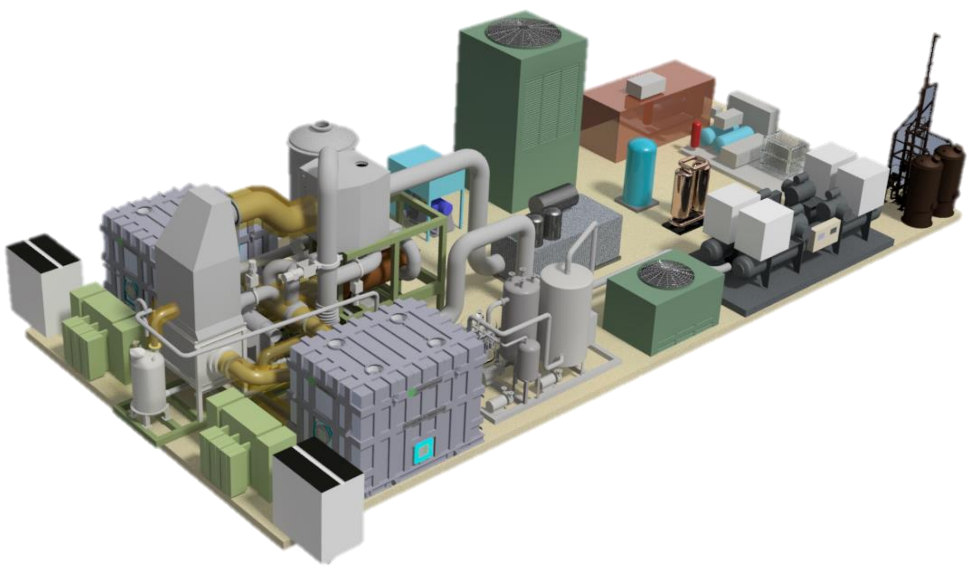
Pre-FEED Study of a MW-Class Molten Carbonate Fuel Cell System for Carbon Capture Demonstration at an Oil Sands Facility

Final Report



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Disclaimer

Executive Summary

FuelCell Energy Inc. (FCE) conducted a Preliminary Front End Engineering Design (Pre-FEED) study of a MW-class molten carbonate fuel cell (MCFC)-based system to separate and purify CO_2 from a flue gas slipstream for Alberta Innovates (AI). The system is designed to separate 70% of the CO_2 from a natural gas-derived slipstream of flue gas, while simultaneously producing clean electric power. Two potential flue gas sources and host sites for locating the demonstration plant are being considered: a process heater (PH) at the Shell Scotford facility located near Edmonton, Alberta and a Once through Steam Generator (OTSG) at a Husky Energy Steam Assisted Gravity Drainage facility located in rural Saskatchewan (MCFC-4CC-SAGD). The MCFC system is designed to purify and compress the captured CO_2 to 10 MPa for pipeline transport to points of use or storage. The MCFC plant is capable of capturing up to 90% of the CO_2 in the flue gas, albeit at slightly reduced capacity compared to operating at 70% capture.

FCE developed the following design information during the Pre-FEED study: Heat and Material Balance (H&MB) reports for multiple operating cases, equipment specifications and selection, Process Flow Diagram (PFD), system interconnection requirements, conceptual 3-D Computer Aided Design (CAD) models, preliminary area classification information, and tie-in locations. Jacobs Engineering reviewed and accepted the design inputs.

The analysis results show that the carbon capture system, utilizing two MW-class MCFC modules, can capture 60-72 tonnes/day of CO_2 while simultaneously producing 1200-1485 kW,net of clean electric power. The system is also capable of operating in standalone mode (no carbon capture from flue gas), in which it produces 2,800 kW,net at 50% efficiency (based on LHV of natural gas). During normal operating conditions, the MCFC system does not consume water and produces excess clean water that can be used at the host site or sent to drain. A 3-D Computer Aided Design (CAD) rendering of the system was developed to estimate the plant footprint and tie-in locations. The footprint of the system is 50’ x 115’ (15m x 35m).

A budgetary Class IV cost analysis for the MCFC carbon capture system demonstration project was developed for both potential host sites. The estimates include costs for the MCFC system equipment and execution of the demonstration project (management, engineering, certification to applicable codes/standards, fabrication, installation, commissioning and operation for one year). The total project cost for the 2-module demonstration project at Shell site is $21,608,000 USD. The costs for the demonstration project at the Husky site are very similar at $21,599,000 USD.

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1 Introduction

FuelCell Energy Inc. (FCE) conducted a Preliminary Front End Engineering Design (Pre-FEED) study of a MW-class molten carbonate fuel cell (MCFC)-based system to separate and purify CO_2 from a flue gas slipstream for Alberta Innovates (AI). The system is designed to separate 70% of the CO_2 from a natural gas-derived slipstream of flue gas, while simultaneously producing clean electric power. Two potential flue gas sources and host sites for locating the demonstration plant are being considered: a process heater (PH) at the Shell Scotford facility located near Edmonton, Alberta and a Once through Steam Generator (OTSG) at a Husky Energy Steam Assisted Gravity Drainage facility located in rural Saskatchewan (MCFC-4CC-SAGD). The MCFC system is designed to purify and compress the captured CO_2 to 10 MPa for pipeline transport to points of use or storage. The MCFC plant is capable of capturing up to 90% of the CO_2 in the flue gas, albeit at slightly reduced capacity compared to operating at 70% capture.

The core molten carbonate fuel cell technology that is utilized for this application is essentially identical to that used in FCE's carbonate fuel cell products featuring internal (methane steam) reforming and carrying the trade name of SureSource. The MW-class MCFC carbon capture system is based upon FCE's SureSource 3000 power plant which is sold commercially for stationary power generation applications. The SureSource 3000 power plant is shown in Figure 1.

Figure 1: SureSource 3000 Power Plant

2 Molten Carbonate Fuel Cell (MCFC) Technology and Systems Background with Cost Reduction Roadmap

2.1 MCFC Operating Principles

The MCFC utilizes CO_2 in the flue gas as a reactant (oxidant) for the electrochemical reaction to produce power, while synergistically transferring CO_2 from the flue gas to the anode exhaust stream. A supplementary fuel such as natural gas is used as the fuel cell anode feed to provide H_2 (primary fuel) needed to complete the electrochemical power generation cycle. The unused fuel (mainly H_2) present in the CO_2-rich anode exhaust stream is recovered before further processing the captured CO_2 for sequestration or other use. Given the large molecular weight difference between CO_2 and H_2, the separation is relatively straightforward, achieved by compressing and cooling the gas. The hydrogen can be internally recycled within the system, exported for industrial use, or further purified for sale.

Additional information regarding FCE's development of carbon capture systems is available in references [1-12][1].

The MCFC operates at 550-650°C and atmospheric pressure. Unlike conventional membrane technologies that rely on pressure (partial pressure) differentials and permeability properties, the MCFC separates CO_2 at a rate dependent on the electrical current drawn. The higher operating temperature of MCFC provides the opportunity for achieving high overall system efficiencies and high carbon dioxide transfer rates. A benefit associated with the high operating temperature is that noble metal catalysts are not required for the cell electrochemical oxidation and reduction processes. Because of fast electrode kinetics, the MCFC does not require high CO_2 concentration in the flue gas feed. Additionally, the flue gas does not need to be pressurized and vacuum operation is not required on the permeate side. Planar geometry and large gas flow channels of the MCFC enable processing of large volumetric flow of flue gas without significant backpressure.

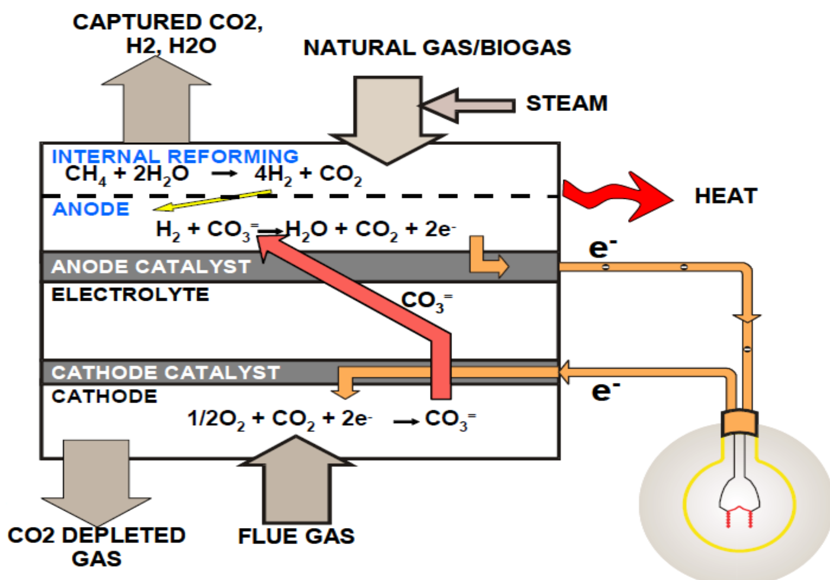

Figure 2: Transport of CO_2 in the MCFC: CO_2 is used at the cathode as an oxidant and transferred to the anode via carbonate ions

The operating principle of the molten carbonate fuel cell, including the mechanism for transport of CO_2 (by migration of carbonate ions through electrolyte) from the cathode to the anode of the cell, is shown in Figure 2, along with the electrochemical reactions. Due to the internal reforming capability of the fuel cell, methane in the fuel is converted (steam reformed) into hydrogen (the primary fuel for the MCFC) according to the following reaction:

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2 \tag{1}$$

Hydrogen is used as a reactant at the anode. Carbon dioxide and oxygen present in the flue gas are used as reactants at the cathode. The electrochemical reaction at the cell cathode involves the formation of carbonate ions (CO_3^{2-}) by combination of O_2, CO_2 and two electrons:

[1] Bracketed numbers refer to cited references included in Section 6.

$$\frac{1}{2}O_2 + CO_2 + 2e^- \rightarrow CO_3^{2e-} \quad (2)$$

Carbonate ions produced at the cathode migrate to the anode side via the electrolyte in the cell. The membrane cell reaction for the anode is:

$$H_2 + CO_3^{2e-} \rightarrow H_2O + CO_2 + 2e^- \quad (3)$$

The internal transport of carbonate ions in the MCFC and the flow of electrons in the external circuit results in power generation as a consequence of the CO_2 separation process. DC power produced is converted to AC power using an inverter. The overall reaction, with CO_2 transport shown, is:

$$H_2 + \frac{1}{2}O_2 + CO_2(cathode) \rightarrow H_2O + CO_2(anode) \quad (4)$$

Overall, the operating mechanism of the MCFC results in the separation (from flue gas) and transfer of CO_2 into the anode exhaust stream which has a much reduced volumetric flow (resulting in a CO_2-rich stream) compared to the flue gas stream. The CO_2 flux (rate of transport) is equivalent to the rate of reaction and is directly proportional to the DC current drawn from the cell, based on Faraday's law:

$$R_e = \frac{i}{2F} \quad (5)$$

where, F is Faraday's constant (96,485.3 Coulombs/mole), i is current density (amp/m^2), and R_e is overall electrochemical reaction rate, or CO_2 transport rate (mole/s-m^2). The electrochemical reactions result in an electrical potential or voltage across the electrolyte. The voltage across the cell provides the driving force for the electron movements (current flow) and power production. FCE's electrochemical performance modelling, as fit to experimental data, is discussed by Ma, et al. [13]. At open-circuit (i.e. no-load) conditions, the cell voltage is ~1 V/cell. The operating cell voltage is in the range of 0.7-0.8 V/cell.

2.2 MCFC Technology Development and Cost Reduction Roadmap

Material development status for carbonate fuel cell has been reviewed extensively [14-26]. The selection of carbonate fuel cell materials is based on intensive materials research carried out during the past three-plus decades, focusing on performance and endurance improvements, and cost reduction, and confirmed by extensive MCFC operating experience accumulated through long-term field operations for power generation applications. These results are expected to directly apply to operations in carbon capture conditions, as no material changes are required. Based on understanding of rate-controlling processes and decay mechanisms, electrode and electrolyte designs have been advanced to improve cell power output and to achieve the stack useful life of >5 years for power generation applications. An expanded description of factors and ongoing R&D which have the potential to extend the MCFC life even further is included at the end of this section.

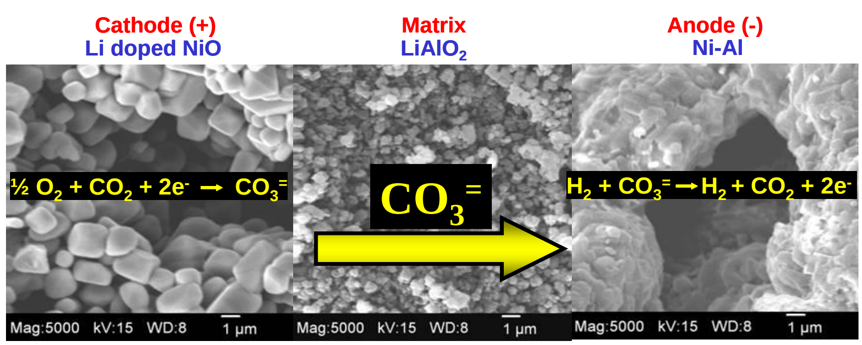

Figure 3: Structure of Electrochemical Membrane Electrode Assembly and Mechanism of CO_2 Transport

The electrochemical membrane, as illustrated in Figure 3, is composed of anode and cathode electrode/current collector combinations (current collectors not shown), which are separated from one another by an electrolyte matrix. The membrane is made from inexpensive inorganic materials. The anode is a porous layer comprised of nickel-aluminum (Ni-Al) alloy and provides the electro-catalytic sites for fuel (H_2) oxidation. The cathode is a porous layer of lithiated nickel oxide (NiO) and provides the electro-catalytic sites for oxygen reduction. Each electrode is backed by a sheet metal current collector, which is formed to provide reactant gas passages. The anode and cathode electrodes are electronically isolated from one another by a porous ceramic ($LiAlO_2$) matrix layer, which is filled with an alkali carbonate electrolyte. The electrolyte matrix separates the reactant gases in the electrode compartments and conducts carbonate ions from the cathode to the anode. Each unit cell has a thickness of approximately 0.635 cm (0.25 inch), with an effective area of ~7825 cm^2 available for CO_2 separation. The electrochemical membrane cell assembly is planar for ease of fabrication and integration into large stacks. The membrane assemblies are sandwiched between stainless steel bipolar plates in a unitized cell package. The corrugated flow channels are inserted adjacent to the electrodes (cathode and anode), providing a cross-flow arrangement, similar to a plate-and-frame heat exchanger.

Figure 4 shows the progression of the membrane module fabrication from a unit cell package (membrane assembly) to a stack of ~400 cells, and finally to a 4-stack module as a building block for larger plants. The flue gas flows inside (shell side) of the module enclosure and is distributed evenly to the stacks and individual cells within the stacks using manifolds.

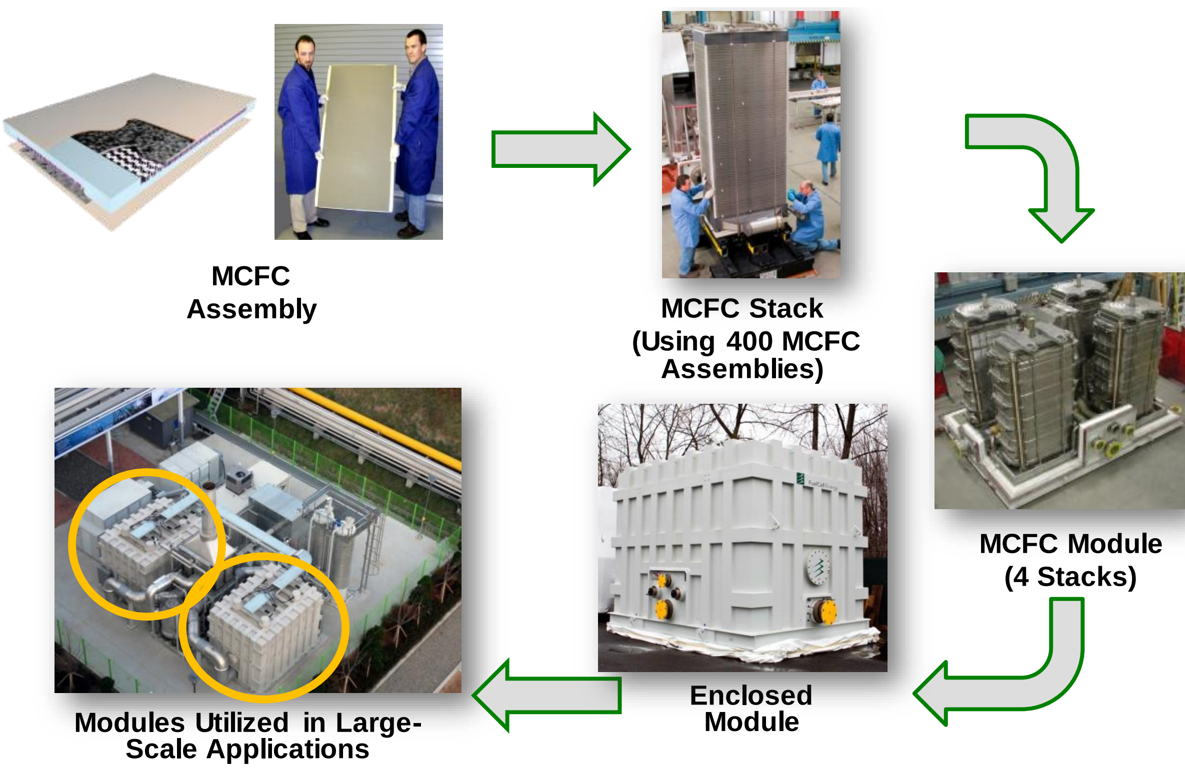

Figure 4: Planar MCFC Assemblies are Stacked and Incorporated into MW-Class Modules

FCE has developed global manufacturing facilities to produce MCFC modules, in cooperation with its partners. Figure 5 shows an overview of the global manufacturing footprint for MCFC module production. All MCFC module manufacturing in North America is accomplished at FCE's facility in Torrington, Connecticut, USA, which has an annual production capacity of 100 MW. An expansion of the 65,000ft^2 Torrington facility is currently underway, which, when complete, will add an additional

102,000ft^2 of floor space and increase the capacity to 200 MW/yr. Manufacturing in Asia is performed by POSCO Energy at a facility in Pohang, South Korea under a licensing agreement with FCE. This facility came on-line in 2015, and is configured with initial manufacturing capability for an annual production rate of 100 MW with the ability to ramp up to 200 MW/yr in the future. Europe is served by a 20,000ft^2 manufacturing facility in Ottobrun, Germany that has the capability to produce up to 20 MW per year of sub-megawatt SureSource power plants. This facility produced its first fuel cell stack in 2013.

Figure 5: Carbonate Fuel Cell Module Global Manufacturing Footprint

FCE has aggressively pursued product cost reduction programs since launching its SureSource (formerly DFC) products in the early 2000s. Cost reductions have been realized through the areas of design/manufacturing improvement, global sourcing, and economies of scale with increasing volume. FCE has assembled a global supply chain to supply materials utilized in the module manufacturing process, as well as for supply of balance-of-plant components. Figure 6 shows FCE's historical capital cost reduction achievements for SureSource power plants, and mid-term projections for future reductions. Going forward, the main source of significant cost reductions are projected due to manufacturing volume increases and fuel cell endurance improvement. Increasing volume is supported by the above-mentioned manufacturing capabilities. The versatility of the core MCFC module to serve multiple markets (on-site power, large-scale grid-support power generation, carbon capture systems, and hydrogen co-production systems) is expected to contribute to volume growth.

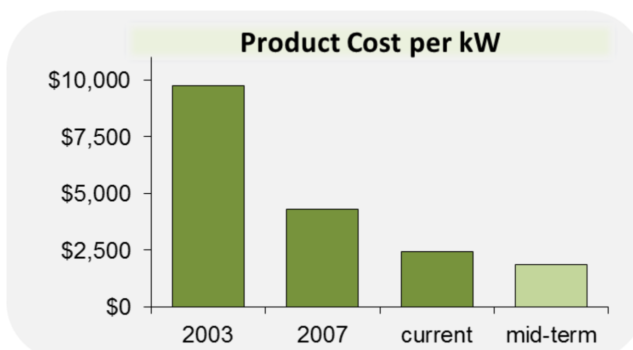

Figure 6: FCE SureSource Power Plant Product Cost

Cost reductions for technologies historically follow a learning curve trend as they move from market-entry stage through mature market saturation. Figure 7 shows an 85% learning curve for MCFC stack cost reductions, including historical costs and near-term forecasted costs. At high production rates of 20,000 stacks per year, the cost is expected to be reduced by over 70%. Learning curve predictive models have been proven accurate in numerous industries, including gas turbines and solar energy equipment. Those industries have historically shown close to an 80% learning factor, relative the conservative 85% learning factor presented here. The SureSource stack cost reductions are still on the steep end of the curve, showing the potential for large cost reductions as production rate increases to support the growing demand for both carbon capture and power generation systems.

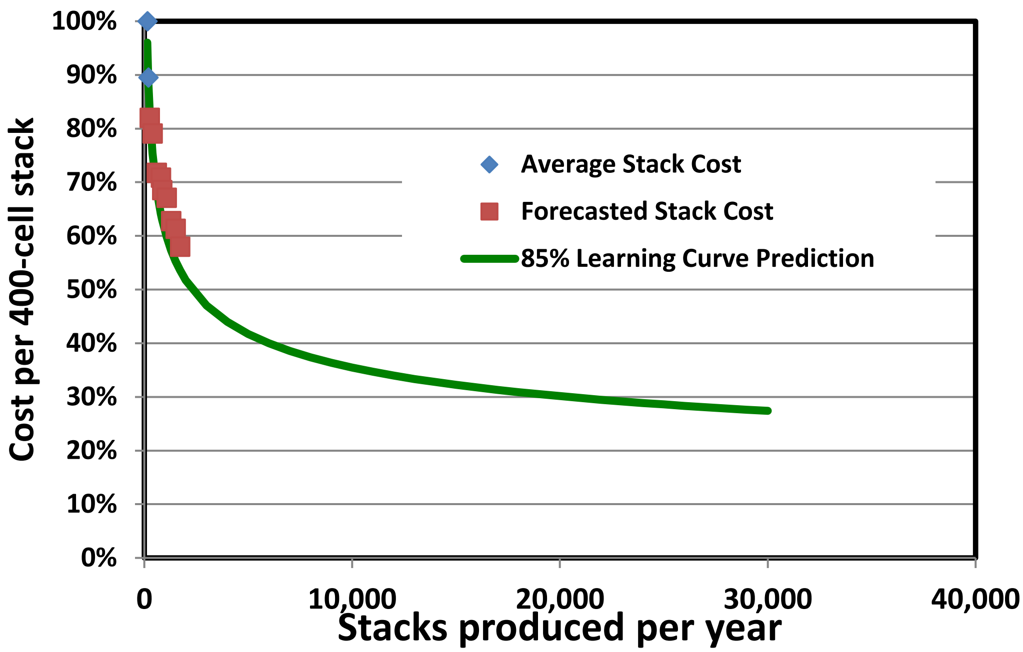

Figure 7: Learning Curve Prediction for MCFC Stack Cost Reduction

FCE has internal R&D programs in place with the goal of extending the MCFC operating lifetime and thereby reducing replacement costs over the life of a plant. A 7-year life fuel cell stack is in the final stages of validation, with planned commercial rollout in the second half of 2017. Advanced technologies are also under development to further extend the stack life to 10 years in power generation mode. For perspective, a stack-life improvement from 5 to 10 years has the potential to reduce O&M costs by ~40% over the life of the plant.

In addition to stack endurance gains expected through ongoing R&D efforts, longer stack life is expected when operating in carbon capture conditions (compared to power generation mode) due to more-favorable operating parameters. Extensive testing of the MCFC technology has been performed under operating conditions representative of carbon capture from flue gases of various compositions. Testing has been successfully completed at the laboratory, bench, and full stack levels. Under a Cooperative Agreement with the U.S. Department of Energy, a bench-scale MCFC-based CO_2 capture system was designed, fabricated, and operated for nearly two years (2014 – 2016). The objective of the demonstration was to show the capability of full-size MCFC cells to separate >90% of CO_2 from a simulated flue gas stream (13% CO_2) through extended duration testing. The system utilized an MCFC stack containing cells with a total electrochemical membrane area of 11.7 m^2. Gross DC output is approximately 8 kW at normal operating conditions (12 kW at peak power), with high-purity liquid CO_2 production of ~90 tonnes/year. The test stack included 14 full-area cells identical to those used in commercial MCFC stacks, which were obtained directly from FCE's Torrington, CT commercial fuel cell manufacturing plant. The system completed 15,700 hours of operation. The MCFC stack demonstrated stable performance during 9-months of steady-state endurance testing while separating 93% of carbon from flue gas at constant CO_2 flux (Figure 8). The MCFC stack showed extraordinarily low degradation in power output compared to typical rates observed when operating in power generation mode. The CO_2 flux remained constant throughout the endurance test. The demonstration stack displayed a projected life of over 10 years operating under carbon capture conditions.

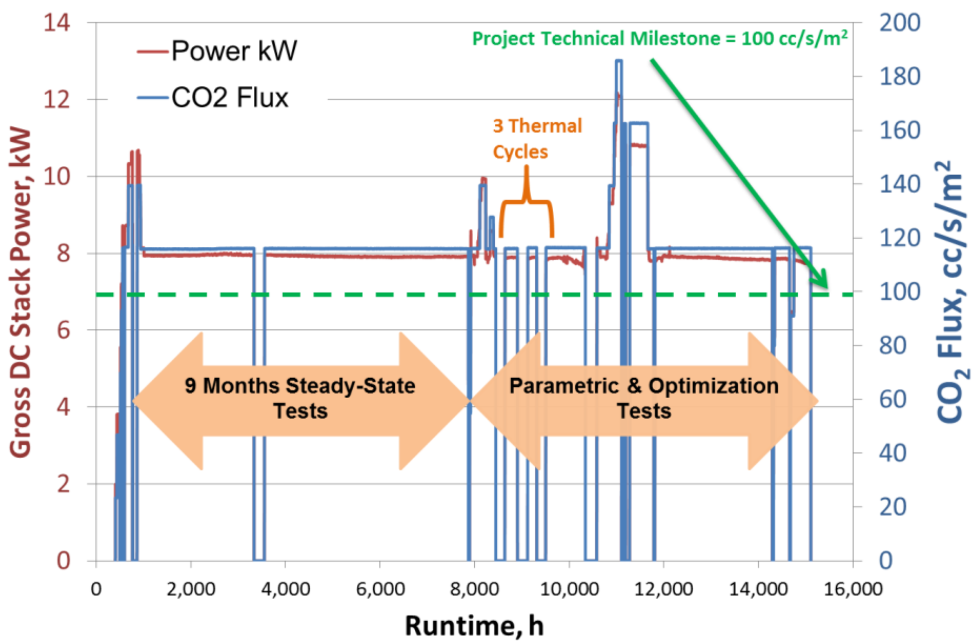

Figure 8: Bench-Scale MCFC-based CO_2 Separation System has Demonstrated Constant CO_2 Flux and Stable Power Output for over 15,000 Operating Hours

At the conclusion of the steady-state hold, parametric testing was performed to show the system response to thermal cycles and various operating parameters. Parametric testing showed the ability of the MCFC to operate at a CO_2 flux (proportional to power density) of up to 185 cc/s/m^2, a 57% increase relative to the steady state testing at 93% CO_2 capture. The high CO_2 flux, shown near the 11,000 mark in the graph, was achieved by lowering the CO_2 capture rate to 60%, while simultaneously increasing the amount of CO_2 captured (due to higher flue gas flow into the system). In summary, the testing demonstrated the benefits of carbon capture operating conditions on expected MCFC life, as well as identifying operating parameters (such as CO_2 capture percentage) which can be optimized to reduce the number MCFC stacks required for a given application.

2.3 Techno-Economic Analyses of MCFC Systems

Numerous MCFC-based system case studies have been performed for a wide range of applications and scales. An overview of the results of two case studies is presented here.

In 2013, Jacobs Consultancy developed an independent analysis of an MCFC-based system for CO_2 capture applied to a 33,000 Barrels of Oil per Day (BOPD) Steam Assisted Gravity Drainage (SAGD) facility under a study supported by Alberta Innovates (Alberta, Canada) [27]. The MCFC system was configured to capture 90% of CO_2 from the natural gas-fueled Once Through Steam Generator (OTSG) flue gas. Results of the study indicated significant advantages of the MCFC system compared to conventional amine scrubbing capture technologies, shown in Figure 9. In addition to the cost advantage, the MCFC system produces 62 MWe net, enough to cover all SAGD power requirements and export 48 MWe. The MCFC also resulted in a 44% reduction in the SAGD facility makeup water requirements, compared to the base plant without carbon capture.

To quantify the benefits of MCFC-based systems for CO_2 capture from coal-fired power plants, FCE and its engineering partner AECOM Corporation performed a Techno-Economic Analysis (TEA) for a large-scale MCFC-based system designed to capture and compress >90% of the CO_2 from the flue gas of a reference 550 MW (net AC) Pulverized Coal (PC) power plant. The TEA was performed under US Department of Energy cooperative agreements (DE-FE0007634 and DE-FE0026580), in accordance with DOE guidelines [28,29]. The analysis was based on the PC plant designs specified in Cases 11 (base supercritical PC plant) and 12 (supercritical PC plant with Amine CO_2 capture) of the referenced DOE –

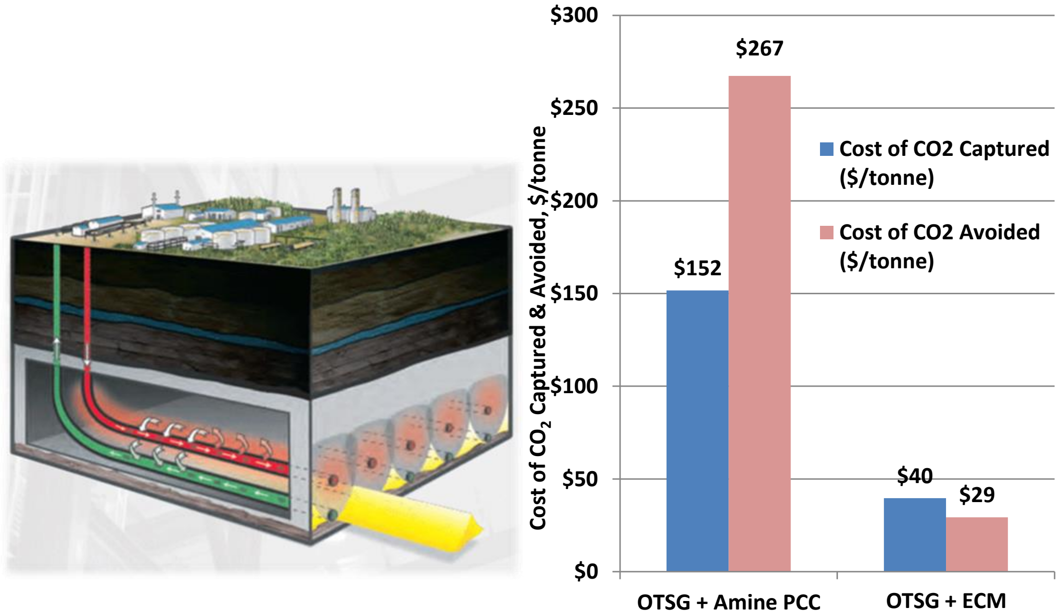

Figure 9: Results of Independent Techno-Economic Analysis of MCFC-System Applied to SAGD Oil Recovery Facility [27]

NETL Baseline Bituminous Studies (BBS) reports [30,31]. The results of the TEA were documented in a detailed topical report which was submitted to the U.S. DOE.

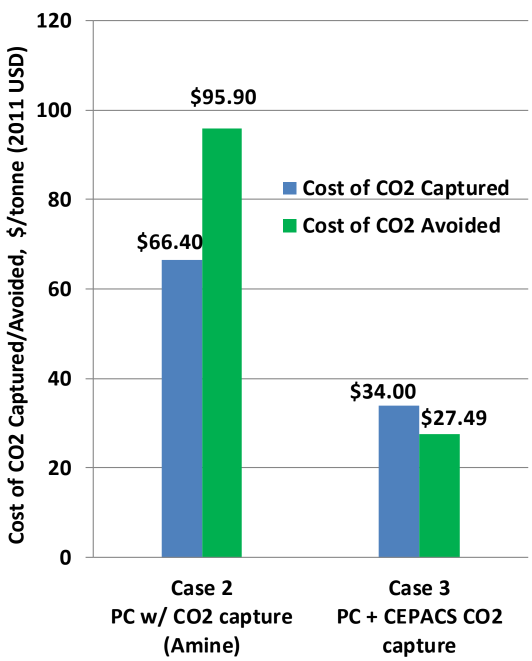

Figure 10: Results of Techno-Economic Analysis of MCFC-System (CEPACS) Applied to Reference 550 MW Supercritical Pulverized Coal Power Plant, Compared to Amine Technology

The TEA showed that an MCFC-based system applied to the 550 MW PC plant simultaneously generates 320 MW of additional power (net AC, after deducting system auxiliary power requirements) while capturing >90% of CO_2 from the flue gas. An economic analysis of the system was developed by AECOM (formerly URS Corporation). The MCFC-equipped PC plant offered the lowest cost of electricity (COE) of all cases with carbon capture at 101.8 mills/kWh (2011 USD), with an incremental COE of only 25.5% (compared to the baseline COE of 81.1 mills/kWh). The MCFC system cost of CO_2 captured is estimated to be $34.00/tonne and the cost of CO_2 avoided is estimated to be $27.49/tonne. A comparison of the estimated costs of CO_2 captured and avoided to those for amine technology is presented in Figure 10.

A conceptual plant layout was developed as part of the Techno-Economic Analysis. The layout of the MCFC system was developed specifically to minimize balance-of-plant

(BOP) capital costs. Specifically, the “hot” balance-of-plant equipment was de-centralized into eight separate sections with one section located proximate to each of the eight large-scale MCFC enclosures, as shown in Figure 11. This modular design minimizes the lengths of “hot” piping and the quantities of fittings, significantly reducing capital costs while simplifying the sparing of parts and potentially increasing the capacity factor. These large-scale field-erected modules significantly reduce BOP costs for large plants (> 100 MW capacity). For plants up to ~100 MW, FCE’s existing MW-class modules can be economically arrayed.

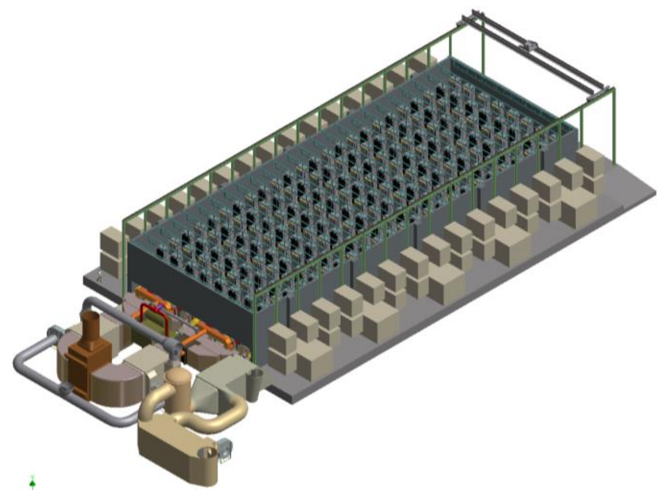

Figure 11: General Arrangement of a Large-Scale MCFC Enclosure and Associated “hot” BOP Equipment

The general arrangement of the MCFC enclosures and associated “hot” BOP equipment is shown in Figure 12, along with the piping for the distribution of flue gas to the eight sections and collection of the CO_2-rich anode exhaust gas from the eight sections. Including access ways and the centralized equipment, the CEPACS system sized for 90% CO_2 capture from a 550 MW PC plant is estimated to require ~10 acres. The footprint is comparable to that of an amine-based scrubbing system of similar capacity.

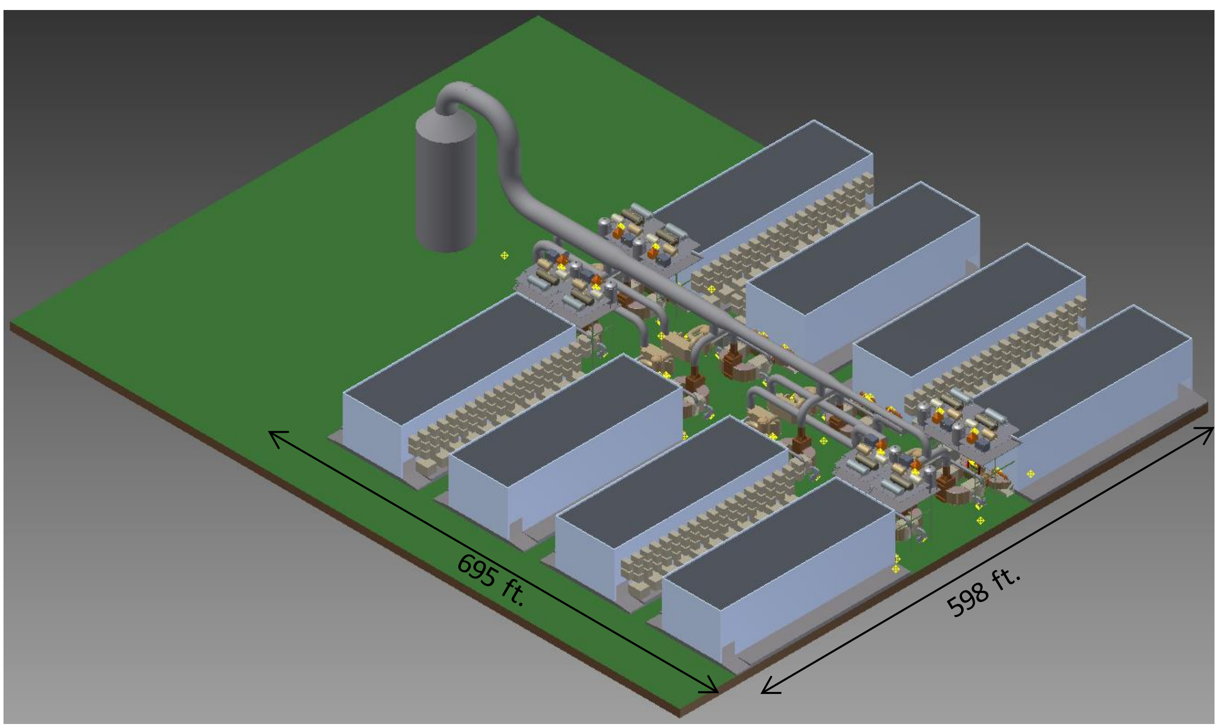

Figure 12: General Arrangement of MCFC Enclosures, BOP Equipment and Piping for 90% Capture from 550 MW Pulverized Coal Power Plant

3 MW-Class Demonstration System Scope of Work Overview

The overall objective of the demonstration project is to show the capability of a MW-Class MCFC-based system to separate and purify CO_2 from a flue gas slipstream. FCE worked with Jacobs Engineering (under separate contract with AI) to complete the Pre-FEED design and Class IV cost estimate for the demonstration system at both sites. A simplified schematic of the MCFC system integrated with the host OTSG plant or PH is shown in Figure 13. The top-level breakdown of scope between FCE and Jacobs is also shown in the Figure.

