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Heavy Oil

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Quest CCS Project

Reliability, Availability and Maintainability Report addressing sparing, RRM and turndown

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2014-08-22	Originator	Aaron Balaban	
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Summary

This document outlines current status for the RRM, sparing and turnaround requirements for the Quest project. Inputs into this report include application of Value Improvement Practices PG08c Design Class VIP and Project Guide08e Availability, Assurance & Reliability Modelling VIP. It is estimated that the quest facility will be available 95.4% per annum excluding turnarounds which are planned for a 4 year cycle. This exceeds the design premise of the project of 90% availability.

Keywords

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SUMMARY

Prior to the Value Assurance Review (VAR) 4 the Quest Operations Readiness team contracted Shell Global Solutions to complete a reliability, availability and maintainability study to ensure the plant as designed would meet the project premise of 1.08 mT CO2 stored per year and 90% availability. The SGS team built a block flow diagram of the system using available industry reliability data for the equipment and conducted a Monte-Carlo simulation of the Quest facility. This study concluded that Quest as designed would have an availability of 95.5%.

Since the VAR 4, new site specific reliability information, better understanding of the equipment's limitations, generally from other operators, and changes to the flow sheet have necessitated a re-running of the simulation to ensure Quest will still perform as needed. As such, SGS was contracted to update the model with the latest information available and re-run the simulation. Once this was completed the availability of the Quest equipment was determined to 95.4% well above the requirements of the project premise.

Following is the SGS study report which details the methodology, data sources, sensitivity analysis and changes to the block flow diagram since VAR4 used to determine the availability of the Quest facility as being constructed.

QUEST CCS PROJECT
Scotford CO_2 Capture to CO_2 Pipeline RAM Study
Final Report

Shell Global Solutions

Quest CCS Project

Scotford CO_2 Capture to Wells RAM Study Final Report

2013 Update

by

Aaron Powell

Document History:

Date	Issue	Reason for change	Author Name
November 21, 2008	Rev 1	Draft Study Basis for comments	Study Team
December 5, 2008	Rev 2	Incorporate Compression System	Study Team
May 5, 2010	Rev 1-2010	Incorporate Upgrades of Compression and Dehydration Systems	Ryan Stephens
May 20, 2010	Rev 2-2010	Incorporate updated assumptions for Sensitivity Cases	Ryan Stephens
June 24, 2010	Draft Report	Incorporate Results	Ryan Stephens
September 21, 2011	Rev 1-2011	Incorporate updated assumptions and results	Study Team
October 14, 2011	Rev 2-2011	Incorporate Sensitivity Cases	Study Team
November 17, 2011	Rev 3-2011	Updated with Comments	Study Team
November 12, 2013	Rev 1-2013	Incorporate Results	Aaron Powell

1. INTRODUCTION

The Athabasca Oil Sands Project (AOSP) is a joint venture between Shell Canada Limited, Chevron Canada Limited and Western Oil Sands L. P. The existing AOSP ("Base Plant") was brought into operation in early 2003. The Base Plant consists of an Upstream facility at the Muskeg River Mine site and a Downstream facility (the Scotford Upgrader) located near Fort Saskatchewan. A southbound diluted bitumen ("dilbit") pipeline and a northbound diluent pipeline, owned and operated by Terasen, connect the two sites.

To position the Athabasca Oil Sands Project with the necessary stakeholder support for the initial project and for future growth, a significant voluntary commitment was made by Shell Canada to reduce the Base Plant's full cycle green house gas (GHG) emissions by 50%. The technology that will contribute to meeting this commitment is to capture CO_2 from the existing Base Plant and Expansion 1 Upgrader Hydrogen Manufacturing Units (HMUs) located at Shell's Scotford Upgrader site near Ft. Saskatchewan, Alberta.

Shell Canada is planning to build CO_2 Capture and Compression facilities to process 1.2 million tons of CO_2 per year. These facilities would capture the CO_2 produced at the Upgrader HMUs where hydrogen is produced for the conversion of bitumen to synthetic crude oil.

A high-level reliability study was performed during year 2009 to determine the overall availability of the proposed CO_2 Capture System in order to assess any potential effect of unavailability on the HMU units.

An update to the original study was completed in 2010 and again in 2011. Shell Canada has since requested another update to the reliability study to incorporate the following changes to the Base Case:

- Compressor
    - Removed individual compressor stages and replaced with 3 FMs
        - Seals: MTBF=2.5 years, MTBR=120-168 hours
        - Bearing: MTBF=10 years, MTBR=408 hours
        - Gearbox: MTBF=20 years, MTBR=504
    - Modified Fin-Fan configuration
        - E-24706: 1 bay, 3 fans, 15% loss / fan failure
        - E-24707: 2 bays, 6 fans, 10% loss / fan failure
- Heat Exchangers
    - Modify MTBF & MTBR
        - MTBF: 9.3 years (from 35 years)
        - MTBR: 96 hours (from 148 hours)
- Add Stripper Inlet Valves
    - 2 Valves on the Amine Stripper

- Case 1: MTBF=9 years, MTBR=168 hours
- Case 2: MTBF=9 years, MTBR=36 hours

- Lean TEG Cooler
  - Changed from parallel to series

This document details the basic data, study results, and assumptions from which the reliability model of the CO_2 Capture System was constructed. The study was conducted using the reliability simulation software TARO.

2. SCOPE, OBJECTIVES AND DELIVERABLES

2.1. Objectives

Shell Projects & Technology have been requested to perform an update to the reliability study of the CO_2 Capture System that was conducted during year 2009. The objective of the study is primarily to identify potential plant availability gaps and areas for improvement. This can be achieved by the following:

- Determine the availability of the proposed CO_2 Capture System
- Identify key equipment that contribute to downtime of proposed CO_2 Capture System

2.2. Scope

The study only includes the equipment associated with the proposed CO_2 Capture System and the CO_2 Compression & Dehydration System. It assumed a constant gas feed rate as well as 100% availability of the downstream units. The following sub-systems were modeled as the Base Case:

- CO_2 Absorption
- ADIP-X (Accelerated MDEA) Regeneration
- CO_2 Compression
- CO_2 Dehydration

Chemical Injection and Utilities are part of the CO_2 capture facility, but are not considered to be critical to production (i.e. production can continue without these elements during reduced periods of time). Therefore, these systems were included in the model.

Utilities required to operate the CO2 Capture System are linked to the Upgrader. Failures of Utilities will take the Upgrader offline, in which case there will be no CO2 to capture. For this reason, Utilities have not been modeled in the Base Case for the CO2 Capture System. Two sensitivity cases have been analyzed to assess the impact of including two critical Cooling Water Booster Pumps in the model. See Section 6 of this report for details of the sensitivity analysis.

2.3. Deliverables

Key findings, conclusions and recommendations following the completion of the study were also summarized in presentation format, which contained the following:

- Overall availability and production efficiency of CO_2 Capture System
- Criticality ranking of the equipment in the system, identifying the key contributors to lost production (downtime)

2.4. General Assumptions

The CO_2 capture facility separates CO_2 for sequestration in a geological formation to reduce the green house gas emission from the Scotford Upgrader. The CO_2 capture facility is designed to remove CO_2 from the process gas streams of the Hydrogen Manufacturing Units (HMUs) and to further dehydrate and compress the captured CO_2 to a supercritical state to allow for efficient pipeline transportation to a suitable long-term storage site. The CO_2 capture scope includes three HMUs, two identical existing HMU trains in the base Upgrader and one being designed as part of the Upgrader Expansion 1 project.

The CO_2 is removed from the HMU "syngas" by contacting the mixed gas stream of methane, carbon dioxide, carbon monoxide and hydrogen, with accelerated MDEA (ADIP-X). Three amine absorbers used to remove the CO_2 will be situated in the HMUs upstream of the pressure swing absorber (PSA) block. The CO_2 is separated from the amine in a common amine regeneration process that produces 99% pure CO_2 at a pressure slightly above atmospheric pressure. The purified CO_2 stream will then be compressed and dehydrated to a supercritical state by a multi-stage compressor and then transported via pipeline to off-site disposition. The purified CO_2 stream can then be used in Enhanced Oil Recovery (EOR) and sequestration.

The following assumptions have been made for the modeling of the CO_2 Capture System:

The table below shows the expected inlet Feed Gas flowrates:

Flow to Unit	Tag ID	Feed Gas Flow		Feed Gas CO_2 Content	
		Kmol/hr	tons/hr	Kmol/hr	tons/hr
Amine Absorber #1	C-1	7,189.7	316.3	1,187.0	52.2
Amine Absorber #2	C-2	7,189.7	316.3	1,187.0	52.2
Amine Absorber #3	C-3	10,321.0	454.1	1,745.3	76.8
Total		**24,700.4**	**1,086.7**	**4,119.3**	**181.2**

Table 2-1, Inlet Feed Gas Flowrates

Shell Canada Energy operates two existing Hydrogen Manufacturing Units (HMU1 & HMU2) and is in the process of designing and constructing a 3rd HMU (Expansion 1 HMU) at the AOSP Scotford Upgrader.

The CO_2 Capture System is designed to process 1,086.7 tonnes/hour of CO_2 rich hydrogen gas:

- C-1 and C-2 absorbers are each designed to treat 316.3 tonnes/hour of CO_2 rich hydrogen gas from HMU1 and HMU2

- C-3 absorber is designed to treat 454.1 tonnes/hour of CO_2 rich hydrogen gas from HMU3
- It is based on the Design that 80% of the Feed Gas CO_2 is removed – 145 tonnes/hr (1.2 MTPY)
- It is assumed that there is a 100% availability of the upstream gas feed and downstream units

Base Case premises include:

- System life: 25 years
- Start date: 2015
- Number of simulations: 500

2.5. Level of Study

Failure modes were defined on an equipment level (i.e. not on a component level). For each production critical equipment item, the model includes one or more failure modes depending on the utilized data source. The equipment was characterized through the frequency and duration of equipment outages. This equipment could be characterized by a number of failure modes.

2.6. Study Input Data

The study is based on the following data provided by the project team:

- Updated project PFDs for the proposed CO_2 Capture System issued on 30 September 2009, supplied by Shell Canada – Lean /SemiLean Case
- Updated PFDs issued in June 2010 - Lean Only Case
- Updated PFDs issued in March 2011
- The reliability data from previous studies

3. MODELING ASSUMPTIONS

3.1. Introduction

This section contains the assumptions used to create the simulation life-cycle models for this analysis. It consists of the following sections:

- Section 3.2: Overall System Assumptions
- Section 3.3: Equipment Modeling Assumptions

3.2. Overall System Assumptions

3.2.1. Overall System Configuration

The CO_2 Capture System model was divided into the following groups, representing the unit's processing sections. The following systems were modeled:

- CO_2 Absorption
    - Absorber #1 feed from HMU 1
    - Absorber #2 feed from HMU 2
    - Absorber #3 feed from HMU 3
- ADIP-X (Accelerated MDEA) Regeneration
    - Amine Stripper
- CO_2 Compression & Dehydration
    - 8-stage compression
    - TEG Dehydration
- Note: the Base Case is no longer predominately Air Cooled as was the case for the 2009 and 2010 studies.

