LG&E/KU – E.W. Brown Station

Phase II Air Quality Control Study

Sparing and Capacity

April 26, 2011
Revision B – Issued For Client Review

B&V File Number 41.0814.2

LG&E KU

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1.0 Introduction

As part of the Phase II Air Quality Control Studies (AQCS) for LG&E/KU, Black & Veatch has completed a Reliability, Availability, and Maintainability (RAM) analysis on the components of E.W. Brown Units 1 - 3 AQCS upgrades and modifications in order to evaluate system availability. The availability model will reflect the expected configuration and redundancy of major equipment critical to plant operation on a per unit basis. The model will use Monte Carlo simulation to provide the expected average availability.

2.0 Methodology

In its simplest terms, generating unit availability is a function of mean time between failure (MTBF) and mean time to restore (MTTR) to service for the individual system components. It is a measure of the percent of time a unit is available to produce power while taking into account both planned and forced outages. The formula relating MTBF and MTTR to availability is Availability = MTBF / (MTBF + MTTR).

An assessment of Brown's AQCS availability requires design and configuration information, with a list of critical components, and full information about the reliability of each item, the modes and frequencies of failure, time to repair for each failure mode, and unit impact (percent load loss) upon failure of each component or group of components.

Process flow diagrams along with associated equipment lists were developed by Black & Veatch as part of the conceptual design effort. These diagrams and lists were the basis for the development of critical component data sets to be used as model inputs to a Monte Carlo model (PowerRAM) developed by Black & Veatch. Logic diagrams were constructed as functional representations of the conceptual design modifications/upgrades for Brown Units 1 - 3. A summary of component data for Units 1 - 3 is provided in Table 2-1. Both component data sets and logic diagrams can be found in Appendix A and B, respectively.

Data used in the analysis were based on data from North American Electric Reliability Corporation (NERC) Generating Availability Data System (GADS) for similar sized solid fueled plants and supplemented with in-house Black & Veatch data sources.

TABLE 2-1
BROWN AQC System included in the LG&E/KU RAM Analysis

UNIT 1	
PJFF	1x100%
FD Fan	1x100%
Air Heater	1x100%
SCR	1x100%
PAC Injection	3x50%
Sorbent Injection	3x50%
Fly Ash Handling	2x100%

UNIT 2	
PJFF	1x100%
ID Fan	1x100%
FD Fan	1x100%
Air Heater	1x100%
SCR	1x100%
PAC Injection	3x50%
Sorbent Injection	3x50%
Fly Ash Handling	2x100%

UNIT 3	
PJFF	1x100%
PAC Injection	3x50%
Fly Ash Handling	2x100%

Logic diagrams constructed for each subsystem describe the functional state of the subsystem based on the status of Brown's AQC system components. Sequences of failure and repair events are generated by application of probability distributions to input specified mean values. The model determines the status (percent of maximum capability)

for each subsystem as the outcome of the simulation events. The integrated effect of the events constitutes the reliability/availability projection of the AQC system.

Within the logic diagrams of the model seven different types of gates were used to trigger equipment components:

COMPONENT	Represents a single component or a series of components that can be functionally represented as one block and assigned a MTBF and a MTTR.
OR gate	Has two possible states – failed when one or more of its inputs are failed and not failed otherwise
AND gate	Has two possible states - failed when all of its inputs are failed and not failed otherwise
ADDAND gate	Assumes the value of the sum of its inputs
ADDAND–1 gate	Assumes a value based on the sum of its inputs. It requires an accompanying capacity table containing gate values for all possible values of the input sum. The table is one-dimensional in the sense that one value, the input sum, determines the gate value. The table may be defined as seasonal to have different capacity values for summer and non-summer.
ADDAND–2 gate	Similar to the ADDAND-1 except only two inputs are allowed and a two-dimensional table is required. The table must include gate values for all possible combinations of the two inputs. The table may be defined as seasonal to have different values for summer and non-summer.
AUCLOW gate	Assumes a value equal to the smallest capacity value among its inputs
REMOTE gate	References a gate that has been defined in another subsystem

The logic gates are distinguished by the number and type of inputs and the way the value of the gate is determined. In most cases gate values reflect fraction of maximum capacity. For numerical convenience these gate values are carried as 1 minus fraction of capacity. Thus, a failed gate has the value 1, a full capacity gate has the value 0, and a gate of 30 percent capacity, the value of 0.7.

Each “block” in the logic diagram represents a single component, or a series of components that can be functionally represented as one block. These “blocks” represent

physical entities (pumps, fans, etc) or functional entities (scheduled maintenance, time delays, etc.) with binary status (failed or not failed, active or inactive). A component referred to as a "pump" represents not only the pump itself but also the motor, bearings, couplings, impeller, and shaft. Failure of any of these subcomponents is assumed to effectively eliminate the use of all of them.

3.0 Results

The model is an event-oriented simulation of the operation of a system. The majority of reliability / availability data (MTBF, MTTR) used in the Brown RAM analysis were based on EPRI AP-2071 entitled "Component Failure and Repair Data for Coal-Fired Power Units" and the North American Electric Reliability Corporation (NERC) Generating Availability Data System (GADS).

Key modeling assumptions for the Brown RAM analysis:

- Reliability data representing the AQCS were adjusted from the typical industry average contained in the above EPRI document. The adjustments were necessary since the EPRI data recorded in AP-2071 is more than 20 years old and does not accurately reflect the forced outage rates experienced while operating new SCR systems on Units 1 and 2. Current reliability data were compiled from NERC GADS for years 2000 – 2009 to better reflect current industry average.
- Similarly reliability data for Units 1 - 3 were compiled from NERC GADS for years 1990 – 2000 to better reflect refurbished units already in service.

The templates below characterize the RAM model system configurations for Brown Units 1 through 3. Both component data sets and logic diagrams can be found in Appendix A and B, respectively.

UNIT 1: AQCS Included in the Brown RAM Analysis	
Number	**System**
1	Particulate Control
2	Forced Draft Fan
3	Air Heater
4	Selective Catalytic Reduction
5	Powder Activated Carbon Injection
6	Sorbent Injection
7	Fly Ash Handling
25	Total Availability

UNIT 2: AQCS Included in the Brown RAM Analysis	
Number	**System**
1	Particulate Control
2	Induced Draft Fan
3	Forced Draft Fan
4	Air Heater
5	Selective Catalytic Reduction
6	Powder Activated Carbon Injection
7	Sorbent Injection
8	Fly Ash Handling
25	Total Availability

UNIT 3: AQCS Included in the Brown RAM Analysis	
Number	**System**
1	Particulate Control
2	Powder Activated Carbon Injection
3	Fly Ash Handling
25	Total Availability

Only new equipment identified in the conceptual design for Units 1 - 3 were considered in the RAM analysis, thus the results show the differential impact of this new equipment. The total availability listed in Table 3.1 reflects the equivalent availability (EA) for the new equipment for each of the Brown Units as a whole and by system.

TABLE 3.1 - Equivalent Availability

	UNIT 1	UNIT 2	UNIT 3
PJFF	99.992%	99.992%	99.992%
ID Fan	N/A	99.947%	N/A
FD Fan	99.971%	99.971%	N/A
SCR	99.970%	99.970%	N/A
PAC Injection	99.999%	100.000%	100.000%
Sorbent Injection	100.000%	100.000%	N/A
Air Heater	98.957%	98.964%	N/A
Fly Ash Handling	99.933%	99.937%	99.930%
Total Availability	**98.785%**	**98.740%**	**99.958%**

These results provide the expected duration of time per year that each system will be available for operation taking into account forced outages, deratings, partial capacity states excluding scheduled outages. The equivalent Outage Hours (EOH), the expected average hours per year of full outage that is equivalent to forced and partial outages, can be calculated by (1 - EA) * 8,760. For example, in Unit 2 forced draft fan, the equivalent unavailability (1 – EA) of 0.029% multiplied by 8,760 hours per year yields the equivalent of 2.54 hours of outage. Multiplying this EOH by unit rating and capacity factor provides an estimate of the MWH per year of lost generation for the system.

The results in Table 3-1 demonstrate high availability for all the Brown AQCS additions proposed. Typically, balance of plant systems should each have an EA in the 99.9% or better range to ensure that these systems do not appreciably impact unit equivalent availability. Optimizing the design for reliability is a matter of comparing the differential MWH saved for a higher EA to the capital costs for higher redundancy. These systems have high EA because of relatively reliable equipment and redundancy for lower cost or potentially less reliable equipment necessitating redundant pumps for the injection systems.