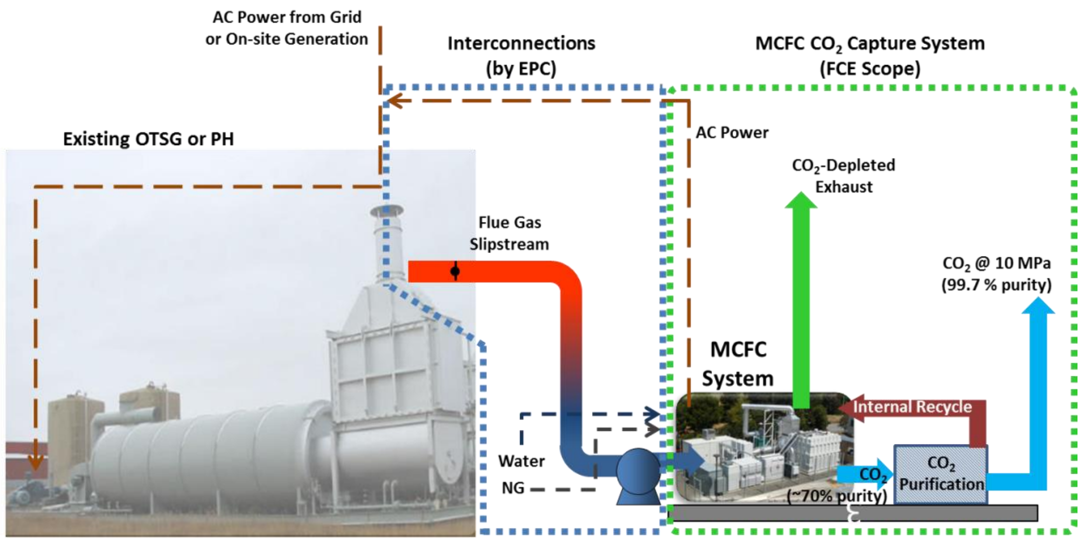

Figure 13: Simple Schematic of Pilot MCFC Carbon Capture System Integrated with OTSG (or PH)

Details of the system design basis are included in the Design Basis Memorandums issued by Jacobs (Process Design Basis [Husky] - EE060101-PR-REP-0002 Rev C, and Process Design Basis - EE060101-PR-REP-0001 Rev C, both issued February 8, 2017). The Pre-FEED Study Work Breakdown Structure is shown in Figure 14**.** Results of each task are discussed in the following sections. Task 4 results (design and cost for the second site) are reported alongside the results for Tasks 2 and 3.

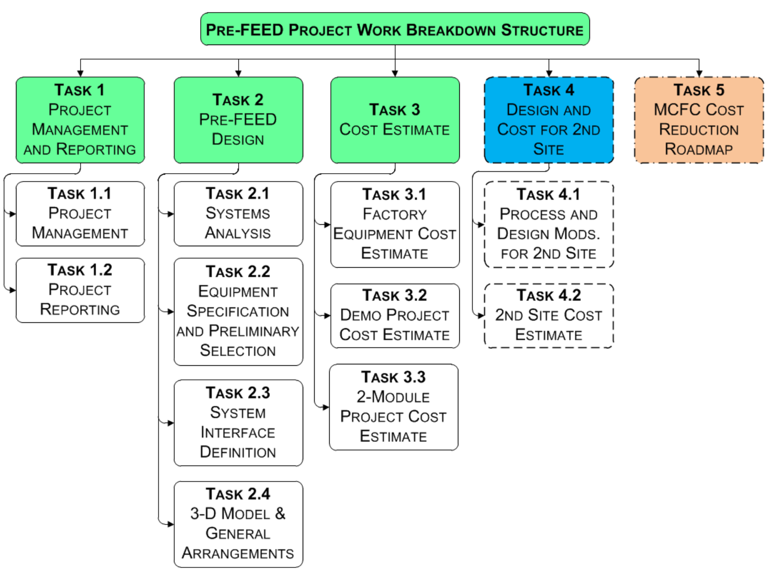

Figure 14: MCFC Carbon Capture System Pre-FEED Study Project Work Breakdown Structure

4 Results and Discussion

This section presents the results of the Pre-FEED study, including system design and cost estimate for carbon capture systems at both the Shell Scotford facility and the Husky Energy SAGD site.

4.1 Pre-FEED System Design

4.1.1 Process Description

The block flow diagram of the MCFC-based carbon capture system is shown in Figure 15. The BFD shows the major process sections for preparing the natural gas fuel, preheating the flue gas, and separating, purifying, and compressing CO_2. A description of the process is included below.

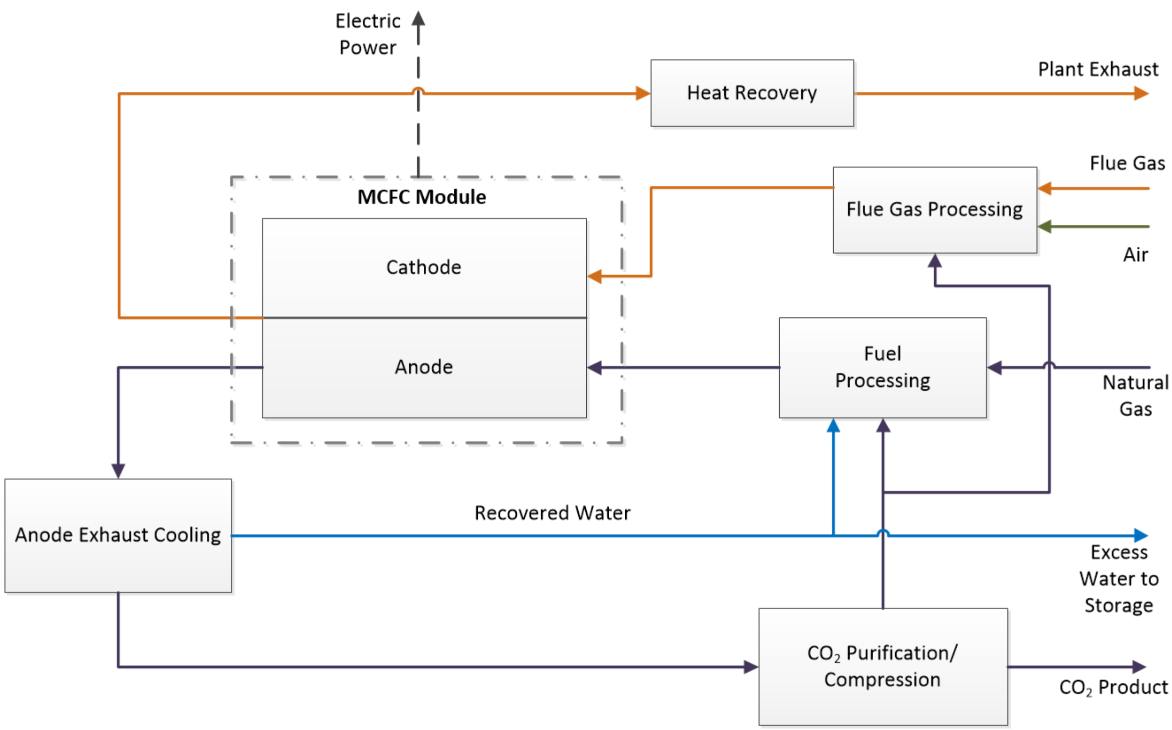

Figure 15: MW-Class MCFC-Based System for Carbon Capture BFD

The flue gas slipstream from the Process Heater or OTSG is routed to the CEPACS system via a centrifugal blower (part of the OSBL – Outside Battery Limits – scope). In the Flue Gas Processing sub-system, supplemental air is added to the flue gas to boost the O_2 concentration in the stream to a level suitable for MCFC operation. The mixed flue gas/air stream is partially pre-heated using MCFC waste heat from the cathode exhaust stream, and is then directed to a catalytic oxidizer. A hydrogen-rich recycle stream originating from the CO_2 Purification/Compression sub-system provides the fuel for the oxidizer. The H_2 is oxidized on the catalyst to increase the flue gas stream temperature to that required by the MCFC. The hot stream exiting the oxidizer is then fed to the cathode-side of the MCFC. Within the MCFC stacks, CO_2 from the flue gas is transferred from the cathode side to the anode side. For every mole of CO_2 transferred, ½ mole of O_2 is also consumed in the cathode reaction.

The CO_2-depleted stream exiting the MCFC cathode side (cathode exhaust) is routed to a multi-stage Heat Recovery system. The heat from the cathode exhaust stream is utilized to: 1) humidify and preheat the natural gas - steam fuel mix (fuel gas) that is fed to the fuel cell anodes; 2) heat the incoming flue gas stream (as mentioned above); 3) produce cooling (via absorption chilling) to condense CO_2 in the CO_2 Purification/Compression sub-system. Following Heat Recovery operations, the clean CO_2-depleted exhaust stream is vented to the environment through an exhaust stack.

Natural gas is supplied as a supplementary fuel to the MCFC anodes to drive the simultaneous production of electric power and separation of CO_2. The natural gas is first desulfurized using an (ambient temperature) solid sorbent fixed bed system. The sorbent effectively removes all organic (e.g. mercaptans) and inorganic (e.g. H_2S) sulfur compounds which could damage the MCFC anode electrodes. The desulfurized natural gas is then humidified using recovered process water and preheated (as mentioned above) prior to the feed to MCFC module. Methane in the NG fuel is internally reformed in the MCFC stacks to generate H_2, the primary fuel required at the anode. The DC electricity generated by MCFC stacks (simultaneously while separating CO_2 from flue gas and transferring it to the anode side) is converted to AC power using inverters.

The stream leaving the MCFC anodes (anode exhaust) contains the CO_2 transferred from the cathodes, unutilized fuel (primarily H_2 and some CO), and water produced in the cell electrochemical process. This CO_2-rich stream enters the Anode Exhaust Cooling unit, where it is cooled and directed to a shift converter to convert the CO to additional CO_2 for capture. The stream leaving the shift converter flows to a condenser where water is recovered for use in the process (includes water feed for humidification of NG, mentioned above). The dried stream then enters the CO_2 Purification/Compression sub-system where it is first compressed in multiple stages with water separation. After the final stage of compression, a chiller lowers the stream temperature to a point at which the CO is a liquid. At this condition, H_2 remains in the gaseous phase and is easily separated from the liquid CO_2. The separation of hydrogen gas from liquid CO_2 occurs in a simple flash drum. The H_2-rich stream is recycled to the process. The liquid CO_2 stream is then pumped to the final delivery pressure (10 MPa) for pipeline transport or sequestration.

4.1.2 Equipment Specifications and Selection

Although the MCFC demonstration system is configured with significant differences compared to FCE's commercial SureSource systems for power generation applications, the system was designed to utilize as much of the same equipment as possible. The following equipment is carried over from the SureSource 3000 power plant as-is or with minor modifications:

- Natural Gas Desulfurizers
- Fuel Humidifier
- Preconverter
- Start-Up Burner
- Fresh Air Blower
- MCFC Stacks
- Power Conditioning System

The Power Conditioning System (PCS) is designed to convert DC electricity produced by the MCFC stacks into AC electricity and feed power to the utility grid. The standard connection voltage is 13,800 volts. Table 1 shows key specifications for the power conversion system. Optionally, custom output voltages can be provided to meet the site requirements (e.g. 4160 V at the Scotford site). However, through consultation with Jacobs and project stakeholders, it was decided to maintain the standard MCFC output voltage. A secondary transformer to meet the customer connection voltage will be supplied by Jacobs if needed.

Table 1: Key Power Conditioning System Specifications

Parameter	Specification
Output Nominal Voltage	3-Phase 13.8 kV AC
Power Conversion Capacity	2800 kW, 3100 kVA Net
Frequency	60 Hz (50 Hz optional)
Output Current Harmonics	< 5% THD
Power factor, max leading	+ 0.9
Power factor, max lagging	- 0.9
Connection Configuration	Grounded Wye
Power Quality	Complies with IEEE 519
Current Applicable Codes & Certifications	UL-1741, CA Rule 21, NEC, IEEE-1547

The PCS also controls the current draw from the MCFC stacks. A major power electronics vendor supplies the PCS in accordance with FCE specifications. The PCS has been independently certified to the requirements of UL 1741 (Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources, 2nd Edition, January 28, 2010). The PCS is also compliant with IEEE 1547, (NEC) NFPA 70, and California Rule 21. Jacobs has reviewed the PCS design information and certifications. Project-specific certification considerations are discussed in Section 4.1.7.

The MCFC modules house the molten carbonate fuel cell stacks, and are the heart of the demonstration system. The modules required for the demonstration system will be identical to those utilized in FCE's newly-released high efficiency power plant product, the SureSource 4000. The SureSource 4000 utilizes three MW-class modules to produce 3.7 MW net AC power at 60 % efficiency (based on the LHV of natural gas). The MW-class modules utilized in the carbon capture system are very similar to those used in FCE's SureSource 3000 product, except with the addition of a piping connection to bring the CO_2-containing anode exhaust out of the module. In the SureSource 3000-type modules, the anode exhaust stream is internally consumed (by recycle to the cathode stream) and therefore does not require an anode exhaust pipe connection. Fortunately, the SureSource 4000 modules are of the same configuration as those needed in the carbon capture demonstration system.

Figure 16 photograph of a MW-class 4-stack module. Four stacks are arrayed vertically within the internally insulated vessel. The vessel also serves as a manifold to route the cathode inlet gases (i.e. flue gas) into the open-face of the MCFC stack. As a safety feature, the vessel is designed to contain a deflagration in the unlikely event that a stoichiometric mixture of fuel (natural gas) and air accumulates within the module and ignites. A fuel Superheater is included as part of the stack module design. The Superheater is a heat exchanger integrated within the stack base plate which serves to superheat the humidified natural gas fuel stream using heat available in the cathode exhaust stream.

Figure 16: MW-Class 4-Stack MCFC Module

The Flue Gas Processing Subsystem includes equipment that has specific requirements for the carbon capture demonstration system. Gas-to-gas heat exchangers are utilized to preheat the incoming flue gas/air blend to the required MCFC cathode inlet temperature. Process specifications were developed for the exchangers, and requests were issued to vendors for preliminary sizing and budgetary costs. Due to the relatively large surface area requirements, shell and tube exchangers are not feasible. Plate-fin type exchangers were selected for this application. The final stage in preheating the flue gas involves mixing and subsequent catalytic oxidation of recycled hydrogen-rich gas from the CO_2 purification subsystem. A monolithic-type catalyst is utilized for this application. The catalyst type, sizing, and budgetary cost were provided by FCE's established supplier for similar oxidizers used in the SureSource 3000 plants.

The Flue Gas Processing Subsystem also includes a flue gas desulfurization system to remove any SO_2 to ppb-levels. The MCFC is susceptible to reduced life if exposed to sulfur levels exceeding certain thresholds in the reactant streams, primarily due to catalyst deactivation over time. Both the Scotford PH and Husky OTSG utilize odorized natural gas in the combustion process, which results in low levels of SO_2 in the flue gas. Although the levels are low (0.1 – 1 ppmv SO_2 expected), the flue gas desulfurization system is included to de-risk the demonstration testing. A solid-sorbent type fixed bed vessel is utilized to treat the flue gas. Given the low levels of SO_2 expected in the flue gas, a disposable (e.g. not regenerable) type system is used. The sorbent is replaced approximately every six months of operation. In commercial embodiments of the MCFC carbon capture technology for natural-gas based flue gases, the natural gas would first be desulfurized before combustion in the host process, eliminating the need for flue gas desulfurization.

Key components of the CO_2 purification subsystem include the CO_2 Compressor, the Chiller (to condense CO_2), and the supercritical CO_2 pump (to achieve 10 MPa delivery pressure). FCE prepared process specifications and issued requests for quotations (RFQs) to several vendors for each piece of equipment. Several major compressor OEMs as well as equipment packagers provided quotations. The key drivers for selection of the compressor vendor were: high efficiency (to maximize the MCFC system power production), operational flexibility and turndown capability, vendor reputation, and cost competitiveness. Multiple quotations were also received for the Chiller and CO_2 pump. The vendor offerings were selected based upon similar criteria as for the CO_2 Compressor.

A key component of the Anode Exhaust Cooling Subsystem is the dry coolers that reject low-level process heat to the atmosphere. The coolers do not require any cooling water supply. Equipment was selected based on a similar design utilized in the SureSource 4000 system. Provisions for extreme winterization, including sufficient insulation, air flow isolation and supplemental heaters, were discussed with the vendor and included in the design.

The carbon capture system includes a small water treatment system that is utilized only during system start-up or standby operating modes. During normal operation, the system is a net producer of condensate-type water. Due to the infrequent use and low capacity requirements of the water treatment system, a simple, low-cost system was selected. The treatment system is comprised of particulate filtration and replaceable (or refillable) mixed-bed deionization tanks. The water treatment system is not needed if de-mineralized water is supplied for start-up operations (Shell site).

4.1.3 Process Simulation Results

Heat and Material Balances (H&MBs) for the MW-Class MCFC-based carbon capture demonstration system were performed using CHEMCAD process simulation software in combination with FCE proprietary models to simulate MCFC performance as a function of operating conditions. H&MBs were developed for 70% and 90% capture cases for each site. Table 2 and

Table 3 show a summary of the system performance, by case, for Site 1: Shell – Alberta and Site 2: Husky – Saskatchewan, respectively.

Table 2: Shell Scotford Upgrader – Alberta (Site 1) System Performance Summary by Case

Performance \ Case	Site 1: Shell – Alberta		
	90% CC	70% CC	Standalone – No Flue Gas
Gross AC, kWe	1674.8	2024.3	2950.8
Net Power, kWe	1231.7	1484.6	2800.4
CEPACS Net Plant Efficiency (LHV Natural Gas), % [1]	36.6	33.8	50.1
Carbon Separation (of C in Flue Gas Slipstream), %	90.0	69.9	-
Carbon Separation (of total C entering system), %	92.5	76.7	-
CO_2 Captured, from Flue Gas (metric tonnes/day)	44.0	51.1	-
Total CO_2 Captured (metric tonnes/day)	60.4	72.4	-
Flue Gas Processed (kg/hr)	16266	24292	-
Fuel Flow (kg/hr)	256.3	334.4	424.8
CO_2 Purity, mol %	99.5	99.5	-

Table 3: Husky Lashburn SAGD – Saskatchewan (Site 2) System Performance Summary by Case

Performance \ Case	Site 2: Husky – Saskatchewan		
	90% CC	70% CC	Standalone – No Flue Gas
Gross AC, kWe	1662.8	2024.3	2950.8
Net Power, kWe	1205.7	1464.9	2800.4
CEPACS Net Plant Efficiency (LHV Natural Gas), % [1]	35.0	32.5	50.1
Carbon Separation (of C in Flue Gas Slipstream), %	90.1	69.9	-
Carbon Separation (of total C entering system), %	92.6	76.8	-
CO_2 Captured, from Flue Gas (metric tonnes/day)	43.8	50.7	-
Total CO_2 Captured (metric tonnes/day)	60.1	72.1	-
Flue Gas Processed (kg/hr)	15170	22639	-
Fuel Flow (kg/hr)	262.0	343.1	424.8
CO_2 Purity, mol %	99.4	99.4	-

1. Excludes Flue Gas Blower (OSBL)

The MCFC system can process more flue gas when operating at a lower carbon capture (70% CC vs. 90% CC). As a result, the 70% CC case actually captures more CO_2 than the 90% CC case, while also generating more power.

The system is also capable of operating in a "Standalone" power generation mode when no flue gas is available or when CO_2 capture is not desired. During this mode, the flue gas supply to the plant is isolated, resulting in no process interaction with the host facility. Within the MCFC system, the CO_2 required at the cathodes for the electrochemical reaction is recycled internally from the anode exhaust stream (similar to the SureSource power generation systems). The CO_2 purification subsystem is not operating and the system is isolated from the CO_2 pipeline. In Standalone power generation mode, the system produces 2,800 kW at 50.1% efficiency.

4.1.4 3-D Model and General Arrangements

The layout of the carbon capture system is shown in Figure 17. It depicts the relative location of the major process equipment in a 50' x 115' area. The highest vertical structure is approximately 30' tall. The major process equipment is organized onto skids and includes the Fuel Cell Modules, Inverter and Switch Gear, the Main Process Skid, the Anode Gas Cooling Skid, CO_2 Purification Skid, CO_2 Compression and Drying Skid, Chiller Skid, Water Handling and Control Skid, Water Cooling Skids and Natural Gas Desulfurization skid.

The arrangement of the skids facilitates efficient pipe routes within the plant footprint and ease of perimeter access to host site utilities for water, natural gas and electrical power interconnections. The system is designed in a modularized skid-based approach. To the maximum extent practical, the process skids will be shop-fabricated, including equipment, piping, instrumentation and control hardware, and electrical wiring. This approach is expected to reduce costs and increase quality.

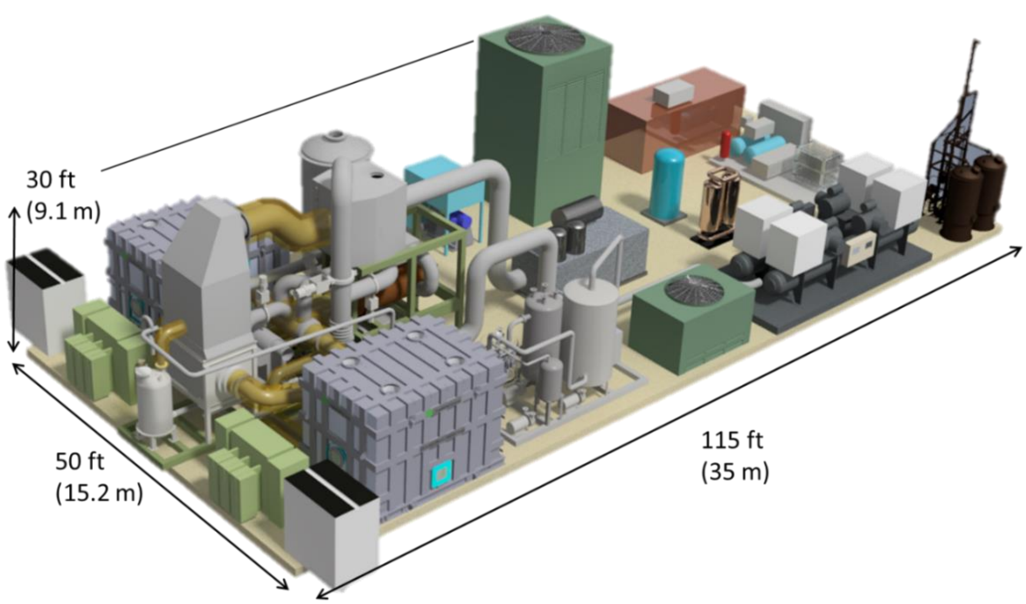

Figure 17: SureSource Carbon Capture System Layout

The principle characteristics that would govern the configuration of the major equipment for each process skid has been evaluated to produce a general footprint and estimate of weight for each skid. These estimated values are summarized in Table 4 below.

Table 4: Plant Process Skid Summary

Skid Name	Estimated Installed Skid Weight (LBS)	Estimated Skid Dimensions (LxWxH)
Natural Gas Desulfurizer Skid	15,000	10 FT x 10 FT x 25.5 FT
Nitrogen Dewar	8,500	4.5 FT x 4.5 FT x 9.5 FT
Main Process Skid	60,000	38 FT x 8.5 FT x 20.5 FT
Anode Gas Cooling Skid	7,000	18 FT x 7.5 FT x 17 FT
CO_2 Compressor	15,000	20 FT x 12 FT x 11 FT
Regeneration Gas Drying/Cooling Skid	4,000	8 FT x 6 FT x 10 FT
CO_2 Chiller Skid	12,000	14 FT x 6.5 FT x 10.5 FT
CO_2 Purification Skid	15,000	12 FT x 10 FT x 6.5 FT
Water Handling and Control Skid	20,000	20 FT x 8 FT x 8.5 FT
Water Cooling Skid	25,000	15 FT x 8 FT x 9 FT
Fuel Cell Module	107,000	20 FT x 13 FT x 13.5 FT
EBOP	26,500	22 FT x 8.5 FT x 8.5 FT

4.1.5 Area Classification

An important aspect of the plant design is the management of equipment relative to the requirements for flammable gases or vapors that are or could be present in quantities sufficient to produce explosive or ignitable mixtures. Due to the presence of hydrogen and natural gas in the process, the layout area has been generally evaluated to identify skids or areas within skids that are associated with a Class 1, Division 1, Group B and Class 1, Division 2, Group B designation. The affected skids have been identified in Figure 18. The equipment and instrumentation located within the classified areas is rated to the appropriate classification.

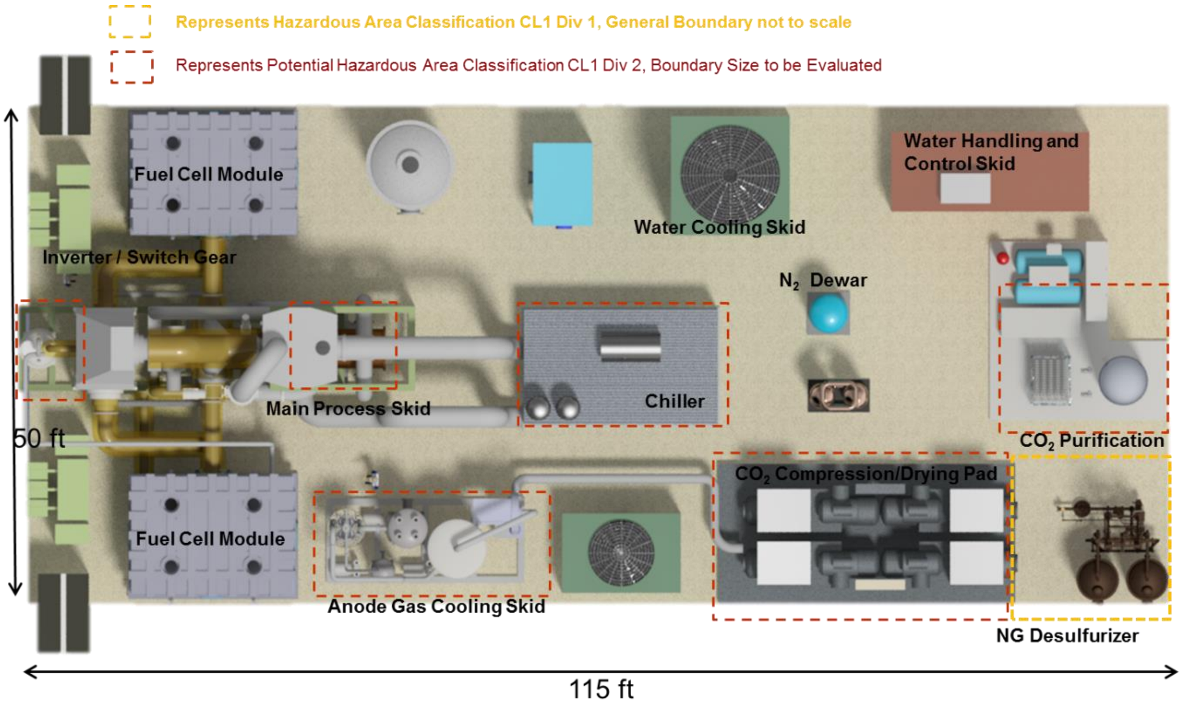

Figure 18: Carbon Capture System Plan View with Preliminary Hazardous Area Classifications

4.1.6 System Interface

The MW-Class MCFC-based system utilizes the typical process and electrical interfaces of a SureSource 3000 power plant, with the addition of a flue gas supply connection and product CO_2 pipeline connection.

Process Connections: The process interconnections for the MW-class MCFC-Based System are as follows:

- Flue Gas
- Supercritical CO_2
- Natural Gas
- Water Supply
- Drains (Qty. 2)
- Nitrogen supply (purge gas)

Communication Connections: Communication connections to the power plant are required to support remote monitoring, alarming, remote diagnostics, and remote control. One internet broadband high speed data connection and one backup analog phone line are necessary to support communications with the power plant. The broadband high speed connection should include a static routable IP address upstream of any firewall and have a minimum bandwidth or data transfer rate of 128 kbps (T1 line preferred). The MCFC system also includes a cellular antenna to broadcast pages from the control system.

A control interface is required between the MCFC system and the interconnection system developed/supplied by EPC. Analog (e.g. 4-20 mA), digital, and/or, other communication protocols (such as wireless I/O) are supported by the MCFC system PLC.

In addition, a MCFC system performance interface will be configured to display key plant parameters such as power output (net and gross), natural gas consumption, water consumption, and CO_2 separation performance.

A port for taking gas samples will also be located in the cathode exhaust line within the MCFC system to periodically confirm the calculated CO_2 capture rate using gas chromatography or other analytical method(s). It is assumed that the analytical instruments required for this analysis are provided by others (not in FCE scope).

4.1.7 Code Compliance and Certifications

FCE's SureSource power plant products are certified to the following standards:

- ANSI/CSA America FC1-2014 (IEC 62282-3-100:2012,MOD) American National Standard For Fuel Cell Power Systems
- UL 1741 Standard for Power Conversion Systems
- CARB 07 California Air Resources Board Distributed Generation Certification Program

In addition, SureSource power plant products comply with the following standards:

- IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems
- (NEC) NFPA 70 National Electrical Code
- California Rule 21 California Grid Interconnection Standard
- ASME Piping and Vessel Codes (as applicable per process conditions)
- OSHA 29 CFR Part 1910 General Industry Standards

FCE has also developed a line of SureSource power plants that conform to the following European Directives and standards:

- Pressure Equipment Directive 97/23/EC
- Machinery Directive 2006/42/EC
- Electromagnetic Compatibility Directive 2004/108/EC
- Stationary Fuel Cell Power Systems EN 62282-3-100

Given the expanded capabilities of the carbon capture system (carbon capture and power generation) and the demonstration-nature of the project, the MCFC carbon capture system will not carry the ANSI/CSA America FC1-2014 nor the CARB 07 certifications.

Based on feedback from project stakeholders, it was determined that additional CSA-C (Canadian mark) certification of the electrical equipment (e.g. the inverter and switchgear) is required for the demonstration plant. During the follow-on design phase, the detailed requirements of the CSA-C certification for electrical equipment will be reviewed. Given FCE's familiarity with CSA certification requirements, and established relationships with leading multi-national electrical equipment OEMs, FCE is fully capable of certifying the demonstration system electrical components to CSA-C standards. CSA field certification programs for select equipment will be explored during the design phase as a method of controlling costs.

4.2 Demonstration Project Cost Estimate

This section presents the Class IV budgetary (+30%/-15%) cost estimates for the MW-class MCFC carbon capture demonstration project at each site. The cost estimate for the Shell site is $21,198,957 for the installed system, with an additional $408,831 estimated for the first year of operation. The cost estimate for the Shell site is $21,190,291 for the installed system, with an additional $408,831 estimated for the first year of operation. A description of the cost items included, methodology and assumptions follows.

Project Management includes labor and periodic travel to manage the project scope, cost, schedule and risk mitigation activities to meet the overall objectives.

Engineering includes all labor to complete the detailed process, mechanical, and electrical design of the system. FCE is currently engaged in the detailed engineering of a MCFC carbon capture system under a Cooperative Agreement with the U.S. Department of Energy. The design is expected to be complete in Q4 2017. Therefore, the engineering costs for the system are significantly lower than if a completely new design was required. There will be some engineering changes to adapt the DOE plant for natural-gas flue gas applications, including: removal of the coal flue gas cleanup system and design of the polishing solid-sorbent flue gas desulfurizer, application-specific engineering such as extreme winterization and revision of the process cooling system, and revisions to the control philosophy and logic programming.

Equipment category includes all packaged skids and "ship-loose" components for inter-connecting the skids at the site. The costs were estimated based on a combination of sources, including vendor quotations for key equipment, FCE's in-house production cost tracking databases for fuel cell modules, prior purchases of carry-over BoP equipment from the SureSource 3000 power plants, and estimates based on prior purchases or quotations for similar equipment in the DOE carbon capture project.

The equipment cost is marginally lower at the Shell site due to the availability of demineralized water, negating the need for water treatment deionization beds in the MCFC system.

Certification category includes engineering labor to review code/standard applicability and requirements, to implement design changes as required, and to manage the certification process with component suppliers and certifying entities. Costs required for component supplier (e.g. inverter) engineering charges, as well certification services (by CSA or others) are included.

Construction/Installation includes all costs to load and transport (via truck) the modules and process skids to the host site. Fabrication was assumed to occur in the East Coast USA area. Budgetary quotations were received from FCE's logistics supplier based upon the plant layouts and skid tables developed. The shipping costs are marginally lower to the Husky site due to slightly reduced travel distance from the eastern U.S.

This category also includes costs to install the skid-to-skid interconnecting piping, wiring, and communications connections. Field insulation and jacketing of the high-temperature lines by a local insulation contractor is included. The estimate was based upon experienced FCE technicians and engineers completing the installation activities. However, local mechanical and electrical contractors could likely be utilized at similar cost.

Commissioning includes on-site engineering and technician labor to commission the plant. Commissioning includes electrical and instrumental loop checks, equipment performance and functional checks, control logic shakedown testing, verification of protection logic and safety systems, culminating with the initial start-up of the system.

Operations includes materials and labor for scheduled preventative maintenance, nitrogen purge gas tank fills, budget for unplanned response by local contractors (or host site personnel), 24-7 remote monitoring of the system, as well as engineering support and periodic data analysis. Utility costs are not included in the estimate.

Preventative maintenance occurs in 6-month intervals and includes flue gas desulfurization media removal (for disposal off-site) and replacement, plant safety system component and functional inspections, equipment inspections and lubrication, periodic natural gas sulfur analysis, air and electrical cabinet filter inspections and change-out, water treatment system consumables replacement and natural gas desulfurization media removal (for disposal off-site) and replacement. Note that not all activities listed are performed during each 6-month maintenance interval.

The testing period was assumed to be one year. That is sufficient time to perform 4-months of parametric testing of operating conditions (e.g. effect of current density, fuel flow rate, carbon capture percentage, internal recycle conditions affecting reactant compositions, CO_2 purification system operating temperature and pressure, and more) followed by a 8-month steady-state hold at the design operating point for the remainder of the test period. The parametric testing will be valuable to determine the MW-class module performance sensitivity at each operating point. However, longer duration testing is required to understand the impact of operating conditions on MCFC lifetime. The one year test period will allow for parametric testing and lifetime data at one test point. Longer-duration testing, discussed in the next section, will enable lifetime testing at multiple operating points.

5 Project Schedule

The project schedule for the 33-month demonstration project is shown in Figure 19. The project schedule benefits from acceleration of the design phase, made possible by FCE's parallel detailed design effort currently underway for its coal-based DOE project.

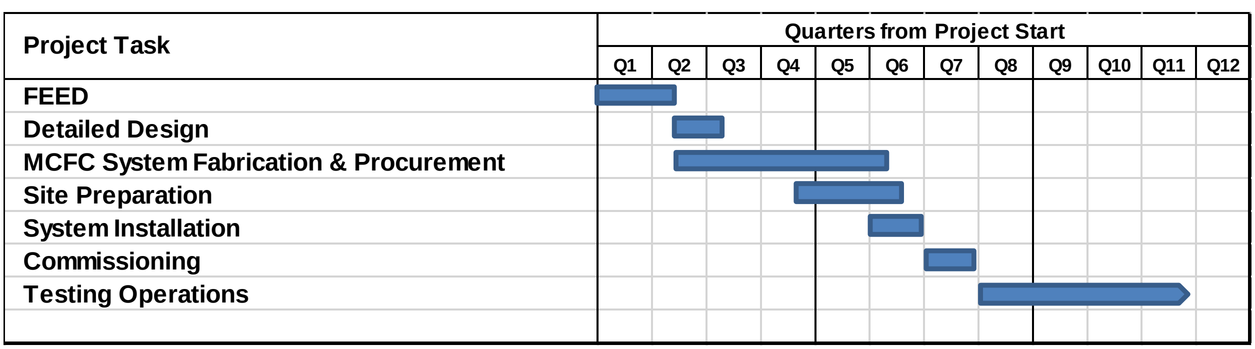

Figure 19: MW-Class MCFC Carbon Capture Demonstration Project Schedule

6 Items Deferred to Next Phases

This section summarizes select items considered in the Pre-FEED phase, which require follow-up actions or decisions in the next phase of the project.

Analysis of the fuel and flue gas streams is required to determine the sulfur species present and the composition of the natural gas. This will provide the data necessary for sizing the desulfurization media. A water analysis is also required to determine the water purification requirements which may include filtration and deionization beds.

An important decision point required in the next phase of the project (or prior to the start of the next phase) is the definition of boundary conditions and monitoring requirements for the carbon dioxide product stream. The boundary conditions include

- Pressure and state of the CO_2 product - gaseous, liquid or supercritical CO_2.
- Purity of the CO_2 product.

If the Husky site is selected to host the project, a trade-off analysis shall be completed to determine the best the method of flue gas desulfurization to ensure that the cathode inlet sulfur concentration meets the requirements of the fuel cell. The two options include desulfurizing the natural gas to the OTSG and desulfurization of the flue gas. A study will be performed to determine the most economical option.

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1.4 MW Molten Carbonate Fuel Cell Demonstration Unit

Shell Scotford Upgrader Host Site

Pre-FEED Study

Prepared for

Alberta Innovates – Clean Energy

May 8, 2017

JACOBS

Project Name

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Document title:	1.4 MW Molten Carbonate Fuel Cell Demonstration Unit Pre-FEED Study
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Contents

List of Acronyms

Acronym	Full Name
AC	Alternating Current
ACCE	Aspen Capital Cost Estimator
ANSI	American National Standards Institute
API	American Petroleum Institute
ATM	Atmospheric
AWG	American Wire Gauge
BFD	Block Flow Diagram
BOP	Balance of Plant
CAC	Criteria Air Contaminants
CAD	Canadian Dollar
CCS	Carbon Capture and Storage
CEC	Canadian Electrical Code
CEPACS	Combined Electric Power and Carbon Dioxide Separation
COSIA	Canada's Oil Sands Innovation Alliance
DC	Direct Current
DCS	Distributed Control System
DEP	Design and Engineering Practices
DP	Differential Pressure
EHT	Electrical Heat Tracing
ESD	Emergency Shutdown
ESTG	Engineering Standards and Technical Guidelines
FCE	Fuel Cell Energy
FDS	Fused Disconnect Switch
FGR	Flue Gas Recirculation
FLA	Full Load Amperes
GC	Gas Chromatography
FEED	Front End Engineering Design
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HDPE	High Density Polyethylene
HMB	Heat and Material Balance
HMU	Hydrogen Manufacturing Unit
HSE	Health Safety Environment
IAP	Interactive Planning
IP	Intermediate Pressure
ISBL	Inside Battery Limits
LED	Light Emitting Diode
LEL	Lower Explosive Limit
LP	Low Pressure
MCC	Motor Control Center
MCFC	Molten Carbonate Fuel Cell
MMSCF	Million Standard Cubic Feet
MTO	Material Take Off
OSBL	Outside Battery Limits
OTSG	Once Thru Steam Generator
PFD	Process Flow Diagram
PLC	Programmable Logic Controller
PO	Purchase Order

Acronym	Full Name
PSA	Pressure Swing Adsorber
RCC	Recovered Clean Condensate
RTD	Resistance Temperature Detectors
SAFOP	Safe Operability
SCADA	Supervisory Control and Data Acquisition
SLD	Single Line Diagrams
SMR	Steam Methane Reformer
TIC	Total Installed Cost
UPS	Uninterruptible Power Supply
USD	United States Dollar
VFD	Variable Frequency Drive
VPN	Virtual Private Network

Executive Summary

Alberta Innovates – Clean Energy has a vision that Alberta will lead the world in developing innovative energy and environmental techniques building on our natural advantages to achieve a prosperous, environmentally and socially sustainable diversified economy. One of Alberta Innovates' focus areas is to develop low cost carbon capture technologies to help achieve Alberta's greenhouse gas (GHG) emission reduction goals.

