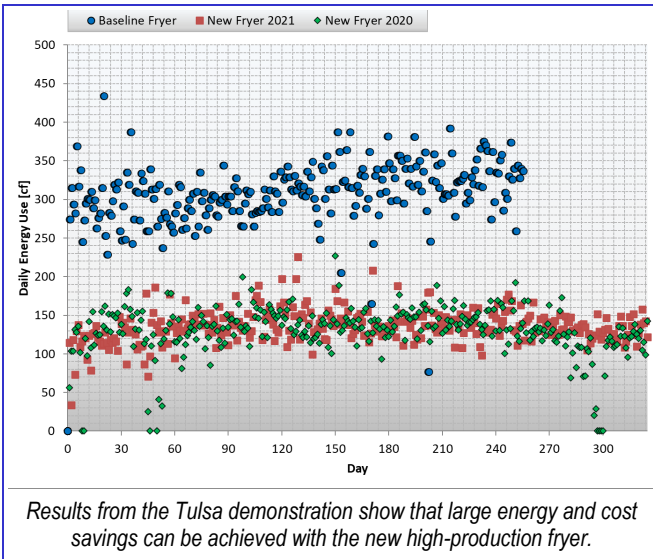
### Results

In 2018, the research team conducted a field demonstration of a high-production fryer in Oklahoma, with a one-day test demonstration comparing four different fryers. The fryer was installed at a field test site and data and results are being collected.

A high-production fryer was demonstrated in collaboration with UTD CFS demonstration project 1.14.B. This high-end gas fryer was compared in a test kitchen one-day evaluation with a low-cost ENERGY STAR gas fryer, a baseline gas fryer, and an additional standard gas fryer the site had on hand (as well as a comparison to an estimated electric fryer). Energy use was monitored in real time with gas and electric meters, while also measuring recovery time with thermocouples in the oil. Results showed that the unit saved 56% energy use while also recovering quicker and cooking the food faster than the baseline gas model. The unit also saved 32% over a low-cost ENERGY STAR gas model.

The project team purchased one of these same fryers for installation at a barbecue restaurant in Tulsa that had already been baselined. In 2019, the new fryer was delivered and installed in Tulsa.





A second site was found in Detroit and baseline monitoring completed. At the test sites, detailed energy usage, cost analysis, and usage profile reports are being produced to demonstrate the benefits of high-production gas fryers. The high-production gas fryers are being compared to standard electric and gas fryers.

Researchers also monitored the baseline electric fryer in Detroit. The project team specified and ordered a high-production, high-efficiency fryer to finish out this testing. The new fryer is planned to be delivered and installed in the fall of 2023.

In 2020-2022, researchers monitored the high-production fryer in Tulsa. The fryer monitoring had issues with a temperature



Tulsa test fryer.

sensor and control that was leading to the oil being too hot, and this led to the installation of a new controller. Finding this issue as part of the demonstration will lead to permanent changes for the model design and make this high-production fryer operate more efficiently in the future.

The research team completed analysis of the site in Tulsa, finding around a 50% reduction of gas use with their new high-production fryer.

## Status

The first fryer demonstration has been completed and large cost and energy savings have been shown. The second fryer demonstration at a restaurant in Detroit was delayed for a long time due to the impacts of Covid-19, and remains on hold. The project team specified and ordered a high production and efficiency fryer to finish out this testing and the fryer was delivered during the last quarter, but the restaurant is waiting on other equipment to arrive as well as to complete some facility renovation work before the new high production and efficiency fryer is put into service and performance data on it can be obtained.

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## Residential Cooking Pollutants and Indoor Air Quality

**Researchers are conducting an analytical and laboratory investigation on the impact of residential cooking on indoor air quality (IAQ). Rigorous scientific methods are being used to determine emissions. Novel new burner designs are also being investigated.**



### Project Description

A research team is conducting an analytical and laboratory investigation on issues and concerns for indoor air quality (IAQ) with residential cooking based on information from a review of existing literature and data from this project.

The project uses rigorous scientific techniques to experimentally determine the impact of residential cooking on IAQ and to identify opportunities to advance technologies.

Phase 1 of the project studied capture hoods and showed that the capture effectiveness of residential hoods was less than 50% for cooking on the front burners and would be ineffective at capturing cooking and combustion emissions. The current phase of the project is being conducted to determine what types and the volumes of emissions that are present in residential cooking, including NO<sub>x</sub>, particulates, heat, and moisture. Phase 1 also conducted a review of the relevant scientific literature, and the characterization of some studies in some popular press articles. This review also analyzed the methodology of measuring emissions and conclusions drawn based on that data.

Information from Phase 1 was used to guide Phase 2 laboratory tests, including determining which emissions should be measured and what technology improvements may be needed to improve IAQ.



*Shakedown of cook-testing equipment.*

The objective of Phase 3 is to develop and test new burner designs for residential ranges. These will include drop-in designs for existing ranges and power burners for new models. The goal is to design a drop-in solution for residential range burners with at least a 50% improvement in efficiency and 60% improvement in NO<sub>x</sub> emissions compared to existing burners. Reviews of new technical publications pertinent to this topic will also be performed.

### Benefits / Market Implications

With increased concerns about tight homes and Net Zero Energy homes data is needed to fully understand the impact that residential cooking has on indoor air quality and what changes may be needed to residential cooking ranges, burners, and capture hoods to meet consumer's needs.

### Technical Concept & Approach

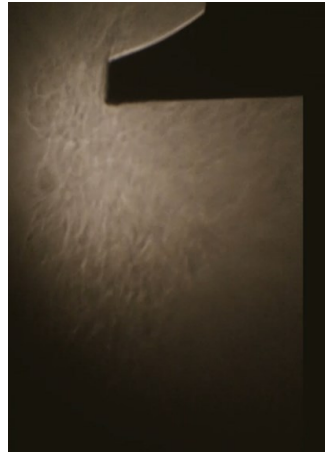
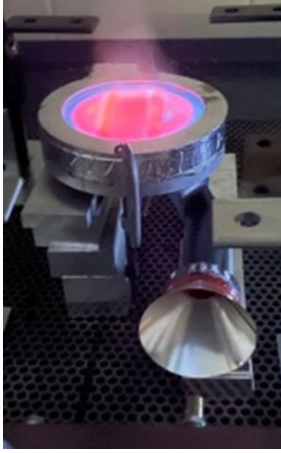
Researchers are using an existing residential cooking setup to perform an analytical and laboratory investigation into the pollutants contributed by gas and electric residential cooking for a standard residential range that includes rangetop and oven cooking. These emission types were identified in the literature as the ones most negatively associated with cooking with natural gas. Established testing protocols and procedures for cook testing emissions capture are used to quantify the emissions. A comparison will be completed for gas and propane vs. electric ovens and an evaluation completed to establish emission capture impact on IAQ and implications for range-hood design.

Research is being conducted to determine how improvements in emissions and efficiency can be achieved by modifying the existing residential burner design or using a new burner concept. The impact in IAQ issues will be calculated based on the improvements in emissions and efficiency, including percent reductions in NO<sub>x</sub> and other combustion products.

The technical approach includes:

- A complete review of existing literature and data on cooking with natural gas and IAQ
- Data and analysis from the laboratory investigation on burner and hood performance, and





- Details on how burner design and performance impact IAQ.

Testing were conducted with propane as well as natural gas under co-funding provided to UTD by the Propane Education and Research Council (PERC).

## Results

A review of existing articles and presentations on the effects of cooking with natural gas on residential IAQ found many examples of conclusions or statements based on inconclusive or inadequate data. These results create more questions than answers for what conclusions can be determined for the effects of residential cooking on IAQ for both gas and electric as the primary energy source.

This project's researchers found that many of the publications had questionable conclusions on NO<sub>x</sub> and asthma – specifically making conclusions about the relationship between cooking with natural gas and asthma that appeared to be more coincidence than causality. The articles tended to use implied results from several studies to make a single conclusion against natural gas when none of the articles make a definitive claim on the causes of asthma and all stated that more research is needed. One report did not include NO<sub>x</sub> emissions data from the oven or data on how NO<sub>x</sub> disperses from the oven into the living environment. Basically, no attempt was made to correlate the NO<sub>x</sub> emissions from the oven to total value of measured NO<sub>x</sub> in the home. Another almost

universal conclusion from the reviewed articles was that proper ventilation for both gas and electric cooking greatly improved indoor air quality.

Cook testing is providing consistent results such that the data can be used to compare natural gas, propane, and electricity. Results showed cooking emissions were more a function of the cooking vessel and food product cooked than energy source. In some tests, electric ranges had higher food emissions than electric, apparently due to difference in the consistency of the heat provided for cooking.

The project team designed a prototype burner concept that had NO<sub>x</sub> emissions of less than 10 ppm compared to 80-100 ppm for a standard range burner. The prototype also had improved efficiency.

## Status

The team is completing ventilation testing for Phase 4. In Phase 5 and 6, more cook testing will be completed including comparing gas to induction in terms of cooking emissions, cooking performance and combustion emissions including source emissions. Results will be presented at the 2024 ASHRAE Winter Conference.



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## High-Efficiency Smart Convection Oven



**Efforts are under way to develop a prototype high-efficiency smart convection oven that increases energy efficiency by 5% to 10% and integrates superior smart operating controls to maximize food preparation quality and consistency.**

### Project Description

Commercial convection ovens use a high-temperature cooking process, which means that the flue products need to leave the system at no less than the oven setpoint temperature of 350°F-500°F. Convection ovens by design also constantly flow heat out of the oven as they operate (with the fan flowing air across the oven and then out the flue), which results in high standby energy use.

There are currently 36 gas ENERGY STAR convection ovens available, but they deliver only 44%-55% cooking efficiency.

In this project, researchers are incorporating a heat exchanger to recover heat from the flue and feed it back into the combustion air. The objective is to develop a prototype high-efficiency smart convection oven that increases efficiency by at least 5%, and also integrates superior smart operating controls to maximize food preparation quality and consistency.

This project will also demonstrate the design through a field demo of prototype units at one or two field test sites selected in partnership with UTD project funders.

Earlier, researchers investigated a high-efficiency oven design, showing that this design in bench-scale tests was

able to achieve a 3% improvement to cooking efficiency and a 10% improvement to preheat energy use despite not being fully optimized. Based on these results and areas for improvement that were found in that initial design, the project team anticipates that a 5%-10% cooking efficiency should be achievable once the design has been optimized. In addition, a targeted 10%-20% reduction in NO<sub>x</sub> and CO emissions are expected.

### Benefits / Market Implications

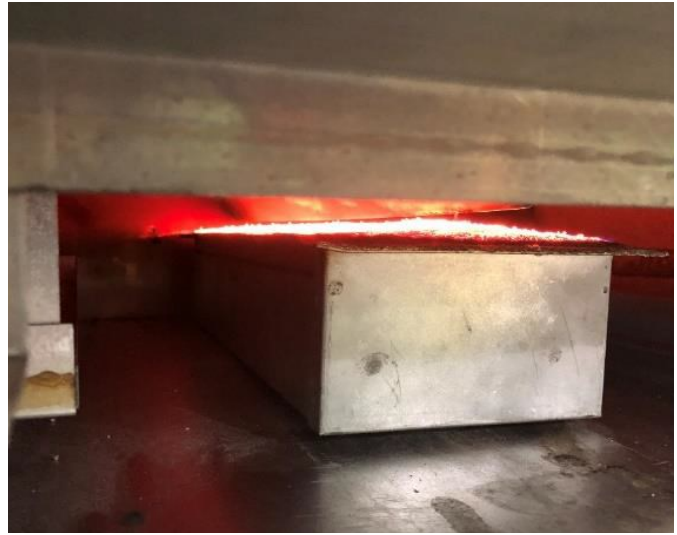
The population of convection ovens in the U.S. is estimated to be around 650,000-700,000, according to a 2015 U.S. Department of Energy study. About 32% of commercial foodservice operations have at least one standard convection oven.

Convection ovens currently use 800 therms annually according to the ENERGY STAR calculator tool. A 2013 California Energy Commission analysis found that replacing existing convection ovens with even 44% minimum ENERGY STAR level ovens resulted in an average energy use reduction of 40% across three field test sites.

The proposed design is targeted to be 10% more efficient than current ENERGY STAR designs. When compared to



*Laboratory analysis of a commercial oven*



*Left: Burner firing in the combustion chamber. Right: Premix burner installed on the bottom of an oven.*

installed ovens, it could save more than 50% of the energy use (i.e., over 400 therms per year). A 50% savings translates to \$300 in savings annually for the customer (assuming \$0.75 per therm) compared to baseline existing ovens. It would be expected to pay back in one to two years, since the cost premium may only be around \$300-\$400.

The project team is also incorporating experimental smart system controls for end users to enhance the quality and consistency of food preparation. Smart system controls may also provide a useful data stream to a manufacturer to provide enhanced warranties, superior customer service, and identify future product marketing and development priorities.

## Technical Concept & Approach

This project focuses on developing and demonstrating a prototype next-generation, high-efficiency, smart convection oven in coordination with a leading manufacturer. An innovative heat-recovery heat exchanger and burner design will be incorporated into an existing oven, with the goal of reaching 5%-10% improvement to the cooking efficiency and standby energy use of the oven. In addition, the project team will determine if sensors can be incorporated to make the oven smarter.

## Results

In 2020, baseline testing of a current ENERGY STAR oven was completed. A computational fluid dynamics model was made to model several different heat-exchanger designs that could be applied to this oven design. Several heat-exchanger designs and variations were created and researchers began modeling their performance.

Technicians fabricated a prototype heat-exchanger design and installed it on the convection oven for testing in the labor-

atory along with a blower and controls. The initial testing showed that the standby energy use was reduced by 15%. A few additional design modifications were decided on in coordination with a leading manufacturer and modeling designs were completed. A final heat-exchanger design was selected based on all of the modeling results.

A potato cook test was completed using the prototype oven. Results showed a 4%-5% increase in efficiency over the baseline. A heat-exchanger modification was made to further boost efficiency and installed in the oven. All of this testing was done with the existing oven burner setup. Researchers specified and ordered a new prototype burner to be used with a premix system.

The team completed ASTM testing of the premix burner system. The results of premix without modulation didn't show improvement over the standard burner system with heat recovery, but it's possible it could be further improved by modulation.

## Status

A final report has been submitted for Phase 1, showing the cook efficiency improved by 12% and the standby energy use by 15% with the heat recovery system. The team is seeking a manufacturing partner to take the technology to market.

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## FOOD PREPARATION AND SERVICE

PROJECT NO. 1.19.B  
SUMMARY REPORT

# Gas-Fired Warewasher



**Efforts are under way to develop prototype gas-fired door- and conveyor-type warewashers in the laboratory. When commercialized, consumers could achieve significant energy and cost savings by using a new option of gas-fired warewashers.**

## Project Description

Most commercial dishwashers (also called warewashers) are electric driven, and many electric warewashers use chemicals (i.e., “chemical warewashers”) rather than high temperatures to disinfect, which further increases their environmental impact. This project is developing reliable gas-fired warewashers so that consumers can have more energy choices and reduce their environmental impact and operating costs.

Four types of commercial dishwashers are available to wash and sanitize plates, eating and cooking utensils, and other items: flight type; rack conveyor; stationary door; and undercounter. Flight-type and conveyor warewashers are used for high-volume applications.

This research project is developing prototypes of both door-type and conveyor-type gas-fired warewashers. These are two very popular warewasher types, representing a combined 43% segment of the warewasher market.

would provide large operating savings for commercial foodservice facility owners and operators while also reducing source-energy and chemical use.

Initial estimates indicate a site will only use one-third of the source energy with a gas warewasher compared to alternative technologies. Even a representative low-usage restaurant, with only 1,100 therms of annual usage, would reduce the carbon footprint of the restaurant from 49,610 pounds of CO<sub>2</sub> per year with electric units to 16,088 pounds of CO<sub>2</sub> per year. In addition, it would cost the restaurant three times more (using national average gas and electric prices) to run that warewasher on electricity instead of gas. The restaurant would save more than \$1,900 a year on operating costs with switching to a gas warewasher.

Data from earlier UTD project 1.18.B showed that a gas-fired conveyor warewasher would save a restaurant \$15,115 per year over a standard electric warewasher and \$5,118 per year over a more efficient electric warewasher with heat recovery.

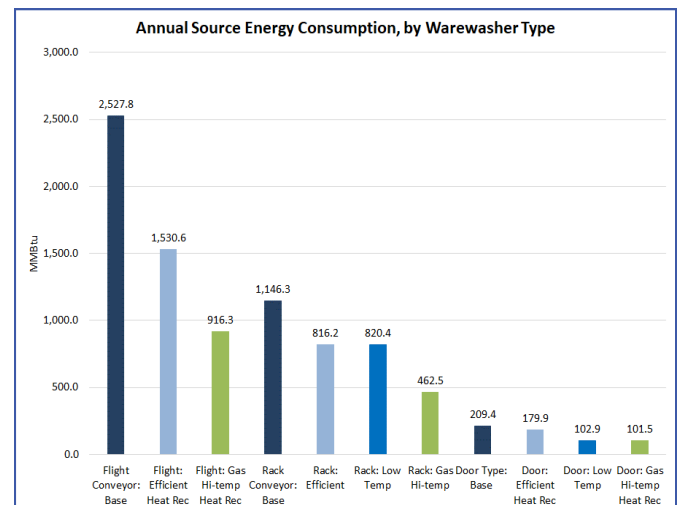
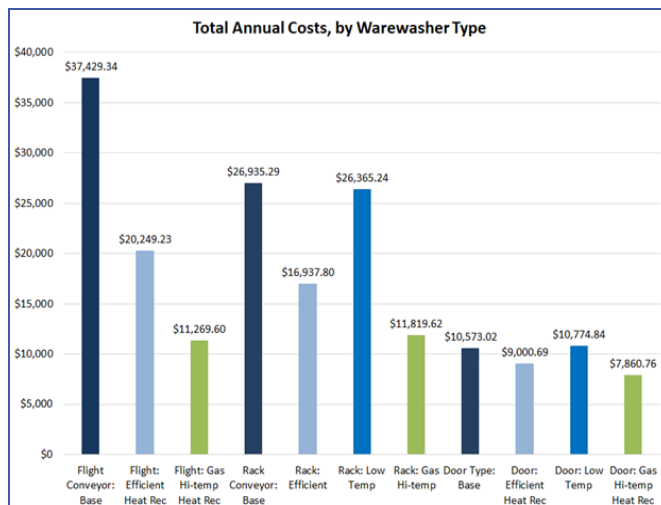
## Benefits / Market Implications

Warewashing equipment is a significant part of the commercial foodservice business, with global equipment capital costs estimated to be approximately \$4 billion per year. There are more than 100,000 conveyor-type warewashers in the U.S. alone. A reliable gas warewasher

## Technical Concept & Approach

In this project, researchers and a manufacturing partner are modifying current electric-driven warewashers as they develop prototype gas-fired warewashers.

Different heat exchanger designs are being modeled to



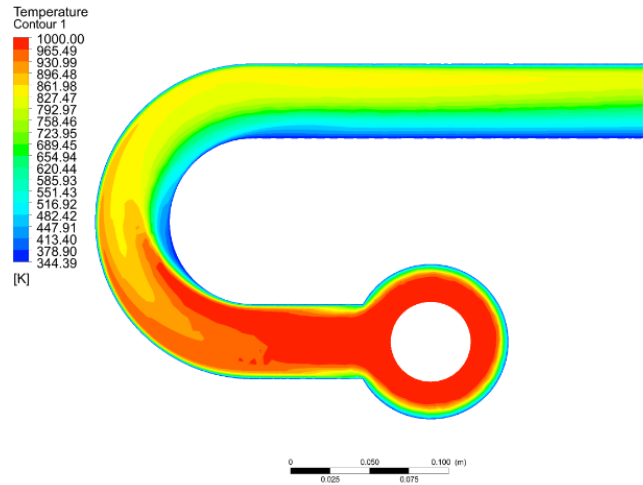


determine the best-performing designs that fit into the needed footprint of an existing electric warewasher. Prototype heat exchanger(s) will then be fabricated and put into prototype warewashers along with a burner and blower. The design will be tested and refined to continue to improve performance and address any issues that occur with initial testing.

Functional prototypes will be tested for combustion efficiency, safety, and emission standards. The results from testing will also assess improvements over electric units.

One prototype will be tested by a manufacturer partner in its facilities and one in a laboratory to prove the performance of the machine. The results will be used to finalize the design or any potential issues that may need to be resolved.

A field demonstration will be conducted at test sites. Test sites will be baseline-monitored for six months, followed by at least six months of monitoring the prototype gas-fired warewashers.



Example CFD model.

## Results

### Door Gas-Fired Warewasher

In 2020 and 2021, the project team continued to work closely with a manufacturing partner. Researchers modeled 13 variations of different heat-exchanger designs and tested the combustion system in the laboratory with the prototype warewasher tank and heat exchanger.

The project team developed some basic heat-exchanger designs that would fit into a given warewasher tank space. The main constraints were the small dimensions of the tank as well as avoiding contact with and allowing for access to the strainer.

Researchers investigated a variety of burner types to fit in the heat exchanger and provide the needed surface area for heat exchange. Two burners were provided, both of which performed well on emissions.

Technicians assembled the burner, blower, and gas valve assembly, along with a new control for the combustion system. Initial testing of the combustion system in the prototype heat exchanger was completed.

### Conveyor Gas-Fired Warewasher

Modeling was conducted to determine the heat-exchanger designs that could have the best performance in a conveyor warewasher. The team was able to test the real-world performance of this at an installation in the Chicago area to get actual performance data of the heat exchanger and burner. After some modifications, the test results did align with the expectations of the model.

## Status

Next steps in this project will involve demonstrating in coordination with the manufacturing partner the effectiveness, cost savings, and energy savings of gas-fired conveyor warewashers for end users at field test sites.

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## FOOD PREPARATION AND SERVICE

# Field Evaluation of Indoor Air Quality in Residential Kitchens



**Efforts are under way to determine the effect of cooking emissions on residential indoor air quality in a scientific manner in real-world situations through field evaluations. This project presents the opportunity to collect field data to differentiate emissions from cooking processes versus emissions from appliances.**

## Project Description

Some publications reporting on residential indoor air quality (IAQ) have suggested that emissions from cooking can negatively affect a home's air quality. Specific emphasis is sometimes put on combustion emissions instead of emissions produced from the food, whether cooked using electric or gas. This project will help address the need for scientific data to quantify the effects on IAQ from natural gas cooking, and collect real-world scientific data.

A field evaluation study of overall building performance on two geometrically twin multifamily buildings is being conducted in Chicago. The uniqueness of the location is that it represents one of the only buildings in North America that not only meets rigorous energy-design standards, but includes natural gas for cooking purposes.

This UTD project is using the unique ready-made field test project site to help quantify the effects on IAQ from natural gas cooking and collect scientific data.

## Benefits / Market Implications

This project presents the opportunity to collect field data to differentiate emissions from the cooking processes versus emissions from the appliance (gas and electric) in order to aid consumer understanding.

## Technical Concept & Approach

To determine the emissions attributed to cooking food versus emissions attributed to residential ranges, emissions testing is being conducted with gas ranges in 12 units (six direct-vent outdoor hoods in an ENERGY STAR building; six recirculating hoods in another building).

Researchers will evaluate trends in concentrations of various emissions, temperature, and humidity in the kitchen space during cooking with the gas range. Technicians will cook two of the same meals in at least eight of the 12 apartments in addition to the laboratory. Emissions among apartments will be analyzed.

In the second configuration, a select number of gas ranges will be replaced with electric-induction ranges. Emissions

testing will be conducted in the same manner as with gas ranges.

Energy consumption data on the heat pump space conditioning systems that are already installed will also be collected.

Specific tasks include:

- **Site and Instrumentation Preparation**

The project team prepared an information guide for tenants, site agreements, pre- and post-tenant surveys, a survey of existing instrumentation, and specifications for sensors.

- **Installation and Commissioning**

All IAQ instrumentation was installed. Cooking event log/surrogate will also be installed prior to commissioning.



*Frying Bacon and Eggs on a Gas Range Top in the ENERGY STAR Residential Unit with a Direct Vent Range Hood*



*IAQ sensor installed in kitchen with an energy-recovery ventilator.*

#### • Field Test

The project team is providing on-site monitoring and troubleshooting. Complementary support from a testing laboratory will be provided to ensure consistent cooking in housing units by providing same-ingredient meals.

#### • Data Analysis and Reporting

Preliminary analyses will include general trends and correlations. Results will compare cooking emissions from gas and electric residential ranges.

Project participants include a researcher from a leading university.

## Results

The IAQ sensor packages and range cooking-location sensors gathered gas and particulate measurements from six kitchens in ENERGY STAR units and six Phius-occupied units. (Phius is non-profit organization committed to decarbonization.) The gas and particulate data are being analyzed during cook events and non-cooking periods. Re-

searchers are comparing ventilation strategies based on gas and particulate measurements between the direct-vent range hood in the ENERGY STAR units and the recirculating hood and heat-recovery ventilator in the other units.

A variety of food products – including bacon, eggs, pasta, and chicken nuggets – were cooked in an apartment to evaluate the hood performance and IAQ effects. The apartment was constructed to Phius energy standards. The cooking processes included pan frying, boiling, and baking. Foods were cooked on both the gas range and induction hob. A recirculating range hood and an energy-recovery ventilation system was operating in the apartment used for the IAQ cooking evaluation.

The team has completed analysis of:

- 1-second gas and particulate measurement data during the natural gas and induction cooking events and non-cooking periods in the ENERGY STAR and PHIUS buildings
- IAQ sensor data for NO<sub>2</sub>, CO<sub>2</sub>, CO, RH, TVOC, PM<sub>2.5</sub> and Formaldehyde during ambient and background conditions
- IAQ sensor data during cooking tests conducted in apartments and comparing ambient, background conditions.
- Time weighted averages
- Ventilation strategies between the direct vent range hood in the Energy Star units and the recirculating hood and heat recovery ventilator in the PHIUS units

For Phase 2, the team sourced and purchased typical residential range hoods, both direct vent and recirculating, reviewed current residential hood performance standards and performance test methods, and characterized typical hood airflow measurements. The team is in the process of measuring performance characteristics of the baseline hood such as airflow rates and capture and containment effectiveness.

## Status

The Final Report for Phase 1 was submitted to UTD members in December 2023. The project team will continue measuring performance characteristics of the baseline hood such as airflow rates and capture and containment effectiveness, and work with the Association of Home Appliance Manufacturers (AHAM) to choose the best-in-class hood for Phase 2.

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## Technical Support to Address Gas Foodservice Technologies



**This project provides technical support and assistance to commercial foodservice industry groups and manufacturers to make advancements so that end users can increase energy efficiency, decarbonize, reduce emissions, and enhance cooking performance.**

### Project Description

The majority of appliances used in the projected \$900 billion North American commercial foodservice (CFS) industry use natural gas as the main fuel source. Compared to other commercial products, CFS has traditionally had fewer regulations in terms of efficiency, emissions, and other operational requirements. However, with the push for more efficient technology, improved emissions (especially in California) and decarbonization, newer regulations are being developed and implemented. Concerns with new regulations and misinformation about the performance of gas-fired units compared with electric units resulted in many CFS locations deciding to purchase electric equipment. In some cases, the advantages of the electric equipment justify its use, but in most cases gas fired would still have the advantage in terms of cooking performance and energy costs.

Energy-efficient options for most categories of cooking equipment are currently available; however, the industry has been reluctant to adopt new technologies. CFS owners and operators have traditionally been hesitant to replace functioning equipment or buy new efficient equipment because of first costs and concerns that the new equipment will not cook to the same quality as the current equipment. The main issue is that end users do not have information readily available de-

tailoring the long-term savings vs. the initial costs of more energy-efficient equipment and have not had a chance to observe and compare the cooking performance. Post COVID recovery of the industry has also resulted in the sales of cheaper less efficient equipment to increase because of the initial cost savings.

For previous projects similar in scope to this one, the project team attended meetings or served on committees that addressed over 40 issues associated with CFS equipment, including NOx emissions in California, gas vs. electric cost for a CFS fryer for two chain accounts, data protocols for CFS, and meetings with various trade organizations and industry groups.

More than a dozen cooking demonstrations were conducted at conferences and other industry events. At the events, information on the energy and cost savings of efficient gas equipment was conveyed to consumers using the CFS tools and calculators developed with funding from the UTD.

This project provides technical support and assistance to CFS groups and manufacturers to make advancements related to energy efficiency, environmental impact, decarbonization, cooking performance, and COVID recovery.

Project representatives represent gas ratepayer interests by assisting in consensus-development efforts within technical advisory committees, including ASTM F26 for commercial foodservice, the North American Association of Food Equipment Manufacturers (NAFEM) Technical Advisory Committee, ASHRAE CFS Ventilation, and the Blue Flame Alliance Technical Advisory Committee. Technical information that helps CFS manufacturers meet California's low-NOx requirements will be provided.

The project team will also work with CFS manufacturers and end users to provide data and education on the benefits of developing and adopting efficient, low-emission gas appliances.

### Benefits / Market Implications

CFS is a large market with sales of about \$900 billion in North America before COVID. Post COVID projections show



*Cooking demonstration at Louisiana Restaurant Expo of energy-efficient CFS Applications.*



the industry is expected to recover and grow at a rate greater than 5% for next several years. This growth is significantly ahead of most other commercial industries. The National Restaurant Association also projects total employment grow to over 16.9 million by 2029.

Of the approximate nine million commercial cooking appliances installed and operating in North America, roughly 70% are powered by natural gas (in categories where there are gas and electric options), with an estimated five billion therms of natural gas consumed annually. This large customer base needs accurate information about equipment performance, impacts, rules, regulations, and other topics related to energy selection.

## Technical Concept & Approach

The following tasks are being performed:

- **Technical Assistance to CFS Industry**

In this task, a project team provides scientific and technical information to support technical committees as they consider changes to existing or new standards and methods of test relevant to CFS equipment design and use. Focus areas include decarbonization and NOx emissions.

- **CFS Consumer Education and Outreach**

Researchers demonstrate the value of efficient, clean-burning gas-fired cooking equipment and promote advanced CFS equipment by providing data using the CFS tools and calculators developed in previous UTD projects and also by developing new calculators.

- **Technical Assistance to CFS Manufacturers**

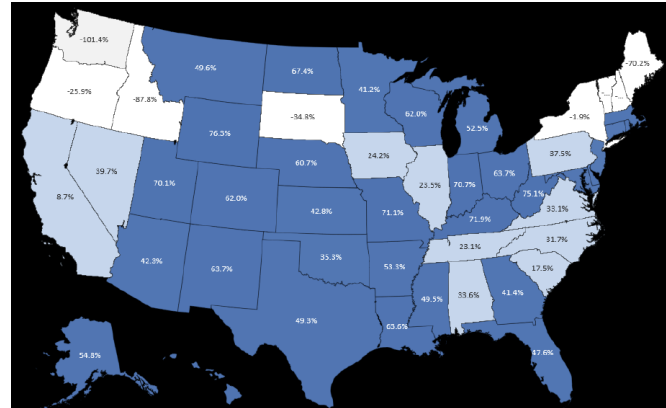
The project team assists manufacturers with addressing technical issues related to gas burner design and operation. This includes complying with pending NOx and efficiency standards, specifically distributing information on testing procedures and required testing equipment.

## Results

In 2023, the project team provided technical support and/or expertise to organizations including NAFEM, Blue Flame Alliance, and a major gas utility. The team also met with a residential range manufacturer to discuss technology issues with current designs for burners in residential ranges.

A project representative led the Fuels Group in NAFEM's Technical Liaison Committee. The group presents and discusses energy usage and supply issues with CFS manufacturers and other energy-related organizations.

The project team has provided information to the gas industry



Percent Difference in Annual CO2e Emissions (efficient gas compared to electric; example output from <http://cfscalc.gastechnology.org/>)

about the use of hydrogen in CFS and how CFS industry is changing post pandemic. One of the biggest changes in the industry has been increased consolidation of CFS equipment manufacturers due to acquisitions of competing OEMs. The project team conducted several webinars on indoor air-quality issues with residential cooking.

An existing tools and calculators website is being modified to have a new user interface including highlighting decarbonization calculations (<http://cfscalc.gastechnology.org/>).

In 2023 the team helped inform technical issues by continuing to serve as the chair of the Fuels committee for NAFEM, supplying information and data for developing energy efficiency measures for range tops in California, and providing information and expertise on potential NOx emissions rules at the state level.

The team worked with various manufacturers on concerns ranging from resolving issues with a stove burning a mix of gas and hydrogen, providing information on past projects and discuss involvement in upcoming projects, evaluating and providing recommendations on issues with a gas fryer.

## Status

The project team released a Final Report for Phase 2 to UTD members in July 2023. Phase 3 is currently in progress, with activities such as providing technical support to NAFEM's Technical Liaison Committee and the ASTM F26 committee.

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# CFS Burner Technology Carbon Reduction Including Hydrogen Blending

**Efforts are under way to determine the potential decarbonization of typical CFS appliances using improved burner technologies, enhanced control systems, and blending natural gas with hydrogen on existing CFS appliances in a laboratory setting.**



## Project Description

Because commercial foodservice (CFS) has lagged in terms of technological advancement, it presents several challenges when considering using fuels blended with hydrogen.

While controls, construction materials, and insulation have improved in the CFS industry, most burner designs have varied little over the past decades and are atmospheric stamped metal or cast iron with drilled ports. Previous efforts by manufacturers to improve the cooking characteristics of these burners typically focused on modifying the existing designs by changing the configuration of the burner ports or the air-to-fuel ratio and not by investing in advanced combustion technology. This lack of advanced technology makes CFS appliance less tolerant to changes in the fuel content. There is also concern that changing fuel content will change the cooking performance of the appliance. This includes inconsistent crust color on breads, over or under cooking of fried foods, and inconsistent cook times on other products. Most food in quick-service restaurants is cooked using timers and are not being watched by employees.

Efficiency gains and improved emissions have been limited in CFS due to issues with the willingness of owners and operators to pay a premium for units with advanced combustion systems. The result is that most gas-fired CFS appliances use relatively simple, old, and inexpensive technology. These older technologies are less likely to operate correctly if the content of energy source is changed. A previous study showed that several appliances (including some high-efficiency appliances) were incapable of safe operation when the heat content of the natural was increased due to the addition of liquefied natural gas (LNG). Hydrogen represents another issue because the increase in flame speed is likely

to cause flashback on many of the older CFS burner technologies. Also, changes in flame appearance will cause concern among restaurant operators, even if the flame is still safe.

Because of these issues, the objective of this project is to determine the potential decarbonization of typical CFS appliances using natural gas blended with hydrogen and using improved burner technologies and enhanced control systems. Specific topics being addressed include energy-reduction technologies and controls, including burner modulation.

## Benefits / Market Implications

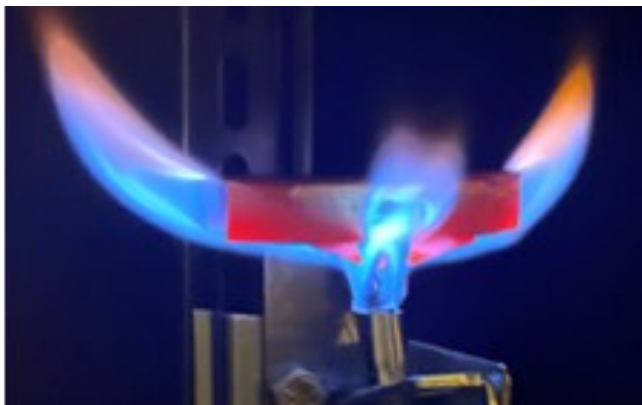
CFS is a large market with sales of about \$900 billion before COVID. Post COVID projections show the industry is expected to recover and grow at a rate greater than 5% for next several years. This growth is significantly ahead of most other commercial industries. The National Restaurant Association also projects total employment growth to over 16.9 million by 2029.

Of the approximately nine million commercial cooking appliances installed and operating in North America, roughly 70% are powered by gas (in categories where there are gas and electric options), with an estimated five billion therms of natural gas consumed annually. Increasing the amount of hydrogen blended into natural gas will retain end-users options for gaseous fuels and customer choice while increasing decarbonization.

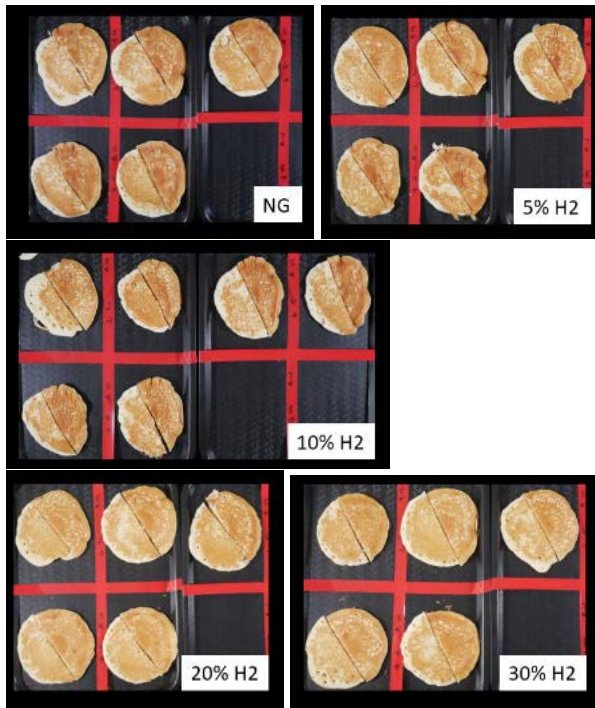
This project will help the industry determine the potential for improved burner technologies, control systems, and blending with hydrogen in CFS appliances.

## Technical Concept & Approach

A research team will test an existing stock of CFS burners using a range of natural gas mixtures blended with hydrogen (0%-30%). The burners will be tested for combustion emissions and flame appearance. A determination will be made on the compatibility of each burner to the different blends of up to 30% hydrogen, as was done in previous interchangeability studies. Specifically, researchers are looking to see if the cooking performance changes such that it would not be acceptable to end users. Safety issues (e.g., such as carbon monoxide emissions and flashback) will also be investigated.



*Fryer pilot light using 100% natural gas.*



*Pancake Comparison*

The goal is to determine the level of decarbonization that can be achieved for a standard-efficiency CFS appliance by using advanced burner technology and improved burner controls. A standard appliance will be baseline tested for efficiency and combustion emissions and then updated with new technology and retested for comparison to the baseline.

The deliverable for this project will be a report with data and calculations for the decarbonization of CFS appliances using hydrogen blending and advance burner and control systems. The results will show if hydrogen blending of up to 30% will have a negative impact on performance and safety.

Key performance indicators to measure the success of this project will include:

- Efficiency and emissions data for a variety of stock CFS appliance burners when operating on 0%-30% hydrogen blended with natural gas, including changes in cooking efficiency and emissions
- Initial recommendations for relevant limits on hydrogen for a spectrum of stock CFS appliances based on measured changes in cooking performance, emissions, and safety based on existing standards
- An assessment of the potential of some possible near-term modifications (e.g., controls) to increase allowable hydrogen content, and
- The development of energy-savings and decarbonization calculations for current N.A. appliance populations.

This project builds upon earlier research to assess the interchangeability of domestic natural gas with imported LNG.

Phase 2 and 3 of this project focuses on determining if using blends of hydrogen have an affect on the cooking performance including the quality and quantity of food prepared. Common CFS appliances are being tested and images of the food prepared compared to determine if changes occur.

## Results

Of the 13 CFS burners that were tested, flash back and flame appearance do not appear to be an issue for blends of natural gas and hydrogen of up to 30% for the burner types tested. Flashback did not occur during testing for any of the test conditions except for the stock pot burner. This incident was the function of how the burner was shut off and not of the addition of hydrogen to the fuel mix. The appearance of the flame did not significantly change with the addition of up to 30% hydrogen to the fuel mix and would unlikely be noticed by operators.

Burner emissions of CO and NOx were shown to be more affected by changes in firing rate than the percentage of hydrogen in the fuel. Typically, the values were within the same ranges for each percent of hydrogen. The only exceptions were CO for the fryer and NOx for the Infrared burner where both slightly, but consistently decreased with an increase in the percentage in hydrogen.

In order to test combustion and cooking performance, the team developed a method to conduct performance tests by cooking pancakes on a range top. The tests are designed to compare the appearance of the food that was cooked using the different blends of natural gas and hydrogen. The team also tested French fries in a standard commercial fryer and will be testing a charboiler and griddle. The images show the results for the range (pancakes) and fryer (fries and hash brown) tests. The pancakes were noticeably lighter in color as the percent of blended hydrogen increased, raising concerns that operators would notice the change in gas content. The fries and hash brown were not noticeably different. A color mapping method to compare the doneness of the cooked products is also being developed.

## Status

The Final Report for Phase 1 has been released to UTD members. The team is currently comparing results for the range and fryer and preparing for testing of the charbroiler and griddle.

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## CLEAN TRANSPORTATION

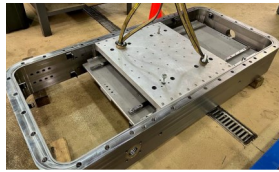






## CLEAN TRANSPORTATION

# Cost-Effective CNG/GH2 Pre-Cooling Technologies



**A research team is developing an innovative, cost-effective system to pre-cool compressed natural gas (CNG) or hydrogen prior to it being dispensed into a vehicle. Pre-cooling will enable full fills and extend operating range, improve user experience, and effectively reduce the volume, weight, and cost of on-board storage tanks.**

## Project Description

Compressing gas into a compressed natural gas (CNG) or gaseous hydrogen (GH2) fuel storage tank causes a significant temperature increase, resulting in the pressure limit being reached prior to transferring the total mass that defines a full fill. Pre-cooling the gas before it enters the vehicle is essential to achieve consistent full fills under most fueling and ambient conditions.

Research has been ongoing to improve full fills by developing improved dispenser algorithms, investigating vehicle-to-dispenser communication, and analyzing pre-cooling systems. These activities have concluded that some form of pre-cooling is necessary to guarantee a full fill.

The most obvious method for pre-cooling is to use a vapor-compression chiller to cool the gas being delivered to the vehicle. This method is being used for some virtual pipeline filling stations but is too expensive for most CNG vehicle filling stations. Alternatively, existing CNG compressors could be used to drive a Joule-Thomson cooling loop that is used to store cooling capacity between vehicle fills, and then use that cooling capacity to pre-cool the CNG going into the vehicles during a fill. This strategy can reduce capital cost since it uses existing CNG station equipment, but will add run time, complexity, and maintenance cost to the CNG compressor; operating costs will also increase.

It is also possible to use a turbo-expander or similar device to pull energy out of the gas as it flows into the vehicle. An expander causes the gas to get colder than it would with Joule-Thomson cooling, allowing more gas to enter the vehicle before the pressure limit is reached. Expanders show the most promise since they do not require additional input energy to achieve the desired pre-cooling, but conventional radial expanders would need to be custom-designed for the high pressures required for CNG or compressed GH2 storage and would likely be difficult to operate over the necessarily-wide range of pressure ratios.

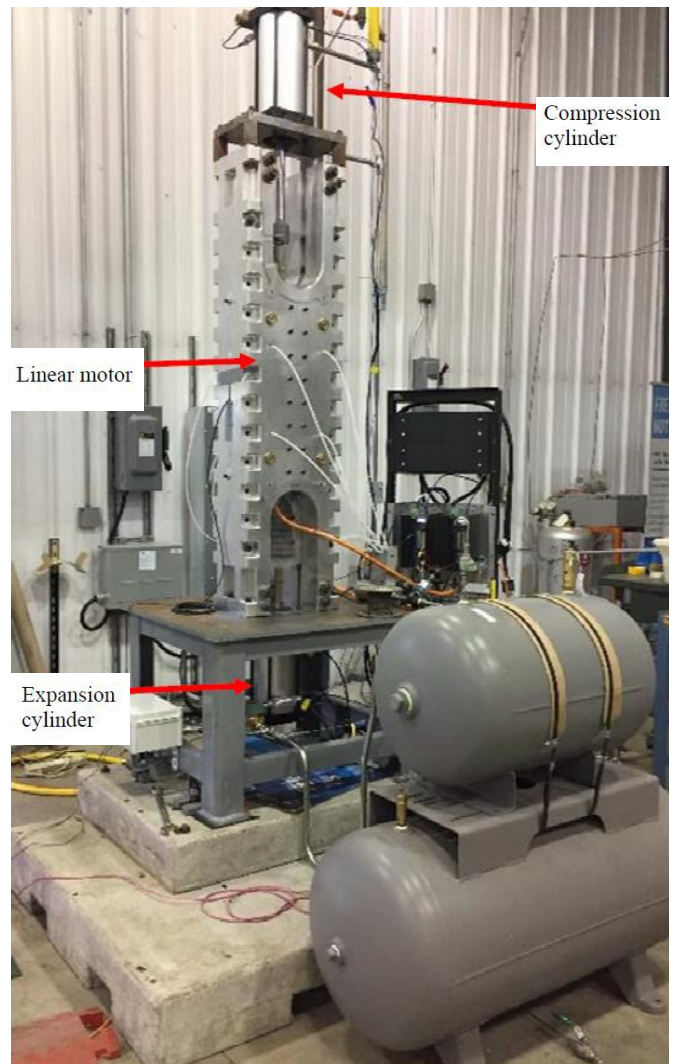
The objective for this project is to design, build, and demonstrate in a laboratory a prototype of a novel linear piston expander to pre-cool CNG or compressed hydrogen, in order to achieve full fills of gaseous fueled vehicles and thus increase effective storage capacity by 20%-25%.

This UTD project is providing co-funding to a significant

prime contract funding award from the U.S. Department of Energy.

## Benefits / Market Implications

The issue of under-filling directly impacts the volume of storage required on a vehicle. By providing consistent full fills, a vehicle requires a smaller fuel system, reducing the cost and weight of the vehicle's CNG or hydrogen cylinders. This improves the vehicle's range, economics, and the user experience.



*Early prototype linear expander in laboratory test.*

The use of pre-cooling would improve the quality of the fueling procedure since the gas temperature would be controlled by the station and would have less variability than occurs in existing fueling stations. This technology can provide significant potential benefits to economically fill zero-tailpipe-emission, gaseous-hydrogen-fueled vehicles, for which market interest is rapidly growing.

## Technical Concept & Approach

The project team will perform a preliminary design analysis of a novel expander for pre-cooling CNG. The design will include detailed models, simulation, and schematics of the selected technology that estimate the expected cooling performance and how much it impacts CNG full fills, as well as the estimated capital and operating cost of the technology in a simulated station. Based on the optimized design, a complete working prototype will then be fabricated and tested under simulated operating conditions.

## Results

The project team developed a design for the free piston expander that will remove energy from the CNG and hydrogen and reject that energy as heat. In the future that energy could be converted to power that can be used to reduce the cost of operating the fueling station.

A simulation of the free piston expander was completed to better estimate the performance of the system. The simulation optimized stroke, frequency, and other relevant design parameters. The initial goal was to simulate an "ideal" expansion cycle at nearly 100% efficiency, and then start adding system losses into the simulation to accurately represent the real-world expander performance. The simulation determined how the expander attributes such as stroke length and piston diameter impact the efficiency.

The simulation also allowed the team to finalize the expander geometry and components. The project team developed custom valves that can be actuated by the expander piston. However, commercial valves were later identified and used to test the expander operation. The custom valves are still being actively considered, but the commercial valves reduced some of the risk associated with the prototype development.

The project team completed the design, fabrication, and assembly of the prototype expander. The expander was initially tested with nitrogen up to about 12,000 psi to test the controls and operation of the design. During operation, several operational issues were identified and corrected. This included inconsistent signals from the encoder which required the expander to be partially disassembled to correct.

Following the successful completion of the nitrogen testing, the team switched to 12,000 psi hydrogen testing before switching again to CNG testing. In preparation for the switch to hydrogen, helium was used to verify that the seals were working properly and that no hydrogen would enter the motor



*Fabricated expander currently being tested in laboratory.*

housing. This was done by pressurizing the fluid ends using helium and then taking gas samples from the motor housing and looking for the presence of helium using a gas chromatograph.

Following the validation that the seals were working as intended, the expander was tested with hydrogen at pressures up to 12,000 psi. The team consistently achieved thermal efficiencies around 70% and believes this could be improved to 80-85% with some relatively simple modifications to the design. The expander is also producing power at about 50-60% efficiency which can be used to offset some of the power consumed by CNG or hydrogen compressors at fueling stations.

The team is now in the process of testing the expander with natural gas. Efficiencies are lower than with hydrogen, at around 40%. However, this is not completely unexpected since the design was optimized for both hydrogen and CNG fueling, which led to some compromises for either fluid service. The team believes that the CNG performance can also be significantly improved by optimizing seals, valves, and the piston geometry. However, this will not be tested under the current scope. Overall, the results look very promising, and the project team believes that the expander development was a success in that it is the first of a kind design that is operating at these pressures and efficiencies, while also adjusting in real time to variable expansion ratios as a vehicle cylinder is filled from stationary ground storage.

## Status

The project team is finalizing testing with natural gas, and then will release the final report. Next steps to advance and commercialize this technology are being explored, such as seeking additional funding to install a prototype linear expander at a working CNG or compressed H2 fueling station.

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## CNG Dispenser – Tank Communication

**Researchers are designing, building, and demonstrating a prototype compressed natural gas (CNG) station that includes a smart CNG dispenser and a smart natural gas vehicle (NGV). Pre-commercial prototype hardware and protocols are being designed to enable the vehicle and station to communicate about the vehicle's fuel system to deliver safer, fuller fills for end users.**



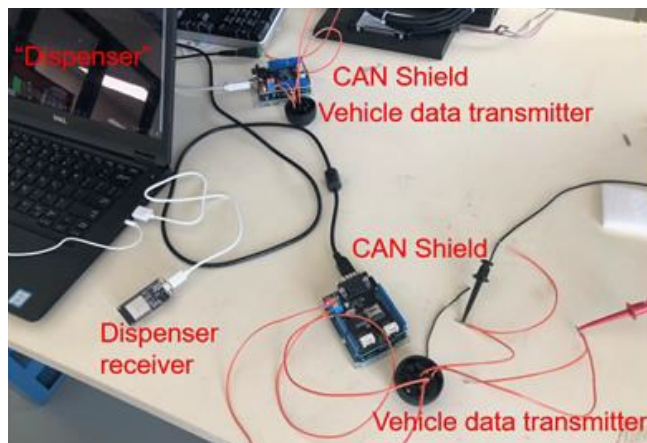
### Project Description

Research is under way to improve natural-gas-vehicle (NGV) full fills using a multi-tiered approach. This includes the development of an improved dispenser algorithm, establishing vehicle-to-dispenser communications, and an investigation into various pre-cooling technologies. Improvements in all three areas are necessary to deliver a full fill.

Pre-cooling has been receiving more attention lately as fleets become aware of under-filling drawbacks. While it is simple (although expensive) to add a pre-cooling loop into the fueling process, over-filling of storage systems can occur if the algorithm does not account for the below-ambient gas temperature and pre-cooling alone will not ensure that the vehicle is filled accurately or safely. Earlier UTD-funded research developed an advanced full-fill algorithm that was shown to accurately fill vehicles to nearly 100% full across a range of test conditions; however, that algorithm requires information about the vehicle's real-time pressure and temperature and pre-cooling is necessary to achieve full fills on warm days. A means for communicating the vehicle's real-time pressure and temperature is needed.

Development of a smart compressed natural gas (CNG) dispenser and vehicle would enable vehicle sensors to transmit temperature and pressure to the CNG dispenser. This system could also be programmed with the age and volume of the vehicle's CNG cylinders, improving accuracy and safety of the fill and effectively reducing operating costs.

In summary the objective of this project is to design, build,



*Smart dispenser components being bench tested.*

and demonstrate a prototype CNG station that includes a smart CNG dispenser and a smart NGV. A project team will develop pre-commercial prototype hardware and protocols to enable a vehicle and station to communicate information about the vehicle's fuel system. This information will allow safer, fuller fills while also enabling fleets to more accurately track their vehicle's fuel consumption. Low-cost, off-the-shelf data transmission hardware will be used to guarantee that NGVs safely and consistently receive the maximum amount of gas possible during every filling event. By maximizing the volume of gas received, the volume of the NGV fuel system can be minimized, thus saving cost and weight of the vehicle.

This UTD project is co-funding a \$2.6 million smart CNG station research project award from the U.S. Department of Energy's National Renewable Energy Laboratory. UTD's project partners also include CSA Group, a leading CNG tank and fuel system provider, and a major concrete supply company as the end-user host site.

### Benefits / Market Implications

Improving full fills using communications can lower the cost of an NGV by up to 10%. The lower cost per vehicle reduces the risk of adoption for fleets considering CNG and reduces costs for end users.

Active communication will also improve the safety of a CNG fill. Testing of existing algorithms demonstrated that it is unlikely, but possible, to over-fill a vehicle. Using communications, researchers developed a filling algorithm that should never result in an over-filled vehicle.

The primary target market impacted will be NGVs with a focus on heavy-duty trucks. Secondary applications may include for example virtual pipeline gas transport, locomotives, and some marine ferries. While the core technology being developed in this project will be demonstrated for CNG applications, it is expected to be transferrable and also benefit achieving full fills of vehicles fueled with gaseous hydrogen (GH<sub>2</sub>).





*Smart dispenser components being tested with storage.*

## Technical Concept & Approach

Tasks for this project are to develop and validate wireless connection protocol, develop CSA standard with stakeholder input, and build and test smart dispenser and vehicle. Project efforts are being coordinated with the work under way in UTD project 2.20.G.

## Results

The project team finalized the design of a pre-commercial smart vehicle data-acquisition and wireless communication system to install on CNG vehicles. Researchers completed bench-scale development of a smart dispenser module that can communicate with the smart vehicle to improve full fills.

One data logger connected to the vehicle fuel system recorded the vehicle's pressure and temperature, adding the measured data to the CAN Bus data and then broadcasting everything to the cloud over a cellular connection while also broadcasting over WiFi for local devices. The cloud storage allowed the team to monitor the vehicle's fuel consumption and fill quality during real driving cycles. The local WiFi allowed the vehicle to communicate data with local devices such as the smart dispenser being developed.

The dispenser and smart module shared information from the smart module to control the dispenser's fill logic when a smart vehicle was identified. The team also developed a connection protocol that will ensure the correct CNG vehicle is always identified. If the system is unable to identify the vehicle, then the system will revert to a standard CNG fill.

Project researchers also supported efforts by CSA Group NGV 4.3 Committee to incorporate language related to pre-cooling and communications to enable improved fills into the tests for certifying dispensers.

In 2021, with the development of the data-collection system and the start of a smart CNG module, the demonstration of a smart vehicle and dispenser was initiated. Once the smart dispenser module was complete, research began to integrate the module with a dispenser. Efforts were made to determine the capabilities and limitations of controllers and if they are suitable for the short-term and long-term needs of the application.

In 2022, the project team completed the bench scale development of a smart dispenser module that can communicate with the smart vehicle to improve full fills. The team installed the bench scale system in a test cell for testing during CNG fills.

In 2023, data loggers were fully installed on the concrete mixer trucks. Data was received and the team developed automated data processing software to organize and analyze the large volumes of data being received. The smart dispenser module has been installed in a laboratory test cell and is connecting to the CNG cylinders and transmitting that data to a LabVIEW dispenser.

The team developed a modified version of the smart dispenser module that will interface with multiple dispensers at a single station from a central processing point. This device can also manage time fill stations and process vehicle data as vehicles enter the station. No new hardware is required inside the dispenser, just a modbus connection.