Appendix A
Component Data

UNIT 1

LG&E/KU - Unit 1 Component Data

SYSTEM 1 PARTICULATE CONTROL				
Component ID	**Description**	**MTBF**	**MTTR**	**Source**
X01	Pulse Jet Fabric Filter	122,640	10.0	AP-2071

LG&E/KU - Unit 1 Component Data

SYSTEM 2 FORCED DRAFT FAN				
Component ID	**Description**	**MTBF**	**MTTR**	**Source**
X01	Bearings 1	750,000	38.0	AP-2071
X02	Miscellaneous 1	750,000	35.0	AP-2071
X03	Vibrations 1	497,000	53.0	AP-2071
X04	Couplings 1	750,000	34.0	AP-2071
X05	Seal Rubs 1	750,000	22.0	AP-2071
X06	Motor 1	3,740,000	360.0	AP-2071
X07	Outlet Damper 1	1,000,000	24.0	AP-2071

LG&E/KU - Unit 1 Component Data

SYSTEM 3 AIR HEATER				
Component ID	**Description**	**MTBF**	**MTTR**	**Source**
X01	Fly Ash Buildup	8,760	74.0	AP-2071
X02	Motor	394,200	177.0	AP-2071
X03	Gear Reducer	788,400	457.0	AP-2071
X04	Guide Bearing	262,800	97.0	AP-2071
X05	Support Bearing	197,100	122.0	AP-2071

LG&E/KU - Unit 1 Component Data

SYSTEM 4 SELECTIVE CATALYTIC REDUCTION				
Component ID	**Description**	**MTBF**	**MTTR**	**Source**
X01	SCR	236,757	69.29	NERG GADS

LG&E/KU - Unit 1 Component Data

SYSTEM 5 POWDER ACTIVATED CARBON INJECTION				
Component ID	Description	MTBF	MTTR	Source
X01	Feeder Hopper 1	1,095,000	2,037	NERG GADS
X02	Eductor 1	46,105	11.0	NERG GADS
X03	Blowers 1	4,380,000	360.0	NERG GADS
X04	Feeder Hopper 2	1,095,000	2,037	NERG GADS
X05	Eductor 2	46,105	11.0	NERG GADS
X06	Blowers 2	4,380,000	360.0	NERG GADS
X07	Feeder Hopper 3	1,095,000	2,037	NERG GADS
X08	Eductor 3	46,105	11.0	NERG GADS
X09	Blowers 3	4,380,000	360.0	NERG GADS
X10	Silo 1	1,095,000	2037.0	NERG GADS
X11	Silo 2	1,095,000	2037.0	NERG GADS

LG&E/KU - Unit 1 Component Data

SYSTEM 6 SORBENT INJECTION				
Component ID	Description	MTBF	MTTR	Source
X01	Feeder Hopper 1	1,095,000	2,037	NERG GADS
X02	Eductor 1	46,105	11.0	NERG GADS
X03	Blowers 1	4,380,000	360.0	NERG GADS
X04	Feeder Hopper 2	1,095,000	2,037	NERG GADS
X05	Eductor 2	46,105	11.0	NERG GADS
X06	Blowers 2	4,380,000	360.0	NERG GADS
X07	Feeder Hopper 3	1,095,000	2,037	NERG GADS
X08	Eductor 3	46,105	11.0	NERG GADS
X09	Blowers 3	4,380,000	360.0	NERG GADS
X10	Silo 1	1,095,000	2037.0	NERG GADS
X11	Silo 2	1,095,000	2037.0	NERG GADS

LG&E/KU - Unit 1 Component Data

SYSTEM 7 FLY ASH HANDLING				
Component ID	Description	MTBF	MTTR	Source
X01	Vacuum Exhauster 1	13,140	8.0	NERG GADS
X02	Vacuum Exhauster 2	13,140	8.0	NERG GADS
X03	Filter Separator 1	718	4.0	NERG GADS
X04	Filter Separator 2	718	4.0	NERG GADS
X05	Feeder 1	2,920	4.0	NERG GADS
X06	Feeder 2	2,920	4.0	NERG GADS
X07	Pressure Transfer Blower 1	13,140	8.0	NERG GADS
X08	Pressure Transfer Blower 2	13,140	8.0	NERG GADS
X09	Ash Hopper Delay			
X10	Silo Unloading	110,000	120.0	NERG GADS

LG&E/KU - Unit 1 Component Data

SYSTEM 25 AQCS				
Component ID	Description	MTBF	MTTR	Source
X01	Air Compressor 1	4,348	82.0	B&V Internal Database / Expert Opinion
X02	Air Compressor 2	4,348	82.0	B&V Internal Database / Expert Opinion

UNIT 2

LG&E/KU - Unit 2 Component Data

SYSTEM 1 PARTICULATE CONTROL				
Component ID	Description	MTBF	MTTR	Source
X01	Pulse Jet Fabric Filter	122,640	10.0	AP-2071

LG&E/KU - Unit 2 Component Data

SYSTEM 2 INDUCED DRAFT FAN				
Component ID	Description	MTBF	MTTR	Source
X01	Couplings 1	769,000	33.0	AP-2071
X02	Bearings 1	769,000	37.0	AP-2071
X03	Miscellaneous 1	769,000	34.0	AP-2071
X04	Vibrations 1	512,000	53.0	AP-2071
X05	Inlet Vanes 1	179,000	30.0	AP-2071
X06	Seal Rubs 1	769,000	21.0	AP-2071
X07	Motor 1	3,850,000	360.0	AP-2071
X08	Outlet Damper 1	1,000,000	24.0	AP-2071

LG&E/KU - Unit 2 Component Data

SYSTEM 3 FORCED DRAFT FAN				
Component ID	Description	MTBF	MTTR	Source
X01	Bearings 1	750,000	38.0	AP-2071
X02	Miscellaneous 1	750,000	35.0	AP-2071
X03	Vibrations 1	497,000	53.0	AP-2071
X04	Couplings 1	750,000	34.0	AP-2071
X05	Seal Rubs 1	750,000	22.0	AP-2071
X06	Motor 1	3,740,000	360.0	AP-2071
X07	Outlet Damper 1	1,000,000	24.0	AP-2071

LG&E/KU - Unit 2 Component Data

SYSTEM 4 AIR HEATER				
Component ID	Description	MTBF	MTTR	Source
X01	Fly Ash Buildup	8,760	74.0	AP-2071
X02	Motor	394,200	177.0	AP-2071
X03	Gear Reducer	788,400	457.0	AP-2071
X04	Guide Bearing	262,800	97.0	AP-2071
X05	Support Bearing	197,100	122.0	AP-2071

LG&E/KU - Unit 2 Component Data

SYSTEM 5 SELECTIVE CATALYTIC REDUCTION				
Component ID	Description	MTBF	MTTR	Source
X01	SCR	236,757	69.29	NERG GADS

LG&E/KU - Unit 2 Component Data

SYSTEM 6 POWDER ACTIVATED CARBON INJECTION				
Component ID	Description	MTBF	MTTR	Source
X01	Feeder Hopper 1	1,095,000	2,037	NERG GADS
X02	Eductor 1	46,105	11.0	NERG GADS
X03	Blowers 1	4,380,000	360.0	NERG GADS
X04	Feeder Hopper 2	1,095,000	2,037	NERG GADS
X05	Eductor 2	46,105	11.0	NERG GADS
X06	Blowers 2	4,380,000	360.0	NERG GADS
X07	Feeder Hopper 3	1,095,000	2,037	NERG GADS
X08	Eductor 3	46,105	11.0	NERG GADS
X09	Blowers 3	4,380,000	360.0	NERG GADS
X10	Silo 1	1,095,000	2037.0	NERG GADS
X11	Silo 2	1,095,000	2037.0	NERG GADS

LG&E/KU - Unit 2 Component Data

SYSTEM 7 SORBENT INJECTION				
Component ID	Description	MTBF	MTTR	Source
X01	Feeder Hopper 1	1,095,000	2,037	NERG GADS
X02	Eductor 1	46,105	11.0	NERG GADS
X03	Blowers 1	4,380,000	360.0	NERG GADS
X04	Feeder Hopper 2	1,095,000	2,037	NERG GADS
X05	Eductor 2	46,105	11.0	NERG GADS
X06	Blowers 2	4,380,000	360.0	NERG GADS
X07	Feeder Hopper 3	1,095,000	2,037	NERG GADS
X08	Eductor 3	46,105	11.0	NERG GADS
X09	Blowers 3	4,380,000	360.0	NERG GADS
X10	Silo 1	1,095,000	2037.0	NERG GADS
X11	Silo 2	1,095,000	2037.0	NERG GADS

LG&E/KU - Unit 2 Component Data

SYSTEM 8 FLY ASH HANDLING				
Component ID	Description	MTBF	MTTR	Source
X01	Vacuum Exhauster 1	13,140	8.0	NERG GADS
X02	Vacuum Exhauster 2	13,140	8.0	NERG GADS
X03	Filter Separator 1	718	4.0	NERG GADS
X04	Filter Separator 2	718	4.0	NERG GADS
X05	Feeder 1	2,920	4.0	NERG GADS
X06	Feeder 2	2,920	4.0	NERG GADS
X07	Pressure Transfer Blower 1	13,140	8.0	NERG GADS
X08	Pressure Transfer Blower 2	13,140	8.0	NERG GADS
X09	Ash Hopper Delay			
X10	Silo Unloading	110,000	120.0	NERG GADS