In 2012, Alberta Innovates' predecessor corporation Alberta Innovates – Energy and Environmental Solutions (AI-EES) introduced a molten carbonate fuel cell (MCFC) technology to the oil sands industry in Alberta. Since then, Alberta Innovates – Clean Energy has led two joint industry projects to evaluate the potential of a MCFC for carbon capture called a Combined Electric Power and Carbon-dioxide Separation (CEPACS) Unit at SAGD facilities. The results have been very encouraging and the final reports are available on the Alberta Innovates website.

Alberta Innovates – Clean Energy, a number of Canada's Oil Sands Innovation Alliance (COSIA) members, and other oil sands producers are initiating a new project to further understand the cost of using an MCFC for carbon capture at a bitumen upgrading or refining facility (MCFC-4CC-PH) and at a steam-assisted gravity drainage (SAGD) facility (MCFC-4CC-SAGD).

Fuel Cell Energy (FCE) was engaged by Alberta Innovates to complete the pre-FEED design and cost estimate for the MCFC module and its balance of plant (BOP). Jacobs' scope included outside of the FCE battery limit, which involves integration of the FCE package into the host site. The preliminary design and Class IV cost estimate (+30%/-15%) for the installation of the demonstration unit were developed as part of the Pre-FEED study. Due to the temporary nature of the demonstration unit, deviations from host site specifications were considered as part of the preliminary design and cost estimate.

Facilities broadly consist of the Fuel Cell Module and Process BOP skids and Electrical BOP skids supplied by FCE for their Inside Battery Limit (ISBL) scope. The Outside Battery Limit (OSBL) scope mainly consists of the following

a) **Flue Gas supply** - A slip stream of flue gas through a 24" duct from the Steam Methane Reformer (SMR) stack in the Hydrogen Manufacturing Unit (HMU-2). A new flue gas blower with VFD and flow meter will be used to boost the flue gas pressure to the required supply pressure.
b) **Natural Gas supply** - 2" CS natural gas line (ANSI 150) from odorized gas supply line going to the Quest compressor building including flowmeter, pressure control valve and pressure safety valve.
c) **Demin Water supply** – ¾" Pre-insulated/pre-traced tube bundle from the suction of the demin water pumps in Quest unit.
d) **Produced Water return** – ½" Pre-insulated/pre-traced tube bundle to Quest unit CO_2/dehydration catchment sump.
e) **Civil works** – includes foundations for the individual FCE supplied skids in addition to the OSBL scope.
f) **Electrical** – 600V power supply and MCC section for the new flue gas blower, new 5kV MCC section, 4160V/480V transformer, interconnecting cables, power for electric heat tracing, grounding and lighting for FCE skids.
g) **Communications** between host site control systems and FCE PLC, including Ethernet and phone cable for remote monitoring by FCE.
h) **Liquid CO_2 return (optional scope)** – 2" SS line (ANSI 1500) from FCE skid to Quest unit compressor discharge. Scope and cost estimate for the CO_2 return downstream of the FCE package battery limit was not part of the Pre-FEED study; however, the costs to install the line are broken out and presented for reference only.

The total estimated cost for the OSBL scope of work (Jacobs scope) is **$2,792,779**.

The above costs include a future escalation of 3% and contingency of 20%.

The total estimated cost for the ISBL scope of work (FCE scope) including all interconnections between individual skids and freight to site was estimated by FCE and is **$27,444,807** CAD ($21,111,390 USD).

Total capital cost for the Project is **$30,237,586**.

Costs for removal / demolition of the demonstration unit are estimated at **$1,097,177** for the OSBL and ISBL scopes.

Annual operating costs for the project are estimated at $624,124 (Host site to confirm site specific utility and operator costs). This includes mainly utility costs for Natural gas, FCE and Shell operations costs and cost credits for Electrical power generated by the Fuel Cell. Absorbent bed, desulfurization bed and filter element change outs are not included in the operating costs as it is expected that no change outs would be required for the anticipated 1 year testing period based on discussions with FCE.

1. Introduction

Alberta Innovates – Clean Energy has a vision that Alberta will lead the world in developing innovative energy and environmental techniques building on our natural advantages to achieve a prosperous, environmentally and socially sustainable diversified economy. One of Alberta Innovates' focus areas is to develop low cost carbon capture technologies to help achieve Alberta's greenhouse gas (GHG) emission reduction goals.

In 2012, Alberta Innovates' predecessor corporation Alberta Innovates – Energy and Environmental Solutions (AI-EES) introduced a molten carbonate fuel cell (MCFC) technology to the oil sands industry in Alberta. Since then, Alberta Innovates – Clean Energy has led two joint industry projects to evaluate the potential of a MCFC for carbon capture called a Combined Electric Power and Carbon-dioxide Separation (CEPACS) Unit at SAGD facilities. The results have been very encouraging and the final reports are available on the Alberta Innovates website.

Alberta Innovates – Clean Energy, a number of Canada's Oil Sands Innovation Alliance (COSIA) members, and other oil sands producers are initiating a new project to further understand the cost of using an MCFC for carbon capture at a bitumen upgrading or refining facility (MCFC-4CC-PH) and at a steam-assisted gravity drainage (SAGD) facility (MCFC-4CC-SAGD).

The Shell Scotford Upgrader near Fort Saskatchewan, Alberta is a potential host site considered for the installation of the MCFC demonstration plant. The proposed MCFC will capture CO_2 from the flue gas off a Steam Methane Reformer (SMR) stack where it is then compressed and injected into offsite storage facilities. The MCFC plant will be capable of capturing up to 90% of the CO_2 in the flue gas being treated. The gross power output for the proposed MCFC can be as high as 1.4 MW. The demonstration plant is anticipated to operate for a minimum of 1 year to evaluate its performance.

Fuel Cell Energy (FCE) has been engaged by Alberta Innovates to complete the pre-FEED design and cost estimate for the MCFC module and its balance of plant (BOP). Jacobs scope is outside of the FCE battery limit, which involves integration of the FCE package into the host site. The preliminary design and Class IV cost estimate (+30%/-15%) for the installation of the demonstration unit are given in the following sections of this document. Due to the temporary nature of the demonstration unit, deviations from host site specifications were considered as part of the preliminary design and cost estimate.

Broadly, the scope of work for the pre-FEED consisted of:

a) Preparation of Project Design Basis
b) Process Flow Diagram (PFD) and Mass Balance Tables
c) Preliminary Equipment Sizing and Preparation of Equipment List
d) Plot Plan
e) Preliminary Control Philosophy
f) Obtaining budget pricing from vendors for major process equipment
g) Preparation of preliminary sketches and preliminary MTOs for estimation purposes
h) Preparation of Class IV cost estimate.

The Process Design Basis, Process Flow Diagrams, Mass Balance Table, Preliminary Plot Plan, Mechanical Equipment List and discipline sketches used for supporting the cost estimate are given in the Appendices of this report for reference.

Based on direction from Alberta Innovates, due to differences in the CO_2 integration between the two host sites, for the current scope for the Pre-FEED, FCE will design for a 10 MPa supercritical CO_2 stream at their battery limits but is not tied into a disposal system. For the Pre-FEED study and cost estimate, the supercritical liquid CO_2 scope ends at the battery limit of the FCE package. However, for the purpose of comparison, tying the CO_2

stream into the Quest unit pipeline was considered and a high level cost associated with this was evaluated and is presented in the study report.

2. Process Description / Control Philosophy

A representative Block Flow Diagram (BFD) for the MCFC and BOP showing the scope demarcation is shown in Figure 2.1.

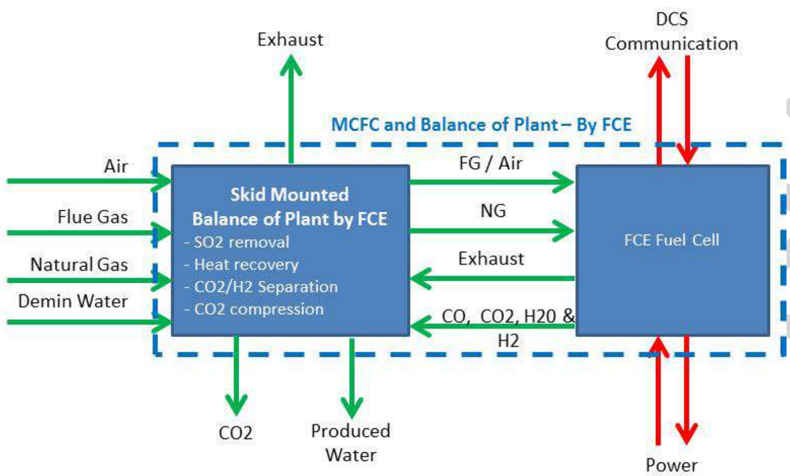

Figure 2.1 – MCFC Block Flow Diagram

2.1 BOP and MCFC Modules (ISBL)

A high level BFD depicting the MCFC system is shown in Figure 2.2.

The reactions that take place within the MCFC are listed in Equations 2.1, 2.2, and 2.3.

The cathode reaction is:

$CO_2 + 1/2O_2 + 2e^- \rightarrow CO_3^{2-}$ Eq. 2.1

The anode reactions are:

$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$ (Internal Reforming) Eq. 2.2

$H_2 + CO_3^- \rightarrow H_2O + CO_2 + 2e^-$ Eq. 2.3

Flue gas is treated to remove sulfur contaminants (mainly SO_x) using a high temperature solid absorbent bed prior to being heated and combined with supplemental air provided by a blower. The mixed flue gas / air stream is heated and routed to a catalytic oxidizer where it is combined with a hydrogen recycle stream that was separated from the product CO_2. The hydrogen is oxidized on the catalyst to increase the flue gas temperature required by the MCFC (550°C to 650°C). The hot stream exits the oxidizer and is routed to the cathode side of the fuel cell. CO_2 from the flue gas is transferred from the cathode to the anode. The CO_2 depleted stream exiting the fuel cell cathode is used to preheat the natural gas and flue gas streams and for heat integration in the adsorption refrigeration system before exiting the system through the exhaust stack.

Natural gas is supplied as a supplementary fuel to the MCFC anode. The natural gas feed is routed through a desulfurization bed to remove all organic and inorganic sulfur species that could damage the electrodes. The desulfurized natural gas is humidified using recovered process water (or demin water during start-up or hot stand-by mode) before being routed to the fuel cell. Methane in the natural gas stream is internally reformed in the fuel cell to generate hydrogen which is the fuel required on the anode side of the fuel cell. The fuel cell generated DC power which is converted to AC power using an inverter.

The CO_2 rich stream (mostly CO_2 with H_2, water and CO) exiting the anode is cooled and routed to a low temperature shift converter to convert CO to additional CO_2. The outlet of the shift converter is routed to a condenser where water is recovered. The condenser outlet is then compressed in multiple stages before being chilled to a point where the CO_2 is a liquid to separate the residual hydrogen.

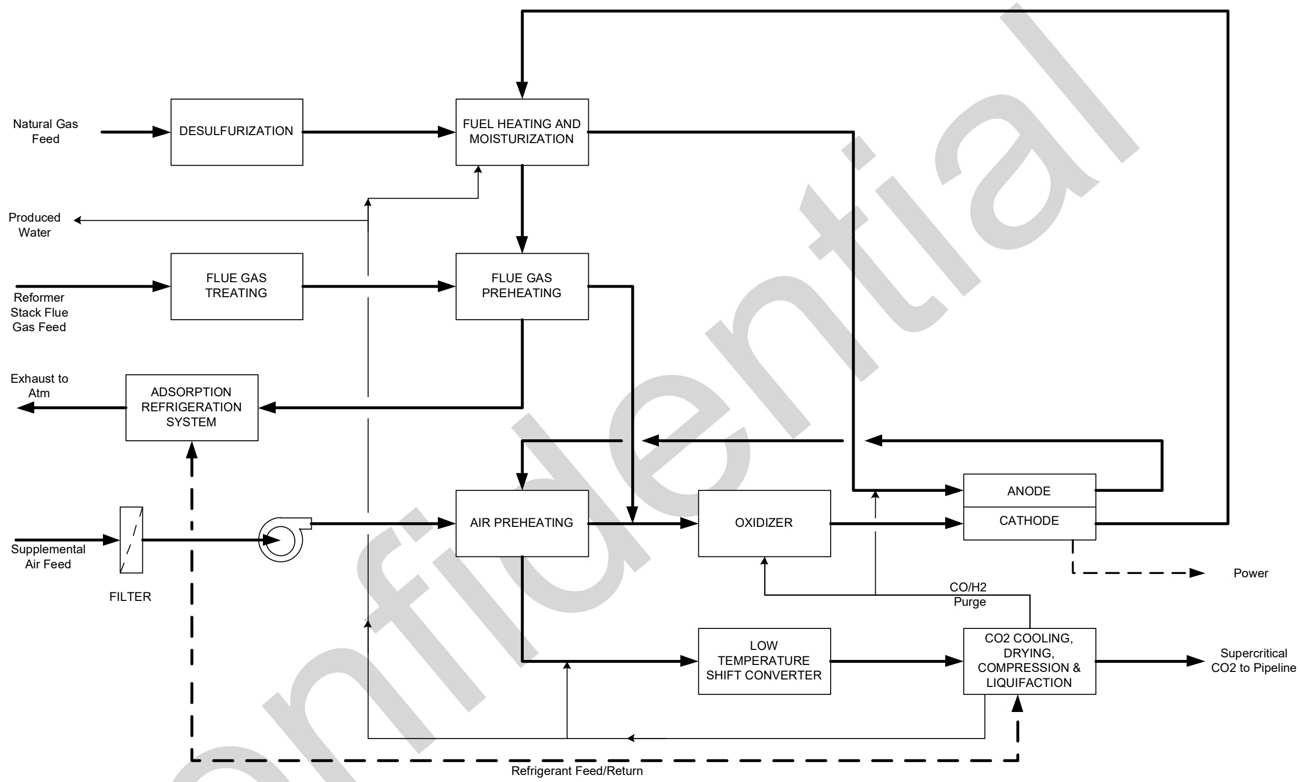

Figure 2.2 – CEPACS BFD

2.2 OSBL

The Process Flow Diagrams (PFD) and Material Balance tables are given in Appendix A.

A slip stream of the flue gas from the Hydrogen Manufacturing Unit HMU-2 Steam Methane Reformer (SMR) stack, S-24203, will be routed to the BOP and MCFC modules. Due to the distance of the stack from the proposed location and battery limit pressure requirements of 2 to 3 psig (14 to 21 kPag) for the fuel cell skid, a blower will be provided near the HMU stack area. An isolation damper will be provided on the blower suction to isolate the system from the reformer stack during shutdown conditions. A flow meter will be provided on the blower discharge. Flue gas flow to the MCFC will be controlled by a VFD on the blower.

Natural gas supply line will be connected to an odorized natural gas header that supplies fuel to the nearby compressor building (R-24701) heaters and air handling units at the Quest Carbon Capture facility. A pressure regulator, flow meter and pressure relief valve will be installed on the natural gas line.

Demineralized water will be used for start-up purposes and will be routed from the supply header upstream of the Demin Water Supply Pumps, P-24610A/B to the MCFC module.

The produced water from the FCE package will be routed to the nearby CO_2 /Dehydration area catchment sump.

The captured CO_2 product integration downstream of the FCE package battery limit into the existing site is outside the scope of this current pre-FEED study. However, it is anticipated that this stream will be tied into the existing Quest Carbon Capture and Storage (CCS) unit. The costs associated with installing a line tying into the existing Quest CCS unit have been broken out separately in the study report for comparison purposes. The captured CO_2 will be pumped to pipeline pressure within the MCFC module to tie-in to the discharge of the final stage compressor, C-24701H, within the Quest unit. The captured CO_2 from the MCFC skid would be routed via pipeline to a sequestration facility along with the CO_2 from the Quest unit.

2.3 Control Philosophy

The MCFC and BOP skids will be controlled by a local PLC / control panel provided by FCE within the skid boundaries. FCE will also be remotely monitoring the skids and be able to control it remotely when required. FCE's standard design for the MCFC system is a highly automated system which is capable of running autonomously with minimal local operator intervention or monitoring. It is anticipated that remote monitoring of the unit by FCE combined with local operator collaboration as required will be done to ensure safe and smooth operation at all times.

The flue gas flow rate to the MCFC module will be measured with a flow meter downstream of the flue gas blower. The flue gas flow rate will be set based on a flow set point signal from the FCE package and will be controlled by a VFD on the blower.

A flue gas damper will be in place upstream of the flue gas blower to isolate the system from the reformer stack during a system shutdown. The reformer stack is equipped with an analyzer that measures NOx. FCE indicated that a CO_2 analyzer on the flue gas line may be required, and will be included and housed inside the FCE BOP.

It is anticipated that the fuel cell control panel will require a start permissive from the host site when flue gas and the CO_2 pipeline is available. If flue gas or the CO_2 pipeline is not available, the fuel cell will operate in stand-alone power generation mode where it only requires natural gas, air and water to produce power. A hard-wired emergency shutdown (ESD) signal from the host site will override the controls of the fuel cell and a shutdown sequence will be initiated.

An on/off valve on the CO_2 product line was included as part of the separate CO_2 product line cost estimate. The valve would be used to isolate the MCFC skid from the CO_2 pipeline during a system shutdown. When the downstream CO_2 disposal system is not available, the produced CO_2 will be vented from the MCFC skid through the exhaust stack to the atmosphere. Note that this would only occur only during the time the MCFC skid switches from carbon capture mode to stand-alone power generation mode. Switching between operating modes is fully automated in the standard FCE design.

Combustible gas detectors for the skid areas will be provided by FCE and will be set up to trip the unit upon detection of lower explosive limit (LEL). Requirement for high CO and / or CO_2 detectors and low O_2 detectors near the CO_2 vent and liquid CO_2 areas will be evaluated during FEED phase.

Continuous online analyzers for CO_2 product quality are currently not included in FCE design to keep the design cost effective. Based on discussions with FCE, it is anticipated that this will be estimated indirectly using pressure and temperature and discrete sampling and laboratory Gas Chromatography (GC) analysis.

3. Project Design Basis

The project design basis is detailed in a separate document attached in Appendix B. A summary of the feed rates, composition and conditions are presented in this section.

3.1 Flue Gas

The MCFC and BOP have been specified to capture 70% and up to 90% CO_2 in the flue gas. The 70% capture case is the governing case for design in terms of flow rates. The flow rate range for testing of the demonstration unit is anticipated to be in the range of 25% - 110% of flue gas requirement for the 70% CO_2 capture flow rate. The flue gas flow rates are shown in Table 3.1. [redacted]

Table 3.1 – Flue Gas Rates

	Units	Turndown Case	90% CO_2 Capture	70% CO_2 Capture	Design Case
Flue Gas Flow	Sm^3/hr	2,552	6,571	10,208	11,229

The flue gas compositions are shown in Table 3.2. The cases shown cover the range of CO_2 expected in the flue gas. The Flue Gas Recirculation (FGR) 30% Load case is based on 100% CO_2 removal from the Pressure Swing Adsorber (PSA) feed. The 100% FGR Load case is based on 82.4% CO_2 removal from the PSA feed. The average amount of NOx measured and composition of the stack gas sample analysis obtained from Shell is also shown for comparison.

Note that the O_2 level in the stack gas sample is higher than the other cases shown. The O_2 level is to be clarified during FEED phase as it affects the air blower design within FCE's module.

SO_2 values in Table 3.2 were based on a rough estimate provided by Shell. An analysis was received; however, it included only trace sulphur components. An analysis for SO_2 will need to be completed during the FEED phase. FCE design has considered provision of a high temperature sorbent bed for removal of SOx from the flue gas.

Table 3.2 – Flue Gas Composition

Component	Units	FGR 30% Load	FGR 100% Load	Lab Sample
N_2	mol %	68.54	66.66	69.9 – 71.2
O_2	mol %	2.98	1.70	4.1
CO_2	mol %	7.45	9.80	7.4 – 8.4
H_2O	mol %	20.22	21.06	16.2 – 17.9
Argon	mol %	0.81	0.78	-
SO_2	ppm	1	1	HOLD
NO_x	ppm	< 60	< 60	51.8

The flue gas operating parameters are shown in Table 3.3.

Table 3.3 – Flue Gas Operating Parameters

	Units	Norm	Max	Design
Temperature	°C	150 [Note 1]	172 [Note 2]	250 [Note 3]
Pressure	kPag	Atm	Atm	Atm

Notes:
1. Based on Uhde HMU HMB Table (100% FGR Load with 82.4% CO_2 removal from PSA Feed)
2. Based on maximum temperature shown from stack gas analysis received from Shell
3. Based on stack mechanical design temperature

3.2 Natural Gas

Natural gas will be supplied from a nearby odorized natural gas header that feeds the unit heaters and air handling unit in the compressor building at the Quest unit. Other options for natural gas evaluated in the pre-FEED include the main low pressure (LP) and intermediate pressure (IP) headers within the HMU and Cogen units, respectively. Obtaining natural gas from these locations will result in longer piping runs for the natural gas supply line to the FCE unit. The odorized natural gas header was selected due to the proximity to the proposed location of the MCFC skid. A natural gas desulfurizer is considered in FCE's design to remove the trace sulfur components that are in the natural gas supply. A trace sulfur analysis will be required during FEED stage to confirm the amount of sulfur contaminants in the natural gas.

The natural gas flow rate required to the feed the MCFC skid is 228 Sm^3/hr. In stand-alone power generation mode, the natural gas flow rate required is 278 Sm^3/hr.

The operating pressure, temperature and composition of the odorized natural gas are to be confirmed during the FEED stage.

3.3 Demineralized Water

Demineralized water is used for start-up purposes and will be supplied from the suction side of the Demin Water Supply Pumps, P-24610A/B. The operating parameters for the Demin Water are shown in Table 3.4.

Table 3.4 – Demineralized Water Operating Parameters

	Units	Min	Norm	Max	Design
Temperature	°C	5	25	35	45
Pressure	kPag	416	416	750	750
Flow Rate	m^3/hr	-	1.2	-	-

Due to the high quality of the Demin water available at site, additional water treatment will not be required within the FCE unit. Recovered Clean Condensate (RCC) was also considered as a potential water source for the MCFC skid due to its proximity to the proposed MCFC skid location. [redacted] which is unsuitable for FCE's standard water storage tank and piping which is made of high density polyethylene (HDPE). [redacted] FCE indicated that a detailed water analysis would be required to determine the water treatment scope within the BOP skid. For the purpose of the pre-FEED cost estimate, the demin water supply was selected as the tie-in location for water supply to the FCE unit.

3.4 Produced Water

The produced water stream is mainly water with small amounts of dissolved CO_2 (Based on FCE's input, a pH of ~ 5 would be expected for this stream). During normal operation, a portion of the produced water is used as make-up water to the plant allowing the demineralized water to be used for start-up purposes only.

FCE base design will be based on a high temperature solid absorbent bed for removal of SOx instead of a caustic scrubber; therefore, there is no additional waste water stream.

The estimated flow rate for the produced water is 0.45 m^3/hr.

3.5 Carbon Dioxide

The captured CO_2 product OSBL scope is outside the scope of this current pre-FEED study; however, the costs associated with installing a line tying into the Quest CCS unit were broken out as a separate item for comparison.

The composition of the captured CO_2 product stream from the MCFC system is shown in Table 3.5.

Table 3.5 – Captured CO_2 Composition

Component	mol %
CO_2	99.5
CO	0.1
H2	0.3
N2	0.1

The captured CO_2 stream composition meets the existing CO2 pipeline specifications [redacted] The water content specification is a maximum of 6 lb per MMSCF during summer months and a maximum of 4 lb per MMSCF during the required periods of the remaining seasons with ambient temperatures up to approximately 20°C.

[redacted]

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

3.6 Exhaust

The exhaust stream from the MCFC module is vented through the stack provided by FCE. Note that 70% of the NOx in the flue gas would be converted to nitrogen by the fuel cell. The exhaust stream composition is shown in Table 3.7.

Table 3.7 – MCFC Exhaust Stream Composition

Component	Units	70% CO2 Capture	90% CO2 Capture
CO_2	mol%	1.9	0.7
H_2O	mol%	15.3	15.6
N_2	mol%	77.6	79.1
O_2	mol%	5.0	4.4
Argon	mol%	0.2	0.2
NOx	ppm	< 18	< 18

3.7 Nitrogen

A micro bulk liquid nitrogen tank with a vaporizer will be provided as part of FCE's standard design. The MCFC requires a nitrogen purity of 99.995 mol % with only 2 ppm O_2 (max).

[redacted] During FEED stage, the O_2 level will be confirmed to determine if the site nitrogen supply could be used to lower the FCE skid footprint and whether the micro bulk liquid nitrogen tank and vaporizer can be removed from the scope.

3.8 Cooling Water

Cooling water is available from the main header within the Quest unit. [redacted] Cooling water could potentially be used as an alternative to air cooling to help in reduction of the foot print of the FCE unit.

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

3.9 Instrument Air

Based on discussions with FCE, instrument air will not be required for the MCFC and BOP skids as all skid mounted control valves will be electrically actuated,.

Instrument air from the existing distribution system at the HMU and Quest units will be used to actuate all OSBL on/off valves as required. [redacted]

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

3.10 Flare System

The relief discharge from the BOP and MCFC skids is expected to be small (~ 6 m^3 of vented gas) with a composition similar to natural gas and will be vented to atmosphere at a high point. A connection to the site flare system is not required.

3.11 Potable Water

Potable water for safety showers and eye wash stations is not required since a high temperature solid absorbent bed will be used for removal of SO_x from the flue gas instead of a caustic scrubber.

3.12 Fire Water

Based on discussions with FCE, there are no specific requirements for fire water or specialty protection for the ISBL area. It should be noted that fire water is available at site from nearby hydrants.

4. Plant Performance

4.1 Fuel Cell Performance Summary

The fuel cell performance is based on the net power output, CO_2 separation capacity and percentage. The fuel cell performance summary is shown in Table 4.1 for the 70% and 90% CO_2 capture scenarios. Note that the OSBL blower load is included in the system net power value. The ISBL system auxiliary loads consist of the air blower, anode blower, compressor, CO_2 pump, condensate pump, aerial cooling and chiller, transformers losses and miscellaneous losses.

The gross power with the CEPACS unit operating is less than the specified 1.4 MW gross power output since CO_2 affects the current density and de-rates the power output. The 1.4 MW gross power output is achievable when the fuel cell operates in stand-alone mode (power generation mode) when the fuel cell is consuming natural gas, air and water only. The fuel cell would be in this mode only during start-up or if the flue gas source or CO_2 disposal system was not available. The fuel cell performance for the stand-alone case is also shown in Table 4.1.

Table 4.1 – Fuel Cell Performance

	70% CO2 Capture	90% CO2 Capture	Stand Alone
MCFC Module Power, Gross AC, kWe	1,004.9	831.4	1,475.4
ISBL System Auxiliary Loads, kWe	269.2	221.8	75.2
OSBL Loads (Blower), kWe	160	112	-
Overall System Net Power, kWe	575.7	497.6	1,400.2
Carbon Separation Percentage (of C in Flue Gas)	70.1%	90.1%	-
Carbon Separation Percentage (of total C entering system)	76.8%	92.5%	-
CO_2 Captured, Total, tonnes / day	36.2	30.2	-
CO_2 Purity, mole %	99.5%	99.5%	-

5. Plot Plan

5.1 Location

The preliminary foot print required for the MCFC and BOP module is 30.5 m x 14.2 m (100 ft x 50 ft).

Four location options were considered during the pre-FEED:

Option 1 – SE corner of the Quest unit
Option 2 – South of the HMU near "H" Street
Option 3 – NW corner of the HMU near "F" Street and 9th Avenue
Option 4 (Initial Location Proposed by Shell) – NE of the Quest unit near the Cogen Area

It was decided that the initial location proposed by Shell (Option 4) was too far away from the tie-ins required and would require additional infrastructure in order for the location to be viable. The location was ruled out during the initial site visit due to the higher costs associated with this option.

The other 3 location options were evaluated from an integration, cost, and access point of view. [redacted]

Based on the high level cost comparison and further discussions with Shell, Option 1 (SE corner of the Quest unit) was selected as the basis for further development of the Pre-FEED study. This is the preferred option from an overall integration and operation point of view and keeps the fuel cell demonstration unit within the existing Quest area.

[redacted]

5.2 Integration with Existing Facilities

Due to the temporary nature of the demonstration unit, deviations from host site specifications were considered as part of the preliminary design when possible based on direction received from the host site to lower costs.

5.2.1 Flue Gas Tie In

Flue gas will be routed from the HMU-2 reformer stack, S-24203, to the MCFC skid using mainly 24" circular pre-insulated ducting (See Piping Scope Section for details). Initially, the flue gas tie-in was located on the main stack and would be need to be completed during a planned March 2018 outage. Based on discussion with Shell operations, the tie-in point was relocated to downstream of the isolation damper to the existing Flue Gas Recirculation (FGR) Blower suction. This allows the tie-in to be done without shutdown of the entire HMU unit. Preliminary hydraulic checks were done for the common section of ducting which would see the combined flow of the FGR blower and the new blower feeding the FCE unit. It was found that the pressure drop increase in this section is very small and no impact on the existing FGR blower performance is expected.

5.2.2 Natural Gas Tie In

A 2" low temperature carbon steel pipe will be routed from the odorized natural gas header to the MCFC skid. The tie-in point will be located upstream of the existing flow meter and pressure regulator to ensure that the capacity of the instruments is not exceeded with the additional natural gas load. An existing ¾" drain valve will be used for the tie-in; therefore, no shutdown is required to implement this tie in. A separate flow meter and pressure control valve will be provided on the new natural gas supply line to the FCE unit.

5.2.3 Demineralized Water Tie In

Demin Water will be routed to an HDPE storage tank within the MCFC skid using ¾" pre-insulated and heat traced tubing. An existing 1" drain valve will be used for the tie-in. The tie-in is located upstream of the Demin Water Supply Pumps and the bypass valve, HV-027, ensuring that Demin Water would still be available even when the pumps are out of service. Pre-insulated and pre-traced tube bundle is considered for water lines instead of hard piping to minimize material and construction costs.

The option of using a temporary hose connection instead of a permanent water connection was reviewed, but was ruled out based on discussions and inputs from FCE. FCE has a strong preference for a permanent water connection and recommended leaving it in place to allow the fuel cell to operate in stand-alone mode and keep the entire system hot under any host site upset conditions. The concern is mainly around system cool down and restarting resulting in additional stress on the system due to temperature swings. Note that a cold start-up period may last up to 4 days as the MCFC needs to warm up to 550°C - 650°C. The standard storage tank within the MCFC skid is 1000 gallons and would need to be filled frequently or potentially increased in size for a situation when the fuel cell operates in hot standby mode without a permanent water connection.

5.2.4 Produced Water Tie In

The produced water will be routed to the nearby CO_2 /Dehydration area catchment sump using ½" pre-insulated and heat traced tubing. The catchment routes the area drains to the storm water system and then eventually routed to Waste Water Treatment Plant 271.

5.2.5 CO_2 Tie In

The CO_2 product line optional scope is based on routing a 2" (ANSI 1500#) stainless steel line to the CO_2 compressor area within the Quest unit. The captured CO_2 will be pumped to pipeline pressure within the MCFC module to tie-in to the discharge of the final stage compressor, C-24701H.

Since the proposed tie-in location is downstream of the existing analyzer fast loop take off (located on the compressor 7^{th} stage KO drum) and downstream of the pipeline custody transfer flow meter (FT-004), FCE will provide the necessary instrumentation within the MCFC skid to measure the flow rate and to ensure that the captured CO_2 meets pipeline specifications.

The 3^{rd} stage knockout drum was discussed during the pre-FEED as a potential destination for the captured CO_2. The CO_2 pressure at the MCFC skid boundary would need to be lowered from supercritical conditions to the operating pressure of the 3^{rd} stage knockout drum to minimize the cooling effect of flashing liquid CO_2 and avoiding freezing conditions.

Since CO_2 is supercritical at the MCFC skid boundary, introducing the supercritical phase directly into a knockout drum may require an atomizing spray nozzle to reduce the liquid droplet size in order to improve the cold liquid / warm vapour contact and allow for rapid vaporization of the liquid.

Further evaluation will be completed during the FEED phase to confirm the final tie-in location for CO_2 [redacted]

5.2.6 Cooling Water Tie In

The costs for providing cooling water to the MCFC and BOP skids were broken out as a separate item for comparison as the other host site at Lashburn does not have cooling water and would require aerial coolers.

The maximum cooling load for the MCFC and BOP skids is 1.2 MW. The cooling water rate was estimated to be 28.7 m^3/hr, [redacted]

A 3" line would be required for both the cooling water supply and return lines. An existing 1½" vent located on the suction side of the Cooling Water Booster Pumps, P-24611A/B, would be used for the cooling water supply tie-in. A hot tap would be required for the tie-in on the cooling water return header.

It is anticipated that using cooling water in shell and tube exchangers instead of aerial coolers would result in a smaller footprint and cost reduction for the MCFC and BOP module.

5.2.7 Battery Limits

Battery limit requirements for the main process lines were provided by FCE. The battery limit table developed for the pre-FEED is located in Appendix D.

5.2.8 Electrical Tie-Ins

The Shell Scotford Upgrader site has a dedicated natural gas fired cogeneration plant [redacted] located at site which is owned and operated by ATCO Power. Under normal operation in carbon capture mode the net export power from the MCFC unit is in the range of 410 to 535 kW [redacted] With the MCFC unit operating in stand-alone mode, the net power export will be 1.4MW [redacted] With the export of power from the MCFC unit, the Cogen load will accordingly get slightly reduced. If the MCFC unit is out of operation, the load on the Cogen would be back to existing operation. From an electrical perspective, the impact of the MCFC unit on the existing plant is minimal.

A detailed description and scope for the electrical tie-ins are presented in Section 9 of this report.

6. Process / Mechanical Scope

6.1 Line Sizing

Jacobs in-house spreadsheet was used to size the gas and liquid lines between the MCFC system and the site tie-ins. Velocity recommendations in Shell DEP 31.38.01.11 were referenced for line sizing.

A summary of the line sizing is shown in Table 7.1.

Table 7.1 – Line Sizing Summary

System	Size	Design Flow	Velocity (m/s)	DP (kPa/100m)
Flue Gas	24"	11,229 Sm^3/hr	15.5	0.28
Natural Gas	2"	308 Sm^3/hr	17.3	10.1
Demin Water	¾" Tubing	1.2 m^3/hr	0.8	60.2
Produced Water	½" Tubing	0.45 m^3/hr	1.0	132.6
CO_2	2"	1.8 m^3/hr	0.2	1.1
Cooling Water	3"	28.7 m^3/hr	1.7	35.9

6.2 Cold Weather Operation Considerations

Electrical heat tracing (EHT) with a hold temperature of 10°C was specified for freeze protection on the water lines.

Low temperature carbon steel is considered for the natural gas line.

Aerials coolers are to be winterized if there is a potential for freezing.

The flue gas water dew point is ~ 57°C as estimated by HYSYS. Based on the operating temperature and size of the flue gas ducting, 2" heat conservation insulation was considered for the Pre-FEED based on the insulation tables in the Shell ESTG. This will be re-evaluated against the DEP during the FEED. When the flue gas line is shut down for long durations in cold weather, it is expected that water may condense and settle at the low points of the piping. Low point drains are to be installed to allow operations to remove water prior to start-up and during long outages in cold weather to prevent freezing.

6.3 Flue Gas Blower

The proposed Flue Gas Blower is a non-API unit. Shell DEP 31.29.47.31 refers to API 673 for blower design; however, since this installation is temporary, a non-API unit was considered based on inputs from Shell during Design Basis development. The static pressure is based on a 21 kPag battery limit pressure requirement specified by FCE. The blower speed is 3600 RPM due to the high fan static pressure required. The blower motor is 250 HP (190 kW) and will operate on a VFD.

6.4 Mechanical Equipment List

The mechanical equipment list is located in Appendix E of this report. The mechanical equipment list also shows the breakdown of the 12 individual skids that make up the MCFC and BOP scope of supply.

7. Piping Scope

A tie-in list and line list was developed for the pre-FEED and are located in Appendix F.

The piping scope for the pre-FEED was to develop a preliminary design, routing and material take off (MTO) for the cost estimate.

A summary of each piping system is provided in this section.

OSBL piping design referred to Shell line class specifications; however, deviations from the line specifications were considered for the Demin Water and Produced Water lines to reduce costs as the installation is temporary.

It should be noted that material and installation costs for all interconnecting piping between FCE skids is being estimated by FCE and is excluded from Jacobs scope for the Pre-FEED study.

Pipe routing sketches are given in Appendix G for reference.

Flue Gas

Scope includes routing of a new 24" circular duct flue gas line from tie-in point TP-01 (line between S-24203 Stack to C-24203 Recycle Fan) to a new Flue Gas Blower, C-242XX. From the discharge of blower C-242XX, the flue gas duct will be run from north to south along Desulphurization vessels V-24205, V-24201, V-24202 & V-24002. The flue gas line will be elevated ~4 m at this location to clear the location of the catalyst removal nozzles of the individual vessels and will be supported by scaffolds. The flue gas duct will eventually join up with the existing pipe rack that runs East-West. At the existing pipe rack location, the flue gas line will run West to East and will be supported from the existing rack. The flue gas duct will eventually drop down to grade level at the skid module location (reference equipment V-24218/24118). The duct will be routed on grade level on the underside of the skid module and will eventually rise up to pipe rack level to cross "G" street. After crossing "G" street, the duct will drop again to grade level at the skid module location (reference equipment P-24609A/B) and will be routed underside of the skid module with (2) 14" circular duct (twin line) to address the height clearance limitation. The duct routing will rise up to the pipe rack level 2 more times with the use of 24" circular duct to maintain existing access way and will eventually connect to the MCFC module location.

The flue gas line is to be pre-insulated with 2" insulation for heat conservation.

Pre-insulated circular ducting was chosen over schedule 10 carbon steel pipe to minimize material and installation costs. Note that square ducting was not chosen since the required flue gas operating pressure exceeded the design for square ducting.