The smart controller was tested using simulated data from multiple CNG fills. The controller was able to positively identify the connected vehicle for each dispenser. These simulated fills are a good indicator that the controller will work when connected to the actual CNG dispenser. The team tested communication with a commercial CNG dispenser. The team is able to monitor the dispenser variables using Modbus communication.

The commercial CNG dispenser was installed into a laboratory environmental chamber and the team conducted test fills to validate that smart hardware can communicate with the CNG dispenser. This has been verified and the team can see real time dispenser data.

## Status

The team is editing and refining control code that enables the vehicle and dispenser to be matched. Final testing of smart components is underway and the project is expected to conclude in 2024.

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# Next-Generation NGV Driver Information System



**This research project is developing and demonstrating a next-generation NGV driver information system to provide an accurate miles-to-empty estimate for the vehicle. By increasing confidence in the fuel gauge, excess fuel storage capacity can be reduced and the cost of the fuel system can be lowered by as much as 20%.**

## Project Description

Maximizing the fuel used in onboard storage is a well-identified impediment to greater adoption of natural gas vehicles (NGV), and similar challenges will apply to vehicles fueled by compressed hydrogen. The U.S. Department of Energy's (DOE) Clean Cities program performed a nationwide survey of NGV drivers, and unreliable fuel gauges were a consistently mentioned deterrent to adoption due to causing range anxiety, frequent and unnecessary fueling stops, reduced driver productivity, and disrupted workflow for the fleet operator.

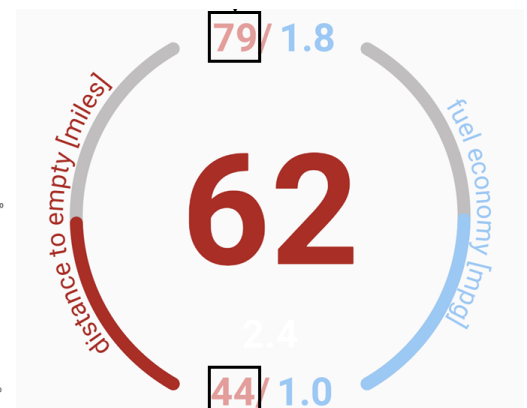
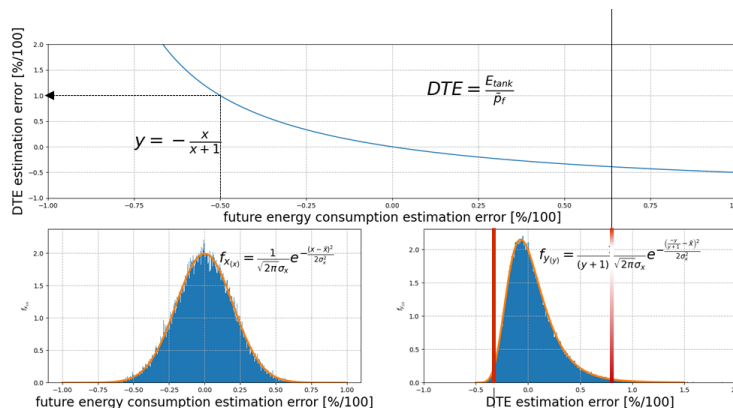
The goal of this project is to provide the NGV driver with an accurate estimate of the distance the vehicle can travel with the fuel left on board, which is a crucial piece of the driver's information system. While often simplified to a pressure measurement, large variations in gaseous fuel pressure can occur due to large swings in temperature. During fueling, the gas in the tank heats up to as high as 185°F, which can provide a premature "full" indication. As the gas cools down, the pressure drops sharply, giving the appearance that a full tank leaving the fueling station has drained very quickly. The gas in the tank also expands and cools as fuel is consumed (to temperatures as low as 80°F below ambient temperature), which further reduces tank pressure and leads the driver to mistakenly believe that the tank is almost empty. In summary this project will demonstrate how additional information such as the fuel consumption rate of the vehicle in various driving situations (traffic, weather, terrain, etc.), knowledge of the route to be followed, and storage tank performance can be used to provide an accurate miles-to-empty estimate for the driver in real-world applications.

UTD is partnering with the DOE on this effort by providing co-funding to a major research contract with prime funding provided by the DOE. Other project team members include Argonne National Laboratory (ANL) and a leading concrete delivery supplier.

## Benefits / Market Implications

Heavy-duty NGVs (Class 8-10 trucks) and vehicles fueled by compressed hydrogen will benefit the most from an advanced driver information system due to the larger savings in fuel-system size and cost. Medium- and light-duty NGVs can also benefit. Market entry, however, will focus on the large existing fleet of heavy-duty fleet NGVs.

The benefits of an improved NGV driver information system will depend upon the driver's risk tolerance and driving behavior, but discussions with vehicle drivers indicate that they typically return for fueling when their vehicle tanks are 20%-40% full. Decreasing this remaining fuel reading to below 10% would result in significant savings in fuel-system costs, driver productivity, and fueling efficiency. NGV fuel systems are typically oversized due to concerns about achieving a full fill and range-anxiety issues. By increasing confidence in the fuel gauge reading, the vehicle fuel capacity can be reduced, lowering the cost of the fuel system by as much as 20%. The productivity of the driver can increase as the truck would make fewer trips to refuel, and fewer refueling trips will lower emissions and save energy.



*The information system output will include an upper and lower bound of expected range based on historical truck operation. This display concept was adapted from common displays for electric and hybrid vehicles which also have a high variation of expected range based on driving behavior.*

## Technical Concept & Approach

### • Data Collection and Application Development

Instrument a fleet of vehicles to collect compressed natural gas temperature and pressure data during filling events and regular operation. Combine this data with data from controlled laboratory testing to enable development and validation of a thermodynamic model to estimate the usable fuel status of a vehicle's fuel system at any given time. Equip the fleet vehicles with data-acquisition systems that transmit data via a cellular modem. Conduct laboratory testing that includes controlled-rate tank de-fueling to measure temperature and pressure behavior. Use this temperature/pressure behavior to determine the relationship between measured parameters and the amount of usable fuel remaining in the fuel system.

Develop a more accurate miles-to-empty prediction method and integrate it into previously developed fleet-management software, which already contains information about routes and duty cycles. From this estimate, the dispatch center can determine if a refueling stop will be necessary, determine if changes to vehicle routes could improve fleet performance, and evaluate driver performance for maximum efficiency.

### • Application Validation and Deployment

Validate models using laboratory data to ensure proper operation of all data collection and transfer systems. Use data from fleet vehicles to validate the thermodynamic model in the field.

### • Performance Monitoring, Improvement, and Knowledge Transfer

Compare NGV fuel gauge predictions to driver reports and operating data gathered from the data-acquisition systems on the vehicles. Solicit driver feedback to evaluate the perception of system accuracy and identify changes in driver behavior. Approach potential commercialization partners.

## Results

In 2020, an analytical model was built to calculate the gas remaining in the fuel tank based on tank pressure and temperature – with accuracy >95% for a wide range of gas compositions between -60°F and 140°F.

In 2021, data-acquisition systems were installed on all 12 trucks participating in this program, including sensors to measure internal tank temperature and pressure. The collected data was used to validate and improve the calculation of remaining fuel on board the vehicle. The upload speed and time intervals of the data loggers were adjusted to ensure the loggers can successfully upload all information in the allotted

time. These modifications were applied to all new logger units. Calculation of the remaining fuel on board the vehicle was finalized.

In 2022, a data visualization tool was completed and beta-tested. This tool uses cellular phones with customized cases installed by ANL that allow display of only desired information and prevent their use as phones. Researchers found that the driver information display needs to include an upper and lower bound for range in addition to the central estimated value, due to the variability observed in the vehicle duty cycle. Because the test vehicles are concrete trucks the duty cycle varies with large amounts of time spent idling, the energy used to turn the drum, and driving differences between urban and rural environments.

Fuel gauge displays were installed on eight concrete delivery trucks. The fuel gauges use data from the sensors installed on the vehicle as well as engine data (distance traveled and fuel mass flow rate). Distance-to-empty is predicted using readings from these sensors combined with operating history data. This distance-to-empty calculation has been validated to be accurate within the upper and lower bounds displayed. The prediction does not require any knowledge of the fuel system size or gas composition; this information is calculated on a per-vehicle basis each day the vehicle is operated.

A custom end plug incorporating an in-cylinder temperature sensor was designed. This will enable the temperature data to be uploaded through the CAN system without requiring an expensive data acquisition unit. This information will then be picked up by the fleet dispatch software and calculations completed in a cloud server to display the relevant information.

Meetings were held with the concrete delivery company, their drivers, and representatives of their dispatch system supplier to discuss how the new fuel gauge and data will be integrated with their truck monitoring software, how this could be utilized to improve truck efficiency and driver habits, and to incorporate their feedback.

## Status

Next steps for the team will be to: collect additional data on functionality and reliability of the fuel gauge systems; work with the concrete delivery company and its supplier to incorporate the distance-to-empty calculation into its dispatch system; finalize end plug design for commercial applications; and prepare a technical paper for submittal to an industry journal and further explore commercialization options.

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## Smart CNG Station Field Demonstration

**A novel CNG fueling system is being developed to increase the utilization of the onboard CNG storage capacity by 10%-25%. The smart fueling system will use improved sensors and algorithms to provide consistent full fills, resulting in up to 25% lower capital cost for fuel storage. The technology could likewise benefit compressed H2 fueling stations.**



### Project Description

A “smart” compressed natural gas (CNG) fueling system is being developed that will increase the utilization of onboard CNG storage capacity by 10%-25% compared to current practices and provide substantial savings to end users. The smart CNG fueling system will use improved sensors and algorithms to provide consistent full fills, resulting in up to 25% lower capital cost for fuel storage on natural gas vehicles (NGVs). While currently focused on CNG applications, if successful the innovations in this project could also greatly benefit compressed hydrogen fueling stations.

CNG vehicles are often under-filled because the gas heats up and expands during the filling process; 20%-25% under-filling is frequently cited by fleets and industry experts. This is further supported by the fact that commercial fuel systems are nominally designed 30% larger than the “usable” fuel capacity quoted by the manufacturer. On many heavy-duty CNG vehicles, adding 30% extra storage can easily be the difference between needing three versus four storage cylinders to achieve the vehicle’s required driving range. By eliminating the fourth cylinder, the weight and cost of the fuel-storage system can be significantly reduced.

Researchers will install sensors and communications equipment on the vehicle and station and feed the information to an improved CNG filling algorithm. The project team will

demonstrate the system at one fueling location to analyze the real-world improved filling performance, and any increase in the vehicle or dispenser costs. Fuel-system and operational savings will be calculated to determine the true net benefits, and the results will be used to support a commercialization strategy.

In this project, UTD is partnering with the U.S. Department of Energy (DOE) and leading manufacturers and end users. UTD is providing co-funding to a significant prime contract from the DOE.

### Benefits / Market Implications

The initial target markets for this technology are heavy-duty trucks, with the focus on reducing the frequency of fills to improve the productivity of CNG-fueled trucks. Higher productivity can lead to greater economy for end users.

Developing and commercializing a smart CNG fueling system would reduce the capital cost differential between CNG and diesel trucks. This expands customer’s competitive choices for fuels, including potential applications for hydrogen fueling. It is estimated that the smart CNG fueling system could reduce the capital cost for fuel storage by about 25%.



(LEFT) One of the HEM DAS with a built-in streamer. (CENTER) The router connected to the HEM DAS. (RIGHT) The micro-controller that connects the dispenser to the vehicle.





- Dave Miller  
National Accounts and CNG  
ONE Gas

*"Oklahoma Natural Gas is pleased to partner with the U.S. DOE and others through UTD to demonstrate this innovative smart station. We're excited about its potential to increase onboard CNG storage capacity by up to 25% while reducing station and fleet operating costs. With 127 CNG stations in our Oklahoma service area, this significant technology advancement can potentially provide substantial savings for our CNG customers and help reduce greenhouse gas emissions in our state."*

## Technical Concept & Approach

This project addresses the major technical issues by working closely with commercial partners and using real-world testing. Tasks include developing and deploying an advanced dispenser algorithm and wireless vehicle-to-station communication devices that will transmit real-time fueling information between the vehicle and the dispenser for the first time.

The project team will assemble and deploy data-acquisition systems on multiple demonstration sites and vehicles to collect necessary filling data. Station components for vehicles and dispensers will be developed. These smart components will be designed to securely transmit real-time data (e.g., temperatures and pressures) between the vehicle and station, enabling a safer, more accurate full fill using an advanced fueling algorithm. Components will be designed to applicable wireless data-transmission standards.

Researchers will initially test and validate the performance of the components and algorithm in a controlled laboratory setting. Testing will include validation that the dispenser wirelessly connects to the correct vehicle and then accurately transmits the required data when filling a variety of CNG cylinder types, volumes, and configurations. Upon successful validation of the smart component performance, the systems will be integrated into test dispensers and vehicles, and then operated for a year at a demonstration site.

The research team will monitor data collected from a variety of CNG stations and vehicles during smart-filling events. This data will be analyzed and compared to the baseline to quantify the improved performance and accuracy of the prototype system. The project team will also begin initial commercialization steps for the technology.

## Results

Researchers deployed 18 HEM data-acquisition systems (HEM DAS) onboard a local fleet of concrete mixers. This allows the project team to collect fueling and fuel-consumption data onboard each vehicle in order to better



*The fully installed ANG1 dispenser*

understand how baseline dispensers operate and how much they truly underfill vehicles. The system is transmitting data about the fuel system to the cloud where investigators download and evaluate fills and driver filling practices.

The team has also installed a commercial dispenser in an environmental test chamber to test smart fills across a wide range of operating conditions. Two vehicle cylinders were also installed along with HEM DAS to test the vehicle communication with the station. As the vehicles are filled, they are broadcasting the vehicle information to the station's Wi-Fi network. A smart controller is monitoring the vehicle via the Wi-Fi network and comparing that information to data received from the dispenser via a Modbus connection. The smart controller then determines which vehicle is connected to which dispenser so that it can override the dispenser and assure the vehicle receives a full fill. This system is fully operational and the project team is working out some of the bugs in the smart controller algorithm to ensure more accurate and consistent operation.

## Status

The team is actively testing the smart controller and algorithm using a commercial CNG dispenser and two target cylinders connected to HEM DAS.

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## CNG/RNG Locomotive Field Demonstration

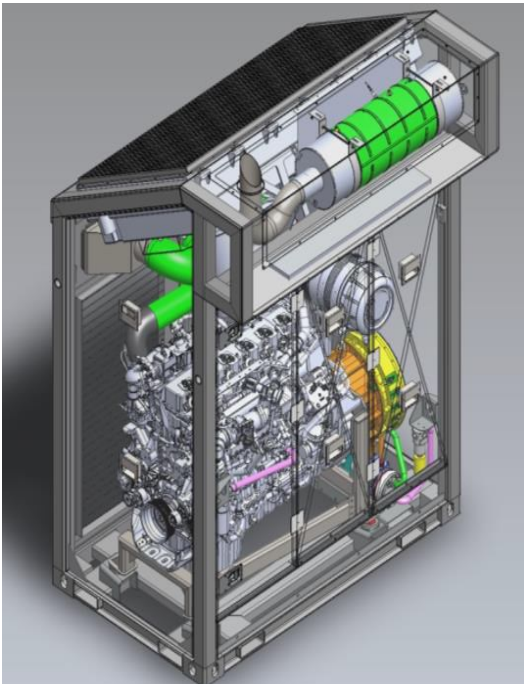


**Researchers are designing, building, and testing a pre-production compressed natural gas/electric hybrid line-haul locomotive to demonstrate the commercially available Cummins X15N near-zero-emission engine in rail service in order to substantially reduce GHG and particulate emissions while also reducing operating costs.**

### Project Description

For this project, a natural-gas-powered locomotive will be designed, built, and tested at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC) testing facility. The locomotive will operate on a 50-mile test loop in real-world conditions. Operation at TTC will allow researchers to perform controlled testing and gather critical data for emissions, fuel consumption, specified performance metrics, dynamic and other safety characteristics, and reliability during revenue service simulations. This locomotive demonstration will provide needed solutions and support the Class I, II, and III railroads as they seek ways to reduce the adverse environmental impacts of aging high-emission, diesel-fueled locomotives.

A key technical component of this demonstration – the Cummins X15N engine – is an evolution of ISX12N engine developed with earlier support from UTD. This project is funded primarily by the U.S. Department of Energy (DOE) and will demonstrate the first use of the on-road Cummins engine in off-road markets, which may open additional markets for other end users (e.g., marine and agriculture). UTD and others are partnering with DOE by providing co-funding.



*Refined engine pod design*

DOE's objective to increase commercialization of alternative fuels in the railroad industry has been limited by the pace of engine technology development from traditional locomotive manufacturers. This project will expand the use of natural gas to serve a new class of off-road customers with large potential by demonstrating two significant challenges that can be met: 1) achieving near-zero emission operation, and 2) multi-engine, line-haul service feasibility.

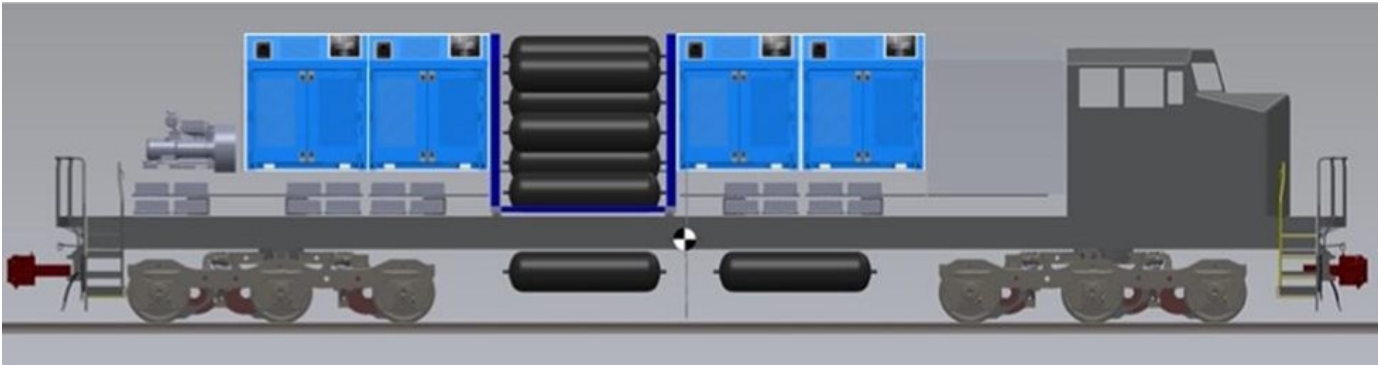
The locomotive will use U.S. Environmental Protection Agency certified rail engines and will reduce criteria emissions by more than 95% vs. current Tier 4 standards, reduce fuel costs, and reduce greenhouse gas (GHG) emissions by more than 40%. Reducing criteria pollutant emissions is of critical importance because railyards tend to be in environmental justice areas where underserved populations are exposed to some of the lowest air quality.

The intent of this project is to document that multiple CNG (compressed natural gas) engines in hybrid locomotives can increase overall system energy efficiency and reduce fuel consumption by 20% to 40% by including the utilization of regenerative braking. This project also intends to show that Class I, II, and III railroads can dramatically lower GHG emissions compared to diesel by using compressed renewable natural gas (RNG). There will also be significant importance to validating success in the most challenging applications (i.e., line-haul) to remove concerns for the rail sector to adopt RNG or CNG as a viable fuel.

### Benefits / Market Implications

This technology program will demonstrate how a suite of commercially-available products can be integrated to create a viable CNG hybrid system to power locomotives with near-zero emissions. This solution will be safe and reliable, while at the same time, reducing fuel costs, having a nominal maintenance impact, and creating a roadmap for accelerated deployment with predictable costs and production schedules. Anticipated benefits include:

- 20% lower fuel consumption than diesel, with negative GHG emissions when consuming carbon-negative RNG
- Capital costs of the CNG hybrid (when commercialized) will be comparable (or lower) to conventional Tier 4 diesel loco-



*Overall layout of engine pods, batteries and storage modules*

motives

- Demonstrate that a 4,300 HP line-haul locomotive can be re-powered as a natural gas hybrid locomotive at near-zero emissions – to exceed Tier 4 emission standards and meet proposed Tier 5 standards, and
- Advance the potential for gas-driven engines to serve a key role in addressing emission challenges and environmental justice concerns in dense urban areas affected by railyards or commuter operations.

Validating the performance and maintainability of the Cummins engine in highly-challenging line-haul locomotive service will support commercialization in all rail sectors (e.g., passenger rail and switching locomotives) and provide a springboard to expand applications in off-road transportation, construction, and other markets.

## Technical Concept & Approach

Specific tasks for this project include:

- **Specification, Engineering, and Design**  
 Create detailed system specifications for the locomotive that will drive quantitative metrics to be used during systems validation and operational testing.
- **Procurement and Production**  
 Use feedback from manufacturing to update the designs and identify process improvements.
- **System Testing and Validation**  
 Conduct functional testing, including dynamics and static vehicle testing as well as full operation on a 50-mile test loop at FRA's TTC facility in Pueblo, CO.

## Results

An innovative design for the locomotive was developed which will employ individual modules (engine pods, fuel storage,

batteries) locked onto platforms and to each another, which will allow quick and easy assembly and serviceability. A variety of modules are being designed, including eight natural gas engine pods (45 inches wide x 80 inches deep x 80 inches high), each with a water-cooled 380 kW generator, associated water-cooled power electronics, and radiator-based cooling system. Each engine pod will be tightly connected to adjacent pods and to the top of each battery pack bay.

Baseline power will be provided by eight 510 Hp Cummins X15N natural gas engines to provide 4,000 hp (minimum). The project initially planned to use Cummins ISX12N engine but switched to the X15N after its successful initial demonstrations in trucks during 2022-23, with expected wide-scale adoption in 2024. To get the goal of 4,400 hp, 400 hp of batteries will be used to be added in a hybrid configuration. The configuration of the engine modules on the locomotive is optimized to increase air flow to the radiator of each module while providing upper space for the catalyst and the radiators.

The team also switched the locomotive platform to an EMD SD90M-2, allowing more space on the locomotive deck to arrange the engine/RNG modules and move the batteries below deck. The two above-deck RNG storage modules (with a total of 1,700 DGEs) are the middle of the locomotive to help balance of the locomotive (front to back) to help tractive effort be applied evenly on both trucks, as well as yielding compact plumbing to the storage modules. Work also continued on the design of power electronics, primarily built around BAE's Modular Power Control Systems (MPCS).

## Status

The project team is continuing to work on locomotive design and procurement of long-term components (CNG tanks, batteries, engines, alternators, and power electronics).

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## CLEAN TRANSPORTATION

# Distributed RNG or Biogas Production and Cleanup

**Researchers are analyzing and improving the productivity of renewable natural gas production and cleanup technologies suitable for distributed small-scale operations by investigating a variety of anaerobic digestion and gasification technologies, assessing unique feedstock opportunities, and helping optimize technology performance.**



## Project Description

While large-scale anaerobic digestion is feasible at many locations across the country, this project focuses on small-scale anaerobic digestion to enable an even wider range of applications and locations, allowing for the growth of renewable natural gas (RNG) production that is needed to meet decarbonization goals.

There is an increasing variety of anaerobic digestion technologies to consider. Each method has unique technical and economic barriers to overcome. Conventional anaerobic digesters are physically large, specially-designed for each facility, and constructed on site with correspondingly high costs. Anaerobic digesters can be used to treat wastewater and have potential to be used at small- and medium-sized facilities such as breweries, distilleries, cideries, dairies, cheesemakers, seafood processors, and campuses could benefit from anaerobic digesters. However, their operations are normally too small to afford the capital expense of a traditional digester.

Significant effort is needed to: analyze applications; optimize novel, emerging technology packages and other potential high-value co-products; and find ways of increasing reliability and productivity without increasing the need for labor and management.

This project seeks to determine technical and market requirements to build and operate novel, integrated technology packages to convert various organic wastes into high-value RNG. In particular, there is a need to assess to what extent

these systems can be commercially viable at much smaller scales than previously possible via enabling strategies such as: novel modular technology packages; optimized co-production, co-product development, marketing and sales of co-products given the geographic location; and alternative and innovative business models to capitalize the equipment.

In summary, researchers are investigating anaerobic digestion and gasification technologies that are suitable for small-scale onsite service, potential feedstocks, feedstock preparation and pre-treatment options, reactor designs, biogas and producer gas cleanup, economic modeling and performance analyses, and methods of digester monitoring and control to increase the throughput of small-scale digesters.

This project serves the end users, society, and the environment by advancing RNG in distributed energy applications. This technology can lower greenhouse gas (GHG) emissions, increase energy resiliency, and decrease solid waste disposal costs paid by the onsite user.

## Benefits / Market Implications

Example target markets are smaller municipal waste management facilities, food processing plants, small farms and dairies, and campuses with foodservice for large populations. Potential secondary target markets are horticultural operations, restaurants, grocery companies, and microbreweries.

A 2019 assessment of RNG by the American Gas Foundation illustrates RNG potential as a GHG emission-reduction strategy. According to this study, "...there is a portfolio of potential feedstocks and technologies that are or will be commercialized in the near-term future that will help realize the potential of the RNG market." Most RNG continues to be produced using anaerobic digestion paired with conditioning and upgrading systems. The post-2025 outlook for RNG will increasingly rely on thermal gasification of sustainably harvested biomass, including agricultural residues, forestry and forest product residues, and energy crops."

This project focuses on broadening the quantity of organic waste accessible for RNG production and is intended to advance technology that can be deployed for smaller dairies, farms, water-resource-recovery facilities, and food processing plants.



*Prefabricated units drive down capital costs and allow for quick delivery.*

*Credit for image above: Chomp*



## Technical Concept & Approach

This project is analyzing small-scale RNG production technologies with feedstock inputs ranging from hundreds to thousands of pounds of waste feedstock per day. Two technologies are being considered: anaerobic digestion and gasification. Gas cleanup technologies such as membranes, solvents, or more novel solutions are being studied for small-scale as well as medium-scale applications such as farms with herds of 100 to 1,000 head of cows.

Technical barriers will be identified for each application and potential solutions will be identified and analyzed. Efforts will be made to identify, develop, or implement better sensing and control technology that is affordable to small-scale installations in order to increase uptime and therefore annual productivity without upsizing major equipment.

For the most promising applications and technologies, a detailed technical-economic analysis will be conducted to examine costs, benefits, risks, uncertainties, and timeframes of the studied technologies.

## Results

The team conducted a literature review and collaborated with a small scale digester vendor to identify known and hypothesized limiting factors of long-term small scale anaerobic digester productivity, and assess sensing, control, and analytical strategies to increase digester productivity.

A detailed experimental plan was created with the goal of studying typical digester behavior, especially focusing on typical small scale digesters being used to process food waste. The nature of upsets and performance challenges was logged and multiple monitoring approaches for small-scale digesters were simultaneously used for optimal monitoring and control. This project has collected substantial operating logs from an operating, 480-gallon, continuously-mixed digester designed for onsite organic waste treatment service.

Data collection for this effort includes the FOS/TAC score via the Nordmann method, biogas quality (% CH<sub>4</sub>), biogas quantity (flowrate), digestate pH, and digestate alkalinity. Data was collected for a baseline, first, and second level of digester feed rate in an experimental test series. The first increase in feed rate (100 lb/day to 140 lb/day) was completed in early Q2 2023, and definitively verified that successful long-term performance was viable at this level of digester duty.

The second increase in feed rate was to 180 lb/day. A rise in FOS/TAC score was then noted (from about 0.14 to 0.59), which alerted the digester operators of a developing over-fed, also known as over-acidified state. Operators were then able to cease feeding of the digester. The FOS/TAC score then returned to normal levels within a couple of days, upon which in a commercial installation, normal feeding could once again be resumed. Both the normal operating state as well as the



- Jan Allen  
President  
Impact Bioenergy [now called Chomp]

*"Impact Bioenergy has built and deployed over 17 small-scale, onsite, modular anaerobic digester solutions since 2013. We are excited about how our distributed and modular systems empower their owners to divert organic waste from landfill, reduce the waste-transportation footprint, generate energy, and generate organic plant food that supports food production onsite or in the community or campus hosting the digester. We appreciate UTD's support and partnership."*

over-fed state were simultaneously evaluated using all of the digester monitoring parameters that were being trialed to evaluate their effectiveness.

## Status

Some of the other monitoring techniques that were tried in the experimental program did produce some indication of the overfed state, and ongoing efforts are underway to find more technologies and methodologies for real time monitoring of anaerobic digesters with minimal labor requirements. This project has now documented about eleven products for monitoring digester status that are commercialized or in commercial development, but in most cases they are currently either too expensive for small-scale digestion installations, too labor intensive to be conducted frequently enough for ongoing monitoring, or have not been proven to provide reliable monitoring and timely detection. This project plans to continue to evaluate these products and where appropriate, support their commercial development progress and application strategies.

Specific to envisioning a pathway to broader implementation of these digesters, the team will be identifying pathways to improve automation and remote access to these technologies, by utilizing experience and in-house knowledge on these topics. Increasing automation and allowing remote monitoring of the systems will help decrease overhead associated with manual intervention of these systems, and thus reduce costs for distributed RNG or biogas production.

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## Improved Hydrogen Fueling for Heavy-Duty Vehicles



**In partnership with the National Renewable Energy Laboratory and others, a research team is creating a publicly available draft protocol for high-pressure, high-flow hydrogen fueling of heavy-duty vehicles.**

### Project Description

Deployment of heavy-duty fuel-cell vehicles is currently limited by the availability of hydrogen fueling technologies that can affordably and reliably dispense hydrogen. High-flow fueling (approximately five times faster than current light-duty hydrogen-vehicle fueling) is necessary because heavy-duty trucks need to store 50 to 100 gasoline gallon equivalent (GGE) of hydrogen onboard, which is at least 10 times what is typically stored on current light-duty hydrogen vehicles.

While the fill rate required will vary depending upon a truck's class and vocation, the U.S. Department of Energy's (DOE) fueling rate target for Class 8 long-haul trucks is 10 kilograms (kg) per minute (one kg of hydrogen is approximately one GGE) to enable full fills within timeframes comparable to those for today's diesel trucks (e.g., approximately five to six minutes). This target is based on a desire for hydrogen fuel-cell trucks to achieve a 750-mile driving range between refueling, which will require onboard storage of approximately 60 kg of hydrogen.

One accepted fueling procedure is a protocol that was developed with support of current National Renewable Energy Laboratory (NREL) researchers that allows for more flexible and lower cost fueling stations while maintaining safety and reliability. Currently, a prescriptive protocol for high-flow hydrogen

fueling does not exist. This project – in partnership with NREL and in coordination with Southern California Gas (SoCalGas), a major public transit agency, and others – involves the development of a standardized prescriptive fueling protocol which is applicable to a wide range of vehicles and storage system designs and can be used for public-access fueling stations.

Researchers will conduct the modeling and testing required to validate the fueling protocol and facilitate its potential adoption in future international consensus standards, within the limits of the project resources.

### Benefits / Market Implications

In order to achieve deep decarbonization goals in the transportation sector, a wide variety of alternative pathways are needed. It is clear that just one solution will not satisfy the diverse needs and duty cycles required, especially for heavy-duty vehicles. This sector is particularly important because it is a critical growing industry for goods movement, and it is challenging to electrify because of the energy-density requirements. U.S. DOE data shows that heavy-duty trucks produce approximately 25% of the greenhouse gas emissions in the transportation sector while comprising only 5% of the total



*Example of heavy-duty hydrogen vehicle. Image credit: Nikola Corp.*



Hydrogen fueling dispenser. Image credit: California Energy Commission

vehicles. This shows the environmental impact that is caused by each truck as well as the potential emissions reductions that could be caused by switching to zero-emission technologies.

This project will facilitate the installation of public high-flow hydrogen stations for heavy-duty vehicles to expand the range and operation area of these vehicles. This is especially important as California and other states adopt aggressive zero-emission vehicle targets for heavy duty vehicles (e.g., California's Advanced Clean Truck Regulation and the 15-state initiative signed in 2020 to advance the market for electric medium- and heavy-duty vehicles).

## Technical Concept & Approach

Specific activities of the UTD project team include:

- Organizing and coordinating discussions with relevant stakeholders on process and interfacing specifications.
- Supporting the data analysis of modeling and experimental results, and
- Performing validation testing, if time and budget allows, including fueling and defueling vehicle pressure vessels.

Key project goals are:

- Creation of a simulation model to validate fueling proce-

dures across a wide variety of scenarios

- Testing to correlate modeling to real-world results to validate modeling results and safety
- Creation of a draft fueling scientific protocol for high-flow fueling of heavy-duty vehicles, which can be endorsed or modified by consensus standards-setting organizations for use at public access fueling stations, and
- Develop a validation calculator to allow station or dispenser manufacturers to validate equipment performance.

## Results

The UTD project team participated with NREL in several technical meetings, and a definition of protocol specifications (e.g., expected fuel-system size and target final fill conditions) was created.

NREL conducted modeling tasks in order to validate the temperature/pressure behavior of ground storage tanks during fueling events. They developed a matrix of simulations to find end-of-fill conditions for a range of cases and conducted high-flow fueling component testing. They have obtained data allowing them to finalize their fueling protocol for high flow applications. These results will be used to guide a safe fueling protocol. They are also developing a validation tool, which the project team will assist with in coordination with NREL.

The project team has focused on conducting testing on an extremely valuable pathway for heavy-duty fueling, which is developing a time-fill protocol. Heavy-duty vehicles have seen huge benefits from time-fill fueling in CNG applications, and the same potential exists in hydrogen fueling. Significant challenges exist in this area to ensure the tanks remain within their temperature limits, while achieving full fills and maintaining flow rates above the minimum check valve chatter flow rates advised in the high-flow fueling protocol. Developing this protocol will also lead to a preliminary time-fill fueling station design that can be utilized for station deployments in the future.

## Status

The team has begun construction of the time-fill test unit. The Hazard and Operability review is complete. Operation of the test unit is expected to begin in early Q1 2024. The team will also assist NREL in validating the fueling protocol developed for high-flow fueling.

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## CLEAN TRANSPORTATION

# Technical Support for Clean Transportation Testing, Performance, and Safety



**This project provides technical support and input related to natural gas vehicle standards development and refinement, including revisions to temperature compensation guidelines and compressed natural gas dispensers.**

## Project Description

Over the past several decades, the natural gas industry has supported the development of minimum safety standards that guide natural gas vehicle (NGV) industry stakeholders. As a result, the NGV industry developed and improved a suite of compressed natural gas (CNG) and NGV components and systems while satisfying standards that allow for continuous improvement in technologies while ensuring the safety of vehicles, fueling infrastructure, and end users.

Ongoing innovations and changes necessitate that careful attention be placed on codes and standards. Knowledgeable technical input into the consensus-building process is critical to ensuring proper coverage to protect users and the general public. This includes clarifying coverage between new vs. existing standards and, where appropriate, expanding coverage to new applications and technologies. Outdated standards should not create an obstacle to product advancements that can benefit end users. As manufacturers of vehicle and station components expand their businesses to broader markets, harmonization of standards across North America, South America, and Europe is also gaining importance.

This project provides technical support and input related to NGV standards development and refinement, for consideration and/or ultimate consensus action by the technical committees of:

- CSA standards such as NGV 4.3 (Temperature Compensation Guidelines), NGV 4.1 (CNG Dispensers), NGV 4.8 (NGV compressors), and NGV 6.1 (CNG Fuel Storage)
- Gas quality standards from the CSA Group, ASTM International, American National Standards Institute (ANSI), and others, and
- National Fire Protection Association 52 revisions.

This project also provides technical data and information to the NGV America (NGVA) Technology and Development Committee to support accident investigations and help establish safety, technical, and environmental priorities.

## Benefits / Market Implications

Enhancing the performance and safety of NGVs, the fueling infrastructure, and maintenance facilities helps end users

and facility owner/operators reduce costs and incidents while gaining the environmental benefits of CNG.

This project provides technical support to enhance consensus-developed standards and introduce new or updated minimum safety requirements affecting compression equipment, dispensers, vehicle components, and natural gas storage products in the North American marketplace.

By striving for single, globally-acceptable technical standards and conformance tests, new or improved products to benefit end users can be introduced at a broader scale and with lower cost and shorter time to market.

By participating on technical advisory groups, experts share best practices learned over decades of experience and influence the standards developers and product manufacturers.

The primary markets to benefit are:

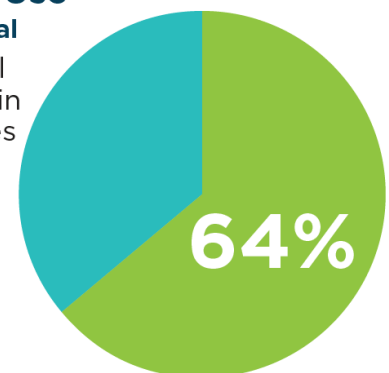
- Overall NGV industry, including end-users and end-user fleets, vehicle and engine manufacturers, CNG station providers, and
- Additional stakeholders such as utilities and first responders.

## 2021 NGV Fuel Use

**610 Million GGE Total**

In 2021, **64%** of all on-road fuel used in natural gas vehicles was RNG

- Conventional Natural Gas  
**220 Million GGE**
- Renewable Natural Gas  
**390 Million GGE**



## RNG Production Facilities



**250**

in operation



**112**

under construction



**125**

in development

*The development of renewable natural gas (RNG) production is directly tied to the transportation sector and credits for RNG use in vehicles.*

Source: NGVA Data on RNG Use in NGVs



## Technical Concept & Approach

Project representatives participate as voting members in the Technical Advisory Group's standards groups and chair the NGVA Technical and Development Committee. Updates are provided through various tasks, including:

- **Technology Committee Support for Standards Development, Updates, Monitoring and Review**

Project representatives participate in regular technical discussions and committee meetings scheduled by standards-setting organizations, testing organizations, and vendors to monitor and support by open meeting consensus the updates and progress of key standards and code documents.

- **NGVA Technical Development Committee Support**

The project team's participation provides extensive NGV and fueling experiences.

## Results

In 2022-23, the project team continued to participate in the development of CSA NGV 4.3 (Temperature compensation guideline for compressed natural gas vehicle fueling) which led to its finalization by CSA and its publication; this included serving as Vice Chair of the applicable CSA Working Group. NGV 4.3 underwent a major overhaul to include testing for new dispensers as well as updates to better reflect accurate temperature compensation. Researchers supported the base technical case for updates being evaluated by the entire Working Group. The process required defining specific operating conditions and test scenarios.

The project team also provided technical support to ANSI and CSA committees for the technical development of temperature compensation requirements in NGV 4.1, 4.8 and 6.1.

The project team also provided technical support to advance CSA NGV 5.1 (Residential Fueling Appliances) and CSA NGV 5.2 (Vehicle Refueling Appliances), which were finalized and published by CSA.

The project team also provided technical support for the NGVA Technology and Development (TD) Committee, including serving as TD Committee Co-Chair. Activities of NGVA's TD Committee included the assessing technical issues critical to end users and public safety, such as:

- Discussed and investigated, on a quarterly basis, the root causes of safety accidents and then communicated findings.
- Updated the Guide to Safe Vehicle Conversions with the latest requirements listed in FMVSS 304, NFPA 52, and EPA/CARB compliance regulations.



- Julie Cairns  
Sr. Project Manager, Alternative Energy  
CSA Group

*"CSA recognizes the input and insight that our committee members provide on NGV technical subcommittees. Through participation in the standards-development process, UTD contributes to the deployment of safe and reliable components, equipment, and practices for the industry."*



- Paul Sandsted  
Director of Technology and Sustainability  
NGVAmerica

*"NGVAmerica's Technology & Development Committee largely relies on the voluntary efforts of member companies and their representatives to address important issues in the NGV industry related to technology, innovation, safety, and sustainability. UTD's support to provide representation on the Committee and each of the subcommittee working groups has been instrumental in the many achievements to date for the advancement of natural gas as the most proven, cost-effective, and ready-now solution for decarbonizing transportation."*

- Held a Technology Webinar in September 2022 on the use of Modal Acoustic Emission (MAE) technology and its applications for vehicular and tube trailer CNG cylinder inspection.
- Created Recommended Practices for Unattended CNG Time-fill Refueling Stations document which can be found at: <https://ngvamerica.org/wp-content/uploads/2021/09/ANGI-FDS-White-Paper-8.31.21.pdf>
- The CNG Fuel System Inspection working group produced a CNG Cylinder Pressure Indication Safety Bulletin -[https://ngvamerica.org/wp-content/uploads/2023/02/NGVA\\_safetybulletin\\_CNGcylinderpressureindication\\_28Feb2023.pdf](https://ngvamerica.org/wp-content/uploads/2023/02/NGVA_safetybulletin_CNGcylinderpressureindication_28Feb2023.pdf)

## Status

This project continues to provide technical support in relevant CNG and NGV codes and standards technical committees as well as supporting key technical initiatives of the NGVA Technology and Development Committee.

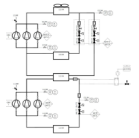
## For more information:

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## CLEAN TRANSPORTATION

# Cost-Effective Pre-Cooling for High-Flow Hydrogen Vehicle Fueling



**Researchers will design, fabricate, and validate design of a cost-effective, high-efficiency chilling system to pre-cool hydrogen for high-flow fueling of heavy-duty trucks at 10,000 psi. This pre-cooling system will reduce the life-cycle cost of hydrogen fueling and reduce greenhouse gas emissions from heavy-duty vehicles.**

## Project Description

The goal of this project is to design, fabricate and validate a sub-scale version of a cost-effective, high-efficiency chilling system which uses commercially-available components and natural refrigerants to pre-cool hydrogen for high-flow fueling of heavy-duty vehicles at 10,000 psi (70 MPa).

High pressure is required to provide reasonable vehicle range. However, the high pressure gas must be pre-cooled because the gas heats up significantly when compressed and the gas must remain below the maximum allowable temperature of the vehicle's hydrogen storage system. Equipment capable of cost-effectively delivering pre-cooled hydrogen at high flows for heavy-duty trucks is not commercially available. Applying commercially-available pre-coolers which are currently used for fueling light-duty hydrogen fuel cell vehicles would require five light duty chiller units at approximately \$250,000 each for a heavy-duty hydrogen fueling station. For context, fueling stations for light-duty vehicles currently deliver hydrogen at approximately 2 kg/min, while typical targets for fueling stations for heavy-duty hydrogen vehicles are to deliver 10 kg/min.

Light-duty hydrogen pre-cooling units typically utilize a single refrigerant in a loop with a two-stage compressor and economizer to chill a large aluminum block to approximately -45°C. The hydrogen gas is then chilled from temperatures that can exceed 60°C down to -40°C in a single step. This design is suitable for intermittent light-duty fills because added complexity is cost-prohibitive at this small scale.

This project will utilize a cascade refrigeration cycle design that is more complex but provides large efficiency and energy savings - more than a 100% improvement in total coefficient of performance (COP). The economic trade-offs of this option will be weighed against simpler single-refrigerant designs.

The US Department of Energy (DOE) is providing prime funding for this project, which focuses on developing near-term solutions utilizing commercial products while solving a considerable problem for end users. This low risk, high reward approach is expected to lead to rapid commercialization of a critical technology in this growing market segment. UTD is partnering with DOE by providing co-funding, along with the Southern California Gas Company (SoCalGas). Other project team partners include Argonne National Laboratory (ANL).

At the end of the project, the technology will be ready to transfer to a chiller manufacturer for detailed design of a full-scale system for subsequent installation and testing in a heavy-duty hydrogen fueling station. Key performance targets are for the pre-cooler design to fill a 60kg fuel system in 6 minutes (equivalent to diesel fueling speeds) at the temperature required by the applicable fueling protocol (currently under development), cost less than \$500,000, and have a maximum power requirement under 200 kW. The team will build and validate a 2-3 kg/min lab-scale unit and develop a promising commercialization plan and economic analysis, with support from an industrial partner.

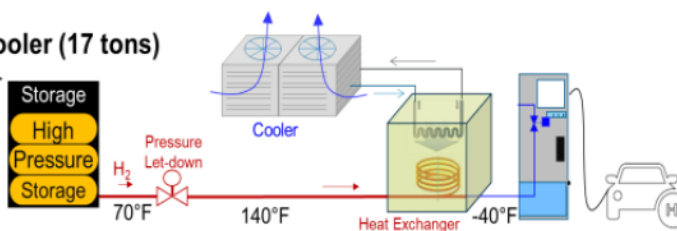
## Benefits / Market Implications

The primary target market impacted will be heavy-duty trucks that require high pressure (70 MPa) hydrogen fueling. The development of this heavy-duty pre-cooling unit will reduce the life-cycle cost of hydrogen fueling, while accelerating a transition toward use of natural refrigerants – such as CO<sub>2</sub> and NH<sub>3</sub>. This will reduce barriers to adopt heavy-duty hydrogen vehicles by lowering the cost of fueling stations.

Transitioning to hydrogen fuel cell heavy-duty vehicles would significantly reduce greenhouse gas emissions. Heavy-duty vehicles make up a small fraction of the vehicle fleet in the United States and travel only 10% of the total annual vehicle miles

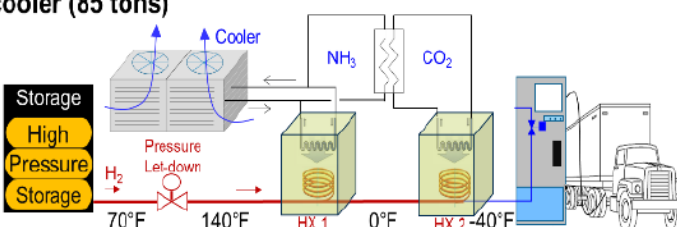
### Light-Duty Pre-cooler (17 tons)

- One heat exchanger cools over wide temperature range  
 - COP < 1



### Heavy-Duty Pre-cooler (85 tons)

- Cascade w/ 2 heat exchangers  
 - COP > 1.8
- Higher complexity beneficial for higher cooling duty



driven, but they contribute 23% of transportation emissions of greenhouse gases according to the Environmental Protection Agency.

## Technical Concept & Approach

This project will develop an optimized pre-cooler design which will significantly benefit from refrigeration cycles that utilize several evaporator stages such as cascade refrigeration or more complex single-refrigerant circuits. The end product will be a fully-designed, optimized, and performance-verified chiller system capable of efficiently and cost-effectively fueling 70 MPa hydrogen vehicles at an average of 10 kg/min. The following tasks will be performed:

### Task 1: Preliminary Chiller Design

Develop a preliminary design of a full-scale chiller system capable of fueling a heavy-duty vehicle within acceptable conditions, which include filling a 60kg storage system in less than 6 minutes with the flow profile and temperature defined by a heavy duty hydrogen fueling protocol currently being developed (e.g. see UTD project 2.21.H).

### Task 2: Detailed Design and Build, and Economic Analysis

Complete the detailed design and build of a test unit, and perform laboratory testing. Also perform an economic analysis of the full-scale unit assuming production volumes of 100 units per year and assess if the targeted capital and operating costs of the system appear likely to be achieved.

### Task 3: Lab Testing Set-up and Final Design

Perform lab testing of the test unit built in Task 2. The performance data and know-how gained from this testing can be incorporated into the design of a full-scale system suitable for commercialization by a manufacturing partner (to be identified) who would be interested in supporting subsequent demonstration at a high-flow hydrogen fueling station. Task 3 will also include commercialization planning to ensure the design is available for purchase by future stations.

## Results

Modeling the worst-case scenario of a heavy-duty hydrogen vehicle fuel system showed that a pre-cooling temperature of -30°C is required to ensure a full fill at high ambient temperature. This matches recent progress reports from the team developing the fueling protocol. For the preliminary chiller design, the team only considered refrigerants which have a zero Ozone Depletion Potential and low Global Warming Potential (less than 10), which left only three refrigerant options: CO<sub>2</sub>, ammonia, and propane. A total of nine refrigerant systems have been selected for further consideration, all of which are

various combinations of these three refrigerants.

A heat exchanger to cool the high-pressure hydrogen to -30°C was sourced from two vendors. This heat exchanger is designed to withstand 15,000 psig of hydrogen on one side and a heat transfer fluid on the other side. Modeling of heat exchanger location revealed a delay of 100 seconds before the delivered hydrogen temperature fell below 25°C, which would cause an extended time delay for the fueling process. Therefore, locating the final stage of pre-cooling at the dispenser will likely be needed in most station configurations to ensure fueling efficiency.

The project team completed the preliminary design of the full-scale pre-cooling unit. One of the main decision points was whether to use propane or CO<sub>2</sub> for the low stage of the chiller. The advantage of propane is the low operating pressure, making components cheaper and easier to procure. The downside is the high flammability that presents an additional hazard to the site. The team ultimately chose to move forward with CO<sub>2</sub>, even though the higher operating pressure of CO<sub>2</sub> makes parts more expensive.

Modeling of the Coefficient of Performance and maximum power requirement was completed. The modeled maximum power for the NH<sub>3</sub>/CO<sub>2</sub> system was found to be 110kW. This is before any over-design margin is allowed and some ancillary components (like cooling fans) are specified. The team expects this requirement to increase to a peak power requirement of 120-130kW for this system capable of filling a 70kg fueling system in six minutes at an ambient temperature of 20°C.

For early-stage testing to inform the final design of the system, the team is conducting testing of the lower stage of the cascade chilling system. This CO<sub>2</sub> stage will provide the final cooling before fuel delivery and will carry the requirement of achieving the final pre-cooling temperature. The cooling demand for this system is very transient and must respond quickly to changes in fueling flow rate. For this reason, the team decided it was important to test this stage alone prior to completing the design of the full test unit.

## Status

The test unit design has been completed and undergone a full HAZOP review. Major components have been received. The team is currently constructing the low-stage test unit, and commissioning is expected in Q1 2024.

## For more information:

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## CLEAN TRANSPORTATION

# Heavy-duty Hydrogen Vehicle Development and Deployment



**Researchers will design, build, and demonstrate a hydrogen-fueled, zero-emissions regional-haul Class 8 vehicle to accelerate adoption of this type of vehicle in the market in order to reduce GHG emissions, enhance air quality, and delivering superior operating range for end users.**

## Project Description

The goal of this project is to design, build, and demonstrate a hydrogen-fueled, zero-emission regional-haul Class 8 vehicle. With major funding support from the California Energy Commission (CEC) and Southern California Gas Company (SoCalGas), the tactical objectives are to integrate an advanced hydrogen fuel cell, hydrogen storage, battery, motive, and control systems to collectively provide a zero-emission solution for the challenging duty cycle associated with drayage and regional-haul operations. UTD is partnering with CEC by providing co-funding to the CEC-prime-funded project, which will lower greenhouse gas emissions and criteria area pollutants for consumers and the environment. Key performance indicators of the project success include:

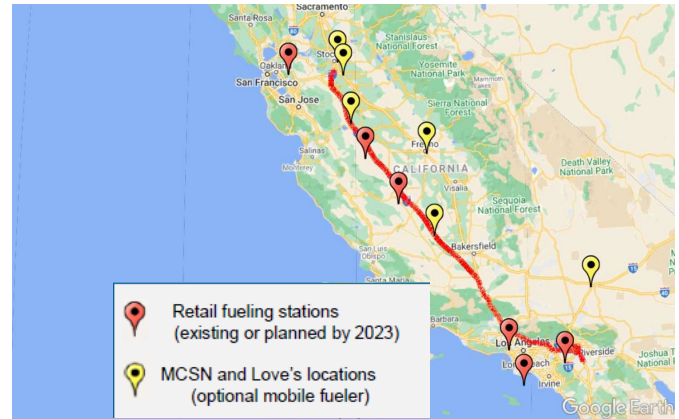
- Develop and demonstrate a Class 8 fuel cell truck that can achieve one-to-one replacement of diesel truck
- Improve performance, durability, and maintainability of a regional-haul fuel cell truck
- Demonstrate reduced total cost of ownership (TCO) and other benefits in order to encourage adoption

## Benefits / Market Implications

The project seeks to demonstrate a zero-emission alternative for the current market of diesel trucks used for regional haul and powered by 15-liter engines rated at 455 hp / 1650 lb-ft



*Hydrogen tanks installed on the truck*



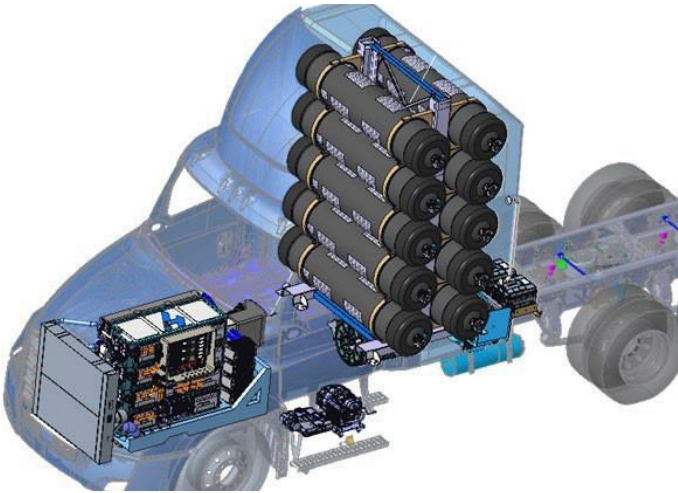
and equipped with 300 gallons of fuel tanks.

A typical loaded trailer being moved along the 400-mile demonstration route can weigh 23,500 to 57,000 lbs. The vehicle typically returns with an empty trailer weighing 13,500 lbs. The 300-gallon onboard fuel storage offers a 1,500+ mile range, theoretically supporting two roundtrips, which is not likely a critical need for a typical fleet. Currently, no zero-emission technology offers this amount of onboard energy storage and projected operating range.

The demonstration vehicle will overcome these barriers by storing 66.8kg of 700-bar hydrogen onboard, utilizing a 400-kW fuel cell, taking a strategic route with intra-route fueling in California's Central Valley, and employing a carefully-designed powertrain with components sized specifically for this duty cycle. US Department of Energy (DOE) national data suggests that 93% of the Class 8 trucks and 80% of their vehicle miles traveled (VMTs) can be served by vehicles with a 500-mile range. The 450-mile range vehicle will be able to perform both drayage and regional transport duties and the team has selected this application as not only a showcase of hydrogen fuel cell technology, but also because it can offer range that effectively covers most of intra-state California freight movement. The technology will also provide a substantial reduction in noise due to quieter powertrains and no need to use engine retarders on downgrades.

Over the last decade, the cost of fuel cell technology has been lowered by approximately 85%. It is expected that this trend will support the market to attain DOE's cost target of \$80 per kW through technological improvement and volume production. Hydrogen fuel cost remains a concern among





*Truck Packaging*

fleet operators. By demonstrating the viability of hydrogen fuel cell trucks as a feasible zero-emission solution for long-distance operation, it will encourage the adoption of hydrogen-powered trucks and help create substantial demand for hydrogen as a transportation fuel.

According to a Total Cost of Operation (TCO) study by the National Renewable Energy Laboratory (NREL), fuel cell trucks could be cost-competitive with diesel trucks if the vehicle purchase price is \$258,000 and hydrogen fuel prices are \$4/kg. The project team believes that the successful execution of this project and the path-to-market strategies will align the TCO at scale with NREL's targets by 2025.