Figure 3-1 and Figure 3-2 depict the configuration of the CO_2 Capture System that was modeled for the Base Case.

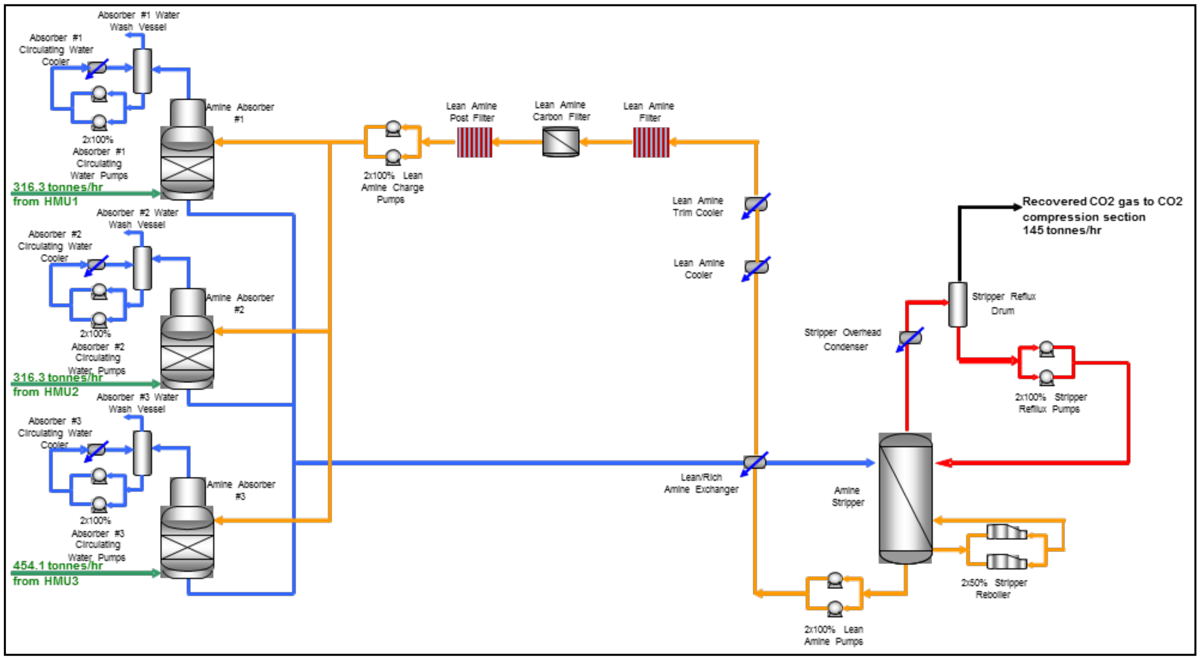


Figure 3-1, CO_2 Absorption Section Block Flow Diagram

The CO_2 Absorption Section is shown in Figure 3-1 and the CO_2 Compression and Dehydration Sections are shown in Figure 3-2.

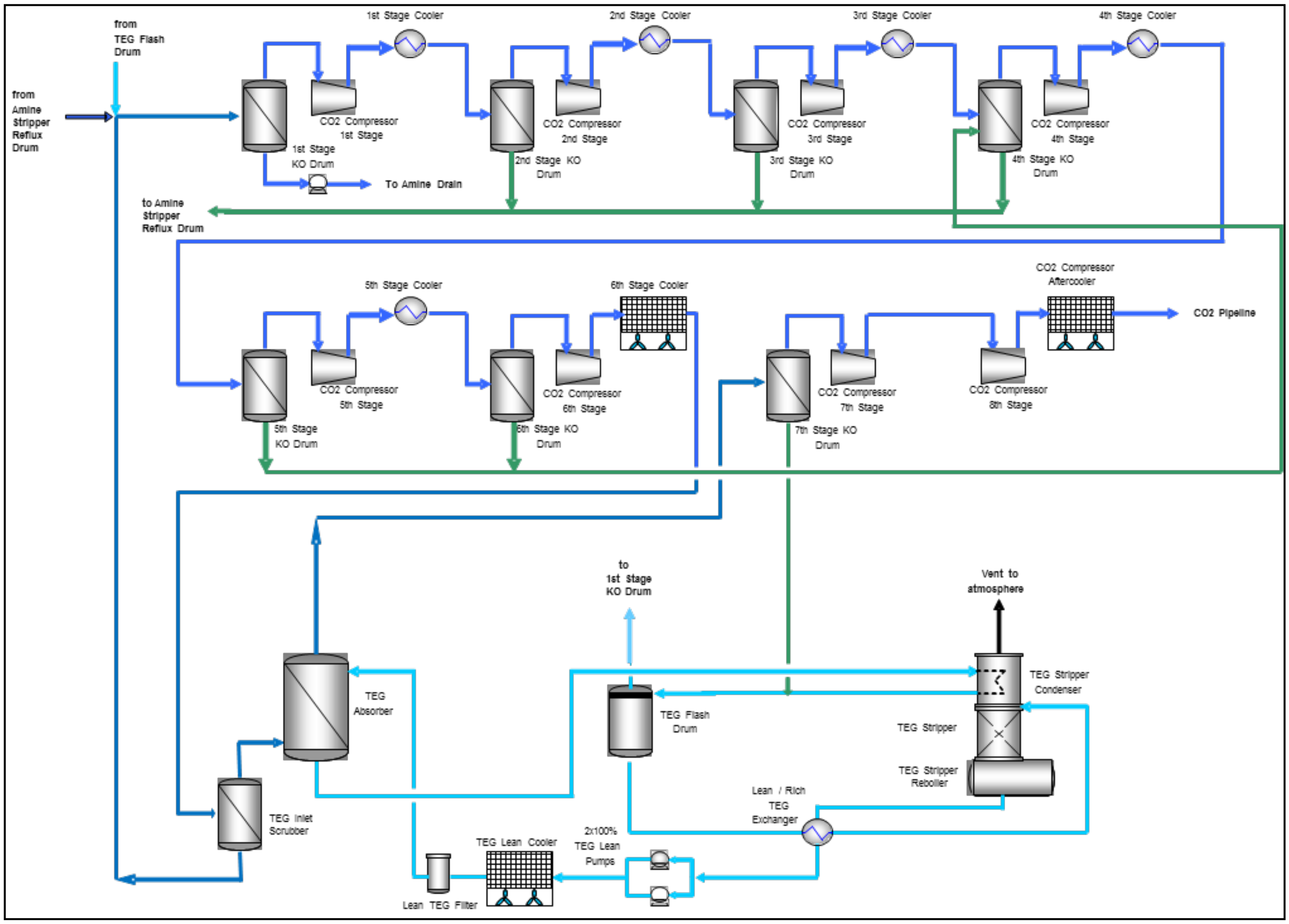


Figure 3-2, CO_2 Compression & Dehydration Sections Block Flow Diagram

3.3. Equipment Modeling Assumptions

3.3.1. Introduction

All equipment listed in this section is assumed to be critical to production unless otherwise indicated. For all equipment that has redundancy, it is assumed that there is only sufficient equipment online to allow 100% throughput. For example, if there are 3 x 50% pumps, it is assumed that there are two active and one passive (standby) spare pump.

3.3.2. Reliability Block Diagrams

To understand the impact that loss of a system or component will have on the performance of the unit, the process flow diagrams (PFDs) of the CO_2 Capture System sections were translated into a series of logic dependency models or reliability block diagrams (RBDs). RBDs graphically depict the interaction of equipment from a reliability perspective and do not necessarily indicate the actual physical connections or process flow. In addition to depicting interaction from a reliability perspective, RBDs are also used to illustrate the following:

- Equipment redundancy – duty/duty versus duty/standby for spared equipment
- Equipment configuration – series or parallel arrangement
- Equipment capacity – 2 x 50% versus 2 x 100%, etc.

Appendix A of this report contains detailed RBDs for the CO_2 Capture System. These RBDs should be reviewed in conjunction with the assumptions listed in the subsequent report sections.

In the following sections, each of the CO_2 Capture System sub-systems is discussed in detail, covering equipment configuration, sparing and criticality.

3.3.3. CO2 Absorption Section

Two separate syngas streams from HMU1 and HMU2 are fed to the bottom of Amine Absorber #1 (V-24118) and Amine Absorber #2 (V-24218), respectively, whilst Syngas streams from expansion HMU (HMU3) is fed to the bottom of Amine Absorber #3 (44118). A combined stream of semi-lean amine and loaded amine from the top section first treats these feed gas streams in the bottom section of their respective columns. Semi-lean amine is introduced on the distribution tray in the middle part of the column. This distribution tray also receives loaded amine from the collector tray in top section.

Lean amine solution enters the contactors at the top of the tower and absorbs the remaining CO_2 from the gas that has been treated in the bottom sections to achieve an overall 80% CO_2 removal from these columns.

Rich amine leaves the bottom of all three absorber columns under level control. Rich amine streams from the three amine absorbers are combined in a single line. The combined rich amine line is depressurized and fed to the low pressure still in the regeneration section.

The treated gas streams from the amine absorbers are cooled in their respective gas coolers Absorber #1/2/3 Circulating Water Cooler (E-24129/24229/44129) to 35 °C to meet treated gas temperature requirement. This temperature is the same as the feed gas temperature. Therefore, the CO_2 capture facility will not be increasing the temperature of PSA inlet gas streams coming from the HMUs. To prevent amine carryover with the treated gas, Absorber #1/2/3 Water Wash Vessel (V-24119/24219/44119) will be installed downstream of the gas coolers for the three treated gas streams.

The table below shows the equipment to be included in the CO_2 Absorption Section:

Equipment	Tag ID	Configuration	Comment
Amine Absorber #1	V-24118	1x100%	Processes 29% of total Hydrogen flow to system
Absorber #1 Circulating Water Cooler	E-24129	1x100%	S&T Heat Exchanger
Absorber #1 Water Wash Vessel	V-24119	1x100%	Low Pressure Vessel
Absorber #1 Circulating Water Pumps	P-24108 A/B	2x100%	Centrifugal, motor driven pumps
Amine Absorber #2	V-24218	1x100%	Processes 29% of total Hydrogen flow to system
Absorber #2 Circulating Water Cooler	E-24229	1x100%	S&T Heat Exchanger
Absorber #2 Water Wash Vessel	V-24219	1x100%	Low Pressure Vessel
Absorber #2 Circulating Water Pumps	P-24208 A/B	2x100%	Centrifugal, motor driven pumps
Amine Absorber #3	V-44118	1x100%	Processes 42% of total Hydrogen flow to system
Absorber #3 Circulating Water Cooler	E-44129	1x100%	S&T Heat Exchanger
Absorber #3 Water Wash Vessel	V-44119	1x100%	Low Pressure Vessel
Absorber #3 Circulating Water Pumps	P-44108 A/B	2x100%	Centrifugal, motor driven pumps
Wash Water Make-up Cooler	E-44014	1x100%	Not Critical, S&T Heat Exchanger

Table 3-1, CO_2 Absorption Section Equipment

3.3.4. ADIP-X (Accelerated MDEA) Regeneration Section

3.3.4.1. Amine Flash Regeneration Section

The Amine Flash Regeneration Section has been removed from the Scotford design since the previous study completed in 2010.