Natural Gas

Scope involves routing of approximately 70 meters of new 2" ANSI 150# low temperature carbon steel pipe (RLB line class specification) from tie-in point TP-02 to the MCFC module location.

Demineralized Water

Scope involves routing of approximately 120 meters of new 3/4" pre-insulated and heat traced tubing from tie-in point TP-03 to the MCFC module location. The proposed routing will be to run underneath the existing skid modules.

Pre-insulated and heat traced tube bundle was chosen over hard pipe with EHT to minimize material and installation costs.

Produced Water

Scope includes routing of approximately 20 meters of new 1/2" pre-insulated and heat traced tubing from the MCFC module to the nearby CO_2 / dehydration catchment sump.

Pre-insulated and heat traced tube bundle was chosen over hard pipe with EHT to minimize material and installation costs.

CO_2 (Currently outside of Pre-Feed Scope)

Scope includes routing of approximately 70 meters of new 2” ANSI 1500# stainless steel pipe (PJL line class specification) from the MCFC system to tie-in point TP-05, located near the compressor building, R-24701.

Cooling Water Supply (Optional Scope)

Scope includes routing of approximately 5 meters of new 3” ANSI 150# carbon steel pipe (UAB line class specification) from tie-in point TP-06 on the cooling water supply line to the MCFC system.

Cooling water supply will require 1 ½” insulation and EHT.

Cooling Water Return (Optional Scope)

Scope includes routing of approximately 15 meters of new 3” ANSI 150# carbon steel pipe (UAB line class specification) from the MCFC system to tie-in point TP-07 on the cooling water return line. A hot tap is expected for this tie-in as there are no spare valves or flanges located nearby.

Cooling water return will require 1 ½” insulation and EHT.

Instrument Air

Scope includes routing of approximately 40 meters of new 2” pipe from tie-in point TP-08 at unit 240 pipe rack to the new Flue Gas Blower C-24XXX.

8. Civil / Structural Scope

Sketches were developed as part of the pre-FEED phase to support the cost estimate and are located in Appendix H. The foundation designs were based on the equipment weights listed in the Mechanical Equipment List (Appendix E).

8.1 ISBL Earth Works

Proposed site is already graded (rough grade). ISBL area will be graded with crushed gravel. The gravel grading is around 4" thick for the entire ISBL area. Civil works will also involve local excavation, backfilling and compaction required for those skid foundations that are not supported on screw piles.

8.2 ISBL Foundations

Foundations typically consist of screw piles. The MCFC and BOP skids will be resting directly on the pile cap plate. Two skids, (Fuel Cell Module and CO_2 compression/drying pad) will have concrete pile cap in addition to the screw piles. These two skids will be bolted down to the concrete pile cap using Hilti bolts.

Electrical skids (switchgear, transformer, inverter etc.) will be supported on a concrete mat foundation. No screw piles are anticipated for these foundations.

Screw piles are assumed to be 300mm (10") diameter and around 10 to 12m deep. Screw piles were assumed for most of the ISBL skids as this is required to avoid relative movement. Screw piles were considered based on ease of installation and cost effectiveness. The option of using concrete mat foundations instead of screw piles for all skids was discussed with FCE. Due to concern around potential differential settling between skids impacting the interconnecting piping between the Fuel Cell Module and Balance of Plant skids, this option was not pursued. Mat foundations were only considered for electrical equipment due to the flexible cable connections associated with these equipment.

Structural cap plate for skids with concrete pile cap will have nelson studs welded on top.

Precast concrete walkway slabs will be installed on the gravel top for accessible areas.

8.3 Blower Foundation

The new Flue Gas Blower will rest on a shallow mat foundation. No piles are anticipated. Scope also involves excavation, compaction and backfilling. New equipment will be bolted down to the concrete pad using Hilti Bolts.

For the pre-FEED, a concrete pad foundation weighing three (3) times the weight of equipment is considered for the cost estimate. As more details are available during the FEED phase, this assumption will be revisited.

8.4 OSBL Transformer Foundation

The new transformer located directly next to the MCFC system will rest on a shallow mat foundation. No piles are anticipated. Scope also involves excavation, compaction and backfilling. New equipment will be bolted down to the concrete pad using Hilti Bolts.

8.5 Structural Considerations

All new piping/ducting will be supported on temporary scaffoldings and/or under the existing skids. No Structural scope was considered in the estimate for these supports. Precast concrete sleepers were assumed in the scope where the flue gas ducting ties into the ISBL skid area.

9. Electrical Scope

The Single Line Diagrams (SLD) are located in Appendix I of this study report.

Electrical sketches were developed as part of the pre-FEED phase to support the cost estimate and are located in Appendix J.

9.1 Blower Electrical Integration

Electrical tie-in for the new Flue Gas Blower will be from 240-MCC-401B of the R-24003 Building (Unit 240 HMU Sub MCC Room).

Discussion with Vendor (Westburne/Rockwell Automation) were conducted to discuss the physical sizing requirements of a new 400AT/AF MCC wrapper fused disconnect switch (FDS). Initial candidates for extension on either 240-MCC-401A or 240-MCC-401B were explored; however, further analysis yielded 240-MCC-401B as the sole candidate due to bus loading.

It was determined that:

- The spacing requirements for the new 400AT/AF MCC wrapper FDS would require an entire new MCC section, due to the frame size of the wrapper unit and requirement to be fixed-mounted (non-withdrawable) to the bus bar
- It is not possible to retrofit into existing MCC vertical section (even if current PM-24005 MCC wrapper was relocated from Section 1A, freeing up the entire MCC section)
- A complete bus bar extension would be required, which would necessitate 2 new MCC vertical sections, as the current MCC configuration has a bus bar of an U-shaped design, with Section 9 (Front) and Section 10 (Rear) as the transition point.
- The addition of the anticipated flue gas blower motor load Full Load Amperes (FLA) of approximately 242A (based on the 2015 CEC Table 44) on 240-MCC-401A would not be possible, as this addition would exceed the [redacted] bus rating [redacted]

Consequently, (1) new MCC vertical section housing the 400AT/AF MCC Wrapper FDS c/w doors (blanks) for rest of section, to be situated adjacent Section 9 (Front), tentatively called Section 9A if 240-MCC-401B. (1) new MCC vertical section housing 12" doors (blanks) for future withdrawable loads, to be situated adjacent Section 10 (Rear), tentatively called Section 10A of 240-MCC-401B.

Discussions with Shell were conducted to discuss the possibility of execution of associated works as "on-the-run" scope. This scope would entail moving critical loads from 240-MCC-401B (during outage for bus extension works on 240-MCC-401B) over to 240-MCC-401A. For the pre-FEED, associated costs for this work have been excluded from the Estimate. Associated engineering design works to be determined in the FEED stage.

New external VFD and dv/dt output filter to be mounted and installed on the building wall inside the R-24003 MCC Building. Exact installation location will need to be determined in the FEED stage.

New cabling, 2 runs of 1000V TECK90 3C #1/0 AWG cable, to be installed from MCC wrapper location to the VFD and output filter location, and another 2 runs from the VFD and output filter location to the Flue Gas Blower motor location. Cables to be run in existing cable tray and/or channel tray leading to above grade location outside the R-24003 MCC Building, and then on cable support cones outside the R-24003 MCC Building to the Flue Gas Blower motor.

New cabling, 1 run of 1000V TECK90 2C #8 AWG cable, to be installed from the motor VFD to the motor space heater location (field), on cable support cones outside the R-24003 MCC Building to the Flue Gas Blower motor.

Note that there is a potential option to install a longer cable to the Quest 600V construction power junction box near the west side of the Quest unit for the electrical tie-in. This would be explored further in the FEED stage.

9.2 MCFC Electrical Integration

Initial investigation of MCFC Electrical Integration determined a possible candidate in 248-MCC-501 bus extension for a new vertical MCC section, which would be located left of Section 3A, facing south, in the Quest RCDU R-24801 building. However, it was later determined as an inadequate candidate, as there would be another project which would also utilize 248-MCC-501 for bus extension, directly behind the MCFC new vertical MCC section, posing maintenance clearance issues. Furthermore, conversation with Rockwell deemed that an additional transition cell would be required, so the combined footprint for both the transition cell and the new vertical MCC section would not be possible due to proximity from the DCS Relay Cabinet 248PCS001 and also possible existing cable tray obstruction for the required equipment chimney arc chute vent clearances.

Subsequently, a candidate for a bus extension in 284-MCC-501B, located in the R-28404 building (Unit 284), is found to be able to accommodate a new vertical MCC section housing the 1200A high voltage circuit breaker and the new transition cell.

A new 1800kVA, 4160V-480V Delta-Wye Oil-Filled Transformer is required to step down from the Shell source 4160V to the electrical tie-in point of 480V at the FCE switchgear. This transformer would be installed on skid and located directly next to the MCFC system module.

New cabling, 1 run of 5kV TECK90 3C #2/0 AWG cable, to be where possible run in existing cable tray where possible, and installed underground as direct buried (especially road crossings) from the new MCC vertical section in 284-MCC-501B to the primary of the new 1800kVA transformer. The actual cable routing is to be finalized at the FEED stage.

New cabling, 4 runs of 1000V TECK90 3-1/C single conductor #500 kcmil cables to be installed above ground (free air) from the secondary of the new 1800kVA transformer to the 480V MCFC switchgear. For pre-FEED, the assumption forward is for these cables to be installed above ground (free air).

Note that preliminary ampacity calculations for underground conduit configuration based on CEC-2015, Table D11A, yielded that 8 runs/conduits (or 8 cables per phase) of 1000V TECK90 3-1/C single conductor #500 kcmil cables required. Discussions with FCE and Jacobs determined that underground entry into the MCFC 480V switchgear needs to be avoided (further design considerations for cable entry of the 480V MCFC switchgear in the FEED stage).

It was also noted late in the pre-FEED that due to excessive risk (i.e. the Main Substation Unit 284 would not be permitted as there would be complicated logic requirements for that bus), the 5kV bus extension would be installed on 284-MCC-503A or 284-MCC-503B in Electrical Building R-28405. Further evaluation will be conducted in the FEED stage.

9.3 Electrical Heat Tracing

EHT power required to be supplied via spares in 246-HCP-C Heat Tracing Control Panel Skid.

Demin Water line and Produce Water line to use pre-insulated EHT tubing c/w temperature sensor installed. Electrical scope will be to run power cable and RTD cable only.

Cooling Water Supply line and Cooling Water Return line would require Electrical to run power cable, RTD cable, RTD, Power Connection Kit, End Kit and Heat Trace Cable.

New cabling for power, 1000V RW90 2C #2 AWG cable, to be installed from the 246-HCP-C skid spare circuits to the pre-insulated tube trace. Cables to be run in existing cable tray and/or new channel tray outside the existing cable tray.

New cabling for RTD, 300V, 1 Triad #16 AWG ACIC cable, to be installed from the EHT controller (to be designed in FEED stage) to the RTD at the pre-insulated tube trace. Cables to be run in existing cable tray and/or new channel tray outside the existing cable tray.

EHT design for the Cooling Water Supply line and Cooling Water Return line to be explored further in FEED stage.

9.4 Area Classification

Teck cable connectors shall meet the requirements with appropriate cable glands and shall have poured seals, as required for classified areas.

The proposed location of the new Flue Gas Blower is located in an unclassified area. Refer to Appendix J for the area classification drawing.

Area classification drawing for the MCFC facility will be provided by FCE.

9.5 Grounding

Per the Canadian Electrical Code (CEC), a ground grid will be installed to ensure all equipment is sufficiently grounded and bonded.

For the Pre-FEED, grounding design to use typical perimeter grid grounding around the MCFC system module and new transformer skid with 3m copper ground rods tied back to the existing ground grid. Cabling used for perimeter grid to be #4/0 AWG bare-stranded, annealed copper ground conductors.

It is assumed that there are 2 bolted connections to each skid, and they are tied back (compression connected) to the perimeter grounding. Cabling used for these tails is #2/0 AWG green insulated, FT4 rated, stranded copper ground conductors.

The ground grid will be buried 600mm MIN below grade. The ground rods will be steel, copper clad, 19mm X 3000MM ground rods.

9.6 Lighting

Lighting power required to be supplied via 20A spare in 248-LP-A lighting panel.

New cabling, 1000V 2C #4 AWG RW90 cable, are to be installed from the 248-LP-A to the light locations around the MCFC system module. Lighting are assumed to be LED type (Champ VMV series) temporarily mounted at 20 feet high and the luminaires are on 25 degree angled stanchion mounted.

9.7 Electrical Considerations

The cables from the secondary of the new 1800kVA to the 480V FCE switchgear were sized to the protective device rating of the main breaker, i.e. 2000A, instead of 125% secondary FLA of transformer, and using the CEC-2015, Table 1 for single unshielded copper conductors, with Table 5A Ambient Temperature Factor (assumed at 50°C), and adequate cable spacing (100% cable spacing).

Regardless of the MCFC location in relation to the existing plant, lightning protection is not required for the MCFC facility.

10. Instrumentation and Control Scope

10.1 OSBL Instrumentation

Instrumentation supporting the new Flue Gas Blower (flow meter, temperature transmitter, pressure transmitter, blower vibration and speed sensors, and motor temperature sensors) will be located in the HMU area. The signals for these instruments will be routed through an Analog Junction Box and a Digital Junction Box depending on the signals required by the instrument. It is assumed that these existing junction boxes are located nearby and will have spare terminals. The signals will be terminated in the HMU Remote I/O building where it is assumed that the existing DCS will have spare I/Os. The blower on the Flue Gas line will be controlled by a VFD.

Instrumentation on the natural gas line to the MCFC system consists of a pressure regulator, Coriolis flow meter, pressure transmitter and a pressure relief valve. The signals for the Coriolis meter and pressure transmitter are routed to nearby existing analog and digital junction boxes. It is assumed that the junction boxes have available spare terminals. The signal will be terminated in the nearby remote I/O building, R-24801.

For the optional CO_2 line, there will be an on/off valve that isolates the system from the CO_2 pipeline. The valve will be a pneumatically controlled isolation valve. Limit switches on the valve will provide feedback to the DCS if the valve is in the open or close position. The signals are routed from the valve to a nearby existing instrument junction box. It is assumed that the junction box has available spare terminals. The signals will be terminated in the nearby remote I/O building, R-24801.

An instrument index was developed during the pre-FEED and is located in Appendix K of this report.

10.2 ISBL Instrumentation

All ISBL control valves will be electrically actuated.

All required analytical equipment will be provided by FCE and housed within the control skid trailer.

Gas detectors for the skids will be provided by FCE.

All ISBL instrumentation signals are routed to the local control panel. It is anticipated that signals will be exchanged between FCE and Shell operations and will be determined at a later project phase.

10.3 MCFC Communication

The MCFC system is under the custody of FCE and not Shell; therefore, it will be operated and controlled by FCE with some local help from Shell operations. The MCFC system is designed to run autonomously. There will be an Emergency Shutdown (ESD) push button hardwired to the MCFC system, located on site that will allow Shell Operations to shut down the MCFC system for emergency purposes.

The MCFC system will contain a PLC which will require I/O signals to Shell's DCS as well as an Ethernet and telephone cable connection. The telephone cable is used as a backup in case the Ethernet signal is lost. These cables/signals will be routed to Remote I/O building, R-24801, and assumed that all connections required are available in the building. The Ethernet and telephone cables are required for FCE's ability to support remote monitoring, alarming, remote diagnostics and remote controls. The Ethernet cable will be connected to internet broadband high speed data connection of minimum bandwidth of 193kbps and shall include a static gateway IP address and a routable static IP address upstream of Shell's firewall. Secure remote operations and communication will be through IPSec Virtual Private Network (VPN) which will be connected to FCE's SCADA network. Monitoring through WebView (read-only access) by Shell will also be through a secure VPN connection.

UPS battery for FCE system will be included in FCE design.

A control block diagram was developed during the pre-FEED and is located in Appendix L of this report.

11. Regulatory

In general, it is recommended that the permitting process be initiated during early FEED phase to get the appropriate regulatory authorities engaged early during the design and allow for timely issuing of the necessary permit and license updates.

11.1 Environmental Permitting

Preliminary evaluation of potential environmental permitting requirements was done by Jacobs HSE group which has expertise in executing environmental and regulatory support for projects.

For the pre-FEED study, the streams which will be sent out from the fuel cell package are mainly the exhaust gas stream, the produced water stream and the captured liquid CO_2 stream. Natural gas desulphurization packed bed media and SO_x removal sorbent media will need replacement every year or so and will need to be disposed or sent for regeneration.

The exhaust gas stream quality will be better that the flue gas being fed to the unit as 70% to 90% of the CO_2 will be captured. Any SO_x in the flue gas will be removed and 70% of the NO_x in the flue has will be destroyed (converted to N_2) in the fuel cell. The produced water stream is essentially pure water with some dissolved CO_2.

Preliminary discussions with Shell indicate that the exhaust stack from the fuel cell package would need to be registered with Alberta Environment and Parks even if it is used on a temporary basis. Dispersion modeling will be done during the FEED phase as required.

It is anticipated that the Project regulatory approval will be under plant's existing regulatory approval. This approval of the Project will be a demonstration to the regulatory authorities on reduction of environmental impact specifically different Criteria Air Contaminants (CACs) as indicated above. The regulatory approval process is expected to be straight forward as regulatory permit application package will contain information on how the emission and other environmental impact are going to be reduced compared to the existing plant operations. Requirements from Alberta Environment and Parks and Saskatchewan Environment are anticipated to be similar. A high level environmental permitting roadmap was developed during the pre-FEED and is located in Appendix M.

11.2 Development Permitting

The Shell Scotford facility comes under the purview of Strathcona County. Based on preliminary discussions with the County permitting officials, the units and foundations under the proposed 1.4MW MCFC Demo Plant Project does not require any building permit from the County. The only requirement would be final IFC drawings shall be signed by a P.Eng, (Alberta). This is based on the provisions and exemptions provided under the Alberta Building Code.

The main points under discussions are as below:

- Alberta Building Code, Division 1, Part 1, Section 1.1, under Application of the Code, clause 5e specifies, *"This code does not apply to mechanical process equipment and appliances in an industrial occupancy that are not required for the building services and that are not specifically regulated by this Code"*.
- The proposed facility is for a demo plant and will be temporary in nature.

Based on these discussions, it is assumed that no permitting requirement will be required for the foundations and units under the proposed project. This assumption is also corroborated by one recent project of similar nature executed under the purview of the same County. However this will be further examined with the County officials during the FEED phase when more details will be available.

12. Project Estimate

12.1 General

A Class IV (+30%/-15%) Cost Estimate was prepared as part of the pre-FEED study.

The cost for the CO_2 product line and cooling water lines was broken out as separate line items for comparison purposes.

Budget pricing was obtained from vendors for the Flue Gas Blower, the new transformer, and all major instrument items and are located in Appendix N for reference. Preliminary MTOs were estimated by discipline engineering for the purpose of the pre-FEED study cost estimate. The preliminary MTOs are located in Appendix N for reference. It should be noted that the MTOs generated are at a pre-FEED study level only and based on Plot Plans, PFDs and sketched. More detailed MTOs will be done in the FEED phase of the project as the design details are developed.

12.2 Estimate Basis

The study estimate basis for the pre-FEED study is given in Appendix O.

12.3 Base Cost Estimate

The base cost estimate for the OSBL scope of work is given in Appendix P.

A summary of the OSBL cost estimate is shown in Table 12.1.

Table 12.1 – OSBL Cost Estimate Summary

Description of Cost	Cost (CAD)
Equipment	$170,160
Civil / Structural	$339,368
Duct Work	$194,956
Piping	$98,869
Instrumentation	$67,755
Electrical	$427,039
Direct Support Cost (Scaffolding / Fire Watch / Hole Watch)	$58,818
Total Direct Costs	$1,356,965
Total Indirect Costs	$410,686
Total Engineering Costs	$478,917
Freight	$23,984
Escalation	$68,117
Contingency	$454,110
TOTAL	**$2,792,779**

The total estimated cost for the OSBL scope of work (Jacobs scope) is $2,792,779.

The above costs include a future escalation of 3% and contingency of 20%.

The total estimated cost for the ISBL scope of work (FCE scope) is $21,111,390 (USD). Using an exchange rate of 1.3 CAD to USD, the ISBL scope of work cost is $27,444,807. This includes FCE engineering, equipment supply and fabrication of skids, shipping to site and inter-skid connections.

The total estimated cost for the removal of the OSBL scope of work after the completion of the demonstration period is $668,358. Demolition scope is broadly a reverse of the installation scope. It was assumed that a space would be made available at site to store all removed material and equipment for further disposal. The costs for OSBL demolition include dismantling of all OSBL installations including the individual FCE skids, loading on to a truck and unloading in the designated area at site. Note that the Fuel Cell module skid only will be shipped back to FCE. FCE has included costs for shipping back to their facility in the ISBL demolition/removal scope. As part of the OSBL demolition costs, based on discussions with the host site, all concrete pads were considered as demolished and piles will be cut to 1 ft. below grade level and left buried in place.

The total estimated cost for the removal of the ISBL scope of work after the completion of the demonstration period is $428,819 CAD ($329,861 USD). The ISBL removal costs include the dismantling of all the interconnecting piping between their skids and for shipment of the fuel cell module (1 skid) back to FCE.

A summary of the total capital cost estimate for the project is shown in Table 12.2.

Table 12.2 – Total Cost Estimate Summary

Description of Cost	Cost (CAD)
OSBL Installed Cost	$2,792,779
ISBL Installed Cost	$27,444,807
Total Installed Cost	**$30,237,586**
OSBL Demolition / Removal	$668,358
ISBL Demolition / Removal	$428,819
Total Installed Cost + Removal Cost	**$31,334,763**

12.4 Carbon Dioxide Scope / Cost Considerations

For the Pre-FEED cost estimate, the supercritical CO_2 scope ends at the battery limit of the FCE package and any downstream scope and costs are not included in the base TIC estimate. However, for the purpose of comparison, a high level cost estimate of routing the CO_2 product to the Quest unit compressor discharge was considered.

The total estimated cost for the CO_2 product line installation is $182,282. It should be noted that with the 2018 cost of CO_2 at $30/ton. The total cost savings from the CO_2 captured would be $300,000 to $350,000 annually based on 8000 hours of operation and capture rate in the 30 to 35 ton/day range. Payback on the installation of piping to tie in the captured CO_2 in to the Quest unit would be 7 months.

12.5 Optional Cooling Water Cost Estimate

An option to use cooling water instead of aerial coolers was considered during the Pre-FEED. The total estimated cost for the cooling water supply and return installation is $255,671. Operating costs for cooling water are negligible as the cooling water flow rate is less than 0.5% of the total cooling water circulating rate for the Quest unit. Installation of water coolers would eliminate the air coolers and. Anode exhaust cooler would be a shell and tube type. Potential reduction in cost savings for the FCE supply is $275,872 CAD (212,209 USD). In addition it is anticipated that the foot print could be potentially reduced, which would be evaluated during FEED if this option was selected. Based on these costs, there does not appear to be any major benefits of cooling water. Furthermore, for a demonstration unit, use of aerial coolers could be applied to any site.

12.6 Operating Costs

The estimated operating costs of the MCFC system are shown in Table 12.3.

The quantity of natural gas is based on 8,000 operating hours in a year. The natural gas cost was based on the Aeco Spot year-to-date price.

The operating costs for Demin Water and Nitrogen were not considered since they would be only used for start-up purposes.

Cost credits for electrical power generated by the Fuel Cell were based on 8,000 operating hours in a year using the net power for the 70% Capture Case. Electrical rate was based on Direct Energy's oil field rate.

Since the operation of the MCFC system will be by FCE, the support costs were estimated by FCE.

[redacted]

The cost for discrete sampling and laboratory GC analysis of the CO_2 product is not included in Table 12.3 since a third party contractor will be utilized for the lab analysis and the costs will be site specific.

It was indicated by FCE that the desulfurization bed would last ~ 1.5 years, which would be longer than the anticipated minimum testing period of the demonstration unit. The initial fill for the beds are included in the ISBL TIC. Costs to change out the beds are not included in the operating costs summary.

Table 12.3 – Operating Costs

Cost Description	Quantity	Cost	Total Cost (CAD)
Utilities			
Natural Gas	78,432 GJ	$2.5 / GJ	$196,080 *
Electrical Power	4606 MWh	$35 / MWh	-$161,210 *
Operating Support			
FCE Support	lot	$421,272 (USD)	$547,654
Shell Operations	[redacted]	[redacted]	$41,600 *
		Total Operating Cost	**$624,124**

* - These costs are site specific and are to be confirmed by Shell

13. Project Schedule

A high level project schedule for the remaining phases of this project was developed during the pre-FEED and is located in Appendix Q.

The critical path for the project is delivery of the long lead CO_2 compressors (12 months after PO). Inputs for ISBL engineering, fabrication, commissioning and testing time durations were provided by FCE.

OSBL scope is relatively smaller compared to the ISBL scope and can be accommodated within the overall schedule. (Delivery time for the new Blower is 14 weeks after received of approved drawings)

A formal Interactive Planning (IAP) session with engagement of all stake holders (Host Site, FCE, Engineering, Procurement and Construction) will be done during the beginning of FEED stage to develop a detailed overall project schedule.

14. Risk Assessment

A project risk assessment was completed during the pre-FEED. The risks identified were brainstormed by those in attendance which included FCE, Jacobs, Alberta Innovates, Host site contacts and steering committee members. The probability of the risks was ranked as well as the impact level to Safety, Cost, Schedule and Impact to Site.

The risk assessment worksheet is located in Appendix R of this report.

Broadly, the risks could be grouped into four main categories as indicated in the Risk Grouping column, namely:

1) Organization
2) Technology
3) Legal/Statutory
4) Site Integration

The High risk items identified by the team are mainly related to organization aspects to be resolved prior to FEED design commencement.

A thorough HAZID, HAZOP and detailed Project Risk Review will be conducted during the FEED phase of the project. Due to the nature of the project and electrical integration aspects, it is also recommended that an Electrical Systems Safe Operability Review (SAFOP) be done during the FEED phase.

15. Future Considerations for FEED Phase

Main aspects which impact the design and basis during the next phase are summarized below:

1) Sampling and analysis of natural gas composition including detailed sulphur species analysis.
2) Sampling and analysis of flue gas including SO_x content.
3) CO_2 integration scope finalization.
4) Use of cooling water versus aerial coolers.
5) N2 sampling for O_2 content.
6) Exhaust stack dispersion modeling for CO_2 venting scenario.
7) Continuous online analysers for CO_2 product quality are currently not included in FCE design as this will be estimated indirectly using pressure and temperature and discrete sampling and laboratory GC analysis
8) Review of FCE standards and approvals from host site considering the temporary nature of the demonstration unit.
9) Evaluate and confirm the use of non-API blower versus an API blower considering the temporary nature of the demonstration unit.
10) Evaluate and confirm deviations from host site standards considering the temporary nature of the demonstration unit.
11) Evaluation of “on-the-run” scope versus an outage requirement for the integration of the MCC Bus Extension in Unit 240.
12) Evaluate flue gas blower electrical tie-in option of Quest 600V construction power junction box versus the MCC Bus Extension in Unit 240.
13) MCFC electrical tie-in option of 5kV bus extension to be installed on 284-MCC-503A or 284-MCC-503B.
14) Evaluation of CO_2 intensity of the power generating only mode versus the CO_2 capture mode
15) Evaluate potential of cooling the flue gas to condense water in order to reduce flue gas blower power to improve overall system net power.

Host site comments received on the Design Basis and IFR Pre-FEED study report have been tabulated along with the resolution path and are given in Appendix S for reference.

Appendix A. Process Flow Diagrams

UNITS	Skid	MCFC Skid	MCFC Skid	MCFC Skid	Water from MCFC Skid	Exhaust
°C	150	20	25	9	62	224
kPa(g)	21	140	416	10000	ATM	0
kg/h	12140	166	1200	1512	450	14533
m3/h	-	-	1.2	1.83	0.45	-
Sm3/h	10706	254	-	-	-	13158
-	27.74	16.00	18.02	43.85	18.02	27.02
Mole %	0.00	HOLD	0.00	0.30	0.00	0.00
Mole %	0.00	HOLD	0.00	0.10	0.00	0.00
Mole %	7.90	HOLD	0.00	99.50	TRACE	1.90
Mole %	17.00	HOLD	100.00	0.00	100.00	15.30
Mole %	71.00	HOLD	0.00	0.10	0.00	77.60
Mole %	4.10	HOLD	0.00	0.00	0.00	5.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.20
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
ppm	0	HOLD	0	0	0	0
ppm	0	HOLD	0	0	0	0
ppm	0	HOLD	0	0	0	0
ppm	1	HOLD	0	0	0	0
ppm	<60	HOLD	0	0	0	< 18
	2	3	4	5	1	

	1	2	3	4	5	6
	Flue Gas to MCFC Skid	Odourized NG to MCFC Skid	Demin Water to MCFC Skid	CO2 from MCFC Skid	Produced Water from MCFC Skid	Exhaust
UNITS						
°C	150	20	25.0	9	62	202
kPa(g)	21	140	416	10000	ATM	0
kg/h	8133	128	1200	1260	450	9423
m3/h	-	-	1.2	1.53	0.45	-
Sm3/h	7173	196	-	-	-	8611
-	27.74	16.00	18.02	43.85	18.02	26.77
Mole %	0.00	HOLD	0.00	0.30	0.00	0.00
Mole %	0.00	HOLD	0.00	0.10	0.00	0.00
Mole %	7.90	HOLD	0.00	99.50	TRACE	0.70
Mole %	17.00	HOLD	100.00	0.00	100.00	15.60
Mole %	71.00	HOLD	0.00	0.10	0.00	79.10
Mole %	4.10	HOLD	0.00	0.00	0.00	4.40
Mole %	0.00	HOLD	0.00	0.00	0.00	0.20
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
Mole %	0.00	HOLD	0.00	0.00	0.00	0.00
ppm	0	HOLD	0	0	0	0
ppm	0	HOLD	0	0	0	0
ppm	0	HOLD	0	0	0	0
ppm	1	HOLD	0	0	0	0
ppm	<60	HOLD	0	0	0	< 18
	2	3	4	5	1	

5) CO2 Stream is Optional Scope

JACOBS

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	DATE			

SHELL SCOTF

1.4 MW MOLTEN CARBONATE FU

TITLE

MATERIAL BA
70% and 90% C

PLANT NO. | SCALE

PREPARED BY TL | CHECKED BY E

SHEET 1 of 1 | DOCUMENT NO. EE06

Appendix B. Design Basis

ALBERTA INNOVATES

1.4 MW MOLTEN CARBONATE FUEL CELL DEMONSTRATION UNIT SHELL SCOTFORD UPGRADER SITE

DESIGN BASIS

JACOBS PROJECT NUMBER: EE060101

DOCUMENT NUMBER: EE060101-PR-REP-0001

Rev.	Description	Date	Prepared	Checked	Project Approval	Client
A	Issued for Review – Process Sections Only	10 Nov 2016	TL	ESD / DSL	ESD	C. PATON
B	Issued for Review – Client Comments Incorporated	22 Dec 2016	TL	ESD	ESD	C. PATON
C	Issued for Information	7 Feb 2017	TL	ESD	ESD	C. PATON

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List of Attachments

1.0 INTRODUCTION

Alberta Innovates – Clean Energy introduced a molten carbonate fuel cell (MCFC) technology for carbon capture called a Combined Electric Power and Carbon-dioxide Separation (CEPACS) Unit to the oil sands industry in Alberta in 2012. Leading on from previous pilots and studies undertaken, Alberta Innovates will lead the project along with Canada's Oil Sands Innovation Alliance (COSIA) members BP, Canadian Natural Resources Limited, Cenovus Energy, Devon Canada Corporation, Shell and Suncor as well as non-COSIA participants Husky Energy and MEG. The project includes the preliminary front end engineering (pre-FEED) phase to understand the cost of using an MCFC at a bitumen upgrader facility.

The Shell Scotford Upgrader near Fort Saskatchewan, Alberta is a potential host site considered for the installation of the MCFC demonstration plant. The proposed MCFC will capture CO_2 from the flue gas off a steam reformer stack where it is then compressed and injected into offsite storage facilities. The MCFC plant will be capable of capturing up to 90% of the CO_2 in the flue gas. The gross power output for the proposed MCFC can be as high as 1.1 MW.

Fuel Cell Energy (FCE) has been engaged by Alberta Innovates to complete the pre-FEED design and cost estimate for the MCFC module and its balance of plant (BOP). The Jacobs scope is outside of the FCE battery limit, which involves integration of the FCE package into the host site. The basis of design for the pre-FEED study is given in the following sections of this document.

2.0 BASIC PROCESS DESCRIPTION

2.1 MCFC and Balance of Plant

A representative Block Flow Diagram (BFD) for the MCFC and BOP showing the scope demarcation is shown in Figure 2.1.

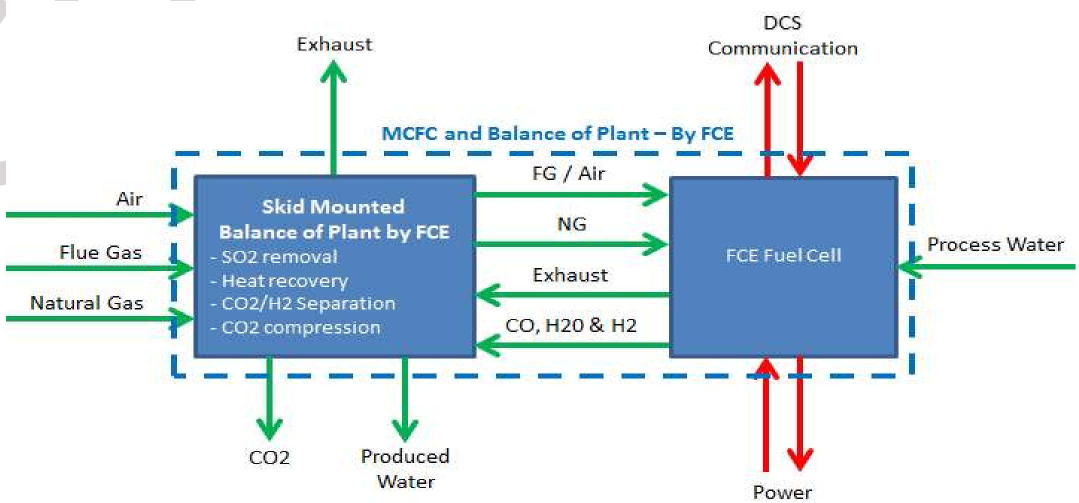

Figure 2.1 – MCFC Block Flow Diagram

A portion of the flue gas from the Hydrogen Manufacturing Unit (HMU-1 or HMU-2) steam reformer stack, S-24103 or S-24203, will be routed to the BOP and MCFC skids provided by FCE. Either flue gas stack could be used for the tie-in because the tie-in is downstream of the isolation damper to the Flue Gas Recycle Blower suction; therefore, a shutdown of the unit is not required. Due to the distance of the stack from the proposed location and battery limit requirements for the skid, a blower will be provided near the HMU stack area. An isolation damper will be provided on the blower suction to isolate the system from the reformer stack. A flow meter will be provided on the blower discharge. Flue gas flow to the MCFC will be controlled by either a VFD on the blower or a control valve on the blower suction (similar to the existing flue gas recycle blower).

Natural gas will be supplied to the BOP and MCFC skids potentially from the low pressure header within the HMU that supplies natural gas to the reformer burners. Another potential source of natural gas will be from within the Cogen Unit area. Odorized natural gas that supplies fuel to building heaters and air handling units is also available within the Quest Carbon Capture unit located south of the HMU. (HOLD – To be confirmed with Shell) A pressure regulator will be installed on the natural gas line near the BOP and MCFC skids.

Demineralized water is used for start-up purposes and will be supplied from the Quest unit.

The captured CO_2 will be pumped to pipeline pressure within the MCFC module to tie-in to the discharge of the final stage compressor, C-24701H, within the Quest unit. The captured CO_2 from the MCFC skid and the Quest facility would be routed via pipeline to a sequestration facility.

3.0 CAPACITY, FEEDSTOCK AND PRODUCTS

3.1 Capacity and Turndown

The MCFC and BOP have been specified to capture 70% and up to 90% CO_2 in the flue gas. The MCFC module will be designed for the flue gas rates shown in Table 3.1. Flow rates are based on FCE simulations and Heat/Mass balance. Based on email received from FCE on 16 January 2017, flow rate range for testing is anticipated to be in the range of 25% - 110% of flue gas requirement for the 70% CO_2 capture flow rate.

Table 3.1 – Flue Gas Flow Rate

	Units	Turndown Case	90% CO_2 Capture	70% CO_2 Capture	Design Case
Flue Gas Flow	Sm^3/hr	2,552	6,571	10,208	11,229

[redacted]

3.2 Flue Gas

Flue gas from the HMU steam reformer stack will be supplied to the BOP skid. The flue gas tie-in will be located on the take off to the Flue Gas Recycle (FGR) fan, C-24103 or C-

24203 for HMU-1 and HMU-2, respectively. An isolation damper exists on the take off to either FGR fan, which allows for the tie-in work to be completed without a shutdown of either stack. The flue gas composition taken from the Uhde HMU HMB Table is shown in Table 3.2. The cases shown cover the range of CO_2 in the flue gas composition. The FGR 30% Load case is based on 100% CO_2 removal from the Pressure Swing Adsorber (PSA) feed. The 100% FGR Load case is based on 82.4% CO_2 removal from the PSA feed.

The average amount of NO_x measured and composition of the stack gas sample analysis obtained from Shell is also shown for comparison.

Table 3.2 – Flue Gas Composition

Component	Units	FGR 30% Load	FGR 100% Load	Lab Sample
N_2	mol %	68.54	66.66	69.9 – 71.2
O_2	mol %	2.98	1.70	4.1
CO_2	mol %	7.45	9.80	7.4 – 8.4
H_2O	mol %	20.22	21.06	16.2 – 17.9
Argon	mol %	0.81	0.78	-
SO_2	ppm Note 1	1	1	HOLD
NO_x	ppm	< 60	< 60	51.8

Notes:
1. SO_2 values based on rough estimate provided by Shell Operation's Engineer. An analysis was received; however, it included only trace sulphur components. Analysis for SO_2 will need to be done during the FEED phase. B

The MCFC module is to be designed to accommodate the range of flue gas compositions shown in Table 3.2 and operating temperatures and pressures shown in Table 3.3.

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

3.3 Natural Gas

[redacted] Natural gas source is to be confirmed by Shell) The natural gas composition obtained from the base plant Basic Utility Design Data (DS-200-B-0001 – Rev 0, 2000-07-11) is shown in Table 3.4.

Table 3.4 – Natural Gas Composition

Component	Units	Summer	Winter	Average
C1	vol %	90.9	96.88	93.89
C2	vol %	4.69	1.06	2.88
C3	vol %	1.17	0.32	0.75
n-C4	vol %	0.23	0.13	0.18
n-C5	vol %	0.04	0.0	0.02
C6+	vol %	0.01	0.0	0.005
N2	vol %	2.26	0.93	1.6
CO2	vol %	0.70	0.68	0.69
H2O	mg/m^3	64	64	64
H2S	ppm	6.0 max	6.0 max	6.0 max
RSH	ppm	5.0 max	5.0 max	5.0 max
Total Sulphur	ppm Note 1	23.0 max	23.0 max	23.0 max

Notes:
1. Maximum contract specification, normal level is < 10 ppm based on base plant design basis.