## Technical Concept & Approach

The project team will design, build, and demonstrate a hydrogen-fueled, zero-emissions regional-haul Class 8 vehicle. The vehicle design, development, and verification work will take 24 months of the project. The vehicle demonstration will take 12 months. The following tasks will be performed:

### Task 1: Vehicle Design, Build and Verification



*Fuel Cell*



*Proposed envelope for fuel cell and low temperature thermal management equipment*

The technical team will design and build the vehicle based on an existing Freightliner Cascadia platform. The task will include the definition of functional requirements, study of design trade-offs, and computational and numerical engineering. Following the build, the team will commission and verify the vehicle prior to delivery to the fleet operator.

### Task 2: Demonstration, Data Collection and Analysis

Measurement and verification (M&V) activities will be performed and will leverage prior experience in data acquisition from advanced vehicle testing and data analysis.

## Results

The project team has collected baseline data from a diesel truck. A Hydrogen Safety Plan and Safety Analysis Report has been developed, and the team had a project review with the CEC. Work has started to disassemble and convert the donor vehicle. Cooling and fuel cell subassemblies are being assembled. Hydrogen tanks have been received and installed. A fuel cell and component test and validation test bench have been developed. Thermal management systems, electrical and mechanical subsystems layout, control software design, safety design, and completed packaging design for all major components are being refined.

## Status

The team is continuing work on design and assembly, safety plans, and establishing contracts with suppliers. The team will then develop a telematics and data collection system and a fueling plan.

## For more information:

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12/23

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-09**  
**Page 1 of 1**

**REQUEST:**

Regarding fuel conservation, and energy-efficiency programs, provide the following;

- a A list of all programs currently offered by Atmos.
- b The total cost incurred for these programs by Atmos in each of the three most recent calendar years.
- c The total fuel and demand reductions realized through these programs in each of the three most recent calendar years.
- d The total cost for these programs included in the forecasted test period and the expected fuel consumption reductions to be realized therefrom.

**RESPONSE:**

- a. Atmos Energy currently only offers a low-income weatherization DSM program as part of its current Kentucky Tariff on Sheets No. 30-36.
- b. See the table below:

**Atmos Energy Corporation**  
**Kentucky/Mid-States Division**  
**Demand Side Management**

<b>Total Program Cost - 2021 through 2024</b>	
2021	\$50,084.74
2022	\$13,351.80
2023	\$10,639.45
2024	\$3,000.00
Total	\$77,075.99

- c. Approximate Ccf savings for requested years are approximately:

2021: 5,311 Ccf  
2022: 1,770 Ccf  
2023: 1,265 Ccf  
2024: 253 Ccf

- d. Costs for the DSM program are outside of the forecasted test year. See the Company's current Kentucky Tariff Sheets Nos. 30-36 for the program overview.

Respondent: Brannon Taylor



**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-10**  
**Page 1 of 1**

**REQUEST:**

Provide the following information for the most recent calendar year concerning Atmos and any affiliated service corporation or corporate service division/unit:

- a. A schedule detailing the costs charged, either directly or allocated, by Atmos to the service corporation. Indicate Atmos's accounts in which these costs were originally recorded. For costs that are allocated, include a description of the allocation factors utilized.
- b. A schedule detailing the costs charged, either directly or allocated, by the service corporation to Atmos. Identify Atmos's accounts in which these costs were recorded. For costs that are allocated, include a description of the allocation factors utilized.

**RESPONSE:**

See Attachment 1 for direct and allocated costs.

**ATTACHMENT:**

Staff\_1-10\_Att1 - Detail of Direct and Allocated Charges.xlsx

Respondent: Emily Wiebe

Atmos Energy Corporation  
Kentucky Direct and Allocated Expenses  
For Calendar 2023 and Six Months Ended June 2024

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
0	8160	Wells expenses	01000	Non-project Labor	2,396	1,856	3,499	1,655	4,733	4,325	8,044	3,723
2	8160	Wells expenses	01008	Expense Labor Accrual	366	(189)	1,100	(922)	2,249	(2,355)	1,692	(738)
3	8160	Wells expenses	02001	Inventory Materials				8,938				
4	8160	Wells expenses	02004	Warehouse Loading Charge				447				
5	8160	Wells expenses	02005	Non-Inventory Supplies	994	1,140	-	44	5,875	2,467	240	2,545
6	8160	Wells expenses	05111	Postage/Delivery Services		28						
7	8160	Wells expenses	05420	Employee Development								
8	8160	Wells expenses	06111	Contract Labor	1,985	582	1,659	235	5,000	2,000		10,000
9	8160	Wells expenses	07590	Misc General Expense		400						
10	8170	Lines expenses	01000	Non-project Labor	1,967	1,420	448	680	550	612		155
11	8170	Lines expenses	01008	Expense Labor Accrual	460	(192)	(273)	116	17	(255)	(102)	70
12	8170	Lines expenses	02005	Non-Inventory Supplies	332	240	68	330	634	915	256	1,053
13	8170	Lines expenses	04582	Building Maintenance								
14	8170	Lines expenses	04590	Utilities	220	193	171	185	158	177	167	182
15	8180	Compressor station expenses	01000	Non-project Labor	1,755	1,603	2,514	2,503	1,520	2,263	1,581	2,954
16	8180	Compressor station expenses	01008	Expense Labor Accrual	185	(53)	696	(6)	(264)	(611)	97	855
17	8180	Compressor station expenses	02005	Non-Inventory Supplies	257		120	177	122	666	544	(504)
18	8180	Compressor station expenses	04590	Utilities	87	89	993	82	79	80	98	76
19	8180	Compressor station expenses	04599	Capitalized Utility Costs	(79)	(80)	(894)	(73)	(71)	(72)	(88)	(69)
20	8180	Compressor station expenses	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-
21	8190	Compressor station fuel and power	04590	Utilities	124	119	101	97	95	108	93	29
22	8200	Storage-Measuring and regulating station expenses	01000	Non-project Labor	111	633					256	
23	8200	Storage-Measuring and regulating station expenses	01008	Expense Labor Accrual	39	183	(221)				77	(77)
24	8200	Storage-Measuring and regulating station expenses	02005	Non-Inventory Supplies	35	40						
25	8200	Storage-Measuring and regulating station expenses	04590	Utilities	271	372	321	263	292	78	103	98
26	8200	Storage-Measuring and regulating station expenses	07590	Misc General Expense								
27	8210	Storage-Purification expenses	01000	Non-project Labor	6,609	8,499	728	509		155		159
28	8210	Storage-Purification expenses	01008	Expense Labor Accrual	1,309	661	(2,611)	(109)	(254)	26	(26)	71
29	8210	Storage-Purification expenses	02005	Non-Inventory Supplies	428	22				3,064		
30	8210	Storage-Purification expenses	04590	Utilities	267	208	175	206	121	140	155	189
31	8250	Storage well royalties	04580	Building Lease/Rents Capitalized	(80)	(12)		(14)	(28)	(580)	(76)	
32	8250	Storage well royalties	04581	Non 842 Building Lease/Rents	457	74		80	170	1,867	183	
33	8250	Storage well royalties	04590	Utilities	2,292	3,531	2,997	2,015	1,416		125	111
34	8250	Storage well royalties	07603	Rent Cap Accrual	-	-		-	-	-	-	
35	8300	Storage-Maint Supervision & Engineering	05010	Office Supplies			79					
36	8300	Storage-Maint Supervision & Engineering	05377	Cell phone equipment and accessories			52					
37	8300	Storage-Maint Supervision & Engineering	05399	Capitalized Telecom Costs			(30)					
38	8300	Storage-Maint Supervision & Engineering	05411	Meals and Entertainment	172	200	124	132				
39	8300	Storage-Maint Supervision & Engineering	07607	Telecom Cap Accrual			-					
40	8310	Storage-Maintenance of structures and improvements	02005	Non-Inventory Supplies								30
41	8340	Maintenance of compressor station equipment	01000	Non-project Labor	1,385	660	1,748	268	1,955	3,124	719	1,814
42	8340	Maintenance of compressor station equipment	01008	Expense Labor Accrual	80	(254)	643	(740)	1,137	(750)	(305)	601
43	8410	Other storage expenses-Operation labor and expenses	01000	Non-project Labor	18,832	10,835	13,249	13,384	10,156	21,608	12,504	10,812
44	8410	Other storage expenses-Operation labor and expenses	01008	Expense Labor Accrual	1,600	(2,799)	2,833	67	(90)	(3,000)	150	1,114
45	8410	Other storage expenses-Operation labor and expenses	02001	Inventory Materials	2,193		1,521	1,617	181		462	
46	8410	Other storage expenses-Operation labor and expenses	02004	Warehouse Loading Charge	11		76	81	8		21	
47	8410	Other storage expenses-Operation labor and expenses	02005	Non-Inventory Supplies								
48	8410	Other storage expenses-Operation labor and expenses	03003	Capitalized transportation costs							(108)	
49	8410	Other storage expenses-Operation labor and expenses	03004	Vehicle Expense							259	
50	8410	Other storage expenses-Operation labor and expenses	04582	Building Maintenance	65							
51	8410	Other storage expenses-Operation labor and expenses	05411	Meals and Entertainment	194		91		21	227	63	18
52	8410	Other storage expenses-Operation labor and expenses	05413	Transportation	249		1,117					
53	8410	Other storage expenses-Operation labor and expenses	05414	Lodging	119		557				506	
54	8410	Other storage expenses-Operation labor and expenses	05415	Membership Fees	285							
55	8410	Other storage expenses-Operation labor and expenses	05420	Employee Development			1,075					
56	8410	Other storage expenses-Operation labor and expenses	07499	Misc Employee Welfare Exp		99						
57	8410	Other storage expenses-Operation labor and expenses	07601	Vehicle Cap Accrual							-	
58	8550	Other fuel & power for compressor stations	04590	Utilities	40	36	41	36	39	44	39	39
59	8560	Mains expenses	01000	Non-project Labor	7,405	11,853	12,742	13,937	11,342	13,243	7,615	1,628
60	8560	Mains expenses	01008	Expense Labor Accrual	863	1,557	2,222	597	404	(5,165)	78	(1,552)
61	8560	Mains expenses	02001	Inventory Materials								
62	8560	Mains expenses	02004	Warehouse Loading Charge								
63	8560	Mains expenses	02005	Non-Inventory Supplies	692	226	427	2,471	1,940	1,168	396	455
64	8560	Mains expenses	03003	Capitalized transportation costs	(71)	(58)	(25)	(59)	(243)	(54)	(95)	(292)
65	8560	Mains expenses	03004	Vehicle Expense	410	373	168	338	1,484	175	228	615
66	8560	Mains expenses	04302	Heavy Equipment	468	14	233	10,818	159	977	1,692	2,127
67	8560	Mains expenses	04307	Heavy Equipment Capitalized	(459)	(14)	(228)	(10,602)	(156)	(958)	(1,658)	(2,085)
68	8560	Mains expenses	04585	Railroad easements and crossings			139	-				
69	8560	Mains expenses	04590	Utilities	2,667	1,515	2,623	2,048	1,576	2,549	1,745	2,480
70	8560	Mains expenses	04599	Capitalized Utility Costs	(1,482)	(773)	(1,222)	(1,099)	(858)	(1,500)	(1,074)	(1,623)
71	8560	Mains expenses	05111	Postage/Delivery Services				232				
72	8560	Mains expenses	05377	Cell phone equipment and accessories							10	
73	8560	Mains expenses	05399	Capitalized Telecom Costs							(6)	
74	8560	Mains expenses	05411	Meals and Entertainment					189	84	11	95
75	8560	Mains expenses	05419	Misc Employee Expense								
76	8560	Mains expenses	06111	Contract Labor							5,463	(5,463)
77	8560	Mains expenses	07443	Uniforms					159	65		342
78	8560	Mains expenses	07444	Uniforms Capitalized					(26)	(20)		(162)
79	8560	Mains expenses	07499	Misc Employee Welfare Exp				100			150	
80	8560	Mains expenses	07590	Misc General Expense	33			738				
81	8560	Mains expenses	07601	Vehicle Cap Accrual	-	-	-	-	-	-	-	-
82	8560	Mains expenses	07607	Telecom Cap Accrual								
83	8560	Mains expenses	07608	Uniform Cap Accrual					-	-		-
84	8560	Mains expenses	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-

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Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
85	8570	Transmission-Measuring and regulating station expenses	01000	Non-project Labor	609	408		37				
86	8570	Transmission-Measuring and regulating station expenses	01008	Expense Labor Accrual	202	(71)	(143)	18	(18)			
87	8570	Transmission-Measuring and regulating station expenses	04590	Utilities	612	475	648	486	636	599	691	723
88	8630	Transmission-Maintenance of mains	01000	Non-project Labor	2,069	1,487	4,342	5,781	3,480	2,528	913	2,567
89	8630	Transmission-Maintenance of mains	01008	Expense Labor Accrual	(387)	(204)	1,651	719	(628)	(1,841)	(147)	881
90	8630	Transmission-Maintenance of mains	07443	Uniforms	164							
91	8630	Transmission-Maintenance of mains	07444	Uniforms Capitalized	(96)							
92	8630	Transmission-Maintenance of mains	07608	Uniform Cap Accrual	-							
93	8700	Distribution-Operation supervision and engineering	01000	Non-project Labor	55,858	37,811	42,477	41,126	38,142	58,639	46,305	35,218
94	8700	Distribution-Operation supervision and engineering	01001	Capital Labor	618,982	600,563	589,410	620,579	610,006	953,047	663,242	670,955
95	8700	Distribution-Operation supervision and engineering	01002	Capital Labor Contra	(632,498)	(610,935)	(615,469)	(628,557)	(620,723)	(951,767)	(659,667)	(663,150)
96	8700	Distribution-Operation supervision and engineering	01006	O&M Project Labor and Contra				-				
97	8700	Distribution-Operation supervision and engineering	01008	Expense Labor Accrual	5,679	(6,316)	8,005	(675)	4,229	(15,019)	4,118	1,957
98	8700	Distribution-Operation supervision and engineering	01011	Capital Labor Transfer In	422,950	374,959	397,634	403,805	371,165	600,815	398,755	393,069
99	8700	Distribution-Operation supervision and engineering	01012	Capital Labor Transfer Out	(409,435)	(364,587)	(371,575)	(395,827)	(360,448)	(602,095)	(402,330)	(400,873)
100	8700	Distribution-Operation supervision and engineering	01014	Expense Labor Transfer Out								
101	8700	Distribution-Operation supervision and engineering	02001	Inventory Materials				93				
102	8700	Distribution-Operation supervision and engineering	02004	Warehouse Loading Charge				5				
103	8700	Distribution-Operation supervision and engineering	02005	Non-Inventory Supplies	3,075	3,695	6,395	3,102	7,062	4,321	3,336	5,056
104	8700	Distribution-Operation supervision and engineering	03003	Capitalized transportation costs	(628)	(2,049)	(663)	(1,508)	(671)	(934)	(685)	(1,954)
105	8700	Distribution-Operation supervision and engineering	03004	Vehicle Expense	1,000	2,700	1,040	2,108	988	1,344	978	3,280
106	8700	Distribution-Operation supervision and engineering	04002	Required By Law, Safety				47,717				
107	8700	Distribution-Operation supervision and engineering	04018	Safety			1,215		40	633	1,251	1,732
108	8700	Distribution-Operation supervision and engineering	04040	Community Rel&Trade Shows		96		348	970	2,053	1,807	1,785
109	8700	Distribution-Operation supervision and engineering	04046	Customer Relations & Assist								
110	8700	Distribution-Operation supervision and engineering	04145	Printing/Slides/Graphics							10	-
111	8700	Distribution-Operation supervision and engineering	04146	Public Relations								
112	8700	Distribution-Operation supervision and engineering	04201	Software Maintenance								
113	8700	Distribution-Operation supervision and engineering	04212	IT Equipment	297	6,766	5,483	357	218	469	292	189
114	8700	Distribution-Operation supervision and engineering	04301	Equipment Lease		926	1,960	-	1,571	2,084	1,760	1,018
115	8700	Distribution-Operation supervision and engineering	04302	Heavy Equipment			96	136				
116	8700	Distribution-Operation supervision and engineering	04307	Heavy Equipment Capitalized		(908)	(2,014)	(134)	(1,540)	(2,043)	(1,725)	(998)
117	8700	Distribution-Operation supervision and engineering	04564	842 Variable Copier Lease Expense	429				482	1,831	22	29
118	8700	Distribution-Operation supervision and engineering	04575	842 Short Term Lease Expense					6	387		
119	8700	Distribution-Operation supervision and engineering	04582	Building Maintenance	9,833	9,750	30,466	10,443	39,213	62,998	26,968	37,994
120	8700	Distribution-Operation supervision and engineering	04590	Utilities	8,578	5,611	9,583	7,402	8,094	10,589	7,623	10,834
121	8700	Distribution-Operation supervision and engineering	04599	Capitalized Utility Costs	(11,208)	(9,587)	(22,715)	(10,801)	(29,875)	(48,873)	(22,808)	(31,195)
122	8700	Distribution-Operation supervision and engineering	05010	Office Supplies	2,355	3,964	4,389	10,207	3,981	2,660	9,800	10,860
123	8700	Distribution-Operation supervision and engineering	05111	Postage/Delivery Services	219	776	257	433	859	927	267	976
124	8700	Distribution-Operation supervision and engineering	05215	842 Copier Lease Expense	2,866			199	6,726	4,689	3,714	(14)
125	8700	Distribution-Operation supervision and engineering	05310	Monthly Lines and service	3,950	5,575	4,337	5,124	2,782	2,883	3,576	3,604
126	8700	Distribution-Operation supervision and engineering	05312	Long Distance	853	937	483	404	185	128	78	68
127	8700	Distribution-Operation supervision and engineering	05314	Toll Free Long Distance	6,753	6,538	4,991	5,624	4,538	4,807	4,303	3,806
128	8700	Distribution-Operation supervision and engineering	05331	WAN/LAN/Internet Service	6,291	5,069	5,490	4,742	8,276	6,168	5,232	6,581
129	8700	Distribution-Operation supervision and engineering	05364	Cellular, radio, pager charges	10,973	11,010	11,146	11,348	12,345	10,875	10,403	9,895
130	8700	Distribution-Operation supervision and engineering	05376	Cell service for data uses	7,137	3,603	3,104	4,436	5,668	4,532	4,480	4,417
131	8700	Distribution-Operation supervision and engineering	05377	Cell phone equipment and accessories	2,761	1,202	565	353	3,304	994	2,850	2,149
132	8700	Distribution-Operation supervision and engineering	05399	Capitalized Telecom Costs	(17,716)	(15,081)	(14,014)	(15,266)	(18,895)	(15,163)	(16,101)	(16,075)
133	8700	Distribution-Operation supervision and engineering	05411	Meals and Entertainment	5,878	6,429	9,802	5,440	7,613	7,933	14,502	9,908
134	8700	Distribution-Operation supervision and engineering	05412	Spousal & Dependent Travel								
135	8700	Distribution-Operation supervision and engineering	05413	Transportation	495	-		461	3,382	730	3,001	4,391
136	8700	Distribution-Operation supervision and engineering	05414	Lodging	3,416	3,672	9,961	3,994	9,539	5,575	17,239	6,214
137	8700	Distribution-Operation supervision and engineering	05415	Membership Fees			242	309	150	-	3,158	2,722
138	8700	Distribution-Operation supervision and engineering	05416	Club Dues - Nondeductible							110	
139	8700	Distribution-Operation supervision and engineering	05417	Club Dues - Deductible			140		25	-	94	550
140	8700	Distribution-Operation supervision and engineering	05419	Misc Employee Expense						1,350	2,776	900
141	8700	Distribution-Operation supervision and engineering	05420	Employee Development			53	-	354			1,664
142	8700	Distribution-Operation supervision and engineering	05421	Training	7,585	18,957	18,960		54,008	16,922	6,308	-
143	8700	Distribution-Operation supervision and engineering	05424	Books & Manuals								
144	8700	Distribution-Operation supervision and engineering	05425	Regulatory Compliance Training				4,675				4,452
145	8700	Distribution-Operation supervision and engineering	05426	Safety Training					248		225	
146	8700	Distribution-Operation supervision and engineering	05427	Technical (Job Skills) Training					126	-		
147	8700	Distribution-Operation supervision and engineering	05429	Work Environment Training					853			
148	8700	Distribution-Operation supervision and engineering	06111	Contract Labor	11,423	9,556	16,113	2,048	3,358	25,603	8,703	23,365
149	8700	Distribution-Operation supervision and engineering	06121	Legal			53	-		61		
150	8700	Distribution-Operation supervision and engineering	07120	Environmental & Safety		32	266	92			61	3,974
151	8700	Distribution-Operation supervision and engineering	07421	Service Awards							-	
152	8700	Distribution-Operation supervision and engineering	07443	Uniforms	998	1,816	1,558	1,608	2,580	1,212	334	998
153	8700	Distribution-Operation supervision and engineering	07444	Uniforms Capitalized	(538)	(1,151)	(911)	(1,125)	(1,770)	(784)	(225)	(600)
154	8700	Distribution-Operation supervision and engineering	07495	Employee Broadcast and Publication							1,028	-
155	8700	Distribution-Operation supervision and engineering	07499	Misc Employee Welfare Exp	452	1,421	680	1,470	1,435	19,866	1,789	1,776
156	8700	Distribution-Operation supervision and engineering	07510	Association Dues					1,498	3,340	12,175	595
157	8700	Distribution-Operation supervision and engineering	07590	Misc General Expense			273		22		103	
158	8700	Distribution-Operation supervision and engineering	07601	Vehicle Cap Accrual	-	-	-	-	-	-	-	-
159	8700	Distribution-Operation supervision and engineering	07607	Telecom Cap Accrual	-	-	-	-	-	-	-	-
160	8700	Distribution-Operation supervision and engineering	07608	Uniform Cap Accrual	-	-	-	-	-	-	-	-
161	8700	Distribution-Operation supervision and engineering	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-
162	8700	Distribution-Operation supervision and engineering	09911	Reimbursements	(1,804)			(2,856)			(1,174)	
163	8710	Distribution load dispatching	04590	Utilities								
164	8711	Odorization	02001	Inventory Materials	10,531	5,936	20,947	10,736	16,286			
165	8711	Odorization	02004	Warehouse Loading Charge	53	297	1,047	537	733			
166	8711	Odorization	02005	Non-Inventory Supplies								
167	8740	Mains and Services Expenses	01000	Non-project Labor	158,676	187,555	215,534	155,199	174,983	240,888	151,576	164,422
168	8740	Mains and Services Expenses	01006	O&M Project Labor and Contra				12,638				

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Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
169	8740	Mains and Services Expenses	01008	Expense Labor Accrual	16,631	10,108	42,122	(23,848)	29,821	(73,591)	5,325	28,517
170	8740	Mains and Services Expenses	01014	Expense Labor Transfer Out								
171	8740	Mains and Services Expenses	02001	Inventory Materials	12,639	15,847	15,249	40,001	(4,650)	41,084	21,769	5,892
172	8740	Mains and Services Expenses	02004	Warehouse Loading Charge	63	792	762	2,000	(209)	1,879	980	265
173	8740	Mains and Services Expenses	02005	Non-Inventory Supplies	22,959	19,150	13,724	18,608	20,267	31,839	23,404	20,730
174	8740	Mains and Services Expenses	02006	Purchasing Card Charges	-	(168)						141
175	8740	Mains and Services Expenses	03002	Vehicle Lease Payments	105,760	105,017	103,242	103,314	101,743	81,566	101,743	100,889
176	8740	Mains and Services Expenses	03003	Capitalized transportation costs	(119,014)	(162,995)	(136,646)	(131,772)	(145,709)	(136,094)	(116,730)	(134,351)
177	8740	Mains and Services Expenses	03004	Vehicle Expense	93,475	184,363	158,252	113,909	137,689	127,181	120,565	109,563
178	8740	Mains and Services Expenses	03008	842 Vehicle Lease Expense								
179	8740	Mains and Services Expenses	03009	842 Variable Heavy Equip Lease Expense	850	6,784	16,518	2,493	2,485	5,347	2,882	3,238
180	8740	Mains and Services Expenses	04018	Safety							-	324
181	8740	Mains and Services Expenses	04040	Community Rel&Trade Shows								
182	8740	Mains and Services Expenses	04046	Customer Relations & Assist		56						
183	8740	Mains and Services Expenses	04201	Software Maintenance								
184	8740	Mains and Services Expenses	04301	Equipment Lease	33,922	32,876	35,010	35,010	35,327	34,529	33,536	34,263
185	8740	Mains and Services Expenses	04302	Heavy Equipment	17,696	61,087	25,805	15,001	13,134	34,427	12,069	23,874
186	8740	Mains and Services Expenses	04307	Heavy Equipment Capitalized	68,640	(100,577)	(87,547)	(60,064)	54,592	(81,375)	(56,786)	(69,446)
187	8740	Mains and Services Expenses	04309	Non-842 Heavy Equipment	(122,509)	1,882	12,000	8,786	(106,652)	8,733	9,457	9,488
188	8740	Mains and Services Expenses	04560	Non 842 Fleet Lease/Rents	7,305	2,717	3,886	3,715	3,136		(57,691)	2,969
189	8740	Mains and Services Expenses	04563	842 Variable Fleet Lease Expense	6,865	7,880	7,108	13,566	16,404	12,824	12,698	12,918
190	8740	Mains and Services Expenses	04582	Building Maintenance	4,256	600	3,219	2,872	922	1,207	623	9,107
191	8740	Mains and Services Expenses	04585	Railroad easements and crossings			7,884	-				585
192	8740	Mains and Services Expenses	04590	Utilities	6,228	5,058	7,258	5,955	4,963	6,230	4,858	6,831
193	8740	Mains and Services Expenses	05010	Office Supplies	886	1,325	1,406	2,656	950	417	68	394
194	8740	Mains and Services Expenses	05111	Postage/Delivery Services	(47)	491	138	453	242	14	121	16
195	8740	Mains and Services Expenses	05377	Cell phone equipment and accessories				37				
196	8740	Mains and Services Expenses	05399	Capitalized Telecom Costs				(22)				
197	8740	Mains and Services Expenses	05411	Meals and Entertainment	749	1,314	696	398	1,565	1,006	721	375
198	8740	Mains and Services Expenses	05413	Transportation	1,999	1,264	1,130	922	2,441	165	113	164
199	8740	Mains and Services Expenses	05414	Lodging	2,418	1,428	2,321	829	775	7,928		
200	8740	Mains and Services Expenses	05415	Membership Fees		212					(200)	
201	8740	Mains and Services Expenses	05419	Misc Employee Expense								
202	8740	Mains and Services Expenses	05420	Employee Development						91		
203	8740	Mains and Services Expenses	05421	Training	313		2,959		1,719	736	3,981	368
204	8740	Mains and Services Expenses	05427	Technical (Job Skills) Training								
205	8740	Mains and Services Expenses	05429	Work Environment Training	806	368	736		736		736	911
206	8740	Mains and Services Expenses	06111	Contract Labor	224,880	189,709	212,403	202,381	227,370	233,678	298,752	269,540
207	8740	Mains and Services Expenses	07120	Environmental & Safety	309			650	840	284		338
208	8740	Mains and Services Expenses	07443	Uniforms	4,714	2,317	2,421	1,839	5,984	1,941	4,209	14,358
209	8740	Mains and Services Expenses	07444	Uniforms Capitalized	(3,053)	(1,285)	(1,007)	(1,204)	(3,671)	(1,193)	(2,550)	(8,416)
210	8740	Mains and Services Expenses	07499	Misc Employee Welfare Exp	591	115	500	483	150	65		199
211	8740	Mains and Services Expenses	07590	Misc General Expense	1,110	251	777	207	110			1,315
212	8740	Mains and Services Expenses	07601	Vehicle Cap Accrual	-	-	-	-	-	-	-	-
213	8740	Mains and Services Expenses	07607	Telecom Cap Accrual				-				
214	8740	Mains and Services Expenses	07608	Uniform Cap Accrual	-	-	-	-	-	-	-	-
215	8750	Distribution-Measuring and regulating station expenses	01000	Non-project Labor	77,981	73,558	73,120	75,438	71,246	107,704	74,851	77,121
216	8750	Distribution-Measuring and regulating station expenses	01008	Expense Labor Accrual	7,509	(1,548)	10,815	1,159	8,591	(28,359)	4,505	12,249
217	8750	Distribution-Measuring and regulating station expenses	02001	Inventory Materials	7,036	6,117	22,269	6,858	125,862	10,396	1,298	
218	8750	Distribution-Measuring and regulating station expenses	02004	Warehouse Loading Charge	35	306	1,113	343	5,664	468	58	
219	8750	Distribution-Measuring and regulating station expenses	02005	Non-Inventory Supplies	1,297	4,344	366	2,331	1,315	191	1,920	79
220	8750	Distribution-Measuring and regulating station expenses	03003	Capitalized transportation costs	(182)	(97)		(20)	(7)	(1)	(133)	(44)
221	8750	Distribution-Measuring and regulating station expenses	03004	Vehicle Expense	668	216		74	27	5	219	167
222	8750	Distribution-Measuring and regulating station expenses	04302	Heavy Equipment		48						
223	8750	Distribution-Measuring and regulating station expenses	04307	Heavy Equipment Capitalized		(47)						
224	8750	Distribution-Measuring and regulating station expenses	04590	Utilities	506	368	613	503	406	681	498	974
225	8750	Distribution-Measuring and regulating station expenses	05010	Office Supplies			23		94	30		
226	8750	Distribution-Measuring and regulating station expenses	05111	Postage/Delivery Services	70	32	150		31			
227	8750	Distribution-Measuring and regulating station expenses	05377	Cell phone equipment and accessories			64					
228	8750	Distribution-Measuring and regulating station expenses	05399	Capitalized Telecom Costs			(36)					
229	8750	Distribution-Measuring and regulating station expenses	05411	Meals and Entertainment	319	93	108	392	89	28		32
230	8750	Distribution-Measuring and regulating station expenses	05412	Spousal & Dependent Travel	50							
231	8750	Distribution-Measuring and regulating station expenses	05413	Transportation	79	621	255	509	902		190	
232	8750	Distribution-Measuring and regulating station expenses	05414	Lodging			211	428	468			181
233	8750	Distribution-Measuring and regulating station expenses	05415	Membership Fees			66	-				
234	8750	Distribution-Measuring and regulating station expenses	05421	Training	310			166				
235	8750	Distribution-Measuring and regulating station expenses	06111	Contract Labor	10,000	11,553					4,000	-
236	8750	Distribution-Measuring and regulating station expenses	07120	Environmental & Safety								
237	8750	Distribution-Measuring and regulating station expenses	07421	Service Awards	50							
238	8750	Distribution-Measuring and regulating station expenses	07443	Uniforms		159		22				
239	8750	Distribution-Measuring and regulating station expenses	07444	Uniforms Capitalized		(101)		(6)				
240	8750	Distribution-Measuring and regulating station expenses	07499	Misc Employee Welfare Exp		117	-		386			
241	8750	Distribution-Measuring and regulating station expenses	07590	Misc General Expense				3,323	810			
242	8750	Distribution-Measuring and regulating station expenses	07601	Vehicle Cap Accrual	-	-		-	-	-	-	-
243	8750	Distribution-Measuring and regulating station expenses	07607	Telecom Cap Accrual			-					
244	8750	Distribution-Measuring and regulating station expenses	07608	Uniform Cap Accrual		-		-				
245	8760	Distribution-Measuring and regulating station expenses-Industrial	01000	Non-project Labor							283	
246	8760	Distribution-Measuring and regulating station expenses-Industrial	01008	Expense Labor Accrual							85	(85)
247	8760	Distribution-Measuring and regulating station expenses-Industrial	02005	Non-Inventory Supplies								
248	8770	Distribution-Measuring and regulating station expenses-City gate check stations	02005	Non-Inventory Supplies								
249	8770	Distribution-Measuring and regulating station expenses-City gate check stations	04580	Building Lease/Rents Capitalized							(4,455)	
250	8770	Distribution-Measuring and regulating station expenses-City gate check stations	04581	Non 842 Building Lease/Rents							6,500	
251	8770	Distribution-Measuring and regulating station expenses-City gate check stations	04590	Utilities	817	675	559	98	1,072	192	209	321
252	8770	Distribution-Measuring and regulating station expenses-City gate check stations	07499	Misc Employee Welfare Exp								



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253	8770	Distribution-Measuring and regulating station expenses-City gate check stations	07603	Rent Cap Accrual							-	
254	8780	Meter and house regulator expenses	01000	Non-project Labor	67,174	55,828	41,509	46,625	44,399	69,903	50,998	47,314
255	8780	Meter and house regulator expenses	01008	Expense Labor Accrual	3,108	(3,971)	1,215	2,558	5,547	(17,209)	3,649	5,992
256	8780	Meter and house regulator expenses	02005	Non-Inventory Supplies	2,347	247	159	874	632	54	537	284
257	8780	Meter and house regulator expenses	03003	Capitalized transportation costs	(574)	196						
258	8780	Meter and house regulator expenses	03004	Vehicle Expense	928	(305)	-					
259	8780	Meter and house regulator expenses	04040	Community Rel&Trade Shows								
260	8780	Meter and house regulator expenses	04302	Heavy Equipment				42				
261	8780	Meter and house regulator expenses	04307	Heavy Equipment Capitalized				(41)				
262	8780	Meter and house regulator expenses	04582	Building Maintenance			184		(174)			
263	8780	Meter and house regulator expenses	04590	Utilities	1,328	659	2,163	1,201	606	1,932	440	2,103
264	8780	Meter and house regulator expenses	05010	Office Supplies	175	252	(252)	225				
265	8780	Meter and house regulator expenses	05111	Postage/Delivery Services	13	90	139	194	14			14
266	8780	Meter and house regulator expenses	05411	Meals and Entertainment	181	787	748	651	130	509	292	49
267	8780	Meter and house regulator expenses	05413	Transportation		2,353	1,118	422			140	506
268	8780	Meter and house regulator expenses	05414	Lodging		1,428	2,856	2,856	1,159	1,928	234	
269	8780	Meter and house regulator expenses	07443	Uniforms		14	(14)	80				
270	8780	Meter and house regulator expenses	07444	Uniforms Capitalized		(9)	8	(44)				
271	8780	Meter and house regulator expenses	07499	Misc Employee Welfare Exp	279							
272	8780	Meter and house regulator expenses	07590	Misc General Expense				2,393	315		(2,708)	
273	8780	Meter and house regulator expenses	07601	Vehicle Cap Accrual	-	-	-	-				
274	8780	Meter and house regulator expenses	07608	Uniform Cap Accrual		-						
275	8790	Customer installations expenses	02005	Non-Inventory Supplies								
276	8800	Distribution-Other expenses	02005	Non-Inventory Supplies	896		3,239	45				
277	8800	Distribution-Other expenses	03003	Capitalized transportation costs	(63)		(16)	(244)	(7)			
278	8800	Distribution-Other expenses	03004	Vehicle Expense	93		30	343	16			
279	8800	Distribution-Other expenses	04582	Building Maintenance		50						
280	8800	Distribution-Other expenses	04599	Capitalized Utility Costs		(31)						
281	8800	Distribution-Other expenses	05010	Office Supplies	322							
282	8800	Distribution-Other expenses	05111	Postage/Delivery Services	-			24				
283	8800	Distribution-Other expenses	07443	Uniforms	200	44						
284	8800	Distribution-Other expenses	07444	Uniforms Capitalized	(121)	(27)						
285	8800	Distribution-Other expenses	07499	Misc Employee Welfare Exp	112							
286	8800	Distribution-Other expenses	07590	Misc General Expense				42				
287	8800	Distribution-Other expenses	07601	Vehicle Cap Accrual	-	-	-	-	-			
288	8800	Distribution-Other expenses	07608	Uniform Cap Accrual	-	-						
289	8800	Distribution-Other expenses	07609	Utility Cap Accrual		-						
290	8810	Distribution-Rents	02005	Non-Inventory Supplies								
291	8810	Distribution-Rents	04307	Heavy Equipment Capitalized	(26,324)	(19,744)	(19,744)	(19,744)	(19,744)	(25,715)	(20,161)	(19,744)
292	8810	Distribution-Rents	04308	842 Locusview Lease Expense	26,862	20,147	20,147	20,147	20,147	26,240	20,147	20,147
293	8810	Distribution-Rents	04309	Non-842 Heavy Equipment							426	
294	8810	Distribution-Rents	04561	842 Variable Real Estate Lease Expense	83	87	(6)	120	65	61	124	450
295	8810	Distribution-Rents	04578	842 Real Estate Lease Expense	55,773	55,773	55,773	55,773	55,773	55,773	55,773	55,773
296	8810	Distribution-Rents	04580	Building Lease/Rents Capitalized	(34,349)	(34,081)	(31,120)	(40,683)	(34,239)	(36,286)	(37,516)	(36,327)
297	8810	Distribution-Rents	04581	Non 842 Building Lease/Rents		400		9,367		500	200	500
298	8810	Distribution-Rents	04582	Building Maintenance	15,598	14,664	20,578	23,293	9,830	8,779	12,768	9,309
299	8810	Distribution-Rents	04590	Utilities	243	63	150	61	60	61	61	61
300	8810	Distribution-Rents	04599	Capitalized Utility Costs	(8,566)	(8,008)	(12,001)	(11,783)	(5,584)	(4,225)	(7,529)	(5,264)
301	8810	Distribution-Rents	07603	Rent Cap Accrual	-	-	-	-	-	-	-	-
302	8810	Distribution-Rents	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-
303	8850	Distribution-Maintenance supervision and engineering	05111	Postage/Delivery Services	29		29	30	97			
304	8870	Distribution-Maint of mains	01000	Non-project Labor	3,340	1,843	2,025	3,588	820	4,138	3,016	3,134
305	8870	Distribution-Maint of mains	01008	Expense Labor Accrual	(19)	(524)	367	781	(1,261)	157	215	505
306	8870	Distribution-Maint of mains	02005	Non-Inventory Supplies		38	89		168	58	-	
307	8870	Distribution-Maint of mains	03003	Capitalized transportation costs	(169)	(42)						
308	8870	Distribution-Maint of mains	03004	Vehicle Expense	250	69						
309	8870	Distribution-Maint of mains	04302	Heavy Equipment								
310	8870	Distribution-Maint of mains	04307	Heavy Equipment Capitalized								
311	8870	Distribution-Maint of mains	05411	Meals and Entertainment	523	528	1,183	763	346	539	341	864
312	8870	Distribution-Maint of mains	05413	Transportation	1,275	1,489	616	1,824	3,755	611	1,055	
313	8870	Distribution-Maint of mains	05414	Lodging						1,229		116
314	8870	Distribution-Maint of mains	05429	Work Environment Training			90					
315	8870	Distribution-Maint of mains	06111	Contract Labor	(7,103)							
316	8870	Distribution-Maint of mains	07120	Environmental & Safety			231					
317	8870	Distribution-Maint of mains	07443	Uniforms					167			
318	8870	Distribution-Maint of mains	07444	Uniforms Capitalized					(115)			
319	8870	Distribution-Maint of mains	07499	Misc Employee Welfare Exp								
320	8870	Distribution-Maint of mains	07601	Vehicle Cap Accrual	-	-						
321	8870	Distribution-Maint of mains	07608	Uniform Cap Accrual					-			
322	8890	Maintenance of measuring and regulating station equipment-General	01000	Non-project Labor		787						
323	8890	Maintenance of measuring and regulating station equipment-General	01008	Expense Labor Accrual		275	(275)					
324	8890	Maintenance of measuring and regulating station equipment-General	02005	Non-Inventory Supplies	2,503	2,698	3,002	1,123	4,016	1,549	4,886	2,773
325	8890	Maintenance of measuring and regulating station equipment-General	03003	Capitalized transportation costs					(150)			
326	8890	Maintenance of measuring and regulating station equipment-General	03004	Vehicle Expense					219			
327	8890	Maintenance of measuring and regulating station equipment-General	04582	Building Maintenance					186			
328	8890	Maintenance of measuring and regulating station equipment-General	05010	Office Supplies						155		
329	8890	Maintenance of measuring and regulating station equipment-General	05111	Postage/Delivery Services				31				
330	8890	Maintenance of measuring and regulating station equipment-General	06111	Contract Labor				15,000	12,500	12,500	21,897	52,574
331	8890	Maintenance of measuring and regulating station equipment-General	07601	Vehicle Cap Accrual					-			
332	8900	Maintenance of measuring and regulating station equipment-Industrial	06111	Contract Labor		-						
333	8910	Maintenance of measuring and regulating station equipment-City gate check stations	01000	Non-project Labor								
334	8910	Maintenance of measuring and regulating station equipment-City gate check stations	01008	Expense Labor Accrual								
335	8920	Maintenance of services	01000	Non-project Labor		168	1,427	198				
336	8920	Maintenance of services	01008	Expense Labor Accrual	(49)	59	654	(614)	(99)			

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Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
337	8920	Maintenance of services	02005	Non-Inventory Supplies				12				
338	8920	Maintenance of services	03003	Capitalized transportation costs				(43)				
339	8920	Maintenance of services	03004	Vehicle Expense				60				
340	8920	Maintenance of services	07590	Misc General Expense				11				
341	8920	Maintenance of services	07601	Vehicle Cap Accrual				-				
342	8930	Maintenance of meters and house regulators	06111	Contract Labor				28,800	46,000	25,500	15,000	-
343	8940	Distribution-Maintenance of other equipment	02005	Non-Inventory Supplies	459	55	2,593	747	966	378		
344	9020	Customer accounts-Meter reading expenses	01000	Non-project Labor	21,088	23,399	24,559	19,905	22,019	27,148	17,159	21,986
345	9020	Customer accounts-Meter reading expenses	01008	Expense Labor Accrual	2,143	809	4,090	(2,327)	4,360	(9,788)	623	4,746
346	9020	Customer accounts-Meter reading expenses	04212	IT Equipment								
347	9020	Customer accounts-Meter reading expenses	04562	842 Variable Tower Lease Expense	1,881	1,954	1,996	1,996	2,182	2,290	2,381	2,461
348	9020	Customer accounts-Meter reading expenses	04590	Utilities	545	368	480	450	459	457	449	450
349	9020	Customer accounts-Meter reading expenses	05331	WAN/LAN/Internet Service	3,000							
350	9020	Customer accounts-Meter reading expenses	05351	AMI Tower Rent								
351	9020	Customer accounts-Meter reading expenses	05353	842 Tower Lease Expense	26,383	26,379	26,380	26,382	26,385	26,392	26,397	26,397
352	9020	Customer accounts-Meter reading expenses	05399	Capitalized Telecom Costs	(1,708)							
353	9020	Customer accounts-Meter reading expenses	05414	Lodging								
354	9020	Customer accounts-Meter reading expenses	06111	Contract Labor								
355	9020	Customer accounts-Meter reading expenses	07607	Telecom Cap Accrual	-							
356	9030	Customer accounts-Customer records and collections expenses	01000	Non-project Labor	17,148	23,439	36,830	34,165	39,219	52,744	27,059	28,433
357	9030	Customer accounts-Customer records and collections expenses	01008	Expense Labor Accrual	1,437	2,202	10,211	(1,332)	8,410	(16,702)	(673)	4,677
358	9030	Customer accounts-Customer records and collections expenses	02005	Non-Inventory Supplies				33	107	102		
359	9030	Customer accounts-Customer records and collections expenses	03003	Capitalized transportation costs			(65)	(56)	66			
360	9030	Customer accounts-Customer records and collections expenses	03004	Vehicle Expense			112	91	(106)			
361	9030	Customer accounts-Customer records and collections expenses	04040	Community Rel&Trade Shows	156							
362	9030	Customer accounts-Customer records and collections expenses	04590	Utilities		26		235	25		(25)	
363	9030	Customer accounts-Customer records and collections expenses	05010	Office Supplies	272		64	178	444	25	(92)	
364	9030	Customer accounts-Customer records and collections expenses	05111	Postage/Delivery Services	41		59		(59)			
365	9030	Customer accounts-Customer records and collections expenses	05351	AMI Tower Rent								3,895
366	9030	Customer accounts-Customer records and collections expenses	05411	Meals and Entertainment	170	1,376	1,726	1,372	3,166	944	1,070	747
367	9030	Customer accounts-Customer records and collections expenses	05413	Transportation					184		92	-
368	9030	Customer accounts-Customer records and collections expenses	05414	Lodging			-	-	404		595	
369	9030	Customer accounts-Customer records and collections expenses	06112	Collection Fees	-	33	33	33	25		126	94
370	9030	Customer accounts-Customer records and collections expenses	06116	Bill Print Fees	75,296	80,880	79,200	112,936	108,544	72,262	69,564	75,303
371	9030	Customer accounts-Customer records and collections expenses	07499	Misc Employee Welfare Exp				213	382		428	
372	9030	Customer accounts-Customer records and collections expenses	07601	Vehicle Cap Accrual			-	-	-			
373	9040	Customer accounts-Uncollectible accounts	09927	Cust Uncol Acct-Write Off	131,957	189,036	231,477	80,846	(40,986)	40,674	(49,312)	58,188
374	9090	Customer service-Operating informational and instructional advertising expense	01000	Non-project Labor	9,822	9,823	9,823	9,823	9,823	14,735	9,823	9,823
375	9090	Customer service-Operating informational and instructional advertising expense	01008	Expense Labor Accrual	982	0	1,473	0	1,473	(3,929)	491	1,473
376	9090	Customer service-Operating informational and instructional advertising expense	02001	Inventory Materials			1,267	1,993	168	122	100	130
377	9090	Customer service-Operating informational and instructional advertising expense	02004	Warehouse Loading Charge			63	100	8	5	5	6
378	9090	Customer service-Operating informational and instructional advertising expense	02005	Non-Inventory Supplies								
379	9090	Customer service-Operating informational and instructional advertising expense	03003	Capitalized transportation costs	(12)	(12)						(13)
380	9090	Customer service-Operating informational and instructional advertising expense	03004	Vehicle Expense	19	19						19
381	9090	Customer service-Operating informational and instructional advertising expense	04022	Promo Sales, Misc								
382	9090	Customer service-Operating informational and instructional advertising expense	04040	Community Rel&Trade Shows	1,226	1,752			549		519	491
383	9090	Customer service-Operating informational and instructional advertising expense	04046	Customer Relations & Assist	619				477			
384	9090	Customer service-Operating informational and instructional advertising expense	05010	Office Supplies		244						
385	9090	Customer service-Operating informational and instructional advertising expense	05411	Meals and Entertainment		520	790	78	1,802	1,599	121	1,355
386	9090	Customer service-Operating informational and instructional advertising expense	05413	Transportation		499	1,319	-	289	1,338	286	595
387	9090	Customer service-Operating informational and instructional advertising expense	05414	Lodging		362	1,015	-	998	501	211	189
388	9090	Customer service-Operating informational and instructional advertising expense	05415	Membership Fees	110	274						
389	9090	Customer service-Operating informational and instructional advertising expense	05417	Club Dues - Deductible					39	-		
390	9090	Customer service-Operating informational and instructional advertising expense	05419	Misc Employee Expense		34					273	365
391	9090	Customer service-Operating informational and instructional advertising expense	05420	Employee Development								
392	9090	Customer service-Operating informational and instructional advertising expense	05426	Safety Training			170					
393	9090	Customer service-Operating informational and instructional advertising expense	07499	Misc Employee Welfare Exp						140		
394	9090	Customer service-Operating informational and instructional advertising expense	07590	Misc General Expense	510	842	1,852	521	965	520	482	1,856
395	9090	Customer service-Operating informational and instructional advertising expense	07601	Vehicle Cap Accrual	-	-						-
396	9100	Customer service-Miscellaneous customer service	02005	Non-Inventory Supplies			1,002					
397	9110	Sales-Supervision	01000	Non-project Labor	8,102	8,102	8,116	8,130	8,130	12,926	1,203	1,203
398	9110	Sales-Supervision	01008	Expense Labor Accrual	810	0	1,222	7	1,219	(3,130)	(1,793)	181
399	9110	Sales-Supervision	04040	Community Rel&Trade Shows	126		68	54				
400	9110	Sales-Supervision	05010	Office Supplies		253						
401	9110	Sales-Supervision	05111	Postage/Delivery Services								
402	9110	Sales-Supervision	05411	Meals and Entertainment	428	202	235	1,212	364	154	283	1,142
403	9110	Sales-Supervision	05412	Spousal & Dependent Travel					69			
404	9110	Sales-Supervision	05413	Transportation	1,195	1,029	2,048	1,364	610	1,769	1,054	1,333
405	9110	Sales-Supervision	05414	Lodging		157	2,184	538	427	388	808	406
406	9110	Sales-Supervision	05420	Employee Development	125							
407	9110	Sales-Supervision	07499	Misc Employee Welfare Exp					291	-		
408	9120	Sales-Demonstrating and selling expenses	04040	Community Rel&Trade Shows			530					
409	9120	Sales-Demonstrating and selling expenses	04044	Advertising	-	618						475
410	9120	Sales-Demonstrating and selling expenses	04046	Customer Relations & Assist	2,325	2,412	254		1,357	1,169	9,217	2,528
411	9120	Sales-Demonstrating and selling expenses	05411	Meals and Entertainment	98							
412	9120	Sales-Demonstrating and selling expenses	07510	Association Dues	5,000	20,000			1,000	1,740		
413	9130	Sales-Advertising expenses	04021	Promo Other, Misc								
414	9130	Sales-Advertising expenses	04040	Community Rel&Trade Shows	487	3,511	8,703	589		1,049	3,561	
415	9130	Sales-Advertising expenses	04044	Advertising	2,489	3,229	4,100	4,663	2,169	4,122	2,500	5,198
416	9130	Sales-Advertising expenses	04046	Customer Relations & Assist								
417	9130	Sales-Advertising expenses	05010	Office Supplies								
418	9160	Sales-Miscellaneous sales expenses	04046	Customer Relations & Assist				1,060	265			
419	9200	A&G-Administrative & general salaries	01000	Non-project Labor	13,490	13,490	14,001	14,512	14,512	21,769	14,512	16,397
420	9200	A&G-Administrative & general salaries	01008	Expense Labor Accrual	1,349	(0)	2,279	256	2,177	(5,805)	726	3,025

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Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
421	9210	A&G-Office supplies & expense	03003	Capitalized transportation costs								
422	9210	A&G-Office supplies & expense	03004	Vehicle Expense								
423	9210	A&G-Office supplies & expense	04046	Customer Relations & Assist	395	395	395	395	395	395	395	725
424	9210	A&G-Office supplies & expense	04070	Insurance-Other	2,138	1,004	102	342	-	204		
425	9210	A&G-Office supplies & expense	04582	Building Maintenance							186	
426	9210	A&G-Office supplies & expense	05010	Office Supplies								
427	9210	A&G-Office supplies & expense	05111	Postage/Delivery Services		9						
428	9210	A&G-Office supplies & expense	05377	Cell phone equipment and accessories				13				
429	9210	A&G-Office supplies & expense	05411	Meals and Entertainment	138				1	365		
430	9210	A&G-Office supplies & expense	05413	Transportation			545	256	116	169		
431	9210	A&G-Office supplies & expense	05414	Lodging				380	114	1,129		
432	9210	A&G-Office supplies & expense	07499	Misc Employee Welfare Exp		19				22		186
433	9210	A&G-Office supplies & expense	07510	Association Dues	612	(256)						
434	9210	A&G-Office supplies & expense	07590	Misc General Expense								
435	9210	A&G-Office supplies & expense	07592	Vendor Comp Sales Tax	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)
436	9210	A&G-Office supplies & expense	07601	Vehicle Cap Accrual								
437	9230	A&G-Outside services employed	06111	Contract Labor	(259)			2,587	(1,862)	3,512		
438	9230	A&G-Outside services employed	06121	Legal	6,645	41,350	7,355	22,807	24,135	1,449	21,570	23,650
439	9240	A&G-Property insurance	04069	Blueflame Property Insurance	33,886	33,886	35,206	35,206	35,206	35,206	35,206	35,206
440	9240	A&G-Property insurance	04072	Insurance Capitalized	(22,287)	(21,662)	(21,852)	(22,996)	(22,616)	(23,205)	(23,507)	(23,377)
441	9250	A&G-Injuries & damages	01293	Workers Comp Benefits Projects				112				
442	9250	A&G-Injuries & damages	02005	Non-Inventory Supplies				75	106			
443	9250	A&G-Injuries & damages	04018	Safety	37	15	45					
444	9250	A&G-Injuries & damages	04070	Insurance-Other	3,116	3,116	3,116	3,621	3,543	3,543	3,543	3,543
445	9250	A&G-Injuries & damages	05418	Settlement	1,985	177,806	137	5,065	1,494	4,710	23,979	
446	9250	A&G-Injuries & damages	07499	Misc Employee Welfare Exp			32	12	84			
447	9260	A&G-Employee pensions and benefits	01202	Pension Benefits Load	17,179	15,682	19,715	13,961	17,298	15,546	14,756	16,262
448	9260	A&G-Employee pensions and benefits	01203	OPEB Benefits Load	8,999	8,215	10,323	7,332	9,074	8,161	7,747	8,555
449	9260	A&G-Employee pensions and benefits	01251	Medical Benefits Load	93,654	85,492	107,464	76,165	94,342	84,803	80,496	88,767
450	9260	A&G-Employee pensions and benefits	01253	Medical Benefits Projects				2,280				
451	9260	A&G-Employee pensions and benefits	01257	ESOP Benefits Load	21,203	19,355	24,331	17,238	21,355	19,194	18,219	20,086
452	9260	A&G-Employee pensions and benefits	01259	ESOP Benefits Projects				517				
453	9260	A&G-Employee pensions and benefits	01262	Other Benefits Projects				-				
454	9260	A&G-Employee pensions and benefits	01263	RSP FACC Benefits Load	7,191	6,564	8,247	5,862	7,253	6,525	6,194	6,844
455	9260	A&G-Employee pensions and benefits	01265	RSP FACC Benefits Projects				173				
456	9260	A&G-Employee pensions and benefits	01266	Life Benefits Load	1,040	950	1,194	846	1,048	942	894	987
457	9260	A&G-Employee pensions and benefits	01268	Life Benefits Projects				25				
458	9260	A&G-Employee pensions and benefits	01269	LTD Benefits Load	3,329	3,039	3,819	2,708	3,354	3,015	2,862	3,157
459	9260	A&G-Employee pensions and benefits	01271	LTD Benefits Projects				81				
460	9260	A&G-Employee pensions and benefits	01291	Pension Benefits Projects				420				
461	9260	A&G-Employee pensions and benefits	01292	OPEB Benefits Projects				217				
462	9260	A&G-Employee pensions and benefits	01294	NSC-OPEB Benefits Load	(86,695)	(79,147)	(99,578)	(70,146)	(87,100)	(78,165)	(74,183)	(81,458)
463	9260	A&G-Employee pensions and benefits	01296	NSC-OPEB Benefits Projects				(2,159)				
464	9260	A&G-Employee pensions and benefits	01297	NSC-Pension Benefits Load	(9,781)	(8,929)	(11,225)	(7,949)	(9,849)	(8,852)	(8,402)	(9,260)
465	9260	A&G-Employee pensions and benefits	01299	NSC-Pension Benefits Projects				(239)				
466	9260	A&G-Employee pensions and benefits	05411	Meals and Entertainment	108	789	107	763	393	603	20	44
467	9260	A&G-Employee pensions and benefits	07443	Uniforms	8,307	12,140	3,299	1,697	1,382	923	595	841
468	9260	A&G-Employee pensions and benefits	07444	Uniforms Capitalized	(4,770)	(7,490)	(1,718)	(1,017)	(637)	(617)	(215)	(558)
469	9260	A&G-Employee pensions and benefits	07449	Non-Qual Retirement Exp								
470	9260	A&G-Employee pensions and benefits	07452	Variable Pay & Mgmt Incentive Plans		(4,263)	4,263					
471	9260	A&G-Employee pensions and benefits	07454	VPP & MIP - Capital Credit		2,435	(2,435)					
472	9260	A&G-Employee pensions and benefits	07458	Restricted Stock - Long Term Incentive Plan - Performance Based	1,087	982	1,087	1,052	3,687	1,373	4,677	(2,041)
473	9260	A&G-Employee pensions and benefits	07460	RSU-Long Term Incentive Plan - Time Lapse					11,952			
474	9260	A&G-Employee pensions and benefits	07499	Misc Employee Welfare Exp	(33)	765	948	1,905	53	1,331	260	222
475	9260	A&G-Employee pensions and benefits	07608	Uniform Cap Accrual	-	-	-	-	-	-	-	-
476	9270	A&G-Franchise requirements	04044	Advertising								
477	9270	A&G-Franchise requirements	07590	Misc General Expense								
478	9280	A&G-Regulatory commission expenses	06111	Contract Labor					1,162			
479	9280	A&G-Regulatory commission expenses	06121	Legal								
480	9280	A&G-Regulatory commission expenses	07590	Misc General Expense	10,061	10,061	10,061	10,061	10,061	10,061	10,061	10,061
481	9302	Miscellaneous general expenses	05411	Meals and Entertainment	(3,075)							
482	9302	Miscellaneous general expenses	05415	Membership Fees	1,140	(925)	-	1,500				
483	9302	Miscellaneous general expenses	07499	Misc Employee Welfare Exp				112				
484	9302	Miscellaneous general expenses	07510	Association Dues	10,798	(20,430)	10,974	14,024	4,974	4,974	18,124	4,974
485	9302	Miscellaneous general expenses	07590	Misc General Expense		360		105	375		(360)	
Total KY Direct Expenses					1,398,179	1,630,828	1,711,625	1,424,672	1,550,625	1,379,211	1,285,626	1,413,005
Div091 Expenses Allocated to KY Based on Composite Allocation Factor					434,285	371,944	491,346	390,924	496,623	398,551	508,002	518,844
Shared Services Expenses Allocated to Div091 then Allocated to KY based on Customer Count Allocation Factor					201,212	178,519	193,939	168,970	199,192	199,204	185,239	195,277
Shared Services Expenses Allocated to Div091 then Allocated to KY based on Composite Allocation Factor					525,119	395,355	581,901	442,838	702,181	279,491	627,513	549,486
Total Expenses Direct and Allocated for KY					2,558,795	2,576,646	2,978,811	2,427,405	2,948,620	2,256,456	2,606,379	2,676,612