3.3.4.2. Amine Stripper Section

CO2 is removed from the rich amine from the absorbers through steam stripping in the regeneration section. The rich amine stream from the absorbers is fed to the Amine Stripper (V-24601) on flow control. This stream first passes through the Lean/Rich Amine Exchangers (E-24602 A/B) where it is heated by hot lean amine. Then it is enhanced with Amine from the Make-Up Tanks (TK-24601/24603) and Pump (P-24605). The heated rich amine from the heat exchanger then goes through a flow control valve before entering the Amine Stripper at the top of the column.

In the Amine Stripper the acid gas (CO_2) in the amine is removed by stripping steam. Acid gases are removed from the amine solution by a combination of high temperature, low pressure, and stripping steam (to reduce the acid gas partial pressure). Steam generated by re-boiling the solvent provides:

i. Heat for raising the temperature of the feed (rich amine)
ii. Heat of de-sorption of the acid gas
iii. Heat to generate stripping steam (to reduce the acid gas partial pressure)

The heat for generating stripping steam in the Stripper Reboilers (E-24603 A/B) is provided by low pressure steam. The gas stripped from the amine solution leaves the top of the stripper column and flows to Stripper Overhead Condenser (E-24601 A/B), where the gas is cooled. Any condensed liquids are then separated from the CO2-rich gas stream in the Stripper Reflux Drum (V-24602). The liquids are returned to the stripper column and the gas is routed to the CO2 Compression Section. The regenerated lean amine leaves the bottom of the stripper column and is pumped by the Lean Amine Pumps (P-24601 A/B) to the Lean/Rich Amine Exchanger (E-24602 A/B) to cool the regenerated lean amine, before entering the Cooling and Filtering Section.

The table below shows the equipment to be included in the Amine Stripper Section:

Equipment	Tag ID	Configuration	Comment
Lean/Rich Amine Exchangers	E-24602 A/B	2x50%	Plate & Frame Heat Exchanger
Amine Stripper	V-24601	1x100%	
Stripper Reboilers	E-24603 A/B	2x50%	S&T Exchanger (Kettle BKT Type)
Stripper Reboiler Condensate Pots	V-24603 A/B	2x50%	
Lean Amine Pumps	P-24601 A/B	3x50%	Centrifugal, motor driven pumps
Stripper Overhead Condenser	E-24601 A/B	2x50%	S&T Heat Exchanger
Stripper Reflux Drum	V-24602	1x100%	
Stripper Reflux Pumps	P-24603 A/B	2x100%	
Amine Make-Up Tank	TK-24601 / 24603	2x50%	Not Critical
Amine Make-Up Pump	P-24605	1x100%	Not Critical
Amine Inventory Pump	P-24604	1x100%	Not Critical
Amine Drain Drum	V-24606	1x100%	Not Critical
Amine Drain Drum Sump	S-24601	1x100%	Not Critical
Amine Drain Pump	P-24607	1x100%	Not Critical
Drained Amine Filter	V-24605	1x100%	Not Critical
Stripper Inlet Valves		2x50%	

Table 3-2, Amine Stripper Section Equipment

3.3.4.3. Cooling and Filtering Section

The cooled, regenerated lean amine from the Lean/Rich Amine Exchanger (E-24602 A/B) is further cooled in the Lean Amine Cooler (E-24604 A/B) and Lean Amine Trim Cooler (E-24605 A/B) to 35 °C. The temperature of the lean amine supplied to the Amine Absorbers must be at the correct temperature; otherwise the absorption of CO_2 may be negatively affected.

The cooled lean amine is treated in the filtration section before it is returned to the Amine Absorbers. The filtration section consists of one main particulate filter, Lean Amine Filter (V-24604) followed by a slipstream Lean Amine Carbon Filter (V-24608) and its after particulate filter, Lean Amine Post Filter (V-24609).

The filtered lean amine is finally pumped back to the Amine Absorbers by Lean Amine Charge Pumps (P-24602 A/B/C). Before entering the Amine Absorbers, the filtered lean amine is treated with Anti-Foam, from the Anti-Foam Injection Tank (TK-24602) and the Anti-Foam Injection Pumps (P-24606).

The table below shows the equipment included in the Cooling and Filtering Section:

Equipment	Tag ID	Configuration	Comment
Lean Amine Cooler	E-24604 A/B	2x50%	S&T Heat Exchanger
Lean Amine Trim Cooler	E-24605 A/B	2x50%	Plate & Frame Heat Exchanger
Lean Amine Filter	V-24604	1x100%	Not Critical, can be bypassed
Lean Amine Carbon Filter	V-24608	1x100%	Not Critical, can be bypassed
Lean Amine Post Filter	V-24609	1x100%	Not Critical, can be bypassed
Lean Amine Charge Pumps	P-24602 A/B/C	3x50%	Centrifugal, motor driven pumps
Anti-Foam Injection Tank	TK-24602	1x100%	Not Critical
Anti-Foam Injection Pumps	P-24606	1x100%	Not Critical

Table 3-3, Cooling and Filtering Section Equipment

3.3.5. CO_2 Compression Section

The purpose of the CO_2 compression unit is to compress the purified CO_2 stream from ~ 150 KPa to ~ 14,500 KPa.

The 99.0% pure wet CO_2 from the top of the Stripper Reflux Drum (V-24602) is routed to the suction of the CO_2 compression unit, Compressor Suction KO Drum (V-24701). Compression is accomplished by utilizing the 8-stage centrifugal CO_2 Compressor (C-24701 A-H) driven by an electric motor. The compressor configuration utilizes interstage KO Drums (V-24702/3/4/5/6/7/8), interstage coolers (E-24701/2/3/4/5/6), and final CO2 Compressor Aftercooler (E-24707 A/B). Normal operation results in a small amount of water being continuously condensed out in the interstage coolers that is collected in the interstage KO drums and then routed back to a KO drum of a lower compression stage. For purposes of the modeling study, each compression stage was modeled with its own failure modes.

In the event of a failure/shutdown of the compression/dehydration system, the CO_2 from the Stripper Reflux Drum (V-24602) can be diverted to the Vent Stack (S-24603). However, there is no information on restrictions to venting. If the venting is unlimited, the compression/dehydration system becomes a non-critical system with regards to the CO_2 Capture System, as it does not have a direct impact, due to the bypass venting system.

The table below shows the equipment included in the CO_2 Compression Section:

Equipment	Tag ID	Configuration	Comment
Compressor Suction KO Drum	V-24701	1x100%	Low Pressure Vessel
CO_2 Compressor	C-24701	1x100%	8-Stage Centrifugal, electric motor drive
Compressor 1st Stage Cooler	E-24701	1x100%	S&T Heat Exchanger
Compressor 2nd Stage KO Drum	V-24702	1x100%	Low Pressure Vessel
Compressor 2nd Stage Cooler	E-24702	1x100%	S&T Heat Exchanger
Compressor 3rd Stage KO Drum	V-24703	1x100%	Low Pressure Vessel
Compressor 3rd Stage Cooler	E-24703	1x100%	S&T Heat Exchanger
Compressor 4th Stage KO Drum	V-24704	1x100%	Low Pressure Vessel
Compressor 4th Stage Cooler	E-24704	1x100%	S&T Heat Exchanger
Compressor 5th Stage KO Drum	V-24705	1x100%	Low Pressure Vessel
Compressor 5th Stage Cooler	E-24705	1x100%	S&T Heat Exchanger
Compressor 6th Stage KO Drum	V-24706	1x100%	Low Pressure Vessel

Equipment	Tag ID	Configuration	Comment
Compressor 6th Stage Cooler	E-24706	1x100%	Air Cooler – 1 bay, 2x50% fans/motors, 67% bypass
Compressor 7th Stage KO Drum	V-24708	1x100%	Low Pressure Vessel
CO2 Compressor Aftercooler	E-24707 A/B	2x50%	Air Cooler – 2 bay, 2x50% fans/motors per bay, 67% bypass

Table 3-4, CO_2 Compression Section Equipment

3.3.6. CO_2 Dehydration Section

The product CO_2 stream leaving the Shell facility is required to have a water content of less than 450 mg/Sm^3. This is to ensure that a separate liquid water phase does not form anywhere in the pipeline system as it can lead to hydrates formation or accelerated corrosion. The CO_2 dehydration facility is a standard TEG unit that processes gas from the 6th Stage Cooler (E-24706). The CO_2 Dehydration Section removes water from the CO_2 stream to a specified value.

The first step in the dehydration process is to knock out any residual liquid in the wet gas stream in the TEG Inlet Scrubber (V-24707). The wet gas stream is then exchanged with a lean TEG stream in the TEG Absorber (V-24801) where the lean TEG absorbs water from the gas and the dried gas with a water content of less than 450 mg/Sm^3 is then routed to the suction of the 7th stage of compression.

The rich TEG is routed through the TEG Stripper Condenser (E-24801) located in the top section of the regeneration stripping column. The preheated rich TEG is then routed to the TEG Flash Drum (V-24803), where significant quantities of CO_2 vapors are removed and recycled back to the CO_2 compressor 1st stage suction to reduce the amount of CO_2 vapors emitted to the atmosphere. The flashed rich TEG is then routed to the Lean/Rich TEG Exchanger (E-24803), where it is preheated prior to introduction into the TEG Stripper (V-24802). The rich TEG is contacted with stripping vapors in the TEG Stripper and the absorbed water is removed during this contact process. The TEG Stripper Reboiler (E-24802) uses de-superheated high pressure steam as its heat medium. The vapors from the TEG Stripper Column that is predominately water and CO_2 are vented to atmosphere. The hot lean TEG from the bottom of the TEG Stripper is then routed through the Lean/Rich TEG Exchanger and cooled. The cooled lean TEG is then routed to the Lean TEG Pumps (P-24801 A/B) where the pressure is increased, passed through a series of filters (V-24804A/B/24807/24808) and then cooled further in the Lean TEG Cooler (E-24804 A-E). The cooled TEG is then recycled back to the TEG Absorber.

The dried CO_2 stream from the TEG Absorber (V-24801) is routed back to the suction of the 7th stage of compression, the Compressor 7th Stage KO Drum (V-24708). The Dry CO_2 is compressed in the last two compression stages, before being cooled in the CO_2 Compressor Aftercooler (E-24707 A/B). The cooled, dry, CO_2 is then exported to the pipeline. The bottoms from the 2nd/3rd/4th stage KO drums are combined and routed to the Amine Stripper Reflux Drum (V-24602). The bottoms from the 5th/6th stage KO drums is combined with the TEG Inlet Scrubber liquids and and routed to the 4th Stage KO Drum (V-24704). The bottoms from the 7th Stage KO Drum is routed to the TEG Flash Drum (V-24803).