[redacted]

[redacted]

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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[redacted]		[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Odorized natural gas that is used to supply fuel for building heaters and air handling units is also available within the Quest Unit. Note that FCE's design includes consideration of Fuel Gas Desulphurization. (HOLD – Shell to Provide Operating Parameters and Composition Analysis including trace Sulfur Analysis)

The preliminary natural gas flow rate required to feed the BOP and MCFC skids is 228 Sm^3/hr.

3.4 Demineralized Water

Demineralized water will be supplied to the MCFC module from the main header within the Quest unit. Demineralized water will be used for start-up purposes only. FCE has indicated that the start-up period may last up to 4 days and that a permanent water supply connection would be preferred to facilitate unplanned start-ups. B

The operating temperatures and pressures at the tie-in location are based on the Basic Utility Design data table from the Quest BDEP. [redacted]

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

3.5 Produced Water

The produced water stream is mainly water with small amounts of dissolved CO_2. During normal operation, a portion of the produced water is used as make-up water to the plant allowing the demineralized water to be used for start-up purposes only.

The produced water will be routed to the potentially oily water sewer within the Quest unit. FCE base design will be based on a high temperature solid absorbent bed for removal of SO_x instead of a caustic scrubber; therefore, there is no waste water stream. C

The preliminary estimated flow rate for the produced water is ~ 0.45 m^3/hr.

3.6 Carbon Dioxide

The captured CO_2 stream composition from the MCFC module is shown in Table 3.8.

Table 3.8 – Captured CO_2 Composition

C

Component	mol %
CO_2	99.5
CO	0.1
H2	0.3
N2	0.1

Preliminary information provided by FCE indicated that 35.2 tonnes/day and 29.4 tonnes/day of CO_2 would be captured at a 70% and 90% recovery rate, respectively. C

The captured CO_2 from the MCFC module will be routed to the CO_2 compression area within the Quest unit where it is then sent by pipeline to a CO_2 injection well.

FCE indicated that in their standard design, the CO_2 stream is compressed to 1723 kPag (250 psig) and then chilled to -42.8°C (-45°F) to condense the CO_2 to a liquid stream and allow separation from residual H_2. The CO_2 stream is pumped to supercritical conditions to meet the required CO_2 pipeline pressure and is also used for further heat integration within the skid (the stream is heated up by cooling other streams).

Based on discussions with Shell, the CO_2 can be routed to the discharge of the final stage compressor, C-24701H. [redacted] FCE is to provide an analyzer and flow measurement on the CO_2 product stream to ensure proper operation of the MCFC skid. C

[redacted] C

3.7 Exhaust

The exhaust stream from the MCFC module is vented through a stack provided by FCE. The composition of the exhaust stream is shown in Table 3.9. FCE indicated that ~ 70% of the NOx in the flue gas would be converted to Nitrogen by the fuel cell.

Table 3.9 – MCFC Exhaust Stream Composition

C

Component	Units	70% CO2 Capture	90% CO2 Capture
CO_2	mol%	1.9	0.7
H_2O	mol%	15.3	15.6
N_2	mol%	77.6	79.1
O_2	mol%	5.0	4.4
Argon	mol%	0.2	0.2
NOx	ppm	< 18	< 18

Notes:
1. Composition based on flue gas lab sample data in Table 3.2 and Average Natural Gas Composition in Table 3.4.

The operating temperatures and flow rate of the exhaust stream are shown in Table 3.10.

C

Table 3.10 – MCFC Exhaust Stream Operating Parameters

	Units	Min	Max
Temperature	°C	202	232
Flow Rate	Sm^3/hr	7890	13,516

4.0 UTILITIES, METEOROLOGICAL AND SITE DATA

4.1 Nitrogen

Nitrogen can supplied from the main header within the Quest unit. [redacted]

[redacted]

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[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

However, FCE indicated that the MCFC module requires a nitrogen purity of 99.995 mol % with only 2 ppm O_2 (max). FCE will provide a micro bulk liquid nitrogen tank with vaporizer, which is their standard design.

It should be noted that the other proposed host site at Lashburn does not have Nitrogen as a utility. In view of this, the micro bulk liquid nitrogen tank will also keep the design consistent across both sites for comparison purposes.

4.2 Cooling Water

Cooling water is available from the main header within the Quest unit. [redacted]

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

C

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The maximum cooling load required for the BOP and MCFC skids was estimated by FCE to be 1.2 MW. Based on this load and a differential temperature of 10°C, the required cooling water supply rate is 28.7 m^3/hr. The total cooling water flow rate being used in Quest based on the utility summary within the BDEP document is 5,882 m^3/hr with a total rated flow from the cooling water pumps of 6,236 m^3/hr. [redacted] FCE to provide information on potential ISBL footprint and cost reduction for option of using cooling water instead of aerial coolers. C

4.3 Instrument Air

Instrument air will not be required for the MCFC and BOP skids as all skid mounted control valves will be electrically actuated, based on discussion with FCE.

Instrument air from the existing distribution system at the HMU will be used to actuate all OSBL control valves as required. Note that it is expected that a flue gas isolation valve and CO_2 product isolation valve will require instrument air. [redacted] B C

[redacted]

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

4.4 Flare System

The relief discharge within the BOP and MCFC skids is expected to be small with a composition similar to natural gas and will be vented to atmosphere at a high point; therefore a connection to the site flare system is not required. Based on estimates provided by FCE, the highest-volume relief scenario would generate ~ 6 m^3 of vented gas.

4.5 Potable Water

Initially, potable water for safety shower and eye wash stations would have been required if a caustic scrubber system was to be installed as part of the BOP skid. However, a high temperature solid absorbent bed will be used for removal of SO_x; therefore, safety showers and eye wash stations are not required.

4.6 Fire Water

There are no specific requirements for fire water or specialty protection. It should be noted that fire water is available at site from nearby hydrants.

4.7 Electrical Power

The electrical power consumption for the MCFC and BOP skids is expected to be in the range of 0.22 to 0.275 MW based on information from FCE.

Electrical requirements for the flue gas blower is expected to be approximately 190 kW and controlled on a VFD.

4.8 Meteorological and Site Data

The site meteorological and geological data is shown as Attachment 3 in this document.

4.9 Units of Measurement

The units of measurement to be utilized for this project is SI [redacted]

5.0 MCFC DESIGN CONSIDERATIONS

5.1 Battery Limit Requirements

A battery limit table will be created as part of the study.

FCE to confirm the pressure and temperature at all interface points.

5.2 Noise Limits

Equipment will be designed to less than 85 db(A) at 1m.

5.3 Design Standards and Codes

All Canadian Federal, Provincial and municipal laws and regulatory requirements will have to be followed. An evaluation of the codes will occur during FEED stage to determine if they apply as the installation of the MCFC skid is considered temporary.

Shell specific Engineering Standards and Technical Guidelines (ESTGs) and DEPs will be referred to for OSBL scope only. FCE will follow typical Oil and Gas industrial standards and codes for the BOP and MCFC skids. C

A typical list of common codes and standards is given below.

ABC	Alberta Building Code
AFC	Alberta Fire Code
AGMA	American Gear Manufacturers Association
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
AWS	American Welding Society
CEC	Canadian Electrical Code
CISC	Canadian Institute of Steel Construction
CSA	Canadian Standards Association
EEMAC	Electrical Equipment Manufacturer's Association of Canada
IEEE	Institute of Electrical and Electronics Engineers
ISA	Instrument Society of America
NACE	National Association of Corrosion Engineers
NBCC	National Building Code of Canada
NEMA	National Electrical Manufacturers Association
NFC	National Fire Code of Canada

NFPA	National Fire Protection Association
OHSA	Occupational Health & Safety Act
TEMA	Tubular Exchanger Manufacturers Association
ULC	Underwriters Laboratories of Canada

6.0 PROCESS DESIGN CONSIDERATIONS

6.1 Hydraulics

Jacobs in-house spreadsheet will be used to size the gas and liquid lines between the MCFC module and the site tie-ins. Velocity recommendations will be based on DEP 31.38.01.11.

6.2 Winterization

All piping located outdoors and all components of the MCFC and BOP skids will be specified to meet an MDMT of -43°C, unless EHT is provided. B

EHT with a hold temperature of 10°C will be required for freeze protection on water lines.

Equipment / aerial coolers are to be winterized if there is a potential for freezing. Shell ESTG for winterization to be followed.

7.0 PLOT PLAN

7.1 Foot Print

The preliminary foot print required for the MCFC and BOP skids is 30.5 m x 15.2 m (100 ft x 50 ft). C

7.2 Location

Three location options were considered and are shown in the preliminary plot plan in Attachment 4 of this document. A traffic light comparison and listing of pros / cons for the 3 location options of the FCE skids is shown in Attachment 5. Option 1 (SE corner of the Quest unit) was selected based on discussions with Shell as this is the preferred option from an overall integration and operation point of view and keeps the fuel cell demonstration unit within the existing Quest area. C

8.0 CIVIL / STRUCTURAL DESIGN

8.1 Site Geotechnical Data

B

Existing geotechnical reports are available for the locations being considered for the MCFC and BOP skids. They are as below:

- CCS Quest Project Supplemental Geotechnical Investigation report prepared by Thurber dated December 16, 2010
- Shell Athabasca Oil Sands Downstream Utilities and Offsite Project Detailed Geotechnical Investigation (Subcontract No. 757-289-SC-04) prepared by Thurber dated March 30, 2000. (Relevant boreholes are BH98-19 and BH98-35)

8.2 Civil, Paving & Roads

B

The proposed sites are already graded. Civil works will be related to local excavation, backfilling and compaction required for the foundation.

8.3 Pile and Foundation Design

For the current phase of engineering, consideration is that skids will rest on screw piles. The screw piles will be designed to ensure that no frost heave movements are expected on the skids and no relative movement between unit skids. Screw piles are chosen based on their ease of installation and cost effectiveness. During the next phase of engineering, when more information will be available, it will be reviewed whether piling can be avoided and the skids can be supported on shallow foundation. C

All Concrete works shall conform to CSA A23.1, A23.2 and A23.3

8.4 Structural Steel

Structural steel will be designed, fabricated and erected in accordance with the requirement of CSA S16. All welding shall conform to CSA W48 and W59.

8.5 Materials of Construction

B

W, HP, WT, S and WWF shapes	CSA G40.21, Grade 350W or ASTM A992/A992M (Fy= 345 MPa), ASTM A 572 Grade 50
HSS Shapes	CSA G40.21, Grade 350W Class C ASTM A 500 Grade C (Fy= 345 MPa),
Channels, Angles and Plates	CSA G40.21, Grade 300W ASTM A36/36M
Steel Piles (If required)	ASTM A252 Grade 3
Pile Helix Plate	ASTM A 36 or CSA G40.21, Grade 300W
Concrete	Concrete compressive strength (f'c) shall be minimum 30MPa at 28 days.
Reinforcement Steel	CSA G30.18 Grade 400 / 400W
Anchor Bolts	ASTM F1554 or ASTM A307 Grade A

B

8.6 Codes & Standards

NBC	National Building Code of Canada
ABC	Alberta Building Code
AFC	Alberta Fire Code
CSA A23.1	Concrete Materials and Method of Concrete Construction
CSA A23.2	Test Methods and Standard Practices for Concrete
CSA A23.3	Design of Concrete Structures
G40.20/G40.21	General Requirement for Rolled or Welded Structural Quality Steel / Structural Quality Steel
CSA S16	Design of Steel Structures
CSA W48	Filler Materials and Allied Materials for Metal Arc Welding
CSA W59	Welded Steel Construction
OS & H	Alberta Occupational Health and Safety

For the OSBL scope, in addition to above, the following Shell DEPs shall also be considered.

DEP 34.00.01.30-Gen	Structural Design and Engineering of Onshore Structures
DEP 34.28.00.31-Gen	Onshore Steel Structures
DEP 34.28.00.33-Gen	Onshore Ancillary Steel Structures
DEP 34.11.00.10-Gen	Gen Onshore & Nearshore Site Investigation
DEP 34.11.00.12-Gen	Geotechnical & Foundation Engineering Onshore
DEP 34.19.20.31-Gen	Reinforced Concrete Structures

9.0 PIPING DESIGN

9.1 Pipe Specifications

OSBL piping design will refer to Shell ESTG-3-1.03-UPG-2009 Line Class specifications and standards. However, based on discussions with Shell, since the installation of the MCFC skid is temporary, deviations from the line class specifications will be considered to minimize costs. B C

9.2 Codes & Standards

Both OSBL and FCE piping scope is to be designed as per ASME B31.3.

Only OSBL piping will adhere to Shell ESTG 3-1.03-UPG-2009 Line Class, Specifications and Standards as required. B

10.0 MECHANICAL EQUIPMENT DESIGN

10.1 Blower Design

Shell ESTG refers to API 673 for blower design; however based on discussions with Shell, since the installation is temporary, a non-API or fit-for-purpose blower will be considered. C

10.2 Codes & Standards

Mechanical equipment design for FCE package will be based on applicable Codes and Standards.

11.0 ELECTRICAL DESIGN

11.1 Site Power Supply and Distribution

The electrical tie-in for the MCFC skid will likely be a 600V tie-in within the Quest Area Switchgear/MCC room (Unit 248). Spare 600V MCC wrappers/buckets in existing Quest Switchgear/MCC Room (Unit 248) have been identified. Temporary construction power cables (600V) that was used to previously supply the HCU Debottleneck trailers from the downstream distribution panel via the "A" bus of the Unit 284 Main Substation MCC has been requested by Shell to be re-used for this 600V MCFC skid power supply. C

Electrical tie-in of the new 600V blower near the HMU-2 stack would likely be from a spare source in the HMU Sub MCC Room (Unit 240) – 600V MCC section. C

Existing cable trays will be utilized as much as possible; for outside interconnecting rack routing, channel tray installation is typically. However, since the MCFC unit is a temporary installation, a deviation from new cable / channel trays will be evaluated during FEED. Likely installation method is for the cables to be run on the ground on cones. C

11.2 MCFC Power Return

The electrical tie-in for the MCFC skid power return will likely be a 5kV tie-in within the Quest Area Switchgear/MCC room (Unit 248). C

Upstream reverse power relay to prevent export of power to grid needs to be confirmed, as bus outage would be required if implemented, and this would be developed during the later stages of design. (HOLD – To Be Evaluated During FEED) C

11.3 UPS

C

A UPS battery supply will be included as part of FCE's standard design.

C

11.4 Area Classification

Teck cable connectors shall meet the requirements with appropriate cable glands and shall have poured seals, as required for classified areas.

11.5 Lighting

Additional lights for the MCFC skid are to be added by extending nearby local lighting panel circuits. Exterior lights will be designed as temporary installations. (HOLD – To be Confirmed)

11.6 Grounding

A grounding grid will be designed and included as part of the foundations. The process equipment skids supplied by FCE will include provisions for lightning protection and connection points to the ground conductors in the grounding grid. This is to be developed during later stages of the design.

11.7 Codes & Standards

All electrical scope will be designed to meet Canadian Electrical Code (CEC) and Canadian Standards Association (CSA) requirements.

12.0 INSTRUMENTATION / COMMUNICATION DESIGN

12.1 Control Strategy

A local control panel for operation of the MCFC and BOP skids will be provided by FCE.

Control philosophy will be developed during the study. It is anticipated that the flue gas flow rate to the MCFC module will be controlled by either a VFD on the blower or by a control valve on the suction side of the blower. The flue gas flow demand signal from the FCE package will be used to control the flow of flue gas to the MCFC module.

A flue gas damper will be in place upstream of the flue gas blower to isolate the system from the reformer stack during system shutdown.

An on/off valve will be provided near the CO_2 product tie-in to isolate the MCFC skid from the CO_2 pipeline during a system shutdown.

12.2 Communication Tie-In

A wireless connection will be used for remote monitoring of the MCFC and BOP skids.

An ESD of the package from the control room HMI may also be required to hard-stop the MCFC unit during plant emergencies. (HOLD – To Be Confirmed)

12.3 Signals Exchange

FCE indicated that the following information be exchanged:

- Run Status from Host (Indicating Flue Gas Availability)

- Run Status from MCFC Plant – Processing Flue Gas
- Run Status from MCFC Plant – Operating, Not Processing Flue Gas (i.e. standalone mode)
- Run Status from MCFC Plant - Shutdown

12.4 Codes & Standards

All instrumentation scope will be designed to meet Canadian Electrical Code (CEC) and Canadian Standards Association (CSA) requirements.

Attachment 1
Stack Gas Lab Analysis

Appendix I

Emission Data and Calculations

Removed Pages 70-78

2910 12TH STREET NE
CALGARY, ALBERTA
CANADA T2E 7P7
TEL (403)299-2000
FAX (403)299-2010
http://www.agatlabs.com

CLIENT NAME: MISC AGAT CLIENT AB, AB

ATTENTION TO: Steve Millar - 2420 AGAT

PROJECT:

AGAT WORK ORDER: 16C155574

OCCUPATIONAL HYGIENE REVIEWED BY: Rong Jin, Condensate Technician

DATE REPORTED: Nov 02, 2016

PAGES (INCLUDING COVER): 4

VERSION*: 1

Should you require any information regarding this analysis please contact your client services representative at (403) 299-2000

*NOTES

All samples will be disposed of within 30 days following analysis. Please contact the lab if you require additional sample storage time.

AGAT Laboratories

2910 12TH STREET NE
CALGARY, ALBERTA
CANADA T2E 7P7
TEL (403)299-2000
FAX (403)299-2010
http://www.agatlabs.com

Certificate of Analysis

CLIENT NAME: MISC AGAT CLIENT AB
PROJECT:
SAMPLING SITE:

AGAT WORK ORDER: 16C155574
ATTENTION TO: Steve Millar - 2420 AGAT
SAMPLED BY:

Trace Sulphur Analysis (GC/SCD) - Gas (ppm (v/v))

SAMPLE TYPE: Gas
SAMPLE ID: TB1A
DATE RECEIVED: Nov 02, 2016
DATE SAMPLED: Nov 01, 2016
DATE REPORTED: Nov 02, 2016
SAMPLE DESCRIPTION: TEST 8 BAG 1; SCOTFORD HMN3

PARAMETER	UNIT	RESULT	G / S	RDL	DATE ANALYZED	INITIAL	DATE PREPARED
Hydrogen Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Carbonyl Sulphide	ppm (v/v)	0.4		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Methyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Ethyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Dimethyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Carbon Disulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
iso-Propyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
tert-Butyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
n-Propyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Methyl Ethyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
s-Butyl Mercaptan/Thiophene	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
iso-Butyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Diethyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
n-Butyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
tert-Butyl Methyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Dimethyl Disulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Diethyl Disulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Total Unidentified Sulphur Compounds	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Total Organic Sulphur	ppm (v/v)	0.4		0.1	Nov 02, 2016	RJ	Nov 02, 2016

COMMENTS:

RDL - Reported Detection Limit; G / S - Guideline / Standard
Field Hydrogen Sulphide : Not Available.
Identification based on retention time relative to standards.
All compounds quantified as ideal gases. Carbonyl sulphide quantified using its standard response factor, all other compounds quantified using Hydrogen sulphide's response factor.
Total organic sulphur includes compounds with chromatographic retention up to and including that of ethyl disulphide.

Certified By: ____________________

2910 12TH STREET NE
CALGARY, ALBERTA
CANADA T2E 7P7
TEL (403)299-2000
FAX (403)299-2010
http://www.agatlabs.com

Certificate of Analysis

CLIENT NAME: MISC AGAT CLIENT AB
PROJECT:
SAMPLING SITE:

AGAT WORK ORDER: 16C155574
ATTENTION TO: Steve Millar - 2420 AGAT
SAMPLED BY:

Trace Sulphur Analysis (GC/SCD) - Gas (ppm (v/v))

SAMPLE TYPE: Gas
SAMPLE ID: TB2B
DATE RECEIVED: Nov 02, 2016
DATE SAMPLED: Nov 01, 2016
DATE REPORTED: Nov 02, 2016
SAMPLE DESCRIPTION: TEST 8 BAG 2; SCOTFORD HMN3

PARAMETER	UNIT	RESULT	G / S	RDL	DATE ANALYZED	INITIAL	DATE PREPARED
Hydrogen Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Carbonyl Sulphide	ppm (v/v)	0.5		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Methyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Ethyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Dimethyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Carbon Disulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
iso-Propyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
tert-Butyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
n-Propyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Methyl Ethyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
s-Butyl Mercaptan/Thiophene	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
iso-Butyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Diethyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
n-Butyl Mercaptan	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
tert-Butyl Methyl Sulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Dimethyl Disulphide	ppm (v/v)	0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Diethyl Disulphide	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Total Unidentified Sulphur Compounds	ppm (v/v)	<0.1		0.1	Nov 02, 2016	RJ	Nov 02, 2016
Total Organic Sulphur	ppm (v/v)	0.6		0.1	Nov 02, 2016	RJ	Nov 02, 2016

COMMENTS:

RDL - Reported Detection Limit; G / S - Guideline / Standard
Field Hydrogen Sulphide : Not Available.
Identification based on retention time relative to standards.
All compounds quantified as ideal gases. Carbonyl sulphide quantified using its standard response factor, all other compounds quantified using Hydrogen sulphide's response factor.
Total organic sulphur includes compounds with chromatographic retention up to and including that of ethyl disulphide.

Certified By: 金誉

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FAX (403)299-2010
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Method Summary

CLIENT NAME: MISC AGAT CLIENT AB
PROJECT:
SAMPLING SITE:

AGAT WORK ORDER: 16C155574
ATTENTION TO: Steve Millar - 2420 AGAT
SAMPLED BY:

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Occupational Hygiene Analysis			
Hydrogen Sulphide	HC-0801	ASTM D5504-08	GC/SCD
Carbonyl Sulphide	HC-0801	ASTM D5504-08	GC/SCD
Methyl Mercaptan	HC-0801	ASTM D5504-08	GC/SCD
Ethyl Mercaptan	HC-0801	ASTM D5504-08	GC/SCD
Dimethyl Sulphide	HC-0801	ASTM D5504-08	GC/SCD
Carbon Disulphide	HC-0801	ASTM D5504-08	GC/SCD
iso-Propyl Mercaptan	HC-0801	ASTM D5504-08	GC/SCD
tert-Butyl Mercaptan	HC-0801	ASTM D5504-08	GC/SCD
n-Propyl Mercaptan	HC-0801	ASTM D5504-08	GC/SCD
Methyl Ethyl Sulphide	HC-0801	ASTM D5504-08	GC/SCD
s-Butyl Mercaptan/Thiophene	HC-0801	ASTM D5504-08	GC/SCD
iso-Butyl Mercaptan	HC-0801	ASTM D5504-08	GC/SCD
Diethyl Sulphide	HC-0801	ASTM D5504-08	GC/SCD
n-Butyl Mercaptan	HC-0801	ASTM D5504-08	GC/SCD
tert-Butyl Methyl Sulphide	HC-0801	ASTM D5504-08	GC/SCD
Dimethyl Disulphide	HC-0801	ASTM D5504-08	GC/SCD
Diethyl Disulphide	HC-0801	ASTM D5504-08	GC/SCD
Total Unidentified Sulphur Compounds	HC-0801	ASTM D5504-08	GC/SCD
Total Organic Sulphur	HC-0801	ASTM D5504-08	GC/SCD

Attachment 2
CO_2 Pipeline Specifications

[redacted]

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

[redacted]

Attachment 3
Meteorological and General Site Conditions

Table A.2 – Meteorological and Site Data

Normal Atmospheric Pressure 1. For the purposes of mechanical design where design for full vacuum is required: full vacuum is based on standard barometric pressure at sea level, 101.325 kPa (abs). That is, design for full vacuum is design for 101.325 kPa external pressure. Design for ½ vacuum is design for 50.663 kPa external pressure. 2. For the purposes of process design: use barometric pressure of 93.5 kPa (abs). For example: suction pressure for air compressors, fans and blowers with atmospheric air suction; flare tip barometric pressure, etc.	93.5 kPa
Hottest Month Ambient Temperature	2.8°C min, 33.9°C max
Coldest Month Ambient Temperature	-43°C min, 10°C max
Minimum Temperature	-43°C
Summer Wet Bulb Temperature	19°C
Summer Dry Bulb Temperature (July)	28°C
Air Cooled Exchanger Design Dry Bulb Temperature	28°C
Design Temperature for Motors	40°C
Design Temperature for Pipe Expansion	40°C / -43°C
Design Temperature for Freeze Protection	-43°C
Design Temperature for Material Selection	-43°C
Instrument Air Dew Point Max	-60°C
Relative Humidity - Summer	75% @ 28°C
Relative Humidity - Winter	< 1% Min
Average Annual Precipitation	430 mm
15 Minute Precipitation	20 mm
One Day Precipitation	88 mm
Wind	$Q_{1/10}$ = 0.31 kPa $Q_{1/50}$ = 0.43 kPa
Snow (1/50)	S_S = 1.6 kPa S_R = 0.1 kPa
Seismic	Site Response – Site Class D Spectral Accelerations (2% in 50 year probability) S_a (0.2) = 0.116 S_a (1.0) = 0.023 Design factor R, as per table 4.1.8.9 of ABC 2006.
Site Elevation	623.5 m
Frost Protection – Design Depth - Foundations	2.7 m
Soil Conditions	Refer to geotechnical reports

Attachment 4
Preliminary Plot Plan

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Attachment 5
Location Comparison / Selection

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]	[redacted]	[redacted]
Option 1	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	
	[redacted]	
	[redacted]	
	[redacted]	
	[redacted]	
	[redacted]	
	[redacted]	
Option 2	[redacted]	[redacted]
	[redacted]	[redacted]
		[redacted]
		[redacted]
		[redacted]
Option 3	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]

MCFC - 4CC - SAGD Shell Scotford Options Summary

Options	Cost	Utility Integration	CO2 integration	Flue Gas Ducting Length	Accessibility (to FCE)	Electrical Integration	Impact on Access to Existing Plant	Operation Integration	Overall Ranking
Option 1									
Option 2									
Option 3									
Original Shell Location - Baseline									

Appendix C. Preliminary Plot Plan

Removed Pages 94-95

Appendix D. Battery Limit Table

1.4 MW MCFC DEMONSTRATION UNIT	Unit:	SHELL SCOTFORD UPGRADER HOST SITE	Date:	14-
PRE-FEED PHASE	Document #:		Page:	1
	Rev:	A	Issue:	Issued

Process Commodity	Location	Phase L,V,L/V	Line Identification Number				Connection		Installed By	Northing	Easting	Pipe CL	Battery Limit Conditions							De
													Mass Flow			Pressure		Temperature		
			Line Number	Insulation Type/Material	Insulation Thickness	Tracing	Size	Type				EL	Minimum	Normal	Design	Normal	Maximum	Normal	Maximum	Pressure
					mm	Type/ ^{0}C	(NPS)			m	m	mm	Kg/h	Kg/h	Kg/h	kPag	kPag	°C	°C	kPag
ue Gas	A/G	V	-	H	50	-	24"	TBD	TBD	TBD	TBD	TBD		12,140		-	21	172	250	35
atural Gas	A/G	V	-	-	-	-	2"	Flange	TBD	TBD	TBD	TBD		166		140	TBD	15	38	1,900
emin Water	AG	L	-	H	By Vendor	ET/10°C	TBD	TBD	TBD	TBD	TBD	TBD		1,200		TBD	750	25	35	750
oduced Water	AG	L	-	H	By Vendor	ET/10°C	TBD	TBD	TBD	TBD	TBD	TBD		450		TBD	TBD	TBD	TBD	TBD
arbon Dioxide	AG	L	-	-	-	-	2"	Flange	TBD	TBD	TBD	TBD		1,512		10,000	14,890	10	TBD	14,890
ooling Water	AG	L	-	H	38	ET/10°C	3"	Flange	TBD	TBD	TBD	TBD		28,700		420	550	25	25	800
ooling Water	AG	L	-	H	38	ET/10°C	3"	Flange	TBD	TBD	TBD	TBD		28,700		420	550	25	25	800

Appendix E. Mechanical Equipment List

EQUIPMENT LIST - Shell Scotford Site

Date	Description	Rev	Prep	Chk.
15-Feb-17	Preliminary for Pre-FEED study	A	TL	ESD

gn P (kPag)	Design T (°C)	DETAILS (CAPACITY / DIMENSIONS)	MATERIALS	MOTOR RATING	Delivery (weeks ARO)	APPROX. WEIGHT (KG)	NOTES	QTY	COST per UNIT	Total	Vendors / Budget
	-43°C / 250°C	Type: Centrifigual Rated Capacity: 11,229 Sm^3/hr Diff Pressure: 23 kPa Foot Print: 2.6m x 1.7m	Casing: A242 Wheel: A514 Shaft: 416 SS	250 hP	15 to 18	2,056	Cost for VFD is not included	1	$99,060	$99,060	Robinson Fans (RA
		Skid Dimensions: 10 ft L x 10 ft W x 25.5 ft H				6,806	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 4.5 ft L x 4.5 ft W x 9.5 ft H				3,857	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 38 ft L x 8.5 ft W x 20.5 ft H				27,223	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 18 ft L x 7.5 ft W x 17 ft H				3,176	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 20 ft L x 12 ft W x 11 ft H				6,806	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 8 ft L x 6 ft W x 10 ft H				1,815	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 14 ft L x 6.5 ft W x 10.5 ft H				5,445	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 12 ft L x 10 ft W x 6.5 ft H				6,806	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 20 ft L x 8 ft W x 8.5 ft H				9,074	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 15 ft L x 8 ft W x 9 ft H				11,343	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 20 ft L x 13 ft W x 13.5 ft H				48,548	Part of FCE's Module. FCE to provide overall ISBL cost.				
		Skid Dimensions: 22 ft L x 8.5 ft W x 8.5 ft H				12,024	Part of FCE's Module. FCE to provide overall ISBL cost.				

Appendix F. Tie-In List and Line List

							(NOTE 2)	(NOTE 2)			Cl	
-	24"	EE060101-PR-SK-002	-	-	CW	-	-	-	-		III	
-	2"	EE060101-PR-SK-004	-	-	TC	-	-	-	-		II	
-	3/4" PRE-INSULATED/ EHT TUBING	EE060101-PR-SK-005	-	-	TC	-	-	-	-		II	
~~-~~	~~1/2" PRE-INSULATED/ EHT TUBING~~	~~EE060101-PR-SK-008~~	~~-~~	~~-~~	~~-~~	~~-~~	~~-~~	~~-~~	~~-~~		~~II~~	
-	2"	EE060101-PR-SK-007	-	-	FF	-	-	-	-		III	
-	3"	EE060101-PR-SK-006	-	-	FF	-	-	-	-		III	
-	3"	EE060101-PR-SK-006	-	-	HT	-	-	-	-		II	
-	2"	EE060101-PR-SK-007	-	-	TC	-	-	-	-		II	

WORK CLASSIFICATION

I - IMMEDIATE WORK
II - SCHED W/OUT SHUTDOWN OF EQUIP
III - SCHED IN SEQ W/EQUIP SHUTDOWN
IV - INSTALL WHEN LABOUR & MATERIAL IS AVAILABLE
SUFFIX "C" - COORD W/ OTHER TIE-INS SEE REMARKS

NOTES
1. REFER TO SCOPE OF WORK
2. REFER TO LDT FOR TEST TYPE & PRESSURE
3. WELD PROCEDURE BY CONTRACTOR
4. PER SHELL STANDARD DEP 31.38.01.31-SCAN APPENDIX 4.
5. FIELD VERIFY FLANGE RATINGS.
6. WORK CLASSIFICATION IS BASED ON ASSUMPTION THAT ISOLATION VALVES AT THE UPSTREAM/DOWNSTREAM (AS APPLICABLE) ARE OPERATIONAL AND IN GOOD CONDITION.
7. BASED ON UT RESULTS, SITE CONTRACTOR TO MAKE SURE THAT AVAILABLE WALL

A	-	ISSUED
REV	DATE YY/MM/DD	DES

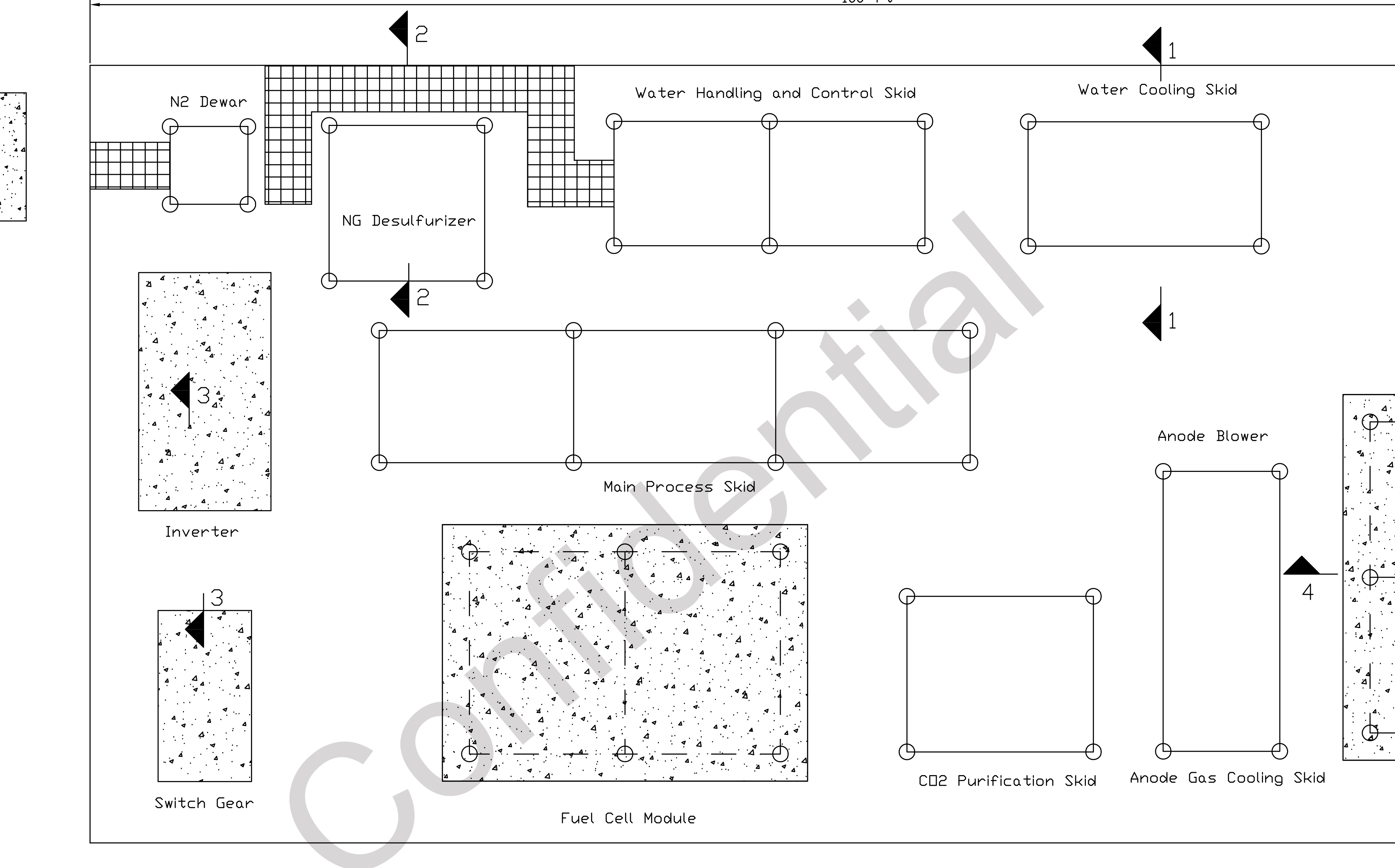
JACOBS

I.D. Code / Commodity	Unit #	Seq.	Line Spec.	Ins. (mm)	Tracing Hold (T) °C	Vapor / Liquid	From / To	Des.-kPa(g) / Op.-kPa(g)	Des.-°C / Op.-°C	Test Medium	Min.-kPa / Max.-kPa	Req'd / PWHT	MDMT °C	
GW FLUE GAS	240	XX1	Circular Ducting	50	-	V --------------	S-24203 -------------- FLUE GAS BLOWER	35 -------------- 21	250 -------------- 172		--------------	--------------		
GW FLUE GAS	240	XX2	Circular Ducting	50	-	V --------------	FLUE GAS BLOWER -------------- MCFC SKID EDGE	35 -------------- 21	250 -------------- 172		--------------	--------------		Note that ther
GN NATURAL GAS	246	XX1	RLB	-	-	V --------------	2"-GN-246002-RLB -------------- MCFC SKID EDGE	1900 -------------- TBD	38 -------------- 15		--------------	--------------	-46	
WI DEMIN WATER	246	-	Tubing	By Vendor	10	-------------- Liquid	6"-WI-246021-UJB (0.4) -------------- MCFC SKID EDGE	750 -------------- 416	45 -------------- 25		--------------	--------------		
WW WATER	246	-	Tubing	By Vendor	10	-------------- Liquid	MCFC SKID EDGE -------------- CO2 / DEHY AREA CATCHMENT	ATM -------------- ATM	TBD -------------- 62		--------------	--------------		
CWS OOLING WATER	246	XX1	UAB	38	10	-------------- Liquid	30"-CWS-246003-UAB -------------- MCFC SKID EDGE	800 -------------- 420	58 -------------- 25		--------------	--------------	-29	
CWR OOLING WATER	246	XX1	UAB	38	10	-------------- Liquid	MCFC SKID EDGE -------------- 30"-CWR-246016-UAB	800 -------------- 240	58 -------------- 45		--------------	--------------	-29	
GC CO2	247	XX1	PJL (C)	-	-	-------------- Liquid	MCFC SKID EDGE -------------- 8"-GC-247059-PJL(C)	14890 -------------- 14890	204 -------------- 10		--------------	--------------	-80	
											--------------	--------------		