Line No.	SEP-23	OCT-23	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
0	6,590	1,786	1,868	2,618	43,093	1,507	1,729	302		2,376	1,102
2	1,620	(2,223)	236	(871)	(36)	166	175	(627)	(151)	396	(120)
3					8,938						
4					447						
5	111	127	3,602	2,762	19,907	1,054	2,744	114		510	308
6					28						
7					-						
8	59,060	12,540	-	-	93,062		1,320	660	779		882
9					400	1,272				100	745
10		287	281	769	7,167	851	2,064	167		1,491	710
11	(70)	172	24	(68)	(100)	212	588	(845)	(84)	249	(71)
12	129	676	262	1,496	6,391	404	1,160	923	612	420	180
13					-				424		
14	175	174	152	162	2,117	196	213	189	169	179	168
15	2,458	1,678	1,178	1,580	23,586	1,936	1,133	2,155	4,629	6,324	1,326
16	(101)	(222)	(182)	(561)	(166)	511	(265)	568	1,700	(1,723)	(722)
17	405			423	2,211			648	218		68
18	82	79	82	82	1,909	82	82	141	102	64	84
19	(74)	(68)	(70)	(70)	(1,708)	(70)	(70)	(121)	(88)	(55)	(72)
20	-				-						
21					766						
22	69				1,069		122		57		
23	35	(35)			-		55	(55)	34	(34)	
24			312	1,738	2,126	435	2,041	379	53		
25	52	133	92	113	2,188	151	173	195	160	143	114
26					-		749				
27	810		2,493	9,167	29,127	12,695	15,536	645			
28	333	(405)	1,745	(217)	524	3,550	1,913	(6,669)	(323)		
29	119	67	738	863	5,302	107	793		12	7,140	
30	186	157	148	257	2,210	313	323	232	207	158	135
31	(84)	(465)			(1,338)	(393)	(64)		(69)	(146)	
32	500	540			3,870	457	74		80	170	-
33	77	82	133	481	13,260	826	1,432	1,243	750	500	147
34	-				-						
35					79						
36					52						
37					(30)						
38					629						
39					-						
40		40		15	85						
41	3,507	2,857	2,232	3,820	24,090	1,718	3,143	4,732	3,646	4,842	1,227
42	937	(39)	(152)	(926)	232	50	727	952	(178)	(1,381)	(500)
43	16,007	11,981	12,323	27,998	179,688	21,126	12,279	13,543	13,424	17,735	15,013
44	3,138	(815)	1,437	(3,960)	(325)	3,784	(2,925)	1,246	1,283	(5,098)	798
45		343	1,804	302	8,423	769	79	23			406
46		17	9	3	226	8	1	0			4
47					-	22					
48					(108)						
49					259						
50					65						
51	113		16	550	1,293		12	156		610	318
52					1,365					20	
53	206		178	134	1,700		372	190		559	314
54	180				465						
55					1,075			350			
56					99						
57					-						
58	38	36	39	41	468	40	40	39	37	36	42
59	7,613	22,415	18,152	15,486	143,431	2,301	9,259	10,239	8,456	11,342	8,631
60	3,074	9,643	(743)	(10,126)	852	(1,661)	3,247	953	(46)	(3,183)	267
61	1,032	8,369			9,401						
62	10	418			429						
63	3,674	1,306	1,301	261	14,316	494	654	643	1,061	3,654	1,221
64		(39)	(2)		(939)	(5)	(59)	(7)	(7)	(24)	(247)
65		206	15		4,012	30	411	37	36	106	685
66	430	1,105	3,047	1,944	23,015	-	(666)			2,501	319
67	(421)	(1,083)	(2,986)	(1,905)	(22,555)		652			(2,451)	(312)
68					139				87		
69	1,001	2,712	2,548	2,004	25,467	2,057	1,437	2,234	2,093	2,249	2,087
70	(547)	(2,332)	(2,191)	(1,723)	(16,425)	(1,769)	(1,236)	(1,921)	(1,874)	(1,934)	(1,795)
71	404				636		32				24
72					10						
73					(6)						
74	109	110			598			85		205	87
75					-		368				
76					-						
77		1,658	4,202	504	6,929				212	505	482
78		(1,426)	(3,613)	(433)	(5,681)				(38)	(114)	(174)
79				33	283						
80	640				1,411			150			
81		-	-		-	-	-	-	-	-	-
82					-						
83					-				-	-	-
84	-				-						



Line No.	SEP-23	OCT-23	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
85	572	739			2,365	659	151				
86	286	157	(443)		(11)	264	(196)				
87	467	565	777	748	7,429	919	721	629	858	820	809
88	2,577	6,417	4,378	3,000	39,539		1,030	508	818	3,259	3,403
89	133	2,562	(786)	(2,565)	(611)	(500)	464	(209)	237	52	308
90					164						
91					(96)						
92					-						
93	39,106	38,137	36,173	81,733	550,725	66,473	46,086	50,374	54,054	76,123	60,116
94	666,890	657,832	684,647	971,355	8,307,509	643,634	707,469	668,499	659,466	986,945	688,140
95	(676,728)	(664,149)	(693,921)	(987,427)	(8,404,991)	(654,471)	(681,033)	(670,620)	(668,175)	(998,657)	(687,006)
96					-		-	2,828	7,336	10,071	
97	3,705	3,329	2,439	(11,699)	(249)	12,967	(4,664)	3,262	7,245	(19,745)	2,342
98	405,629	403,360	424,244	646,378	5,242,764	447,268	397,768	384,308	393,184	556,205	409,920
99	(395,792)	(397,042)	(414,970)	(630,305)	(5,145,282)	(436,432)	(424,203)	(382,186)	(384,475)	(544,493)	(411,054)
100					-			(2,828)	(7,336)	(10,071)	
101					93		31,667				
102					5		317				
103	5,670	1,568	2,370	1,270	46,919	3,717	4,769	2,264	2,649	3,401	1,197
104	(2,106)	(1,789)	(965)	(116)	(14,071)	(419)	(90)	(256)	(2,298)	(239)	(90)
105	3,173	2,880	1,328	201	21,020	636	182	312	2,583	277	255
106					47,717						54,855
107	80	42	1,843	1,297	8,133	2,459	3,554	4,304	1,400	41	454
108	8,610	2,572	5,991	528	24,760	246	481	3,847	914	870	5,036
109					-			42			
110					10						
111	259				259						
112					-						-
113	5,438	90	560	186	20,344	90	90	214	1,522	1,763	298
114	100	1,107	1,112	1,149	12,789	1,155	1,081	1,155	-	649	
115		289	144	276	942		38		610		92
116	(98)	(1,368)	(1,231)	(1,397)	(13,456)	(1,131)	(1,097)	(1,131)	(598)	(636)	(90)
117	10	5	8	24	2,841	6	8	15	48	17	17
118					393						
119	27,561	26,075	16,357	24,166	321,825	32,683	16,268	54,703	42,148	26,476	28,953
120	8,389	11,152	10,796	7,420	106,070	7,890	7,648	8,399	6,564	11,219	7,795
121	(23,011)	(32,016)	(23,352)	(27,164)	(292,606)	(34,893)	(20,568)	(54,268)	(41,893)	(32,418)	(31,604)
122	7,013	4,760	6,050	10,101	76,140	11,518	13,941	11,766	11,925	9,443	8,841
123	986	671	1,067	501	7,939	867	1,316	507	992	542	846
124	(3,598)	-	-	(2,358)	12,223	(2,412)	(1,449)	(2,482)	(2,393)	(2,344)	(2,268)
125	3,592	3,449	3,374	2,516	44,763	2,790	2,791	2,790	2,790	3,123	3,126
126	51	62	281	164	3,694	96	325	509	214	150	71
127	3,817	3,795	5,277	4,374	58,625	2,618	3,277	3,222	4,521	4,063	521
128	5,594	5,461	6,379	6,289	71,572	5,846	6,039	6,542	6,749	5,406	7,816
129	10,264	11,591	10,399	10,520	130,769	3,782	9,100	9,830	9,795	9,618	9,674
130	4,833	4,619	5,146	4,503	56,477	2,912	4,714	4,451	4,073	4,560	5,099
131	743	845	1,130	289	17,185	661	1,038	608	542	1,383	398
132	(15,060)	(22,329)	(22,727)	(20,741)	(209,168)	(13,752)	(20,367)	(20,830)	(20,596)	(20,717)	(22,457)
133	8,693	4,222	6,524	5,128	92,074	6,344	7,039	5,489	8,386	9,401	6,539
134				384	384						
135	531	439	1,797	1,043	16,269	1,405	772	1,873	1,100	2,046	5,155
136	3,102	973	1,271	1,692	66,648	4,407	3,810	2,994	9,409	4,123	12,021
137			45	1,635	8,261	1,000	1,434	59	234	32	653
138					110	50				750	
139	10				819						
140		7,585			12,611	(14,070)	14,720	(6,585)		550	
141	50		49		2,170		200	175	425		
142	2,149				124,888	14,451	434				525
143					-				196	-	
144			4,452		13,579						
145					473			19			
146					126						
147					853						
148	132,598	5,853	4,163	3,651	246,434	9,615	135,132	59,101	63,807	50,649	102,139
149					113	54		150			
150	1,101	214	695	426	6,859	621	79	37	849		516
151					-						
152	2,082	729	1,610	849	16,373	1,195	49	330		607	978
153	(1,363)	(627)	(1,384)	(730)	(11,209)	(1,028)	(30)	(188)		(353)	(766)
154					1,028						
155	941	1,242	1,010	4,962	37,044	910	4,138	3,757	1,641	1,596	1,677
156	(1,000)	5,921	1,100	2,000	25,629	1,647	200	11,285	-	292	425
157			254	(127)	526	11				19	311
158	-	-	-	-	-	-	-	-	-	-	-
159	-				-		-	-			
160	-				-		-	-			-
161	-				-						
162		(611)			(6,444)	(1,083)			(1,845)		
163					-				(20)	-	
164	33,361	34,527	1,191	2,151	135,668		4,253	28,338	40,708	392	-
165	334	1,726	6	22	4,754		43	283	407	4	
166		750	653	30	1,433		925				
167	161,270	157,981	159,217	242,156	2,169,458	153,908	168,828	169,411	142,636	234,851	176,468
168					12,638		2,636	7,635	(3,792)		

Line No.	SEP-23	OCT-23	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
169	6,645	14,154	16,663	(71,093)	1,453	21,204	14,409	10,629	(1,020)	(46,440)	4,975
170					-			(6,479)			
171	28,524	49,756	16,560	20,573	263,245	20,292	(9,828)	17,604	25,755	31,231	32,120
172	285	2,488	83	206	9,594	203	(98)	176	258	312	321
173	34,748	21,940	23,251	18,377	268,996	24,434	41,135	14,804	35,161	21,727	41,615
174					(27)						
175	101,076	105,425	-	(91,269)	918,506	(7,994)	12,567	(31,005)	583	-	-
176	(165,014)	(146,579)	(173,370)	(114,345)	(1,682,618)	(139,747)	(154,869)	(157,481)	(202,117)	(153,325)	(139,472)
177	153,580	126,505	146,882	121,427	1,593,391	130,383	150,249	165,652	239,988	132,724	123,282
178			139,039	182,361	321,400	107,361	112,662	114,324	112,386	110,680	105,196
179	3,776	7,719	9,987		62,079	2,941	4,318	(157)	3,666	2,806	3,938
180	19				344						
181		62			62			480			
182					56						
183					-					2,300	2,300
184	34,607	34,607	-	70,139	413,830	31,382	31,613	35,820	31,084	32,630	31,061
185	26,439	11,621	38,718	33,120	312,993	8,581	22,428	37,787	26,974	29,560	20,776
186	(72,388)	(58,377)	(63,193)	(114,333)	(640,854)	(51,664)	(67,861)	(81,036)	(72,869)	(74,543)	(65,842)
187	9,043	5,621	15,777	13,407	(134,969)	9,814	10,886	9,239	12,633	11,068	11,412
188	9,473	4,235	(985)	(7,288)	(28,529)		(16,893)	4,491	(14,152)	9,826	5,876
189	10,516	17,090	18,272		136,142	17,935	6,313	12,632	13,027	11,418	9,881
190	1,325	7,480	9,014	13,207	53,831	2,056	4,878	4,619	7,929	4,573	11,523
191					8,469				8,172		
192	4,556	5,915	6,286	5,766	69,904	6,003	4,826	6,636	5,156	6,973	5,474
193	170	558	84	460	9,374	294	281	83	164	284	199
194	55	10	14	34	1,539		50	194		55	432
195		69		21	127				32	89	
196		(59)		(18)	(99)				(27)	(77)	
197	34	206	780	1,094	8,938	204	2,958	1,399	470	447	1,349
198			1,911	3,147	13,255	1,394	2,513			832	6,845
199		215	-	1,309	17,223			1,942	-	1,541	8,159
200					12		295				
201					-		182	11			
202		91	-		182		212				
203				345	10,421	835	897				
204					-				736		
205	368	368	1,542		6,571		728	368	1,472	-	668
206	356,685	231,943	203,250	212,432	2,863,024	219,650	203,541	203,630	225,612	255,872	229,782
207	19		107		2,548						136
208	6,906	16,711	18,867	11,141	91,407	10,705	8,170	7,837	11,236	21,831	13,427
209	(4,283)	(14,372)	(16,225)	(9,581)	(66,839)	(9,206)	(5,246)	(4,989)	(6,448)	(13,890)	(8,067)
210	393	1,389	3,913	754	8,553	214	1,077	267	1,685	2,028	115
211	(1,817)	508	(15)		2,447	1,193	449	(95)	973		159
212	-	-	-	-	-	-	-	-	-	-	-
213					-						
214	-				-		-	-	-	-	-
215	76,308	81,181	76,397	109,960	974,867	100,477	83,410	76,870	73,690	100,858	64,337
216	3,450	10,555	4,770	(35,152)	(1,458)	21,864	(2,656)	901	5,779	(27,404)	(726)
217		952	590	7,414	188,791	1,132	2,841	489	721	739	123
218		48	3	74	8,112	11	28	5	7	7	1
219	660		2,604	1,166	16,272	7,228	27,379	3,869	845	2,297	1,566
220				(113)	(598)	(78)	(385)	(51)		(18)	
221				427	1,803	305	621	194		69	
222					48	352					
223					(47)	(345)					
224	1,885	519	570	489	8,012	520	456	545	426	616	567
225					147			42			
226					284						
227					64	40					
228					(36)	(34)					
229	470				1,531	11	54	976	334		16
230					50						
231					2,556	710	465	874			
232	421				1,709	670		299	490		134
233					66						
234					476				1,925		
235	60,000				85,553	10,404	10,000				3,602
236					-						11
237					50						
238				345	527		61	200		154	
239				(297)	(404)		(16)	(52)		(40)	
240				25	528	-	160				
241					4,133					486	1,325
242				-	-	-	-	-		-	
243					-						
244					-		-	-		-	
245					283						
246					-						
247					-			191	105		
248			52		52						
249					(4,455)	(5,160)					
250					6,500	6,000					
251	62	232	249	329	4,816	319	381	380	269	260	144
252					-					20	

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253					-						
254	50,042	62,968	87,420	124,500	748,680	76,799	58,984	53,206	56,445	70,510	57,549
255	3,730	12,760	23,413	(40,444)	347	9,970	(4,177)	60	7,264	(22,115)	2,636
256				(53)	5,081	266	1,048		(930)		
257					(378)						
258					623						
259			158		158						
260					42						
261					(41)						
262					10						
263	452	1,077	1,933	1,091	14,984	1,073	542	1,622	859	1,824	1,160
264					400						
265	82	106		75	726				23		
266	966	-	459	-	4,773	413	279	361	162	1,177	1,453
267	2,035	108	1,078	-	7,761		130	910			1,269
268	5,952				16,412		175		941	3,586	2,945
269					80	80					
270					(45)	(69)					
271		586			865						
272					-						
273					-						
274					-						
275			142		142			146			
276			212		4,392	492	1,098		58		
277	(1,457)	(1,373)			(3,161)			(7)	(58)		
278	2,327	2,334			5,143			12	128		
279					50						
280					(31)						
281					322						
282					24						
283				110	354						
284				(95)	(243)						
285					112						
286					42						
287	-	-			-			-	-		
288					-						
289					-						
290	254				254						
291	(19,744)	(19,744)	(25,715)	(19,744)	(255,866)	(20,161)	(19,744)	(19,744)	(19,744)	(25,708)	(21,214)
292	20,147	20,147	26,240	20,147	260,661	20,573	20,147	20,147	20,147	26,233	21,647
293					426						
294	448	459	208	204	2,302	211	211	211	211	211	
295	59,273	39,856	43,356	43,356	632,024	43,356	43,356	43,356	43,356	43,356	78,158
296	(38,049)	(32,921)	(40,879)	(35,931)	(432,379)	(35,937)	(36,281)	(35,937)	(37,463)	(35,937)	(62,856)
297			5,750		16,717		400		1,775		(3,500)
298	11,725	14,499	5,473	6,087	152,603	1,466	540	434	2,972	6,228	3,461
299	62	133	234	61	1,250	63	62	60	61	63	(107)
300	(6,362)	(12,583)	(4,908)	(5,288)	(92,101)	(1,315)	(517)	(425)	(2,608)	(5,411)	(2,884)
301	-				-						
302	-				-						
303					185						
304	3,585	2,137	1,674	7,623	36,922	8,433	2,080	4,602	5,731	8,058	5,229
305	382	(510)	(110)	99	83	2,103	(2,437)	1,365	1,138	(2,095)	(36)
306					352		104				
307		(333)			(543)			(85)			
308		489			808			138			
309					-				80		
310					-				(78)		
311	54	178	652	463	6,436	1,384	872	350	743	724	562
312		1,790	2,657	1,089	16,161	4,997	2,732	499	324	680	1,397
313			243	145	1,733	6	946		180		405
314					90						
315					(7,103)	1,203		22,904	(3,255)		2,600
316					231						
317					167						
318					(115)						
319					-	97			29		
320		-			-			-			
321					-						
322					787	245					
323					-	98	(98)				
324	7,725	5,247	3,364	2,679	41,566	2,764	1,038	2,354	1,023	639	2,480
325					(150)						
326					219						
327					186						
328					155						
329					31				25		
330	4,000				118,470	400		24,400	30,420	8,399	33,084
331					-						
332					-						
333					-					55	
334					-					9	(9)
335	504			59	2,356			83			
336	252	(252)		10	(39)	(10)		41	(41)		

Line No.	SEP-23	OCT-23	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
337					12						
338					(43)						
339					60						
340					11						
341					-						
342					115,300						
343					5,198						
344	17,754	19,300	17,874	28,399	260,589	18,075	24,547	22,628	18,846	31,708	22,389
345	(1,017)	2,703	932	(7,778)	(504)	2,497	3,816	268	(7)	(6,023)	313
346					-					13,565	3,204
347	2,462	3,125	2,520	2,486	27,733	4,415	2,628	2,640	1,440	2,566	2,609
348	461	431	422	456	5,432	467	383	467	430	455	351
349					3,000						
350					-	1,200				1,200	
351	26,401	26,382	26,378	26,373	316,630	26,373	26,374	26,371	26,372	26,409	26,379
352					(1,708)						
353					-						985
354					-			332	(332)		
355					-						
356	26,642	21,431	16,373	18,273	341,758	10,065	19,462	25,220	23,972	33,535	16,069
357	526	(462)	(1,398)	(8,415)	(1,519)	981	4,732	3,852	1,774	(8,794)	(1,572)
358					242						
359					(55)						
360					97						
361					156						
362					261						
363	36				928	123		507	32		40
364					41						
365	21,490			1,666	27,051						
366	211	1,258	693	2,622	15,355	273	1,827	3,609	3,473	1,507	1,412
367			581	284	1,141	1,374	555				1,167
368		2,856			3,855	7,506	714				
369	263	113	99	614	1,433	436	262	653	192	2,020	1,072
370	72,073	70,098	74,109	72,635	962,900	80,375	77,960	131,358	116,484	76,777	69,833
371			387	-	1,409	300	55		156		1,085
372					-						
373	(28,845)	15,946	142,392	226,613	997,985	209,704	298,981	210,390	(78,230)	122,814	158,813
374	9,823	9,973	10,122	15,184	128,599	10,122	10,122	10,122	10,165	15,311	10,360
375	491	1,072	1,102	(4,555)	75	1,518	506	506	1,038	(3,547)	38
376	(18)	719	32		4,513		498	763	6		
377	(0)	36	0		222		5	8	0		
378					-			103			
379					(25)						
380		(18)			39						
381					-				768	95	
382			7,757	499	12,792	8,369				15	110
383		3,192	311		4,598	466			1,648	300	
384					244		19			227	-
385	300	122	731	165	7,582		2,583	79	314	1,285	995
386	689		2,124	-	7,139	236	2,705	471	1,418	2,367	1,260
387	417		702		4,396		1,055	-	304	510	794
388					384	110	120				
389					39						
390	(100)				572						
391	192				192						
392					170						
393	485			1,089	1,714						
394	151		925		8,626		750	708	2,041	617	26
395		-			-						
396					1,002						
397	7,896	8,014	8,133	12,419	92,373	8,133	8,133	8,133	8,133	12,199	8,255
398	3,406	861	884	(3,623)	44	1,183	407	407	813	(2,846)	31
399			654		901		346	-		144	
400					253						
401				18	18						
402	724	52	302	160	5,257	26	272	364	169	556	237
403					69						
404	3,696	1,382	3,360	1,803	20,644	942	1,918	1,603	2,872	3,106	1,358
405	382		1,218	158	6,665	224	321	733	325	157	519
406					125						
407					291						
408	330				860			1,293	150		
409	10,000		284		11,378					206	184
410	5,964	420	1,725	111	27,481	4,865	762	227	1,718	1,527	3,624
411					98						
412		875		350	28,965	18,620		(480)	25,741	(91)	480
413					-					1,695	
414	133		1,426	139	19,597	220	1,674	1,165	9,214	724	2,206
415	349	3,365	2,440	5,704	40,328	3,701	3,706	4,295	4,794	6,189	318
416	2,522				2,522				13,270		
417					-				1,119		(1,119)
418	689				2,014			1,300		689	
419	9,879	4,940			137,502						
420	(2,439)	(1,976)	(2,964)		(3,372)						



Line No.	SEP-23	OCT-23	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
421	(6)				(6)						
422	21				21						
423	395	395	725	395	5,400	395	395		864	256	395
424	733	102			4,623	2,240	1,105	446			
425					186						
426					-	134	8				
427					9						
428					13						
429	414				918						
430	719				1,806						
431	606				2,228						
432					228						
433					356						
434					-		25,262	-			
435	(50)	(50)	(50)	(50)	(601)	(50)	(50)	(50)	(50)	(50)	(50)
436	-				-						
437	365				4,342						
438	11,032	14,093	32,555	4,191	210,830	3,257	15,174	-	15,238	17,465	4,368
439	35,206	35,206	35,206	35,206	419,832	35,206	35,206	37,154	37,154	37,154	37,154
440	(23,759)	(33,412)	(33,324)	(35,258)	(307,255)	(35,250)	(34,275)	(35,383)	(36,213)	(36,212)	(36,212)
441					112		18	8	(26)		
442					181						
443					97						
444	3,543	3,543	3,543	5,792	43,564	3,543	3,543	3,543	4,955	4,953	4,953
445	3,438	9,195	2,926	565	231,301		3,625	1,725	197	650	12,245
446					128						
447	15,610	13,127	13,092	13,073	185,299	14,983	12,525	12,206	11,730	12,502	11,964
448	8,137	6,738	6,674	6,687	96,641	7,664	6,407	6,244	6,000	6,395	6,120
449	84,976	95,154	94,829	94,727	1,080,869	108,570	90,756	88,450	84,997	90,593	86,689
450					2,280		497	218	(714)		
451	19,251	18,865	18,749	18,754	236,600	21,495	17,968	17,512	16,828	17,936	17,163
452					517		98	43	(141)		
453					-		-	-	-		
454	6,493	7,299	7,222	7,240	82,934	8,298	6,937	6,760	6,497	6,924	6,626
455					173		38	17	(55)		
456	943	1,213	1,208	1,207	12,471	1,383	1,156	1,127	1,083	1,154	1,104
457					25		6	3	(9)		
458	3,018	3,385	3,371	3,369	38,426	3,861	3,228	3,145	3,023	3,222	3,083
459					81		18	8	(25)		
460					420		71	31	(102)		
461					217		35	15	(50)		
462	(79,464)	(79,986)	(80,451)	(79,995)	(976,367)	(91,685)	(76,641)	(74,694)	(71,778)	(76,504)	(73,207)
463					(2,159)		(419)	(1,245)	1,101	(1,039)	
464	(8,887)	(6,109)	(6,093)	(6,084)	(101,420)	(6,973)	(5,829)	(5,681)	(5,459)	(5,818)	(5,568)
465					(239)		(34)	(102)	90	(85)	
466		95	86	118	3,127	89	(118)			146	
467	2,109	3,421	4,434	4,494	43,642	5,819	1,853	1,629	784	5,415	1,861
468	(1,393)	(2,942)	(3,813)	(3,865)	(29,036)	(5,004)	(1,132)	(1,051)	(485)	(3,329)	(1,154)
469		619	1,730	2,849	5,197		60	60		356	
470					-						
471					-						
472					11,905						
473					11,952						
474	224	464	602	51	6,790	659	134	12	300		
475	-				-		-	-	-	-	-
476					-						85
477					-				85		130
478					1,162						1,894
479					-				96		256
480	10,061	10,061	10,061	10,061	120,727	10,061	10,061	10,061	10,061	10,061	10,061
481					(3,075)						
482					1,715						4,091
483					112						
484	27,174	15,369	7,484	5,279	103,714	1,544	5,824	699	1,199	2,072	699
485					480						
	<b>1,669,352</b>	<b>1,318,932</b>	<b>1,386,129</b>	<b>1,390,187</b>	<b>17,558,369</b>	<b>1,527,842</b>	<b>1,714,007</b>	<b>1,518,243</b>	<b>1,347,888</b>	<b>1,435,006</b>	<b>1,569,077</b>
	539,552	211,663	376,186	388,466	5,126,388	323,729	433,306	220,516	363,171	413,143	272,528
	178,867	193,881	200,182	184,693	2,279,174	223,769	194,152	188,962	204,061	211,670	183,690
	311,853	588,548	465,373	582,571	6,052,229	594,342	467,154	547,335	542,551	1,127,076	201,751
	<b>2,699,623</b>	<b>2,313,024</b>	<b>2,427,871</b>	<b>2,545,917</b>	<b>31,016,159</b>	<b>1,141,840</b>	<b>1,094,612</b>	<b>956,814</b>	<b>1,109,783</b>	<b>1,751,889</b>	<b>657,969</b>

**Atmos Energy Corporation**  
**Div 091 Direct Expenses Allocated to Kentucky**  
**For Calendar 2023 and Six Months Ended June 2024**

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
1	8160	Wells expenses	04590	Utilities	-	-	-	-	-	-	-	-
2	8170	Lines expenses	04590	Utilities	48	2	94	47	6	92	1	98
3	8180	Compressor station expenses	04590	Utilities	333	14	658	326	42	644	7	689
4	8180	Compressor station expenses	04599	Capitalized Utility Costs	(299)	(13)	(592)	(293)	(38)	(579)	(6)	(620)
5	8180	Compressor station expenses	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-
6	8190	Compressor station fuel and power	04590	Utilities	6	9	3	2	165	539	1,322	1,114
7	8210	Storage-Purification expenses	04590	Utilities	492	297	265	168	125	99	92	95
8	8240	Storage-Other expenses	04590	Utilities	-	-	-	-	-	-	-	-
9	8250	Storage well royalties	04580	Building Lease/Rents Capitalized	(198)	-	-	(433)	(94)	(282)	-	-
10	8250	Storage well royalties	04581	Non 842 Building Lease/Rents	1,136	-	-	2,493	574	907	-	-
11	8250	Storage well royalties	04590	Utilities	3,069	1,801	1,416	678	580	97	115	104
12	8250	Storage well royalties	07603	Rent Cap Accrual	-	-	-	-	-	-	-	-
13	8560	Mains expenses	04590	Utilities	427	18	846	419	54	827	9	886
14	8560	Mains expenses	04599	Capitalized Utility Costs	(385)	(17)	(762)	(377)	(49)	(744)	(8)	(797)
15	8560	Mains expenses	06111	Contract Labor	-	-	-	-	-	-	-	-
16	8560	Mains expenses	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-
17	8570	Transmission-Measuring and regulating station expenses	04590	Utilities	95	4	188	93	12	184	2	197
18	8600	Transmission-Rents	07120	Environmental & Safety	-	-	-	-	-	-	-	-
19	8700	Distribution-Operation supervision and engineering	01000	Non-project Labor	111,837	109,214	121,460	109,339	113,227	162,417	109,149	108,793
20	8700	Distribution-Operation supervision and engineering	01001	Capital Labor	257,341	272,703	292,149	266,413	268,846	387,184	251,203	267,020
21	8700	Distribution-Operation supervision and engineering	01002	Capital Labor Contra	(244,488)	(265,263)	(269,338)	(258,481)	(261,988)	(376,879)	(244,680)	(255,532)
22	8700	Distribution-Operation supervision and engineering	01006	O&M Project Labor and Contra	-	-	-	-	-	-	-	-
23	8700	Distribution-Operation supervision and engineering	01008	Expense Labor Accrual	8,304	(918)	22,505	(6,060)	18,928	(46,528)	5,675	16,212
24	8700	Distribution-Operation supervision and engineering	01010	PTO Accrual	-	-	-	-	-	7,482	-	-
25	8700	Distribution-Operation supervision and engineering	01011	Capital Labor Transfer In	181,301	188,917	194,984	185,921	185,871	276,664	182,514	178,127
26	8700	Distribution-Operation supervision and engineering	01012	Capital Labor Transfer Out	(194,153)	(196,356)	(217,795)	(193,853)	(192,729)	(286,969)	(189,037)	(189,615)
27	8700	Distribution-Operation supervision and engineering	01014	Expense Labor Transfer Out	-	-	-	-	-	-	-	-
28	8700	Distribution-Operation supervision and engineering	02005	Non-Inventory Supplies	390	153	144	2,849	927	372	53	2,493
29	8700	Distribution-Operation supervision and engineering	03003	Capitalized transportation costs	(61)	(194)	(151)	(191)	(657)	(14)	(39)	(79)
30	8700	Distribution-Operation supervision and engineering	03004	Vehicle Expense	113	282	215	290	1,125	16	68	120
31	8700	Distribution-Operation supervision and engineering	04002	Required By Law, Safety	60,617	43,256	7,559	58,448	12,042	2,905	50,069	28,077
32	8700	Distribution-Operation supervision and engineering	04018	Safety	-	-	-	-	-	-	1,870	-
33	8700	Distribution-Operation supervision and engineering	04022	Promo Sales, Misc	-	-	-	-	-	-	-	-
34	8700	Distribution-Operation supervision and engineering	04040	Community Rel&Trade Shows	-	-	-	87	-	-	-	147
35	8700	Distribution-Operation supervision and engineering	04065	Offsite Storage	512	156	160	160	282	372	372	360
36	8700	Distribution-Operation supervision and engineering	04145	Printing/Slides/Graphics	-	-	-	-	-	-	-	-
37	8700	Distribution-Operation supervision and engineering	04201	Software Maintenance	19,725	15,322	23,222	15,372	16,358	31,398	16,439	13,640
38	8700	Distribution-Operation supervision and engineering	04212	IT Equipment	222	1,497	1,912	504	1,099	521	1,957	1,424
39	8700	Distribution-Operation supervision and engineering	04564	842 Variable Copier Lease Expense	76	-	96	-	79	122	3	7
40	8700	Distribution-Operation supervision and engineering	04582	Building Maintenance	-	-	1,993	528	-	-	-	-
41	8700	Distribution-Operation supervision and engineering	04590	Utilities	1,165	1,106	1,021	1,068	965	1,115	1,246	1,419
42	8700	Distribution-Operation supervision and engineering	04592	Misc Rents	66	66	77	77	77	488	77	77
43	8700	Distribution-Operation supervision and engineering	04599	Capitalized Utility Costs	(991)	(927)	(2,660)	(1,379)	(823)	(963)	(1,081)	(1,233)
44	8700	Distribution-Operation supervision and engineering	05010	Office Supplies	1,250	4,218	3,244	805	956	1,510	1,107	4,678
45	8700	Distribution-Operation supervision and engineering	05111	Postage/Delivery Services	456	331	186	359	744	193	560	420
46	8700	Distribution-Operation supervision and engineering	05215	842 Copier Lease Expense	364	-	363	-	1,186	635	713	113
47	8700	Distribution-Operation supervision and engineering	05310	Monthly Lines and service	(6,161)	(7,064)	(6,312)	1,289	(13,880)	(11,037)	(11,135)	(10,441)
48	8700	Distribution-Operation supervision and engineering	05312	Long Distance	5	14	3	4	3	1	1	1
49	8700	Distribution-Operation supervision and engineering	05314	Toll Free Long Distance	329	328	146	185	186	197	113	113
50	8700	Distribution-Operation supervision and engineering	05317	Telephone Directory	2,444	5,585	-	7,954	4,844	6,417	12,450	5,623
51	8700	Distribution-Operation supervision and engineering	05323	Measurement & Meter Reading	3,166	3,282	4,061	2,538	3,095	2,903	2,900	2,994
52	8700	Distribution-Operation supervision and engineering	05331	WAN/LAN/Internet Service	9,973	10,606	9,929	8,675	10,600	8,464	9,547	9,332
53	8700	Distribution-Operation supervision and engineering	05364	Cellular, radio, pager charges	5,845	4,979	5,896	5,023	5,244	5,942	5,097	5,503
54	8700	Distribution-Operation supervision and engineering	05376	Cell service for data uses	14,994	10,082	11,077	10,697	14,328	11,837	13,930	13,349
55	8700	Distribution-Operation supervision and engineering	05377	Cell phone equipment and accessories	1,308	782	713	1,305	198	296	2,009	436
56	8700	Distribution-Operation supervision and engineering	05399	Capitalized Telecom Costs	(14,971)	(11,244)	(12,200)	(15,956)	(9,734)	(9,354)	(11,867)	(11,036)
57	8700	Distribution-Operation supervision and engineering	05411	Meals and Entertainment	3,504	9,964	37,339	8,924	14,559	7,138	6,139	10,294
58	8700	Distribution-Operation supervision and engineering	05412	Spousal & Dependent Travel	50	202	326	-	-	-	35	70
59	8700	Distribution-Operation supervision and engineering	05413	Transportation	1,168	6,220	8,451	12,135	7,432	8,950	4,852	9,365
60	8700	Distribution-Operation supervision and engineering	05414	Lodging	4,772	9,826	28,067	7,431	9,643	11,951	3,912	8,102
61	8700	Distribution-Operation supervision and engineering	05415	Membership Fees	195	-	-	681	40	380	244	139
62	8700	Distribution-Operation supervision and engineering	05416	Club Dues - Nondeductible	-	-	16	16	33	33	33	33
63	8700	Distribution-Operation supervision and engineering	05417	Club Dues - Deductible	-	-	-	-	110	-	-	-
64	8700	Distribution-Operation supervision and engineering	05419	Misc Employee Expense	-	(1,995)	40,033	5,415	1,310	2,744	13,496	671
65	8700	Distribution-Operation supervision and engineering	05420	Employee Development	1,139	875	3,464	1,891	6,438	703	709	7,450
66	8700	Distribution-Operation supervision and engineering	05421	Training	1,095	2,014	-	-	4,298	1,318	2,149	119
67	8700	Distribution-Operation supervision and engineering	05425	Regulatory Compliance Training	-	-	-	-	-	1,272	124	5,830
68	8700	Distribution-Operation supervision and engineering	05426	Safety Training	300	1,314	1,626	(60)	480	1,580	44	4,600
69	8700	Distribution-Operation supervision and engineering	05427	Technical (Job Skills) Training	-	-	-	-	-	-	-	-
70	8700	Distribution-Operation supervision and engineering	05429	Work Environment Training	-	-	-	-	-	-	-	-
71	8700	Distribution-Operation supervision and engineering	06111	Contract Labor	116	58	-	-	359	58	64	-
72	8700	Distribution-Operation supervision and engineering	07120	Environmental & Safety	-	-	-	94	-	-	12,409	10,439
73	8700	Distribution-Operation supervision and engineering	07421	Service Awards	50	-	-	1,941	-	900	-	6,150
74	8700	Distribution-Operation supervision and engineering	07443	Uniforms	73	-	-	212	-	-	-	-
75	8700	Distribution-Operation supervision and engineering	07444	Uniforms Capitalized	-	-	-	(121)	-	-	-	-
76	8700	Distribution-Operation supervision and engineering	07499	Misc Employee Welfare Exp	1,689	672	768	693	422	113	543	897
77	8700	Distribution-Operation supervision and engineering	07590	Misc General Expense	-	306	-	-	723	-	-	-
78	8700	Distribution-Operation supervision and engineering	07601	Vehicle Cap Accrual	-	-	-	-	-	-	-	-
79	8700	Distribution-Operation supervision and engineering	07607	Telecom Cap Accrual	-	-	-	-	-	-	-	-
80	8700	Distribution-Operation supervision and engineering	07608	Uniform Cap Accrual	-	-	-	-	-	-	-	-
81	8700	Distribution-Operation supervision and engineering	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-
82	8740	Mains and Services Expenses	01000	Non-project Labor	20,814	19,882	21,968	19,699	16,817	22,314	15,684	16,923
83	8740	Mains and Services Expenses	01006	O&M Project Labor and Contra	-	-	-	1,316	-	-	-	-
84	8740	Mains and Services Expenses	01008	Expense Labor Accrual	1,090	(326)	4,025	(477)	423	(7,212)	986	2,910

**Atmos Energy Corporation**  
**Div 091 Direct Expenses Allocated to Kentucky**  
**For Calendar 2023 and Six Months Ended June 2024**

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
85	8740	Mains and Services Expenses	03002	Vehicle Lease Payments	11,094	11,094	10,369	8,446	8,446	8,979	8,297	8,297
86	8740	Mains and Services Expenses	03003	Capitalized transportation costs	(14,445)	(12,609)	(14,412)	(15,740)	(11,798)	(11,938)	(11,224)	(10,174)
87	8740	Mains and Services Expenses	03004	Vehicle Expense	11,531	8,359	12,682	13,776	9,951	10,721	10,283	8,424
88	8740	Mains and Services Expenses	03008	842 Vehicle Lease Expense	-	-	-	-	-	-	-	-
89	8740	Mains and Services Expenses	03009	842 Variable Heavy Equip Lease Expense	-	-	-	-	-	-	-	-
90	8740	Mains and Services Expenses	04301	Equipment Lease	-	-	-	-	-	-	-	-
91	8740	Mains and Services Expenses	04302	Heavy Equipment	-	-	-	-	-	-	-	-
92	8740	Mains and Services Expenses	04307	Heavy Equipment Capitalized	-	-	-	-	-	-	-	-
93	8740	Mains and Services Expenses	04560	Non 842 Fleet Lease/Rents	266	309	1,150	2,414	533	-	533	533
94	8740	Mains and Services Expenses	04563	842 Variable Fleet Lease Expense	764	628	586	586	572	571	572	572
95	8740	Mains and Services Expenses	04590	Utilities	82	77	93	106	82	160	296	183
96	8740	Mains and Services Expenses	05010	Office Supplies	-	-	-	-	-	20	-	-
97	8740	Mains and Services Expenses	05310	Monthly Lines and service	38	38	38	30	58	43	47	39
98	8740	Mains and Services Expenses	05399	Capitalized Telecom Costs	(21)	(21)	(21)	(18)	(34)	(26)	(29)	(24)
99	8740	Mains and Services Expenses	05411	Meals and Entertainment	-	-	-	-	-	291	-	-
100	8740	Mains and Services Expenses	05413	Transportation	-	-	-	-	-	2,175	-	-
101	8740	Mains and Services Expenses	05414	Lodging	-	-	-	-	-	-	-	-
102	8740	Mains and Services Expenses	05421	Training	-	-	-	-	-	-	-	-
103	8740	Mains and Services Expenses	05426	Safety Training	478	965	132	2,119	525	525	773	525
104	8740	Mains and Services Expenses	06111	Contract Labor	-	-	-	-	-	-	-	-
105	8740	Mains and Services Expenses	07443	Uniforms	-	-	126	-	296	191	99	-
106	8740	Mains and Services Expenses	07444	Uniforms Capitalized	-	-	(114)	-	(266)	(109)	(57)	-
107	8740	Mains and Services Expenses	07601	Vehicle Cap Accrual	-	-	-	-	-	-	-	-
108	8740	Mains and Services Expenses	07607	Telecom Cap Accrual	-	-	-	-	-	-	-	-
109	8740	Mains and Services Expenses	07608	Uniform Cap Accrual	-	-	-	-	-	-	-	-
110	8750	Distribution-Measuring and regulating station expenses	01000	Non-project Labor	10,269	10,188	10,536	7,308	7,232	10,903	7,261	7,461
111	8750	Distribution-Measuring and regulating station expenses	01008	Expense Labor Accrual	1,011	(28)	1,702	(1,614)	1,047	(2,884)	361	1,179
112	8750	Distribution-Measuring and regulating station expenses	02001	Inventory Materials	-	-	-	-	-	-	-	-
113	8750	Distribution-Measuring and regulating station expenses	02004	Warehouse Loading Charge	-	-	-	-	-	-	-	-
114	8750	Distribution-Measuring and regulating station expenses	02005	Non-Inventory Supplies	-	2,212	-	492	32	681	-	-
115	8750	Distribution-Measuring and regulating station expenses	03003	Capitalized transportation costs	-	-	-	-	(5)	-	-	(284)
116	8750	Distribution-Measuring and regulating station expenses	03004	Vehicle Expense	-	-	-	-	20	-	-	1,071
117	8750	Distribution-Measuring and regulating station expenses	05010	Office Supplies	-	-	-	-	18	-	-	-
118	8750	Distribution-Measuring and regulating station expenses	05111	Postage/Delivery Services	-	27	-	-	-	-	13	-
119	8750	Distribution-Measuring and regulating station expenses	05323	Measurement & Meter Reading	-	-	-	-	-	-	-	-
120	8750	Distribution-Measuring and regulating station expenses	05377	Cell phone equipment and accessories	-	-	-	-	-	-	-	-
121	8750	Distribution-Measuring and regulating station expenses	05399	Capitalized Telecom Costs	-	-	-	-	-	-	-	-
122	8750	Distribution-Measuring and regulating station expenses	05411	Meals and Entertainment	-	40	1,047	253	1,905	259	-	439
123	8750	Distribution-Measuring and regulating station expenses	05412	Spousal & Dependent Travel	-	-	-	-	-	-	-	-
124	8750	Distribution-Measuring and regulating station expenses	05413	Transportation	-	79	865	-	-	-	-	1,518
125	8750	Distribution-Measuring and regulating station expenses	05414	Lodging	-	-	945	826	159	200	-	-
126	8750	Distribution-Measuring and regulating station expenses	05420	Employee Development	-	-	-	-	9,878	-	-	-
127	8750	Distribution-Measuring and regulating station expenses	05421	Training	-	-	-	-	-	-	-	-
128	8750	Distribution-Measuring and regulating station expenses	07421	Service Awards	-	-	-	-	-	-	-	-
129	8750	Distribution-Measuring and regulating station expenses	07443	Uniforms	848	-	-	481	-	-	-	-
130	8750	Distribution-Measuring and regulating station expenses	07444	Uniforms Capitalized	(231)	-	-	(128)	-	-	-	-
131	8750	Distribution-Measuring and regulating station expenses	07499	Misc Employee Welfare Exp	-	-	-	-	-	-	-	-
132	8750	Distribution-Measuring and regulating station expenses	07601	Vehicle Cap Accrual	-	-	-	-	-	-	-	-
133	8750	Distribution-Measuring and regulating station expenses	07608	Uniform Cap Accrual	-	-	-	-	-	-	-	-
134	8760	Distribution-Measuring and regulating station expenses-Industrial	01008	Expense Labor Accrual	(6)	-	-	-	-	-	-	-
135	8780	Meter and house regulator expenses	01000	Non-project Labor	9,543	10,619	7,743	8,971	7,629	12,590	6,499	10,817
136	8780	Meter and house regulator expenses	01008	Expense Labor Accrual	253	376	155	614	473	(2,860)	(149)	2,918
137	8800	Distribution-Other expenses	05111	Postage/Delivery Services	-	-	-	-	-	-	-	110
138	8800	Distribution-Other expenses	06111	Contract Labor	51,131	65,836	83,989	67,894	123,100	117,664	106,203	75,493
139	8810	Distribution-Rents	04307	Heavy Equipment Capitalized	(1,329)	-	-	-	-	(1,470)	-	-
140	8810	Distribution-Rents	04308	842 Locusview Lease Expense	1,356	-	-	-	-	1,500	-	-
141	8810	Distribution-Rents	04561	842 Variable Real Estate Lease Expense	5,797	3,070	344	4,734	3,070	2,874	1,564	-
142	8810	Distribution-Rents	04578	842 Real Estate Lease Expense	74,054	74,054	73,991	74,112	74,035	74,098	74,007	74,054
143	8810	Distribution-Rents	04580	Building Lease/Rents Capitalized	(51,390)	(49,628)	(47,814)	(50,626)	(49,644)	(49,556)	(48,647)	(47,928)
144	8810	Distribution-Rents	04582	Building Maintenance	1,123	2,094	157	-	-	-	-	-
145	8810	Distribution-Rents	04592	Misc Rents	3,159	333	-	-	-	-	-	-
146	8810	Distribution-Rents	04599	Capitalized Utility Costs	(1,011)	(1,884)	(142)	-	-	-	-	-
147	8810	Distribution-Rents	07603	Rent Cap Accrual	-	-	-	-	-	-	-	-
148	8810	Distribution-Rents	07609	Utility Cap Accrual	-	-	-	-	-	-	-	-
149	8870	Distribution-Maint of mains	01000	Non-project Labor	-	-	-	423	-	-	-	-
150	8870	Distribution-Maint of mains	01008	Expense Labor Accrual	-	-	-	211	(211)	-	-	-
151	8870	Distribution-Maint of mains	05413	Transportation	-	-	-	-	497	-	-	-
152	8910	Maintenance of measuring and regulating station equipment-City gate check stations	01000	Non-project Labor	-	-	-	-	58	-	-	-
153	8910	Maintenance of measuring and regulating station equipment-City gate check stations	01008	Expense Labor Accrual	-	-	-	-	37	(37)	-	-
154	8920	Maintenance of services	01000	Non-project Labor	105	-	-	-	-	3,393	1,897	524
155	8920	Maintenance of services	01008	Expense Labor Accrual	37	(37)	-	-	-	566	4	(333)
156	9010	Customer accounts-Operation supervision	01000	Non-project Labor	8,416	8,416	8,416	8,416	8,416	12,624	8,416	8,416
157	9010	Customer accounts-Operation supervision	01008	Expense Labor Accrual	842	(0)	1,262	-	1,262	(3,366)	421	1,262
158	9010	Customer accounts-Operation supervision	05411	Meals and Entertainment	-	-	465	48	65	-	-	185
159	9010	Customer accounts-Operation supervision	05413	Transportation	-	-	-	-	-	-	-	-
160	9010	Customer accounts-Operation supervision	05414	Lodging	-	-	970	-	801	-	-	1,182
161	9020	Customer accounts-Meter reading expenses	01000	Non-project Labor	2,359	3,752	3,530	2,811	3,264	5,710	2,612	4,251
162	9020	Customer accounts-Meter reading expenses	01008	Expense Labor Accrual	273	488	452	(359)	716	(1,170)	(168)	1,129
163	9030	Customer accounts-Customer records and collections expenses	01000	Non-project Labor	71,977	52,472	69,889	60,225	63,053	78,493	55,701	53,761
164	9030	Customer accounts-Customer records and collections expenses	01008	Expense Labor Accrual	11,430	(6,827)	16,579	(4,832)	10,872	(27,902)	3,628	7,482
165	9030	Customer accounts-Customer records and collections expenses	05010	Office Supplies	-	-	-	-	-	-	-	-
166	9030	Customer accounts-Customer records and collections expenses	05411	Meals and Entertainment	108	-	-	107	570	408	-	88
167	9030	Customer accounts-Customer records and collections expenses	05412	Spousal & Dependent Travel	-	-	-	-	-	-	-	-
168	9030	Customer accounts-Customer records and collections expenses	05413	Transportation	-	-	-	-	-	-	-	274

Atmos Energy Corporation  
Div 091 Direct Expenses Allocated to Kentucky  
For Calendar 2023 and Six Months Ended June 2024