The table below shows the equipment included in the CO_2 Dehydration Section:

Equipment	**Tag ID**	**Configuration**	**Comment**
TEG Inlet Scrubber	V-24707	1x100%	
TEG Absorber	V-24801	1x100%	
TEG Flash Drum	V-24803	1x100%	Low Pressure Vessel
Lean/Rich TEG Exchanger	E-24803	1x100%	Plate & Frame Heat Exchanger
TEG Stripper Condenser	E-24801	1x100%	S&T Heat Exchanger
TEG Stripper	V-24802	1x100%	
TEG Stripper Reboiler	E-24802	1x100%	Coil
TEG Surge Drum	V-24806	1x100%	
TEG Stripper Reboiler Condensate Pot	V-24805	1x100%	
TEG Lean Pumps	P-24801 A/B	2x100%	Positive Displacement, motor driven pumps
Lean TEG Filter	V-24804 A/B	2x50%	
Lean TEG Carbon Filter	V-24807	1x100%	Not Critical, can be bypassed
Lean TEG Post Filter	V-24808	1x100%	Not Critical, can be bypassed
TEG Lean Cooler	E-24804 A	1x100%	
TEG Lean Cooler	E-24804 B	1x100%	
TEG Lean Cooler	E-24804 C	1x100%	
TEG Lean Cooler	E-24804 D	1x100%	
TEG Lean Cooler	E-24804 E	1x100%	
TEG Make-Up Tank	TK-24801	1x100%	Not Critical
TEG Make-Up Pump	P-24802	1x100%	Not Critical

Storm Water Pump	P-24612	1×100%	Not Critical
Flue Gas Recirculation Fan	C-24103	1×100%	Fan
Flue Gas Recirculation Fan	C-24203	1×100%	Fan
Flue Gas Recirculation Fan	C-44105	1×100%	Fan

Table 3-5, CO_2 Dehydration Section Equipment

4. UNIT RELIABILITY DATA

The reliability model for the CO_2 Capture System was developed using previous failure data from similar projects.

Below is a brief explanation of the terms used in the failure data tables:

MTTF: Mean Time to Failure (years)

The average time between consecutive failures calculated by dividing the cumulative observed time by the total number of failures. This term only applies to components with exponential failure distributions.

MTTR: Mean Time to Repair (hours)

It is a measure of the average time taken to diagnose and restore failed equipment to an operational state. If the failure data is reported on the equipment level, this value includes any logistic delays. If only the minimum MTTR was given, then a constant repair time was used. If Minimum and Maximum values were present, then a rectangular distribution was used and the repair duration varied between the two values. If three values are given (Minimum, maximum and Most Likely) then a triangular distribution was used, and the repair time varied between the minimum and maximum values with an increased probability of being close to the Most Likely repair time.

Impact on Unit Rate

It indicates if the failure causes a total shutdown of the system (100%) or a slowdown. If a slowdown is indicated then the rate reduction is shown as percentages (1% to 99%) of the design flow rate through the unit.

When reviewing the reliability data in the next section the following should be noted:

- The failure rates are for critical failures only, i.e. those requiring the equipment to be taken offline immediately to allow repair, prior to resuming normal production. In addition to these critical failures, equipment can also incur incipient failures, which do not require immediate repair of the equipment (for example small leakages). For modeling purposes, it is assumed that these incipient failures can be accommodated until the next plant turnaround at which time they are repaired. These failures have therefore not been included in the simulation models.
- The failure modes used reflect the average number of times a piece of equipment causes total or partial production loss. In order to achieve these 'expected' equipment failure rates, it is assumed that industry standard inspection and maintenance activities are carried out during plant turnarounds.

- Process equipment blocks modeled include equipment plus typical instrumentation (level alarms, pressure control, high temperature, etc.). In other words, the failure data represents an overall reliability figure for each piece of equipment, at the equipment level, rather than individual component level.

4.1. Data Sources

Failure data for equipment utilized in the Shell Canada, CO_2 Capture System have been collected from the following sources:

- Reliability database from Shell Canada projects
- Reliability database from previous Shell projects

The following sections summarize the failure data for the process specific equipment in the CO_2 Capture System. For simulation purposes, the expected MTTF is used. The MTTR is the total repair time associated with the failed equipment.

4.2. Reliability Data Table

The table below shows the failure data that were used for the equipment in the CO_2 Capture System Base Case model.

CO_2 Capture Unit Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
Amine Absorber #1	V-24118	Column Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Absorber #1 Water Wash Vessel	V-24119	Vessel Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Absorber #1 Circulating Water Pump	P-24108A	Pump Failure	4.6	81.0		100	17.6	Generic PAR Pump Data
Absorber #1 Circulating Water Pump	P-24108A	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Absorber #1 Circulating Water Pump	P-24108B	Pump Failure	4.6	81.0		100	17.6	Generic PAR Pump Data
Absorber #1 Circulating Water Pump	P-24108B	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Absorber #1 Circulating Water Cooler	E-24129	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Amine Absorber #2	V-24218	Column Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Absorber #2 Water Wash Vessel	V-24219	Vessel Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel

CO_2 Capture Unit Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
								types
Absorber #2 Circulating Water Pump	P-24208A	Pump Failure	4.6	81.0		100	17.6	Generic PAR Pump Data
Absorber #2 Circulating Water Pump	P-24208A	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Absorber #2 Circulating Water Pump	P-24208B	Pump Failure	4.6	81.0		100	17.6	Generic PAR Pump Data
Absorber #2 Circulating Water Pump	P-24208B	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Absorber #2 Circulating Water Cooler	E-24229	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Amine Absorber #3	V-44118	Column Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Absorber #3 Water Wash Vessel	V-44119	Vessel Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Absorber #3 Circulating Water Pump	P-44108A	Pump Failure	4.6	81.0		100	17.6	Generic PAR Pump Data
Absorber #3 Circulating Water Pump	P-44108A	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Absorber #3 Circulating Water Pump	P-44108B	Pump Failure	4.6	81.0		100	17.6	Generic PAR Pump Data

CO_2 Capture Unit Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
Absorber #3 Circulating Water Pump	P-44108B	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Absorber #3 Circulating Water Cooler	E-44129	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Lean/Rich Amine Exchangers	E-24602A	Exchanger Failure	5.0	96.0		100	19.2	Shell (Scotford SRU Study)
Lean/Rich Amine Exchangers	E-24602B	Exchanger Failure	5.0	96.0		100	19.2	Shell (Scotford SRU Study)
Amine Stripper	V-24601	Column Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Stripper Reboiler	E-24603A	Exchanger Failure	100.0	144.0		100	1.4	PAR Category A S&T Data
Stripper Reboiler Condensate Pot	V-24603A	Vessel Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Stripper Reboiler	E-24603B	Exchanger Failure	100.0	144.0		100	1.4	PAR Category A S&T Data
Stripper Reboiler Condensate Pot	V-24603B	Vessel Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Lean Amine Pump	P-24601A	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Lean Amine Pump	P-24601A	Electric Motor	18.0	72.0	168.0	100	6.7	Previous Studies

CO_2 Capture Unit Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
		Failure						
Lean Amine Pump	P-24601B	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Lean Amine Pump	P-24601B	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Lean Amine Pump	P-24601C	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Lean Amine Pump	P-24601C	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Stripper Overhead Condenser	E-24601A	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Stripper Overhead Condenser	E-24601B	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Stripper Reflux Drum	V-24602	Vessel Failure	98.0	143.0		100	1.5	SHELL Montreal - Failure data is average of all vessel types
Stripper Reflux Pump	P-24603A	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Stripper Reflux Pump	P-24603A	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Stripper Reflux Pump	P-24603B	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Stripper Reflux Pump	P-24603B	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Lean Amine Cooler	E-24604A	Exchanger Failure	35.0	144.0		100	4.1	PAR HCU2 FED2 Category B S&T Data

CO_2 Capture Unit Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
Lean Amine Cooler	E-24604B	Exchanger Failure	35.0	144.0		100	4.1	PAR HCU2 FED2 Category B S&T Data
Lean Amine Trim Cooler	E-24605A	Exchanger Failure	5.0	96.0		100	19.2	Shell (Scotford SRU Study)
Lean Amine Trim Cooler	E-24605B	Exchanger Failure	5.0	96.0		100	19.2	Shell (Scotford SRU Study)
Lean Amine Charge Pump	P-24602A	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Lean Amine Charge Pump	P-24602A	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Lean Amine Charge Pump	P-24602B	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Lean Amine Charge Pump	P-24602B	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Lean Amine Charge Pump	P-24602C	Pump Failure	4.6	32.0		100	7.0	Generic PAR Pump Data
Lean Amine Charge Pump	P-24602C	Electric Motor Failure	18.0	72.0	168.0	100	6.7	Previous Studies
Stripper Inlet Valve 1		Valve Failure	9.0	168.0		100	18.7	OREDA
Stripper Inlet Valve 2		Valve Failure	9.0	168.0		100	18.7	OREDA

Table 4-1, Failure Data for the CO_2 Absorption Sections

Note that in the 2010 analysis, Shell Port Arthur S&T data was used in lieu of Plate & Frame Heat Exchanger data. The current analysis utilizes the same Plate & Frame Heat Exchanger used in the Scotford SRU Study.

CO_2 Compression & Dehydration System Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
6th Stage Cooler Fan/Motor	E-24706-1	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
6th Stage Cooler Fan/Motor	E-24706-2	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
6th Stage Cooler Fan/Motor	E-24706-3	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
CO2 8-Stage Compressor Driver	C-24701	Compressor Motor Failure	10	78		1	3.9	PAR HCU2 FED2 Category A Centrifugal Compressor Data
Compression 1st Stage Cooler	E-24701	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Compression 2nd Stage Cooler	E-24702	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Compression 3rd Stage Cooler	E-24703	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Compression 4th Stage Cooler	E-24704	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Compression 5th Stage Cooler	E-24705	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5

CO_2 Compression & Dehydration System Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
Compression Aftercooler Fan/Motor	E-24707A-1	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
Compression Aftercooler Fan/Motor	E-24707A-2	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
Compression Aftercooler Fan/Motor	E-24707A-3	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
Compression Aftercooler Fan/Motor	E-24707B-1	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
Compression Aftercooler Fan/Motor	E-24707B-2	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
Compression Aftercooler Fan/Motor	E-24707B-3	Fan/Motor/Belt Failure	3	48	72	1	20.0	Scotford Upgrader
Compressor		Seals	2.5	120	168	1	57.6	
Compressor		Bearing	10	408		1	20.4	
Compressor		Gearbox	20	504		1	12.6	
Compressor 2nd Stage KO Drum	V-24702	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types

CO_2 Compression & Dehydration System Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
Compressor 3rd Stage KO Drum	V-24703	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
Compressor 4th Stage KO Drum	V-24704	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
Compressor 5th Stage KO Drum	V-24705	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
Compressor 6th Stage KO Drum	V-24706	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
Compressor 7th Stage KO Drum	V-24707	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
Compressor 8th Stage KO Drum	V-24708	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
Compressor Suction KO Drum	V-24701	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types