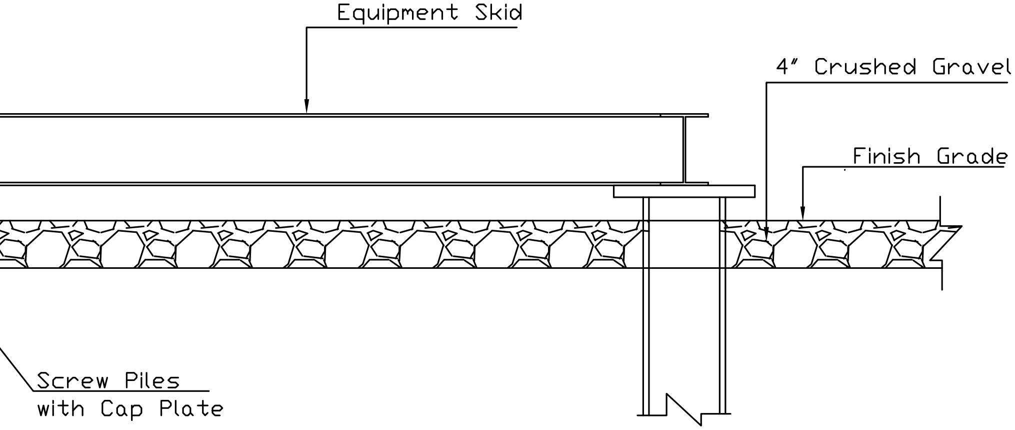
Appendix G. Pipe Routing Sketches

Removed Page 104

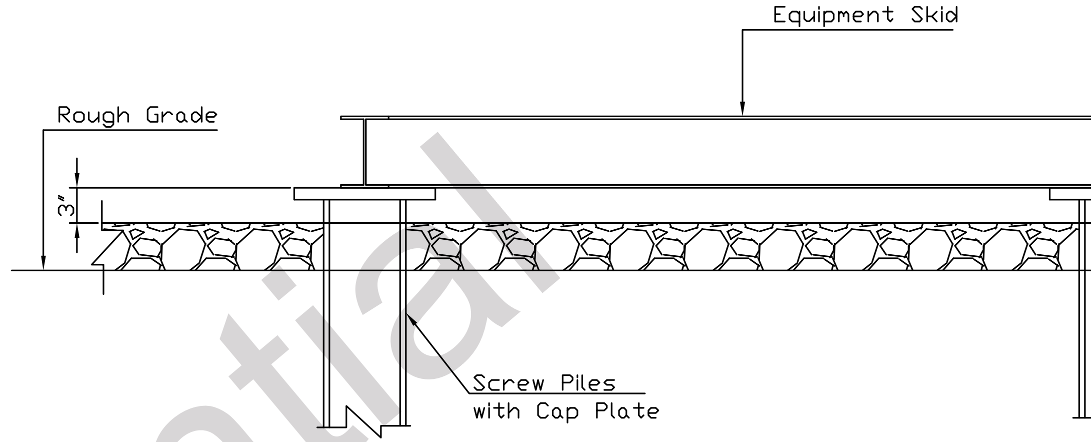
Appendix H. Civil / Structural Sketches



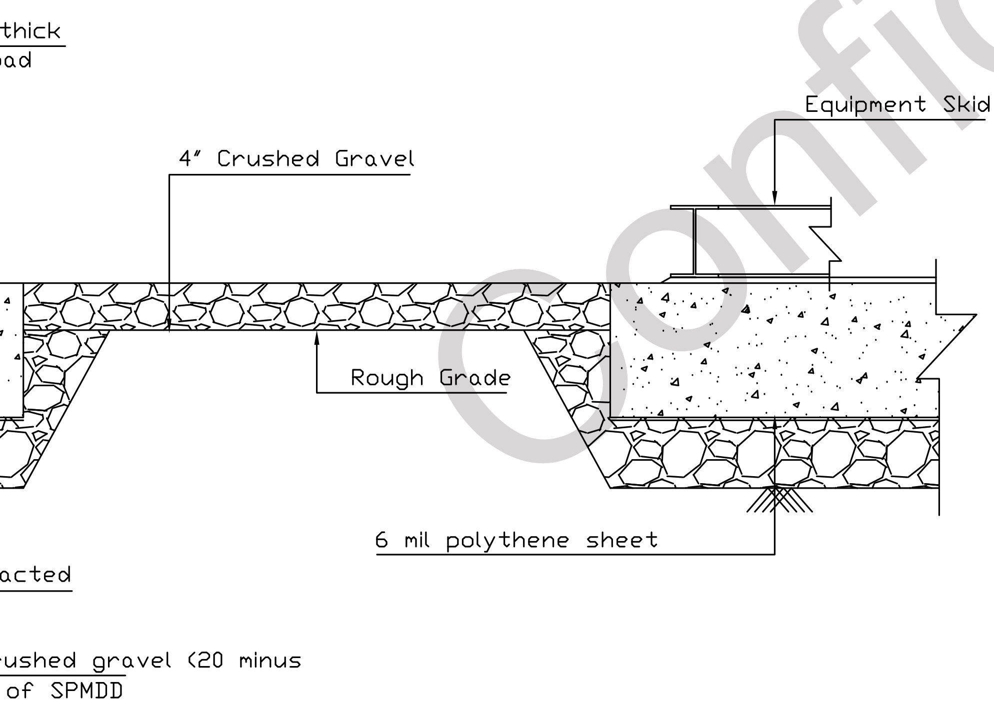
Plan MCFC Skid (ISBL)



Section 1



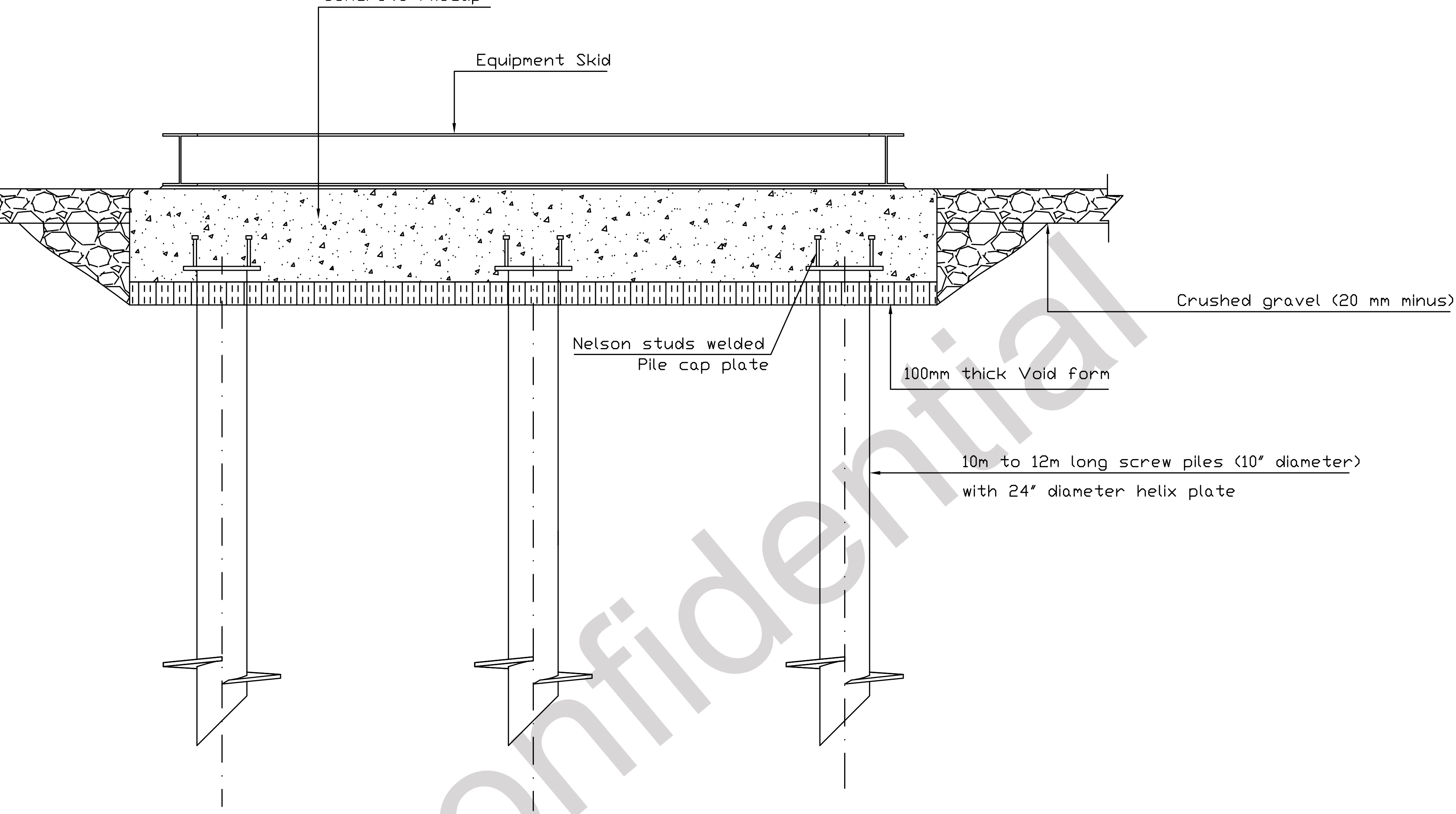
Section 2



Section 3

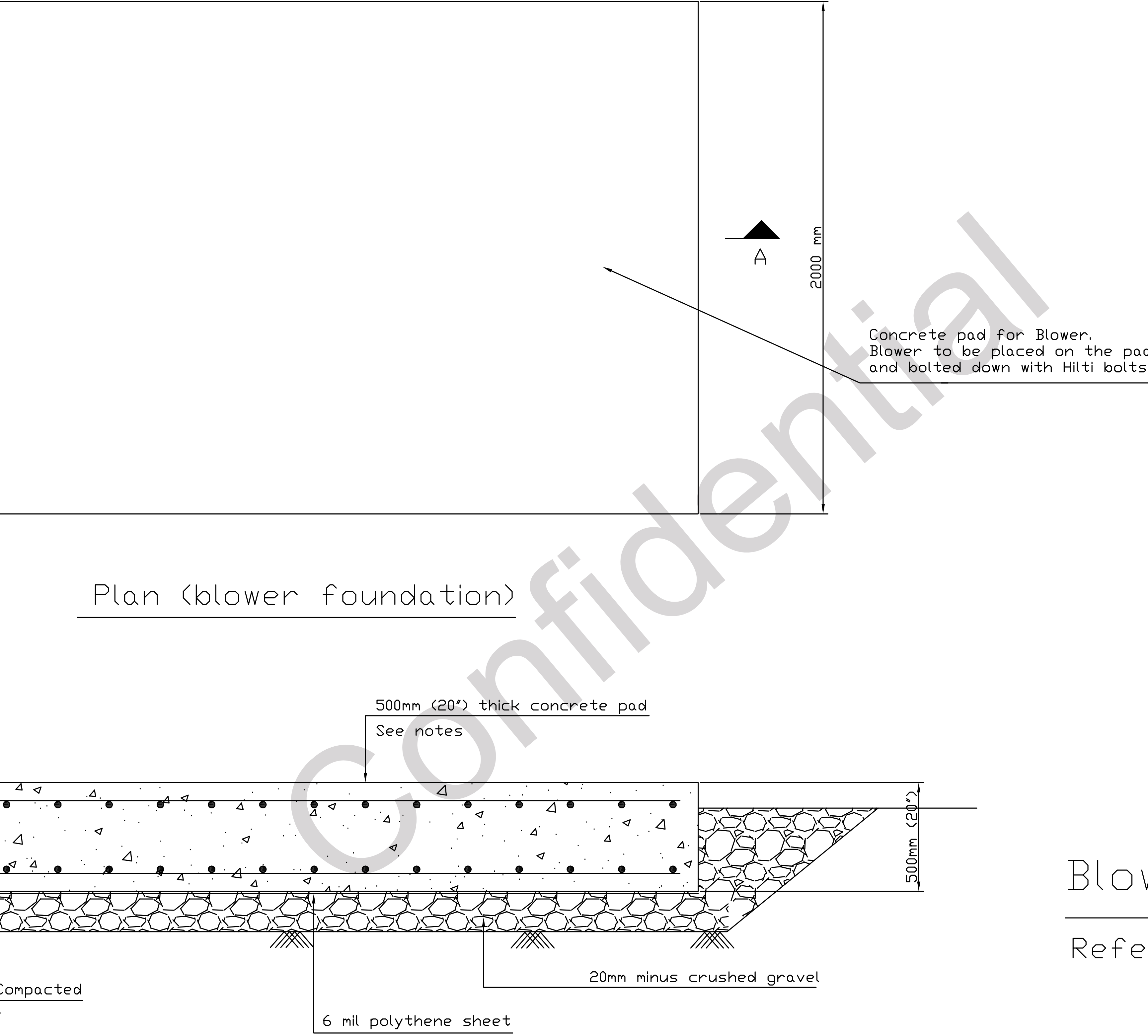
Cross Sec

A	ISSUED F



Section 4

Cross Sec



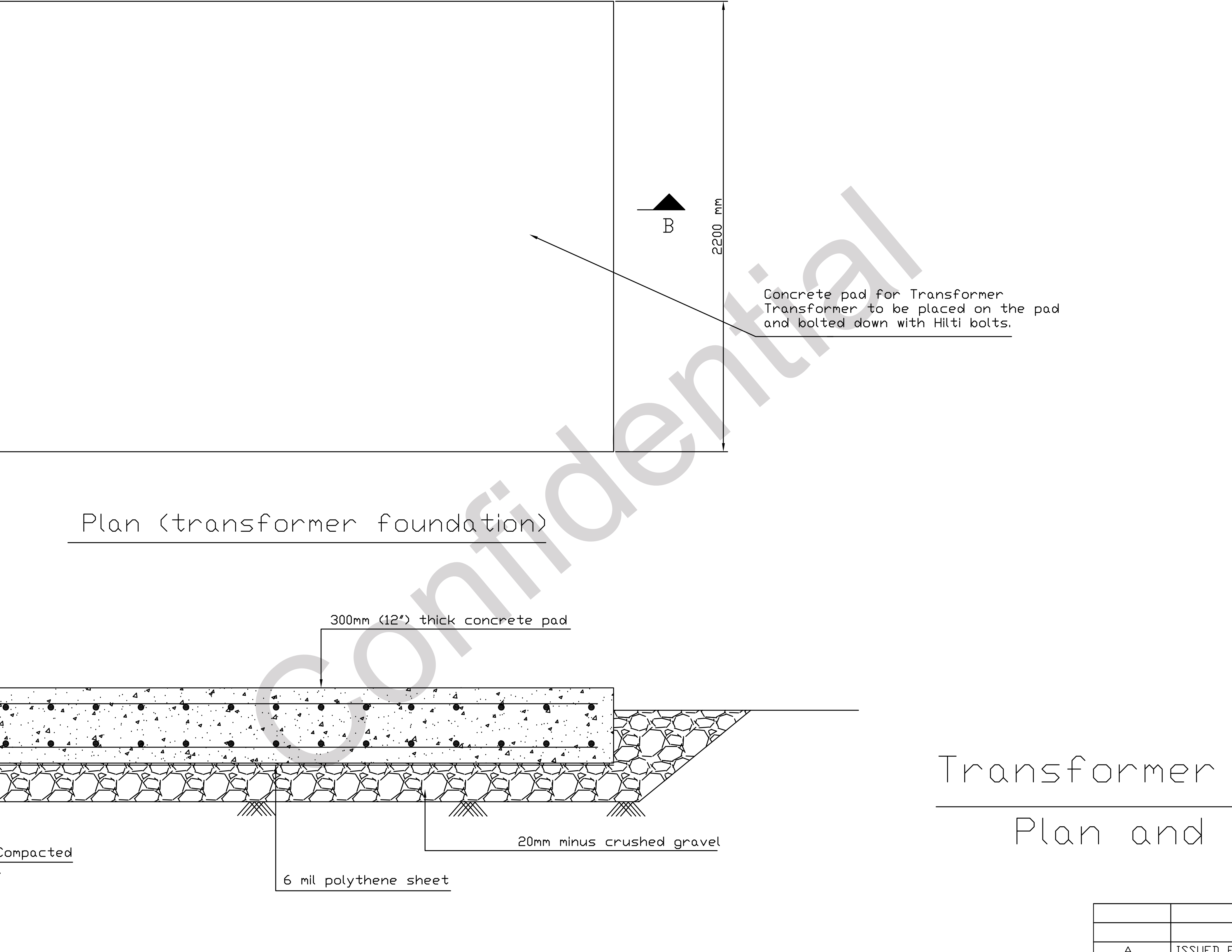
Notes:

Blower Motor is 250
Preliminary design, b
This assumption/ Co
during next phase c

Blower Found

Refer piping layout

A	ISSUED F


B
2200 mm
Concrete pad for Transformer
Transformer to be placed on the pad
and bolted down with Hilti bolts.
Plan (transformer foundation)
300mm (12") thick concrete pad
Compacted
20mm minus crushed gravel
6 mil polythene sheet
Transformer
Plan and
A
ISSUED F

Appendix I. Single Line Diagrams

Removed page 112

Removed page 113

Appendix J. Electrical Sketches

Removed pages 115-124

JACOBS

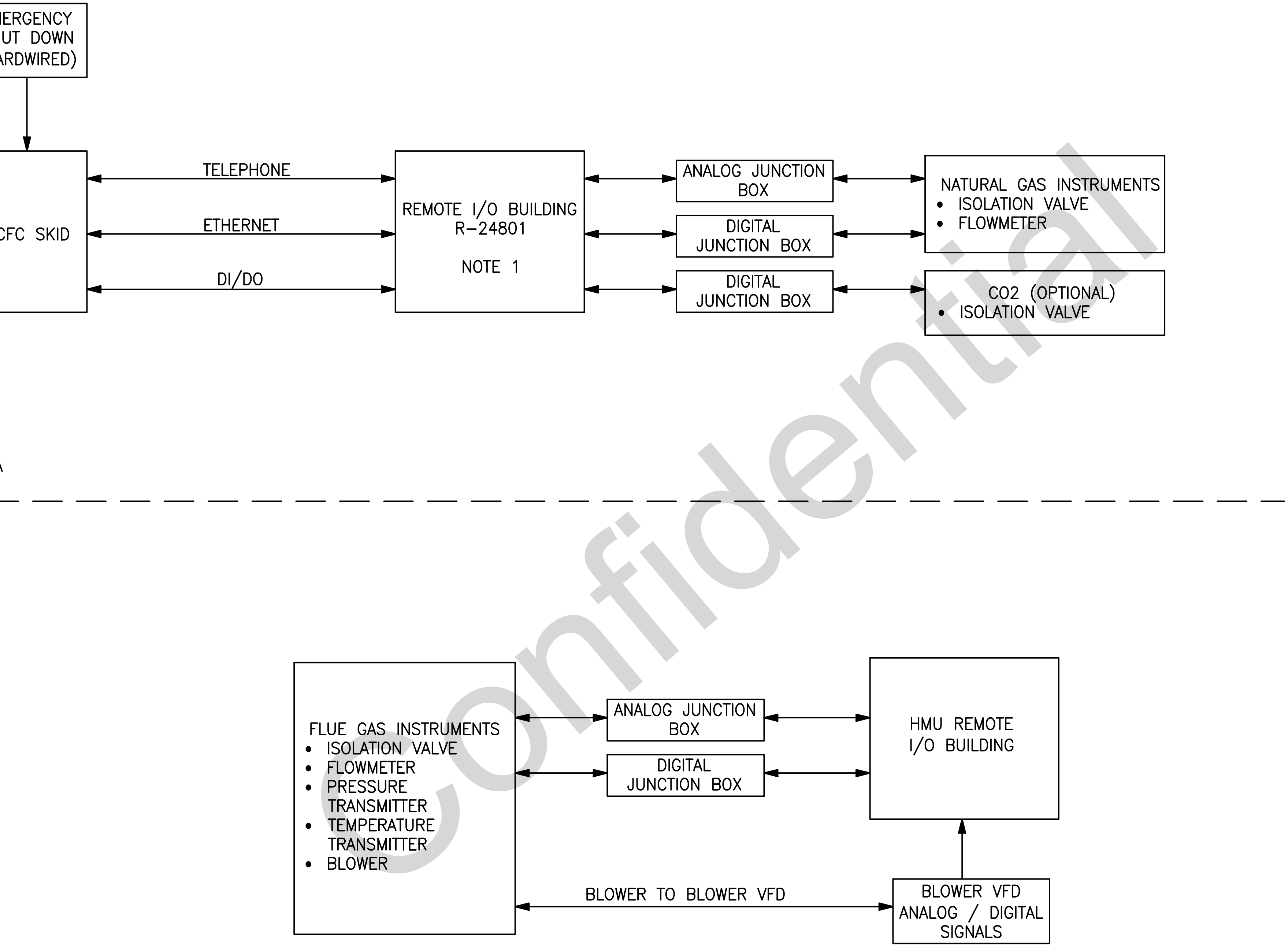
Appendix K. Instrument Index

SHELL INSTRUMENT INDEX (OSBL)

Subject: Issued For Information   Revision: A

	Instrument Type	P&ID	Location	Process Function	IO Type Name	Final Termination Location	Budgetary Price	MR No	Datasheets	Power Supply	Manufacturer Name	Model Name	Calibrated Range	Failure Mode	Process Connection
ation Valve	Air actuated Damper	TBD	Field		DO	TBD	990								
	Transmitter, Flow Orifice	TBD	Field	Flow	AI	TBD	13693								
	Transmitter, Pressure	TBD	Field	Pressure	AI	TBD	3111								
	Transmitter, Temperature	TBD	Field	Temperature	RTD	TBD	968								
	Transmitter, Flow Coriolis	TBD	Field	Flow	AI	TBD	18116								
	Pressure Control Valve	TBD	Field	Pressure	NA		550								
	Pressure Relief Valve	TBD	Field	Pressure	NA		533.37								
	Valve, gate	TBD	Field		DO	TBD	2663								
	Switch, Limit	TBD	Field	Position	DI	TBD	part of valve								
	Switch, Limit	TBD	Field	Position	DI	TBD	part of valve								

Appendix L. Control Block Diagram



KEY PLAN

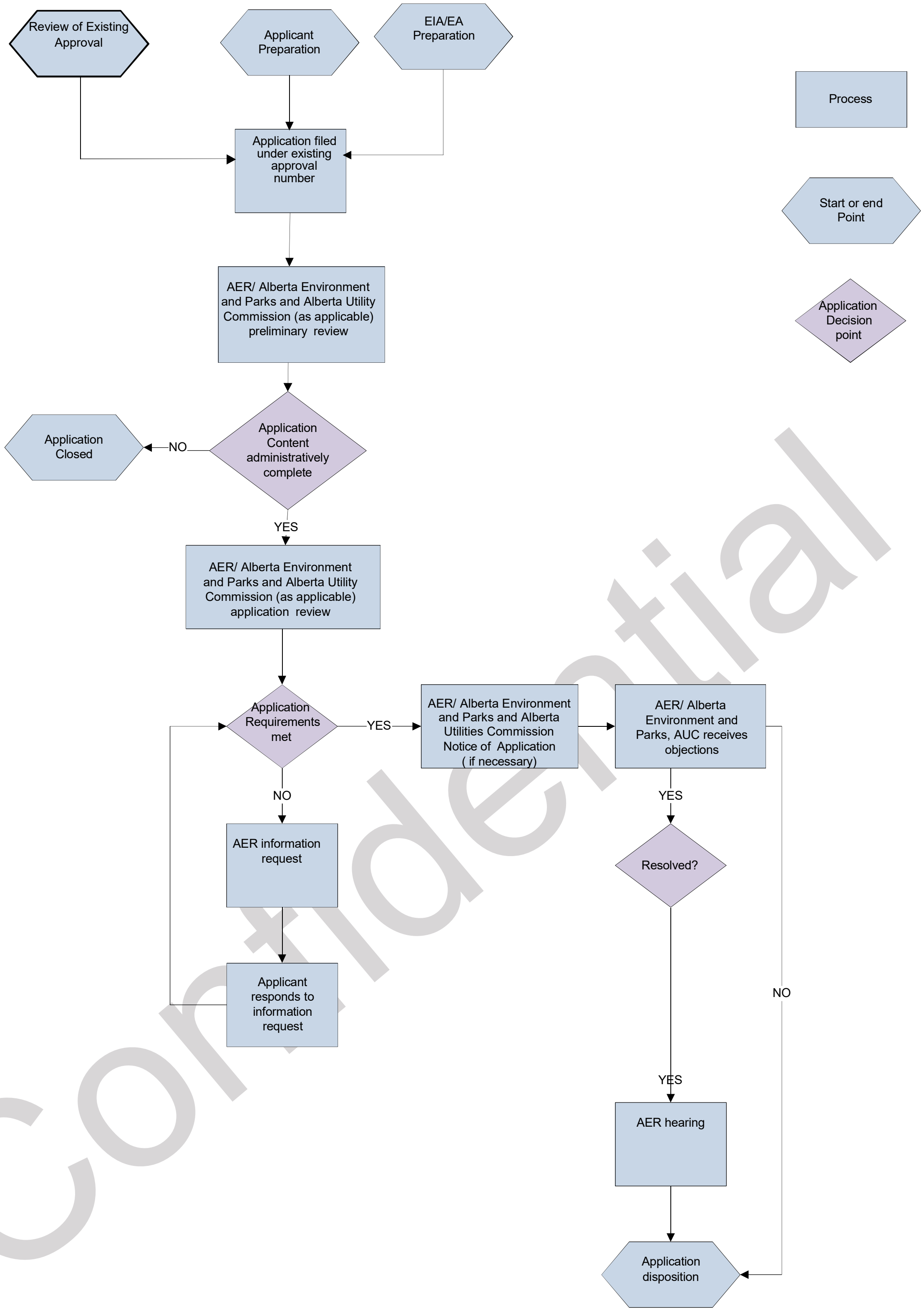
REFERENCE DRAWINGS

REV	ISSUED DATE	DESCRIPTION
A	03/15/17	ISSUED FOR REVIEW

SHELL C
ATHABAS
DOWNSTR

CONTROL BLO

Appendix M. Permitting Roadmap


Review of Existing Approval
Applicant Preparation
EIA/EA Preparation
Application filed under existing approval number
AER/ Alberta Environment and Parks and Alberta Utility Commission (as applicable) preliminary review
Application Content administratively complete
NO
Application Closed
YES
AER/ Alberta Environment and Parks and Alberta Utility Commission (as applicable) application review
Application Requirements met
YES
AER/ Alberta Environment and Parks and Alberta Utilities Commission Notice of Application (if necessary)
AER/ Alberta Environment and Parks, AUC receives objections
NO
AER information request
Applicant responds to information request
YES
Resolved?
NO
YES
AER hearing
Application disposition
Process
Start or end Point
Application Decision point

Appendix N. Budgetary Quotes and Preliminary MTOs

emonstration Plant | Title | Civil Structural MTO (Scotford Site)
Date | 23-Feb-17

Description	Quantity	Unit	Type	Finish	Description/Remarks
	55	m3	20mm minus		Crushed gravel (4" thick) spread on rough grade. No compaction grade required.
" dia x 12m long with 24" dia helix plate)	50	each	ASTM A252 Grade 3 Steel pile		Pile thickness 1/2" and helix thickness 3/4"
500mm square x 25mm thick)	2500	kg	ASTM A36 or CSA G40.21 Grade 300W		50 cap plates
/8" dia) 4 per cap plate	48	each			
ay slab (4" thick and 1m wide)	12	m2			
e sheet	24	m2			
id form	81	m2			
crete (30MPa)	34	m3	30 MPa strength		
	45	m3			
subgrade	30	m2	98% of SPMDD		Compaction assumed only below switchgear and battery. Other a gravel spread above the rough grade
d Blower foundation					
crete (30MPa)	4.5	m3			
	7.5	m3			
e sheet	12	m2			
	3	m3	20mm minus		20mm minus free flowing crushed gravel
subgrade	12	m2	98% of SPMDD		
	0.05	m3			
dia x 250mm long)	8	each			Hilti Hit-Z carbon steel threaded anchor rods complete with Hilti H 200 adhesive system
dia x 200mm long)	4	each			Hilti Hit-Z carbon steel threaded anchor rods complete with Hilti H 200 adhesive system
te Sleeper	5	each			Similar to Lafarge product No. 9321 for estimate purpose

for ISBL
rubbing considered.
nd spread on the rough grade
below foundations not requiring piles

SHELL CANADA PRODUCTS
SCOTFORD, ALBERTA

CARBON CAPTURE PROJECT
DWG No. 00-EE060101-BOM-P-01S

REV.	DATE	DESCRIPTION	ORIGIN
A	-	ISSUED FOR REVIEW	J

MATERIAL TAKE-OFF

line	SERVICE	Size	Rating/ Schedule	Description	Catalogue Number	Pipe Class	Supplier	Purchase by	Unit	Qty.	MR Nu
IG	FLUE GAS	24"	22 Ga.	SPIRAL GALVANIZED DUCT/PIPE		-			m	220.0	
IG	FLUE GAS	14"	24 Ga.	SPIRAL GALVANIZED DUCT/PIPE		-			m	190.0	
IG	NATURAL GAS	2"	SCH 80	ASTM A333 GR.6, SMLS, PE		RLB			m	70.0	
IG	PRODUCED WASTE WATER	1/2"	.035" W.T.	Pre-Insulated/EHT tubing, 316L SS, SML's		-			m	20.0	
IG	DEMINERALIZED WATER	3/4"	.049" W.T.	Pre-Insulated/EHT tubing, 316L SS, SML's		-			m	120.0	
IG	CO2	2"	SCH 160	ASTM A312 GR. TP304/304L, SCH-160, SMLS, PE.		PJL			m	70.0	
IG	COOLING WATER SUPPLY	3"	SCH 40	ASTM A106 GR.B, SMLS, PE		UAB			m	5.0	
IG	COOLING WATER RETURN	3"	SCH 40	ASTM A106 GR.B, SMLS, PE		UAB			m	15.0	
IG	INSTRUMENT AIR	2"	SCH 80	ASTM A333 GR.6, SMLS, PE		ULB			m	40.0	

2 and Cooling water supply/return) are to be done separately.

e below | A | March 3, 2017

Size	Description	Catalogue Number	Reference Notes	Supplier	Purchase By	Unit	Qty.	Pricing	Total Material Cost	Unit Hours	Man-Hours	Unburdened Labor Cost @ $57,19/MHR	Total Labor Cost c/w 1,40 Craft Labor Productivity	Cost Estimate
POWER OUTPUT FROM MCFC SKID TO 284-MCC-501B														
#2/0 AWG	UNSHIELDED THREE CONDUCTOR 100% 5000V, CONDUCTOR: BARE COPPER CLASS B COMPRESSED STRANDED, INSULATION: CROSS-LINKED POLYETHYLENE (XLPE) TYPE RW90, GROUND (BONDING) CONDUCTOR: UNINSULATED STRANDED BARE COPPER CONDUCTOR, INNER JACKET: FLAME-RETARDANT, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), ARMOUR: ALUMINUM INTERLOCKED ARMOUR (AIA), OUTER JACKET: LOW-TEMPERATURE, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), ORANGE, OPTIONS: GALVANIZED STEEL INTERLOCKED ARMOUR (GSIA) OTHER COLOURED JACKET AND CONSTRUCTIONS AVAILABLE UPON REQUEST. BOND (GROUND) WIRE: 6, OUTER JACKET: 1.870"	19003-07-060	1 CABLE RUN **(DIRECT BURIED / EXISTING CABLE TRAY: ROUTING TO BE CONFIRMED IN FEED STAGE)**	TEXCAN		Meter	390	$ 39,22	$ 15,295,80	0,436	170,04	$ 9,724,59	$ 13,614,42	65,421
#500 kcmil	SINGLE CONDUCTOR 1000V, CONDUCTOR: BARE COPPER CLASS B COMPRESSED STRANDED, INSULATION: CROSS-LINKED POLYETHYLENE (XLPE) TYPE RW90, GROUND (BONDING) CONDUCTOR: CONCENTRIC SERVING OF SOLID BARE COPPER WIRES APPLIED OVER INSULATION, INNER JACKET: FLAME-RETARDANT, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), ARMOUR: ALUMINUM INTERLOCKED ARMOUR (AIA), OUTER JACKET: LOW-TEMPERATURE, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), BLACK, OPTIONS: OTHER COLOURED JACKET AND CONSTRUCTIONS AVAILABLE UPON REQUEST. BOND (GROUND) WIRE: 1/0, OUTER JACKET: 1.540"	05020-21-010	12 CABLE RUNS (4 x 3-1C FROM NEW STEP-DOWN TRANSFORMER TO MCFC SWITCHGEAR)	TEXCAN		Meter	75	$ 49,69	$ 3,726,75	0,436	32,7	$ 1,870,11	$ 2,618,16	65,421
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1.5" HUB CABLE OD 1.440" T0 1.965" ALUMINUM CSA/UL APPROVED.	STE150		T&B		Each	26	$ 72,64	$ 1,888,64	2,7	70,2	$ 4,014,74	$ 5,620,63	65,421
	THREE PHASE Δ-Y TRANSFORMER, 1800kVA (MINIMUM), 4160V (DELTA) -480V (WYE)		STEP-UP TRANSFORMER FOR MCFC SKID [SEE WESTBURNE QUOTATION 17-03-0221]	CARTE		Each	1	$ 75,686,60	$ 75,686,60	120	120	$ 6,862,80	$ 9,607,92	65,311
	4160V MCC SECTION C/W 1200A VACUUM CIRCUIT BREAKER, 750VA 4200-120V CPT 1 PH, GE MULTILIN F35 RELAY, 50:0.025 A ZSCT, 400:5A PHASE CTS (3). 1-HIGH SWITCHGEAR CONFIGURATION C/W 1.0M ARC FLASH PLENUM/HOOD ON TOP		ADDITIONAL MV MCC SECTION [SEE WESTBURNE QUOTATION #102500]	ROCKWELL/WESTBURNE		Each	1	$ 81,339,49	$ 81,339,49	60	60	$ 3,431,40	$ 4,803,96	65,312
	TRANSITION CELL, 18" W x 94" H, ADDITIONAL 1M ARC FLASH PLENUM/HOOD ON TOP		ADDITIONAL MV MCC SECTION [SEE WESTBURNE QUOTATION #102500]	ROCKWELL/WESTBURNE		Each	1	See Above	See Above	80	80	$ 4,575,20	$ 6,405,28	65,312
	CABLE SUPPORT CONES			PROLINE OR NORWESCO		Each	80	$ 158,68	$ 12,694,40	0,25	20	$ 1,143,80	$ 1,601,32	65,900
BLOWER														
#1/0 AWG	THREE CONDUCTOR 1000V, CONDUCTOR: BARE COPPER CLASS B COMPRESSED STRANDED, INSULATION: CROSS-LINKED POLYETHYLENE (XLPE) TYPE RW90, GROUND (BONDING) CONDUCTOR: UNINSULATED STRANDED BARE COPPER CONDUCTOR, INNER JACKET: FLAME-RETARDANT, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), ARMOUR: ALUMINUM INTERLOCKED ARMOUR (AIA), OUTER JACKET: LOW-TEMPERATURE, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), BLACK, OPTIONS: GALVANIZED STEEL INTERLOCKED ARMOUR (GSIA), OTHER COLOURED JACKET AND CONSTRUCTIONS AVAILABLE UPON REQUEST. BOND (GROUND) WIRE: 6, OUTER JACKET: 1.650"	05019-03-010	6 CABLE RUNS (2 RUNS MCC TO VFD, 2 RUNS FROM VFD TO OUTPUT FILTER, 2 RUNS OUTPUT FILTER TO MOTOR)	TEXCAN		Meter	100	$ 32,50	$ 3,250,00	0,436	43,6	$ 2,493,48	$ 3,490,88	65,421
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1.5" HUB CABLE OD 1.440" T0 1.965" ALUMINUM CSA/UL APPROVED.	STE150		T&B		Each	12	$ 72,64	$ 871,68	2,7	32,4	$ 1,852,96	$ 2,594,14	65,421
#8 AWG	TWO CONDUCTOR 1000V, CONDUCTOR: BARE COPPER CLASS B COMPRESSED STRANDED, INSULATION: CROSS-LINKED POLYETHYLENE (XLPE) TYPE RW90, GROUND (BONDING) CONDUCTOR: UNINSULATED STRANDED BARE COPPER CONDUCTOR, INNER JACKET: FLAME-RETARDANT, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), ARMOUR: ALUMINUM INTERLOCKED ARMOUR (AIA), OUTER JACKET: LOW-TEMPERATURE, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), BLACK, OPTIONS: GALVANIZED STEEL INTERLOCKED ARMOUR (GSIA), OTHER COLOURED JACKET AND CONSTRUCTIONS AVAILABLE UPON REQUEST. BOND (GROUND) WIRE: 10, OUTER JACKET: 0.860"	05018-02-010	1 CABLE RUN (VFD TO MOTOR SPACE HEATER) (ASSUME 600W HEATER @120V)	TEXCAN		Meter	40	$ 6,15	$ 246,00	0,436	17,44	$ 997,39	$ 1,396,35	65,421
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1/2" HUB CABLE OD 0.600" T0 0.985" ALUMINUM CSA/UL APPROVED.	STE050		T&B		Each	2	$ 15,19	$ 30,38	2,7	5,4	$ 308,83	$ 432,36	65,421
	CABLE SUPPORT CONES			PROLINE OR NORWESCO		Each	20	$ 158,68	$ 3,173,60	0,25	5	$ 285,95	$ 400,33	65,900

e below

A | March 3, 2017

Size	Description	Catalogue Number	Reference Notes	Supplier	Purchase By	Unit	Qty.	Pricing	Total Material Cost	Unit Hours	Man-Hours	Unburdened Labor Cost @ $57.19/MHR	Total Labor Cost c/w 1.40 Craft Labor Productivity	Cost Estimate
	30" MCC WRAPPER C/W 400AT/400AF FUSED DISCONNECT SWITCH, BUSSMANN TYPE LPS-RK-400 FUSES (3), FRAME-MOUNTED (FIXED) IN NEW VERTICAL SECTION AND REST OF SECTION: DOOR - BLANKS; 1 NEW MCC VERTICAL SECTION AS PART OF ENTIRE BUS EXTENSION C/W 6 X 12" DOORS - BLANKS FOR ENTIRE SECTION	2100-BK10	BLOWER FDS IN NEW MCC SECTION 9A OF 240-MCC-401A (ENTIRE VERTICAL SECTION) & 1 NEW VERTICAL SECTION (REFER TO WESTBURNE PROPOSAL #103507: ITEM 1)	ROCKWELL/WESTBURNE		Each	1	$ 7,370.00	$ 7,370.00	20	20	$ 1,143.80	$ 1,601.32	65.300
	POWERFLEX 735 AC DRIVE WITH EMBEDDED I/O, AIR COOLED, AC INPUT WITH PRECHARGE, NO DC TERMINALS, OPEN TYPE, 242 AMPS, 250 HP ND, 200HP HD, 600 VAC, 3PH, FRAME 7, FILTERED, CM JUMPER REMOVED, DB TRANSISTOR, BLANK (NO HIM) +PF750 NEMA 1 KIT, FRAME 7 +PF 750 115V I/O MODULE 2AI,2AO,6DI,2RO +POWERFLEX ARCHITECHURE CLASS ENHANCED HIM, NEMA 1 +POWERFLEX 750-SERIES DEVICENET OPTION CARD INSTALLED ON WALL OF MCC BUILDING (LOCATION TBD IN FEED STAGE)	20F1ANE242AA0NNNNN 20-750-NEMA1-F7 20-750-2262D-2R 20-HIM-A6 20-750-DNET	BLOWER VFD (REFER TO WESTBURNE PROPOSAL #103507: ITEM 2 TO 6)	ALLEN-BRADLEY / ROCKWELL AUTOMATION		Each	1	$ 22,631.00	$ 22,631.00	40	40	$ 2,287.60	$ 3,202.64	65.300
	DV SENTRY DV/DT FILTER, NEMA 1/2, 250 AMPS INSTALLED ON WALL OF MCC BUILDING (LOCATION TBD IN FEED STAGE)	DVSG0250E	BLOWER VFD (REFER TO WESTBURNE PROPOSAL #103507: ITEM 7)	ALLEN-BRADLEY / ROCKWELL AUTOMATION		Each	1	$ 1,663.00	$ 1,663.00	40	40	$ 2,287.60	$ 3,202.64	65.300
	SKID GROUNDING													
	#4/0 AWG BARE STRANDED, ANNEALED, COPPER CONDUCTOR		BURIED GROUND LOOP AROUND MCFC SKID			Meter	100	$ 12.10	$ 1,210.00	0.066	6.6	$ 377.45	$ 528.44	65.110
	#2/0 AWG GREEN INSULATED COPPER CONDUCTOR CABLE		GROUND CABLE FROM SKIDS AND TX TO GROUND LOOP			Meter	280	$ 8.62	$ 2,413.60	0.066	18.48	$ 1,056.87	$ 1,479.62	65.110
3m	COPPER GROUND RODS, 3m LONG, 3/4" DIAMETER					Each	2	$ 25.49	$ 50.98	1.2	2.4	$ 137.26	$ 192.16	65.110
	COMPRESSION CONNECTOR, FIGURE 6 TO 8, T&B TYPES 54875LR34	54875LR34	GROUND ROD CONNECTORS	T&B		Each	2	$ 85.13	$ 170.26	1.5	3	$ 171.57	$ 240.20	65.110
	COMPRESSION CONNECTOR, FIGURE 6 TO 6, T&B TYPES 54875L	54875L	GRID CROSS CONNECTORS ON EACH CORNER OF LOOP	T&B		Each	4	$ 67.77	$ 271.08	1.5	6	$ 343.14	$ 480.40	65.110
	CONNECTOR, SERVICE POST, T&B TYPES SP6SL C/W NUT & LOCK WASHER	SP6SL	BOLTED CONNECTORS TO SKIDS AND TX	T&B		Each	26	$ 61.53	$ 1,599.78	1.5	39	$ 2,230.41	$ 3,122.57	65.110
	COMPRESSION C-TAP CONNECTOR, T&B CTP25020, #4/0 GROUND GRID TO #2/0 TAP CONDUCTOR	CTP25020	COMPRESSION CONNECTORS TO GRID	T&B		Each	26	$ 16.95	$ 440.70	1.5	39	$ 2,230.41	$ 3,122.57	65.110
	EHT													
#2 AWG	TWO CONDUCTOR 1000V, CONDUCTOR: BARE COPPER CLASS B COMPRESSED STRANDED, INSULATION: CROSS-LINKED POLYETHYLENE (XLPE) TYPE RW90, GROUND (BONDING) CONDUCTOR: UNINSULATED STRANDED BARE COPPER CONDUCTOR, INNER JACKET: FLAME-RETARDANT, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), ARMOUR: ALUMINUM INTERLOCKED ARMOUR (AIA), OUTER JACKET: LOW-TEMPERATURE, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), BLACK, OPTIONS: GALVANIZED STEEL INTERLOCKED ARMOUR (GSIA), OTHER COLOURED JACKET AND CONSTRUCTIONS AVAILABLE UPON REQUEST. BOND (GROUND) WIRE: 6, OUTER JACKET: 1.290"	05018-22-010	POWER TO HEAT TRACE 1/2" DEMIN WATER LINE (PREINSULATED TUBE TRACE), 3/4" PRODUCED WATER LINE (PREINSULATED TUBE TRACE), COOLING WATER LINE, COOLING WATER RETURN LINE	TEXCAN		Meter	680	$ 21.43	$ 14,572.40	0.436	296.48	$ 16,955.69	$ 23,737.97	65.421
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1" HUB CABLE OD 0.950" TO 1.375" ALUMINUM CSA/UL APPROVED.	STE100		T&B		Each	8	$ 27.73	$ 221.84	1.5	12	$ 686.28	$ 960.79	65.421
#16 AWG	OVERALL SHIELDED, 1TR, #16AWG, 300V, ACIC CABLE		RTD CABLES (4 CABLES)			Meter	400	$ 2.82	$ 1,128.00	0.498	199.2	$ 11,392.25	$ 15,949.15	65.220
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1/2" HUB CABLE OD 0.600" TO 0.985" ALUMINUM CSA/UL APPROVED.	STE050		T&B		Each	8	$ 15.19	$ 121.52	2.7	21.6	$ 1,235.30	$ 1,729.43	65.220
	HEAT TRACE POWER CONNECTION KIT (SINGLE ENTRY) WITH JUNCTION BOX	DP (Thermon) or JBS-100-A (Raychem)		THERMON (OR RAYCHEM)		Each	2	$ 194.49	$ 388.98	0.56	1.12	$ 64.05	$ 89.67	65.220
	THERMON POWER AND END TERMINATION KIT, PETK	PETK-1D		THERMON (OR RAYCHEM)		Each	2	$ 101.21	$ 202.42	0.56	1.12	$ 64.05	$ 89.67	65.220
			EHT FOR 3" COOLING											