LG&E/KU - Unit 2 Component Data

SYSTEM 25 AQCS				
Component ID	Description	MTBF	MTTR	Source
X01	Air Compressor 1	4,348	82.0	B&V Internal Database / Expert Opinion
X02	Air Compressor 2	4,348	82.0	B&V Internal Database / Expert Opinion

UNIT 3

LG&E/KU - Unit 3 Component Data

SYSTEM 1 PARTICULATE CONTROL				
Component ID	Description	MTBF	MTTR	Source
X01	Pulse Jet Fabric Filter	122,640	10.0	AP-2071

LG&E/KU - Unit 3 Component Data

SYSTEM 2 POWDER ACTIVATED CARBON INJECTION				
Component ID	Description	MTBF	MTTR	Source
X01	Feeder Hopper 1	1,095,000	2,037	NERG GADS
X02	Eductor 1	46,105	11.0	NERG GADS
X03	Blowers 1	4,380,000	360.0	NERG GADS
X04	Feeder Hopper 2	1,095,000	2,037	NERG GADS
X05	Eductor 2	46,105	11.0	NERG GADS
X06	Blowers 2	4,380,000	360.0	NERG GADS
X07	Feeder Hopper 3	1,095,000	2,037	NERG GADS
X08	Eductor 3	46,105	11.0	NERG GADS
X09	Blowers 3	4,380,000	360.0	NERG GADS
X10	Silo 1	1,095,000	2037.0	NERG GADS
X11	Silo 2	1,095,000	2037.0	NERG GADS

LG&E/KU - Unit 3 Component Data

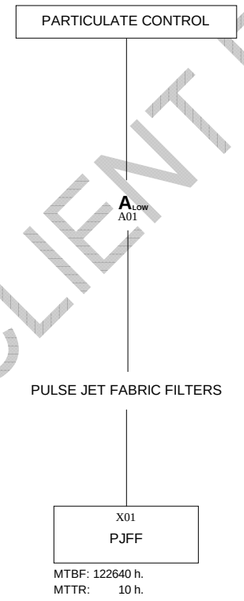
SYSTEM 3 FLY ASH HANDLING				
Component ID	Description	MTBF	MTTR	Source
X01	Vacuum Exhauster 1	13,140	8.0	NERG GADS
X02	Vacuum Exhauster 2	13,140	8.0	NERG GADS
X03	Filter Separator 1	718	4.0	NERG GADS
X04	Filter Separator 2	718	4.0	NERG GADS
X05	Feeder 1	2,920	4.0	NERG GADS
X06	Feeder 2	2,920	4.0	NERG GADS
X07	Pressure Transfer Blower 1	13,140	8.0	NERG GADS
X08	Pressure Transfer Blower 2	13,140	8.0	NERG GADS
X09	Ash Hopper Delay			
X10	Silo Unloading	110,000	120.0	NERG GADS

LG&E/KU - Unit 3 Component Data

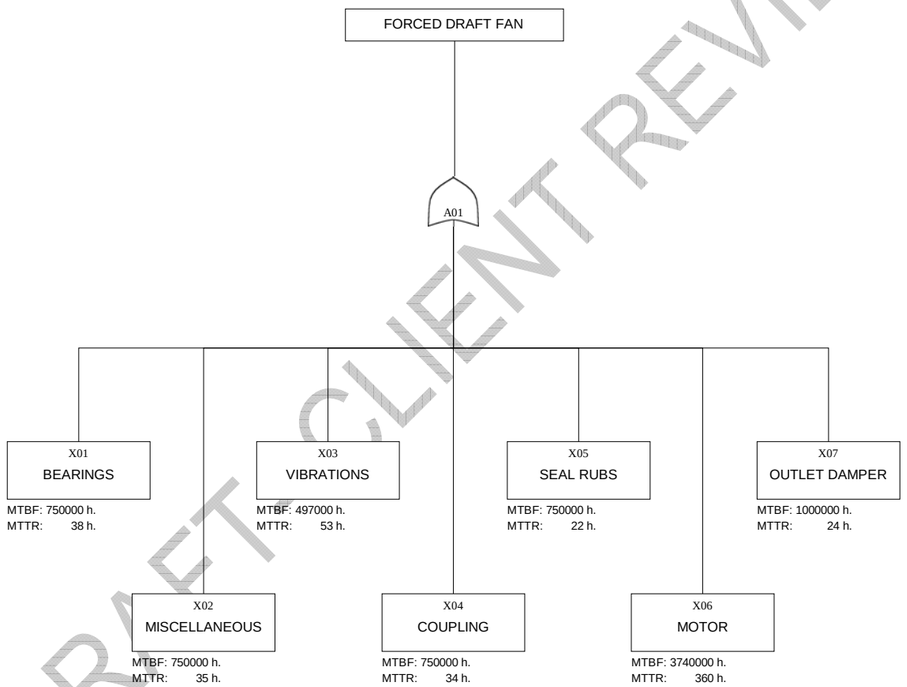
SYSTEM 25 AQCS				
Component ID	Description	MTBF	MTTR	Source
X01	Air Compressor 1	4,348	82.0	B&V Internal Database / Expert Opinion
X02	Air Compressor 2	4,348	82.0	B&V Internal Database / Expert Opinion

Appendix B
Logic Diagrams

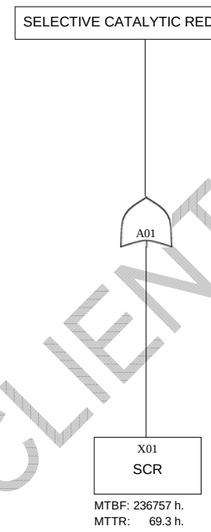
&E: Brown 1
Particulate Control (System 1)
Wed, Mar 2, 2011



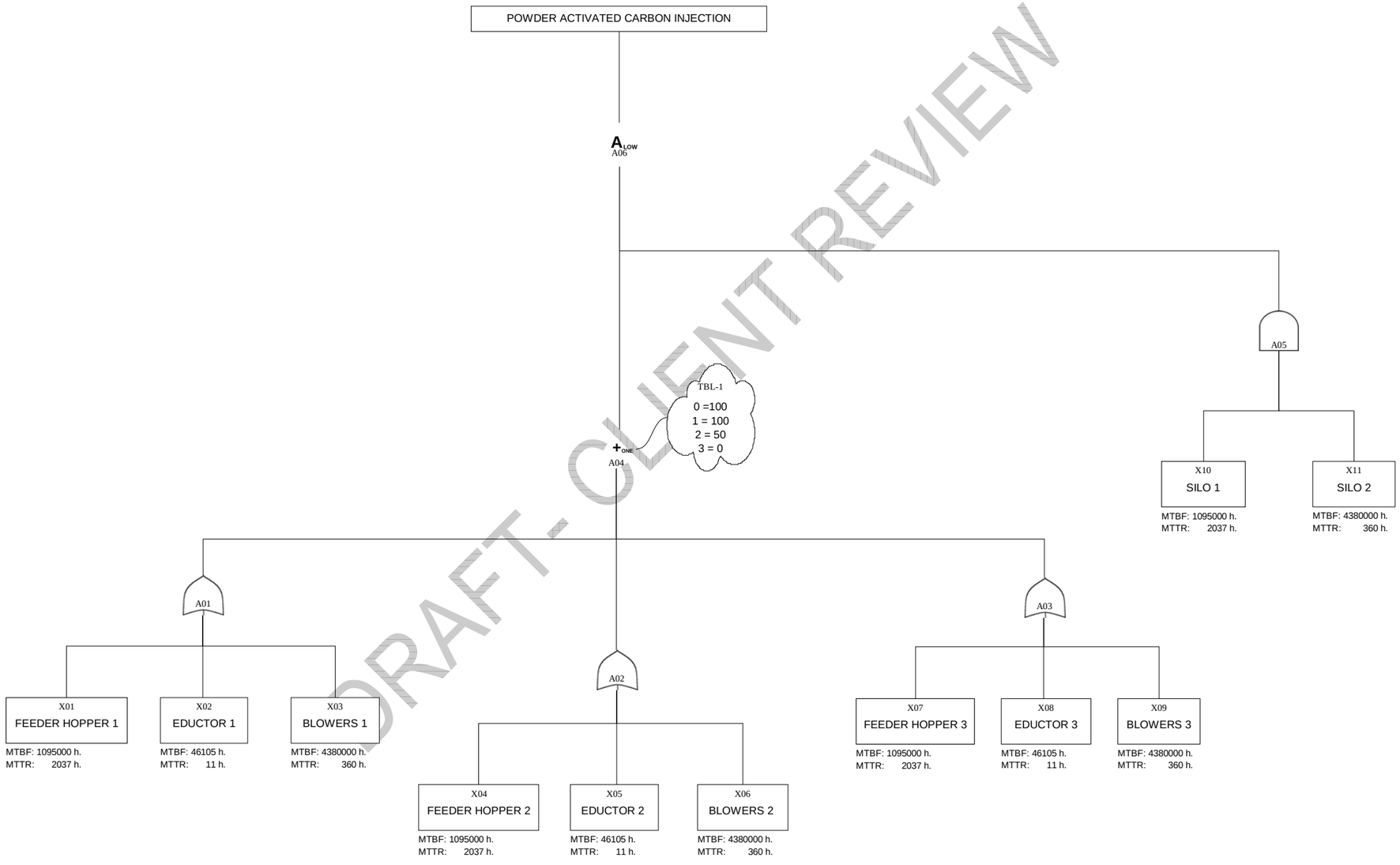
LG&E: Brown 1
Forced Draft Fan (System 2)
Wed, Mar 2, 2011