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
169	9030	Customer accounts-Customer records and collections expenses	06111	Contract Labor	1,080	965	1,137	1,159	1,177	1,198	1,215	1,232
170	9030	Customer accounts-Customer records and collections expenses	06112	Collection Fees	3	(69)	-	-	-	-	-	-
171	9030	Customer accounts-Customer records and collections expenses	06113	Payment Services	135,297	157,498	151,243	151,744	122,276	116,532	98,749	111,507
172	9030	Customer accounts-Customer records and collections expenses	06116	Bill Print Fees	2,057	2,202	2,160	2,233	2,941	2,480	1,986	2,003
173	9030	Customer accounts-Customer records and collections expenses	07421	Service Awards	-	-	-	-	-	-	-	-
174	9030	Customer accounts-Customer records and collections expenses	07499	Misc Employee Welfare Exp	-	76	-	-	-	-	-	-
175	9040	Customer accounts-Uncollectible accounts	09929	Misc Uncol Acct-Write Off	-	-	-	-	-	-	-	-
176	9090	Customer service-Operating informational and instructional advertising expense	01000	Non-project Labor	13,187	13,187	13,187	13,187	13,187	19,780	13,187	13,187
177	9090	Customer service-Operating informational and instructional advertising expense	01008	Expense Labor Accrual	1,319	-	1,978	-	1,978	(5,275)	659	1,978
178	9090	Customer service-Operating informational and instructional advertising expense	04212	IT Equipment	-	-	-	-	-	-	-	-
179	9090	Customer service-Operating informational and instructional advertising expense	05411	Meals and Entertainment	802	149	555	16	163	498	1,195	545
180	9090	Customer service-Operating informational and instructional advertising expense	05412	Spousal & Dependent Travel	-	-	-	-	1,333	-	10	-
181	9090	Customer service-Operating informational and instructional advertising expense	05413	Transportation	706	938	1,403	901	1,616	2,109	1,108	1,618
182	9090	Customer service-Operating informational and instructional advertising expense	05414	Lodging	241	585	572	208	451	816	801	380
183	9090	Customer service-Operating informational and instructional advertising expense	05420	Employee Development	-	-	-	-	-	660	713	-
184	9100	Customer service-Miscellaneous customer service	04040	Community Rel&Trade Shows	-	-	-	-	-	-	-	-
185	9100	Customer service-Miscellaneous customer service	04046	Customer Relations & Assist	8	-	60	61	26	29	32	-
186	9110	Sales-Supervision	01000	Non-project Labor	13,240	13,015	13,011	12,907	12,928	19,496	12,793	12,639
187	9110	Sales-Supervision	01008	Expense Labor Accrual	1,403	(79)	1,950	(52)	1,949	(5,154)	589	1,850
188	9110	Sales-Supervision	03003	Capitalized transportation costs	-	(4)	-	(6)	-	-	-	-
189	9110	Sales-Supervision	03004	Vehicle Expense	-	16	-	24	-	-	-	-
190	9110	Sales-Supervision	04022	Promo Sales, Misc	-	-	-	-	-	-	-	2,627
191	9110	Sales-Supervision	04046	Customer Relations & Assist	-	-	-	-	-	492	-	-
192	9110	Sales-Supervision	04145	Printing/Slides/Graphics	-	-	-	-	-	-	-	-
193	9110	Sales-Supervision	05010	Office Supplies	-	391	-	-	-	-	-	-
194	9110	Sales-Supervision	05111	Postage/Delivery Services	123	41	-	-	-	-	-	-
195	9110	Sales-Supervision	05411	Meals and Entertainment	347	1,822	1,471	652	182	720	114	775
196	9110	Sales-Supervision	05412	Spousal & Dependent Travel	-	-	39	-	1,318	-	-	-
197	9110	Sales-Supervision	05413	Transportation	401	732	1,578	1,076	1,271	1,967	136	2,001
198	9110	Sales-Supervision	05414	Lodging	168	1,862	781	718	1,111	1,411	348	1,542
199	9110	Sales-Supervision	05415	Membership Fees	-	76	-	-	-	-	-	-
200	9110	Sales-Supervision	07499	Misc Employee Welfare Exp	-	-	-	-	461	-	-	-
201	9110	Sales-Supervision	07601	Vehicle Cap Accrual	-	-	-	-	-	-	-	-
202	9120	Sales-Demonstrating and selling expenses	04022	Promo Sales, Misc	-	-	-	2,402	-	-	-	-
203	9120	Sales-Demonstrating and selling expenses	04046	Customer Relations & Assist	-	-	-	-	-	-	-	-
204	9130	Sales-Advertising expenses	04021	Promo Other, Misc	-	-	-	-	-	3,287	-	-
205	9130	Sales-Advertising expenses	04040	Community Rel&Trade Shows	-	-	-	-	-	-	-	-
206	9200	A&G-Administrative & general salaries	04863	A&G Overhead Clearing	(8,526)	(40,049)	(21,044)	(10,058)	(35,814)	(10,794)	(6,833)	(30,018)
207	9210	A&G-Office supplies & expense	02001	Inventory Materials	-	-	-	-	-	-	-	-
208	9210	A&G-Office supplies & expense	02004	Warehouse Loading Charge	-	-	-	-	-	-	-	-
209	9210	A&G-Office supplies & expense	04582	Building Maintenance	-	-	-	-	-	-	-	-
210	9210	A&G-Office supplies & expense	05010	Office Supplies	-	-	-	-	-	-	-	-
211	9210	A&G-Office supplies & expense	05111	Postage/Delivery Services	-	-	-	-	-	-	-	-
212	9210	A&G-Office supplies & expense	05419	Misc Employee Expense	-	-	-	-	6,471	-	-	-
213	9210	A&G-Office supplies & expense	05421	Training	-	-	-	-	-	-	-	-
214	9210	A&G-Office supplies & expense	06111	Contract Labor	-	-	-	-	-	-	-	-
215	9210	A&G-Office supplies & expense	07590	Misc General Expense	-	-	-	-	-	-	-	-
216	9230	A&G-Outside services employed	06111	Contract Labor	2,953	299	2,912	3,114	770	3,174	2,283	2,821
217	9230	A&G-Outside services employed	06121	Legal	2,226	11,088	15,700	5,737	-	-	28,383	32,273
218	9240	A&G-Property insurance	04069	Blueflame Property Insurance	229	229	245	245	245	245	245	245
219	9240	A&G-Property insurance	04072	Insurance Capitalized	(323)	(323)	(332)	(391)	(384)	(392)	(399)	(397)
220	9250	A&G-Injuries & damages	01208	Workers Comp Benefits Variance	(12,764)	(691)	(2,337)	(166)	(943)	4,618	(907)	3,044
221	9250	A&G-Injuries & damages	01221	Workers Comp Benefits Load	10,058	9,027	10,759	8,306	9,993	9,171	8,720	9,850
222	9250	A&G-Injuries & damages	01293	Workers Comp Benefits Projects	-	-	-	12	-	-	-	-
223	9250	A&G-Injuries & damages	04070	Insurance-Other	338	338	338	422	413	413	413	413
224	9260	A&G-Employee pensions and benefits	01202	Pension Benefits Load	9,048	7,489	10,140	7,331	8,980	7,866	7,782	8,703
225	9260	A&G-Employee pensions and benefits	01203	OPEB Benefits Load	5,251	4,170	5,807	4,166	5,127	4,408	4,433	4,925
226	9260	A&G-Employee pensions and benefits	01206	Pension Benefits Variance	(5,019)	(1,511)	(7,578)	(504)	(6,488)	(4,339)	(2,944)	(6,536)
227	9260	A&G-Employee pensions and benefits	01207	OPEB Benefits Variance	(3,516)	(1,694)	(4,843)	(1,121)	(4,247)	(3,093)	(2,361)	(4,238)
228	9260	A&G-Employee pensions and benefits	01251	Medical Benefits Load	50,911	41,593	56,816	40,974	50,270	43,774	43,530	48,581
229	9260	A&G-Employee pensions and benefits	01252	Medical Benefits Variance	3,414	(30,527)	(13,545)	12,492	47,641	(22,375)	14,812	(24,452)
230	9260	A&G-Employee pensions and benefits	01253	Medical Benefits Projects	-	-	-	237	-	-	-	-
231	9260	A&G-Employee pensions and benefits	01257	ESOP Benefits Load	11,372	9,342	12,714	9,179	11,254	9,824	9,748	10,889
232	9260	A&G-Employee pensions and benefits	01258	ESOP Benefits Variance	(2,340)	(1,260)	(2,283)	(26,257)	23,072	640	2,083	(911)
233	9260	A&G-Employee pensions and benefits	01259	ESOP Benefits Projects	-	-	-	54	-	-	-	-
234	9260	A&G-Employee pensions and benefits	01261	Other Benefits Variance	1,009	1,008	999	929	961	896	449	935
235	9260	A&G-Employee pensions and benefits	01262	Other Benefits Projects	-	-	-	-	-	-	-	-
236	9260	A&G-Employee pensions and benefits	01263	RSP FACC Benefits Load	4,311	3,388	4,752	3,402	4,192	3,587	3,622	4,018
237	9260	A&G-Employee pensions and benefits	01264	RSP FACC Benefits Variance	2,240	3,731	1,431	4,089	1,678	11,385	3,275	2,026
238	9260	A&G-Employee pensions and benefits	01265	RSP FACC Benefits Projects	-	-	-	18	-	-	-	-
239	9260	A&G-Employee pensions and benefits	01266	Life Benefits Load	575	467	641	461	567	492	490	547
240	9260	A&G-Employee pensions and benefits	01267	Life Benefits Variance	8,315	153	5,108	89	(189)	7,604	(97)	(247)
241	9260	A&G-Employee pensions and benefits	01268	Life Benefits Projects	-	-	-	3	-	-	-	-
242	9260	A&G-Employee pensions and benefits	01269	LTD Benefits Load	1,841	1,494	2,050	1,477	1,813	1,574	1,569	1,749
243	9260	A&G-Employee pensions and benefits	01270	LTD Benefits Variance	8,424	(3,447)	2,298	(3,234)	(4,367)	6,171	(3,656)	(4,320)
244	9260	A&G-Employee pensions and benefits	01271	LTD Benefits Projects	-	-	-	8	-	-	-	-
245	9260	A&G-Employee pensions and benefits	01291	Pension Benefits Projects	-	-	-	44	-	-	-	-
246	9260	A&G-Employee pensions and benefits	01292	OPEB Benefits Projects	-	-	-	23	-	-	-	-
247	9260	A&G-Employee pensions and benefits	01294	NSC-OPEB Benefits Load	(37,027)	(33,607)	(42,793)	(31,496)	(38,174)	(34,833)	(33,260)	(37,731)
248	9260	A&G-Employee pensions and benefits	01295	NSC-OPEB Benefits Variance	28,142	10,085	41,311	4,773	35,621	24,464	17,265	35,784
249	9260	A&G-Employee pensions and benefits	01296	NSC-OPEB Benefits Projects	-	-	-	(225)	-	-	-	-
250	9260	A&G-Employee pensions and benefits	01297	NSC-Pension Benefits Load	(5,161)	(4,268)	(5,782)	(4,180)	(5,121)	(4,484)	(4,437)	(4,962)
251	9260	A&G-Employee pensions and benefits	01298	NSC-Pension Benefits Variance	8,304	6,283	9,770	5,405	8,962	7,495	6,645	8,786
252	9260	A&G-Employee pensions and benefits	01299	NSC-Pension Benefits Projects	-	-	-	(25)	-	-	-	-



Atmos Energy Corporation  
Div 091 Direct Expenses Allocated to Kentucky  
For Calendar 2023 and Six Months Ended June 2024

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23
253	9260	A&G-Employee pensions and benefits	05411	Meals and Entertainment	1,229	1,282	339	(238)	1,008	927	695	-
254	9260	A&G-Employee pensions and benefits	07421	Service Awards	8,831	1,918	4,174	1,714	8,886	-	15,195	13,586
255	9260	A&G-Employee pensions and benefits	07443	Uniforms	-	166	216	535	-	288	84	354
256	9260	A&G-Employee pensions and benefits	07444	Uniforms Capitalized	-	(95)	(123)	(305)	-	(164)	(48)	(202)
257	9260	A&G-Employee pensions and benefits	07450	Capitalized Restrictd Stock	(10,723)	(9,691)	(10,725)	(10,377)	(93,633)	(13,508)	(48,237)	(20,889)
258	9260	A&G-Employee pensions and benefits	07452	Variable Pay & Mgmt Incentive Plans	254,000	229,000	202,737	169,000	160,000	156,000	467,000	643,128
259	9260	A&G-Employee pensions and benefits	07454	VPP & MIP - Capital Credit	(145,000)	(131,000)	(115,565)	(97,000)	(91,000)	(89,000)	(267,000)	(369,399)
260	9260	A&G-Employee pensions and benefits	07458	Restricted Stock - Long Term Incentive Plan - Performance Based	15,539	14,035	15,539	15,038	54,158	19,805	73,888	38,906
261	9260	A&G-Employee pensions and benefits	07460	RSU-Long Term Incentive Plan - Time Lapse	5,073	4,582	5,073	4,909	112,666	5,958	17,572	-
262	9260	A&G-Employee pensions and benefits	07463	RSU-Managment Incentive Plan	52	47	52	50	52	50	155	-
263	9260	A&G-Employee pensions and benefits	07487	COLI CSV & Premiums	(5,610)	4,379	(2,881)	(1,030)	2,180	(5,364)	(2,387)	3,272
264	9260	A&G-Employee pensions and benefits	07489	NQ Retirement Cost	2,634	2,634	2,634	2,634	2,653	2,653	2,653	2,653
265	9260	A&G-Employee pensions and benefits	07490	SERP Capitalized	(1,501)	(1,501)	(1,501)	(1,501)	(1,512)	(1,512)	(1,512)	(1,512)
266	9260	A&G-Employee pensions and benefits	07492	NSC-NQ Retirement Cost	3,701	3,701	3,701	3,701	3,780	3,780	3,780	3,780
267	9260	A&G-Employee pensions and benefits	07493	NSC-SERP Capitalized	(616)	(616)	(616)	(616)	(661)	(661)	(661)	(661)
268	9260	A&G-Employee pensions and benefits	07499	Misc Employee Welfare Exp	143	305	76	1,196	1,898	398	108	522
269	9260	A&G-Employee pensions and benefits	07604	Restricted Stock Cap Accrual	-	-	-	-	-	-	-	-
270	9260	A&G-Employee pensions and benefits	07608	Uniform Cap Accrual	-	-	-	-	-	-	-	-
271	9302	Miscellaneous general expenses	04046	Customer Relations & Assist	-	-	-	-	-	-	-	-
272	9302	Miscellaneous general expenses	05415	Membership Fees	480	-	-	-	-	-	-	-
273	9302	Miscellaneous general expenses	07510	Association Dues	-	-	-	-	7,500	-	-	-
274	9302	Miscellaneous general expenses	07590	Misc General Expense	-	-	763	-	-	-	390	-
Div 091 Expenses					854,556	731,886	966,836	769,233	977,219	784,240	999,611	1,020,945
Div091 Expenses Allocated to KY Based on Composite Allocation Factor					434,285	371,944	491,346	390,924	496,623	398,551	508,002	518,844

Line No.	SEP-23	OCT-23	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
1	-	-	-	-	-	-	-	-	-	-	-
2	2	47	96	43	575	45	1	71	25	87	47
3	14	330	668	303	4,027	318	7	496	175	608	330
4	(12)	(96)	(194)	(88)	(2,831)	(261)	(5)	(407)	(143)	(499)	(271)
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	3,160	-	-	-	-	-	-
7	96	94	96	96	2,016	100	154	115	90	85	80
8	-	-	-	-	-	-	-	-	-	-	-
9	-	(297)	-	-	(1,303)	(932)	(32)	-	(1,871)	(223)	(292)
10	-	1,023	-	-	6,133	1,136	39	-	2,282	272	356
11	54	116	252	544	8,824	531	518	506	239	129	66
12	-	-	-	-	-	-	-	-	-	-	-
13	17	424	859	389	5,176	409	8	638	225	782	425
14	(16)	(123)	(249)	(113)	(3,639)	(335)	(7)	(523)	(184)	(641)	(348)
15	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-
17	4	94	191	87	1,151	91	2	142	50	174	94
18	4,000	60	1,008	-	5,068	-	-	-	-	555	-
19	107,931	114,163	122,692	173,226	1,463,448	109,471	109,380	109,207	114,314	167,320	110,407
20	267,483	281,997	301,383	426,560	3,540,281	285,932	317,167	314,043	320,402	466,446	313,611
21	(257,329)	(270,903)	(289,124)	(410,033)	(3,404,037)	(273,405)	(292,909)	(287,320)	(303,155)	(442,527)	(299,044)
22	-	-	-	-	-	-	-	-	-	-	-
23	5,008	14,533	17,387	(57,014)	(1,968)	14,917	5,433	5,383	13,985	(40,701)	(285)
24	-	-	-	-	7,482	-	-	-	-	-	-
25	181,331	195,844	210,994	317,605	2,480,072	210,342	210,158	209,632	221,451	312,181	207,523
26	(191,485)	(206,937)	(223,253)	(334,133)	(2,616,316)	(222,868)	(234,416)	(236,355)	(238,697)	(336,100)	(222,089)
27	-	-	-	-	-	-	-	(2,558)	-	-	-
28	346	74	276	170	8,247	-	265	24	92	524	805
29	(130)	(115)	(43)	(5)	(1,678)	(918)	-	(109)	(34)	(95)	(637)
30	193	127	68	9	2,628	1,117	-	136	66	155	905
31	12,042	60,627	23,382	128	359,151	77,905	259,425	3,193	65,728	2,829	5,341
32	-	-	-	-	1,870	170	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	50
34	1,138	-	-	-	1,373	-	-	-	-	44	-
35	424	332	372	372	3,874	372	372	372	372	372	160
36	148	-	-	-	148	-	-	-	-	-	-
37	13,649	16,023	20,012	34,575	235,735	15,047	17,159	15,357	16,145	15,311	20,609
38	279	334	497	576	10,823	952	570	70	64	959	928
39	3	2	-	-	388	-	-	-	-	-	-
40	-	-	-	-	2,521	-	-	-	-	-	-
41	1,443	1,136	1,092	1,034	13,810	1,146	1,198	1,053	1,044	1,371	1,345
42	3,643	77	77	77	4,877	77	77	575	77	77	77
43	(1,258)	(329)	(317)	(300)	(12,263)	(940)	(983)	(863)	(856)	(1,124)	(1,103)
44	1,515	2,196	740	1,251	23,470	1,765	2,663	1,279	832	948	3,030
45	967	1,050	217	212	5,694	656	1,181	139	968	738	166
46	(608)	-	657	623	4,046	661	663	686	546	550	553
47	(10,460)	(8,223)	(79)	(9,626)	(93,129)	(3,700)	(3,693)	(3,699)	(3,718)	(5,087)	(5,019)
48	1	0	2	0	35	0	1	1	0	0	2
49	112	118	116	31	1,973	31	31	31	31	31	30
50	11,145	2,984	7,173	4,540	71,160	7,683	8,839	6,293	6,238	5,441	4,953
51	2,992	3,017	2,372	3,243	36,563	2,899	2,994	2,965	2,891	3,109	3,079
52	9,332	9,346	9,356	9,439	114,599	8,418	8,719	9,171	10,255	9,313	9,226
53	5,435	5,470	5,116	5,567	65,117	5,384	5,118	8,158	7,103	6,295	6,487
54	14,408	14,505	13,857	13,085	156,149	12,401	15,283	15,183	14,667	16,165	17,672
55	75	820	922	229	9,094	829	24	863	538	894	397
56	(11,375)	(6,390)	(8,494)	(5,430)	(128,052)	(19,158)	(20,896)	(24,361)	(23,679)	(22,640)	(23,612)
57	7,921	5,878	9,979	8,387	130,025	7,323	12,378	6,560	7,656	15,307	9,813
58	-	-	-	756	1,439	-	253	117	115	-	107
59	8,279	5,208	8,711	6,538	87,309	4,771	5,395	6,921	8,524	16,973	9,401
60	6,611	6,764	7,972	4,492	109,541	3,948	13,419	5,987	10,662	27,605	10,174
61	503	25	17	-	2,224	25	5	16	260	-	45
62	33	33	33	33	295	33	16	-	16	16	16
63	-	-	-	-	110	-	-	-	-	-	-
64	9	9	643	5,865	68,199	-	6,405	67,850	47	-	-
65	2,087	553	214	883	26,405	350	6,045	179	50	18,411	-
66	2,149	-	-	-	13,140	1,125	412	4,086	3,417	-	175
67	-	-	5,830	-	13,056	-	-	-	-	-	-
68	560	465	-	546	11,454	420	960	1,402	1,223	1,764	514
69	-	-	-	-	-	-	-	95	-	-	-
70	-	-	-	-	-	-	-	690	-	-	-
71	235,016	(210,616)	-	139,507	164,560	(139,007)	-	-	-	-	-
72	4,355	-	-	656	27,954	-	337	-	-	-	1,778
73	1,648	-	1,200	-	11,888	-	-	-	-	-	-
74	-	-	-	-	285	-	-	-	-	297	252
75	-	-	-	-	(121)	-	-	-	-	(267)	(227)
76	4,953	861	2,423	3,789	17,822	1,315	2,221	1,369	4,353	1,827	1,911
77	-	-	1,643	-	2,672	-	-	-	-	-	53
78	-	-	-	-	-	-	-	-	-	-	-
79	-	-	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-	-	-
81	-	-	-	-	-	-	-	-	-	-	-
82	14,168	15,633	19,429	26,973	230,305	23,097	18,666	16,569	26,492	29,509	12,258
83	-	-	-	-	1,316	-	-	-	-	-	-
84	(532)	2,296	4,221	(9,105)	(1,700)	4,743	(839)	(115)	7,610	(10,977)	(1,854)

Line No.	Calendar					JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
	SEP-23	OCT-23	NOV-23	DEC-23	2023						
85	9,443	9,443	-	(8,556)	85,351	691	(292)	64	-	-	-
86	(16,277)	(13,378)	(17,434)	(12,591)	(162,020)	(11,596)	(13,690)	(10,841)	(16,862)	(11,733)	(15,846)
87	14,261	11,055	16,337	10,414	137,792	8,945	11,869	7,739	19,977	9,716	11,940
88	-	-	10,639	17,692	28,330	9,443	9,443	7,250	7,751	7,206	8,096
89	(622)	2,987	63	-	2,429	63	63	(5)	63	5	59
90	1,195	1,195	-	2,445	4,835	1,204	1,195	1,258	1,195	1,253	1,195
91	(5)	18	5	24	42	(4)	10	10	15	5	9
92	(558)	(4,117)	(66)	(2,419)	(7,160)	(1,238)	(1,243)	(1,238)	(1,247)	(1,238)	(1,238)
93	793	533	533	533	8,129	-	1,449	952	1,083	587	614
94	1,861	641	2,012	-	9,364	1,023	422	812	1,036	2,025	3,848
95	166	228	207	103	1,783	103	100	100	106	129	118
96	-	-	38	-	58	-	-	-	-	-	-
97	57	42	43	43	515	43	43	43	25	58	34
98	(34)	(12)	(12)	(12)	(265)	(35)	(35)	(35)	(20)	(47)	(28)
99	-	-	-	-	291	-	-	-	-	-	-
100	-	-	-	-	2,175	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	1,428	-
102	-	-	-	-	-	-	-	-	-	122	-
103	525	525	525	525	8,140	5,790	(4,745)	522	522	522	522
104	-	9,848	-	-	9,848	-	-	-	-	-	-
105	-	214	301	217	1,445	864	393	1,038	325	-	-
106	-	(62)	(87)	(63)	(758)	(709)	(344)	(918)	(216)	-	-
107	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-
109	-	-	-	-	-	-	-	-	-	-	-
110	7,487	7,400	7,887	11,982	105,913	8,212	8,278	7,848	7,824	11,735	8,016
111	386	696	1,081	(3,524)	(587)	1,288	440	199	770	(2,739)	48
112	-	-	-	-	-	927	-	-	-	-	-
113	-	-	-	-	-	9	-	-	-	-	-
114	28	-	-	-	3,445	1,107	465	(51)	-	-	-
115	-	-	-	-	(289)	(26)	(2)	-	(4)	-	-
116	-	-	-	-	1,091	103	6	-	16	-	-
117	-	48	(9)	53	109	7	24	10	72	-	31
118	-	-	13	-	52	-	-	72	-	-	-
119	-	-	-	40	40	10	-	-	-	-	-
120	-	-	-	-	-	-	-	11	15	-	-
121	-	-	-	-	-	-	-	(9)	(12)	-	-
122	1,197	-	-	419	5,560	76	2,087	-	1,447	81	637
123	-	-	-	68	68	-	-	-	-	-	-
124	-	-	-	829	3,291	-	753	-	-	-	865
125	613	-	-	435	3,177	-	-	603	299	191	913
126	-	-	-	-	9,878	-	-	-	-	-	-
127	-	-	-	1,500	1,500	-	-	-	-	-	-
128	-	-	-	-	-	-	-	-	-	-	-
129	-	161	446	-	1,935	-	-	-	-	377	-
130	-	(47)	(129)	-	(535)	-	-	-	-	(97)	-
131	-	-	-	-	-	-	-	89	-	-	-
132	-	-	-	-	-	-	-	-	-	-	-
133	-	-	-	-	-	-	-	-	-	-	-
134	-	-	-	-	(6)	-	-	-	-	-	-
135	7,576	13,646	21,348	15,733	132,713	10,170	7,256	6,672	7,210	13,126	10,661
136	(1,080)	4,400	6,756	(12,321)	(465)	1,446	(803)	71	990	(2,138)	478
137	69	-	73	57	308	27	-	-	-	36	-
138	61,610	37,083	51,798	34,260	876,062	36,001	36,795	42,386	40,149	61,533	15,458
139	-	-	-	(1,484)	(4,282)	-	-	-	-	-	-
140	-	-	-	1,514	4,370	-	-	-	-	-	-
141	-	367	-	4,603	26,422	4,665	952	62	11,051	5,599	16,263
142	74,053	88,045	88,044	88,043	930,589	87,980	89,387	89,387	89,387	89,387	63,311
143	(48,002)	(25,514)	(25,514)	(26,849)	(521,113)	(75,918)	(74,028)	(73,297)	(82,309)	(77,803)	(65,184)
144	-	-	-	-	3,374	-	-	-	-	-	-
145	-	-	-	-	3,492	3,159	333	-	-	-	-
146	-	-	-	-	(3,036)	-	-	-	-	-	-
147	-	-	-	-	-	-	-	-	-	-	-
148	-	-	-	-	-	-	-	-	-	-	-
149	41	-	-	-	463	-	-	-	350	-	-
150	20	(20)	-	-	-	-	-	-	210	(210)	-
151	-	-	-	-	497	-	-	-	-	-	-
152	-	-	-	-	58	-	-	-	-	-	79
153	-	-	-	-	-	-	-	-	-	-	20
154	-	-	-	-	5,918	-	-	-	-	-	-
155	(236)	-	-	-	0	-	-	-	-	-	-
156	8,416	8,552	8,689	13,034	110,225	8,689	8,689	8,689	8,689	13,034	8,820
157	421	924	951	(3,910)	68	1,303	434	434	869	(3,041)	33
158	199	-	-	-	961	-	463	-	68	-	342
159	54	-	-	-	54	-	132	-	-	-	132
160	-	-	-	-	2,953	-	376	-	-	-	378
161	4,024	3,478	2,460	3,019	41,271	2,928	3,153	3,571	2,615	5,108	4,882
162	99	75	(365)	(1,219)	(49)	668	248	367	(217)	(718)	369
163	54,665	52,173	56,029	84,169	752,606	76,295	73,137	69,813	72,838	104,086	52,495
164	3,140	3,971	7,917	(25,192)	266	16,490	2,394	1,995	8,796	(26,355)	(4,224)
165	-	-	-	-	-	82	-	-	-	-	-
166	-	-	15	43	1,339	-	-	-	-	3,510	-
167	-	-	-	-	-	-	-	-	-	-	-
168	-	-	-	-	274	-	-	-	-	-	-

Line No.	Calendar					JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
	SEP-23	OCT-23	NOV-23	DEC-23	2023						
169	1,252	1,270	1,297	1,319	14,300	1,334	1,360	1,385	1,406	1,422	1,437
170	-	-	-	-	(66)	-	-	-	-	-	-
171	108,862	103,253	105,509	105,756	1,468,227	114,932	129,367	139,080	137,552	133,225	131,153
172	1,930	1,906	1,947	1,832	25,679	1,930	1,862	2,331	2,963	2,511	1,937
173	-	-	-	-	-	-	-	-	-	-	-
174	-	-	-	162	238	-	-	-	-	-	-
175	-	-	-	-	-	-	-	-	-	-	1,358
176	13,187	13,319	13,451	20,176	172,220	13,451	13,556	13,451	13,451	20,176	13,451
177	659	1,398	1,424	(6,053)	66	2,018	720	625	1,345	(4,708)	-
178	-	-	-	-	-	-	-	-	-	-	268
179	141	185	78	131	4,459	14	14	138	-	-	-
180	-	-	-	26	1,369	-	-	-	-	-	-
181	2,678	213	1,772	546	15,608	633	218	397	57	103	651
182	804	859	644	326	6,688	226	181	339	-	171	-
183	-	-	-	-	1,373	-	-	-	-	-	-
184	-	-	-	-	-	1,810	-	-	-	-	-
185	29	2,589	25	2	2,862	80	33	-	28	3	-
186	12,589	12,808	13,186	19,495	168,106	12,980	12,992	13,048	13,220	19,668	13,074
187	607	1,390	1,546	(5,981)	18	1,943	654	677	1,408	(4,654)	(9)
188	(6)	-	-	-	(16)	-	-	-	-	-	-
189	24	-	-	-	64	-	-	-	-	-	-
190	-	-	-	-	2,627	-	-	-	-	-	-
191	-	-	-	-	492	-	-	-	-	-	-
192	-	-	-	-	-	-	-	-	2,330	-	-
193	-	-	-	-	391	-	52	-	302	-	-
194	-	-	-	-	163	-	-	-	-	-	-
195	632	59	650	-	7,423	269	772	1,329	344	844	697
196	-	-	-	-	1,357	-	-	-	-	1,151	-
197	654	16	471	31	10,335	405	999	368	1,750	547	1,145
198	575	424	510	325	9,776	325	713	1,208	1,098	303	446
199	-	-	-	-	76	-	-	-	-	-	-
200	-	-	-	392	853	147	344	-	-	-	-
201	-	-	-	-	-	-	-	-	-	-	-
202	-	-	-	-	2,402	-	-	-	-	-	-
203	331	-	-	-	331	1,798	-	570	2,601	-	-
204	385	5,614	-	-	9,286	-	-	-	-	-	-
205	-	-	7,130	587	7,717	-	-	-	113	-	-
206	(19,069)	(6,712)	(23,165)	(8,587)	(220,671)	(8,202)	(28,148)	(83,719)	(5,656)	(25,190)	(6,052)
207	151,250	(151,250)	-	-	-	-	-	-	-	-	-
208	1,513	(7,563)	-	-	(6,050)	-	-	-	-	-	-
209	-	-	-	-	-	-	-	3,250	-	-	-
210	-	-	-	-	-	57	(4)	-	-	-	-
211	-	-	-	-	-	-	-	-	45	-	-
212	-	-	-	-	6,471	-	-	-	-	-	-
213	-	-	-	-	-	-	-	-	-	-	-
214	-	-	-	-	-	-	-	(175,400)	-	3,492	-
215	-	-	-	-	-	-	(511)	-	-	-	-
216	1,669	4,753	2,511	2,481	29,739	1,891	3,473	2,195	15,435	10,334	5,387
217	9,955	52,344	24,206	23,803	205,713	-	19,390	-	(19,390)	(100,353)	-
218	245	245	245	245	2,904	245	245	261	261	261	261
219	(396)	(191)	(191)	(267)	(3,985)	(539)	(539)	(553)	(608)	(608)	(608)
220	1,886	8,157	(848)	(36,744)	(37,693)	(1,366)	(256)	1,910	77	(332)	784
221	8,939	7,711	7,673	7,372	107,579	8,326	7,138	6,928	7,273	7,884	7,168
222	-	-	-	-	12	-	-	-	-	-	-
223	413	413	413	675	5,004	413	413	413	480	480	480
224	7,567	6,758	7,566	6,042	95,272	7,672	6,530	6,406	7,526	7,136	5,708
225	4,316	4,144	4,818	3,789	55,354	4,870	4,135	4,039	4,686	4,472	3,497
226	(3,686)	(3,798)	(3,720)	(1,772)	(47,896)	(4,931)	(2,639)	(1,234)	(4,260)	(4,524)	(2,161)
227	(2,754)	(1,271)	(1,236)	(214)	(30,588)	(1,822)	(698)	25	(1,570)	(1,647)	(443)
228	42,344	49,978	56,222	44,808	569,800	56,983	48,486	47,540	55,766	52,916	42,211
229	12,019	(17,926)	(24,902)	(21,241)	(64,590)	33,678	(33,224)	(20,197)	(34,409)	(105,486)	(28,587)
230	-	-	-	-	237	-	-	-	-	-	-
231	9,481	10,661	12,189	9,651	126,303	12,337	10,486	10,263	11,974	11,394	9,001
232	(1,528)	2,433	2,698	3,328	(325)	3,727	4,000	7,109	132	2,877	3,144
233	-	-	-	-	54	-	-	-	-	-	-
234	919	-	659	4	8,767	2,502	1,535	(1,760)	875	935	927
235	-	-	-	-	-	-	-	-	-	-	-
236	3,528	4,610	5,387	4,228	49,027	5,443	4,620	4,511	5,225	4,990	3,890
237	3,536	1,869	2,497	13,130	50,887	2,769	4,484	5,227	2,850	13,418	5,413
238	-	-	-	-	18	-	-	-	-	-	-
239	477	650	735	584	6,686	744	633	620	727	690	549
240	7,596	(29)	(24)	6,179	34,457	(68)	7	6,436	1,815	1,994	2,210
241	-	-	-	-	3	-	-	-	-	-	-
242	1,527	1,815	2,051	1,631	20,591	2,078	1,767	1,732	2,029	1,926	1,532
243	6,246	(4,304)	(4,261)	5,371	924	(4,658)	(3,983)	5,945	(1,201)	(1,286)	(645)
244	-	-	-	-	8	-	-	-	-	-	-
245	-	-	-	-	44	-	-	-	-	-	-
246	-	-	-	-	23	-	-	-	-	-	-
247	(32,249)	(31,132)	(32,203)	(26,582)	(411,087)	(32,882)	(28,141)	(27,854)	(33,608)	(31,440)	(26,350)
248	21,102	(4,428)	(4,702)	(17,659)	191,759	1,333	(10,608)	(17,638)	102	749	(14,057)
249	-	-	-	-	(225)	-	-	(407)	407	-	-
250	(4,315)	(3,144)	(3,520)	(2,811)	(52,183)	(3,569)	(3,038)	(2,980)	(3,501)	(3,320)	(2,656)
251	7,121	5,154	5,095	4,314	83,334	5,826	4,504	4,044	4,988	5,521	4,347
252	-	-	-	-	(25)	-	-	(33)	33	-	-



Line No.	Calendar										
	SEP-23	OCT-23	NOV-23	DEC-23	2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
253	-	-	-	-	5,241	-	-	-	-	-	-
254	9,366	5,270	3,593	1,664	74,197	1,603	516	10,399	(197)	6,661	8,331
255	203	400	83	811	3,140	28	519	2,000	331	-	373
256	(117)	(116)	(24)	(235)	(1,429)	(23)	(133)	(1,641)	(239)	-	(306)
257	-	(12,500)	(5,038)	(5,210)	(240,532)	(14,732)	(13,781)	(14,732)	(14,256)	(147,319)	(21,699)
258	-	151,903	186,704	235,560	2,855,031	257,575	239,963	193,732	173,918	1,499,298	(114,675)
259	-	(125,151)	(153,822)	(194,075)	(1,778,011)	(212,212)	(197,702)	(159,613)	(143,289)	(1,235,250)	144,635
260	-	40,849	13,405	13,851	315,013	13,851	12,958	13,851	13,405	128,256	23,718
261	-	5,921	5,730	5,921	173,404	5,921	5,539	5,921	5,730	60,936	4,999
262	-	52	91	106	708	106	99	106	103	106	103
263	6,362	2,919	(9,862)	(5,272)	(13,295)	(1,545)	(4,428)	(3,404)	5,960	6,252	(8,550)
264	2,653	1,393	1,393	1,395	27,983	1,395	1,395	1,395	1,395	1,395	1,395
265	(1,512)	(1,142)	(1,142)	(1,144)	(16,996)	(1,144)	(1,144)	(1,144)	(1,144)	(1,144)	(1,144)
266	3,502	3,853	3,853	3,840	44,970	3,840	3,840	3,840	3,840	3,840	3,840
267	(383)	(1,111)	(1,111)	(1,101)	(8,812)	(1,101)	(1,101)	(1,101)	(1,101)	(1,101)	(1,101)
268	765	533	59	205	6,205	175	433	119	(4)	(23)	61
269	-	-	-	-	-	-	-	-	-	-	-
270	-	-	-	-	-	-	-	-	-	-	-
271	9,966	-	-	-	9,966	-	-	-	-	-	-
272	-	-	-	-	480	-	480	-	-	-	-
273	-	-	-	-	7,500	-	-	-	-	7,500	-
274	-	-	-	-	1,152	241	-	-	-	-	230
<b>1,061,692</b>						<b>647,846</b>	<b>867,132</b>	<b>441,297</b>	<b>726,778</b>	<b>826,783</b>	<b>545,382</b>
<b>539,552</b>						<b>323,729</b>	<b>433,306</b>	<b>220,516</b>	<b>363,171</b>	<b>413,143</b>	<b>272,528</b>

**Atmos Energy Corporation**  
**Shared Services Expenses Allocated to Div 091 and KY**  
**For Calendar 2023 and Six Months Ended June 2024**

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23	SEP-23	OCT-23
1	8520	Communication system expenses	02001	Inventory Materials	-	-	-	-	-	-	-	-	-	-
2	8520	Communication system expenses	02005	Non-Inventory Supplies	-	-	-	-	-	-	-	-	-	376
3	8520	Communication system expenses	05316	Telecom Maintenance & Repair	-	-	-	-	-	-	-	-	-	-
4	8520	Communication system expenses	06111	Contract Labor	-	-	-	-	-	-	-	-	-	-
5	8560	Mains expenses	01002	Capital Labor Contra	-	-	-	-	-	-	23,771	39,497	-	-
6	8560	Mains expenses	01011	Capital Labor Transfer In	-	-	-	-	-	-	-	(232)	-	-
7	8560	Mains expenses	02005	Non-Inventory Supplies	-	-	-	-	-	-	-	232	-	-
8	8560	Mains expenses	03004	Vehicle Expense	-	-	-	-	-	-	-	-	-	-
9	8560	Mains expenses	04201	Software Maintenance	-	-	15,134	4,760	161	-	-	-	-	-
10	8650	Transmission-Maintenance of measuring and regula	02005	Non-Inventory Supplies	-	-	-	-	-	-	-	-	-	-
11	8660	Transmission-Maintenance of communication equipr	02005	Non-Inventory Supplies	13,746	-	-	10,796	-	-	-	-	-	-
12	8660	Transmission-Maintenance of communication equipr	05331	WAN/LAN/Internet Service	-	1,041	-	-	-	-	-	-	-	-
13	8700	Distribution-Operation supervision and engineering	01000	Non-project Labor	-	-	-	-	-	-	-	-	-	-
14	8700	Distribution-Operation supervision and engineering	01002	Capital Labor Contra	(3,592)	(2,484)	(1,942)	(1,082)	(1,867)	(6,206)	(3,011)	(11,333)	(4,745)	(6,092)
15	8700	Distribution-Operation supervision and engineering	01006	O&M Project Labor and Contra	-	-	-	-	-	-	-	48	-	-
16	8700	Distribution-Operation supervision and engineering	01008	Expense Labor Accrual	(205)	-	-	-	-	-	-	-	-	-
17	8700	Distribution-Operation supervision and engineering	01011	Capital Labor Transfer In	3,592	2,484	1,942	1,082	1,867	6,206	3,011	11,333	4,745	6,092
18	8700	Distribution-Operation supervision and engineering	01014	Expense Labor Transfer Out	-	-	-	-	-	-	-	(48)	-	-
19	8700	Distribution-Operation supervision and engineering	02005	Non-Inventory Supplies	-	-	-	-	4,109	-	-	3,113	-	-
20	8700	Distribution-Operation supervision and engineering	04002	Required By Law, Safety	-	-	-	-	-	-	-	-	-	-
21	8700	Distribution-Operation supervision and engineering	04212	IT Equipment	23	-	-	-	-	-	-	-	-	-
22	8700	Distribution-Operation supervision and engineering	05010	Office Supplies	-	176	-	-	-	-	-	-	-	-
23	8700	Distribution-Operation supervision and engineering	05411	Meals and Entertainment	-	2,391	862	-	-	1,285	-	378	2,230	419
24	8700	Distribution-Operation supervision and engineering	05413	Transportation	-	1,023	624	-	-	593	-	-	-	-
25	8700	Distribution-Operation supervision and engineering	05414	Lodging	-	1,028	1,068	-	-	584	-	-	-	-
26	8700	Distribution-Operation supervision and engineering	06111	Contract Labor	-	-	-	-	2,781	2,400	-	-	-	-
27	8700	Distribution-Operation supervision and engineering	07499	Misc Employee Welfare Exp	-	-	-	-	-	-	-	-	-	-
28	8740	Mains and Services Expenses	01000	Non-project Labor	-	-	-	-	-	144	-	-	-	-
29	8740	Mains and Services Expenses	01008	Expense Labor Accrual	-	-	-	-	-	24	(24)	-	-	-
30	8740	Mains and Services Expenses	02001	Inventory Materials	-	15,695	(481)	-	-	-	-	-	7,533	-
31	8740	Mains and Services Expenses	02005	Non-Inventory Supplies	-	-	-	-	159	-	-	-	599	-
32	8740	Mains and Services Expenses	03002	Vehicle Lease Payments	8,969	11,688	8,176	8,176	9,310	8,451	7,716	7,720	7,849	7,849
33	8740	Mains and Services Expenses	03004	Vehicle Expense	11,502	(25,934)	6,488	9,928	10,198	7,586	12,844	9,317	11,022	10,566
34	8740	Mains and Services Expenses	03008	842 Vehicle Lease Expense	-	-	-	-	-	-	-	-	-	-
35	8740	Mains and Services Expenses	03009	842 Variable Heavy Equip Lease Expense	-	-	-	-	-	-	-	-	-	-
36	8740	Mains and Services Expenses	04201	Software Maintenance	-	-	-	-	-	-	-	3,012	102	-
37	8740	Mains and Services Expenses	04301	Equipment Lease	-	-	-	-	-	-	-	-	-	-
38	8740	Mains and Services Expenses	04302	Heavy Equipment	571	1,743	192	785	1,418	77	2,144	3,093	1,568	2,025
39	8740	Mains and Services Expenses	04309	Non-842 Heavy Equipment	54	54	54	54	54	54	54	54	54	54
40	8740	Mains and Services Expenses	04560	Non 842 Fleet Lease/Rents	275	275	628	275	275	-	(1,839)	325	346	325
41	8740	Mains and Services Expenses	04563	842 Variable Fleet Lease Expense	1,038	3,167	29,203	1,536	1,280	57	57	57	36	57
42	8740	Mains and Services Expenses	05111	Postage/Delivery Services	-	-	-	-	-	-	-	-	-	-
43	8740	Mains and Services Expenses	05411	Meals and Entertainment	-	-	-	-	-	-	128	-	-	-
44	8740	Mains and Services Expenses	05413	Transportation	-	-	714	-	-	-	-	-	-	-
45	8740	Mains and Services Expenses	05414	Lodging	-	-	537	-	-	-	-	-	-	-
46	8740	Mains and Services Expenses	05420	Employee Development	-	-	3,191	-	-	-	-	-	-	-
47	8740	Mains and Services Expenses	05427	Technical (Job Skills) Training	-	-	-	-	-	-	-	70	-	-
48	8740	Mains and Services Expenses	06111	Contract Labor	1,232	-	-	-	-	-	8,487	-	-	-
49	8740	Mains and Services Expenses	06121	Legal	-	-	-	-	-	-	-	-	-	-
50	8740	Mains and Services Expenses	07443	Uniforms	-	-	-	-	79	-	-	-	-	-
51	8740	Mains and Services Expenses	07499	Misc Employee Welfare Exp	-	-	-	-	-	-	-	-	-	-
52	8780	Meter and house regulator expenses	05010	Office Supplies	-	-	-	-	-	-	-	-	-	-
53	8800	Distribution-Other expenses	02001	Inventory Materials	-	-	2,597	287	28	185	6	-	-	-
54	8800	Distribution-Other expenses	02005	Non-Inventory Supplies	5,528	210	-	-	176	-	20,795	370	6,544	-
55	8800	Distribution-Other expenses	05111	Postage/Delivery Services	-	-	-	-	-	-	-	-	-	-
56	8800	Distribution-Other expenses	05316	Telecom Maintenance & Repair	-	-	-	-	-	-	-	-	1,476	-
57	8800	Distribution-Other expenses	05364	Cellular, radio, pager charges	-	1,784	-	-	-	-	-	-	-	-
58	8800	Distribution-Other expenses	05421	Training	-	-	-	-	-	-	-	-	-	-
59	8800	Distribution-Other expenses	05426	Safety Training	-	-	-	-	-	-	-	-	-	-
60	8800	Distribution-Other expenses	06111	Contract Labor	1,482	-	-	-	-	-	-	-	-	-
61	8810	Distribution-Rents	04308	842 Locusview Lease Expense	444	-	-	-	-	-	-	-	-	-
62	8810	Distribution-Rents	04561	842 Variable Real Estate Lease Expense	(258)	(258)	(1,560)	(1,500)	(4,878)	(1,778)	1,058	(1,488)	(1,488)	(2,445)
63	8810	Distribution-Rents	04581	Non 842 Building Lease/Rents	-	-	-	-	-	-	200	92	-	0
64	9010	Customer accounts-Operation supervision	01000	Non-project Labor	289,337	272,961	251,211	257,454	260,176	380,289	255,846	257,283	246,280	246,731
65	9010	Customer accounts-Operation supervision	01008	Expense Labor Accrual	27,583	(5,732)	30,069	3,121	40,388	(105,733)	13,372	39,024	7,362	24,899
66	9010	Customer accounts-Operation supervision	04212	IT Equipment	65	-	159	-	160	-	179	-	-	-
67	9010	Customer accounts-Operation supervision	04564	842 Variable Copier Lease Expense	-	-	-	-	-	-	-	-	-	-
68	9010	Customer accounts-Operation supervision	05010	Office Supplies	115	-	305	60	111	76	-	14	272	-
69	9010	Customer accounts-Operation supervision	05215	842 Copier Lease Expense	-	-	-	-	-	-	-	-	-	-
70	9010	Customer accounts-Operation supervision	05377	Cell phone equipment and accessories	-	70	-	-	-	-	-	-	-	-
71	9010	Customer accounts-Operation supervision	05411	Meals and Entertainment	875	662	2,271	1,345	3,987	2,427	2,422	1,529	5,441	3,442
72	9010	Customer accounts-Operation supervision	05412	Spousal & Dependent Travel	92	-	-	-	71	-	-	-	3,422	-
73	9010	Customer accounts-Operation supervision	05413	Transportation	-	853	1,569	2,333	1,634	2,455	1,766	1,533	3,375	898
74	9010	Customer accounts-Operation supervision	05414	Lodging	-	3,592	295	391	1,751	3,020	3,066	1,517	1,263	1,507
75	9010	Customer accounts-Operation supervision	05417	Club Dues - Deductible	-	-	-	-	-	-	-	-	-	-
76	9010	Customer accounts-Operation supervision	05420	Employee Development	-	-	-	3,750	1,700	-	-	-	-	-
77	9010	Customer accounts-Operation supervision	05421	Training	-	-	-	-	-	-	-	-	-	-
78	9010	Customer accounts-Operation supervision	07421	Service Awards	-	-	-	-	-	-	-	-	300	-
79	9010	Customer accounts-Operation supervision	07443	Uniforms	-	-	-	-	-	-	-	173	-	-
80	9010	Customer accounts-Operation supervision	07499	Misc Employee Welfare Exp	-	-	492	239	567	174	-	215	1,897	277
81	9020	Customer accounts-Meter reading expenses	01000	Non-project Labor	9,202	7,653	7,578	8,370	7,629	13,381	8,497	7,532	9,077	8,781
82	9020	Customer accounts-Meter reading expenses	01008	Expense Labor Accrual	755	(542)	1,110	396	774	(2,729)	319	840	1,149	730
83	9020	Customer accounts-Meter reading expenses	03002	Vehicle Lease Payments	-	-	-	-	-	-	-	-	-	-
84	9020	Customer accounts-Meter reading expenses	03004	Vehicle Expense	-	-	-	-	-	-	-	-	-	-

Atmos Energy Corporation  
Shared Services Expenses Allocated to Div 091 and KY  
For Calendar 2023 and Six Months Ended June 2024

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23	SEP-23	OCT-23
85	9020	Customer accounts-Meter reading expenses	04560	Non 842 Fleet Lease/Rents	-	-	-	-	-	-	-	-	-	-
86	9020	Customer accounts-Meter reading expenses	05411	Meals and Entertainment	-	-	10	-	-	-	-	-	-	-
87	9020	Customer accounts-Meter reading expenses	05414	Lodging	-	866	-	-	-	-	-	-	-	-
88	9020	Customer accounts-Meter reading expenses	07499	Misc Employee Welfare Exp	-	-	-	-	-	-	-	-	-	-
89	9030	Customer accounts-Customer records and collection	01000	Non-project Labor	1,997,379	1,955,856	1,925,274	1,929,000	1,888,469	2,891,865	1,940,894	1,920,333	1,915,510	1,968,279
90	9030	Customer accounts-Customer records and collection	01008	Expense Labor Accrual	219,847	(14,533)	278,087	1,863	263,005	(745,527)	100,291	281,881	93,606	223,212
91	9030	Customer accounts-Customer records and collection	02005	Non-Inventory Supplies	-	-	-	-	-	-	-	-	77	-
92	9030	Customer accounts-Customer records and collection	02006	Purchasing Card Charges	-	-	-	-	-	-	-	62	-	-
93	9030	Customer accounts-Customer records and collection	04040	Community Rel&Trade Shows	-	-	-	-	69	-	-	-	31	-
94	9030	Customer accounts-Customer records and collection	04130	Bank Service Charge	49,190	12,355	188	41,023	8,265	4,971	53,011	8,091	8,745	58,365
95	9030	Customer accounts-Customer records and collection	04145	Printing/Slides/Graphics	-	-	-	-	-	-	-	-	-	-
96	9030	Customer accounts-Customer records and collection	04212	IT Equipment	-	-	138	-	-	-	-	-	212	-
97	9030	Customer accounts-Customer records and collection	04582	Building Maintenance	-	-	-	-	-	-	-	-	-	19
98	9030	Customer accounts-Customer records and collection	04590	Utilities	5,417	5,401	6,122	5,960	6,084	7,509	8,407	9,479	9,836	9,910
99	9030	Customer accounts-Customer records and collection	05010	Office Supplies	290	-	27	35	-	-	840	-	3,882	71
100	9030	Customer accounts-Customer records and collection	05111	Postage/Delivery Services	-	-	114	-	100	-	-	8	268	-
101	9030	Customer accounts-Customer records and collection	05377	Cell phone equipment and accessories	-	-	-	51	-	-	-	-	-	-
102	9030	Customer accounts-Customer records and collection	05411	Meals and Entertainment	14,114	1,880	17,516	5,737	17,413	5,255	12,171	3,477	6,185	12,805
103	9030	Customer accounts-Customer records and collection	05412	Spousal & Dependent Travel	232	-	-	-	-	-	-	-	26	-
104	9030	Customer accounts-Customer records and collection	05413	Transportation	334	756	1,721	913	5,066	2,108	1,250	3,066	1,375	2,299
105	9030	Customer accounts-Customer records and collection	05414	Lodging	-	124	1,483	2,142	4,911	1,209	1,461	2,136	1,620	2,310
106	9030	Customer accounts-Customer records and collection	05415	Membership Fees	-	-	-	85	244	-	-	-	-	-
107	9030	Customer accounts-Customer records and collection	05417	Club Dues - Deductible	150	245	-	-	-	-	-	-	-	-
108	9030	Customer accounts-Customer records and collection	05420	Employee Development	-	-	199	1,330	1,056	499	499	5,758	-	-
109	9030	Customer accounts-Customer records and collection	05421	Training	-	-	-	-	1,250	-	-	-	-	-
110	9030	Customer accounts-Customer records and collection	05424	Books & Manuals	-	-	-	-	116	-	-	-	-	-
111	9030	Customer accounts-Customer records and collection	05425	Regulatory Compliance Training	-	-	-	-	-	-	-	-	-	-
112	9030	Customer accounts-Customer records and collection	05428	Computer Skills & Systems Training	-	-	-	-	-	-	-	-	-	-
113	9030	Customer accounts-Customer records and collection	07421	Service Awards	46	100	-	-	-	-	500	-	450	-
114	9030	Customer accounts-Customer records and collection	07443	Uniforms	-	-	-	139	173	-	-	-	-	-
115	9030	Customer accounts-Customer records and collection	07499	Misc Employee Welfare Exp	109	465	-	315	489	338	1,653	121	2,149	801
116	9030	Customer accounts-Customer records and collection	07590	Misc General Expense	-	-	-	-	-	-	-	-	-	-
117	9070	Customer service-Supervision	05010	Office Supplies	-	-	-	-	-	-	-	-	-	165
118	9090	Customer service-Operating informational and instr.	01002	Capital Labor Contra	-	-	-	-	-	(1,899)	-	-	-	-
119	9090	Customer service-Operating informational and instr.	01011	Capital Labor Transfer In	-	-	-	-	-	1,899	-	-	-	-
120	9090	Customer service-Operating informational and instr.	07499	Misc Employee Welfare Exp	-	-	1,112	-	-	-	-	-	-	-
121	9100	Customer service-Miscellaneous customer service	04582	Building Maintenance	-	-	-	-	-	-	-	-	-	-
122	9100	Customer service-Miscellaneous customer service	05010	Office Supplies	-	-	-	-	-	-	-	-	34	-
123	9100	Customer service-Miscellaneous customer service	05413	Transportation	-	-	464	-	-	-	-	-	-	-
124	9100	Customer service-Miscellaneous customer service	05414	Lodging	-	-	178	-	-	-	-	-	-	-
125	9100	Customer service-Miscellaneous customer service	07499	Misc Employee Welfare Exp	-	-	-	-	-	-	58	1,331	1,839	131
126	9110	Sales-Supervision	05413	Transportation	-	-	638	-	-	-	-	-	-	-
127	9110	Sales-Supervision	05414	Lodging	-	-	468	-	-	-	-	-	-	-
128	9120	Sales-Demonstrating and selling expenses	04044	Advertising	8,236	8,236	12,899	16,961	8,271	6,720	9,305	18,609	2,585	8,359
129	9120	Sales-Demonstrating and selling expenses	04046	Customer Relations & Assist	-	463	-	-	129	-	604	1	191	2,585
130	9120	Sales-Demonstrating and selling expenses	07510	Association Dues	-	-	-	-	-	-	-	-	158,289	-
131	9130	Sales-Advertising expenses	06111	Contract Labor	-	-	-	-	-	-	-	-	-	-
132	9160	Sales-Miscellaneous sales expenses	07499	Misc Employee Welfare Exp	-	-	-	18	-	-	-	-	-	-
133	9200	A&G-Administrative & general salaries	01000	Non-project Labor	4,903,302	4,668,523	4,717,008	4,678,686	4,549,492	6,953,829	4,679,161	4,735,002	4,715,871	4,716,519
134	9200	A&G-Administrative & general salaries	01001	Capital Labor	79,076	164,108	179,183	154,266	316,563	342,102	212,015	222,007	173,431	137,745
135	9200	A&G-Administrative & general salaries	01002	Capital Labor Contra	(68,177)	(157,815)	(165,858)	(145,982)	(294,099)	(300,016)	(197,532)	(207,407)	(154,103)	(123,368)
136	9200	A&G-Administrative & general salaries	01006	O&M Project Labor and Contra	-	-	-	-	-	423	363	423	302	982
137	9200	A&G-Administrative & general salaries	01008	Expense Labor Accrual	481,851	(82,172)	724,521	(18,461)	617,725	(1,798,650)	244,739	727,084	227,145	472,414
138	9200	A&G-Administrative & general salaries	01010	PTO Accrual	-	-	-	-	-	159,738	-	-	-	-
139	9200	A&G-Administrative & general salaries	01011	Capital Labor Transfer In	32,655	60,152	80,733	59,737	147,598	127,125	87,101	99,320	65,958	49,731
140	9200	A&G-Administrative & general salaries	01012	Capital Labor Transfer Out	(43,554)	(66,445)	(94,058)	(68,021)	(157,384)	(169,211)	(101,583)	(113,919)	(85,286)	(64,109)
141	9200	A&G-Administrative & general salaries	01013	Expense Labor Transfer In	-	-	-	-	-	423	363	423	302	982
142	9200	A&G-Administrative & general salaries	01014	Expense Labor Transfer Out	-	-	-	-	-	(423)	(363)	(423)	(302)	(982)
143	9200	A&G-Administrative & general salaries	02001	Inventory Materials	-	-	-	-	-	-	-	-	-	-
144	9200	A&G-Administrative & general salaries	04863	A&G Overhead Clearing	(8,515,635)	(8,446,092)	(8,347,115)	(7,987,273)	(8,845,996)	(11,972,973)	(8,655,718)	(9,835,855)	(10,827,865)	(7,796,744)
145	9200	A&G-Administrative & general salaries	05010	Office Supplies	-	-	503	-	-	9,057	-	-	-	-
146	9200	A&G-Administrative & general salaries	05111	Postage/Delivery Services	-	-	-	-	-	-	-	-	2,386	-
147	9200	A&G-Administrative & general salaries	05415	Membership Fees	-	1,029	-	-	517	-	-	-	-	-
148	9200	A&G-Administrative & general salaries	05419	Misc Employee Expense	-	-	-	-	-	-	-	-	-	-
149	9200	A&G-Administrative & general salaries	05421	Training	-	1,500	44	-	-	-	-	-	-	-
150	9200	A&G-Administrative & general salaries	06111	Contract Labor	65,557	101,122	96,447	69,171	75,489	615,601	82,292	114,585	194,244	27,405
151	9200	A&G-Administrative & general salaries	07499	Misc Employee Welfare Exp	-	-	-	-	-	-	-	-	-	-
152	9200	A&G-Administrative & general salaries	07590	Misc General Expense	(3)	-	0	0	-	5	0	1	-	10
153	9210	A&G-Office supplies & expense	02001	Inventory Materials	15,834	18,547	31,285	31,438	34,523	35,825	57,262	30,082	51,445	16,285
154	9210	A&G-Office supplies & expense	02005	Non-Inventory Supplies	67,975	25,508	155,661	129,464	79,436	63,504	55,827	89,025	76,944	78,942
155	9210	A&G-Office supplies & expense	02006	Purchasing Card Charges	-	-	-	993	958	1,965	3,764	469	2,469	2,129
156	9210	A&G-Office supplies & expense	03004	Vehicle Expense	2,589	268	18	1,364	333	22	61	(1,516)	316	103
157	9210	A&G-Office supplies & expense	04002	Required By Law, Safety	-	-	-	-	-	-	-	-	-	-
158	9210	A&G-Office supplies & expense	04021	Promo Other, Misc	1,151	-	-	226	2,817	-	-	-	43,311	35
159	9210	A&G-Office supplies & expense	04040	Community Rel&Trade Shows	1,432	721	5,363	780	3,558	1,936	36,246	1,768	134	3,725
160	9210	A&G-Office supplies & expense	04044	Advertising	-	-	-	10,262	-	-	248	10,134	-	226
161	9210	A&G-Office supplies & expense	04046	Customer Relations & Assist	139	-	-	1,651	14	695	543	1,234	-	-
162	9210	A&G-Office supplies & expense	04120	News wire/Blast Fax/Mail List	-	-	-	-	-	26,502	-	-	-	-
163	9210	A&G-Office supplies & expense	04121	Inv Relations/Bnkg Inst	12,863	12,728	13,089	12,815	12,815	13,177	13,177	13,538	9,977	12,710
164	9210	A&G-Office supplies & expense	04122	Annual Report Design, Printing & Dist.	-	-	-	-	16,209	6,319	11,400	-	18,120	40
165	9210	A&G-Office supplies & expense	04130	Bank Service Charge	9,720	10,422	9,989	10,905	9,171	10,737	-	18,160	9,218	8,345
166	9210	A&G-Office supplies & expense	04141	Web Site	-	497	-	1,138	1,089	1,263	-	22	42,237	1,317
167	9210	A&G-Office supplies & expense	04145	Printing/Slides/Graphics	325	-	-	-	-	-	-	108	1,330	-
168	9210	A&G-Office supplies & expense	04201	Software Maintenance	2,967,042	2,784,704	2,836,804	2,911,722	2,948,745	2,690,939	2,900,397	3,159,068	3,178,587	2,967,062