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Size	Description	Catalogue Number	Reference Notes	Supplier	Purchase By	Unit	Qty.	Pricing	Total Material Cost	Unit Hours	Man-Hours	Unburdened Labor Cost @ $57.19/MHR	Total Labor Cost c/w 1.40 Craft Labor Productivity	Cost Estimate
	LINE SENSING, 100 OHM, PLATINUM RESISTANCE TEMPERATURE DETECTORS, 3 WIRE, CLASS 1 ZONE 2 RATED, 125VAC.	RTD-100 (Thermon) or RTD4AL (Raychem)	FOR BOTH COOLING WATER LINES	THERMON (OR RAYCHEM)		Each	2	$ 213.82	$ 427.64	3	6	$ 343.14	$ 480.40	65.220
	LIGHTING													
	25 DEGREE ANGLED STANCHION MOUNTED LUMINAIRE, 120-277VAC, 60HZ, 43W LED (EATON CROUSE-HINDS CHAMP VMV SERIES: VMV5L), WITH 120V PHOTOCELL CONTROL. (FOR UNCLASSIFIED AREA). MOUNTED 20 FT. HIGH.			COOPER/CROUSE-HINDS		Each	2	$ 2,437.46	$ 4,874.92	40	80	$ 4,575.20	$ 6,405.28	65.431
#4 AWG	TWO CONDUCTOR 1000V, CONDUCTOR: BARE COPPER CLASS B COMPRESSED STRANDED, INSULATION: CROSS-LINKED POLYETHYLENE (XLPE) TYPE RW90, GROUND (BONDING) CONDUCTOR: UNINSULATED STRANDED BARE COPPER CONDUCTOR, INNER JACKET: FLAME-RETARDANT, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), ARMOUR: ALUMINUM INTERLOCKED ARMOUR (AIA), OUTER JACKET: LOW-TEMPERATURE, MOISTURE AND SUNLIGHT RESISTANT POLYVINYL CHLORIDE (PVC), BLACK, OPTIONS: GALVANIZED STEEL INTERLOCKED ARMOUR (GSIA), OTHER COLOURED JACKET AND CONSTRUCTIONS AVAILABLE UPON REQUEST. BOND (GROUND) WIRE: 8, OUTER JACKET: 1.140"	05018-14-010		TEXCAN		Each	130	$ 12.75	$ 1,657.50	0.29	37.7	$ 2,156.06	$ 3,018.49	65.421
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1" HUB CABLE OD 0.950" T0 1.375" ALUMINUM CSA/UL APPROVED.	STE100		T&B		Each	2	$ 27.73	$ 55.46	1.35	2.7	$ 154.41	$ 216.18	65.421
	INSTRUMENTATION													
	COOPER/CROUSE-HINDS, EDS FACTORY SEALED PUSHBUTTON STATION, FRONT OPERATED, 600VAC HEAVY DUTY, CLASS 1 DIV 2, GAS GROUP B,C,D HAZARDOUS AREA RATED, MAINTAINED CONTACT MUSHROOM HEAD WITH LOCKOUT AND GUARD. SPECIAL CONSIDERATION FOR GAS GROUP B RATING. CAT# "EDS2184 S769 GB"	EDS2184 S769 GB	ESD	COOPER/CROUSE-HINDS		Each	1	$ 384.16	$ 384.16	12	12	$ 686.28	$ 960.79	65.300
#16 AWG	1PR #16 AWG ACIC, OVERALL SHIELD, 300V INSULATION, 7 STRAND TINNED CLASS B CONCENTRIC COPPER, XLPE INSULATION (THICKNESS: 0.025"), INDIVIDUAL SHIELD: ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE OVER EACH PAIR, OVERALL SHIELD: OVERALL ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE, FLAME-RETARDANT POLYVINYL CHLORIDE (PVC), AIA ARMOUR.LOW-TEMPERATURE (-40 DEGREES CENTIGRADE), FLAME AND SUNLIGHT RESISTANT PVC, GREY OUTER JACKET. OUTER JACKET: 0.620"	C3-9124-1601-19	ESD to MCFC Module PLC	TEXCAN		Meter	10	$ 4.20	$ 42.00	0.29	2.9	$ 165.85	$ 232.19	65.423

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March 3, 2017

Size	Description	Catalogue Number	Reference Notes	Supplier	Purchase By	Unit	Qty.	Pricing	Total Material Cost	Unit Hours	Man-Hours	Unburdened Labor Cost @ $57.19/MHR	Total Labor Cost c/w 1.40 Craft Labor Productivity	Cost Estimate
#14 AWG	10C #14 AWG ARMOURED UNSHIELDED CSA CONTROL CABLE, TECK90, 600V, STRANDED BARE COPPER, XLPE, PVC INNER JACKET, UNINSULATED BC GROUND WIRE, BLACK PVC OUTER JACKET, OUTER JACKET: 0.950"	C5508	Signals from MCFC Module PLC to Remote I/O Building R-24801	BELDEN		Meter	120	$ 6.99	$ 838.80	0.29	34.8	$ 1,990.21	$ 2,786.30	65.422
23 AWG, CAT Ethernet)	4PR #23 AWG, 300VAC, CAT 6, BONDED-PAIRS, SOLID BC, INTERNAL TAPE SEPARATOR, NON-PLENUM, POLYOLEFIN INSULATION, 0.030" INDUSTRIAL GRADE SUNLIGHT- AND OIL-RESISTANT BLACK PVC JACKET. OUTER JACKET: 0.250"	7940A	Ethernet from MCFC Module PLC to Remote I/O Building R-24801	BELDEN		Meter	120	$ 3.20	$ 383.76	0.29	34.8	$ 1,990.21	$ 2,786.30	65.423
#22 AWG hone Cable)	CATEGORY 1, 300VAC, PVC INSULATED, CHROME PVC JACKET, SOLID TINNED COPPER CONDUCTORS, TWISTED PAIRS, CMG FT4, TELEPHONE CABLE. NOMINAL O.D.: 0.264"	8757	Telephone Cable from MCFC Module PLC to Remote I/O Building R-24801	BELDEN		Meter	120	$ 4.49	$ 538.20	0.29	34.8	$ 1,990.21	$ 2,786.30	65.423
#16 AWG	2PR #16 AWG ACIC, OVERALL SHIELD, 300V INSULATION, 7 STRAND TINNED CLASS B CONCENTRIC COPPER, XLPE INSULATION (THICKNESS: 0.025"), INDIVIDUAL SHIELD: ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE OVER EACH PAIR, OVERALL SHIELD: OVERALL ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE, FLAME-RETARDANT POLYVINYL CHLORIDE (PVC), AIA ARMOUR.LOW-TEMPERATURE (-40 DEGREES CENTIGRADE), FLAME AND SUNLIGHT RESISTANT PVC, GREY OUTER JACKET. OUTER JACKET: 0.676"	C3-9324-1602-19	N.G. Instrument - Flowmeter to Remote I/O Building R-24801	TEXCAN		Meter	135	$ 4.16	$ 561.60	0.29	39.15	$ 2,238.99	$ 3,134.58	65.423
#14 AWG	10C #14 AWG ARMOURED UNSHIELDED CSA CONTROL CABLE, TECK90, 600V, STRANDED BARE COPPER, 14AWG BARE COPPER GROUND WIRE, ALUMINUM INTERLOCKED ARMOR, 0.030" XLPE INSULATION, PVC INNER JACKET, UNINSULATED BC GROUND WIRE, BLACK PVC OUTER JACKET, OUTER JACKET: 0.950"	C5508	N.G. Instrument - Isolation Valve to Remote I/O Building R-24801	BELDEN		Meter	135	$ 6.99	$ 943.65	0.29	39.15	$ 2,238.99	$ 3,134.58	65.422
#14 AWG	2C #14 AWG ARMOURED UNSHIELDED CSA CONTROL CABLE, TECK90, 600V, STRANDED BARE COPPER, 14AWG BARE COPPER GROUND WIRE, ALUMINUM INTERLOCKED ARMOR, 0.030" XLPE INSULATION, PVC INNER JACKET, UNINSULATED BC GROUND WIRE, BLACK PVC OUTER JACKET, OUTER JACKET: 0.660"	C5500	N.G. Instrument - Flowmeter (Power) to Remote I/O Building R-24801	BELDEN		Meter	135	$ 2.32	$ 313.20	0.29	39.15	$ 2,238.99	$ 3,134.58	65.422
#14 AWG	10C #14 AWG ARMOURED UNSHIELDED CSA CONTROL CABLE, TECK90, 600V, STRANDED BARE COPPER, 14AWG BARE COPPER GROUND WIRE, ALUMINUM INTERLOCKED ARMOR, 0.030" XLPE INSULATION, PVC INNER JACKET, UNINSULATED BC GROUND WIRE, BLACK PVC OUTER JACKET, OUTER JACKET: 0.950"	C5508	CO2 Instrument - Isolation Valve to Remote I/O Building R-24801	BELDEN		Meter	135	$ 6.99	$ 943.65	0.29	39.15	$ 2,238.99	$ 3,134.58	65.422
#14 AWG	10C #14 AWG ARMOURED UNSHIELDED CSA CONTROL CABLE, TECK90, 600V, STRANDED BARE COPPER, 14AWG BARE COPPER GROUND WIRE, ALUMINUM INTERLOCKED ARMOR, 0.030" XLPE INSULATION, PVC INNER JACKET, UNINSULATED BC GROUND WIRE, BLACK PVC OUTER JACKET, OUTER JACKET: 0.950"	C5508	Instrument: Isolation Valve to HMU I/O Building R-24004	BELDEN		Meter	45	$ 6.99	$ 314.55	0.29	13.05	$ 746.33	$ 1,044.86	65.422
R #16 AWG	16PR #16 AWG ACIC, OVERALL SHIELD, 300V INSULATION, 7 STRAND TINNED CLASS B CONCENTRIC COPPER, XLPE INSULATION (THICKNESS: 0.025"), INDIVIDUAL SHIELD: ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE OVER EACH PAIR, OVERALL SHIELD: OVERALL ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE, FLAME-RETARDANT POLYVINYL CHLORIDE (PVC), AIA ARMOUR.LOW-TEMPERATURE (-40 DEGREES CENTIGRADE), FLAME AND SUNLIGHT RESISTANT PVC, GREY OUTER JACKET. OUTER JACKET: 1.442"	C3-9324-1616-19	Instrument: Flow Meter (2 Pair), Pressure Transmitter (1 Pair), Temperature Transmitter (1 Pair), Analyzer (4 Pair) from Flu Gas Line Instruments to HMU I/O Building R-24004	TEXCAN		Meter	45	$ 17.88	$ 804.60	0.2	9	$ 514.71	$ 720.59	65.423
#12 AWG	4C #12 AWG, ARMOURED UNSHIELDED CSA CONTROL CABLE, TECK90, 600V, STRANDED BARE COPPER, 14AWG BARE COPPER GROUND WIRE, ALUMINUM INTERLOCKED ARMOR, 0.030" XLPE INSULATION, PVC INNER JACKET, UNINSULATED BC GROUND WIRE, BLACK PVC OUTER JACKET, OUTER JACKET: 0.730"	C5532	Instrument: Analyzer (Power) from Flu Gas Line Instruments to HMU I/O Building R-24004	BELDEN		Meter	45	$ 4.12	$ 185.40	0.29	13.05	$ 746.33	$ 1,044.86	65.422
#14 AWG	4C #14 AWG ARMOURED UNSHIELDED CSA CONTROL CABLE, TECK90, 600V, STRANDED BARE COPPER, 14AWG BARE COPPER GROUND WIRE, ALUMINUM INTERLOCKED ARMOR, 0.030" XLPE INSULATION, PVC INNER JACKET, UNINSULATED BC GROUND WIRE, BLACK PVC OUTER JACKET, OUTER JACKET: 0.71"	C5502	Blower VFD (Signals) to Blower; Blower VFD to HMU I/O Building R-24004	BELDEN		Meter	115	$ 3.34	$ 384.10	0.29	33.35	$ 1,907.29	$ 2,670.20	65.422
#16 AWG	8PR #16 AWG ACIC, OVERALL SHIELD, 300V INSULATION, 7 STRAND TINNED CLASS B CONCENTRIC COPPER, XLPE INSULATION (THICKNESS: 0.025"), INDIVIDUAL SHIELD: ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE OVER EACH PAIR, OVERALL SHIELD: OVERALL ALUMINUM/POLYESTER TAPE SHIELD WITH 7 STRAND DRAIN WIRE, FLAME-RETARDANT POLYVINYL CHLORIDE (PVC), AIA ARMOUR.LOW-TEMPERATURE (-40 DEGREES CENTIGRADE), FLAME AND SUNLIGHT RESISTANT PVC, GREY OUTER JACKET. OUTER JACKET: 1.126"	C3-9324-1608-19	Blower VFD (Signals) to Blower; Blower VFD to HMU I/O Building R-24004	TEXCAN		Meter	115	$ 10.05	$ 1,155.75	0.2	23	$ 1,315.37	$ 1,841.52	65.423
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1/2" HUB CABLE OD 0.600" TO 0.985" ALUMINUM CSA/UL APPROVED.	STE050		T&B		Each	6	$ 15.19	$ 91.14	2.7	16.2	$ 926.48	$ 1,297.07	65.422
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1/2" HUB CABLE OD 0.600" TO 0.985" ALUMINUM CSA/UL APPROVED.	STE050		T&B		Each	4	$ 15.19	$ 60.76	2.7	10.8	$ 617.65	$ 864.71	65.423
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 3/4" HUB CABLE OD 0.860" TO 1.205" ALUMINUM CSA/UL APPROVED.	STE075		T&B		Each	8	$ 22.25	$ 178.00	2.7	21.6	$ 1,235.30	$ 1,729.43	65.422
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1" HUB CABLE OD 0.950" TO 1.375" ALUMINUM CSA/UL APPROVED.	STE100		T&B		Each	2	$ 27.73	$ 55.46	2.7	5.4	$ 308.83	$ 432.36	65.423
	THOMAS & BETTS STAR TECK EXTREME SERIES FITTING FOR TECK CABLE AND ACWU CABLE 1" HUB CABLE OD 1.150" TO 1.625" ALUMINUM CSA/UL APPROVED.	STE125		T&B		Each	2	$ 67.98	$ 135.96	3.24	6.48	$ 370.59	$ 518.83	65.423
	COOPER/CROUSE-HINDS, CGB CORD GRIP/CABLE FITTING, STRAIGHT BODY MALE THREAD, 3/8", NPT, NEMA 3, CORD RANGE: 0.250" - 0.375"	CGB3816		COOPER/CROUSE-HINDS		Each	4	$ 17.16	$ 68.64	1.35	5.4	$ 308.83	$ 432.36	65.423

Prepared by: Rick Kaiser
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Zelienople Pa 16063
Phone: 724-452-7020 **Fax:** 724-452-0388
Email: rick.kaiser@robinsonfans.com

Quote Number: 29272 Rev: 1
Ref #: Replacement Fan for 1207720
Jacobs Engineering Group

Budgetary Quote

Quote To: Jacobs Engineering Group
205 Quarry Park Blvd. SE
Calgary, AB T2C 3E7
Canada

Jason Lee
780-969-1969
403-692-1341
Jason.Lee@jacobs.com

Date: 4/26/2017
Expires: 5/26/2017
Sales Representative: RAMCO Energy Products LTD
Phone: 403-252-3336
Fax: 403-252-1918
Email: dscott@ramco-energy.com

Line	Part Number	Description	Quantity	Price Each
2	RB1610-6	Flue Gas Fan - Shell	1.00	$34,351.00

Diameter	Tip Width	Fan Type	Arrangement	Class	Rotation	DWDI/SWSI	Design Temp	Discharge
41.0000 in	1.7500 in	RB1610-6	8	IV	CW	SWSI	550°F	90.0

Fan Weight	WR²	Casing Mtl	Wheel Mtl	Shaft Mtl	Motor / Brng Base Mtl	Inlet Box Pos
3,692 lbs	123 lb-ft²	A242	A242	416 SS	A36	

	Speed	Flow	FSP	Inlet Pr.	Density	Temp	Elevation	Power
Condition	RPM	ACFM	in WC	in WC	lb/ft³	°F	FASL	BHP
Design	3550	10,540	92.00	.00	0.0600	342	1968	232.00

Accessories Included

Casing Drain W/ Plug (2" NPT)
Coupling Grd (Std)
Flanged Inlet
Flanged Outlet
Heat Flinger
Inspection Door (Non-Raised)
Machine Primary Drive Base
Mill Certs (Plate Only)
Radiation Shield
Residual Unbalance Check
RFI Std High Temp Primer
Rotation Arrows
Separate Base & Insulate (Customer Is To Confirm If The Fan Housing Will Not Be Insulated In The Field)
Shaft Grd (Std)
Shaft Seal (Packing Gland)
Split Casing
SS Shims
Special Balance Grade (G1.0)
Weld Procedures (AWS As Applicable)
Welder Qualifications (AWS As Applicable)
Static oil lubricated BLO monoblock bearing

Optional Equipment not included in base fan price:

Item	Description	Price Per	
ACTUATOR (RID)	Kinetrol 107-100-L (177 ft-lbs at 60 psig PAS) double acting actuator for direct mounting, low-temperature prepped. Equipped with a Siemens 760E analog positioner, 4-20 mAdc input, 4-20 mAdc output, (2) Westlock 316SB-4 Silver Bullet limit switches mounted in the positioner bracket, a Norgren B07 AFR-G, completely assembled and piped with ss tubing and tube fittings.	**$4,181.00**	**Ea.Fan**
COUPLINGS	RENOLD HI-TEC PM COUPLING (max. bore 2.8800")(50.5000 lb).	**$2,855.00**	**Ea.Fan**
DETECTORS	Two (1 per brg) T-TEC #1060 100 ohm Pt RTD's, monitor by others.	**$1,177.00**	**Ea.Fan**
EVASE	Outlet evase fabricated from A242 material with A242 flanges, drilled to match 24-inch Class 150 Pipe Flange, Inlcudes a 3/4" NPT connection and a 1/2" connection	**$1,102.00**	**Ea.Fan**
INSULATION PINS	3" Insulation pins (only), Insulation and installation by others.	**$567.00**	**Ea.Fan**
INLET TRANSITION	A242 Material, includes 1/2" NPT Connection	**$581.00**	**Ea.Fan**
MOTOR	250 HP TECO-Westinghouse Max-E2 IEEE/841 motor, 3600 RPM, TEFC, 1.0 SF on inverter power, 460v/3ph/60hz, Premium efficient, 449TS frame, includes Space Heater with auxiliary box (M2A), Insulated both bearings (M8B), Shaft grounding ring (M23), Stator Windings RTD's -100 ohm Platium - 2/phase with Auxiliary box (M4B), suitable for inverter duty, 1.0 SF on inverter power, quoted as a standard catalog offering to no customer specifications, sized & designed for VFD starting only.	**$18,921.00**	**Ea.Fan**
PAINT	Fan Paint- SP10 Surface Preparation with one coat of Carboline Carbozinc 11	**$3,527.00**	**Ea.Fan**
DETECTORS	Two (1 per brg) IMI - EX640B71 (RFI Part #VIB0080) Industrial vibration sensor, 4 to 20 mA output, 0 to 1 in/sec peak, 3 to 1k Hz, top exit 2 pole terminal block, ambient temp range -40 Deg. F to 176 Deg. F, ¼" NPT mounting thread, ATEX/CSA/EX approved with explosion proof conduit elbow, Class 1, Div. 1 & 2, Group A,B,C & D. This model has a top exit 2 pole terminal block; Monitor by others.	**$1,627.00**	**Ea.Fan**
SHAFT SPEED SENSOR	Electro-Sensor FB420 shaft speed sensor with relay and shaft wrap with magnets. "L" shaped mounting bracket by Robinson, Wiring and Monitor supplied by others.	**$1,734.00**	**Ea.Fan**
DRIVE TRAIN SIMPLIFIED TORSIONAL ANALYSIS PER RFI STDS	Simple Drive Train Torsional Analysis - Identification of the first torsional natural frequency for the drive train. This excludes synchronous speed motors. The analysis may reveal a change to coupling is recommended. It will not include any analysis of torsional interference points that may exist in the avoidance range which is typically ± 10% of operating speed. Time for completion is 2-3 weeks after all required information is collected. (8)	**$2,500.00**	**Ea.Fan**
DAMPER (RID)	Radial inlet damper fabricated from A242, with 304L blade shafts, with linkage extended for automatic control (161 Lb).	**$2,865.00**	**Ea.Fan**
WITNESSED MECH RUN TEST (RFI STD)	Mechanical Run Test (Witnessed, 2 Hours, Max Vibration- 0.15 in/sec), per Robinson Work Instruction For Mechanical Run Test DS-247-1A.5 (copy attached).	**$5,947.00**	**Ea.Fan**

NOTES:
- Robinson will supply electronic manuals. Hard copies are available for an additional charge.
- Due to the current volatile raw material situation, we reserve the right to re-evaluate the price and delivery of equipment at the time of order placement.
- Lead time for the fan equipment is based on Robinson standards, delivery of the fan equipment will be based on the longest lead time of the optional equipment.
- Expansion joints are not included and shall be supplied by others.
- Fan will be built per Robinson standards. Specification wasnt provided with RFQ.
- The fan is not guaranteed against erosion or corrosion.
- An evasé is required to meet the stated performance and must be furnished by others if not purchased from RFI.
- Bearing RTD's and vibration switch will be provided as pickups only, wiring by others.
- The fan has been quoted for variable speed operation, the VFD shall be provided by others. Precautions should be taken to eliminate or reduce shaft currents that may be imposed on the motor by the VFD as stated per NEMA MG1 Part 31.4.4.3.
- Robinson Fans recommends that a drive train torsional analysis be performed by the end user.
- Records and documentation shall be as per Robinson Fans, Inc. standards. Certified Material Reports will be collected and retained for all plate and sheet material only (does not include hardware).
- Minimum ambient air temperature is presumed to be -20°F. If Charpy Impact Testing is required, consult with RFI so an appropriate cost adder can be determined. No Area classification considered.
- Exception to Re-balance of the wheel & shaft assembly after installation of the fan half-coupling; not available due to BLO Bearing.
- This quotation was prepared without the benefit of a complete written fan specification. Please review the quoted equipment to ensure that it meets your requirements.

Shipment: Approximately 12 to 14 Weeks after ARAD

Drawings: Submitted for Approval 3 to 4 Weeks ARO or sooner if possible

Orders in excess of $50,000 progress payment shall be required, pending credit approval at time of order placement.
10% Due Upon Order Placement,
20% Due Upon Submittal Dwgs,
35% Due Upon Start of Fabrication,
Balance Due Upon Shipment or Readiness to Ship Based On The Contract Ship Date.
All Payments to be ½% 10 Net 30 Days. Point of Manufacture: Zelienople PA; Salt Lake City, UT; Lakeland, FL or Abilene, TX (TBD after order placement, unless a specific request is made by customer and reviewed and approved by Robinson prior to order placement). All freight, fees, taxes, insurance & export packaging shall be paid & provided for by the customer.

Terms: 1/2% 10 NET 30 Pending credit approval at time of order placement. **Shipping Term: Ex-Works**

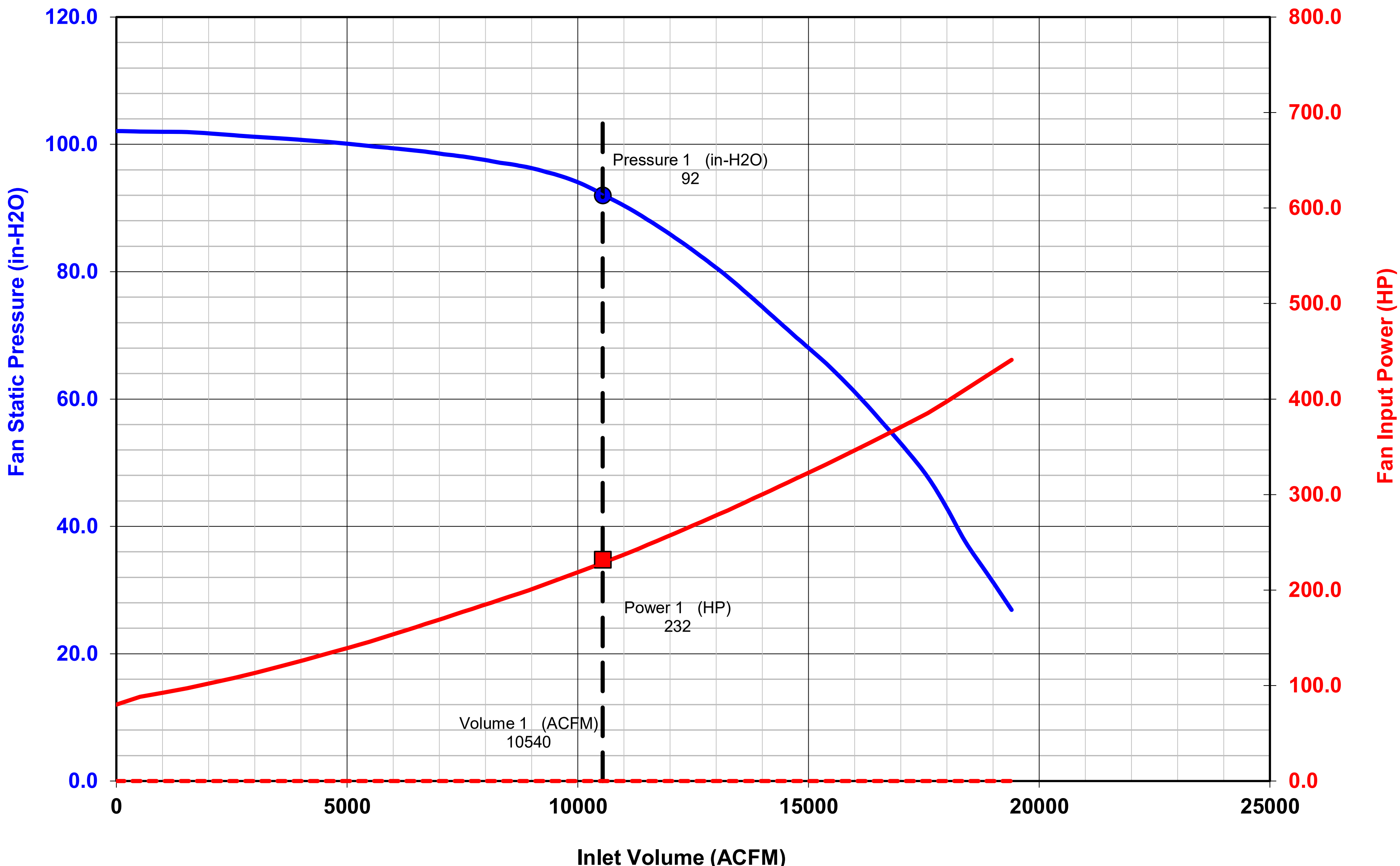
Robinson Fans, Inc. Terms and Conditions of Sale, found at http://www.robinsonfans.com/support/terms-of-sale are expressly incorporated and shall apply.

Fan: 41 in x 1.75 in SWSI RB1610-6 | Density: 0.06 lbs/ft^3 | Temperature: 342 °F | Fan Speed: 3550 rpm | 4/26/2017 14:43

For: Jacobs for Shell

Quote # 29271-1+Shell

User: rk



Robinson Fans, Inc.

SE =1, EF =0.98, inlet Ps = 0 in-H2O

Robinson Fans

Sound Output Data

Customer:	Jacobs for Shell	**Date:**	26-Apr-17
Quote Number:	29271-1+Shell	**FO Number:**	
Width:	SWSI	**CFM:**	10540
Fan Type:	RB1610-6	**Diameter:**	41 In
Blades:	16	****Static Pressure:**	92 In H2O
		RPM:	3550

Near Field Approximately : 3 Ft

Sound Power level ratings shown are decibels referred to 10-12 Watt and obtained in accordance with AMCA Standard 300. Related air performance ratings per AMCA Standard 210. PWL for each band and DBA are calculated per AMCA Standard 301. Levels shown do not include motor or other auxiliary equipment.

Operating conditions other than the above stated values can result in significantly different sound levels.

Data is for use by a system acoustical design engineer for evaluation of the fan singularity and within a system. Because of the infinite variations in system arrangements and the many factors which affect sound pressure levels, it is the designers responsibility to properly apply this data based on his knowledge of the system. Some guidelines for use of this data are for "Near Field" computer data to apply to ducted inlet and outlet installations, any opening in the duct must be a minimum of 100 feet remote the fan. Openings within this range are assumed to emit a sound pressure equal to the sound power level. This also applies to untreated inlet and outlet expansion joints. Note that for ducted inlet/outlet the ductwork thickness and density must equal that of the fan housing to achieve the sound levels noted.

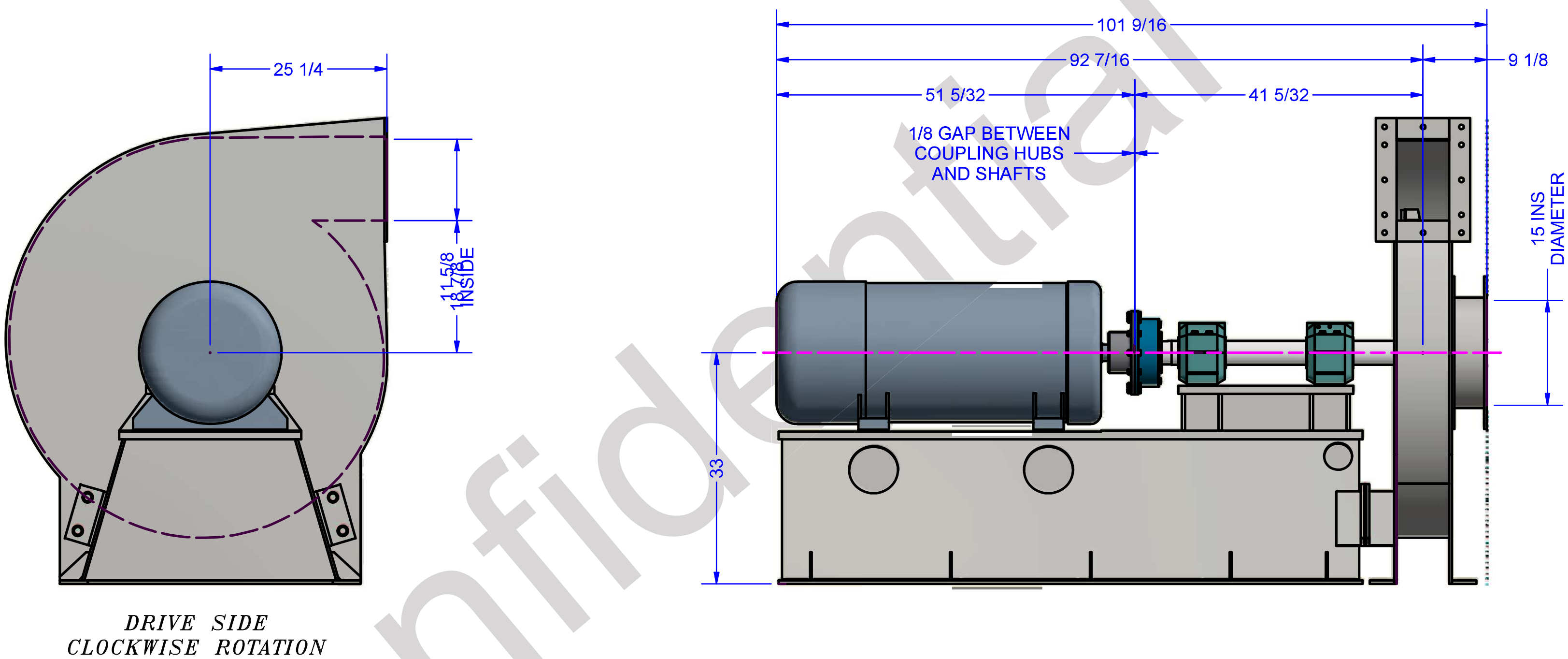
Near Field- A Hemispherical space where sound pressure waves from one radiating surface tend to interfere with waves generated by other surfaces. Near Field boundry, distance from radiating surface, is related to the wavelength of the lowest frequency and overall size of source.

Free Field- Area beyond near field, with no obstructions, where sound pressure levels decay 6 dB for each doubling of distance from near field.

*****Levels Shown do not include motor or other auxiliary equipment*****

Band No.	1	2	3	4	5	6	7	8	DBA
Mid Freq	63	125	250	500	1000	2000	4000	8000	
Sound Power Levels at Acoustic Center of Fan									
PWL+/-2dB	108	111	114	117	108	107	104	99	116
For Ducted Inlet and Outlet Installation Estimated sound pressure level for near field with 0.375 Inch casing loss									
SPL+/-2dB	92	90	90	91	78	76	68	60	89
Estimated Sound pressure level at 3 Feet beyond near field of casing									
SPL+/-2dB	86	84	84	85	72	70	62	54	83

Sound Pressure Levels are approximate based upon near field calculations.



Reference Drawing
#29271-1+Shell_Dwg-1 For Fan Flange Drillings

OVERALL ENVELOPE: 75ht. **x** 59w.

TOLERANCES UNLESS OTHERWISE MARKED
FRACTIONS±1/32",ANGLES±1°,DEC.±.005"

FAB TOLERANCE ON OVERALL DIMENSIONS
UNDER 54"DIA. FAN ±1/8"
54"DIA. FAN & ABOVE +3/16"/-1/8"

COMPUTER GENERATED DRAWING, DO NOT CHANGE BY HAND

Robinson Fans

TYPE	**41" RB1610-6, Arr. #8, CW @ 90, IBP @ 0, Cl. #4, SWSI**		
FOR	Jacobs_for_Shell		
	BY	DATE	*ALL DIMENSIONS ARE IN INCHES*
DRAWN	RPA	4/26/2017	Proposal Drawing #29271-1+Shell_Dwg
SHEET 1 OF 2			

PROJECT QUOTATION

ATTENTION: Jonathan Kwan

COMPANY: Jacobs Canada

PROJECT NAME: FUEL CELL PROJECT - SHELL SCOTFORD UPGRADER TRANSFORMER

LOCATION: ALBERTA

CLOSING DATE: MARCH 13TH 2017

QUOTATION NUMBER: 17-03-0221

TOTAL PRICE: SEE MATERIALS FOR PRICING TNIP

FREIGHT	:	FOB PREPAID
TERMS	:	SEE ATTACHED TERMS & CONDITIONS
FEDERAL SALES TAX	:	NOT INCLUDED
GOODS & SERVICES TAX	:	NOT INCLUDED
PROVINCIAL SALES TAX	:	NOT INCLUDED
PRICING FIRM FOR	:	30 DAYS FROM DATE OF QUOTATION

Thank you for the opportunity to bid your project request. This quotation is Westburne Electric's interpretation of the information that your company and its representatives have provided us. Any changes to our bill of material may result in a price change.