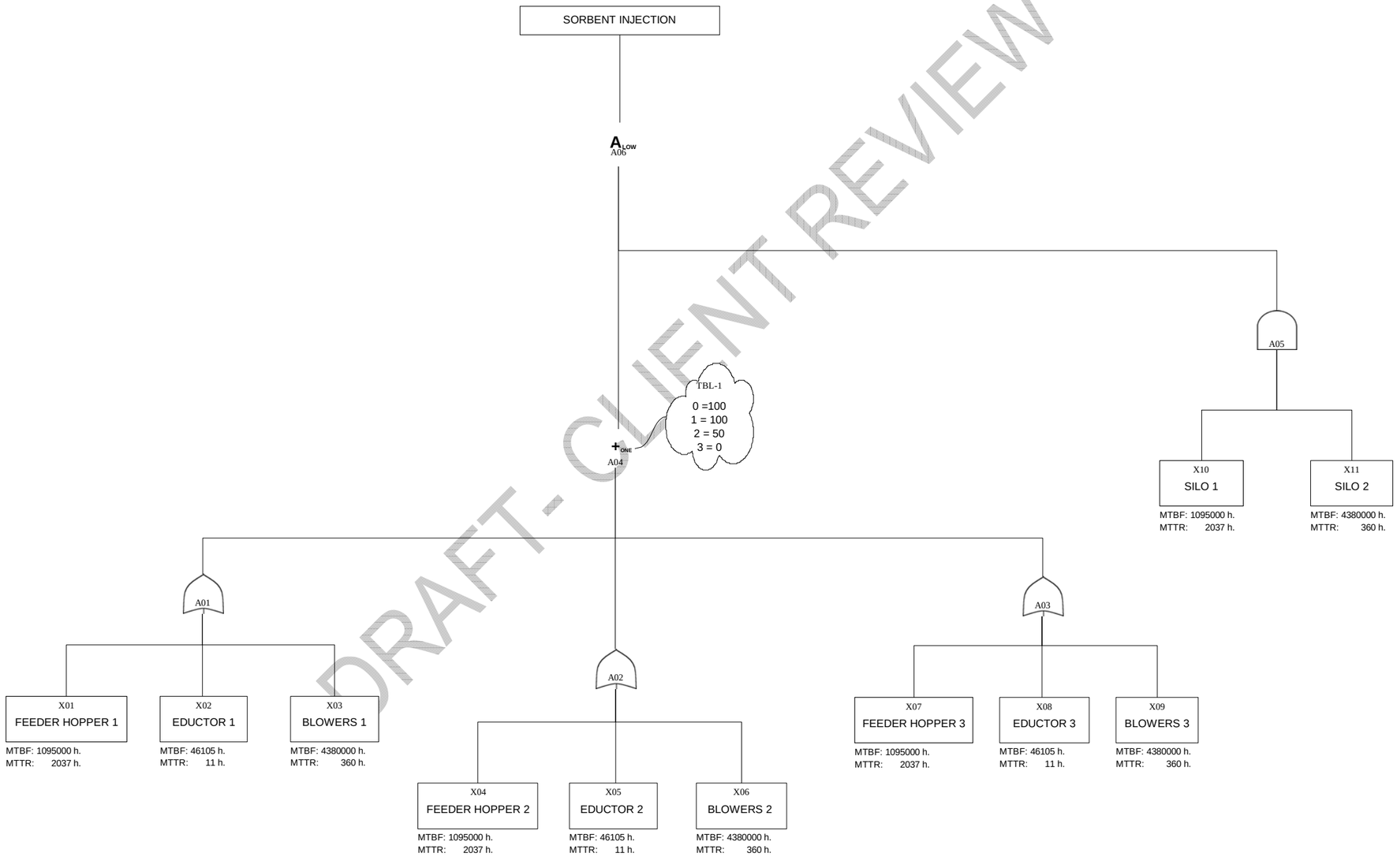
LG&E: Brown 1
Selective Catalytic Reduction (System 3)
Wed, Mar 2, 2011



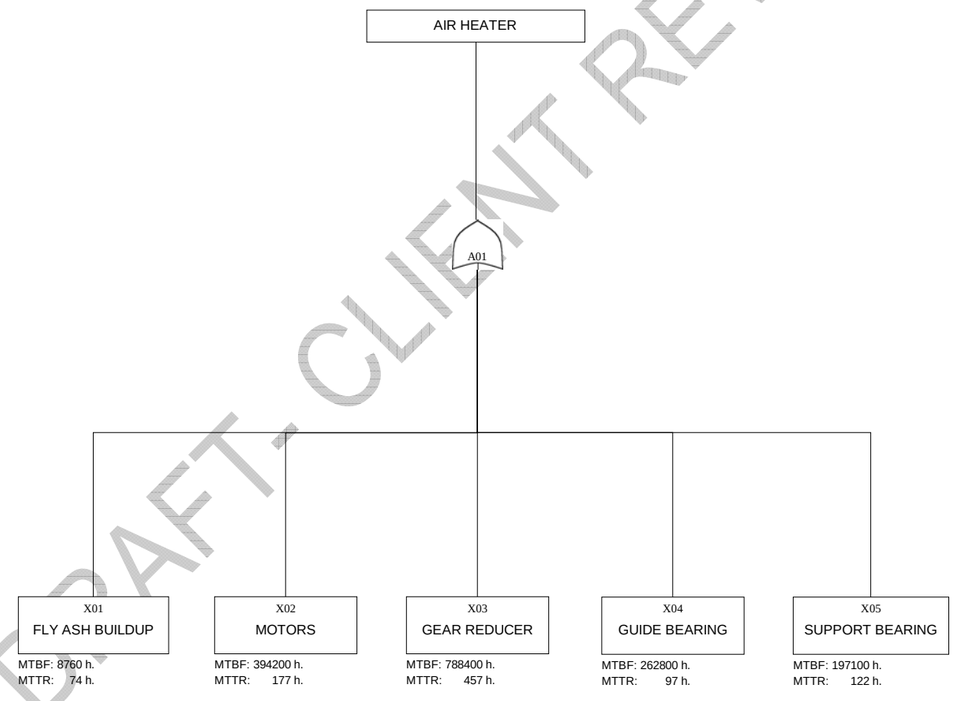
E: Brown 1
Powder Activated Carbon (System 4)
Wed, Mar 2, 2011



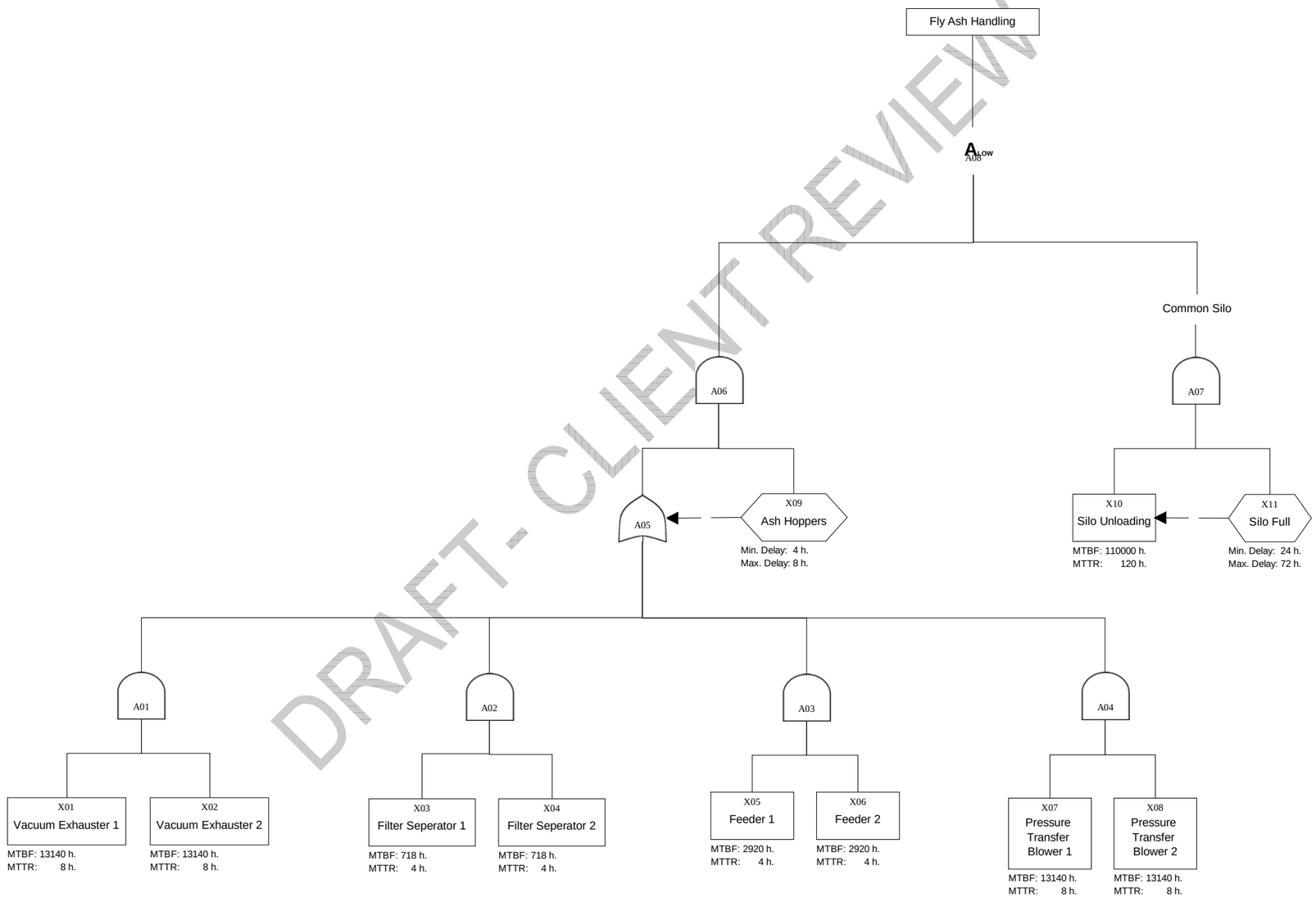
E: Brown 1
Sorbent (System 5)
Wed, Mar 2, 2011