CO_2 Compression & Dehydration System Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
Lean TEG Cooler	E-24804A	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Lean TEG Cooler	E-24804B	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Lean TEG Cooler	E-24804C	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Lean TEG Cooler	E-24804D	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Lean TEG Cooler	E-24804E	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
Lean TEG Filter	V-24804A	Critical	100	24		1	0.1	Previous Studies
Lean TEG Filter	V-24804B	Critical	100	24		1	0.1	Previous Studies
Lean/Rich TEG Exchanger	E-24803	Exchanger Failure	5	96		1	9.6	Shell (Scotford SRU Study)
TEG Absorber	V-24801	Column Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
TEG Flash Drum	V-24803	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types

CO_2 Compression & Dehydration System Equipment	Tag ID	Failure Mode	MTTF (Years)	MTTR (hrs)		Impact on Equipment	Annual equivalent downtime	Source
			Years	Min	Max	%	hours	
TEG Inlet Scrubber	V-24707	Column Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
TEG Lean Pump	P-24801A	Pump Failure	4.6	32		1	3.5	Generic PAR Pump Data
TEG Lean Pump	P-24801A	Electric Motor Failure	18	72	168	1	6.7	Previous Studies
TEG Lean Pump	P-24801B	Pump Failure	4.6	32		1	3.5	Generic PAR Pump Data
TEG Lean Pump	P-24801B	Electric Motor Failure	18	72	168	1	6.7	Previous Studies
TEG Stripper	V-24802	Column Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
TEG Stripper Condenser	E-24801	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
TEG Stripper Reboiler	E-24802	Exchanger Failure	9.3	96		1	5.2	OREDA 3.1.5
TEG Stripper Reboiler Condensate Pot	V-24805	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types
TEG Surge Drum	V-24806	Vessel Failure	98	143		1	0.7	SHELL Montreal - Failure data is average of all vessel types

Table 4-2, Failure Data for the CO_2 Compression & Dehydration Sections

4.3. Maintenance & Operations

The following are the assumptions used for modeling maintenance activities/constraints for the CO_2 Capture System:

4.3.1. Work Prioritization

Maintenance/repair activities are only carried out for items that have failed critically and will result in either unit shutdown or production slow down. It was assumed that all incipient type failures (failures which do not impact on production rates) will be addressed on an opportunity basis (i.e. they will be addressed if the unit is down for other reasons).

4.3.2. Mobilization and Delay Times

The CO_2 Capture System is a continuous processing unit operated 24 hours per day. Critical failures, i.e. those failures that result in loss of capacity at failure were assumed to require immediate mobilization of a repair crew. A delay time of 4 hours will be incurred when mobilizing maintenance personnel (from failure to start of repair).

It was assumed that the failure data in the previous section will not incorporate any mobilization time required for repairs.

4.3.3. Restart Times

The failure data for the individual unspared equipment reported in the previous section include any restart times of the equipment/unit.

4.3.4. Spare Parts

The model assumes that spares are available to enable immediate repair of all equipment.

4.3.5. Scheduled Unit Shutdowns

It was assumed that scheduled maintenance will take place in line with the HMU scheduled maintenance shutdowns. The Base Case did not include scheduled maintenance shutdowns.

5. BASE CASE RESULTS

The Base Case efficiency results are contained in Table 5-1. The average efficiency of CO_2 exported to pipeline is 95.4%. This is a decrease from the 2011 study results (97.1%). The average supply efficiency loss of 4.6% is equivalent to 17 days downtime per annum. The CO_2 supply to the export pipeline is at maximum capacity for 93.6% of the time, equivalent to 341.6 days per annum.

CO2 Capture System Parameters	
Average CO2 Production Efficiency	95.4%
	348.2 days
Average Production Losses	4.6%
	16.8 days
Period during which maximum capacity is available	93.6%
	341.6 days
Average CO2 Export	138.4 tons/hour

Table 5-1, CO2 Capture System Efficiency Results

The overall CO_2 Capture System section is predicted to be in a state of complete shutdown for 3.4% of the time. Production losses due to operating at reduced capacity accounts for 1.2% of losses. The Vent Stack is used for the equivalent of 12 days, due to the slowdown and shutdown of the Compression & Dehydration sections. Results are summarized in *Table 5-2*.

CO2 Capture System Loss Breakdown	
Complete Compression & Dehydration Shutdown	3.4%
	12.4 days
Average Complete Compression & Dehydration Shutdowns per annum	2.2
Average Compression & Dehydration Shutdown Duration	135.0 hours
Unit Slowdown (equivalent)	1.1%
	4.2 days
Average Utilization of Vent stack Bypass (equivalent)	3.32%
	12.1 days

Table 5-2, CO_2 Capture System Loss Breakdown

The 2.9% efficiency losses are broken down by the three main subsystems in Table 5-3. The majority of the losses are due to the compression section (1.7%).

Loss Breakdown by Section Contribution	% loss	tonnes/hr
Losses Due to Capture Section	1.1%	1.6
Losses Due to Dehydration Section	3.5%	5.1
Total	**4.6%**	**6.7**

Table 5-3, Loss Breakdown by Section Contribution

The contributions of individual equipment items to the losses in each subsystem (Capture Section, Compression Section, and Dehydration Section) are displayed in Figure 5-1, Figure 5-2, and Figure 5-3, respectively.