**Atmos Energy Corporation**  
**Shared Services Expenses Allocated to Div 091 and KY**  
**For Calendar 2023 and Six Months Ended June 2024**

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23	SEP-23	OCT-23
169	9210	A&G-Office supplies & expense	04212	IT Equipment	308,943	298,652	321,565	294,654	297,834	318,667	328,043	304,539	301,525	284,048
170	9210	A&G-Office supplies & expense	04302	Heavy Equipment	-	-	3,743	-	-	-	-	-	-	24,884
171	9210	A&G-Office supplies & expense	04564	842 Variable Copier Lease Expense	-	-	-	-	-	-	-	35	784	0
172	9210	A&G-Office supplies & expense	04575	842 Short Term Lease Expense	-	-	-	-	1,005	1,328	2,503	-	-	-
173	9210	A&G-Office supplies & expense	04582	Building Maintenance	171,899	144,051	187,149	138,218	107,025	160,093	107,434	175,665	166,131	95,360
174	9210	A&G-Office supplies & expense	04590	Utilities	16,540	14,508	15,868	25,293	13,540	21,054	12,614	20,873	16,769	21,028
175	9210	A&G-Office supplies & expense	04592	Misc Rents	19	19	19	19	1	-	-	-	-	-
176	9210	A&G-Office supplies & expense	05010	Office Supplies	16,866	18,713	11,904	14,509	21,628	24,316	21,608	23,100	13,483	(2,410)
177	9210	A&G-Office supplies & expense	05111	Postage/Delivery Services	35,702	17,557	55,475	32,079	29,876	29,169	41,515	29,580	31,821	46,947
178	9210	A&G-Office supplies & expense	05215	842 Copier Lease Expense	12,862	15,447	13,773	21,658	14,825	15,010	11,686	16,984	14,124	30,540
179	9210	A&G-Office supplies & expense	05310	Monthly Lines and service	57,463	65,100	51,089	76,239	43,920	42,489	60,475	47,176	57,384	59,463
180	9210	A&G-Office supplies & expense	05312	Long Distance	6,243	6,633	5,237	4,535	4,255	4,299	3,905	4,065	4,179	4,010
181	9210	A&G-Office supplies & expense	05314	Toll Free Long Distance	15,698	16,502	10,152	10,647	9,007	10,601	9,718	9,016	9,804	9,172
182	9210	A&G-Office supplies & expense	05316	Telecom Maintenance & Repair	89,878	49,051	47,479	73,070	46,856	46,849	50,399	49,846	49,719	52,859
183	9210	A&G-Office supplies & expense	05331	WAN/LAN/Internet Service	167,325	216,976	182,607	165,846	206,321	184,372	164,565	212,901	173,902	165,542
184	9210	A&G-Office supplies & expense	05364	Cellular, radio, pager charges	33,793	2,365	62,131	33,160	31,441	33,339	32,821	29,780	33,163	33,816
185	9210	A&G-Office supplies & expense	05376	Cell service for data uses	49,116	51,748	54,317	51,202	50,561	52,456	51,230	51,691	50,967	51,367
186	9210	A&G-Office supplies & expense	05377	Cell phone equipment and accessories	3,433	1,018	14,346	1,860	5,088	3,790	2,898	3,172	1,663	2,610
187	9210	A&G-Office supplies & expense	05390	Audio Conference	76	38	3,232	80	70	99	87	22	65	21
188	9210	A&G-Office supplies & expense	05410	Misc - Nondeductible	-	165	50	50	50	-	60	268	-	(322)
189	9210	A&G-Office supplies & expense	05411	Meals and Entertainment	36,515	35,653	60,458	59,160	68,479	53,644	70,492	91,391	101,733	78,897
190	9210	A&G-Office supplies & expense	05412	Spousal & Dependent Travel	87	591	151	25	-	144	105	121	1,489	2,847
191	9210	A&G-Office supplies & expense	05413	Transportation	21,637	16,940	43,618	39,342	44,197	45,530	34,041	59,117	62,431	27,449
192	9210	A&G-Office supplies & expense	05414	Lodging	13,208	28,886	30,622	37,737	44,424	49,026	38,005	57,164	78,422	34,983
193	9210	A&G-Office supplies & expense	05415	Membership Fees	84,407	48,197	51,603	(38,125)	57,870	3,652	82,217	127,542	(36,396)	61,656
194	9210	A&G-Office supplies & expense	05416	Club Dues - Nondeductible	150	-	-	-	-	-	-	-	-	120
195	9210	A&G-Office supplies & expense	05417	Club Dues - Deductible	10,405	15,487	3,009	-	5,000	219	240	-	-	-
196	9210	A&G-Office supplies & expense	05419	Misc Employee Expense	1,053	(3,241)	30,801	-	650	9,110	73	37,872	10,462	324
197	9210	A&G-Office supplies & expense	05420	Employee Development	19,085	23,096	31,645	21,896	23,128	49,316	29,210	36,378	57,661	25,283
198	9210	A&G-Office supplies & expense	05421	Training	24,315	2,780	28,094	24,296	5,954	3,811	79,315	19,418	20,857	517
199	9210	A&G-Office supplies & expense	05424	Books & Manuals	27,559	20,716	22,103	37,464	22,698	20,858	36,877	20,508	34,813	34,728
200	9210	A&G-Office supplies & expense	05425	Regulatory Compliance Training	-	-	295	-	-	921	-	-	285	-
201	9210	A&G-Office supplies & expense	05426	Safety Training	5,032	11,400	16,110	19,400	6,172	5,456	5,765	5,878	5,826	5,944
202	9210	A&G-Office supplies & expense	05427	Technical (Job Skills) Training	1,137	375	319	2,647	1,325	2,680	3,457	1,482	1,215	850
203	9210	A&G-Office supplies & expense	05428	Computer Skills & Systems Training	52	-	-	-	598	1,320	-	-	-	-
204	9210	A&G-Office supplies & expense	05430	Gas Supplies Services	-	-	-	-	76,750	-	-	-	23,700	-
205	9210	A&G-Office supplies & expense	06111	Contract Labor	457,585	745,077	126,188	521,535	341,356	565,775	274,605	328,868	667,355	208,338
206	9210	A&G-Office supplies & expense	06116	Bill Print Fees	-	24,246	-	-	-	-	-	-	-	-
207	9210	A&G-Office supplies & expense	06121	Legal	-	-	248	6	-	-	-	6	-	-
208	9210	A&G-Office supplies & expense	07120	Environmental & Safety	-	-	-	-	-	-	-	-	-	-
209	9210	A&G-Office supplies & expense	07421	Service Awards	40	31	-	-	-	474	-	11,494	14,078	9,936
210	9210	A&G-Office supplies & expense	07443	Uniforms	808	256	172	200	993	153	628	538	630	878
211	9210	A&G-Office supplies & expense	07495	Employee Broadcast and Publication	8,124	11,119	6,944	29,169	8,731	16,404	42,754	15,049	38,451	39,160
212	9210	A&G-Office supplies & expense	07499	Misc Employee Welfare Exp	51,028	8,797	11,554	7,953	13,736	18,171	9,726	11,777	48,899	9,737
213	9210	A&G-Office supplies & expense	07510	Association Dues	47,173	45,104	45,104	45,104	45,104	105,171	52,738	55,620	52,738	52,738
214	9210	A&G-Office supplies & expense	07590	Misc General Expense	-	1,555	(87,548)	56	106	220	69	224	188	-
215	9210	A&G-Office supplies & expense	09911	Reimbursements	-	-	-	(70,970)	-	-	-	-	-	-
216	9230	A&G-Outside services employed	01006	O&M Project Labor and Contra	-	-	-	2,878	921	1,868	875	-	-	-
217	9230	A&G-Outside services employed	01008	Expense Labor Accrual	-	-	-	739	(739)	235	28	(262)	-	-
218	9230	A&G-Outside services employed	04201	Software Maintenance	18,476	18,476	18,476	18,476	18,476	19,377	19,377	19,377	19,377	19,377
219	9230	A&G-Outside services employed	05111	Postage/Delivery Services	-	9	-	-	-	-	-	-	-	-
220	9230	A&G-Outside services employed	05411	Meals and Entertainment	-	-	66	-	-	350	-	-	14	-
221	9230	A&G-Outside services employed	05413	Transportation	-	-	-	-	-	88	-	-	374	-
222	9230	A&G-Outside services employed	05414	Lodging	-	-	-	-	-	-	-	-	284	-
223	9230	A&G-Outside services employed	05415	Membership Fees	-	-	3,915	-	-	2,450	-	-	-	-
224	9230	A&G-Outside services employed	05418	Settlement	-	-	-	-	-	-	-	-	-	-
225	9230	A&G-Outside services employed	05421	Training	3,548	105	-	-	-	-	-	64	-	4
226	9230	A&G-Outside services employed	05425	Regulatory Compliance Training	-	-	-	-	-	-	-	4,446	-	-
227	9230	A&G-Outside services employed	06111	Contract Labor	1,123,243	1,114,100	970,764	2,526,620	1,580,766	851,945	1,159,380	1,228,158	1,422,752	1,140,018
228	9230	A&G-Outside services employed	06121	Legal	261,657	944,354	410,046	709,106	(149,254)	337,054	936,205	1,529,363	577,580	1,139,991
229	9230	A&G-Outside services employed	07496	Admin Fees Pension	9,215	10,530	13,340	17,003	10,947	14,888	2,709	24,847	36,513	11,032
230	9230	A&G-Outside services employed	07497	Admin Fees SERP	13,556	13,005	17,763	23,648	55,503	25,696	39,922	22,436	9,484	54,437
231	9230	A&G-Outside services employed	07590	Misc General Expense	-	-	-	-	-	12,990	-	440	-	-
232	9230	A&G-Outside services employed	09911	Reimbursements	-	-	-	-	-	-	-	-	(1,000,000)	-
233	9240	A&G-Property insurance	04069	Blueflame Property Insurance	15,623	15,623	16,800	16,800	16,800	16,800	16,800	16,800	16,800	16,800
234	9250	A&G-Injuries & damages	01208	Workers Comp Benefits Variance	(14,926)	1,105	(12,178)	942	1,062	(17,501)	391	6,966	(17,922)	13,690
235	9250	A&G-Injuries & damages	01221	Workers Comp Benefits Load	9,515	8,162	9,522	8,233	9,152	9,105	8,692	9,562	8,660	8,431
236	9250	A&G-Injuries & damages	01293	Workers Comp Benefits Projects	-	-	-	3	16	3	1	1	1	8
237	9250	A&G-Injuries & damages	04070	Insurance-Other	30,373	10,162	10,540	10,587	10,580	10,580	10,767	10,767	30,978	10,887
238	9250	A&G-Injuries & damages	07115	Insurance Reserve	-	-	-	-	-	1,600,000	-	(1,000,000)	1,000,000	-
239	9250	A&G-Injuries & damages	07119	Insurance - D&O	235,944	235,944	235,944	235,944	235,944	235,944	231,052	231,052	231,052	231,052
240	9250	A&G-Injuries & damages	07121	Insurance - Public Liability	3,554,524	3,547,566	3,409,807	3,549,314	3,556,814	3,549,314	3,549,314	3,231,143	3,549,314	4,212,491
241	9260	A&G-Employee pensions and benefits	01202	Pension Benefits Load	215,670	185,015	215,828	186,624	207,452	206,370	197,013	216,749	196,287	174,755
242	9260	A&G-Employee pensions and benefits	01203	OPEB Benefits Load	164,924	141,482	165,045	142,712	158,640	157,812	150,657	165,749	150,102	148,695
243	9260	A&G-Employee pensions and benefits	01206	Pension Benefits Variance	(34,558)	(2,293)	(37,055)	(2,826)	(35,093)	(22,581)	(16,473)	(37,783)	(12,443)	(15,005)
244	9260	A&G-Employee pensions and benefits	01207	OPEB Benefits Variance	(19,279)	5,285	(21,292)	4,921	(20,008)	(10,201)	(5,574)	(21,900)	(2,432)	(6,695)
245	9260	A&G-Employee pensions and benefits	01251	Medical Benefits Load	1,336,838	1,146,819	1,337,817	1,156,793	1,285,898	1,279,190	1,221,190	1,343,526	1,216,693	1,353,585
246	9260	A&G-Employee pensions and benefits	01252	Medical Benefits Variance	(29,029)	(169,252)	18,631	(216,486)	(1,068,186)	(7,202)	224,718	(110,135)	194,951	(9,618)
247	9260	A&G-Employee pensions and benefits	01253	Medical Benefits Projects	-	-	-	485	2,293	386	209	71	201	1,171
248	9260	A&G-Employee pensions and benefits	01257	ESOP Benefits Load	287,032	246,233	287,242	248,374	276,094	274,654	262,201	288,468	261,235	334,181
249	9260	A&G-Employee pensions and benefits	01258	ESOP Benefits Variance	33,303	20,960	51,506	(18,912)	72,542	11,584	(43,763)	56,668	13,421	(40,767)
250	9260	A&G-Employee pensions and benefits	01259	ESOP Benefits Projects	-	-	-	104	492	83	45	15	43	251
251	9260	A&G-Employee pensions and benefits	01261	Other Benefits Variance	7,233	6,983	7,051	6,922	6,732	6,976	3,763	7,110	7,141	17,511
252	9260	A&G-Employee pensions and benefits	01262	Other Benefits Projects	-	-	-	-	-	-	-	-	-	-



Atmos Energy Corporation  
Shared Services Expenses Allocated to Div 091 and KY  
For Calendar 2023 and Six Months Ended June 2024

Line No.	Account	Account Description	Sub Account	Sub Account Description	JAN-23	FEB-23	MAR-23	APR-23	MAY-23	JUN-23	JUL-23	AUG-23	SEP-23	OCT-23
253	9260	A&G-Employee pensions and benefits	01263	RSP FACC Benefits Load	143,516	123,116	143,621	124,187	138,047	137,327	131,101	144,234	130,618	171,689
254	9260	A&G-Employee pensions and benefits	01264	RSP FACC Benefits Variance	(24,006)	(5,202)	(28,865)	(7,151)	(27,621)	47,626	(11,880)	(23,868)	(4,793)	(50,488)
255	9260	A&G-Employee pensions and benefits	01265	RSP FACC Benefits Projects	-	-	-	52	246	41	22	8	22	126
256	9260	A&G-Employee pensions and benefits	01266	Life Benefits Load	15,858	13,604	15,870	13,722	15,254	15,174	14,486	15,937	14,433	18,395
257	9260	A&G-Employee pensions and benefits	01267	Life Benefits Variance	71,006	1,641	43,287	1,740	(1,209)	66,243	656	(972)	70,138	1,152
258	9260	A&G-Employee pensions and benefits	01268	Life Benefits Projects	-	-	-	6	27	5	2	1	2	14
259	9260	A&G-Employee pensions and benefits	01269	LTD Benefits Load	50,746	43,533	50,783	43,911	48,812	48,558	46,356	51,000	46,185	51,354
260	9260	A&G-Employee pensions and benefits	01270	LTD Benefits Variance	3,802	4,306	264	4,222	(3,593)	(5,343)	970	(4,066)	5,530	541
261	9260	A&G-Employee pensions and benefits	01271	LTD Benefits Projects	-	-	-	18	87	15	8	3	8	44
262	9260	A&G-Employee pensions and benefits	01291	Pension Benefits Projects	-	-	-	78	370	62	34	12	32	189
263	9260	A&G-Employee pensions and benefits	01292	OPEB Benefits Projects	-	-	-	60	283	48	26	9	25	144
264	9260	A&G-Employee pensions and benefits	01294	NSC-OPEB Benefits Load	(210,120)	(180,253)	(210,274)	(181,821)	(202,113)	(201,059)	(191,943)	(211,171)	(191,236)	(187,019)
265	9260	A&G-Employee pensions and benefits	01295	NSC-OPEB Benefits Variance	24,976	(6,326)	27,534	(5,859)	25,886	13,406	7,508	28,307	3,508	(49,472)
266	9260	A&G-Employee pensions and benefits	01296	NSC-OPEB Benefits Projects	-	-	-	(76)	(360)	(61)	(33)	(12)	(32)	(169)
267	9260	A&G-Employee pensions and benefits	01297	NSC-Pension Benefits Load	(123,693)	(106,111)	(123,784)	(107,034)	(118,980)	(118,359)	(112,993)	(124,312)	(112,577)	(81,246)
268	9260	A&G-Employee pensions and benefits	01298	NSC-Pension Benefits Variance	55,155	36,108	56,089	36,616	53,881	47,887	44,164	56,241	42,152	31,468
269	9260	A&G-Employee pensions and benefits	01299	NSC-Pension Benefits Projects	-	-	-	(45)	(212)	(36)	(19)	(7)	(19)	(80)
270	9260	A&G-Employee pensions and benefits	07421	Service Awards	9,631	3,300	9,013	11,949	20,289	-	19,641	13,972	18,795	25,779
271	9260	A&G-Employee pensions and benefits	07443	Uniforms	-	17	9	17	-	8	8	8	-	-
272	9260	A&G-Employee pensions and benefits	07447	Education Assistance Program	22,455	5,365	14,327	16,478	74,876	28,449	14,836	45,235	19,683	33,601
273	9260	A&G-Employee pensions and benefits	07452	Variable Pay & Mgmt Incentive Plans	1,581,000	1,417,132	1,300,868	1,054,000	999,000	971,000	2,915,921	3,564,502	-	920,607
274	9260	A&G-Employee pensions and benefits	07458	Restricted Stock - Long Term Incentive Plan - Perf	403,486	385,618	382,058	411,419	1,664,940	400,243	2,049,030	1,053,161	(67,175)	1,172,040
275	9260	A&G-Employee pensions and benefits	07460	RSU-Long Term Incentive Plan - Time Lapse	159,892	144,418	124,803	165,247	3,579,396	210,178	529,422	-	(27,744)	177,738
276	9260	A&G-Employee pensions and benefits	07463	RSU-Management Incentive Plan	4,089	3,693	4,089	3,957	4,618	7,880	13,103	-	-	4,637
277	9260	A&G-Employee pensions and benefits	07486	Rabbi Trust Realized Gain/Loss-Div	(19,116)	(53,578)	(149,687)	(49,070)	1,266,905	(172,097)	(84,917)	(44,780)	(176,942)	(83,995)
278	9260	A&G-Employee pensions and benefits	07487	COLI CSV & Premiums	(3,081)	(185,157)	(1,048)	(73,461)	(1,941)	(2,001)	(136,735)	(1,424)	14,324	(17,130)
279	9260	A&G-Employee pensions and benefits	07488	COLI Loan Interest	73,466	3,441	67,100	67,607	67,607	69,001	69,001	69,001	69,001	69,470
280	9260	A&G-Employee pensions and benefits	07489	NQ Retirement Cost	54,487	54,487	54,487	54,487	59,724	56,416	56,107	57,416	57,416	(14,885)
281	9260	A&G-Employee pensions and benefits	07492	NSC-NQ Retirement Cost	365,864	365,864	365,864	365,864	364,962	364,962	364,962	364,962	377,544	381,121
282	9260	A&G-Employee pensions and benefits	07499	Misc Employee Welfare Exp	3,984	3,367	-	-	8,836	3,820	-	-	-	5,118
283	9302	Miscellaneous general expenses	01006	O&M Project Labor and Contra	-	-	-	-	-	-	-	-	891	5,964
284	9302	Miscellaneous general expenses	01008	Expense Labor Accrual	-	-	-	-	-	-	-	-	446	3,133
285	9302	Miscellaneous general expenses	01013	Expense Labor Transfer In	-	-	-	-	-	-	-	-	891	5,964
286	9302	Miscellaneous general expenses	01014	Expense Labor Transfer Out	-	-	-	-	-	-	-	-	(891)	(5,964)
287	9302	Miscellaneous general expenses	03004	Vehicle Expense	-	-	-	25	-	-	-	-	-	-
288	9302	Miscellaneous general expenses	04111	Director's Fees	353,630	(239,999)	322,745	9,537	30,885	-	364,131	-	-	408,367
289	9302	Miscellaneous general expenses	04113	Directors Retirement Expenses	-	-	1,646,867	-	-	153,942	-	-	154,937	-
290	9302	Miscellaneous general expenses	04120	NewsWire/Blast Fax/Mail List	-	9,208	11,764	416	5,993	3,250	7,516	3,263	-	295
291	9302	Miscellaneous general expenses	04125	Proxy Solicitation Exp	257,670	25,631	43,409	14,633	(13,353)	-	-	-	-	18,823
292	9302	Miscellaneous general expenses	04127	Tr & Reg of Bonds/Debt Fee	166,181	51,726	44,542	73,676	44,542	101,404	66,051	56,384	53,065	106,978
293	9302	Miscellaneous general expenses	04129	NYSE Fees & Exps	17,693	17,678	56,981	19,240	19,113	19,113	19,113	19,109	19,113	18,998
294	9302	Miscellaneous general expenses	04135	Reimbursement of Fraud Payments	566	-	-	-	(550)	-	-	629	139	139
295	9302	Miscellaneous general expenses	04140	Analyst Activities	3,318	2,016	-	3,323	-	-	3,214	109	-	3,214
296	9302	Miscellaneous general expenses	04145	Printing/Slides/Graphics	66,344	590	-	-	-	-	-	-	-	1,199
297	9302	Miscellaneous general expenses	04201	Software Maintenance	41,317	34,762	34,563	44,454	34,680	34,803	39,224	51,630	146,972	69,475
298	9302	Miscellaneous general expenses	04212	IT Equipment	-	-	-	4,797	-	162	-	-	-	-
299	9302	Miscellaneous general expenses	05010	Office Supplies	-	-	-	-	-	-	73	-	-	-
300	9302	Miscellaneous general expenses	05111	Postage/Delivery Services	-	-	-	-	-	-	-	48	-	-
301	9302	Miscellaneous general expenses	05411	Meals and Entertainment	-	-	-	-	-	673	-	-	-	-
302	9302	Miscellaneous general expenses	05415	Membership Fees	-	-	-	-	-	-	-	-	-	-
303	9302	Miscellaneous general expenses	05427	Technical (Job Skills) Training	-	-	-	-	-	-	-	-	-	-
304	9302	Miscellaneous general expenses	06111	Contract Labor	111,743	37,909	(3,382)	30,403	20,447	(13,347)	720	2,145	28,471	12,903
305	9302	Miscellaneous general expenses	06121	Legal	-	-	-	-	-	-	-	-	-	-
306	9302	Miscellaneous general expenses	07443	Uniforms	46	-	-	-	-	-	-	-	-	-
307	9302	Miscellaneous general expenses	07510	Association Dues	3,867	21,883	3,867	3,867	3,867	3,867	3,867	3,867	3,867	3,867
308	9302	Miscellaneous general expenses	07590	Misc General Expense	859	10,691	63,941	234	(75,147)	146,489	(144,419)	5,036	(5,274)	122
309	9310	A&G-Rents	02005	Non-Inventory Supplies	-	-	-	-	-	20	1	-	-	-
310	9310	A&G-Rents	04201	Software Maintenance	-	-	7,987	11,161	20,748	129	-	14,043	18,045	6,536
311	9310	A&G-Rents	04212	IT Equipment	-	22,231	-	-	21,263	-	-	4,035	137	-
312	9310	A&G-Rents	04561	842 Variable Real Estate Lease Expense	68,293	105,444	60,836	102,711	96,461	14,069	106,870	95,655	107,153	304,119
313	9310	A&G-Rents	04578	842 Real Estate Lease Expense	478,145	478,145	478,145	478,145	478,145	478,630	478,630	478,630	478,630	479,232
314	9310	A&G-Rents	04581	Non 842 Building Lease/Rents	-	19	2,258	2,258	2,444	2,304	2,268	2,503	2,339	2,272
315	9310	A&G-Rents	04582	Building Maintenance	7,923	6,052	41,635	11,603	8,574	9,960	7,814	4,535	19,279	12,525
316	9310	A&G-Rents	04590	Utilities	2,499	2,948	2,837	5,989	(32,097)	2,965	3,734	3,327	3,270	3,421
317	9310	A&G-Rents	06111	Contract Labor	7,214	5,541	11,713	14,799	(1,330)	1,274	7,508	7,721	5,606	7,500
318	9310	A&G-Rents	07499	Misc Employee Welfare Exp	160	-	(60)	-	-	128	-	-	-	26
319	9320	A&G-Maintenance of general plant	02001	Inventory Materials	-	-	32,158	-	-	-	-	-	-	-
320	9320	A&G-Maintenance of general plant	04065	Offsite Storage	14,918	32,856	16,319	467	31,067	16,342	15,099	16,365	14,909	14,680
321	9320	A&G-Maintenance of general plant	04201	Software Maintenance	2,138	1,167	55,260	10,555	2,304	2,179	16,555	26,925	481	79,472
322	9320	A&G-Maintenance of general plant	04212	IT Equipment	9	1,072	83,694	(124)	12,217	2,093	3,838	3,143	55,713	989
323	9320	A&G-Maintenance of general plant	05010	Office Supplies	-	-	-	-	-	-	-	-	-	-
324	9320	A&G-Maintenance of general plant	05111	Postage/Delivery Services	378	-	188	244	151	-	-	54	194	96
325	9320	A&G-Maintenance of general plant	06111	Contract Labor	1,529	3,224	4,420	3,257	10,918	2,001	1,721	6,343	12,205	5,893
Shared Services Expenses					15,969,884	13,522,270	16,613,041	15,278,819	18,712,555	12,747,969	18,295,319	16,654,709	11,701,053	17,547,888
Shared Services Costs Allocated to Div091 Based on Customer Count Allocation Factor					403,797	358,256	389,201	339,094	399,742	399,767	371,741	391,887	358,955	391,995
Shared Services Costs Allocated to Div091 Based on Composite Allocation Factor					1,033,291	777,951	1,145,024	871,386	1,381,703	549,963	1,234,775	1,081,240	613,642	1,177,802
					1,437,088	1,136,208	1,534,225	1,210,479	1,781,445	949,729	1,606,516	1,473,127	972,597	1,569,797
Shared Services Costs Allocated to Div091 then Allocated to KY based on Customer Count Allocation Factor					201,212	178,519	193,939	168,970	199,192	199,204	185,239	195,277	178,867	193,881
Shared Services Costs Allocated to Div091 then Allocated to KY based on Composite Allocation Factor					525,119	395,355	581,901	442,838	702,181	279,491	627,513	549,486	311,853	588,548
					726,331	573,874	775,840	611,809	901,373	478,695	812,751	744,763	490,720	782,428

Line No.	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
1	-	-	-	-	6,067	-	405	(405)	-
2	2,361	2,585	5,322	3,864	8,167	1,746	636	17,050	3,285
3	-	-	-	-	-	1,366	-	-	-
4	-	-	63,268	-	-	-	-	-	8,205
5	-	(2,835)	(3,067)	(3,827)	(8,110)	(7,930)	(7,982)	(14,682)	(8,260)
6	-	2,835	3,067	3,827	8,110	7,930	7,982	14,682	8,260
7	-	-	-	-	-	(1,223)	-	-	-
8	-	-	-	3,779	128	-	-	-	-
9	-	-	20,055	-	-	27,066	284	21,427	(21,427)
10	-	-	10,796	-	-	-	-	-	-
11	-	-	13,746	-	-	-	-	-	-
12	-	-	1,041	-	-	-	-	-	-
13	-	989	989	-	-	-	-	-	-
14	(4,865)	(5,056)	(52,276)	(2,570)	(4,465)	(4,252)	(6,781)	(6,631)	(18,838)
15	-	-	48	-	-	-	-	-	-
16	-	165	(40)	(165)	-	-	-	-	-
17	4,865	5,056	52,276	2,570	4,465	4,252	6,781	6,631	18,838
18	-	-	(48)	-	-	-	-	-	-
19	-	-	7,223	-	-	-	-	-	-
20	-	-	-	-	517	-	-	840	28
21	-	-	23	-	61	-	-	-	-
22	-	-	176	-	-	-	-	-	-
23	-	-	7,565	-	-	-	1,147	-	97
24	-	-	2,240	-	-	-	868	242	-
25	-	-	2,680	-	-	-	1,132	120	-
26	-	1,873	7,054	902	-	2,914	-	-	-
27	214	-	214	-	-	-	-	-	-
28	292	-	436	-	-	-	-	495	-
29	204	(204)	-	-	-	-	-	83	(83)
30	-	-	22,747	-	-	-	-	-	-
31	-	-	758	-	524	-	-	-	-
32	-	(7,918)	77,986	5,687	(5,960)	(7,496)	-	-	-
33	10,885	9,958	84,360	13,314	11,006	12,535	15,915	2,277	2,186
34	7,444	15,293	22,737	3,039	14,055	8,363	9,012	8,602	4,697
35	-	-	-	-	-	-	-	68	18
36	-	-	3,113	-	-	-	-	-	-
37	-	-	-	-	-	-	-	690	225
38	514	41	14,172	170	166	274	1,544	377	3,100
39	54	54	650	54	54	54	54	50	54
40	275	275	1,435	-	700	791	(9,913)	200	200
41	57	0	36,544	1,240	210	249	(11,281)	2,606	987
42	-	-	-	-	-	79	-	-	-
43	-	203	331	-	279	-	-	-	89
44	-	-	714	-	2,501	20	-	-	-
45	-	-	537	-	1,403	-	-	-	164
46	-	-	3,191	-	-	-	-	-	-
47	376	-	446	-	-	-	-	-	-
48	-	1,232	10,951	-	-	-	-	-	-
49	-	-	-	-	3,722	-	-	-	-
50	-	-	79	-	-	-	-	-	-
51	-	345	345	-	-	-	-	-	-
52	-	-	-	-	-	26	-	-	-
53	-	-	3,102	-	-	-	-	-	-
54	-	-	33,622	-	-	-	-	-	-
55	-	-	-	-	26	-	-	-	-
56	-	-	1,476	-	-	1,612	55	-	-
57	-	-	1,784	-	-	-	-	-	-
58	-	-	-	-	-	-	-	-	3,483
59	-	-	-	-	-	-	-	-	5,000
60	-	-	1,482	21,096	11,771	-	11,088	23,784	46,436
61	-	-	444	-	-	-	-	-	-
62	(200)	(2,675)	(17,470)	(2,445)	(2,735)	(2,445)	2,490	75,694	291
63	-	-	292	-	-	-	-	-	-
64	241,465	363,122	3,322,155	241,960	241,685	241,960	236,245	325,575	208,892
65	20,987	(108,505)	(13,165)	36,264	11,974	12,222	20,767	(87,485)	(2,039)
66	54	-	617	-	-	-	-	-	-
67	-	201	201	142	363	256	254	294	303
68	-	335	1,287	363	568	556	344	1,126	1,287
69	-	(536)	(536)	(472)	(717)	(599)	(598)	(1,420)	(1,498)
70	-	37	107	-	-	-	-	-	-
71	1,140	8,104	33,645	1,254	945	2,051	2,007	2,521	1,535
72	-	6,741	10,326	-	-	-	-	-	-
73	1,110	1,532	19,058	1,422	1,782	2,982	2,871	3,373	1,365
74	222	753	17,377	669	2,097	1,762	2,607	2,514	638
75	-	-	-	-	-	-	-	250	-
76	-	-	5,450	-	2,345	-	-	979	-
77	-	-	-	-	-	3,100	-	-	-
78	-	-	300	-	-	-	-	-	-
79	-	-	173	-	-	-	-	-	-
80	231	505	4,597	89	-	106	778	257	-
81	11,665	22,248	121,614	13,829	9,303	9,996	8,233	13,292	11,483
82	2,897	(4,458)	1,242	1,824	(1,346)	812	(58)	(2,724)	655
83	-	-	-	-	-	-	-	-	-
84	-	-	-	-	-	69	478	93	12

Line No.	NOV-23	DEC-23	Calendar 2023	JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
85	-	-	-	-	-	25	25	25	25
86	-	-	10	38	-	-	-	-	-
87	-	-	866	-	-	-	-	-	-
88	-	-	-	-	-	70	-	-	-
89	2,055,980	3,062,502	25,451,340	2,290,656	2,169,637	2,073,229	2,028,064	2,898,674	1,899,753
90	258,219	(928,769)	31,181	405,845	60,074	60,278	180,224	(733,726)	(8,174)
91	-	-	77	-	46	-	-	84	134
92	-	-	62	244	-	-	-	-	-
93	-	-	100	118	-	-	1,759	-	365
94	8,959	8,107	261,269	50,585	12,967	16,627	44,840	26,480	21,652
95	-	19	19	-	-	-	-	-	-
96	-	-	349	-	-	-	660	52	61
97	-	-	19	-	-	-	-	-	2,243
98	8,180	6,355	88,660	5,736	5,530	6,265	6,069	6,340	7,288
99	38	73	5,255	97	166	250	86	2,129	74
100	32	52	574	-	-	-	-	-	-
101	22	-	72	-	22	-	41	-	16
102	18,503	6,709	121,765	9,581	6,312	5,831	16,734	8,601	14,222
103	-	1,399	1,658	-	-	213	-	-	-
104	2,450	1,531	22,869	2,099	(1,362)	5,591	8,083	5,327	4,335
105	1,570	118	19,082	223	2,760	1,696	7,031	8,470	1,309
106	-	-	329	100	-	-	97	-	-
107	245	-	640	-	245	-	-	264	-
108	2,318	-	11,657	90	-	1,650	2,350	2,590	-
109	-	-	1,250	-	-	450	-	-	-
110	-	73	189	79	-	-	-	-	-
111	-	-	-	-	-	219	-	-	-
112	-	-	-	-	-	4,549	-	-	-
113	-	-	1,096	-	-	-	-	-	-
114	-	-	311	-	-	-	-	-	-
115	297	860	7,597	532	49	2,989	362	186	27
116	-	-	-	-	-	-	(44)	-	-
117	6	-	170	-	-	-	-	-	-
118	-	-	(1,899)	-	-	-	-	-	-
119	-	-	1,899	-	-	-	-	-	-
120	-	-	1,112	-	-	-	-	-	-
121	-	-	-	-	(1,539)	1,539	-	-	-
122	1	-	35	-	-	-	-	-	-
123	-	-	464	-	-	-	-	-	-
124	-	-	178	-	-	-	-	-	-
125	235	110	3,704	-	-	-	-	-	-
126	-	-	638	-	-	-	-	-	-
127	-	-	468	-	-	-	-	-	-
128	10,943	8,359	119,483	10,943	10,943	13,519	5,783	10,943	13,011
129	-	-	3,974	-	-	-	465	-	-
130	-	-	158,289	-	-	-	-	-	-
131	-	-	-	-	-	-	-	3,028	-
132	-	-	18	-	-	-	-	-	-
133	4,662,653	6,911,190	60,891,235	4,632,313	4,618,913	4,688,006	4,710,586	7,336,278	4,891,887
134	146,644	246,206	2,373,346	115,525	241,960	245,183	246,078	410,175	273,382
135	(124,946)	(214,436)	(2,153,740)	(104,745)	(225,629)	(229,370)	(233,278)	(392,683)	(249,488)
136	1,373	4,347	8,213	3,390	285	7,928	7,410	5,600	5,343
137	434,317	(2,112,228)	(81,715)	701,660	190,544	255,673	530,331	(1,619,651)	13,161
138	-	-	159,738	-	-	-	-	-	-
139	47,740	49,892	907,742	32,444	90,056	94,208	114,870	202,090	138,163
140	(69,439)	(81,662)	(1,114,670)	(43,224)	(106,387)	(110,021)	(127,670)	(219,581)	(162,057)
141	1,246	374	4,113	-	-	1,993	810	1,557	128
142	(1,246)	(374)	(4,113)	-	-	(1,993)	(810)	(1,557)	(128)
143	11,662	-	11,662	-	-	-	-	-	-
144	(8,927,613)	(8,489,816)	(108,648,694)	(8,786,221)	(9,061,453)	(8,597,454)	(8,433,060)	(8,816,164)	(14,654,815)
145	-	-	9,559	-	-	-	-	-	-
146	-	-	2,386	-	-	-	-	-	-
147	-	-	1,546	-	-	-	-	-	-
148	-	-	-	-	-	-	-	65	39
149	-	-	1,544	-	-	-	-	-	-
150	47,598	96,430	1,585,942	100,360	86,008	61,798	75,050	65,014	41,267
151	-	-	-	-	48	-	56	-	-
152	(10)	-	4	-	1	-	0	4	(4)
153	16,057	39,286	377,868	45,637	46,926	22,625	58,586	19,942	30,779
154	49,034	53,210	924,529	67,101	58,971	35,285	119,029	14,360	40,966
155	18,419	-	31,166	113	320	123	2,137	1,205	-
156	157	-	3,716	152	462	581	808	160	128
157	-	-	-	-	-	-	-	-	35
158	-	3,885	51,425	-	245	8	50,588	2,668	-
159	18	3,646	59,325	217	513	1,155	2,310	(889)	431
160	-	-	20,870	-	-	-	-	-	-
161	66	2,585	6,926	1,327	7,608	(2,496)	937	834	399
162	2,508	-	29,010	-	28,147	-	1,020	1,497	-
163	16,376	3,305	146,569	12,782	22,636	12,556	12,782	13,506	13,144
164	-	-	52,089	-	-	-	-	9,770	-
165	9,295	9,144	115,105	9,768	10,357	10,463	10,604	9,956	9,163
166	44	34	47,641	2,584	-	-	109	79	-
167	129	-	1,892	-	35	75	-	-	-
168	2,884,597	3,138,249	35,367,916	3,263,580	3,162,357	2,966,919	3,284,019	3,225,261	3,227,569

Line No.	Calendar			JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
	NOV-23	DEC-23	2023						
169	295,203	305,607	3,659,281	283,455	281,559	280,229	280,348	279,854	259,844
170	6,092	1,033	35,752	-	-	-	-	-	-
171	163	-	982	-	-	-	(0)	-	-
172	-	-	4,837	-	-	-	-	-	-
173	153,518	493,592	2,100,136	100,343	103,818	133,263	141,995	106,736	111,681
174	18,453	17,835	214,375	14,461	12,846	13,876	9,338	20,448	15,836
175	233	-	308	-	-	-	-	-	-
176	11,808	20,466	195,990	11,213	9,325	14,247	21,970	13,827	15,834
177	16,470	31,339	397,529	20,385	36,505	48,875	21,943	23,681	30,752
178	3,541	25,463	195,914	14,471	14,647	14,206	14,189	14,348	6,181
179	54,238	53,819	668,855	58,088	60,797	69,425	70,307	56,792	68,334
180	4,157	4,052	55,570	4,096	4,639	4,622	3,844	3,726	3,639
181	9,925	8,871	129,113	8,510	10,428	10,935	11,634	11,572	63,967
182	80,880	29,239	666,123	27,234	23,882	12,061	148,334	41,592	36,629
183	161,697	186,293	2,188,348	182,779	163,723	185,336	178,226	181,340	184,931
184	32,844	34,302	392,955	33,108	1,786	68,892	32,894	33,740	34,219
185	51,655	52,572	618,914	51,909	49,430	56,886	53,871	52,453	53,169
186	2,228	1,189	43,266	2,726	1,438	9,688	6,038	5,801	2,185
187	69	68	3,926	249	-	-	-	-	-
188	-	-	320	-	-	-	-	-	25
189	54,233	69,975	780,629	57,819	54,072	59,072	105,291	72,758	114,385
190	43	-	5,601	121	180	-	79	-	-
191	23,718	13,023	431,043	27,961	34,299	46,723	53,231	59,857	40,441
192	21,941	10,882	445,301	24,153	44,525	84,965	(1,945)	51,142	49,701
193	48,649	94,631	585,904	103,079	26,160	6,169	(149,716)	255,590	8,263
194	-	-	270	150	-	-	-	-	-
195	5,169	175	39,705	19,404	6,100	65	-	2,500	2,669
196	344	672	88,120	(10,910)	1,360	9,197	8,928	2,859	37,318
197	21,096	30,224	368,018	30,813	29,612	27,244	34,202	30,737	53,856
198	31,914	5,366	246,638	21,644	17,971	19,339	10,249	10,192	44,300
199	20,675	24,416	323,414	33,953	20,253	26,528	36,575	65,544	46,029
200	-	-	1,501	1,300	-	361	-	1,840	170
201	4,811	6,181	97,975	36,305	7,988	20,032	17,551	7,043	6,250
202	5,361	-	20,848	260	1,923	753	5,625	1,330	3,990
203	995	-	2,965	827	-	-	497	1,499	5,376
204	-	-	100,450	-	-	-	-	-	-
205	303,945	763,279	5,303,905	295,804	461,884	476,421	422,432	425,029	643,063
206	-	-	24,246	-	23,420	-	3,558	(3,558)	-
207	-	-	260	-	10	-	-	-	35
208	250	-	250	-	51	-	-	-	-
209	20,500	-	56,554	(1,325)	-	-	23,995	220	2,908
210	1,115	1,365	7,737	1,139	1,113	1,931	209	200	635
211	25,516	25,356	266,778	29,069	24,972	43	14,168	35,227	8,006
212	9,020	24,441	224,839	27,337	12,828	10,250	10,255	13,210	14,829
213	65,661	53,492	665,746	47,999	45,104	45,104	45,104	45,104	111,261
214	-	-	(85,130)	-	-	(107,320)	-	13	249
215	-	-	(70,970)	-	-	-	-	-	-
216	-	-	6,542	-	386	-	-	-	-
217	-	-	-	-	174	(174)	-	-	-
218	19,377	19,377	228,023	19,377	19,377	19,377	19,377	19,377	23,928
219	-	-	9	-	699	-	-	-	572
220	-	-	430	-	1,274	-	-	-	-
221	-	-	463	-	7,830	-	-	-	-
222	-	-	284	-	5,360	-	-	1,984	-
223	-	2,450	8,815	-	-	-	-	-	-
224	-	-	-	-	-	2,250,000	-	-	-
225	-	-	3,720	-	-	-	-	-	-
226	-	-	4,446	-	-	-	-	-	-
227	1,055,538	1,426,785	15,600,069	1,543,248	753,617	1,066,260	1,098,612	1,263,283	1,424,071
228	718,948	1,144,928	8,559,977	234,886	1,915,191	(923,359)	1,023,176	292,458	559,051
229	16,979	7,628	175,632	9,841	10,969	7,652	8,934	30,151	8,581
230	12,639	428	288,515	64,283	30,953	8,837	51,334	16,338	20,888
231	-	-	13,430	-	-	-	-	-	-
232	-	-	(1,000,000)	-	-	(2,250,000)	-	-	-
233	16,800	16,800	199,247	16,800	16,800	17,391	17,391	17,391	17,391
234	277	(15,993)	(54,087)	(284)	859	(16,393)	1,348	933	(4,568)
235	8,458	7,922	105,415	9,157	7,949	7,972	8,487	8,861	7,717
236	8	5	47	4	2	10	10	8	7
237	10,887	11,109	168,216	10,887	10,887	10,887	11,018	11,018	11,018
238	-	500,000	2,100,000	-	4,000,000	-	-	-	500,000
239	231,052	231,052	2,801,970	231,052	231,052	231,052	231,052	231,052	231,052
240	4,247,577	4,247,563	44,204,744	4,247,563	4,247,563	4,247,563	4,247,563	4,247,563	4,247,563
241	175,312	164,206	2,341,282	189,791	164,752	165,240	175,904	183,654	159,956
242	149,169	139,719	1,834,707	161,489	140,184	140,599	149,672	156,267	136,103
243	(19,707)	(4,152)	(239,968)	(31,525)	(7,639)	(7,181)	(18,866)	(27,414)	592
244	(10,716)	2,489	(105,400)	(20,745)	(579)	(149)	(10,101)	(17,411)	6,451
245	1,357,901	1,271,876	15,308,127	1,470,163	1,275,993	1,279,882	1,362,482	1,422,516	1,238,961
246	(93,094)	(123,695)	(1,388,398)	216,549	(163,641)	(153,881)	(372,047)	(746,452)	72,147
247	1,261	768	6,845	622	315	1,524	1,612	1,240	1,180
248	335,246	314,008	3,414,968	362,935	315,052	315,984	336,377	351,199	305,882
249	(49,554)	(39,804)	67,182	(47,452)	(47,245)	(26,511)	(55,755)	(8,839)	(33,589)
250	311	190	1,535	154	73	376	398	306	291
251	(12,388)	(63)	64,972	(102,317)	12,152	69,232	7,032	6,957	(12,193)
252	-	-	-	-	-	-	-	-	-



Line No.	Calendar			JAN-24	FEB-24	MAR-24	APR-24	MAY-24	JUN-24
	NOV-23	DEC-23	2023						
253	172,237	161,325	1,721,018	186,462	161,861	162,341	172,818	180,432	157,150
254	(48,232)	45,653	(138,826)	(290,716)	(21,132)	(23,015)	(33,555)	37,960	(12,356)
255	160	97	774	79	37	193	204	157	150
256	18,454	17,285	188,473	19,978	17,342	17,394	18,516	19,332	16,838
257	648	59,300	313,630	(500)	1,613	56,313	18,774	17,751	21,717
258	17	10	85	8	4	21	22	17	16
259	51,517	48,253	581,009	55,772	48,414	48,557	51,691	53,969	47,005
260	(857)	(6,726)	(950)	(4,323)	2,629	11,279	(4,126)	(6,653)	(3,392)
261	48	29	260	24	12	58	61	47	45
262	168	103	1,048	83	46	204	215	166	158
263	138	84	817	68	37	167	177	136	130
264	(187,615)	(175,729)	(2,330,352)	(203,110)	(176,313)	(176,835)	(188,248)	(196,542)	(171,181)
265	(44,312)	(60,653)	(35,496)	(32,085)	(55,838)	(56,731)	(44,120)	(34,591)	(64,915)
266	(174)	(106)	(1,024)	17	(46)	(211)	(223)	(171)	(163)
267	(81,505)	(76,341)	(1,286,935)	(88,236)	(76,595)	(76,822)	(81,780)	(85,383)	(74,366)
268	33,634	26,281	519,675	39,139	27,497	27,436	32,828	36,660	23,771
269	(82)	(50)	(550)	60	(24)	(99)	(105)	(81)	(77)
270	7,723	5,704	145,795	5,726	11,469	12,846	3,241	7,011	12,114
271	-	26	92	-	-	259	18	-	518
272	16,924	77,459	369,688	19,975	11,952	28,451	19,343	95,896	44,102
273	1,569,129	1,460,329	17,753,488	1,561,029	1,454,292	1,174,107	1,054,028	8,819,674	(668,113)
274	377,173	373,962	8,605,956	390,245	365,069	390,245	378,552	3,974,627	729,338
275	172,004	177,738	5,413,090	176,095	164,734	176,095	171,371	2,006,381	151,632
276	249,346	4,504	299,916	3,842	3,594	3,842	4,454	4,603	4,454
277	(82,737)	(191,148)	158,839	(74,853)	(73,684)	(133,010)	(78,890)	43,942	(178,673)
278	(730,498)	2,946	(1,135,206)	2,899	2,851	2,804	(67,833)	3,706	(1,261)
279	(64,753)	51,570	611,511	51,570	51,570	51,570	53,093	53,093	53,093
280	(14,885)	(7,200)	468,054	(7,200)	(7,200)	(7,200)	(7,200)	(7,200)	(7,200)
281	381,121	1,115,358	5,178,449	339,489	339,489	339,489	339,489	339,489	339,489
282	4,891	7,984	38,000	4,181	-	4,291	-	5,377	5,225
283	5,766	-	12,621	132	295	700	1,717	1,420	1,340
284	457	(4,036)	-	-	-	350	680	(793)	98
285	5,766	-	12,621	132	295	700	1,717	1,420	1,340
286	(5,766)	-	(12,621)	(132)	(295)	(700)	(1,717)	(1,420)	(1,340)
287	-	-	25	-	-	-	-	-	-
288	18,052	-	1,267,348	364,131	-	-	364,131	-	355,131
289	-	169,640	2,125,386	-	-	1,675,250	-	(4,591)	178,279
290	416	2,091	44,211	5,159	6,029	7,258	4,781	8,961	8,720
291	-	8,891	355,703	310,145	35,137	23,473	100,242	3,368	-
292	104,577	57,669	926,793	117,171	78,976	47,885	85,493	47,885	82,562
293	19,113	18,994	264,257	119	553	20,519	20,502	20,499	20,387
294	-	-	922	-	-	-	-	-	-
295	109	-	15,301	3,455	-	-	3,455	-	-
296	-	-	68,133	-	-	-	60,173	-	-
297	(14,434)	40,247	557,696	65,280	55,250	42,286	43,902	124,702	44,626
298	-	-	4,959	-	-	-	-	-	-
299	-	-	73	-	-	-	-	-	-
300	-	-	48	-	-	-	-	-	-
301	-	-	673	-	-	-	-	-	-
302	-	-	-	-	-	-	-	8,271	-
303	-	-	-	-	-	-	-	-	(2,255)
304	6,671	8,471	243,155	14,770	15,577	178	30,194	14,255	5,271
305	231	-	231	-	-	-	-	-	-
306	-	-	46	-	-	-	-	-	-
307	3,867	3,867	64,416	3,867	21,959	3,867	3,867	3,867	3,867
308	225	216	2,972	(3,406)	(131,660)	(40,492)	57,633	4,837	-
309	-	-	20	-	-	-	-	-	-
310	-	-	78,650	-	7,050	239	2,388	5,331	-
311	-	-	47,665	-	-	5,860	-	830	4,465
312	96,639	115,939	1,274,189	111,842	260,811	1,134	219,217	250,389	1,620
313	479,232	479,232	5,742,937	479,232	479,232	479,232	479,232	479,232	479,232
314	2,320	2,309	23,295	2,268	2,304	2,308	2,269	2,309	2,268
315	9,563	37,807	177,269	38,677	35,082	9,404	8,820	10,942	14,516
316	2,808	2,645	4,347	3,672	3,908	3,713	3,376	3,541	3,848
317	3,442	6,648	77,634	7,862	20,050	5,669	3,486	5,601	7,843
318	1	86	341	283	128	135	209	306	224
319	-	-	32,158	-	-	-	-	-	-
320	14,295	484	187,802	29,312	493	32,771	14,971	16,328	(50)
321	3,020	2,380	202,437	3,649	1,898	674	833	5,288	2,842
322	-	1,884	164,528	353	38,158	13,280	50	(13,331)	-
323	-	55	55	38	-	-	-	-	-
324	24	48	1,376	-	79	70	45	163	(18)
325	1,086	620	53,215	9,656	16,294	36,471	49,876	42,501	34,170
	<b>14,194,491</b>	<b>17,932,108</b>	<b>189,170,106</b>	<b>17,049,400</b>	<b>19,500,726</b>	<b>14,497,314</b>	<b>16,337,882</b>	<b>28,720,411</b>	<b>8,533,743</b>
	404,735	373,418	4,582,587	452,425	392,543	382,050	412,577	427,963	371,391
	931,305	1,165,842	11,963,924	1,189,398	934,869	1,095,328	1,085,754	2,255,505	403,745
	<b>1,336,041</b>	<b>1,539,260</b>	<b>16,546,511</b>	<b>1,641,823</b>	<b>1,327,413</b>	<b>1,477,379</b>	<b>1,498,331</b>	<b>2,683,467</b>	<b>775,136</b>
	200,182	184,693	2,279,174	223,769	194,152	188,962	204,061	211,670	183,690
	465,373	582,571	6,052,229	594,342	467,154	547,335	542,551	1,127,076	201,751
	<b>665,555</b>	<b>767,264</b>	<b>8,331,403</b>	<b>818,112</b>	<b>661,306</b>	<b>736,298</b>	<b>746,612</b>	<b>1,338,746</b>	<b>385,442</b>

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-11**  
**Page 1 of 1**

**REQUEST:**

Provide the following information for the most recent calendar year concerning all affiliate-related activities not identified in response to Item 11:

- a. Provide the names of affiliates that provided some form of service to Atmos and the type of service Atmos received from each affiliate.
- b. Provide the names of affiliates to whom Atmos provided some form of service and the type of service Atmos provided to each affiliate.
- c. Identify the service agreement with each affiliate, state whether the service agreement has been previously filed with the Commission, and identify the proceeding in which it was filed. Provide each service agreement that has not been previously filed with the Commission.

**RESPONSE:**

Atmos Energy receives property and casualty insurance coverage from Blueflame Insurance Services. Blueflame Insurance Services, LTD is a wholly-owned subsidiary of Atmos Energy Corporation that was created to provide cost-effective property and casualty insurance coverage for Atmos Energy and its subsidiaries. It was chartered in Bermuda effective December 16, 2003, and became operational as of January 1, 2004. It is incorporated under Bermuda's insurance law and regulations and is fully capitalized under the requirements of applicable Bermuda law. A copy of the agreement was filed with the Commission as Attachment 1 to Staff 1-56 in Case No. 2015-00343.

Atmos Energy has a Storage Agreement with WKG Storage, Inc. for the East Diamond Storage Facility. WKG Storage, Inc. is a wholly-owned subsidiary of Atmos Energy Holdings, Inc., which is itself a wholly-owned subsidiary of Atmos Energy Corporation. WKG Storage, Inc. was created to arrange transportation and storage logistics for Kentucky gas storage facilities. That Storage Agreement is on file with the Commission as part of the WKG Storage, Inc. tariff records and was most recently amended effective March 14, 2019. Although that amendment was filed with the Commission, it was not placed in a docketed proceeding.

Respondents: Greg Waller and Emily Wiebe

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-12**  
**Page 1 of 1**

**REQUEST:**

Describe Atmos's lobbying activities and provide a schedule showing the name, salary, and job title of each individual whose job function involves lobbying on the local, state, or national level.

**RESPONSE:**

See the Direct Testimony of Brannon Taylor, Page 28, line 14 continuing to Page 32, line 13 regarding the Company's lobbying activities. Atmos Energy accounts for all lobbying-related activities in account 4264 and therefore no lobbying related expenses are included in the revenue requirement in the case.