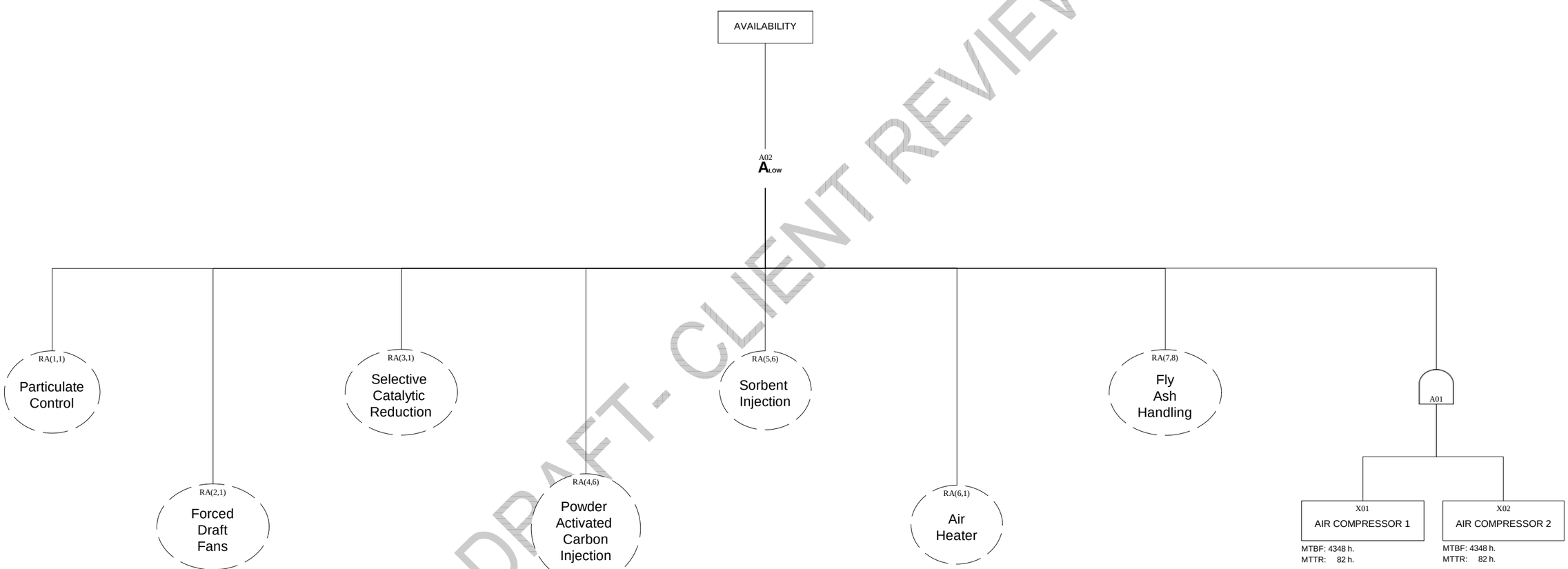
LG&E: Brown 1
Air Heater (System 6)
Wed, Mar 2, 2011



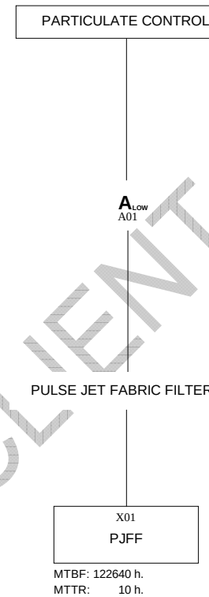
L&E: Brown 1
Fly Ash Handling (System 7)
Wed, Mar 2, 2011



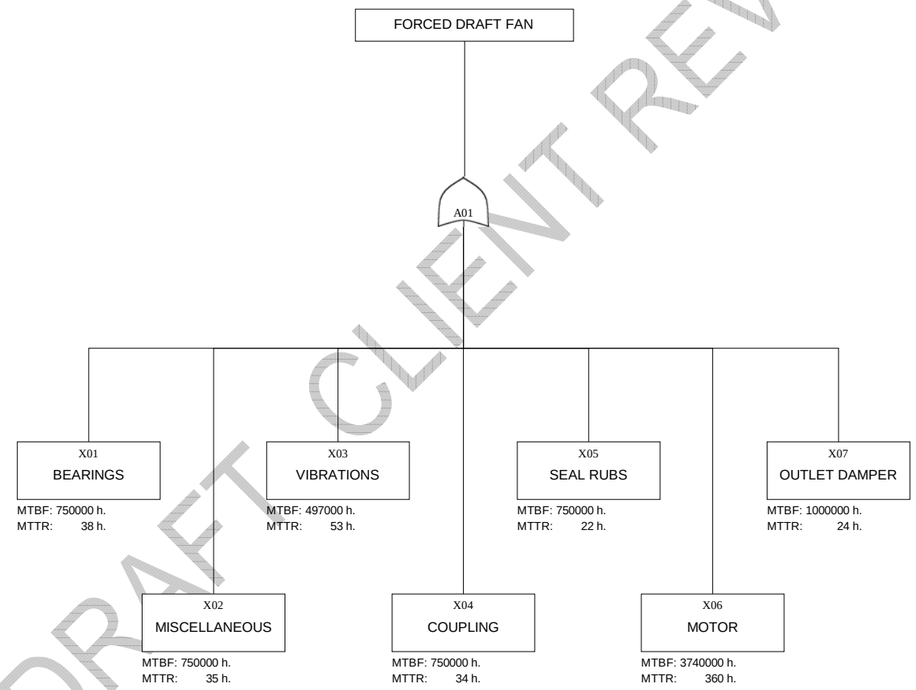
LG&E: Brown 1
Availability (System 25)
Wed, Mar 2, 2011



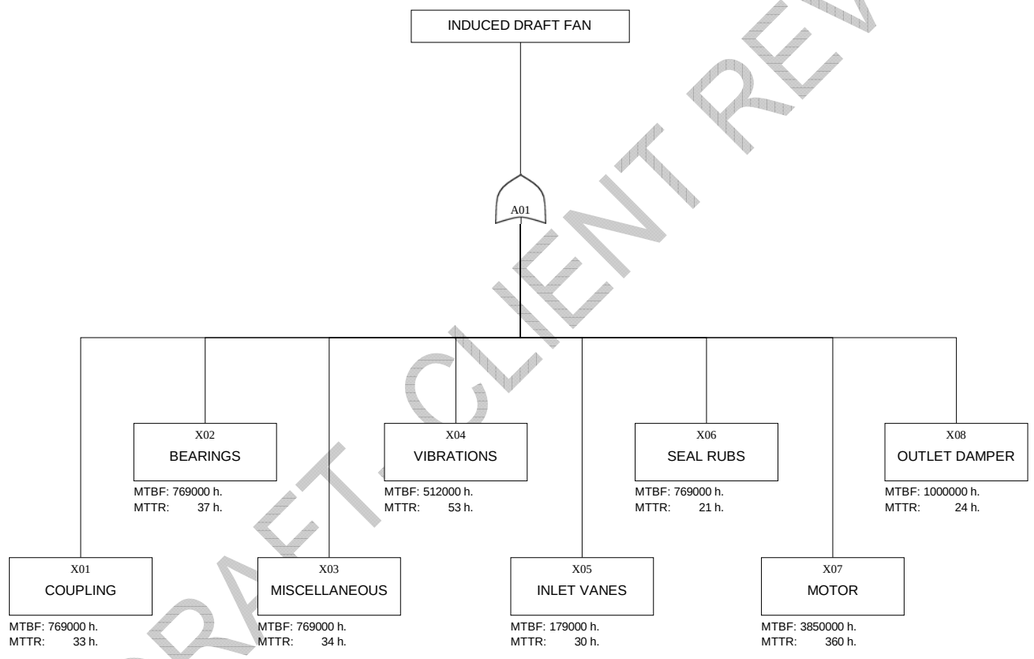
&E: Brown 2
Particulate Control (System 1)
Wed, Mar 2, 2011