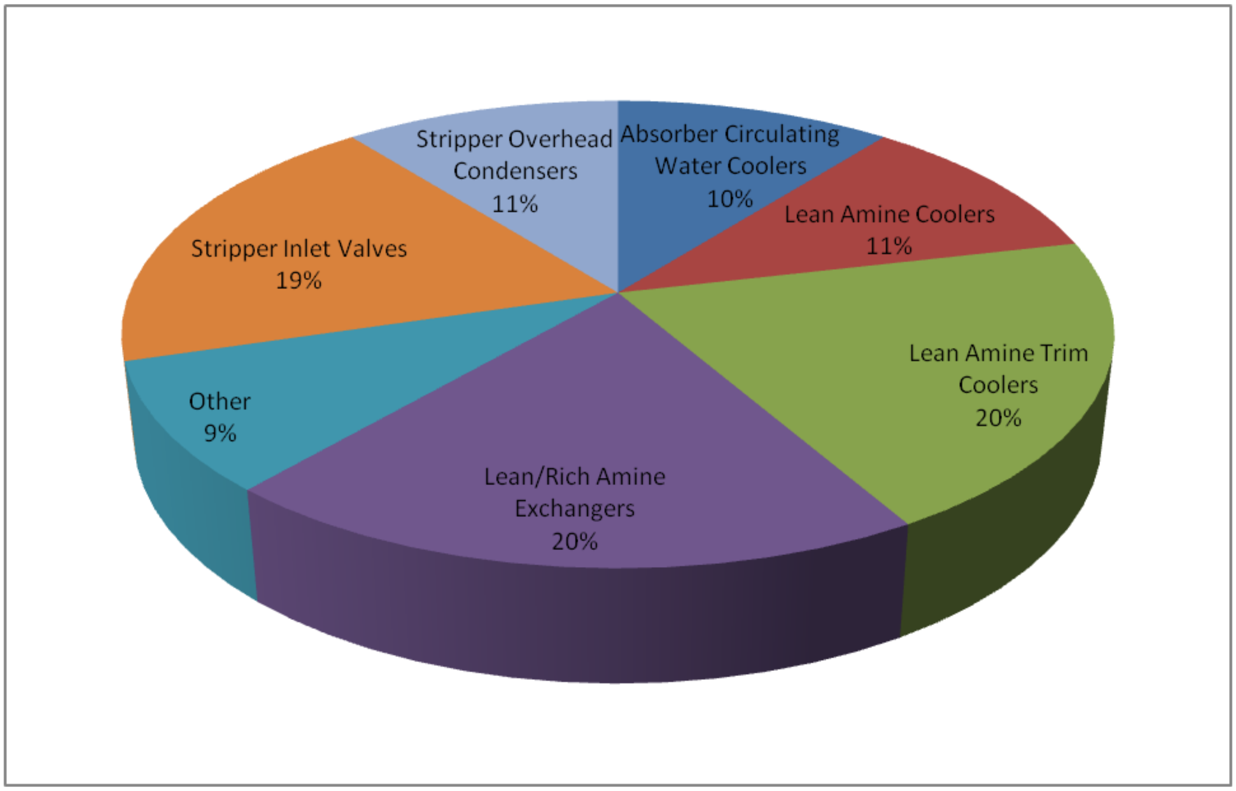


Figure 5-1, Base Case Capture Section Losses Breakdown

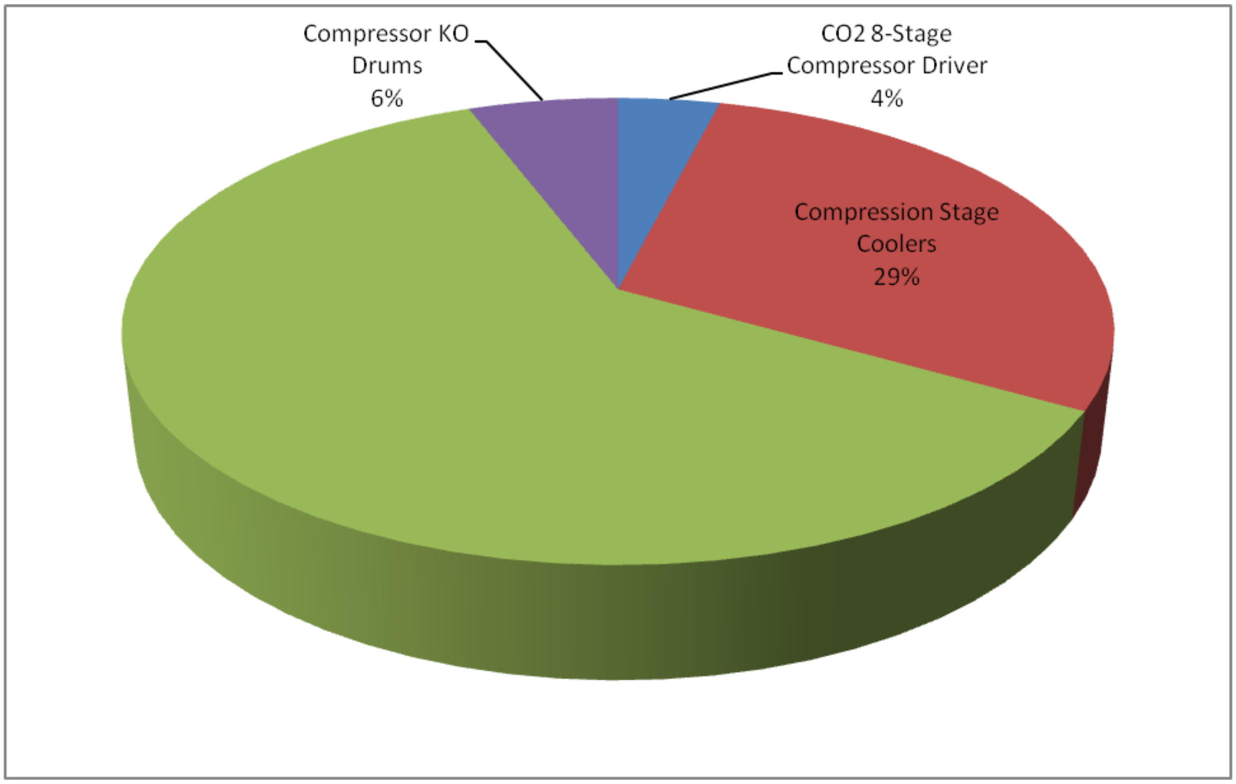


Figure 5-2, Base Case Compression Section Losses Breakdown

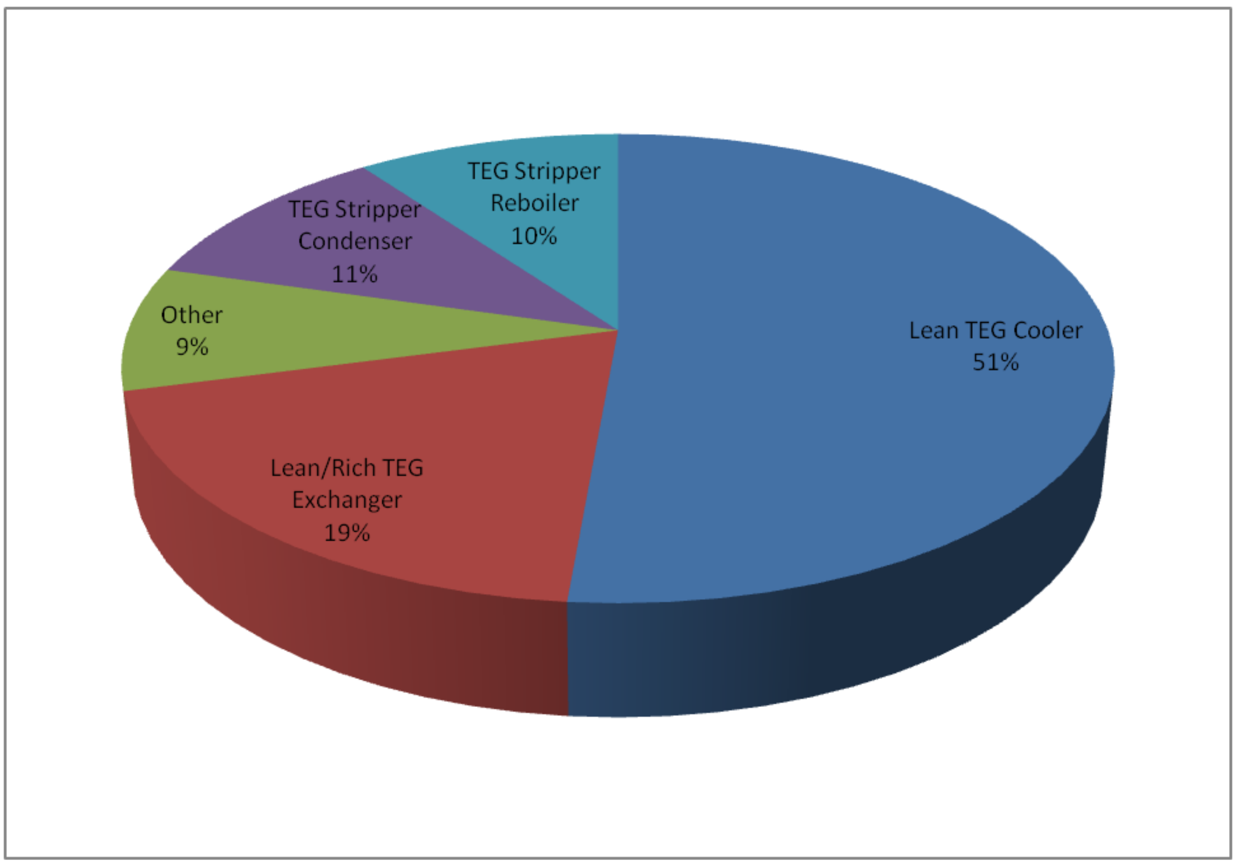


Figure 5-3, Base Case Dehydration Section Losses Breakdown

The availability loss attributed to each category is tabulated in Table 5-4. The previous 2010 study showed the majority of availability losses were caused by the fan and motor components in the compression section. These losses have been reduced by switching many air coolers to shell and tube exchangers. The current analysis shows the majority of losses (3.9%) are caused by the CO2 compressor and exchangers and coolers.

Category	Availability Loss (%)
S&T Exchanger	1.8
Compressor	1.4
Plate & Frame	0.7
Valve	0.2
Vessel – KO Drum	0.1
Compressor Drive	0.1
Fan/Motor – Compression Unit	0.1
Others	0.1

Table 5-4, Base Case Loss Breakdown By Equipment Type

As the reliability predictions were made with a stochastic, event-driven simulator, a distribution of expected production efficiencies was obtained. The histogram and cumulative distribution functions are plotted in Figure 5-4. The P50 value of production efficiency over a 25 year time period is 95.5%, and the P10 and P90 values are 94.8% and 96.1%, respectively.

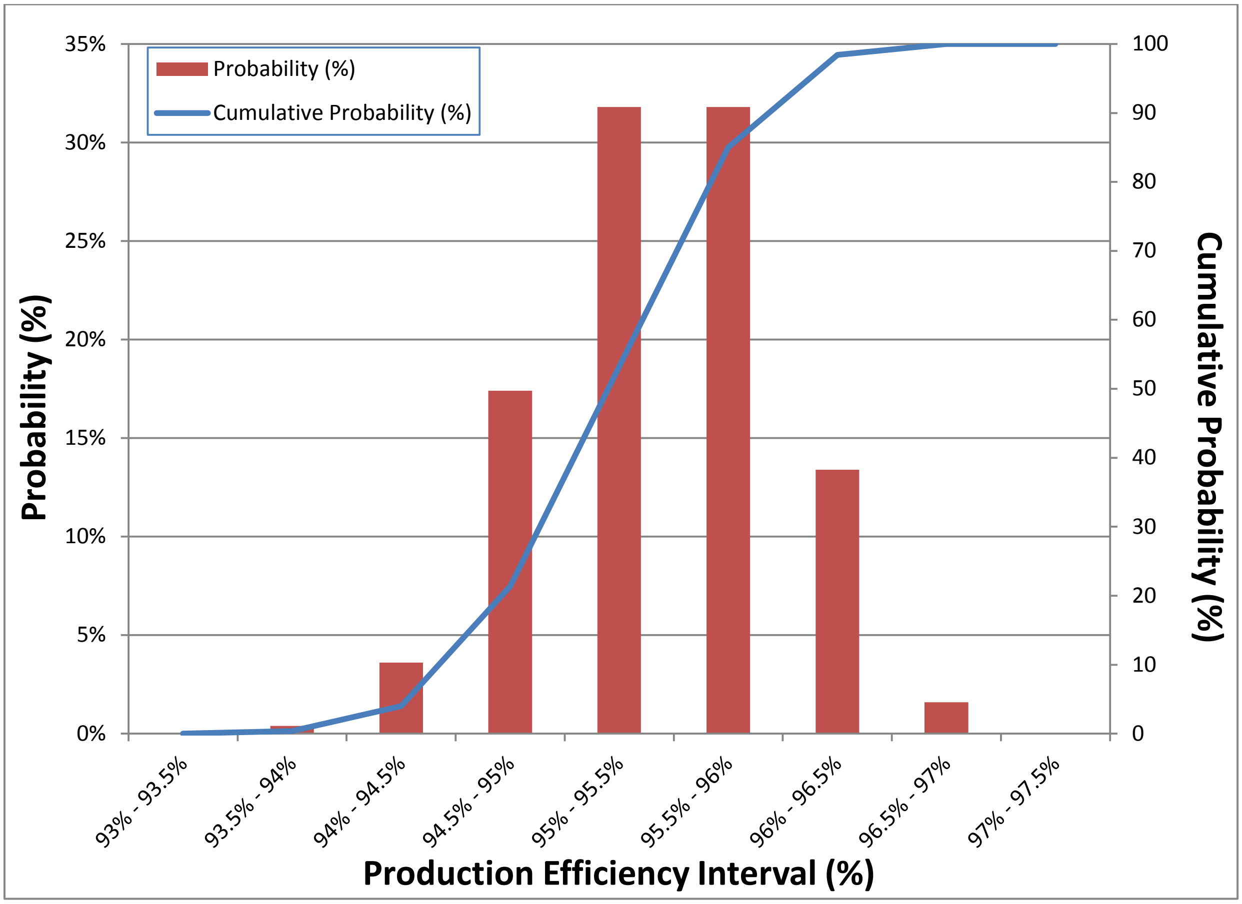


Figure 5-4, Base Case Distribution of Production Efficiency

6. SENSITIVITY CASE

An additional case was run to determine the impact of the repair time of the stripper inlet valves. The base case used a repair time of 168 hours. The long repair time is due to not having an onsite spare. The sensitivity case utilizes a 36 hour repair for the stripper inlet valves. The results are summarized in Table 6-1.

CO2 Capture System Parameters	Base Case	Sensitivity Case	Delta
Average CO2 Production Efficiency	95.4%	95.6%	0.2%
	348.2 days	348.9 days	0.7 days
Average Production Losses	4.6%	4.4%	0.2%
	16.8 days	16.1 days	0.7 days
Period during which maximum capacity is available	93.6%	93.9%	0.3%
	341.6 days	342.7 days	1.1 days
Average CO2 Export	138.4 tons/hour	138.6 tons/hour	0.2 tons/hour

Table 6-1, Results of Sensitivity Analysis

7. CONCLUSIONS

The latest updated design for the Scotford CO_2 capture system is predicted to have an average predicted efficiency of 95.4%, based on Shell reliability data for each equipment item.

This is a drop from the 2011 studies of previous designs. The reported production efficiency for the 2011 study was 97.1%. The main reason for the drop is a change in the data used for the compressor and the failure data used for the shell & tube heat exchangers.