Respondents: Brannon Taylor and Greg Waller

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-13**  
**Page 1 of 1**

**REQUEST:**

Provide the following information concerning the costs for the preparation of this case:

- a. A detailed schedule of expenses incurred to date for the following categories:
  - (1) Accounting;
  - (2) Engineering;
  - (3) Legal;
  - (4) Consultants; and
  - (5) Other Expenses (Identify separately).
- b. For each category identified in Item 13a, the schedule should include the date of each transaction, check number or other document reference, the vendor, the hours worked, the rates per hour, amount, a description of the services performed, and the account number in which the expenditure was recorded. Provide copies of contracts or other documentation that support charges incurred in the preparation of this case. Identify any costs incurred for this case that occurred during the base period.
- c. An itemized estimate of the total cost to be incurred for this case. Expenses should be broken down into the same categories as identified in Item 13a, with an estimate of the hours to be worked and the rates per hour. Include a detailed explanation of how the estimate was determined, along with all supporting workpapers and calculations.
- d. Provide monthly updates of the actual costs incurred in conjunction with this rate case, reported in the manner requested in Items 13a and 13b, and a cumulative total of cost incurred to date for each category. Updates will be due when the utility files its monthly financial statements with the Commission, through the month of the public hearing.

**RESPONSE:**

- a. See Attachment 1 for a detailed schedule of rate case expenses incurred to date.
- b. See Attachment 1 for a detailed schedule of rate case expenses incurred to date. See confidential Attachment 2 for copies of contracts for the external consultants/witnesses.
- c. See the response to FR\_16(8)(f) - Schedule F-6 Projected Rate Case Expenses.
- d. The Company will update the above requested information monthly and will submit it along with the response to Staff 1-03.

**ATTACHMENTS:**

Staff\_1-13\_Att1 - Rate Case Expenses through 2021-07-14.xlsx  
Staff\_1-13\_Att2 - Consultant Agreements (CONFIDENTIAL).pdf

Respondent: Greg Waller



Atmos Energy Corporation, Kentucky  
Rate Case Expenses (050.63110)  
Actuals Through October 18, 2024

Category	Transaction Date	Invoice Number	Vendor	Amount	Hours Worked	Hourly Rate	FERC Account	Expenditure Type	Base Period	Description
Legal	04/03/2024	751	HONAKER LAW OFFICE PLLC	96.00	0.3	320	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	05/09/2024	800	HONAKER LAW OFFICE PLLC	1,056.00	3.3	320	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	06/05/2024	858	HONAKER LAW OFFICE PLLC	256.00	0.8	320	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	08/07/2024	953	HONAKER LAW OFFICE PLLC	276.00	0.1	290.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	08/07/2024	953	HONAKER LAW OFFICE PLLC		0.6	192.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	08/07/2024	953	HONAKER LAW OFFICE PLLC		0.2	275.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	09/06/2024	1004	HONAKER LAW OFFICE PLLC	2,677.50	2.3	275.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	09/06/2024	1004	HONAKER LAW OFFICE PLLC		6.3	320.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	09/06/2024	1004	HONAKER LAW OFFICE PLLC		0.1	290.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	10/06/2024	1049	HONAKER LAW OFFICE PLLC	12,695.50	31.5	320.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	10/06/2024	1049	HONAKER LAW OFFICE PLLC		0.2	290.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Legal	10/06/2024	1049	HONAKER LAW OFFICE PLLC		9.3	275.00	9280	LEGAL	Yes	Legal expenses related to general rate case preparation
Other Expenses	08/07/2024	WEXP-00092724	Taylor, Brannon C (Brannon)	389.96	N/A	N/A	9280	TRAVEL EXPENSE	Yes	Travel to Dallas for general rate case review/preparation
Other Expenses	08/27/2024	WEXP-00094184	Taylor, Brannon C (Brannon)	861.03	N/A	N/A	9280	TRAVEL EXPENSE	Yes	Travel to Dallas for general rate case review/preparation
Consultants	10/01/2024	KENTUCKY_100124	RAAB PAUL H	13,325.00	41	325.00	9280	CONSULTING	Yes	Cost of Service Study /Testimony/Workpapers - Paul Raab
Other Expenses	10/15/2024	24102AA0	KENTUCKY PRESS SERVICES	122,705.40	N/A	N/A	9280	ADVERTISING	Yes	Required public notification of pending rate case to KY customers
Legal	10/15/2024	1024	JOHN N HUGHES PSC	4,112.50	11.75	350.00	9280	LEGAL		Legal expenses related to general rate case preparation
Consultants	10/17/2024	150141546309	WILLIS TOWERS WATSON US LLC	7,156.00	N/A	N/A	9280	CONSULTING	Yes	Annual pension cost by participant for Shared Services, Customer Service, and KY/Mid-States employees (discovery request)
				<u>165,606.89</u>						

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-14**  
**Page 1 of 1**

**REQUEST:**

Provide the following information with regard to uncollectible accounts for the three most recent calendar years:

- a. Reserve account balance at the beginning of the year;
- b. Charges to reserve account (accounts charged off);
- c. Credits to reserve account;
- d. Current year provision;
- e. Reserve account balance at the end of the year; and
- f. Percent of provision to total revenue.

**RESPONSE:**

See Attachment 1. The Company accounts for uncollectible accounts on a Fiscal Year (rather than calendar year) basis. The information provided recognizes that the portion of uncollectibles attributable to gas cost is recovered through the GCA and thus the Company calculates net write-offs and provision for bad debt relative to residential, commercial and public authority gross margin rather than gross revenue. This is consistent with the adjustment for projected bad debt expense described in the Direct Testimony of Greg Waller at page 27.

**ATTACHMENT:**

Staff\_1-14\_Att1 - KY Bad Debt Rollforward FY21 to FY24.xlsx

Respondents: Greg Waller and Emily Wiebe

Atmos Energy Corporation - Kentucky  
Uncollectible Accounts Expense  
FY 2021, FY 2022, FY 2023 and FY 2024

Kentucky (Division 009)

	Beginning Balance	Bad Debt Provision	Bad Debt Collections	Gross W/Os (Non GCA Recoverable)	Ending Balance	Recoveries (Recoverable BD Gas Cost)	Gross W/Os (Recoverable BD Gas Cost)	Net W/Os (Recoverable BD Gas Cost)	Net W/Os (Non GCA Recoverable)	Total Net W/Os (Recoverable & Non- Recoverable)	Revenue (Res/Comm/ PA/Unbill)	Margin Used for Provision	Net W/O % (Non GCA Recov.) % of Margin	Bad Debt Prov. % of Revenue	Bad Debt Prov. % of Margin
2021 FYTD	1,001,165	2,822,569	107,466	(720,892)	3,210,308	98,698	(364,687)	(265,989)	(613,426)	(879,415)	140,424,174	75,650,644	-0.81%	2.01%	3.73%
2022 FYTD	3,210,308	711,048	119,639	(1,823,060)	2,217,934	120,351	(1,234,203)	(1,113,853)	(1,703,422)	(2,817,274)	172,193,414	75,031,959	-2.27%	0.41%	0.95%
2023 FYTD	2,217,934	871,146	103,071	(1,505,038)	1,687,113	117,188	(1,258,474)	(1,141,286)	(1,401,967)	(2,543,252)	198,952,809	78,883,189	-1.78%	0.44%	1.10%
2024 FYTD	1,687,113	1,187,654	86,828	(1,166,531)	1,795,064	154,244	(795,153)	(640,908)	(1,079,704)	(1,720,612)	133,550,078	80,881,319	-1.33%	0.89%	1.47%

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-15**  
**Page 1 of 1**

**REQUEST:**

Provide the amount of excess deferred federal income taxes resulting from the reductions in the corporate tax rate in 1986 and 2018, as of the end of the most recent calendar year. Show the amounts associated with each reduction separately.

**RESPONSE:**

The Company does not have excess deferred federal income taxes resulting from the reductions in the corporate tax rate in 1986.

See confidential Attachment 1 for the amount of excess deferred federal income taxes resulting from the reduction in the corporate tax rate in 2018 as reflected in this filing.

**ATTACHMENT:**

Staff\_1-15\_Att1 - Excess Deferred Income Tax by Deferred Item (CONFIDENTIAL).xlsx.

Respondent: Joel Multer



**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-16**  
**Page 1 of 2**

**REQUEST:**

Provide the following tax data for the most recent calendar year:

- a. Income taxes:
  1. Federal operating income taxes deferred - accelerated tax depreciation.
  2. Federal operating income taxes deferred- other (explain).
  3. Federal income taxes - operating.
  4. Income credits resulting from prior deferrals of federal income taxes.
  5. Investment tax credit net.
    - a. Investment credit realized.
    - b. Investment credit amortized - Revenue Act of 1971.
  6. The information in Item 16a(1-4) for state income taxes.
  7. A reconciliation of book to federal taxable income as shown in Schedule D1 and a calculation of the book federal income tax expense for the base period using book taxable income as the starting point.
  8. A reconciliation of book to state taxable income as shown in Schedule D2 and a calculation of the book state income tax expense for the base period using book taxable income as the starting point.
- b. An analysis of Kentucky Other Operating Taxes as shown in Schedule D3.

**RESPONSE:**

- a.
  1. See Attachment 1.
  2. See Attachment 1.
  3. See Attachment 1.
  4. Below is the amount of income credits resulting from prior deferrals of federal income taxes:

**UCG Regulatory Assets**

Amount realized	\$3,319,295
Amount amortized as of 09/30/2022	\$3,319,295

5. Not applicable.
6. See Attachment 1.
7. The Company does not file tax returns at a "Kentucky only" level. Based on the order in Case No. 2021-00214, the Company has calculated the generation and utilization of NOL ADIT for Kentucky on a jurisdictional standalone basis since this Order. See Exhibit JJM-1 to the Direct Testimony of Joel Multer for this calculation.

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-16**  
**Page 2 of 2**

8. The state of Kentucky requires an affiliated group, whether or not filing a federal consolidated return, must file a consolidated state return, which includes all includible corporations (Ky. Rev. Stat. Ann. §141.202). Taxes are filed and current taxable income is calculated on a utility combined basis only. Kentucky State income taxes are apportioned based upon state tax law. As such, the Company does not currently have the requested calculation readily available.

b. See confidential Attachment 2.

**ATTACHMENTS:**

Staff\_1-16\_Att1 - Federal and State Operating Taxes 12-31-23.xlsx  
Staff\_1-16\_Att2 - Other Operating Taxes CY2023 (CONFIDENTIAL).xlsx,

Respondent: Joel Multer

KY DR Q16 (a) 1&2

Atmos Energy Corporation, Inc.  
Accumulated Deferred Income Taxes  
Division 002 - Shared Services  
Calendar Year End 12/31/2023

ALL NUMBERS ARE TAX EFFECTED

Adjustment Description	Category	Adj Code	Fiscal 2023 12/31/2022	Fiscal 2023 1/31/2023	Fiscal 2023 2/28/2023	Fiscal 2023 3/31/2023	Fiscal 2023 4/30/2023	Fiscal 2023 5/31/2023	Fiscal 2023 6/30/2023	Fiscal 2023 7/31/2023	Fiscal 2023 8/31/2023	Fiscal 2023 9/30/2023	Fiscal 2024 10/31/2023	Fiscal 2024 11/30/2023	Fiscal 2024 12/31/2023
Directors Deferred Bonus	ACC	ACC03	105,661	105,661	105,661	22,804	22,804	22,804	25,212	25,212	25,212	27,790	27,790	27,790	32,244
MIP/VPP Accrual	ACC	ACC04	529,991	529,991	529,991	446,861	446,861	446,861	363,731	363,731	363,731	864,071	864,071	864,071	900,522
Self Insurance - Adjustment	ACC	ACC08	8,173,806	8,173,806	8,173,806	8,173,806	8,173,806	8,173,806	8,173,806	8,173,806	8,173,806	(45,285)	(45,285)	(45,285)	679,877
Vacation Accrual	ACC	ACC11	57,658	57,658	57,658	57,658	57,658	57,658	57,658	57,658	57,658	51,114	51,114	51,114	51,114
Worker's Comp Insurance Reserve	ACC	ACC12	66,587	66,587	66,587	55,673	55,673	55,673	57,101	57,101	57,101	54,222	54,222	54,222	55,754
Accrual - Subtotal			8,933,703	8,933,703	8,933,703	8,756,802	8,756,802	8,756,802	8,677,508	8,677,508	8,677,508	951,912	951,912	951,912	1,719,511
SEBP Adjustment	BEN	NBP03	6,546,922	6,546,922	6,546,922	6,589,332	6,589,332	6,589,332	6,634,440	6,634,440	6,634,440	7,320,985	7,320,985	7,320,985	7,329,364
Restricted Stock Grant Plan	BEN	NBP05	(5,818,540)	(5,818,540)	(5,818,540)	(5,818,540)	(5,818,540)	(5,818,540)	(5,818,540)	(5,818,540)	(5,818,540)	(5,177,922)	(5,177,922)	(5,177,922)	(5,177,922)
Rabbi Trust	BEN	NBP06	895,381	895,381	895,381	895,381	895,381	895,381	895,381	895,381	895,381	896,430	896,430	896,430	896,430
VEBA Trust Contribution Adjustment	BEN	NBP08	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712	4,911,712
Restricted Stock - MIP	BEN	NBP13	12,101,351	12,101,351	12,101,351	12,101,351	12,101,351	12,101,351	12,101,351	12,101,351	12,101,351	11,994,141	11,994,141	11,994,141	11,994,141
Director's Stock Awards	BEN	NBP16	2,845,091	2,845,091	2,845,091	3,214,351	3,214,351	3,214,351	3,214,351	3,214,351	3,214,351	3,248,868	3,248,868	3,248,868	3,085,107
Rabbi Trust Book Gain or Loss	BEN	NBP22	(1,384,637)	(1,384,637)	(1,384,637)	-	-	-	-	-	-	-	-	-	-
Rabbi Trust Tax Gain or Loss	BEN	NBP23	1,384,637	1,384,637	1,384,637	-	-	-	-	-	-	-	-	-	-
Rabbi Trust Unrealized Gain or Loss	BEN	NBP24	(132,914)	(132,914)	(132,914)	(107,937)	(107,937)	(107,937)	(472,139)	(472,139)	(472,139)	2,374,733	2,374,733	2,374,733	2,233,934
Pension Expense	BEN	PEN01	866,606	866,606	866,606	1,228,575	1,228,575	1,228,575	1,592,590	1,592,590	1,592,590	284,183	284,183	284,183	523,469
FAS106 Adjustment	BEN	PRB01	8,180,628	8,180,628	8,180,628	8,102,420	8,102,420	8,102,420	8,071,692	8,071,692	8,071,692	7,667,869	7,667,869	7,667,869	7,591,377
Benefits - Subtotal			30,396,237	30,396,237	30,396,237	31,116,645	31,116,645	31,116,645	31,130,838	31,130,838	31,130,838	33,520,999	33,520,999	33,520,999	33,387,612
CWIP	CWIP/RWIP	FXA26	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,499,174)	(1,499,174)	(1,499,174)	(1,499,174)
CWIP/RWIP - Subtotal			(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,876,575)	(1,499,174)	(1,499,174)	(1,499,174)	(1,499,174)
Fixed Asset Cost Adjustment	FXA	FXA01	(38,670,804)	(38,670,804)	(38,670,804)	(39,165,347)	(39,165,347)	(39,165,347)	(39,659,892)	(39,659,892)	(39,659,892)	(38,309,529)	(38,309,529)	(38,309,529)	(38,372,991)
Depreciation Adjustment	FXA	FXA02	18,760,210	18,760,210	18,760,210	18,999,044	18,999,044	18,999,044	19,064,809	19,064,809	19,064,809	18,862,809	18,862,809	18,862,809	18,625,967
Section 481(a) Cushion Gas	FXA	FXA13	337,426	337,426	337,426	337,426	337,426	337,426	337,426	337,426	337,426	337,426	337,426	337,426	337,426
Section 481(a) Line Pack Gas	FXA	FXA14	40,942	40,942	40,942	40,942	40,942	40,942	40,942	40,942	40,942	40,942	40,942	40,942	40,942
Plant - Subtotal			(19,532,226)	(19,532,226)	(19,532,226)	(19,787,935)	(19,787,935)	(19,787,935)	(20,216,715)	(20,216,715)	(20,216,715)	(19,068,352)	(19,068,352)	(19,068,352)	(19,368,656)
Capital Loss CarryForward	ONT	CAP_LOSS_CF										2,366	2,366	2,366	2,366
Leases - Assets	ONT	DVA10	(9,861,607)	(9,861,607)	(9,861,607)	(9,663,690)	(9,663,690)	(9,663,690)	(9,454,022)	(9,454,022)	(9,454,022)	(9,212,492)	(9,212,492)	(9,212,492)	(9,779,500)
Leases - Liabilities	ONT	DVA20	9,861,607	9,861,607	9,861,607	9,663,690	9,663,690	9,663,690	9,454,022	9,454,022	9,454,022	9,212,492	9,212,492	9,212,492	9,779,500
Allowance for Doubtful Accounts	ONT	ONT02	(5,837)	(5,837)	(5,837)	1	1	1	1	1	1	1	1	1	1
Clearing Account - Adjustment	ONT	ONT03	3,037	3,037	3,037	97,379	97,379	97,379	97,379	97,379	97,379	266,178	266,178	266,178	146,906
Charitable Contribution Carryover	ONT	ONT04	(6,604,894)	(6,604,894)	(6,604,894)	(6,604,753)	(6,604,753)	(6,604,753)	(6,604,753)	(6,604,753)	(6,604,753)	(4,040,191)	(4,040,191)	(4,040,191)	(5,113,253)
Prepayments	ONT	ONT31	(8,572,023)	(8,572,023)	(8,572,023)	(8,212,841)	(8,212,841)	(8,212,841)	(8,070,338)	(8,070,338)	(8,070,338)	(7,403,700)	(7,403,700)	(7,403,700)	(8,571,663)
Rate Case Accrual	ONT	ONT32	4,545,992	4,545,992	4,545,992	4,551,156	4,551,156	4,551,156	4,551,156	4,551,156	4,551,156	-	-	-	-
Federal & State Tax Interest	ONT	ONT61	1,592,426	1,592,426	1,592,426	1,592,426	1,592,426	1,592,426	1,592,426	1,592,426	1,592,426	2,406,214	2,406,214	2,406,214	2,406,214
Intra Period Tax Allocation	ONT	OTH	2,066,699	2,066,699	2,066,699	(11,280,688)	(11,280,688)	(11,280,688)	(5,227,547)	(5,227,547)	(5,227,547)	-	-	-	1,761,667
Reg Liability – Pension & OPEB asset	ONT	RGL02	-	-	-	-	-	-	-	-	-	302,252	302,252	302,252	302,252
Regulatory Liability - NSC	ONT	RGL08	(4,400,042)	(4,400,042)	(4,400,042)	(4,414,239)	(4,414,239)	(4,414,239)	(4,422,482)	(4,422,482)	(4,422,482)	116,801	116,801	116,801	111,776
Fuel Cell ITC	ONT	RGL09	382,925	382,925	382,925	381,063	381,063	381,063	379,201	379,201	379,201	373,362	373,362	373,362	371,500
Other - Subtotal			(10,991,717)	(10,991,717)	(10,991,717)	(23,890,496)	(23,890,496)	(23,890,496)	(17,704,957)	(17,704,957)	(17,704,957)	(7,976,717)	(7,976,717)	(7,976,717)	(8,582,234)
FD-NOL Credit Carryforward - Non Reg	TAX	TAX02NR	(178,972,714)	(178,972,714)	(178,972,714)	(179,951,007)	(179,951,007)	(179,951,007)	(181,392,985)	(181,392,985)	(181,392,985)	(182,172,220)	(182,172,220)	(182,172,220)	(183,632,891)
FD-NOL Credit Carryforward - Utility	TAX	TAX02U	610,865,223	610,865,223	610,865,223	567,447,871	567,447,871	567,447,871	583,275,066	583,275,066	583,275,066	631,058,684	631,058,684	631,058,684	613,526,418
FD-NOL Credit Carryforward - Other	TAX	TAX02OT	8,248,175	8,248,175	8,248,175	8,248,175	8,248,175	8,248,175	8,248,175	8,248,175	8,248,175	9,790,216	9,790,216	9,790,216	8,865,702
ST-State Net Operating Loss	TAX	TAX04	978,371	978,371	978,371	978,371	978,371	978,371	978,371	978,371	978,371	501,177	501,177	501,177	501,177
FD-FAS 115 Adjustment	TAX	TAX06	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)	(2,466,303)
ST- Valuation Allow Enterprise Zone ITC	TAX	TAX37	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)	(127,663)
FD- Valuation Allow Fed Tax Enterprise Zone ITC	TAX	TAX38	26,809	26,809	26,809	26,809	26,809	26,809	26,809	26,809	26,809	26,809	26,809	26,809	26,809
ST-Enterprise Zone ITC	TAX	TAX39	2,408,409	2,408,409	2,408,409	2,408,409	2,408,409	2,408,409	2,408,409	2,408,409	2,408,409	2,399,680	2,399,680	2,399,680	2,399,680
FD-Treasury Lock Adjustment-Realized	TAX	TAX40	(27,050,496)	(26,999,435)	(26,948,374)	(26,897,313)	(26,846,252)	(26,795,191)	(26,744,129)	(26,693,068)	(26,642,007)	(64,972,208)	(64,732,208)	(64,492,207)	(64,252,206)
FD-Treasury Lock Adjustment-Unrealized	TAX	TAX41	(86,164,526)	(77,176,952)	(86,936,232)	(77,511,825)	(80,539,706)	(89,531,553)	(90,245,689)	(99,063,898)	(107,144,119)	(84,994,853)	(94,212,423)	(82,824,782)	(71,201,740)
FD -Federal Tax on Enterprise ITC	TAX	TAX42	(505,766)	(505,766)	(505,766)	(505,766)	(505,766)	(505,766)	(505,766)	(505,766)	(505,766)	(503,933)	(503,933)	(503,933)	(503,933)
Other Tax Effected Items - Subtotal			327,239,519	336,278,154	326,569,936	291,649,759	288,672,939	279,732,153	293,454,295	284,687,147	276,657,987	308,539,386	299,561,816	311,189,458	303,135,050
Total Accumulated Deferred Income Tax			334,168,941	343,207,576	333,499,358	285,968,200	282,991,380	274,050,594	293,464,394	284,697,246	276,668,086	314,468,054	305,490,484	317,118,126	308,792,109
Per Financials:															
A1900-28201			502,204,071	502,204,071	502,204,071	454,932,367	454,932,367	454,932,367	475,199,689	475,199,689	475,199,689	509,219,160	509,219,160	509,219,160	492,223,091
A1900-28206			8,307,744	8,307,744	8,307,744	8,222,741	8,222,741	8,222,741	8,229,919	8,229,919	8,229,919	6,957,625	6,957,625	6,957,625	7,040,447
A2550-28001			(1,076,385)	(1,076,385)	(1,076,385)	(1,067,518)	(1,067,518)	(1,067,518)	(1,058,652)	(1,058,652)	(1,058,652)	(1,049,785)	(1,049,785)	(1,049,785)	(1,040,919)
A2820-28201			(19,690,140)	(19,690,140)	(19,690,140)	(19,925,320)	(19,925,320)	(19,925,320)	(20,319,677)	(20,319,677)	(20,319,677)	(18,916,399)	(18,916,399)	(18,916,399)	(19,192,595)
A2820-28206			(1,718,661)	(1,718,661)	(1,718,661)	(1,739,189)	(1,739,189)	(1,739,189)	(1,773,611)	(1,773,611)	(1,773,611)	(1,651,126)	(1,651,126)	(1,651,126)	(1,675,234)
A2830-28201			(142,795,406)	(134,482,378)	(143,411,237)	(144,249,553)	(146,987,399)	(155,210,434)	(155,587,497)	(163,650,834)	(171,035,426)	(166,928,931)	(175,185,796)	(164,486,690)	(152,977,219)
A2830-28204			-	-	-	-	-	-	-	-	-	-	-	-	-
A2830-28206			(12,146,548)	(11,420,942)	(12,200,301)	(11,274,315)	(11,513,289)	(12,231,040)	(12,285,898)	(12,989,710)	(13,634,277)	(14,21			

KY DR Q16 (a) 1&2

Atmos Energy Corporation, Inc.  
Accumulated Deferred Income Taxes  
Division 012 - Call Center  
Calendar Year End 12/31/2023

ALL NUMBERS ARE TAX EFFECTED

Adjustment Description	Category	Adj Code	Fiscal 2023 12/31/2022	Fiscal 2023 1/31/2023	Fiscal 2023 2/28/2023	Fiscal 2023 3/31/2023	Fiscal 2023 4/30/2023	Fiscal 2023 5/31/2023	Fiscal 2023 6/30/2023	Fiscal 2023 7/31/2023	Fiscal 2023 8/31/2023	Fiscal 2023 9/30/2023	Fiscal 2024 10/31/2023	Fiscal 2024 11/30/2023	Fiscal 2024 12/31/2023
MIP/VPP Accrual	ACC	ACC04	(833,473)	(833,473)	(833,473)	(832,169)	(832,169)	(832,169)	(830,866)	(830,866)	(830,866)	(756,501)	(756,501)	(756,501)	(758,365)
Vacation Accrual	ACC	ACC11	224	224	224	224	224	224	224	224	224	(8,408)	(8,408)	(8,408)	(8,408)
Worker's Comp Insurance Reserve	ACC	ACC12	738	738	738	779	779	779	847	847	847	924	924	924	932
Accrual - Subtotal			(832,511)	(832,511)	(832,511)	(831,166)	(831,166)	(831,166)	(829,795)	(829,795)	(829,795)	(763,985)	(763,985)	(763,985)	(765,841)
FAS106 Adjustment	BEN	PRB01	(1,146,908)	(1,146,908)	(1,146,908)	(1,159,540)	(1,159,540)	(1,159,540)	(1,168,981)	(1,168,981)	(1,168,981)	(1,182,516)	(1,182,516)	(1,182,516)	(1,188,408)
Benefits - Subtotal			(1,146,908)	(1,146,908)	(1,146,908)	(1,159,540)	(1,159,540)	(1,159,540)	(1,168,981)	(1,168,981)	(1,168,981)	(1,182,516)	(1,182,516)	(1,182,516)	(1,188,408)
CWIP	CWIP/RWIP	FXA26	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(68,320)	(68,320)	(68,320)	(68,320)
CWIP/RWIP - Subtotal			(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(62,582)	(68,320)	(68,320)	(68,320)	(68,320)
Fixed Asset Cost Adjustment	FXA	FXA01	(23,144,414)	(23,144,414)	(23,144,414)	(23,251,165)	(23,251,165)	(23,251,165)	(23,357,917)	(23,357,917)	(23,357,917)	(22,696,272)	(22,696,272)	(22,696,272)	(22,699,710)
Depreciation Adjustment	FXA	FXA02	11,049,531	11,049,531	11,049,531	11,449,590	11,449,590	11,449,590	11,877,733	11,877,733	11,877,733	12,096,546	12,096,546	12,096,546	12,384,286
Plant - Subtotal			(12,094,883)	(12,094,883)	(12,094,883)	(11,801,575)	(11,801,575)	(11,801,575)	(11,480,184)	(11,480,184)	(11,480,184)	(10,599,726)	(10,599,726)	(10,599,726)	(10,315,424)
Leases - Assets	ONT	DVA10	(2,297,877)	(2,297,877)	(2,297,877)	(2,243,702)	(2,243,702)	(2,243,702)	(2,189,143)	(2,189,143)	(2,189,143)	(2,115,795)	(2,115,795)	(2,115,795)	(2,235,177)
Leases - Liabilities	ONT	DVA20	2,297,877	2,297,877	2,297,877	2,243,702	2,243,702	2,243,702	2,189,143	2,189,143	2,189,143	2,115,795	2,115,795	2,115,795	2,235,177
Charitable Contribution Carryover	ONT	ONT04	3,269	3,269	3,269	4,920	4,920	4,920	5,616	5,616	5,616	8,496	8,496	8,496	8,991
Prepayments	ONT	ONT31	133,702	133,702	133,702	(28,240)	(28,240)	(28,240)	375,675	375,675	375,675	788,466	788,466	788,466	917,612
Rate Case Accrual	ONT	ONT32	(12,041)	(12,041)	(12,041)	(12,549)	(12,549)	(12,549)	(12,549)	(12,549)	(12,549)	-	-	-	-
Intra Period Tax Allocation	ONT	OTH	(31,006)	(31,006)	(31,006)	(866)	(866)	(866)	(1,562)	(1,562)	(1,562)	-	-	-	(123)
Regulatory Liability - NSC	ONT	RGL08	1,359	1,359	1,359	3,097	3,097	3,097	5,532	5,532	5,532	(5,304)	(5,304)	(5,304)	(4,910)
Other - Subtotal			95,283	95,283	95,283	(33,638)	(33,638)	(33,638)	372,712	372,712	372,712	791,658	791,658	791,658	921,570
Total Accumulated Deferred Income Tax			(14,041,601)	(14,041,601)	(14,041,601)	(13,888,501)	(13,888,501)	(13,888,501)	(13,168,830)	(13,168,830)	(13,168,830)	(11,822,889)	(11,822,889)	(11,822,889)	(11,416,423)
Per Financials:															
A1900-28201			2,241,517	2,241,517	2,241,517	2,071,878	2,071,878	2,071,878	2,370,158	2,370,158	2,370,158	2,679,780	2,679,780	2,679,780	2,908,814
A1900-28206			195,651	195,651	195,651	180,845	180,845	180,845	206,880	206,880	206,880	233,904	233,904	233,904	253,898
A2550-28001			-	-	-	-	-	-	-	-	-	-	-	-	-
A2820-28201			(11,181,485)	(11,181,485)	(11,181,485)	(10,911,723)	(10,911,723)	(10,911,723)	(10,616,132)	(10,616,132)	(10,616,132)	(9,811,635)	(9,811,635)	(9,811,635)	(9,550,154)
A2820-28206			(975,980)	(975,980)	(975,980)	(952,434)	(952,434)	(952,434)	(926,634)	(926,634)	(926,634)	(856,411)	(856,411)	(856,411)	(833,590)
A2830-28201			(3,976,886)	(3,976,886)	(3,976,886)	(3,933,779)	(3,933,779)	(3,933,779)	(3,865,808)	(3,865,808)	(3,865,808)	(3,741,909)	(3,741,909)	(3,741,909)	(3,858,605)
A2830-28204			-	-	-	-	-	-	-	-	-	-	-	-	-
A2830-28206			(344,417)	(344,417)	(344,417)	(343,286)	(343,286)	(343,286)	(337,292)	(337,292)	(337,292)	(326,614)	(326,614)	(326,614)	(336,789)
Total			(14,041,600)	(14,041,600)	(14,041,600)	(13,888,499)	(13,888,499)	(13,888,499)	(13,168,828)	(13,168,828)	(13,168,828)	(11,822,885)	(11,822,885)	(11,822,885)	(11,416,426)
Difference			(1)	(1)	(1)	(2)	(2)	(2)	(2)	(2)	(2)	(4)	(4)	(4)	3



KY DR Q16 (a) 1&2

Atmos Energy Corporation, Inc.  
Accumulated Deferred Income Taxes  
Division **5009000** - Kentucky Division (**fka Div 009**)  
Calendar Year End 12/31/2023

ALL NUMBERS ARE TAX EFFECTED

Adjustment Description	Category	Adj Code	Fiscal 2023 12/31/2022	Fiscal 2023 1/31/2023	Fiscal 2023 2/28/2023	Fiscal 2023 3/31/2023	Fiscal 2023 4/30/2023	Fiscal 2023 5/31/2023	Fiscal 2023 6/30/2023	Fiscal 2023 7/31/2023	Fiscal 2023 8/31/2023	Fiscal 2023 9/30/2023	Fiscal 2024 10/31/2023	Fiscal 2024 11/30/2023	Fiscal 2024 12/31/2023
MIP/VPP Accrual	ACC	ACC04	(296,638)	(296,638)	(296,638)	(296,601)	(296,601)	(296,601)	(296,563)	(296,563)	(296,563)	(253,480)	(253,480)	(253,480)	(252,751)
Vacation Accrual	ACC	ACC11	(66,331)	(66,331)	(66,331)	(66,331)	(66,331)	(66,331)	(66,331)	(66,331)	(66,331)	(67,490)	(67,490)	(67,490)	(67,490)
Worker's Comp Insurance Reserve	ACC	ACC12	141,339	141,339	141,339	146,279	146,279	146,279	150,448	150,448	150,448	157,105	157,105	157,105	159,774
<b>Accrual - Subtotal</b>			<b>(221,630)</b>	<b>(221,630)</b>	<b>(221,630)</b>	<b>(216,653)</b>	<b>(216,653)</b>	<b>(216,653)</b>	<b>(212,446)</b>	<b>(212,446)</b>	<b>(212,446)</b>	<b>(163,865)</b>	<b>(163,865)</b>	<b>(163,865)</b>	<b>(160,467)</b>
FAS106 Adjustment	BEN	PRB01	29,736	29,736	29,736	29,736	29,736	29,736	29,736	29,736	29,736	29,736	29,736	29,736	29,736
<b>Benefits - Subtotal</b>			<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>	<b>29,736</b>
CWIP	CWIP/RWIP	FXA26	(96,103)	(96,103)	(96,103)	(96,103)	(96,103)	(96,103)	(96,103)	(96,103)	(96,103)	(81,088)	(81,088)	(81,088)	(81,088)
RWIP	CWIP/RWIP	FXA47	(43,127)	(43,127)	(43,127)	(43,127)	(43,127)	(43,127)	(43,127)	(43,127)	(43,127)	(52,369)	(52,369)	(52,369)	(52,369)
<b>CWIP/RWIP - Subtotal</b>			<b>(139,230)</b>	<b>(139,230)</b>	<b>(139,230)</b>	<b>(139,230)</b>	<b>(139,230)</b>	<b>(139,230)</b>	<b>(139,230)</b>	<b>(139,230)</b>	<b>(139,230)</b>	<b>(133,457)</b>	<b>(133,457)</b>	<b>(133,457)</b>	<b>(133,457)</b>
Fixed Asset Cost Adjustment	FXA	FXA01	(106,742,671)	(106,742,671)	(106,742,671)	(109,399,745)	(109,399,745)	(109,399,745)	(109,373,523)	(109,373,523)	(109,373,523)	(98,904,501)	(98,904,501)	(98,904,501)	(101,079,155)
Depreciation Adjustment	FXA	FXA02	(25,976,862)	(25,976,862)	(25,976,862)	(25,977,947)	(25,977,947)	(25,977,947)	(26,414,187)	(26,414,187)	(26,414,187)	(32,555,781)	(32,555,781)	(32,555,781)	(32,887,309)
<b>Plant - Subtotal</b>			<b>(132,719,533)</b>	<b>(132,719,533)</b>	<b>(132,719,533)</b>	<b>(135,377,692)</b>	<b>(135,377,692)</b>	<b>(135,377,692)</b>	<b>(135,787,710)</b>	<b>(135,787,710)</b>	<b>(135,787,710)</b>	<b>(131,460,282)</b>	<b>(131,460,282)</b>	<b>(131,460,282)</b>	<b>(133,966,464)</b>
Deferred Gas Costs	GCA	GCA01	(6,911,117)	(6,911,117)	(6,911,117)	(3,066,716)	(3,066,716)	(3,066,716)	991,766	991,766	991,766	3,159,397	3,159,397	3,159,397	2,932,638
Over Recoveries of PGA	GCA	GCA03	-	-	-	(1,855,612)	(1,855,612)	(1,855,612)	(3,852,553)	(3,852,553)	(3,852,553)	(5,105,649)	(5,105,649)	(5,105,649)	(5,017,403)
<b>Gas Cost Adjustment - Subtotal</b>			<b>(6,911,117)</b>	<b>(6,911,117)</b>	<b>(6,911,117)</b>	<b>(4,922,328)</b>	<b>(4,922,328)</b>	<b>(4,922,328)</b>	<b>(2,860,787)</b>	<b>(2,860,787)</b>	<b>(2,860,787)</b>	<b>(1,946,252)</b>	<b>(1,946,252)</b>	<b>(1,946,252)</b>	<b>(2,084,765)</b>
Customer Advances	ONT	CAP01	193,205	193,205	193,205	188,553	188,553	188,553	188,553	188,553	188,553	183,666	183,666	183,666	183,666
Deferred Expense Projects	ONT	DTE09	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)	(8,918)
Leases - Assets	ONT	DVA10	(3,904,043)	(3,904,043)	(3,904,043)	(3,820,561)	(3,820,561)	(3,820,561)	(3,707,257)	(3,707,257)	(3,707,257)	(3,612,666)	(3,612,666)	(3,612,666)	(3,192,885)
Leases - Liabilities	ONT	DVA20	3,904,043	3,904,043	3,904,043	3,820,561	3,820,561	3,820,561	3,707,257	3,707,257	3,707,257	3,612,666	3,612,666	3,612,666	3,192,885
Allowance for Doubtful Accounts	ONT	ONT02	494,750	494,750	494,750	515,157	515,157	515,157	516,086	516,086	516,086	420,935	420,935	420,935	418,378
Charitable Contribution Carryover	ONT	ONT04	586,389	586,389	586,389	613,229	613,229	613,229	636,643	636,643	636,643	954,111	954,111	954,111	1,013,898
Prepayments	ONT	ONT31	5,422	5,422	5,422	22,259	22,259	22,259	(15,235)	(15,235)	(15,235)	(58,765)	(58,765)	(58,765)	(45,298)
Rate Case Accrual	ONT	ONT32	(300,602)	(300,602)	(300,602)	(358,878)	(358,878)	(358,878)	(358,878)	(358,878)	(358,878)	-	-	-	-
Intra Period Tax Allocation	ONT	OTH	582,105	582,105	582,105	2,096,625	2,096,625	2,096,625	1,539,905	1,539,905	1,539,905	-	-	-	587,098
Regulatory Liability - 2017 Gross Up	ONT	RGL06	5,644,052	5,479,115	5,314,178	5,149,242	4,984,305	4,819,368	4,654,431	4,489,494	4,324,557	4,159,620	3,994,683	3,829,746	3,664,810
Regulatory Liability - KY GUD	ONT	RGL07	2,697,562	2,697,562	2,697,562	2,697,562	2,697,562	2,697,562	2,697,562	2,697,562	2,697,562	2,253,273	2,253,273	2,253,273	2,253,273
Regulatory Liability - NSC	ONT	RGL08	78,503	78,503	78,503	235,613	235,613	235,613	294,224	294,224	294,224	21,796	21,796	21,796	78,680
<b>Other - Subtotal</b>			<b>9,972,468</b>	<b>9,807,531</b>	<b>9,642,594</b>	<b>11,150,444</b>	<b>10,985,507</b>	<b>10,820,570</b>	<b>10,144,373</b>	<b>9,979,436</b>	<b>9,814,499</b>	<b>7,925,718</b>	<b>7,760,781</b>	<b>7,595,844</b>	<b>8,145,587</b>
ST-State Net Operating Loss	TAX	TAX04	6,309,845	6,309,845	6,309,845	5,648,517	5,648,517	5,648,517	5,866,650	5,866,650	5,866,650	6,706,624	6,706,624	6,706,624	6,431,960
ST-State Bonus Depreciation	TAX	TAX05	3,381,432	3,381,432	3,381,432	3,381,432	3,381,432	3,381,432	3,381,432	3,381,432	3,381,432	2,869,415	2,869,415	2,869,415	2,869,415
FD-Federal Benefit on State Bonus	TAX	TAX11	(710,101)	(710,101)	(710,101)	(710,101)	(710,101)	(710,101)	(710,101)	(710,101)	(710,101)	(602,577)	(602,577)	(602,577)	(602,577)
FD-Federal Benefit on State NOL	TAX	TAX12	(1,325,068)	(1,325,068)	(1,325,068)	(1,186,189)	(1,186,189)	(1,186,189)	(1,231,997)	(1,231,997)	(1,231,997)	(1,408,391)	(1,408,391)	(1,408,391)	(1,350,712)
STATE NOL_FIN48	TAX	TAX44	(1,959,495)	(1,959,495)	(1,959,495)	(1,959,495)	(1,959,495)	(1,959,495)	(1,959,495)	(1,959,495)	(1,959,495)	(1,782,592)	(1,782,592)	(1,782,592)	(1,782,592)
<b>Other Tax Effected Items - Subtotal</b>			<b>5,696,613</b>	<b>5,696,613</b>	<b>5,696,613</b>	<b>5,174,164</b>	<b>5,174,164</b>	<b>5,174,164</b>	<b>5,346,489</b>	<b>5,346,489</b>	<b>5,346,489</b>	<b>5,782,479</b>	<b>5,782,479</b>	<b>5,782,479</b>	<b>5,565,494</b>
<b>Total Accumulated Deferred Income Tax</b>			<b>(124,292,693)</b>	<b>(124,457,630)</b>	<b>(124,622,567)</b>	<b>(124,301,559)</b>	<b>(124,466,496)</b>	<b>(124,631,433)</b>	<b>(123,479,575)</b>	<b>(123,644,512)</b>	<b>(123,809,449)</b>	<b>(119,965,923)</b>	<b>(120,130,860)</b>	<b>(120,295,797)</b>	<b>(122,604,336)</b>
Per Financials:															
A1900-28201			12,418,281	12,253,344	12,088,407	14,182,021	14,017,084	13,852,148	13,540,765	13,375,828	13,210,891	11,307,893	11,142,956	10,978,020	9,731,157
A1900-28206			7,939,298	7,939,298	7,939,298	7,305,621	7,305,621	7,305,621	7,514,049	7,514,049	7,514,049	8,236,344	8,236,344	8,236,344	7,900,958
A2550-28001			-	-	-	-	-	-	-	-	-	-	-	-	-
A2820-28201			(106,943,862)	(106,943,862)	(106,943,862)	(109,016,278)	(109,016,278)	(109,016,278)	(109,302,759)	(109,302,759)	(109,302,759)	(105,824,825)	(105,824,825)	(105,824,825)	(107,817,929)
A2820-28206			(23,243,571)	(23,243,571)	(23,243,571)	(23,762,973)	(23,762,973)	(23,762,973)	(23,834,773)	(23,834,773)	(23,834,773)	(23,502,075)	(23,502,075)	(23,502,075)	(24,001,601)
A2830-28201			(9,680,326)	(9,680,326)	(9,680,326)	(8,617,763)	(8,617,763)	(8,617,763)	(7,427,093)	(7,427,093)	(7,427,093)	(6,734,916)	(6,734,916)	(6,734,916)	(5,025,068)
A2830-28204			-	-	-	-	-	-	-	-	-	-	-	-	-
A2830-28206			(4,782,507)	(4,782,507)	(4,782,507)	(4,392,189)	(4,392,189)	(4,392,189)	(3,969,762)	(3,969,762)	(3,969,762)	(3,448,344)	(3,448,344)	(3,448,344)	(3,391,849)
<b>Total</b>			<b>(124,292,687)</b>	<b>(124,457,624)</b>	<b>(124,622,560)</b>	<b>(124,301,560)</b>	<b>(124,466,497)</b>	<b>(124,631,434)</b>	<b>(123,479,573)</b>	<b>(123,644,510)</b>	<b>(123,809,446)</b>	<b>(119,965,922)</b>	<b>(120,130,859)</b>	<b>(120,295,796)</b>	<b>(122,604,332)</b>
Difference			(6)	(6)	(6)	1	1	1	(2)	(2)	(2)	(1)	(1)	(1)	(4)

**KY DR Q16 (a) 1&2**

**Atmos Energy Corporation, Inc.**  
**Accumulated Deferred Income Taxes**  
**Division 091 - Brentwood Division**  
**Calendar Year End 12/31/2023**

**ALL NUMBERS ARE TAX EFFECTED**

Adjustment Description	Category	Adj Code	Fiscal 2023 12/31/2022	Fiscal 2023 1/31/2023	Fiscal 2023 2/28/2023	Fiscal 2023 3/31/2023	Fiscal 2023 4/30/2023	Fiscal 2023 5/31/2023	Fiscal 2023 6/30/2023	Fiscal 2023 7/31/2023	Fiscal 2023 8/31/2023	Fiscal 2023 9/30/2023	Fiscal 2024 10/31/2023	Fiscal 2024 11/30/2023	Fiscal 2024 12/31/2023
Environmental Activities	ACC	ACC01	-	-	-	-	-	-	-	-	-	-	-	-	-
Ad Valorem Taxes	ACC	ACC02	-	-	-	-	-	-	-	-	-	-	-	-	-
Directors Deferred Bonus	ACC	ACC03	-	-	-	-	-	-	-	-	-	-	-	-	-
MIP/VPP Accrual	ACC	ACC04	311,957	311,957	311,957	298,613	298,613	298,613	285,296	285,296	285,296	396,122	396,122	396,122	405,946
Accrued Environmental Asset	ACC	ACC05	-	-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous Accrued	ACC	ACC06	-	-	-	-	-	-	-	-	-	-	-	-	-
Self Insurance - Adjustment	ACC	ACC08	-	-	-	-	-	-	-	-	-	-	-	-	-
Vacation Accrual	ACC	ACC11	99,181	99,181	99,181	99,198	99,198	99,198	99,227	99,227	99,227	97,281	97,281	97,281	97,293
Worker's Comp Insurance Reserve	ACC	ACC12	(105,063)	(105,063)	(105,063)	(126,605)	(126,605)	(126,605)	(140,230)	(140,230)	(140,230)	(149,359)	(149,359)	(149,359)	(154,655)
Accrual - Subtotal			306,075	306,075	306,075	271,206	271,206	271,206	244,293	244,293	244,293	344,044	344,044	344,044	348,584
Rabbi Trust - True Up	BEN	NBP01	-	-	-	-	-	-	-	-	-	-	-	-	-
SEBP Adjustment	BEN	NBP03	1,009,647	1,009,647	1,009,647	1,009,626	1,009,626	1,009,626	1,010,310	1,010,310	1,010,310	1,011,675	1,011,675	1,011,675	1,011,495
SERP DTL Offset	BEN	NBP04	-	-	-	-	-	-	-	-	-	-	-	-	-
Restricted Stock Grant Plan	BEN	NBP05	-	-	-	-	-	-	-	-	-	-	-	-	-
Rabbi Trust	BEN	NBP06	-	-	-	-	-	-	-	-	-	-	-	-	-
VEBA Trust Contribution Adjustment	BEN	NBP08	-	-	-	-	-	-	-	-	-	-	-	-	-
Restricted Stock - MIP	BEN	NBP13	-	-	-	-	-	-	-	-	-	-	-	-	-
Director's Stock Awards	BEN	NBP16	-	-	-	-	-	-	-	-	-	-	-	-	-
Director's Stock - Temp	BEN	NBP18	-	-	-	-	-	-	-	-	-	-	-	-	-
Rabbi Trust Book Gain or Loss	BEN	NBP22	-	-	-	-	-	-	-	-	-	-	-	-	-
Rabbi Trust Tax Gain or Loss	BEN	NBP23	-	-	-	-	-	-	-	-	-	-	-	-	-
Rabbi Trust Unrealized Gain or Loss	BEN	NBP24	-	-	-	-	-	-	-	-	-	-	-	-	-
Pension Expense	BEN	PEN01	-	-	-	-	-	-	-	-	-	-	-	-	-
FAS106 Adjustment	BEN	PRB01	(4,953,608)	(4,953,608)	(4,953,608)	(5,310,861)	(5,310,861)	(5,310,861)	(5,698,517)	(5,698,517)	(5,698,517)	(6,937,121)	(6,937,121)	(6,937,121)	(7,227,186)
Benefits - Subtotal			(3,943,961)	(3,943,961)	(3,943,961)	(4,301,235)	(4,301,235)	(4,301,235)	(4,688,207)	(4,688,207)	(4,688,207)	(5,925,446)	(5,925,446)	(5,925,446)	(6,215,691)
CWIP	CWIP/RWIP	FXA26	(126,913)	(126,913)	(126,913)	(126,936)	(126,936)	(126,936)	(126,973)	(126,973)	(126,973)	(127,089)	(127,089)	(127,089)	(127,104)
RWIP	CWIP/RWIP	FXA47	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(107)	(107)	(107)	(107)
CWIP/RWIP - Subtotal			(126,914)	(126,914)	(126,914)	(126,937)	(126,937)	(126,937)	(126,974)	(126,974)	(126,974)	(127,196)	(127,196)	(127,196)	(127,211)
Fixed Asset Cost Adjustment	FXA	FXA01	(959,443)	(959,443)	(959,443)	(959,614)	(959,614)	(959,614)	(959,893)	(959,893)	(959,893)	(960,698)	(960,698)	(960,698)	(960,818)
Depreciation Adjustment	FXA	FXA02	239,698	239,698	239,698	238,096	238,096	238,096	236,520	236,520	236,520	268,197	268,197	268,197	266,830
Book Gain/Loss on Sale of Fixed Asset	FXA	FXA03	-	-	-	-	-	-	-	-	-	-	-	-	-
Tax Gain/Loss on Sale of Fixed Assets	FXA	FXA04	-	-	-	-	-	-	-	-	-	-	-	-	-
Section 481(a) Cushion Gas	FXA	FXA13	-	-	-	-	-	-	-	-	-	-	-	-	-
Section 481(a) Line Pack Gas	FXA	FXA14	-	-	-	-	-	-	-	-	-	-	-	-	-
IRS Audit Assessment - Cost	FXA	FXA15	-	-	-	-	-	-	-	-	-	-	-	-	-
IRS Audit Assessment - Accum	FXA	FXA16	-	-	-	-	-	-	-	-	-	-	-	-	-
Repair % Completion Allowance	FXA	FXA41	-	-	-	-	-	-	-	-	-	-	-	-	-
Section 481(a) TPR	FXA	FXA46	-	-	-	-	-	-	-	-	-	-	-	-	-
Repairs Aggregation Sec 481(a) Adj	FXA	FXA50	-	-	-	-	-	-	-	-	-	-	-	-	-
AFUDC - Equity Asset Cost Adj	FXA	FXA80	-	-	-	-	-	-	-	-	-	-	-	-	-
Plant - Subtotal			(719,745)	(719,745)	(719,745)	(721,518)	(721,518)	(721,518)	(723,373)	(723,373)	(723,373)	(692,501)	(692,501)	(692,501)	(693,988)
Deferred Gas Costs	GCA	GCA01	-	-	-	-	-	-	-	-	-	-	-	-	-
Over Recoveries of PGA	GCA	GCA03	-	-	-	-	-	-	-	-	-	-	-	-	-
PGA - Amended Item	GCA	GCA04	-	-	-	-	-	-	-	-	-	-	-	-	-
Gas Cost Adjustment - Subtotal			-	-	-	-	-	-	-	-	-	-	-	-	-
LGS - Goodwill Amortization	GDW	ONT13	-	-	-	-	-	-	-	-	-	-	-	-	-
TXU - Goodwill Amortization	GDW	ONT49	-	-	-	-	-	-	-	-	-	-	-	-	-
Goodwill - Subtotal			-	-	-	-	-	-	-	-	-	-	-	-	-
Customer Advances	ONT	CAP01	-	-	-	-	-	-	-	-	-	-	-	-	-
Capital Loss CarryForward	ONT	AP_LOSS_CF	-	-	-	-	-	-	-	-	-	-	-	-	-
Amoritzation - LGS Acq. 1810-13523	ONT	DTE01	-	-	-	-	-	-	-	-	-	-	-	-	-
Deferred Expense Projects	ONT	DTE09	-	-	-	-	-	-	-	-	-	-	-	-	-
Amoritzation - LGS Acq. 1810-14155	ONT	DTE12	-	-	-	-	-	-	-	-	-	-	-	-	-
Deferred Projects - TXU Acquisition	ONT	DTE14	-	-	-	-	-	-	-	-	-	-	-	-	-
RAR 91/93 Bond Cost Amortized	ONT	DVA05	22,559	22,559	22,559	22,563	22,563	22,563	22,570	22,570	22,570	22,589	22,589	22,589	22,592
RAR 91/93 Bond Cost Capitalized	ONT	DVA06	-	-	-	-	-	-	-	-	-	-	-	-	-
Leases - Assets	ONT	DVA10	(1,189,253)	(1,189,253)	(1,189,253)	(1,124,343)	(1,124,343)	(1,124,343)	(1,060,125)	(1,060,125)	(1,060,125)	(1,008,700)	(1,008,700)	(1,008,700)	(1,285,194)
DIG on Fixed Assets	ONT	DVA16	-	-	-	-	-	-	-	-	-	-	-	-	-
DIG on Fixed Assets - UCG Storage	ONT	DVA18	(810,516)	(810,516)	(810,516)	(810,660)	(810,660)	(810,660)	(810,896)	(810,896)	(810,896)	(811,576)	(811,576)	(811,576)	(811,677)
DIG on Fixed Assets - WKG	ONT	DVA19	-	-	-	-	-	-	-	-	-	-	-	-	-
Leases - Liabilities	ONT	DVA20	1,189,253	1,189,253	1,189,253	1,124,343	1,124,343	1,124,343	1,060,125	1,060,125	1,060,125	1,008,700	1,008,700	1,008,700	1,285,194
Leases Reclass - Liabilities	ONT	DVA21	-	-	-	-	-	-	-	-	-	-	-	-	-
RAR 86/90 Lease Expense Amortiz.	ONT	DVA26	(116,234)	(116,234)	(116,234)	(116,255)	(116,255)	(116,255)	(116,289)	(116,289)	(116,289)	(120,930)	(120,930)	(120,930)	(120,945)
MVG Right of Way	ONT	DVA35	-	-	-	-	-	-	-	-	-	-	-	-	-
Amortization - ComfurT Goodwill	ONT	DVA37	-	-	-	-	-	-	-	-	-	-	-	-	-
Deferred ITC - GGC	ONT	ITC01	-	-	-	-	-	-	-	-	-	-	-	-	-
Deferred ITC - UCG Non-Utility	ONT	ITC02	-	-	-	-	-	-	-	-	-	-	-	-	-
Deferred ITC - UCG	ONT	ITC03	-	-	-	-	-	-	-	-	-	-	-	-	-
Deferred ITC - MVG	ONT	ITC04	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - GGC	ONT	ITC05	-	-	-	-	-	-	-	-	-	-	-	-	-
Capitalized Selling Expense	ONT	NTE03	-	-	-	-	-	-	-	-	-	-	-	-	-
Industrial Contracts	ONT	NTE05	-	-	-	-	-	-	-	-	-	-	-	-	-
Linder - Partnership Investment	ONT	NTE08	-	-	-	-	-	-	-	-	-	-	-	-	-
UNICAP Section 263A Costs	ONT	NTE11	1,657,312	1,657,312	1,657,312	1,657,607	1,657,607	1,657,607	1,658,090	1,658,090	1,658,090	1,315,979	1,315,979	1,315,979	1,316,143
481(a) UNICAP	ONT	NTE15	-	-	-	-	-	-	-	-	-	-	-	-	-
UNICAP - IRS Audit	ONT	NTE19	-	-	-	-	-	-	-	-	-	-	-	-	-
Allowance for Doubtful Accounts	ONT	ONT02	12,216	12,216	12,216	15,412	15,412	15,412	18,735	18,735	18,735	38,339	38,339	38,339	40,515
Clearing Account - Adjustment	ONT	ONT03	-	-	-	-	-	-	-	-	-	-	-	-	-
Charitable Contribution Carryover	ONT	ONT04	27	27	27	87	87	87	87	87	87	404	404	404	404
RAR CFWE 1990-1985	ONT	ONT06	-	-	-	-	-	-	-	-	-	-	-	-	-
Contributed Contracts	ONT	ONT09	-	-	-	-	-	-	-	-	-	-	-	-	-