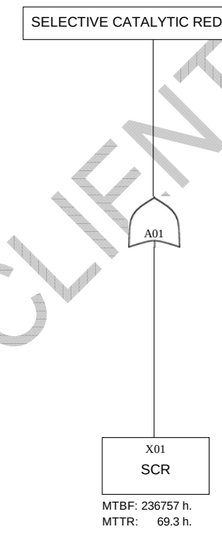
LG&E: Brown 2
Forced Draft Fan (System 2)
Wed, Mar 2, 2011



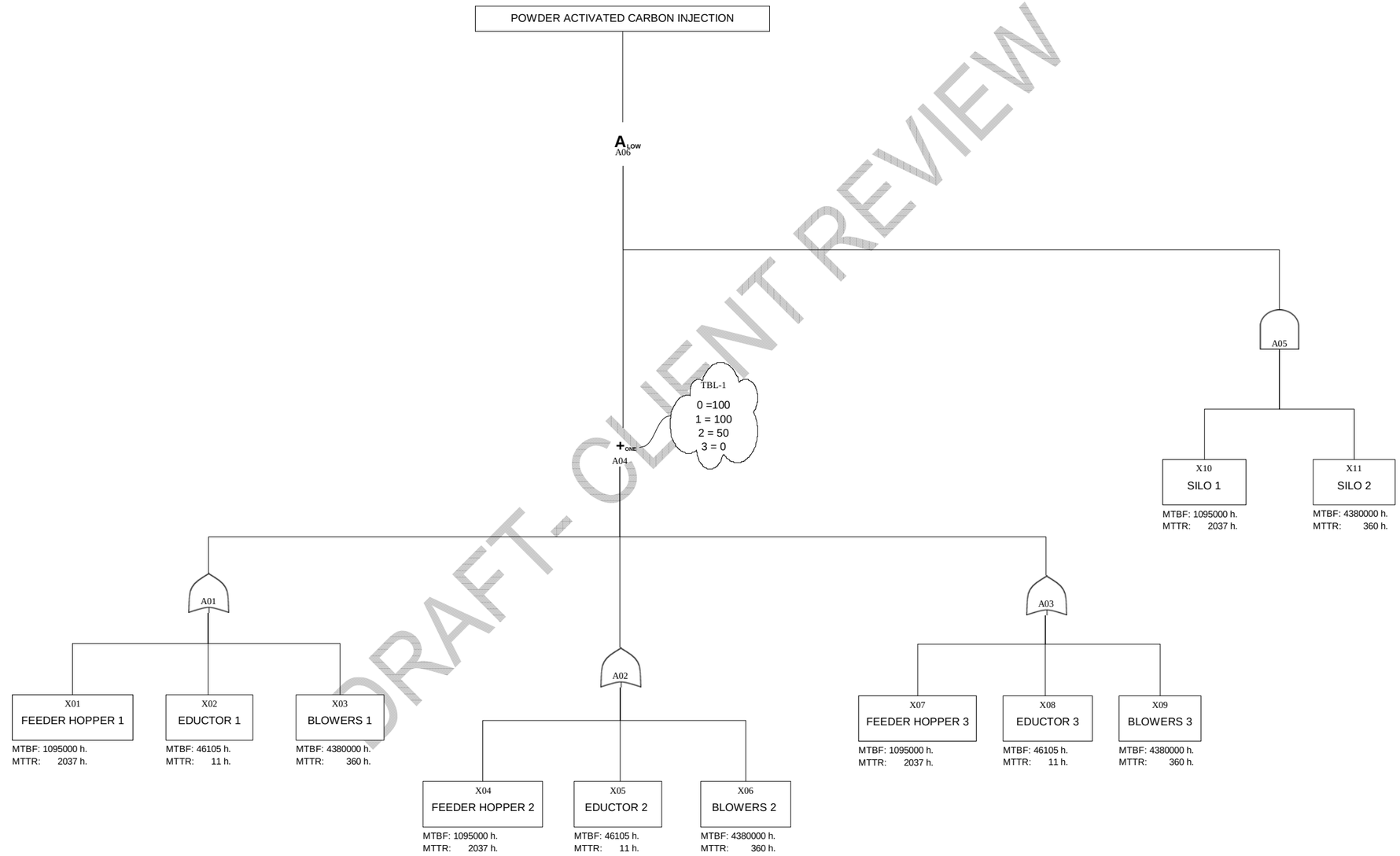
LG&E: Brown 2
Induced Draft Fan (System 3)
Wed, Mar 2, 2011



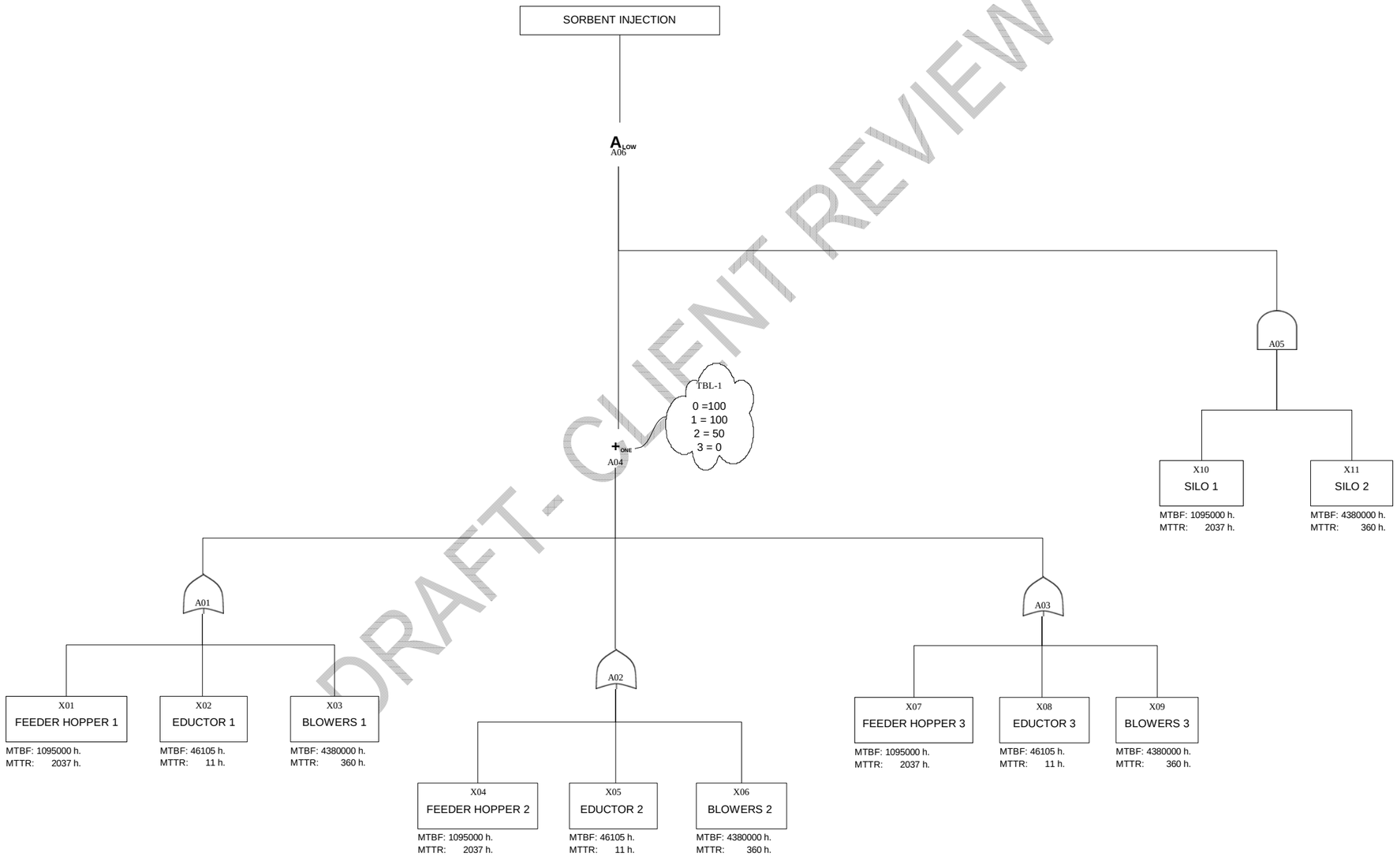
LG&E: Brown 2
Selective Catalytic Reduction (System 4)
Wed, Mar 2, 2011