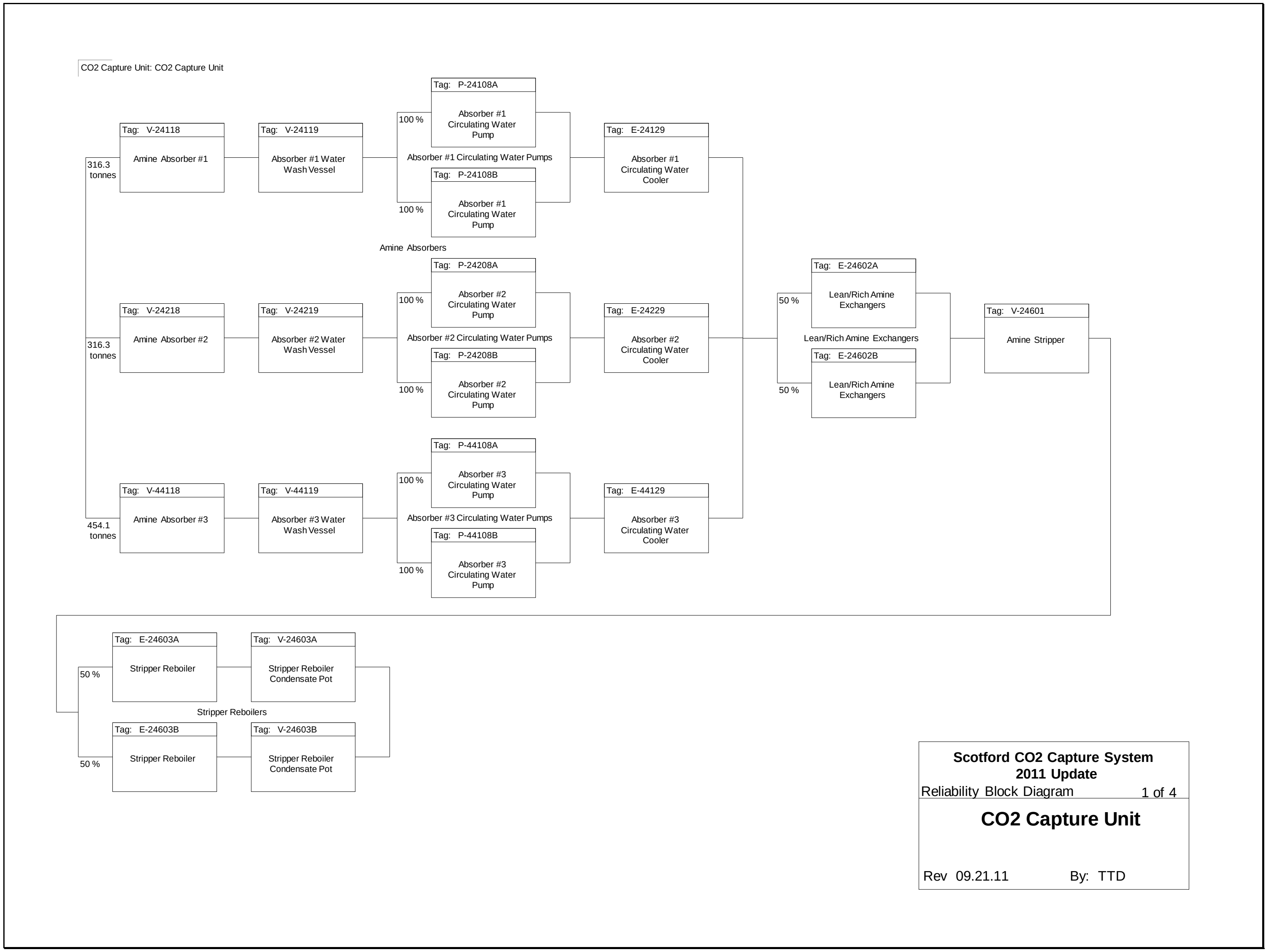
The main causes for losses in the new design are predicted to come from failures of the 8-stage CO_2 compressor and the exchangers/coolers.

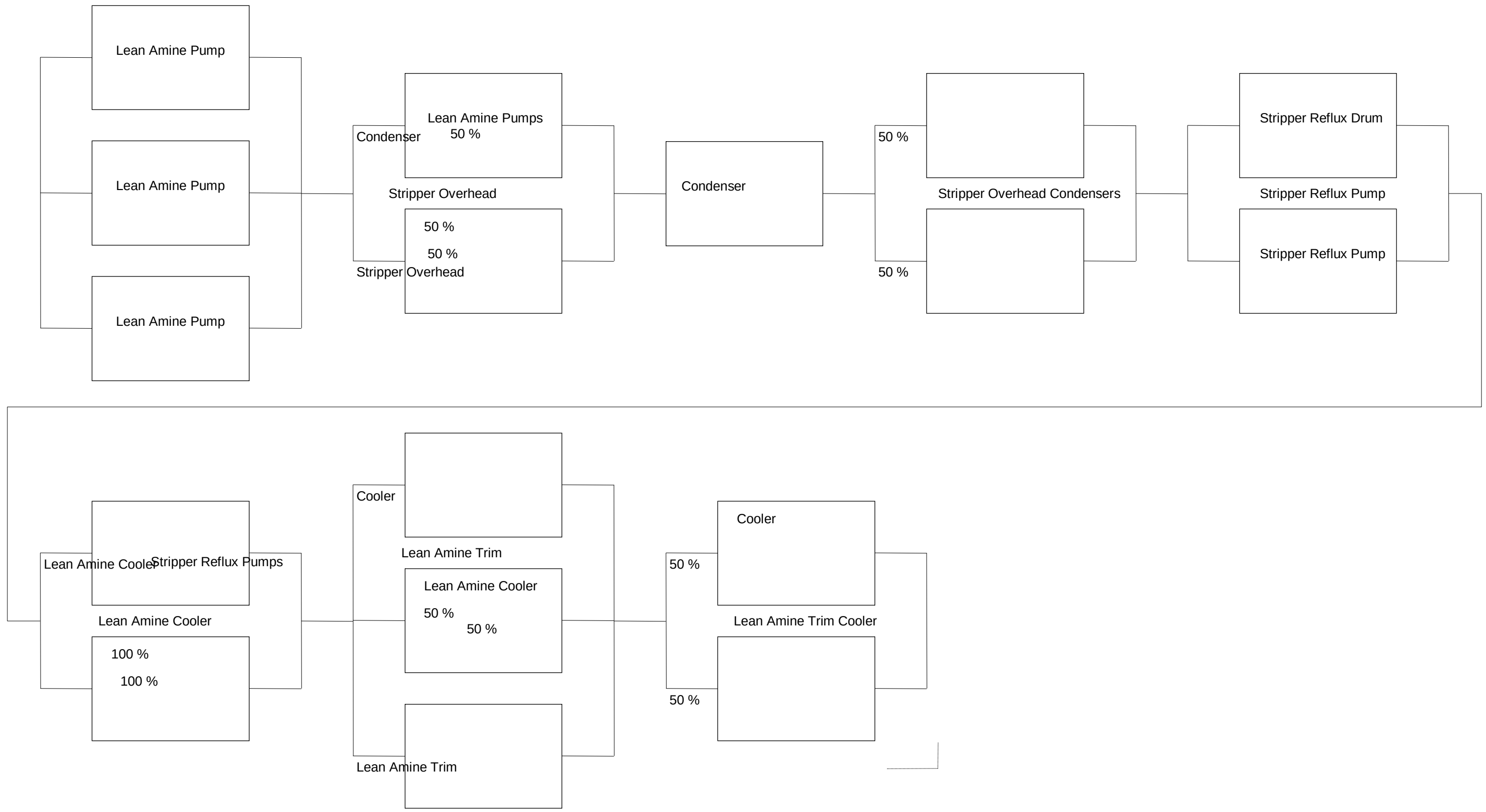
Note that the 95.4% predicted efficiency does not include any downtime caused by planned maintenance.

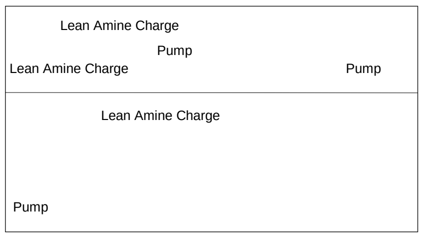
The sensitivity study on the stripper inlet valves shows a rise in predicted efficiency of 0.2%. This change is based on the assumption that a spare stripper inlet valves is kept onsite. The resulting increase is equivalent to 4.8 tons/day, or 1752 tons/year.

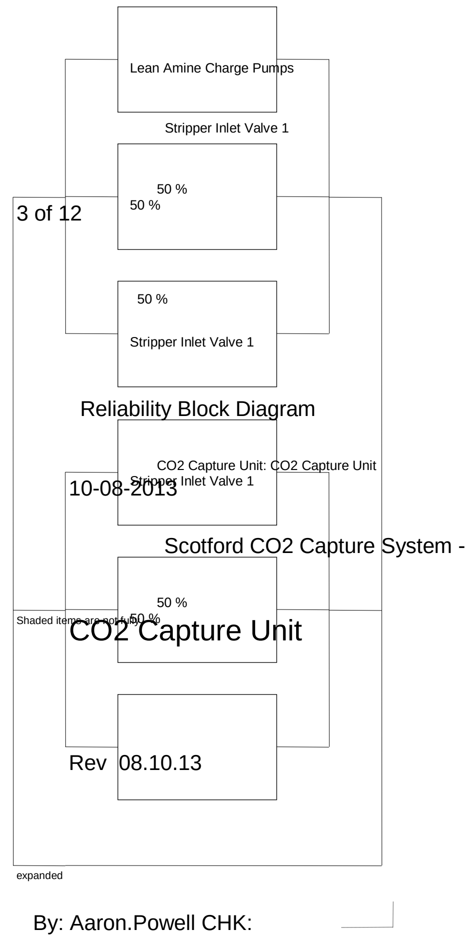
Appendix A – CO_2 Capture System Reliability Block Diagram

Appendix A contains the detailed reliability block diagram for the CO_2 Capture system:

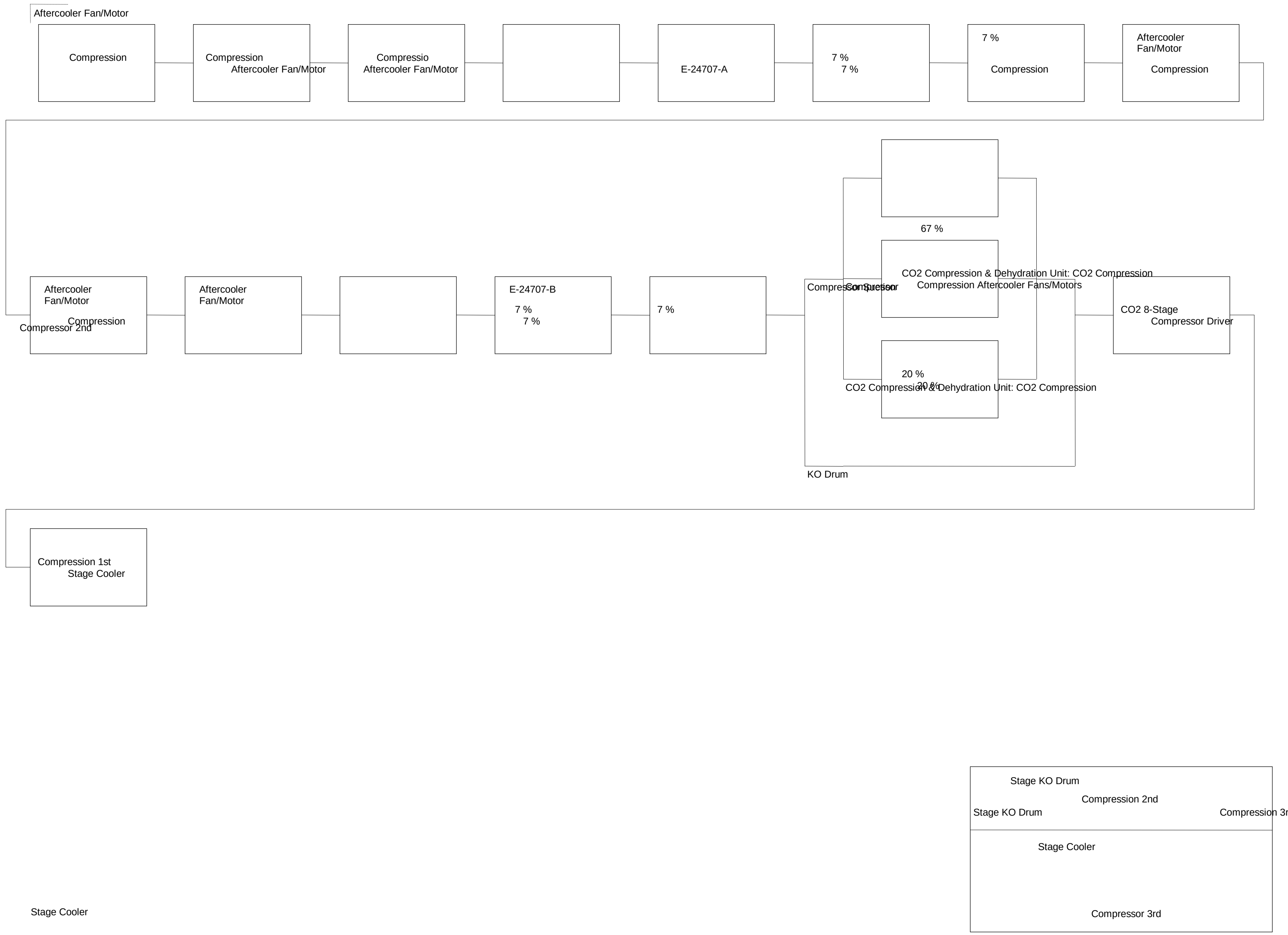

CO2 Capture Unit: CO2 Capture Unit
316.3 tonnes
Tag: V-24118
Amine Absorber #1
Tag: V-24119
Absorber #1 Water Wash Vessel
Tag: P-24108A
100 %
Absorber #1 Circulating Water Pump
Absorber #1 Circulating Water Pumps
Tag: P-24108B
100 %
Absorber #1 Circulating Water Pump
Tag: E-24129
Absorber #1 Circulating Water Cooler
Amine Absorbers
316.3 tonnes
Tag: V-24218
Amine Absorber #2
Tag: V-24219
Absorber #2 Water Wash Vessel
Tag: P-24208A
100 %
Absorber #2 Circulating Water Pump
Absorber #2 Circulating Water Pumps
Tag: P-24208B
100 %
Absorber #2 Circulating Water Pump
Tag: E-24229
Absorber #2 Circulating Water Cooler
Tag: E-24602A
50 %
Lean/Rich Amine Exchangers
Lean/Rich Amine Exchangers
Tag: E-24602B
50 %
Lean/Rich Amine Exchangers
Tag: V-24601
Amine Stripper
454.1 tonnes
Tag: V-44118
Amine Absorber #3
Tag: V-44119
Absorber #3 Water Wash Vessel
Tag: P-44108A
100 %
Absorber #3 Circulating Water Pump
Absorber #3 Circulating Water Pumps
Tag: P-44108B
100 %
Absorber #3 Circulating Water Pump
Tag: E-44129
Absorber #3 Circulating Water Cooler
Tag: E-24603A
50 %
Stripper Reboiler
Tag: V-24603A
Stripper Reboiler Condensate Pot
Stripper Reboilers
Tag: E-24603B
50 %
Stripper Reboiler
Tag: V-24603B
Stripper Reboiler Condensate Pot
Scotford CO2 Capture System
2011 Update
Reliability Block Diagram 1 of 4
CO2 Capture Unit
Rev 09.21.11 By: TTD

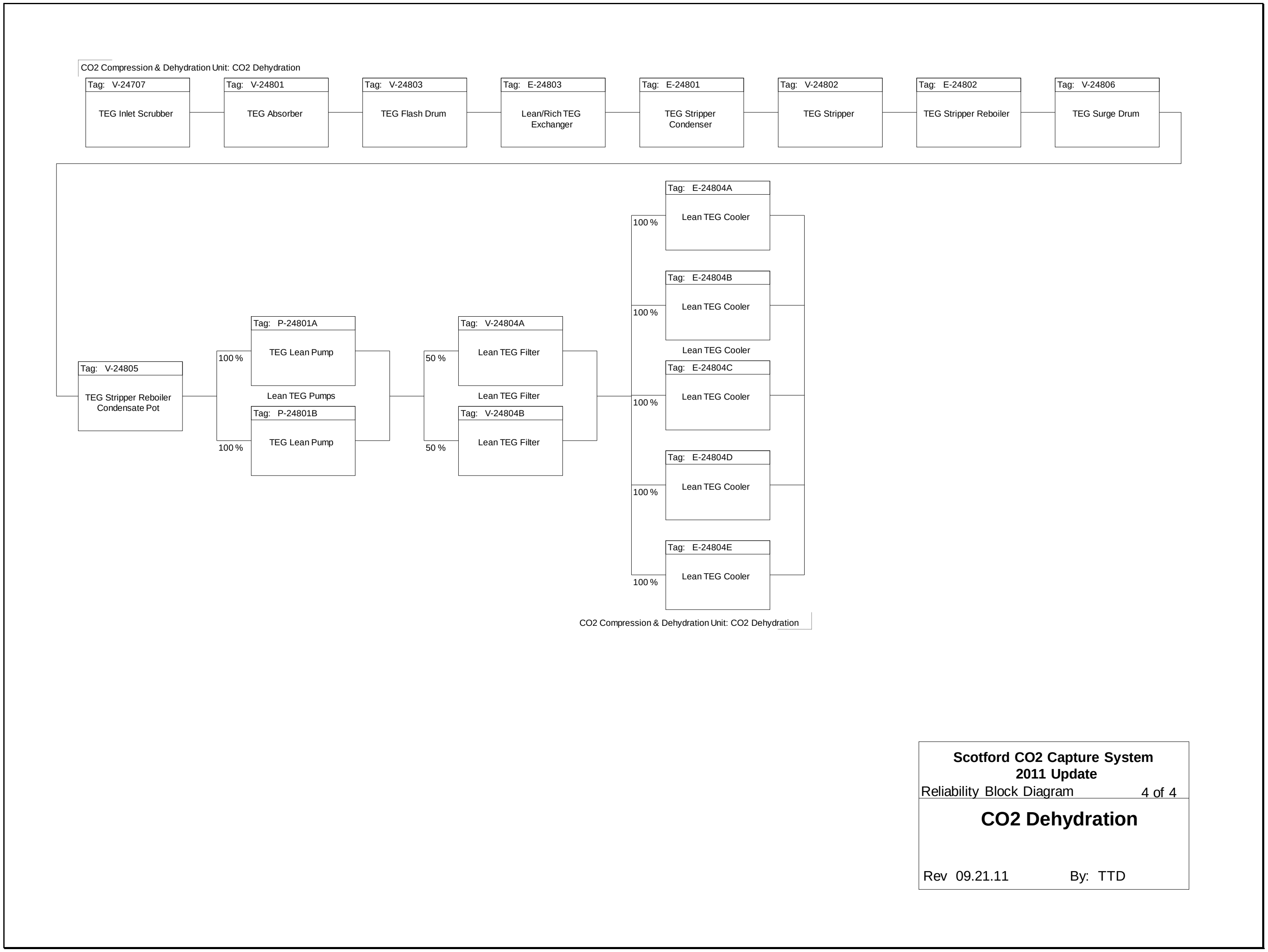

Lean Amine Pump
Lean Amine Pump
Lean Amine Pump
Lean Amine Pumps
50 %
Condenser
Stripper Overhead
50 %
50 %
Stripper Overhead
Condenser
50 %
Stripper Overhead Condensers
50 %
Stripper Reflux Drum
Stripper Reflux Pump
Stripper Reflux Pump
Lean Amine Cooler
Stripper Reflux Pumps
Lean Amine Cooler
100 %
100 %
Cooler
Lean Amine Trim
Lean Amine Cooler
50 %
50 %
Lean Amine Trim
50 %
Cooler
Lean Amine Trim Cooler
50 %


Lean Amine Charge
Pump
Lean Amine Charge
Pump
Lean Amine Charge
Pump


Lean Amine Charge Pumps
Stripper Inlet Valve 1
50 %
3 of 12
50 %
50 %
Stripper Inlet Valve 1
Reliability Block Diagram
CO2 Capture Unit: CO2 Capture Unit
10-08-2013
Stripper Inlet Valve 1
Scotford CO2 Capture System -
50 %
50 %
CO2 Capture Unit
Rev 08.10.13
expanded
By: Aaron.Powell CHK:

v


Aftercooler Fan/Motor
Compression
Compression
Aftercooler Fan/Motor
Compressio
Aftercooler Fan/Motor
E-24707-A
7 %
7 %
7 %
Compression
Aftercooler
Fan/Motor
Compression
67 %
CO2 Compression & Dehydration Unit: CO2 Compression
Compression Aftercooler Fans/Motors
Compressor Suction
Compressor
Aftercooler
Fan/Motor
Compression
Compressor 2nd
Aftercooler
Fan/Motor
E-24707-B
7 %
7 %
7 %
CO2 8-Stage
Compressor Driver
20 %
20 %
CO2 Compression & Dehydration Unit: CO2 Compression
KO Drum
Compression 1st
Stage Cooler
Stage KO Drum
Compression 2nd
Stage KO Drum
Compression 3rd
Stage Cooler
Compressor 3rd
Stage Cooler


CO2 Compression & Dehydration Unit: CO2 Dehydration
Tag: V-24707
TEG Inlet Scrubber
Tag: V-24801
TEG Absorber
Tag: V-24803
TEG Flash Drum
Tag: E-24803
Lean/Rich TEG Exchanger
Tag: E-24801
TEG Stripper Condenser
Tag: V-24802
TEG Stripper
Tag: E-24802
TEG Stripper Reboiler
Tag: V-24806
TEG Surge Drum
Tag: V-24805
TEG Stripper Reboiler Condensate Pot
Lean TEG Pumps
Tag: P-24801A
TEG Lean Pump
100 %
Tag: P-24801B
TEG Lean Pump
100 %
Lean TEG Filter
Tag: V-24804A
Lean TEG Filter
50 %
Tag: V-24804B
Lean TEG Filter
50 %
Lean TEG Cooler
Tag: E-24804A
Lean TEG Cooler
100 %
Tag: E-24804B
Lean TEG Cooler
100 %
Tag: E-24804C
Lean TEG Cooler
100 %
Tag: E-24804D
Lean TEG Cooler
100 %
Tag: E-24804E
Lean TEG Cooler
100 %
CO2 Compression & Dehydration Unit: CO2 Dehydration
Scotford CO2 Capture System
2011 Update
Reliability Block Diagram
4 of 4
CO2 Dehydration
Rev 09.21.11
By: TTD

Following is the SGS study report which details the methodology, data sources, sensitivity analysis and changes to the block flow diagram since VAR4 used to determine the availability of the Quest facility as being constructed. Unclassified