KY DR Q16 (a) 1&2

Atmos Energy Corporation, Inc.  
Accumulated Deferred Income Taxes  
Division 091 - Brentwood Division  
Calendar Year End 12/31/2023

ALL NUMBERS ARE TAX EFFECTED

Adjustment Description	Category	Adj Code	Fiscal 2023 12/31/2022	Fiscal 2023 1/31/2023	Fiscal 2023 2/28/2023	Fiscal 2023 3/31/2023	Fiscal 2023 4/30/2023	Fiscal 2023 5/31/2023	Fiscal 2023 6/30/2023	Fiscal 2023 7/31/2023	Fiscal 2023 8/31/2023	Fiscal 2023 9/30/2023	Fiscal 2024 10/31/2023	Fiscal 2024 11/30/2023	Fiscal 2024 12/31/2023
Book Inc Recognized for MTM Acctg	ONT	ONT19	-	-	-	-	-	-	-	-	-	-	-	-	-
RAR Amortization of Non-Compete	ONT	ONT20	-	-	-	-	-	-	-	-	-	-	-	-	-
Union Gas - Non Compete	ONT	ONT21	281,895	281,895	281,895	281,946	281,946	281,946	282,028	282,028	282,028	282,264	282,264	282,264	282,299
Monarch - Non Compete	ONT	ONT22	-	-	-	-	-	-	-	-	-	-	-	-	-
Palmyra - Non Compete	ONT	ONT23	-	-	-	-	-	-	-	-	-	-	-	-	-
Duke - Purchased Contracts	ONT	ONT27	-	-	-	-	-	-	-	-	-	-	-	-	-
Prepayments	ONT	ONT31	4,563	4,563	4,563	15,808	15,808	15,808	(5,306)	(5,306)	(5,306)	(11,989)	(11,989)	(11,989)	(10,670)
Rate Case Accrual	ONT	ONT32	(16,672)	(16,672)	(16,672)	(37,481)	(37,481)	(37,481)	(37,492)	(37,492)	(37,492)	-	-	-	-
Research and Development Expenses	ONT	ONT33	-	-	-	-	-	-	-	-	-	-	-	-	-
Partnership Investment - Unitary	ONT	ONT37	-	-	-	-	-	-	-	-	-	-	-	-	-
IGS - Purchased Contracts	ONT	ONT39	-	-	-	-	-	-	-	-	-	-	-	-	-
Inventory Adjustment	ONT	ONT44	-	-	-	-	-	-	-	-	-	-	-	-	-
Stock Option Expense	ONT	ONT50	-	-	-	-	-	-	-	-	-	-	-	-	-
Prepayments - MVG	ONT	ONT51	-	-	-	-	-	-	-	-	-	-	-	-	-
WACOG to FIFO Adjustment	ONT	ONT52	1,344,313	1,344,313	1,344,313	1,640,817	1,640,817	1,640,817	1,937,980	1,937,980	1,937,980	1,174,408	1,174,408	1,174,408	593,707
Tax Free Interest - Temp	ONT	ONT58	-	-	-	-	-	-	-	-	-	-	-	-	-
Federal & State Tax Interest	ONT	ONT61	-	-	-	-	-	-	-	-	-	-	-	-	-
Prepayments - IRS Audits	ONT	ONT64	-	-	-	-	-	-	-	-	-	-	-	-	-
Impairment - Atmos Gathering LLC	ONT	ONT66	-	-	-	-	-	-	-	-	-	-	-	-	-
VA Charitable Contributions	ONT	ONT67	-	-	-	-	-	-	-	-	-	-	-	-	-
Reg Asset Benefit Accrual	ONT	ONT68	-	-	-	-	-	-	-	-	-	-	-	-	-
TX Rule 8.209 Reg Asset Deferral	ONT	ONT69	-	-	-	-	-	-	-	-	-	-	-	-	-
LA SIIP Reg Asset	ONT	ONT70	-	-	-	-	-	-	-	-	-	-	-	-	-
TN Reg Asset Deferral	ONT	ONT71	-	-	-	-	-	-	-	-	-	-	-	-	-
Intra Period Tax Allocation	ONT	OTH	16,247	16,247	16,247	24,820	24,820	24,820	46,415	46,415	46,415	-	-	-	10,854
Regulatory Asset - LGS Amortization	ONT	RGA01	-	-	-	-	-	-	-	-	-	-	-	-	-
AFUDC - Equity Gross-Up	ONT	RGA02	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Asset - Mid Tex	ONT	RGA03	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Asset - Winter Weather E	ONT	RGA04	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - Atmos 109	ONT	RGL01	-	-	-	-	-	-	-	-	-	-	-	-	-
Reg Liability – Pension & OPEB asset	ONT	RGL02	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - GGC 109	ONT	RGL03	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - UCGC 109	ONT	RGL04	(2,879)	(2,879)	(2,879)	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - UCGC Rate	ONT	RGL05	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - 2017 Gross Up	ONT	RGL06	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - KY GUD	ONT	RGL07	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - NSC	ONT	RGL08	(114,349)	(114,349)	(114,349)	(59,886)	(59,886)	(59,886)	(38,468)	(38,468)	(38,468)	(48,217)	(48,217)	(48,217)	(27,879)
Fuel Cell ITC	ONT	RGL09	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - LA - Hurricane Ic	ONT	RGL11	-	-	-	-	-	-	-	-	-	-	-	-	-
Regulatory Liability - LA	ONT	ATTD_RGL	-	-	-	-	-	-	-	-	-	-	-	-	-
Fed Reg Liability_Gross Up_FIN48	ONT	ROSS_UP_FIN48 Reg Liab	-	-	-	-	-	-	-	-	-	-	-	-	-
CNG Tax Credit	ONT	ATTD_Alte	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Other - Subtotal</b>			<b>2,278,482</b>	<b>2,278,482</b>	<b>2,278,482</b>	<b>2,634,778</b>	<b>2,634,778</b>	<b>2,634,778</b>	<b>2,957,454</b>	<b>2,957,454</b>	<b>2,957,454</b>	<b>1,841,271</b>	<b>1,841,271</b>	<b>1,841,271</b>	<b>1,295,343</b>
FD-NOL Credit Carryforward - Non Re	TAX	TAX02NR	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-NOL Credit Carryforward - Utility	TAX	TAX02U	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-NOL Credit Carryforward - Other	TAX	TAX02OT	-	-	-	-	-	-	-	-	-	-	-	-	-
ST-State Net Operating Loss	TAX	TAX04	-	-	-	-	-	-	-	-	-	-	-	-	-
ST-State Bonus Depreciation	TAX	TAX05	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-FAS 115 Adjustment	TAX	TAX06	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-Treasury Lock Adjustment	TAX	TAX08	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-Other	TAX	TAX10	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-Federal Benefit on State Bonus	TAX	TAX11	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-Federal Benefit on State NOL	TAX	TAX12	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-Fuel Cell Credit	TAX	TAX15	-	-	-	-	-	-	-	-	-	-	-	-	-
State Texas Margin WWE DTL	TAX	ATTD_ONT:	-	-	-	-	-	-	-	-	-	-	-	-	-
ST-Other	TAX	TAX43	-	-	-	-	-	-	-	-	-	-	-	-	-
ST - Valuation Allow on State NOL	TAX	TAX13	-	-	-	-	-	-	-	-	-	-	-	-	-
FD - Valuation on Fed Tax of St NO	TAX	TAX14	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-FAS 158 Measurement Date Chan	TAX	TAX22	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-AMT Minimum Tax Credit	TAX	TAX23	-	-	-	-	-	-	-	-	-	-	-	-	-
ST- Valuation Allow Enterprise Zone I	TAX	TAX37	-	-	-	-	-	-	-	-	-	-	-	-	-
FD- Valuation Allow Fed Tax Enterpris	TAX	TAX38	-	-	-	-	-	-	-	-	-	-	-	-	-
ST-Enterprise Zone ITC	TAX	TAX39	-	-	-	-	-	-	-	-	-	-	-	-	-
STATE NOL_FIN48	TAX	TAX44	-	-	-	-	-	-	-	-	-	-	-	-	-
STATE NOL_FIN48 TN	TAX	TAX45	-	-	-	-	-	-	-	-	-	-	-	-	-
State FIN48 Reg Liability Gross Up	TAX	TAX46	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-Treasury Lock Adjustment-Realize	TAX	TAX40	-	-	-	-	-	-	-	-	-	-	-	-	-
FD-Treasury Lock Adjustment-Unreali	TAX	TAX41	-	-	-	-	-	-	-	-	-	-	-	-	-
FD -Federal Tax on Enterprise ITC	TAX	TAX42	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Other Tax Effected Items - Subtotal</b>			-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Total Accumulated Deferred Income Tax</b>			<b>(2,206,063)</b>	<b>(2,206,063)</b>	<b>(2,206,063)</b>	<b>(2,243,706)</b>	<b>(2,243,706)</b>	<b>(2,243,706)</b>	<b>(2,336,807)</b>	<b>(2,336,807)</b>	<b>(2,336,807)</b>	<b>(4,559,828)</b>	<b>(4,559,828)</b>	<b>(4,559,828)</b>	<b>(5,392,963)</b>
Per Financials:															
A1900-28201			4,685,879	4,685,879	4,685,879	4,876,759	4,876,759	4,876,759	5,060,410	5,060,410	5,060,410	4,201,714	4,201,714	4,201,714	3,982,343
A1900-28206			1,263,290	1,263,290	1,263,290	1,314,084	1,314,084	1,314,084	1,360,455	1,360,455	1,360,455	1,146,049	1,146,049	1,146,049	1,084,100
A2550-28001			-	-	-	-	-	-	-	-	-	-	-	-	-
A2820-28201			(666,380)	(666,380)	(666,380)	(667,635)	(667,635)	(667,635)	(668,864)	(668,864)	(668,864)	(644,034)	(644,034)	(644,034)	(645,104)
A2820-28206			(180,279)	(180,279)	(180,279)	(180,819)	(180,819)	(180,819)	(181,483)	(181,483)	(181,483)	(175,666)	(175,666)	(175,666)	(176,095)
A2830-28201			(5,752,366)	(5,752,366)	(5,752,366)	(5,969,368)	(5,969,368)	(5,969,368)	(6,219,720)	(6,219,720)	(6,219,720)	(7,140,315)	(7,140,315)	(7,140,315)	(7,571,429)
A2830-28204			-	-	-	-	-	-	-	-	-	-	-	-	-
A2830-28206			(1,556,209)	(1,556,209)	(1,556,209)	(1,616,726)	(1,616,726)	(1,616,726)	(1,687,608)	(1,687,608)	(1,687,608)	(1,947,576)	(1,947,576)	(1,947,576)	(2,066,780)

KY DR Q16 (a) 1&2

Atmos Energy Corporation, Inc.  
Accumulated Deferred Income Taxes  
Division 091 - Brentwood Division  
Calendar Year End 12/31/2023

ALL NUMBERS ARE TAX EFFECTED

Adjustment Description	Category	Adj Code	Fiscal 2023 12/31/2022	Fiscal 2023 1/31/2023	Fiscal 2023 2/28/2023	Fiscal 2023 3/31/2023	Fiscal 2023 4/30/2023	Fiscal 2023 5/31/2023	Fiscal 2023 6/30/2023	Fiscal 2023 7/31/2023	Fiscal 2023 8/31/2023	Fiscal 2023 9/30/2023	Fiscal 2024 10/31/2023	Fiscal 2024 11/30/2023	Fiscal 2024 12/31/2023
Total			(2,206,066)	(2,206,066)	(2,206,066)	(2,243,706)	(2,243,706)	(2,243,706)	(2,336,811)	(2,336,811)	(2,336,811)	(4,559,829)	(4,559,829)	(4,559,829)	(5,392,966)
Difference			3	3	3	0	0	0	4	4	4	1	1	1	3



KY DR Q16(a) 3

Atmos Energy Corporation, Inc.  
Federal Income Taxes - Operating  
Calendar Year End 12/31/2023

Company	Service Area	1/31/2023	2/28/2023	3/31/2023	4/30/2023	5/31/2023	6/30/2023	7/31/2023	8/31/2023	9/30/2023	10/31/2023	11/30/2023	12/31/2023	Check
	10 002DIV	(2,730,848)	(3,137,870)	(46,635,950)	(46,939,727)	(46,271,392)	(32,839,713)	(31,159,924)	(29,625,830)	23,173,636	2,091,767	122,411	(20,019,558)	-
	10 012DIV	344,774	344,774	460,327	460,327	460,327	1,124,036	1,124,036	1,124,036	2,107,307	-	-	376,218	-
Total 10		\$ (2,386,074)	\$ (2,793,096)	\$ (46,175,623)	\$ (46,479,400)	\$ (45,811,065)	\$ (31,715,677)	\$ (30,035,888)	\$ (28,501,794)	\$ 25,280,943	\$ 2,091,767	\$ 122,411	\$ (19,643,340)	
	50 009DIV(S009000)	\$ (1,376,199)	\$ (1,376,199)	\$ 1,518,788	\$ 1,518,788	\$ 1,518,788	\$ 3,809,823	\$ 3,809,823	\$ 3,809,823	\$ 8,484,954	\$ -	\$ -	\$ 62,065	\$ -
	50 091DIV	\$ 3,829,121	\$ 6,671,165	\$ 161,937	\$ 1,540,306	\$ 2,121,246	\$ 88,574	\$ 611,003	\$ 681,152	\$ (1,712,420)	\$ 1,023,867	\$ 2,641,498	\$ (680,038)	\$ -
Total 50		\$ 2,452,922	\$ 5,294,966	\$ 1,680,725	\$ 3,059,094	\$ 3,640,034	\$ 3,898,397	\$ 4,420,826	\$ 4,490,975	\$ 6,772,534	\$ 1,023,867	\$ 2,641,498	\$ (617,973)	
Grand Total		\$ 66,848	\$ 2,501,870	\$ (44,494,898)	\$ (43,420,306)	\$ (42,171,031)	\$ (27,817,280)	\$ (25,615,062)	\$ (24,010,819)	\$ 32,053,477	\$ 3,115,634	\$ 2,763,909	\$ (20,261,313)	

KY DR Q16(a)3

Atmos Energy Corporation, Inc.  
State Income Taxes - Operating  
Calendar Year End 12/31/2023

Company	Service Area	1/31/2023	2/28/2023	3/31/2023	4/30/2023	5/31/2023	6/30/2023	7/31/2023	8/31/2023	9/30/2023	10/31/2023	11/30/2023	12/31/2023	Check
	10 002DIV	(6,082,882)	(11,358,271)	(115,506)	(2,412,930)	(4,110,478)	(165,387)	(1,766,374)	(3,174,735)	442,662	(1,963,153)	28,749	(107,320)	-
	10 012DIV	30,216	30,216	38,839	38,839	38,839	97,744	97,744	97,744	166,668	-	-	31,437	-
Total 10		\$ (6,052,666)	\$ (11,328,055)	\$ (76,667)	\$ (2,374,091)	\$ (4,071,639)	\$ (67,643)	\$ (1,668,630)	\$ (3,076,991)	\$ 609,330	\$ (1,963,153)	\$ 28,749	\$ (75,883)	
	50 009DIV(S009000)	\$ (11,803)	\$ (11,803)	\$ (283,958)	\$ (283,958)	\$ (283,958)	\$ 219,430	\$ 219,430	\$ 219,430	\$ 812,522	\$ -	\$ -	\$ (156,475)	\$ -
	50 091DIV	\$ 554,963	\$ 975,433	\$ 13,845	\$ 217,855	\$ 303,839	\$ 7,570	\$ 92,445	\$ 103,842	\$ (148,129)	\$ 168,389	\$ 434,431	\$ (57,084)	\$ -
Total 50		\$ 543,160	\$ 963,630	\$ (270,113)	\$ (66,103)	\$ 19,881	\$ 227,000	\$ 311,876	\$ 323,272	\$ 664,393	\$ 168,389	\$ 434,431	\$ (213,559)	
Grand Total		\$ (5,509,507)	\$ (10,364,425)	\$ (346,780)	\$ (2,440,194)	\$ (4,051,758)	\$ 159,357	\$ (1,356,755)	\$ (2,753,719)	\$ 1,273,723	\$ (1,794,763)	\$ 463,181	\$ (289,441)	

(6,082,882)

Atmos Energy Corporation, Inc.  
Federal Income Taxes - Operating  
Calendar Year End 12/31/2023

	FY2023						FY2024					
	1/31/2023	2/28/2023	3/31/2023	4/30/2023	5/31/2023	6/30/2023	7/31/2023	8/31/2023	9/30/2023	10/31/2023	11/30/2023	12/31/2023
<b>Operating Revenue</b>												
Total Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Transportation Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Forfeited Discounts	0	0	0	0	0	0	0	0	0	0	0	0
Other Operating Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Realized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Unrealized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Intersegment Revenue Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Operating Revenues</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
Purchased Gas Cost	0	0	0	0	0	0	0	0	0	0	0	0
Intersegment Gas Cost Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Purchased Gas Costs</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Contribution Margin</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Operating Expenses</b>												
Total Operation & Maintenance Exp - Excl Bad Debt	(37,435)	883,717	808,079	2,828,388	1,911,516	3,929,218	4,500,955	4,809,055	5,477,574	790,138	1,433,151	2,959,162
Bad Debt Expense	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation and Amortization	(0)	(0)	(0)	(0)	(0)	(0)	(0)	0	0	(0)	0	0
<b>Taxes-Other Than Income Taxes</b>												
Payroll Taxes	1,579,187	1,929,759	2,368,258	2,724,774	3,194,953	3,550,186	4,015,549	4,540,911	4,880,449	386,931	644,219	1,053,230
Ad Valorem	219,000	277,800	336,600	395,400	454,200	513,000	571,800	630,600	689,400	40,400	80,800	(33,553)
Franchise Taxes	46	46	46	114	114	114	28,941	28,941	28,941	186	186	186
State Gross Receipts	0	0	0	0	0	0	0	0	0	0	0	0
Others	(1,798,233)	(2,207,605)	(2,704,904)	(3,120,287)	(3,649,266)	(4,063,300)	(4,616,290)	(5,200,453)	(5,598,791)	(427,517)	(720,950)	(1,015,608)
<b>Total Taxes - Other Than Income Taxes</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>(0)</b>	<b>4,255</b>	<b>4,255</b>
<b>Total Operating Expenses</b>	<b>(37,435)</b>	<b>883,717</b>	<b>808,079</b>	<b>2,828,388</b>	<b>1,911,516</b>	<b>3,929,218</b>	<b>4,500,955</b>	<b>4,809,055</b>	<b>5,477,574</b>	<b>790,138</b>	<b>1,437,406</b>	<b>2,963,417</b>
<b>Operating Income (Loss)</b>	<b>37,435</b>	<b>(883,717)</b>	<b>(808,079)</b>	<b>(2,828,388)</b>	<b>(1,911,516)</b>	<b>(3,929,218)</b>	<b>(4,500,955)</b>	<b>(4,809,055)</b>	<b>(5,477,574)</b>	<b>(790,138)</b>	<b>(1,437,406)</b>	<b>(2,963,417)</b>
<b>Other Non-Operating Income/Expense</b>												
Interest Income	0	0	0	0	0	(0)	0	0	21,125,446	(0)	(0)	(0)
PBR	0	0	0	0	0	0	0	0	0	0	0	0
Others Income	0	0	0	0	0	0	0	0	0	(0)	(0)	(0)
<b>Total Non-Operating Income</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>(0)</b>	<b>0</b>	<b>0</b>	<b>21,125,446</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>
Long Term Interest Expenses	0	(0)	(0)	(0)	(0)	(0)	(0)	(0)	0	(0)	(0)	(0)
Short Term Interest Expenses	0	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	0	0
Donations	(250)	(250)	(250)	(250)	(250)	(455)	(455)	(558)	(558)	0	0	(0)
Other Non-Operating Expense	(1,349,442)	(500,079)	(918,531)	(1,011,243)	(2,144,337)	(2,032,443)	(2,079,400)	(1,932,501)	(1,240,118)	373,292	(637,658)	(1,497,697)
<b>Total Non-Operating Expense</b>	<b>(1,349,692)</b>	<b>(500,329)</b>	<b>(918,781)</b>	<b>(1,011,493)</b>	<b>(2,144,587)</b>	<b>(2,032,898)</b>	<b>(2,079,856)</b>	<b>(1,933,059)</b>	<b>(1,240,676)</b>	<b>373,292</b>	<b>(637,658)</b>	<b>(1,497,697)</b>
Equity in Earnings	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Other Non-Operating Income/Expense</b>	<b>(1,349,692)</b>	<b>(500,329)</b>	<b>(918,781)</b>	<b>(1,011,493)</b>	<b>(2,144,587)</b>	<b>(2,032,898)</b>	<b>(2,079,856)</b>	<b>(1,933,059)</b>	<b>(22,366,123)</b>	<b>373,292</b>	<b>(637,658)</b>	<b>(1,497,697)</b>
<b>Income (Loss), Before Income Taxes</b>	<b>1,387,127</b>	<b>(383,388)</b>	<b>110,702</b>	<b>(1,816,895)</b>	<b>233,071</b>	<b>(1,896,320)</b>	<b>(2,421,099)</b>	<b>(2,875,996)</b>	<b>16,888,548</b>	<b>(1,163,430)</b>	<b>(799,748)</b>	<b>(1,465,721)</b>
<b>Provision (Benefit) for Income Taxes</b>												
<b>Current Federal Income Tax</b>	<b>(2,730,848)</b>	<b>(3,137,870)</b>	<b>(46,635,950)</b>	<b>(46,939,727)</b>	<b>(46,271,392)</b>	<b>(32,839,713)</b>	<b>(31,159,924)</b>	<b>(29,625,830)</b>	<b>23,173,636</b>	<b>2,091,767</b>	<b>122,411</b>	<b>(20,019,558)</b>
Current State Income Tax	(6,082,882)	(11,358,271)	(115,506)	(2,412,930)	(4,110,478)	(165,387)	(1,766,374)	(3,174,735)	442,662	(1,963,153)	28,749	(107,320)
Deferred Federal Income Tax	1,263,299	1,263,299	58,314,424	58,314,424	58,314,424	38,199,814	38,199,814	38,199,814	(16,220,255)	0	0	16,486,771
Deferred State Income Tax	191,528	191,528	131,748	131,748	131,748	160,619	160,619	160,619	590,920	0	0	3,515,557
Investment Tax Credits	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Provision (Benefit) for Inc Tax</b>	<b>(7,358,903)</b>	<b>(13,041,314)</b>	<b>11,694,716</b>	<b>9,093,514</b>	<b>8,064,303</b>	<b>5,355,334</b>	<b>5,434,135</b>	<b>5,559,868</b>	<b>7,986,963</b>	<b>128,615</b>	<b>151,160</b>	<b>(124,550)</b>
<b>Income (Loss), Before Cumulative Effect</b>	<b>8,746,031</b>	<b>12,657,925</b>	<b>(11,584,014)</b>	<b>(10,910,409)</b>	<b>(7,831,232)</b>	<b>(7,251,653)</b>	<b>(7,855,234)</b>	<b>(8,435,864)</b>	<b>8,901,585</b>	<b>(1,292,045)</b>	<b>(950,908)</b>	<b>(1,341,171)</b>
Cumulative Effect of Acct Change, Net of Tax	0	0	0	0	0	0	0	0	0	0	0	0
<b>Income Statement - Net Income (Loss)</b>	<b>8,746,031</b>	<b>12,657,925</b>	<b>(11,584,014)</b>	<b>(10,910,409)</b>	<b>(7,831,232)</b>	<b>(7,251,653)</b>	<b>(7,855,234)</b>	<b>(8,435,864)</b>	<b>8,901,585</b>	<b>(1,292,045)</b>	<b>(950,908)</b>	<b>(1,341,171)</b>

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Atmos Energy Corporation, Inc.  
Federal Income Taxes - Operating  
Calendar Year End 12/31/2023

	FY2023					FY2024						
	1/31/2023	2/28/2023	3/31/2023	4/30/2023	5/31/2023	6/30/2023	7/31/2023	8/31/2023	9/30/2023	10/31/2023	11/30/2023	12/31/2023
<b>Operating Revenue</b>												
Total Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Transportation Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Forfeited Discounts	0	0	0	0	0	0	0	0	0	0	0	0
Other Operating Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Realized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Unrealized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Intersegment Revenue Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Operating Revenues</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
Purchased Gas Cost	0	0	0	0	0	0	0	0	0	0	0	0
Intersegment Gas Cost Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Purchased Gas Costs</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Contribution Margin</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Operating Expenses</b>												
Total Operation & Maintenance Exp - Excl Bad L	0	0	0	0	0	0	0	0	0	0	0	0
Bad Debt Expense	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation and Amortization	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
<b>Taxes-Other Than Income Taxes</b>												
Payroll Taxes	857,351	1,067,826	1,305,136	1,510,083	1,757,474	1,948,766	2,198,629	2,476,554	2,658,121	212,622	395,222	611,005
Ad Valorem	164,800	209,000	253,200	297,400	341,600	385,800	430,000	474,200	518,400	57,800	115,600	180,920
Franchise Taxes	0	0	0	0	0	0	0	0	0	0	0	0
State Gross Receipts	0	0	0	0	0	0	0	0	0	0	0	0
Others	(1,022,151)	(1,276,826)	(1,558,336)	(1,807,483)	(2,099,074)	(2,334,566)	(2,628,629)	(2,950,754)	(3,176,521)	(270,422)	(515,077)	(796,181)
<b>Total Taxes - Other Than Income Taxes</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>(0)</b>	<b>(0)</b>	<b>0</b>	<b>0</b>	<b>(4,255)</b>	<b>(4,255)</b>
<b>Total Operating Expenses</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>(4,255)</b>	<b>(4,255)</b>
<b>Operating Income (Loss)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>4,255</b>	<b>4,255</b>
<b>Other Non-Operating Income/Expense</b>												
Interest Income	0	0	0	0	0	0	0	0	0	0	0	0
PBR	0	0	0	0	0	0	0	0	0	0	0	0
Others Income	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Non-Operating Income</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
Long Term Interest Expenses	0	0	0	0	0	0	0	0	0	0	0	0
Short Term Interest Expenses	0	0	0	0	0	0	0	0	0	0	0	0
Donations	250	250	250	250	250	455	455	558	558	0	0	0
Other Non-Operating Expense	16,318	18,813	23,450	26,193	38,764	44,066	47,532	57,031	58,608	7,220	9,707	17,900
<b>Total Non-Operating Expense</b>	<b>16,568</b>	<b>19,063</b>	<b>23,700</b>	<b>26,443</b>	<b>39,014</b>	<b>44,521</b>	<b>47,988</b>	<b>57,589</b>	<b>59,166</b>	<b>7,220</b>	<b>9,707</b>	<b>17,900</b>
Equity in Earnings	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Other Non-Operating Income/Expense</b>	<b>16,568</b>	<b>19,063</b>	<b>23,700</b>	<b>26,443</b>	<b>39,014</b>	<b>44,521</b>	<b>47,988</b>	<b>57,589</b>	<b>59,166</b>	<b>7,220</b>	<b>9,707</b>	<b>17,900</b>
<b>Income (Loss), Before Income Taxes</b>	<b>(16,568)</b>	<b>(19,063)</b>	<b>(23,700)</b>	<b>(26,443)</b>	<b>(39,014)</b>	<b>(44,521)</b>	<b>(47,988)</b>	<b>(57,589)</b>	<b>(59,166)</b>	<b>(7,220)</b>	<b>(5,452)</b>	<b>(13,645)</b>
<b>Provision (Benefit) for Income Taxes</b>												
<b>Current Federal Income Tax</b>	<b>344,774</b>	<b>344,774</b>	<b>460,327</b>	<b>460,327</b>	<b>460,327</b>	<b>1,124,036</b>	<b>1,124,036</b>	<b>1,124,036</b>	<b>2,107,307</b>	<b>0</b>	<b>0</b>	<b>376,218</b>
Current State Income Tax	30,216	30,216	38,839	38,839	38,839	97,744	97,744	97,744	166,668	0	0	31,437
Deferred Federal Income Tax	(315,770)	(315,770)	(459,000)	(459,000)	(459,000)	(1,120,842)	(1,120,842)	(1,120,842)	(2,358,860)	0	0	(373,822)
Deferred State Income Tax	(30,269)	(30,269)	(40,140)	(40,140)	(40,140)	(97,969)	(97,969)	(97,969)	(205,894)	0	0	(32,641)
Investment Tax Credits	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Provision (Benefit) for Inc Tax</b>	<b>28,951</b>	<b>28,951</b>	<b>26</b>	<b>26</b>	<b>26</b>	<b>2,969</b>	<b>2,969</b>	<b>2,969</b>	<b>(290,779)</b>	<b>0</b>	<b>0</b>	<b>1,192</b>
<b>Income (Loss), Before Cumulative Effect</b>	<b>(45,519)</b>	<b>(48,014)</b>	<b>(23,726)</b>	<b>(26,469)</b>	<b>(39,040)</b>	<b>(47,490)</b>	<b>(50,957)</b>	<b>(60,558)</b>	<b>231,613</b>	<b>(7,220)</b>	<b>(5,452)</b>	<b>(14,837)</b>
Cumulative Effect of Acct Change, Net of Tax	0	0	0	0	0	0	0	0	0	0	0	0
<b>Income Statement - Net Income (Loss)</b>	<b>(45,519)</b>	<b>(48,014)</b>	<b>(23,726)</b>	<b>(26,469)</b>	<b>(39,040)</b>	<b>(47,490)</b>	<b>(50,957)</b>	<b>(60,558)</b>	<b>231,613</b>	<b>(7,220)</b>	<b>(5,452)</b>	<b>(14,837)</b>

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Atmos Energy Corporation, Inc.  
Federal Income Taxes - Operating  
Calendar Year End 12/31/2023

	FY2023						FY2024					
	1/31/2023	2/28/2023	3/31/2023	4/30/2023	5/31/2023	6/30/2023	7/31/2023	8/31/2023	9/30/2023	10/31/2023	11/30/2023	12/31/2023
<b>Operating Revenue</b>												
Total Gas Revenue	109,026,835	136,645,222	161,277,237	174,576,493	181,888,883	188,715,512	194,727,754	200,616,903	206,773,798	8,446,132	22,439,967	40,369,613
Transportation Revenue	7,736,084	9,558,059	11,524,462	13,231,078	14,900,899	16,442,039	17,851,018	19,350,900	20,852,819	1,775,143	3,629,462	5,526,236
Forfeited Discounts	0	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	0	0	0
Other Operating Revenue	53,636	66,287	80,111	90,937	102,457	112,642	121,132	41,039	45,251	9,928	18,478	23,384
Realized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Unrealized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Intersegment Revenue Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Operating Revenues</b>	<b>116,816,555</b>	<b>146,269,561</b>	<b>172,881,802</b>	<b>187,898,501</b>	<b>196,892,232</b>	<b>205,270,186</b>	<b>212,699,898</b>	<b>220,008,835</b>	<b>227,671,862</b>	<b>10,231,203</b>	<b>26,087,907</b>	<b>45,919,233</b>
Purchased Gas Cost	76,824,722	95,247,098	111,943,003	118,946,690	121,064,029	122,911,521	124,360,349	125,404,881	126,649,928	2,660,460	9,138,927	17,960,159
Intersegment Gas Cost Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Purchased Gas Costs</b>	<b>76,824,722</b>	<b>95,247,098</b>	<b>111,943,003</b>	<b>118,946,690</b>	<b>121,064,029</b>	<b>122,911,521</b>	<b>124,360,349</b>	<b>125,404,881</b>	<b>126,649,928</b>	<b>2,660,460</b>	<b>9,138,927</b>	<b>17,960,159</b>
<b>Contribution Margin</b>	<b>39,991,833</b>	<b>51,022,463</b>	<b>60,938,800</b>	<b>68,951,811</b>	<b>75,828,203</b>	<b>82,358,665</b>	<b>88,339,548</b>	<b>94,603,954</b>	<b>101,021,934</b>	<b>7,570,743</b>	<b>16,948,980</b>	<b>27,959,074</b>
<b>Operating Expenses</b>												
Total Operation & Maintenance Exp - Excl Bad Debt	10,019,368	12,506,081	15,351,863	17,801,311	20,848,804	23,153,987	25,897,351	28,604,854	31,422,280	2,399,089	4,785,872	7,205,014
Bad Debt Expense	390,069	579,105	810,581	891,427	850,441	891,115	841,803	899,991	871,146	15,946	158,338	384,951
Depreciation and Amortization	6,266,529	7,843,086	9,425,026	11,010,583	12,600,352	14,197,358	15,799,857	17,455,894	19,272,159	1,626,809	3,255,050	4,885,046
<b>Taxes-Other Than Income Taxes</b>												
Payroll Taxes	174,558	206,409	229,625	257,099	279,969	333,430	353,200	372,012	398,958	21,334	96,095	129,924
Ad Valorem	3,174,020	4,025,650	4,877,280	5,728,910	6,580,540	7,432,170	8,283,800	9,135,430	8,487,060	1,006,340	2,012,680	3,019,020
Franchise Taxes	566	566	649	737	786	786	786	1,019	1,113	0	85	512
State Gross Receipts	0	0	0	0	0	0	0	0	0	0	0	0
Others	314,271	388,665	547,910	642,011	730,798	800,966	899,080	1,000,006	1,074,896	209,510	156,372	242,153
<b>Total Taxes - Other Than Income Taxes</b>	<b>3,663,415</b>	<b>4,621,289</b>	<b>5,655,465</b>	<b>6,628,756</b>	<b>7,592,093</b>	<b>8,567,352</b>	<b>9,536,866</b>	<b>10,508,467</b>	<b>9,962,028</b>	<b>1,237,184</b>	<b>2,265,232</b>	<b>3,391,608</b>
<b>Total Operating Expenses</b>	<b>20,339,381</b>	<b>25,549,561</b>	<b>31,242,935</b>	<b>36,332,077</b>	<b>41,891,689</b>	<b>46,809,812</b>	<b>52,075,877</b>	<b>57,469,206</b>	<b>61,527,613</b>	<b>5,279,028</b>	<b>10,464,493</b>	<b>15,866,620</b>
<b>Operating Income (Loss)</b>	<b>19,652,452</b>	<b>25,472,902</b>	<b>29,695,864</b>	<b>32,619,734</b>	<b>33,936,513</b>	<b>35,548,853</b>	<b>36,263,671</b>	<b>37,134,748</b>	<b>39,494,320</b>	<b>2,291,715</b>	<b>6,484,488</b>	<b>12,092,454</b>
<b>Other Non-Operating Income/Expense</b>												
Interest Income	130,508	152,771	166,829	174,568	176,178	182,927	183,324	180,043	176,377	57,693	106,100	164,098
PBR	890,623	1,130,323	1,284,735	1,569,901	1,920,223	2,222,529	2,518,669	2,828,837	3,137,416	300,328	584,791	889,925
Others Income	171,952	233,692	294,700	365,526	441,685	526,275	636,265	735,392	783,586	16,533	42,366	77,124
<b>Total Non-Operating Income</b>	<b>1,193,082</b>	<b>1,516,786</b>	<b>1,746,264</b>	<b>2,109,996</b>	<b>2,538,087</b>	<b>2,931,730</b>	<b>3,338,258</b>	<b>3,744,272</b>	<b>4,097,380</b>	<b>374,554</b>	<b>733,256</b>	<b>1,131,147</b>
Long Term Interest Expenses	3,503,175	4,393,765	5,256,826	6,115,116	6,973,406	7,831,696	8,689,986	9,548,275	10,406,565	868,282	1,786,249	2,709,877
Short Term Interest Expenses	28,723	31,391	57,513	57,567	59,689	85,713	94,097	99,120	184,442	26,489	34,567	58,544
Donations	136,417	175,595	203,991	247,134	269,341	282,245	303,384	498,034	617,240	20,838	239,291	509,867
Other Non-Operating Expense	(217,933)	(240,322)	(157,315)	(246,906)	(81,286)	(99,619)	(132,472)	(144,817)	(162,270)	(32,419)	(101,931)	(174,123)
<b>Total Non-Operating Expense</b>	<b>3,450,382</b>	<b>4,360,429</b>	<b>5,361,015</b>	<b>6,172,911</b>	<b>7,221,150</b>	<b>8,100,034</b>	<b>8,954,994</b>	<b>10,000,611</b>	<b>11,045,976</b>	<b>883,189</b>	<b>1,958,176</b>	<b>3,104,164</b>
Equity in Earnings	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Other Non-Operating Income/Expense</b>	<b>2,257,299</b>	<b>2,843,643</b>	<b>3,614,752</b>	<b>4,062,915</b>	<b>4,683,063</b>	<b>5,168,304</b>	<b>5,616,736</b>	<b>6,256,339</b>	<b>6,948,597</b>	<b>508,635</b>	<b>1,224,920</b>	<b>1,973,017</b>
<b>Income (Loss), Before Income Taxes</b>	<b>17,395,153</b>	<b>22,629,259</b>	<b>26,081,112</b>	<b>28,556,819</b>	<b>29,253,450</b>	<b>30,380,550</b>	<b>30,646,935</b>	<b>30,878,409</b>	<b>32,545,724</b>	<b>1,783,080</b>	<b>5,259,567</b>	<b>10,119,437</b>
<b>Provision (Benefit) for Income Taxes</b>												
<b>Current Federal Income Tax</b>	<b>(1,376,199)</b>	<b>(1,376,199)</b>	<b>1,518,788</b>	<b>1,518,788</b>	<b>1,518,788</b>	<b>3,809,823</b>	<b>3,809,823</b>	<b>3,809,823</b>	<b>8,484,954</b>	<b>0</b>	<b>0</b>	<b>62,065</b>
Current State Income Tax	(11,803)	(11,803)	(283,958)	(283,958)	(283,958)	219,430	219,430	219,430	812,522	0	0	(156,475)
Deferred Federal Income Tax	708,059	150,128	(1,642,871)	(2,200,803)	(2,758,734)	(4,120,230)	(4,678,161)	(5,236,092)	(8,369,127)	(557,931)	(1,115,862)	(240,903)
Deferred State Income Tax	318,704	318,704	1,016,551	1,016,551	1,016,551	675,686	675,686	675,686	(245,030)	0	0	456,013
Investment Tax Credits	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Provision (Benefit) for Inc Tax</b>	<b>(361,239)</b>	<b>(919,170)</b>	<b>608,510</b>	<b>50,578</b>	<b>(507,353)</b>	<b>584,709</b>	<b>26,778</b>	<b>(531,153)</b>	<b>683,319</b>	<b>(557,931)</b>	<b>(1,115,862)</b>	<b>120,700</b>
<b>Income (Loss), Before Cumulative Effect</b>	<b>17,756,392</b>	<b>23,548,429</b>	<b>25,472,603</b>	<b>28,506,241</b>	<b>29,760,803</b>	<b>29,795,840</b>	<b>30,620,157</b>	<b>31,409,561</b>	<b>31,862,405</b>	<b>2,341,011</b>	<b>6,375,429</b>	<b>9,998,737</b>
Cumulative Effect of Acct Change, Net of Tax	0	0	0	0	0	0	0	0	0	0	0	0
<b>Income Statement - Net Income (Loss)</b>	<b>17,756,392</b>	<b>23,548,429</b>	<b>25,472,603</b>	<b>28,506,241</b>	<b>29,760,803</b>	<b>29,795,840</b>	<b>30,620,157</b>	<b>31,409,561</b>	<b>31,862,405</b>	<b>2,341,011</b>	<b>6,375,429</b>	<b>9,998,737</b>



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Calendar Year End 12/31/2023

	FY2023						FY2024					
	1/31/2023	2/28/2023	3/31/2023	4/30/2023	5/31/2023	6/30/2023	7/31/2023	8/31/2023	9/30/2023	10/31/2023	11/30/2023	12/31/2023
<b>Operating Revenue</b>												
Total Gas Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Transportation Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Forfeited Discounts	0	0	0	0	0	0	0	0	0	0	0	0
Other Operating Revenue	0	0	0	0	0	0	0	0	0	0	0	0
Realized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Unrealized Gas Trading Margin	0	0	0	0	0	0	0	0	0	0	0	0
Intersegment Revenue Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Operating Revenues</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
Purchased Gas Cost	0	0	0	0	0	0	0	0	0	0	0	0
Intersegment Gas Cost Elimination	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Purchased Gas Costs</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Contribution Margin</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Operating Expenses</b>												
Total Operation & Maintenance Exp - Excl Bad Debt	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	0	0	0
Bad Debt Expense	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation and Amortization	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	0	0	0
<b>Taxes-Other Than Income Taxes</b>												
Payroll Taxes	82,109	110,380	156,878	185,586	226,546	247,564	296,754	351,579	376,763	41,022	12,752	65,115
Ad Valorem	160	200	240	280	320	360	400	440	480	248,400	860	1,290
Franchise Taxes	0	0	0	0	0	0	0	0	0	0	0	0
State Gross Receipts	0	0	0	0	0	0	0	0	0	0	0	0
Others	(82,269)	(110,580)	(157,118)	(185,866)	(226,866)	(247,924)	(297,154)	(352,019)	(377,243)	(289,422)	(13,612)	(66,405)
<b>Total Taxes - Other Than Income Taxes</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Total Operating Expenses</b>	<b>(0)</b>	<b>(0)</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Operating Income (Loss)</b>	<b>0</b>	<b>0</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>
<b>Other Non-Operating Income/Expense</b>												
Interest Income	0	0	0	0	0	0	0	0	0	0	0	0
PBR	0	0	0	0	0	0	0	0	0	0	0	0
Others Income	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Non-Operating Income</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
Long Term Interest Expenses	0	0	0	0	0	0	0	0	0	0	0	0
Short Term Interest Expenses	0	0	0	0	0	0	0	0	0	0	0	0
Donations	0	0	0	0	0	0	0	0	0	0	0	0
Other Non-Operating Expense	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Non-Operating Expense</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
Equity in Earnings	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Other Non-Operating Income/Expense</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Income (Loss), Before Income Taxes</b>	<b>0</b>	<b>0</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>	<b>(0)</b>
<b>Provision (Benefit) for Income Taxes</b>												
<b>Current Federal Income Tax</b>	<b>3,829,121</b>	<b>6,671,165</b>	<b>161,937</b>	<b>1,540,306</b>	<b>2,121,246</b>	<b>88,574</b>	<b>611,003</b>	<b>681,152</b>	<b>(1,712,420)</b>	<b>1,023,867</b>	<b>2,641,498</b>	<b>(680,038)</b>
Current State Income Tax	554,963	975,433	13,845	217,855	303,839	7,570	92,445	103,842	(148,129)	168,389	434,431	(57,084)
Deferred Federal Income Tax	(258,606)	(258,606)	(231,230)	(231,230)	(231,230)	(163,299)	(163,299)	(163,299)	1,591,160	0	0	514,527
Deferred State Income Tax	299,369	299,369	309,636	309,636	309,636	334,812	334,812	334,812	803,366	0	0	834,102
Investment Tax Credits	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total Provision (Benefit) for Inc Tax</b>	<b>4,424,847</b>	<b>7,687,361</b>	<b>254,188</b>	<b>1,836,567</b>	<b>2,503,491</b>	<b>267,657</b>	<b>874,962</b>	<b>956,507</b>	<b>533,977</b>	<b>1,192,256</b>	<b>3,075,929</b>	<b>611,507</b>
<b>Income (Loss), Before Cumulative Effect</b>	<b>(4,424,847)</b>	<b>(7,687,361)</b>	<b>(254,188)</b>	<b>(1,836,567)</b>	<b>(2,503,491)</b>	<b>(267,657)</b>	<b>(874,962)</b>	<b>(956,507)</b>	<b>(533,977)</b>	<b>(1,192,256)</b>	<b>(3,075,929)</b>	<b>(611,508)</b>
Cumulative Effect of Acct Change, Net of Tax	0	0	0	0	0	0	0	0	0	0	0	0
<b>Income Statement - Net Income (Loss)</b>	<b>(4,424,847)</b>	<b>(7,687,361)</b>	<b>(254,188)</b>	<b>(1,836,567)</b>	<b>(2,503,491)</b>	<b>(267,657)</b>	<b>(874,962)</b>	<b>(956,507)</b>	<b>(533,977)</b>	<b>(1,192,256)</b>	<b>(3,075,929)</b>	<b>(611,508)</b>

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-17**  
**Page 1 of 1**

**REQUEST:**

Provide a copy of federal and state income tax returns for the most recent tax year, including supporting schedules.

**RESPONSE:**

See confidential Attachment 1 and confidential Attachment 2 for Atmos Energy's Fiscal Year 2023 Federal tax return and the Fiscal Year 2023 Kentucky State tax return, respectively.

**ATTACHMENTS:**

Staff\_1-17\_Att1 – FY23 Federal Tax Return (CONFIDENTIAL).pdf.  
Staff\_1-17\_Att2 – FY23 Kentucky Return (CONFIDENTIAL).pdf

Respondent: Joel Multer

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-18**  
**Page 1 of 1**

**REQUEST:**

Provide a schedule of franchise fees paid to cities, towns, or municipalities, including the basis of these fees.

**RESPONSE:**

See Attachment 1.

**ATTACHMENT:**

Staff\_1-18\_Att1 - Franchise Fee Payments by City Jul'23-Jun'24.xlsx

Respondent: Emily Wiebe

Atmos Energy Corporation, Kentucky  
Franchise Fee Payment Amounts by City  
July 2023 - June 2024

City	Basis for FF	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Total by City
ADAIRVILLE	Revenue	374.65			232.65			524.97			850.76			1,983.03
AUBURN	Revenue	1,991.81			808.71			1,517.89			3,120.56			7,438.97
BEAVER DAM	Revenue	2,644.55			1,210.63			2,175.41			3,997.48			10,028.07
BOWLING GREEN	Revenue	54,073.00			30,713.89			51,777.79			85,641.55			222,206.23
Burgin	Revenue	497.62			179.21			345.07			725.85			1,747.75
Cadiz	Revenue	1,928.14			907.85			2,037.08			3,418.47			8,291.54
CALHOUN	Revenue	588.21			309.78			549.00			1,011.78			2,458.77
Calvert City	Meter						426.50							426.50
CAMPBELLSVILLE	Revenue	6,425.19			3,379.89			6,148.84			10,270.18			26,224.10
CAVE CITY	Revenue	1,379.38			695.00			1,286.32			2,230.71			5,591.41
Central City	Revenue	3,523.78			1,474.69			2,712.76			5,256.55			12,967.78
CLOVERPORT	Revenue	571.22			205.49			377.10			787.11			1,940.92
CROFTON	Revenue	360.05			218.08			419.79			680.69			1,678.61
DANVILLE	Revenue	30,279.78			13,912.49			23,752.40			43,036.25			110,980.92
DAWSON SPRINGS	Revenue	1,214.66			529.73			1,059.93			1,848.86			4,653.18
Dixon	Meter										89.20			89.20
EARLINGTON	Revenue	749.87			311.86			685.38			1,295.36			3,042.47
Eddyville	Revenue	801.44			484.30			859.85			1,446.79			3,592.38
ELKTON	Revenue	3,587.07			1,564.31			3,206.41			5,337.43			13,695.22
Fordsville	Meter			94.50										94.50
FRANKLIN	Revenue	8,035.01			3,972.21			6,376.56			11,351.15			29,734.93
FREDONIA	Revenue	400.16			173.69			296.30			594.16			1,464.31
GLASGOW	Revenue	38,188.51			17,519.49			28,788.43			55,928.00			140,424.43
Grand Rivers	Meter							95.40						95.40
GREENSBURG	Revenue	4,680.92			2,275.71			3,859.71			6,973.20			17,789.54
Greenville KY	Revenue	3,775.07			1,676.04			3,347.88			6,196.12			14,995.11
HARDINSBURG	Revenue	1,189.93			736.12			1,530.64			2,318.90			5,775.59
HARRODSBURG	Revenue	17,816.47			9,861.85			17,257.84			28,223.62			73,159.78
HARTFORD	Revenue	1,748.35			849.10			1,552.68			2,752.46			6,902.59
Hawesville	Revenue	799.68			365.99			541.76			1,118.65			2,826.08
Hopkinsville	Revenue	45,806.07			1,350.70			2,208.83			3,674.55			53,040.15
HORSE CAVE	Revenue	2,229.12			23,891.59			41,957.93			72,870.34			140,948.98
HUSTONVILLE	Revenue	125.56			74.10			176.86			235.44			611.96
JUNCTION CITY	Revenue	749.40			390.52			832.80			1,391.07			3,363.79
Lancaster	Revenue	1,611.79			739.50			1,545.68			2,737.25			6,634.22
Lawrenceburg	Revenue	11,058.06			4,979.95			9,059.40			16,596.21			41,693.62
Lebanon	Revenue	6,142.73			3,245.60			5,351.80			9,175.24			23,915.37
LIVERMORE	Revenue	1,560.65			655.69			1,043.26			2,214.59			5,474.19
Madisonville	Revenue	13,850.91			6,408.87			12,210.78			22,681.75			55,152.31
MARION	Revenue	3,278.51			1,471.05			2,985.50			5,315.90			13,050.96
MAYFIELD	Revenue	18,989.38			9,841.85			20,474.62			35,417.32			84,723.17
Munfordville	Meter		233.00											233.00
Nortonville	Revenue	374.52			216.40			481.92			746.30			1,819.14
OAKLAND	Revenue	98.66			62.55			135.28			209.39			505.88
OWENSBORO	Revenue	94,485.43			55,777.88			124,467.46			234,291.95			509,022.72
Park City	Revenue	221.47			134.95			267.40			444.15			1,067.97
PERRYVILLE	Revenue	361.40			200.53			471.71			774.64			1,808.28
Powderly	Meter					85.40								85.40
PRINCETON	Revenue	4,947.64			2,222.84			4,468.50			8,001.86			19,640.84
RUSSELLVILLE	Revenue	8,454.31			4,582.05			8,347.87			14,584.35			35,968.58
SACRAMENTO	Revenue	187.73			110.66			219.76			363.69			881.84
SEBREE	Revenue	748.55			296.42			512.12			1,125.90			2,682.99
SMITHS GROVE	Revenue	419.32			250.76			581.76			877.85			2,129.69
SPRINGFIELD	Revenue	3,001.92			1,578.39			2,863.84			4,820.66			12,264.81
STANFORD	Revenue	3,771.73			2,078.20			4,235.40			6,521.28			16,606.61
WHITESVILLE	Revenue	581.00			264.03			461.66			822.67			2,129.36
Wingo	Meter									82.25				82.25
Woodburn	Meter											49.00		49.00
Total Payments		410,680.38	233.00	94.50	215,393.84	85.40	426.50	408,445.33	-	82.25	732,396.19	49.00	-	1,767,886.39



**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-19**  
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**REQUEST:**

Provide the journal entries relating to the purchase of gas utility plant acquired as an operating unit or system by purchase, merger, consolidation, liquidation, or otherwise included in rate base. Also, provide a schedule showing the calculation of the acquisition adjustment at the date of purchase or each item of utility plant, the amortization period, and the unamortized balance at the beginning of the base period.

**RESPONSE:**

The acquisition balance in Account 1140 is \$3,278,547 for Kentucky, rate division 009. This amount has been fully amortized in Account 1150, accumulated provision for amortization for Kentucky, rate division 009.

Respondent: Emily Wiebe

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-20**  
**Page 1 of 1**

**REQUEST:**

Provide Atmos's rate base, capital structure, and statement of income for the most recent 12 months preceding the base period and the for the base period. Provide a reconciliation with detailed explanations.

**RESPONSE:**

An income statement for the Kentucky gas operations for the base period is provided in FR 16(8)(i) of the application. An income statement for the Kentucky gas operations for the twelve months ended June 2024 is also provided in FR 16(8)(i).

FR 16(8)(j) of the application contains the total Company capital structure for the base period. Capital structure for the period ending June 2024 is provided in the Company's response to Staff 1-22. This capital structure applies to all of Atmos Energy's operations, including the Kentucky gas operations.

A calculation of rate base for the base period for the Kentucky gas operations is provided in FR 16(8)(b) Schedule B of the application. The Company prepares detailed rate base calculations for its utility rate base regulated operations on a jurisdictional basis as required for regulatory filings. Therefore, the Company does not have a detailed rate base calculation readily available for periods other than have been provided in the application.

Respondent: Joe Christian and Greg Waller

**Case No. 2024-00276**  
**Atmos Energy Corporation, Kentucky Division**  
**Staff DR Set No. 1**  
**Question No. 1-21**  
**Page 1 of 1**

**REQUEST:**

Provide the capital structure at the end of the five most recent calendar years and each of the other periods shown in Schedule E1 and Schedule E2.

**RESPONSE:**

See Attachment 1 for the requested capital structure.

**ATTACHMENT:**

Staff\_1-21\_Att1 - Capital Structure 2019-2023.xlsx

Respondent: Joe Christian

### Calculation of Average Capital Structure Twelve Months Ended December (In Millions)

[illegible]



**Atmos Energy Corporation**  
**Calculation of Average Capital Structure**  
**Twelve Months Ended December 31, 2023**  
**(In Millions)**

Line No.	Item	Total Capital	Long-Term Debt	Short-Term Debt	Preferred Stock	Common Stock	Retained Earnings	Accumulated Other Comprehensive Income	Total Common Equity
1	Balance as of December 31, 2022	16,390.3	6,554.1	-	-	6,066.5	3,378.5	391.3	9,836.3
2	January-23	16,499.1	6,554.2	-	-	6,068.0	3,516.6	360.2	9,944.8
3	February-23	16,554.0	6,554.4	-	-	6,069.0	3,536.9	393.7	9,999.6
4	March-23	16,759.8	6,554.6	-	-	6,214.2	3,630.0	361.0	10,205.2
5	April-23	16,880.0	6,554.8	49.9	-	6,215.4	3,688.6	371.3	10,275.3
6	May-23	16,986.6	6,555.0	0.0	-	6,400.6	3,628.8	402.2	10,431.6
7	June-23	17,157.5	6,555.2	-	-	6,538.6	3,659.4	404.4	10,602.4
8	July-23	17,381.7	6,555.3	5.0	-	6,678.3	3,708.3	434.8	10,821.3
9	August-23	17,509.9	6,555.5	165.8	-	6,680.1	3,645.9	462.6	10,788.6
10	September-23	17,667.7	6,555.7	241.9	-	6,684.9	3,666.7	518.5	10,870.1
11	October-23	18,411.7	7,445.5	0.0	-	6,687.0	3,729.6	549.6	10,966.3
12	November-23	18,354.4	7,445.5	0.0	-	6,688.4	3,711.1	509.5	10,909.0
13	December-23	18,719.0	7,445.8	0.0	-	6,946.5	3,858.1	468.6	11,273.2
14	Total	225,271.9	87,885.5	462.7	-	83,937.5	47,358.5	5,627.7	136,923.7
15	Average Balance(L14/13)	17,328.6	6,760.4	35.6	-	6,456.7	3,643.0	432.9	10,532.6
16	Average Capitalization Ratios	100.0%	39.0%	0.2%	0.0%	37.3%	21.0%	2.5%	60.8%
17	End-of-period Capitalization Ratios	100.0%	39.8%	0.0%	0.0%	37.1%	20.6%	2.5%	60.2%

Note: The Long-Term Debt balances exclude Storm Uri financing.