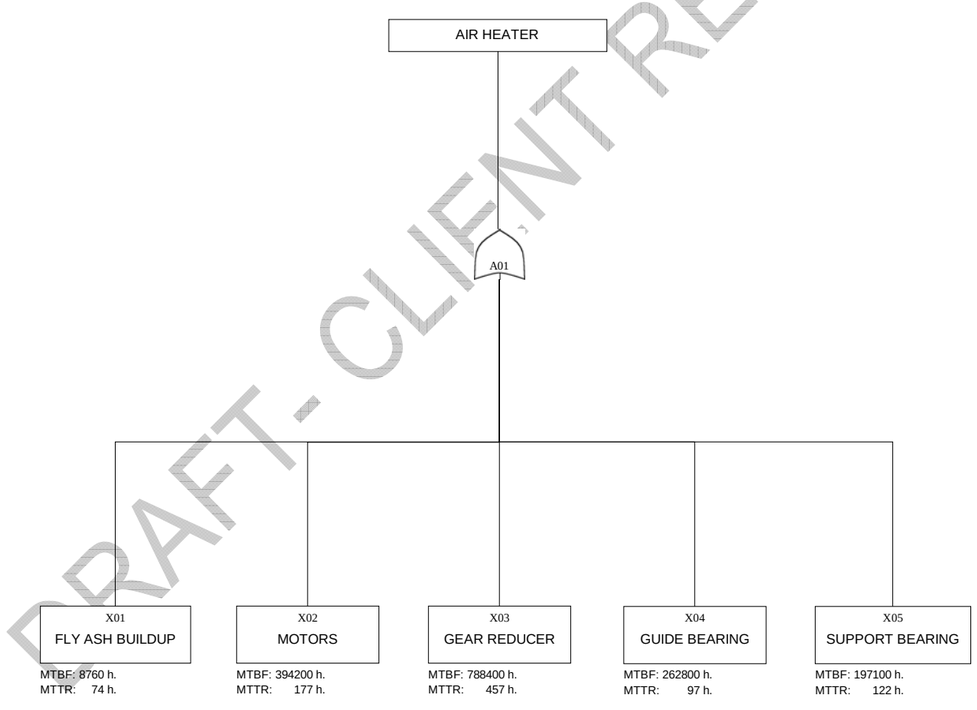
E: Brown 2
Powder Activated Carbon (System 5)
Wed, Mar 2, 2011



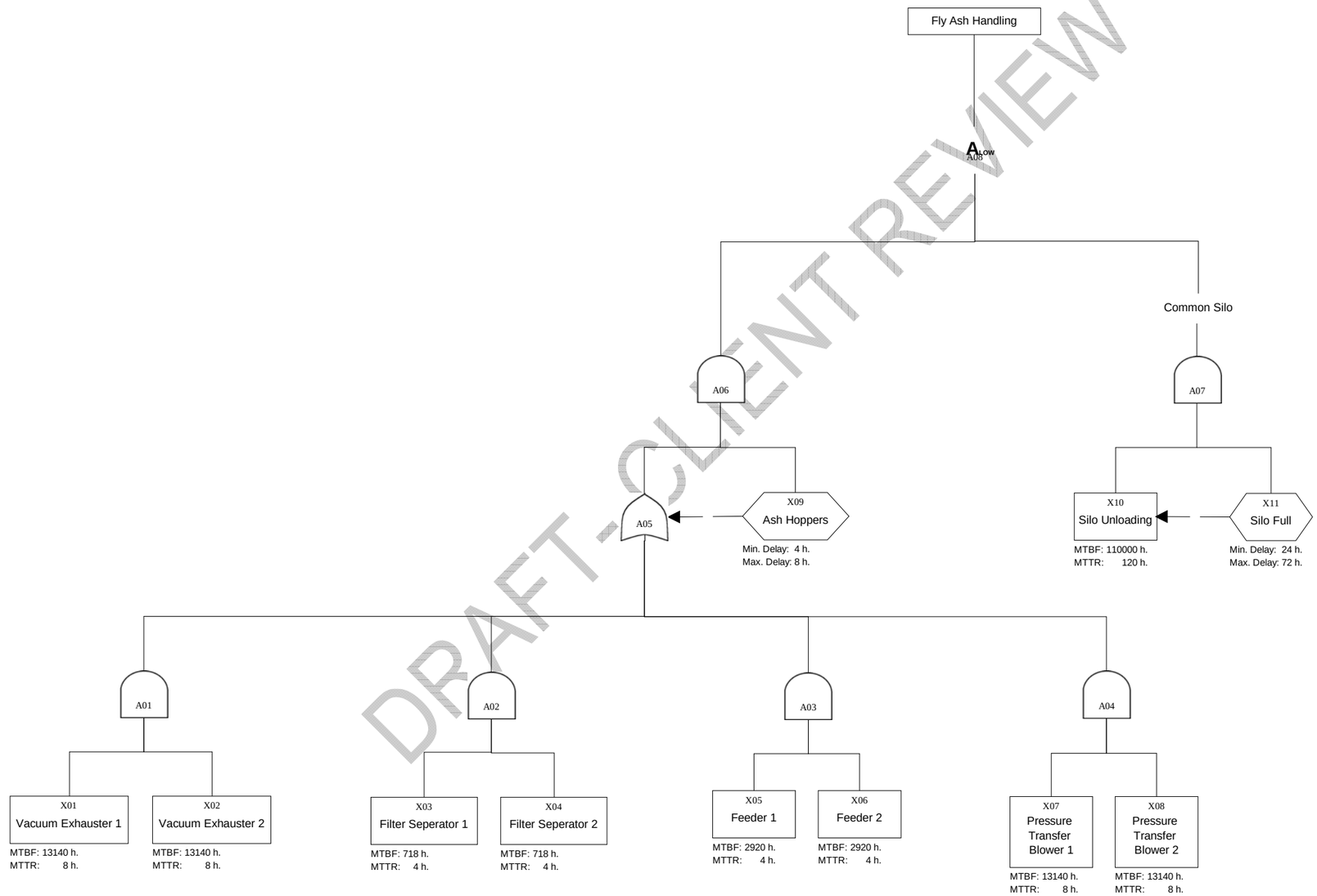
E: Brown 2
Sorbent (System 6)
Wed, Mar 2, 2011



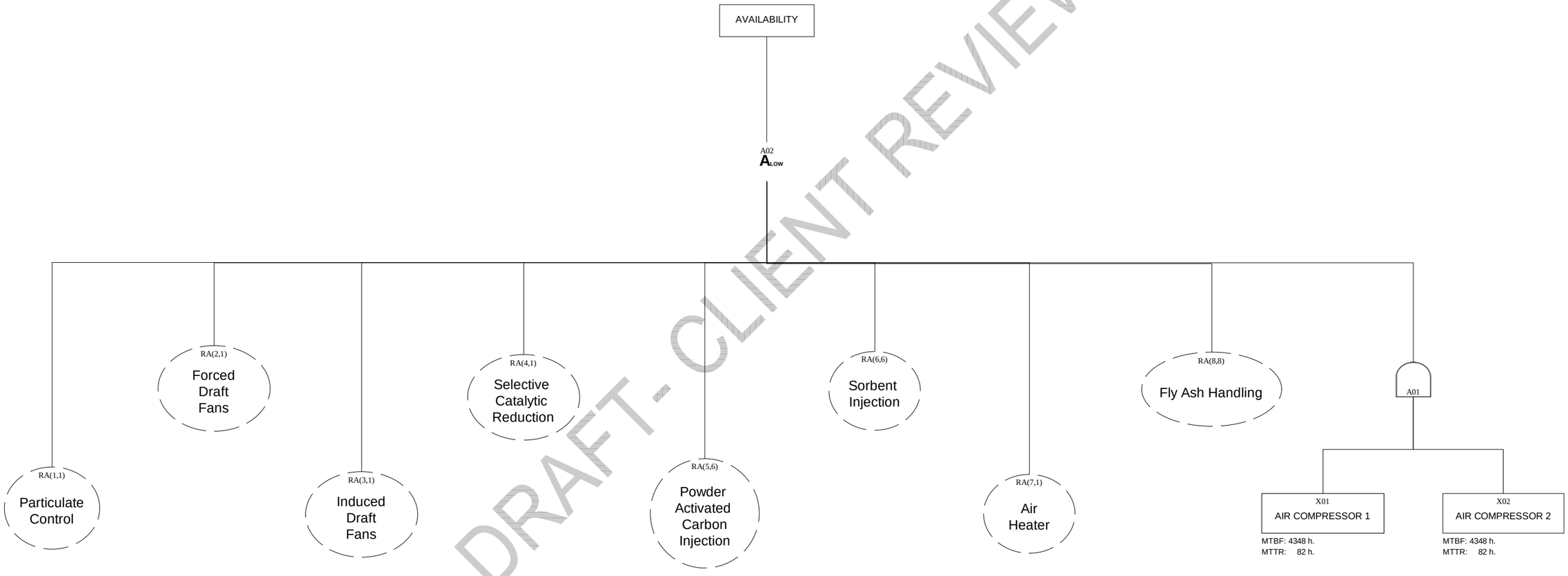
LG&E: Brown 2
Air Heater (System 7)
Wed, Mar 2, 2011



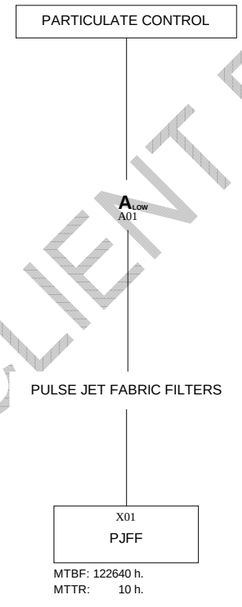
&E: Brown 2
Fly Ash Handling (System 8)
Wed, Mar 2, 2011



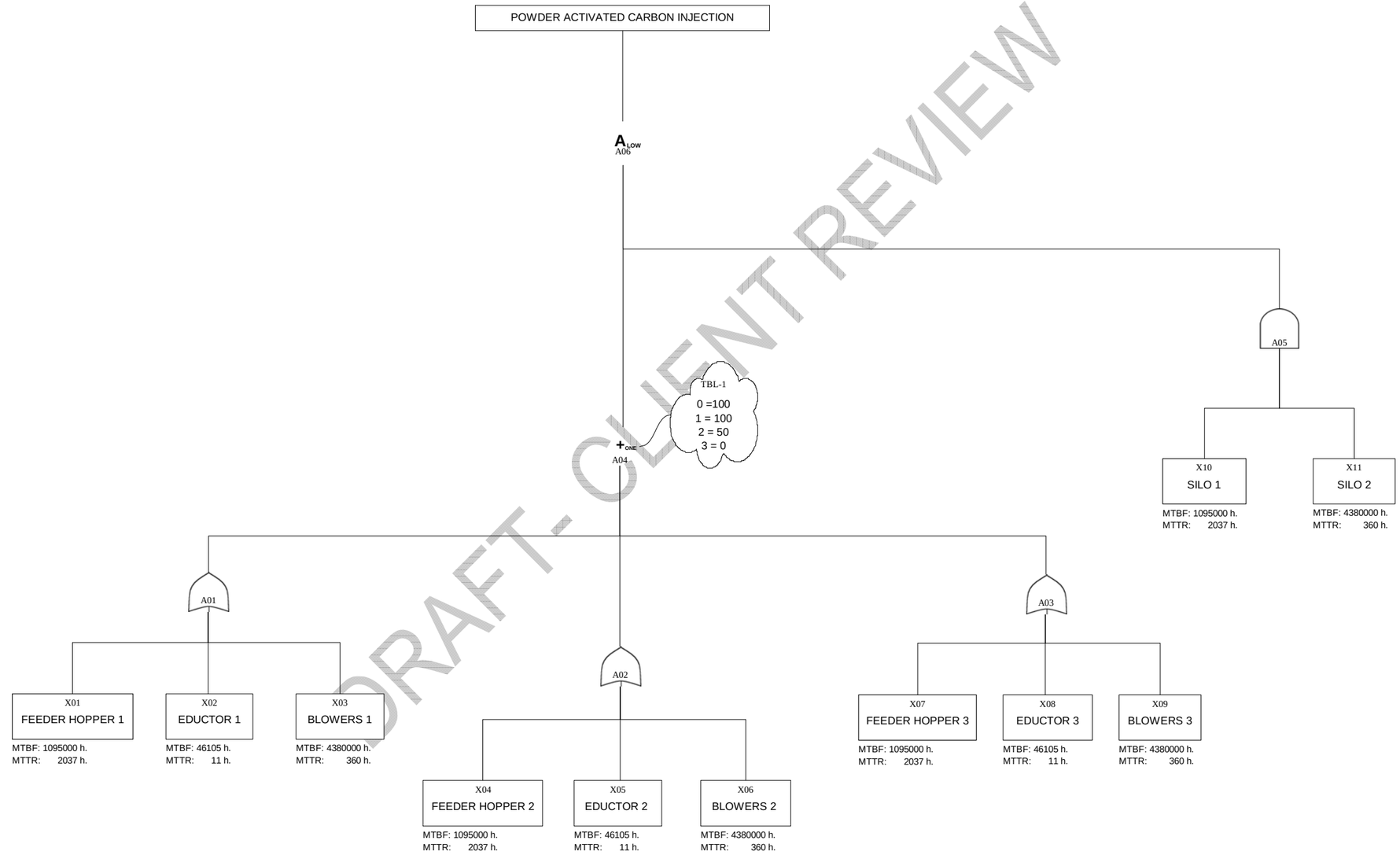
LG&E: Brown 2
Availability (System 25)
Wed, Mar 2, 2011



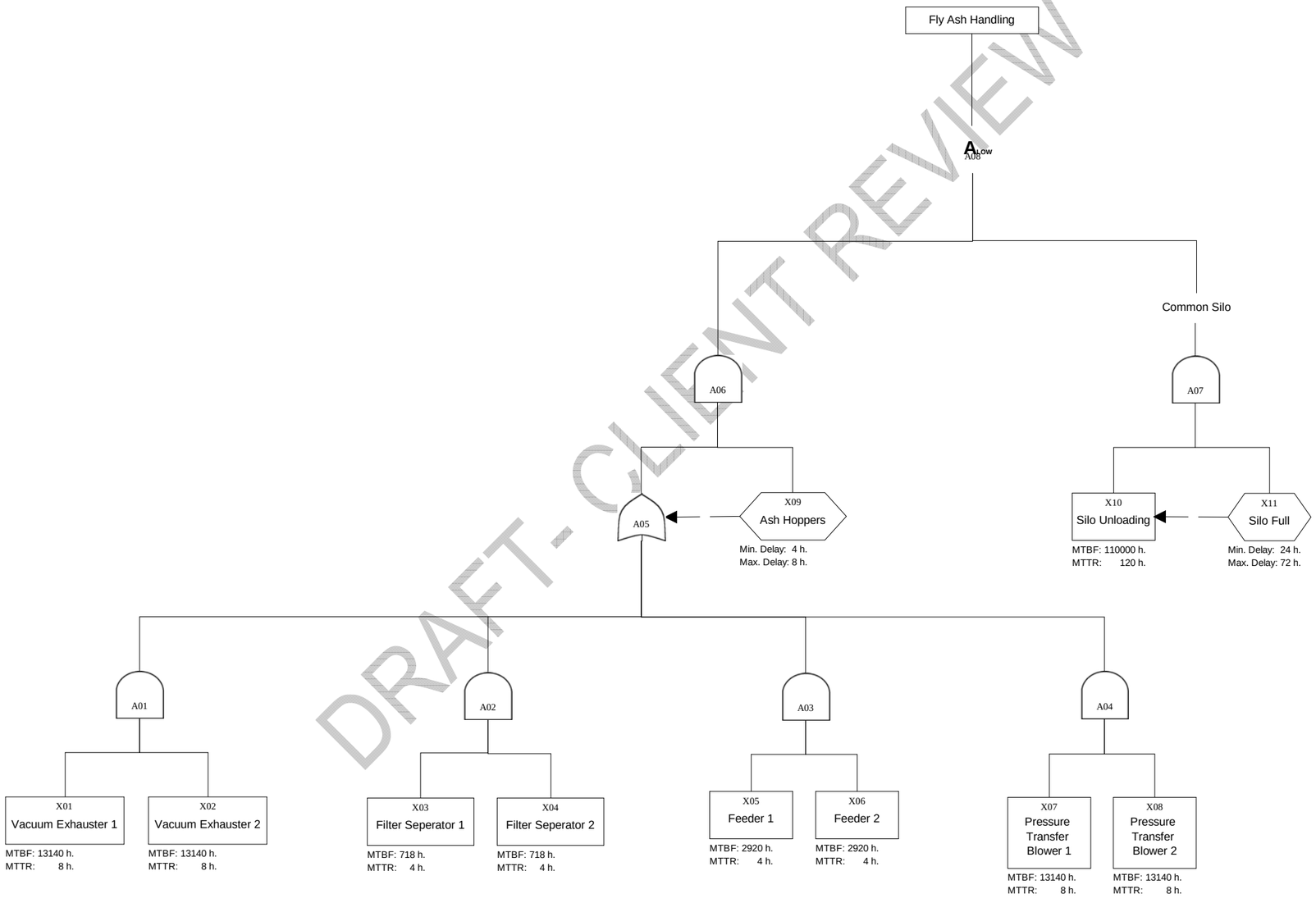
&E: Brown 3
Particulate Control (System 1)
Wed, Mar 2, 2011



E: Brown 3
Powder Activated Carbon (System 2)
Wed, Mar 2, 2011



L&E: Brown 3
Fly Ash Handling (System 3)
Wed, Mar 2, 2011



LG&E: Brown 3
Availability (System 25)
Fri, Apr 1, 2011