FROM:

Taylor Galbraith
QUOTATION SPECIALIST

780-732-7680

Taylor.Galbraith@westburne.ca

WESTBURNE ELECTRIC
10640- 184 STREET
EDMONTON, ALBERTA
T5S 0B2

ITEM	QTY	UOM	MANUFACTURER	DESCRIPTION	UNIT PRICE	TOTAL
1	1	EA	CARTE	OPTION 1: PLEASE SEE ATTACHED BOM	$ 70,852.10	$ 70,852.10
2	1	EA	CARTE	OPTION 2: FR3 ENVIROTEMP	$ 75,686.60	$ 75,686.60
					TOTAL :	**$ 146,538.70**

Attn.
Jacobs Canada Inc.

Quote Number	Contact	Date
20QT001260		2/16/2017

Reference
Thermotube

Bill of Materials

Item #	Product name	Description	Qty	Unit	Unit Price	Total Price
TB_Quote	SE-4F1-45-7-ATP-035	SE-4F1-45-7-ATP-035	21	m	$72.50	$1,522.50
60601	SE-6F1-45-7-ATP-049	SE-6F1-45-7-ATP-049	122	m	$80.25	$9,790.50

Net total amount **$11,313.00**

Notes

Terms & Conditions

All quotations of Thermon are without any engagement.

- All prices are in CAD and excluding VAT
- Payment: N30
- Expiry date: 3/18/2017 12:00:00 AM
- Estimated Delivery time: To be agreed upon
- Delivery: TBA, transport against invoice charges
- Cable lengths: The actual supplied lengths may deviate -0 % to +10 % from quoted lengths.

Thermon's products, technology and services may be subject to applicable U.S. laws, including U.S. export control laws. Export, re-export, use, or diversion contrary to U.S. law is prohibited. If it is discovered at any time that a transaction may result in a violation of applicable U.S. law, Thermon reserves the right to cancel all or such prohibited parts of the transaction and suspend future performance without further liability or penalty of any nature.

1. The Design and Bill of Material provided within this quotation are based exclusively on the drawings, data and specifications provided in the RFQ.
2. After receipt of a purchase order, any changes in specifications or additional drawings provided may result in revisions to the proposed bill of materials, potentially requiring a change order.
3. Please see attached Standard Terms & Conditions.

al Electrically Heat Traced Bundles

SE-4A1-62-7-ATP-035

Number of Tubes [6]

1
2
3
4

Heat Trace Option

1 = BN (HPT Only)
3 = OJ (BSX Only)
7 = OJ/Fluoropolymer
8 = Division 1 Approved [4]

Jacket Type

ATP [5]
TPU

Process Tube(s) Wall Thickness

028 = .028"
030 = .030"
032 = .032" (Copper Only)
035 = .035"
040 = .040" (Plastic Only)
047 = .047" (Plastic Only)
049 = .049"
062 = .062" (Plastic Only)
065 = .065"
083 = .083" (SS Only)

Heat Tracing Type (See Heat Trace Application Below). Contact Thermon for TubeTrace SE/ME instrument tubing bundles with alternative heat trace options such as parallel constant watt and series constant watt including mineral insulated heat tracing.

Self-Regulating Heat Trace		Power-Limiting Heat Trace
30 = VSX 5 w/ft. 120 Vac	60 = HTSX 3 w/ft. 120 Vac	50 = HPT 5 w/ft. 120 Vac
31 = VSX 5 w/ft. 240 Vac	61 = HTSX 3 w/ft. 240 Vac	51 = HPT 5 w/ft. 240 Vac
32 = VSX 10 w/ft. 120 Vac	62 = HTSX 6 w/ft. 120 Vac	52 = HPT 10 w/ft. 120 Vac
33 = VSX 10 w/ft. 240 Vac	63 = HTSX 6 w/ft. 240 Vac	53 = HPT 10 w/ft. 240 Vac
34 = VSX 15 w/ft. 120 Vac	64 = HTSX 9 w/ft. 120 Vac	54 = HPT 15 w/ft. 120 Vac
35 = VSX 15 w/ft. 240 Vac	65 = HTSX 9 w/ft. 240 Vac	55 = HPT 15 w/ft. 240 Vac
36 = VSX 20 w/ft. 120 Vac	66 = HTSX 12 w/ft. 120 Vac	56 = HPT 20 w/ft. 120 Vac
37 = VSX 20 w/ft. 240 Vac	67 = HTSX 12 w/ft. 240 Vac	57 = HPT 20 w/ft. 240 Vac
40 = BSX 3 w/ft. 120 Vac	68 = HTSX 15 w/ft. 120 Vac	
41 = BSX 3 w/ft. 240 Vac	69 = HTSX 15 w/ft. 240 Vac	
42 = BSX 5 w/ft. 120 Vac	70 = HTSX 20 w/ft. 120 Vac	
43 = BSX 5 w/ft. 240 Vac	71 = HTSX 20 w/ft. 240 Vac	
44 = BSX 8 w/ft. 120 Vac		
45 = BSX 8 w/ft. 240 Vac		
46 = BSX 10 w/ft. 120 Vac		
47 = BSX 10 w/ft. 240 Vac		

ble in all materials.)

nc.

(Urethane).

ube are available.

Typical Steam Traced Bun

SP-4F1-3F1-ATP-065/035

Bundle Type

SI = Single Isolated Tube Light Steam Traced
MI = Multiple Isolated Tubes Light Steam Traced
SP = Single Tube Heavy Steam Traced
MP= Multiple Tubes Heavy Steam Traced

Process Tube(s) O.D.

1 = 1/8"
2 = 1/4"
3 = 3/8"
4 = 1/2"
5 = 5/8"

Process Tube(s) Material

A = 316 SS Welded
C = PFA Teflon [2]
D = Monel [3]
E = Titanium
F = 316 SS Seamless
G = 304 SS Welded
H = 304 SS Seamless
J = Alloy C276
K = Alloy 825
L = Alloy 20
M= FEP Teflon
T = TFE Teflon
X = Special

Number of Process Tube(s) [6]

1
2

Tracer Tube O.D.

2 = 1/4"
3 = 3/8"
4 = 1/2"

Number of Tracer Tube(s)

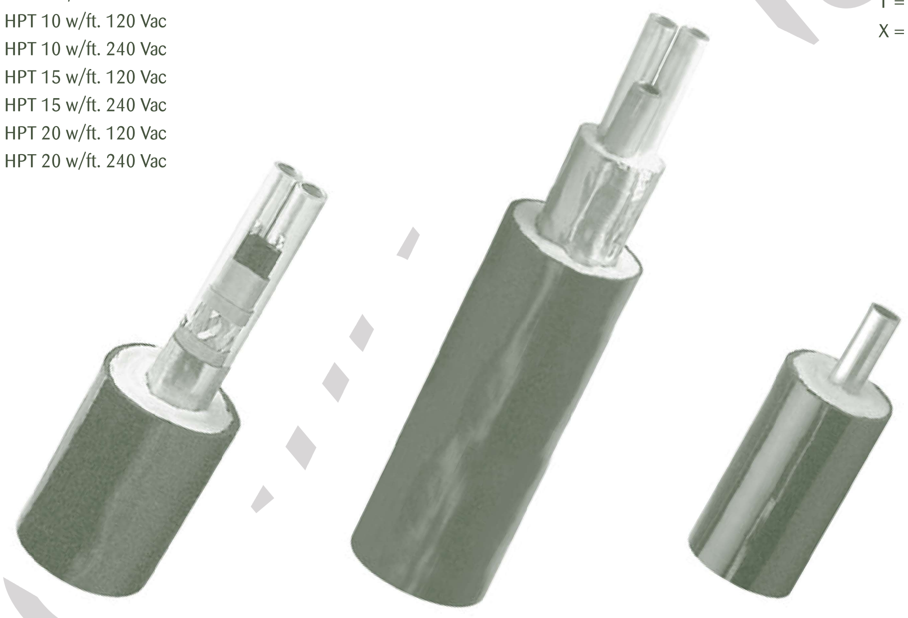
1
2

Jacket Type

ATP [5]
TPU

Tracer Tube Material

A = 316 SS Welded
B = 122 Copper
F = 316 SS Seamless



Typical TubeTrace Type ME   Typical TubeTrace Type MP   Typical ThermoTube Type SL

ThermoTube® Type SL P
(Not Hea

SL-4B13

Bundle Type

SL = Single Tube

Tube O.D.

1 = 1/8"
2 = 1/4"
3 = 3/8"
4 = 1/2"
5 = 5/8"
6 = 3/4"
8 = 1"[1]

Tube Material

A = 316 SS Welded
B = #122 Copper
C = PFA Teflon[2]
D = Monel[3]
E = Titanium
F = 316 SS Seamless
G = 304 SS Welded
H = 304 SS Seamless
J = Alloy C276
K = Alloy 825
L = Alloy 20
M= FEP Teflon

N = N
P = Po
X = Sp

Electrical Heat Trace Application

0°F (65°C) NO STEAM OUTS

35°F (85°C)

braid & overjacket. Standard
al fluoropolymer overjacket.)

c 46 = BSX 10 w/ft. 120 Vac
c 47 = BSX 10 w/ft. 240 Vac
c

For Freeze Protection or Maintain 250°F (121°C)

Heat Trace Exposure* to 420°F (215°C)

HTSX Self-Regulating Heat Tracing (All HTSX includes braid & overjacket BNOJ)

60 = HTSX 3 w/ft. 120 Vac	64 = HTSX 9 w/ft. 120 Vac	68 = HTSX 15 w/ft. 120 Vac
61 = HTSX 3 w/ft. 240 Vac	65 = HTSX 9 w/ft. 240 Vac	69 = HTSX 15 w/ft. 240 Vac
62 = HTSX 6 w/ft. 120 Vac	66 = HTSX 12 w/ft. 120 Vac	70 = HTSX 20 w/ft. 120 Vac
63 = HTSX 6 w/ft. 240 Vac	67 = HTSX 12 w/ft. 240 Vac	71 = HTSX 20 w/ft. 240 Vac

For Freeze Protection or Maintain 300°F (149°C)

Heat Trace Exposure* to 450°F (232°C)

VSX Self-Regulating Heat Tracing (All VSX includes braid & overjacket BNOJ)

30 = VSX 5 w/ft. 120 Vac	33 = VSX 10 w/ft. 240 Vac	36 = VSX 20 w/ft. 120 Vac
31 = VSX 5 w/ft. 240 Vac	34 = VSX 15 w/ft. 120 Vac	37 = VSX 20 w/ft. 240 Vac
32 = VSX 10 w/ft. 120 Vac	35 = VSX 15 w/ft. 240 Vac	

For Freeze Prote

Exp

HPT Power-Limiting Heat Tr

50 = HPT 5 w/ft. 120 Vac 53
51 = HPT 5 w/ft. 240 Vac 54
52 = HPT 10 w/ft. 120 Vac 55

nergized (off). Exceptions are for HTSX and
ent exposure, on or off.

** Standard TubeTrace and ThermoTube b
(204°C) if outer jacket is to remain bel
Extra insulation (bundle option "XINS")

Spiral Manufacturing Co., Inc.

11419 Yellowpine Street N.W. • Minneapolis, MN 55448-3158
Phone: 763-755-7677 • 1-800-426-3643
Fax: 763-755-6184 • www.spiralmfg.com

Date	Quote #
3/3/2017	35278

Sold To:	Ship To:
Jacobs Canada Inc. Jude Javier, P.Eng. 1800-10065 Jasper Avenue, Edmonton, Alberta T5J 3B1 Canada Customer Fax:	

Entered by	Rep	Terms	Customer Phone	Customer E-mail	Your reference #
Kurt	TMM	Net 30		ordereco@gmail.com	

Product Code	Product Description	Qty	Unit Weight	Unit Cost	Total
	Duct is 2" High temp insulated Dual Wall Aluminized inside Pipe, Galvaniuzed outside Pipe				
39224	24 X 28 Dual Wall Spiral Pipe 2" X 1.5 LB Insul. 22Ga. 72 - 10', 1 - 5'	725	23.2	78.79	57,122.75
2441	24 X 28 Dual Wall Pipe Coupling 22Ga.	72	13	27.87	2,006.64
39214	14 X 18 Dual Wall Spiral Pipe 2" X 1.5 LB Insul. 24Ga. 62 - 10, 1 - 5'	625	11.88	34.75	21,718.75
1441	14 X 18 Dual Wall Pipe Coupling 24Ga.	62	7.5	18.69	1,158.78
	Subtotal				82,006.92
Discount	20% Discount			-20.00%	-16,401.38

Total Weight 25646

[redacted]

All Shipments FOB Minneapolis, Freight Collect Unless Otherwise Stated. All Shipping Cost Estimated. Please Check Measurements Carefully!

Special items are made on a time and material basis. Once accepted for production, they cannot be cancelled, nor can they be returned for credit.

Customer Signature ____________________________________

Appendix O. Estimate Basis

Pre-Feed Estimate Basis

Class 4 (+30/-15%)

Alberta Innovates

Shell Scotford Upgrader Host Site
1.4 MW Molten Carbonate Fuel Cell Demonstration

Scotford, Alberta, Canada

Project No: EE-0601-01

Document No:

Issued by : Errol D'Souza

	Issue Date	Page s	Rev Description	Prepared By	Reviewed By	Reviewed By PE	Reviewed By PM
0	Mar 20, 2017	7	Preliminary Draft Issued	M Paul	M Paul	E. D'Souza	E. D'Souza
1	Mar 21, 2017	7	Internal review comments incorporated	M Paul	M Paul	E. D'Souza	E. D'Souza
2	Mar 27, 2017	7	Internal review comments incorporated	M Paul	M Paul	E. D'Souza	E. D'Souza
3	Apr 29, 2017	7	Final Basis – Client review comments incorporated	M Paul	M Paul	E. D'Souza	E. D'Souza

PROJECT SCOPE

Alberta Innovates – Clean Energy introduced a molten carbonate fuel cell (MCFC) technology for carbon capture called a Combined Electric Power and Carbon-dioxide Separation (CEPACS) Unit to the oil sands industry in Alberta in 2012. Leading on from previous studies undertaken, Alberta Innovates led the current study with participation from other Canada's Oil Sands Innovation Alliance (COSIA) members and non COSIA members. The project includes the preliminary front end engineering (pre-FEED) phase to understand the cost of using an MCFC at a bitumen upgrader facility.

Fuel Cell Energy (FCE) was engaged by Alberta Innovates to complete the pre-FEED design and cost estimate for the MCFC module and its balance of plant (BOP). Jacobs' scope included outside of the FCE battery limit, which involves integration of the FCE package into the host site. The preliminary design and Class IV cost estimate (+30%/-15%) for the installation of the demonstration unit were developed as part of the Pre-FEED study.

GENERAL

The Project Estimator worked closely with the Project Manager during the course of the estimating activities. The actual level of detail for individual estimate items was described further in the in the new arrangement drawings and equipment list for the project.

The following common control documents were developed and served as the deliverables for the Estimate:

- Scope Document
- Equipment List - Rev A dated Feb 15, 2017
- 1-Module CEPACS System GA - Rev 1 Jan 27, 2017
- Screw pile quote May 18, 2016
- Civil Structural MTO (Scotford Site)Feb 23, 2017
- with civil Sketches EE060101-SK-S-101 thru 106 dated Feb 22, 2017
- Spiral Duct Quote 35278
- Pipe MTO_00-EE060101-BOM-P-01S
- Pipe Tie-In's MTO_00-EE060101-SK-P-02S
- Plot Plan 246-0000-000-044-001 C
- Blower Location_240.0000.000.044
- Color Plot _ 00-EE060101-SK-P-01S
- AI - Instrument Index Rev A Feb 21, 2017
- Electrical Final Pricing MCFC - MTO (Unit 284 Option) Mar 3, 2017
- R2_MRP_SHELL MCFC - MTO (Unit 284 Option)
- Elect 00-EE060101-SK-E-101 thru 106
- Powell Dwg 2110530100001 thru 004 and 101 & 210
- Site Pictures.
- ACCE v9.1 Indexing 2017-01-11 for piping materials

ALLOWANCES

Jacobs did not include a MTO and Design Allowance on any of the rough quantities in the estimate.

COST CODES

The estimate was organized by Jacobs Standard Cost of Account breakdown. Jacobs did ensure that all levels of detail required by Alberta Innovates were present in the Jacobs cost breakdown.

MECHANICAL EQUIPMENT

The process Flue Gas Blower design and supply would be the responsibility of Jacobs. Vendor budget pricing was obtained for the Flue Gas Blower. Costs for the ISBL equipment skids are not included in the Jacobs estimate. This will be provided by FCE in their estimate (including freight costs for delivery to the host site). Costs for installation of the respective FCE skids on their foundations by the site contractor are included in the Jacobs estimate.

DEMOLITION

No demolition was included in the estimate

SITE EARTH MOVING & SITE IMPROVEMENTS

Jacobs had minor excavation for foundations, some direct buried ditch work and an allowance for hydro trenching for the piles. Jacobs used their Standard manhour units and current material pricing.

PILING

Jacobs included screw piling under the FCE supplied skids. Jacobs obtained current pile subcontract pricing and pile cap plates. Jacobs included a small amount of labor to assist the piling subcontractor.

CONCRETE

Jacobs has included foundation pad and a small amount of grout for some equipment based on the Civil MTOs and sketches. Jacobs used their Standard manhour units and current material pricing

STRUCTURAL STEEL

No structural steel was included in the estimate. Due to the temporary nature of the demonstration unit, based on direction from Shell, scaffolding will be used to support the flue gas duct in areas where it cannot be supported on existing pipe racks or run on sleepers on the ground. This scaffolding will be left in place and rented for the duration of the performance test run for the demonstration unit.

DUCTWORK

Jacobs Piping group furnished the material MTO's for the ductwork. Jacobs used their Standard manhour units and current quoted material pricing. Jacobs included 18 months of temporary scaffolding to support the Shell Site ductwork.

PIPING

Jacobs Piping group furnished the material MTO's for the equipment, and tie-ins. The MTO included material of construction, pipe lengths, fittings and valves. Estimating utilized the ACCE 9.1 estimating tool indexed for the Gulf Coast and the current cost basis is Indexing 2017-01-11. ACCE pipe fabrication cost was increased to $110 CAD. Estimating loaded all the material MTO's into the program and ACCE furnished labor hours, pipe fabrication and materials pricing.

And allowance was made in the estimate for pipe testing and 10% was included for a small bore allowance for drains and vents as required. All the Tie-ins were identified and accounted for in this estimate.

Jacobs also included a break out estimate for the CO2, cooling water supply and cooling water return lines.

Jacobs used their Standard manhour units and current material pricing from indexed ACCE data base.

All interconnecting piping between the respective FCE skids is not included in Jacobs scope and the costs for this will be included in the FCE cost estimate. Jacobs has included all the required piping from the FCE skids to the host facility and from host facility back to the FCE skids.

INSULATION

Pre-insulated duct from supplier will be used for the flue gas line. For the water lines pre-insulated/ pre-traced tube bundle will be used. Based on this approach, an allowance was included for onsite insulation repairs only.

INSTRUMENTATION

Control systems furnished a priced instrument index for the estimate. Jacobs used their Standard man-hour units for the field instruments and their bulks. An allowance for the host site to do the DCS programming between the new and existing facility is included in the estimate.

ELECTRICAL

Jacobs Electrical group furnished material MTO's for both sites that included grounding, instrument and power wiring and terminations. Electrical equipment was also included in the estimate. The electrical interconnects from the FCE skid edge to Shell MCC/infrastructure is included. The interconnecting wiring between the FCE skids In the FCE scope of supply.

Jacobs used their Standard manhour units and current material pricing.

PAINTING

Jacobs excluded all paint.

SCAFFOLDING / FIREWATCH / HOLEWATCH

Scaffolding manhours were calculated from the direct discipline manhours from each account and were adjusted based on the Projects evaluation of the actual needs. Scaffolding Material were calculated at $7.50 per scaffold man hour. Firewatch and Holewatch hours were calculated based on needs as well.

FREIGHT

Freight was calculated at 4% of the total equipment and materials bulks. This estimate assumes all the bulk materials can be purchased locally.

WAGE RATES, PRODUCTIVITY & WORKWEEK

Direct Labor Costs were generated using current union labor rate agreements for Alberta. Composite Prime Code of Account wage rates are developed using individual craft rates and typical industry crew mixes. Other costs are also taken into consideration such as market conditions which may dictate impacts such as per Diems and other incentives. Jacobs will do a complete labor survey for Shell site if they are the successful site.

The project team mutually agreed upon a productivity of 1.4 on all of the direct construction manhours. Jacobs Craft Labor Productivity Calculator was used as backup information. This estimate is based on a 50 hour work week.

Jacobs has taken exception to productivity loose for plant shut downs. The scope of this work this relatively simple and even with a shutdown we should not have to wait long for back to work permits. (Less than 1 hour).

INDIRECT COSTS

All of the construction indirect costs are included as a standard percentage against the total labor dollars. After the estimate review with the client some of these percentages were reduced based on the specific needs of the project. This comes out as $100.30 CAD/hr. This also includes the Fee.

SUPPLEMENTAL FIELD INDIRECT COSTS

Jacobs did not include an allowance for any, heavy rigging, and heavy lifts for this project.

CONSTRUCTION MANAGEMENT

Jacobs's did not include construction management costs because this estimate is based on direct hire. If the construction strategy changes to EPCM then a change notice needs to be included to add the CM costs for the project. All construction field staff is included in the Indirect Estimate.

INTERNAL CLIENT COSTS

Internal client/host site costs are currently not included in the estimate for client project people charging the project. Jacobs has included the DCS Programing and the host site needs to include money for the respective costs to be included with this estimate.

CURRENCY

The TIC Summary and all of the summary pages in the estimate are in CAD.
Blower budgetary quotation was in USD and conversion rate of 1 USD = 1.30 CAD was used.

RISK ALLOWANCE

This is a monetary value allocated to the estimate to cover the costs associated with a potential risk event or combination of risk events. Risk Allowance is based upon event related elements which are assessed during the Risk Review and based upon the probability of occurrence. It is allocated depending upon contractual terms and conditions and lender requirements. In determining how to evaluate the risk events, Jacobs will participate in a Host Site driven discussion on what's included in the Risk Allowance and the assumptions made.

Jacobs did not include a Risk Allowance number in their TIC estimate. During FEED phase, Host Site should allocate a Risk Allowance number based on an overall assessment of the Event Driven Risks for the complete program.

ESCALATION

Escalation is an adjustment to the total project costs for market fluctuations whether they increase or decrease the cost of labor and/or materials between the time that pricing is determined (current day) and the expected purchase date and/or installation date (future day). **Jacobs included 3% escalation for the estimate.**

CONTINGENCY

Contingency is an allowance for unforeseen conditions based on technology unknowns, project specific unknowns, status of engineering, status of design and specifications, quality of pricing, anticipated jobsite conditions, delays in equipment and materials, and estimating errors and omissions; it is a provision to cover unknown elements of cost where previous experience has proven they are most likely to occur; it does not cover the cost for Acts of God, unusual economic situations, labor strikes, material shortages, or the addition or changing of scope by the client after the job has been frozen for the estimate; this allowance is designed to assist in producing the most likely, but not the maximum, cost of the project. Contingency is part of the project costs and is expected to be spent for the existing project scope. **Jacobs included 20% contingency for the estimate based on the estimate accuracy.**

JACOBS PROJECT TEAM REVIEW

The Project Team review was held on March 21, 2017.

JACOBS MANAGEMENT REVIEW

The Jacobs Management Review of the estimate was held on March 29, 2017.

CLIENT ESTIMATE REVIEWS

The review meeting of the TIC Estimate with Alberta Innovates & Shell Site was held on April 11, 2017.

ESTIMATE DUE TO CLIENT

The planned deliverable date to Alberta Innovates for the final revision of the TIC Estimate for the Pre-FEED phase has been scheduled for April 29, 2017

Exceptions & Clarifications

- Contaminated soils
- Asbestos, lead paint
- Underground obstructions (Large rocks, concrete, UG piping etc.)
- Prolonged bad weather conditions (more than a few days)
- Jacobs does not plan on flushing the pipe lines with the use of Glycol so none was included in the estimate.
- Unexpected plant shut downs (permit loss)
- Untimely permitting by host site.
- Host site costs were excluded as stated above.
- Host site Contingency & Escalation
- Host site Risk monies were excluded.
- Host site Pro-Ratable Charges
- This estimate excludes all first fill fluids if required. These will be furnished by host site.
- No winter work is included.

Appendix P. Cost Estimate

CLIENT: Alberta Innovates	**JACOBS SUMMARY** **+ 30% - 15% Class IV ESTIMATE**	**DATE: 02-May-17**
PROJECT: Fuel Cell Demonstration		**ESTM BY : MRP**
LOCATION : Scotford (Fort Saskatchewan), Alberta, Canada		**CHKD BY :**
PROJECT NO: EE-0601-01	JACOBS	**FILE NO : XX-17**
PROJECT MANAGER : Errol D'Souza		**REV NO: 4**

Fuel Cell Demonstration - Summary - Shell Scotford Host Site

CODE	DESCRIPTION		DIR M.H. @ $57.09	SUB M.H. @	QUANTITY UNIT	MATERIAL All CAD	LABOR All CAD	SUB All CAD	TOTAL
	DIRECT COST								
01-49	EQUIPMENT		1,271		2 EA	99,060	71,100		170,160
51	DEMOLITION								
52	SITE EARTHMOVING		264	113	1 LT		14,424	8,250	22,674
53	SITE IMPROVEMENTS		212		1 LT	14,790	11,582		26,372
54	PILING		350	1,000	50 EA		19,086	200,000	219,086
55	BUILDING								
56	CONCRETE		499	45	39 CM	39,073	27,210	4,953	71,236
57	MASONRY,REFRACTORY								
58	STRUCTURAL STEEL								
59	CORRUGATED SIDING & DECKING								
60	FIREPROOFING								
61	DUCT WORK		1,582		411 LM	102,913	92,043		194,956
62	PIPING		1,203		121 LM	26,862	72,007		98,869
63	INSULATION								
64	INSTRUMENTATION		382	8	4 EA	43,490	22,764	1,500	67,755
65	ELECTRICAL		2,759		1 LT	269,252	157,787		427,039
66	PAINTING								
67	FURNITURE , LAB & SHOP								
68	**VENDOR ASSISTANCE & PRE-COMMISSIONING**								
69	DIRECT SUPPORT COST - SCAFFOLDING	9%	774		1 LT	4,148	44,060		48,208
69	DIRECT SUPPORT COST - (F/W) + (H/W) + (R/H)	2%	208		1 LT		10,610		10,610
A	**TOTAL DIRECT COST**	10,671	9,505	1,166	$57.09	599,588	542,675	214,703	1,356,965
	STANDARD INDIRECT COST								
75	CONSTRUCTION SERVICE LABOR	6.0%	570	TDL$	$3.43		32,560		32,560
76	TEMPORARY FACILITIES	5.0%		TDL$	$2.85	27,134			27,134
78	CRAFT PREMIUM TIME	12.0%		TDL$	$6.85		65,121		65,121
79	CRAFT FRINGES	Included		TDL$					
80	CRAFT PT&I	Included		TDL$					
83	SMALL TOOLS	3.0%		TDL$	$1.71	16,280			16,280
84	CONSUMABLES	4.0%		TDL$	$2.28	21,707			21,707
85	CNST. SMALL EQ.	8.0%		TDL$	$4.57			43,414	43,414
87	FIELD STAFF	34.0%	1,230	TDL$	$19.41		184,509		184,509
B	**SUBTOTAL STANDARD INDIRECT COST**	72.0%	of Dir Lab & Sub Lab		$98.20	65,121	282,191	43,414	390,726
	NON-STANDARD INDIRECT COST								
	MAINTAINED - OPERATE HEAVY LIFT & HAUL EQUIP ALLOWANCE								
	LABOR INCENTIVES - Included in the All-In-Wage Rate								
	DIRECT HIRE OH&P -				$2.10 of DMH		19,960		19,960
	SUBCONTRACTOR OH&P - Included in the Contractor Costs								
	COMMISSIONING SUPPORT								
	SALES TAX								
C	**TOTAL INDIRECT COST**					65,121	302,151	43,414	410,686
D	**TOTAL CONSTRUCTION COST**				$100.30	664,709	844,826	258,117	1,767,652
	ALL ENGINEERING COSTS								
	PROFESSIONAL SERVICES PHASE I								
	PROFESSIONAL SERVICES PHASE II								
	PROFESSIONAL SERVICES PHASE III (FEL-3)	3.0%	of Line G						83,783
	PROFESSIONAL SERVICES PHASE IV	10.0%	of Line G						279,278
	PROFESSIONAL SERVICES PHASE V	2.0%	of Line G						55,856
90	CONSTRUCTION MANAGEMENT								
	START-UP ASSISTANCE ALLOWANCE								
	3rd PARTY ENGINEERING	Allowance fpr DCS Programimg 500 hrs x $120							60,000
	HOME OFFICE CONST COST ALLOWANCE								
E	**TOTAL ENGINEERING COSTS**								478,917
	OTHER COSTS								
95	**CLIENT COST**								
70-100	SPARE PARTS - WAREHOUSE (CAPITAL) SPARES		of equipment cost						
70-101	SPARE PARTS - START-UP SPARES **(Mech & Elect Equip) @ 1.5%**								
77-995	FREIGHT - DUTIES & CUSTOMS CHARGES								
77-999	FREIGHT - for EQUIPMENT & MATERIAL BULKS	4.0%	equipment & bulk cost						23,984
	T/A PRORATABLES ($35 per hr)								
	FIRST FILL COSTS (Catalysts & Chemicals) - By Client								
F	**SUBTOTAL PROJECT COSTS**								2,270,552
98-200	ESCALATION	3.0%							68,117
98-300	CONTINGENCY	20.0%							454,110
98-600	RISK ALLOWANCE - SUPPLIED BY Alberta Innovates								
	ROUND-OFF ADJUSTMENT								
G	**TOTAL PROJECT COST**			28.19					2,792,779

CLIENT: Alberta Innovates	**JACOBS SUMMARY**	**DATE: 02-May-17**
PROJECT: Fuel Cell Demonstration	**+ 30% - 15% Class IV ESTIMATE**	**ESTM BY : MRP**
LOCATION : Scotford (Fort Saskatchewan), Alberta, Canada		**CHKD BY :**
PROJECT NO: EE-0601-01		**FILE NO : XX-17**
PROJECT MANAGER : Errol D'Souza		**REV NO: 2**

Fuel Cell Demonstration - Summary - Shell Scotford Host Site

CODE	DESCRIPTION		DIR M.H. @ $57.06	SUB M.H. @	QUANTITY	UNIT	MATERIAL All CAD	LABOR All CAD	SUB All CAD	TOTAL
	DIRECT COST									
01-49	EQUIPMENT									
51	DEMOLITION		**4,445**		**1**	**LT**	**6,000**	**254,392**		**260,392**
52	SITE EARTHMOVING									
53	SITE IMPROVEMENTS									
54	PILING									
55	BUILDING									
56	CONCRETE									
57	MASONRY,REFRACTORY									
58	STRUCTURAL STEEL									
59	CORRUGATED SIDING & DECKING									
60	FIREPROOFING									
61	DUCT WORK									
62	PIPING									
63	INSULATION									
64	INSTRUMENTATION									
65	ELECTRICAL									
66	PAINTING									
67	FURNITURE , LAB & SHOP									
68	**VENDOR ASSISTANCE & PRE-COMMISSIONING**									
69	DIRECT SUPPORT COST - SCAFFOLDING	**7%**	**311**		**1**	**LT**	**1,665**	**17,688**		**19,353**
69	DIRECT SUPPORT COST - (F/W) + (H/W) + (R/H)	**3%**	**119**		**1**	**LT**		**6,052**		**6,052**
A	**TOTAL DIRECT COST**	**4,875**	**4,875**		**$57.06**		**7,665**	**278,132**		**285,797**
	STANDARD INDIRECT COST									
75	CONSTRUCTION SERVICE LABOR	**6.0%**	**292**	**TDL$**	$3.42			**16,688**		**16,688**
76	TEMPORARY FACILITIES	**5.0%**		**TDL$**	$2.85		**13,907**			**13,907**
78	CRAFT PREMIUM TIME	**12.0%**		**TDL$**	$6.85			**33,376**		**33,376**
79	CRAFT FRINGES	**Included**		**TDL$**						
80	CRAFT PT&I	**Included**		**TDL$**						
83	SMALL TOOLS	**3.0%**		**TDL$**	$1.71		**8,344**			**8,344**
84	CONSUMABLES	**4.0%**		**TDL$**	$2.28		**11,125**			**11,125**
85	CNST. SMALL EQ.	**8.0%**		**TDL$**	$4.56				**22,251**	**22,251**
87	FIELD STAFF	**34.0%**	**630**	**TDL$**	$19.40			**94,565**		**94,565**
B	**SUBTOTAL STANDARD INDIRECT COST**	**72.0%**	**of Dir Lab & Sub Lab**		**$98.14**		**33,376**	**144,629**	**22,251**	**200,255**
	NON-STANDARD INDIRECT COST									
	MAINTAINED - OPERATE HEAVY LIFT & HAUL EQUIP ALLOWANCE									
	LABOR INCENTIVES - Included in the All-In-Wage Rate									
	DIRECT HIRE OH&P -				$2.10	of DMH		**10,237**		**10,237**
	SUBCONTRACTOR OH&P - Included in the Contractor Costs									
	COMMISSIONING SUPPORT									
	SALES TAX									
C	**TOTAL INDIRECT COST**						**33,376**	**154,866**	**22,251**	**210,492**
D	**TOTAL CONSTRUCTION COST**				**$100.24**		**41,041**	**432,998**	**22,251**	**496,289**
	ALL ENGINEERING COSTS									
	PROFESSIONAL SERVICES PHASE I									
	PROFESSIONAL SERVICES PHASE II									
	PROFESSIONAL SERVICES PHASE III (FEL-3)		of Line G							
	PROFESSIONAL SERVICES PHASE IV	**5.0%**	of Line G							**33,418**
	PROFESSIONAL SERVICES PHASE V	**2.0%**	of Line G							**13,367**
90	CONSTRUCTION MANAGEMENT									
	START-UP ASSISTANCE ALLOWANCE									
	3rd PARTY ENGINEERING	Allowance fpr DCS Programimg 500 hrs x $120								
	HOME OFFICE CONST COST ALLOWANCE									
E	**TOTAL ENGINEERING COSTS**									**46,785**
	OTHER COSTS									
95	**CLIENT COST**									
70-100	SPARE PARTS - WAREHOUSE (CAPITAL) SPARES		of equipment cost							
70-101	SPARE PARTS - START-UP SPARES **(Mech & Elect Equip) @ 1.5%**									
77-995	FREIGHT - DUTIES & CUSTOMS CHARGES									
77-999	FREIGHT - for EQUIPMENT & MATERIAL BULKS	**4.0%**	equipment & bulk cost							**307**
	T/A PRORATABLES ($35 per hr)									
	FIRST FILL COSTS (Catalysts & Chemicals) - By Client									
F	**SUBTOTAL PROJECT COSTS**									**543,381**
98-200	ESCALATION	**3.0%**								**16,301**
98-300	CONTINGENCY	**20.0%**								**108,676**
98-600	RISK ALLOWANCE - SUPPLIED BY Alberta Innovates									
	ROUND-OFF ADJUSTMENT									
G	**TOTAL PROJECT COST**									**668,358**

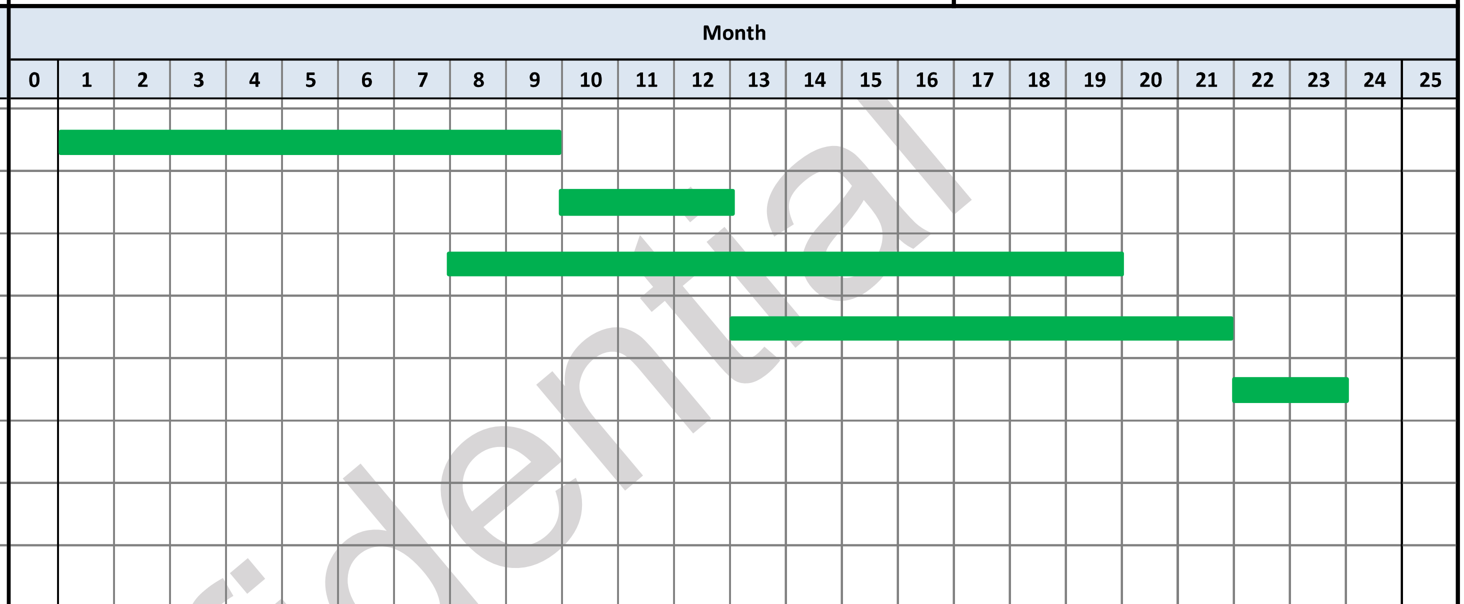
Appendix Q. Project Schedule

ALBERTA INNOVATES – Energy and Environment Solutions

Molten Carbonate Fuel Cell for Carbon Capture from SAGD Flue Gas

Schedule - Issued for Proposal

Activity ID	Activity Name	Original Duration (Month)
A1000	FEED	9
A1010	Detailed Design	3
A1020	Procurement of Long Lead Item (CO2 Compressor) by FCE	12
A1030	Skid Fabrication and Installation	9
A1040	Commissioning and Start-up	2



EE060101

Data Date: 01 May 2017

Issue Date	Revision No.	Approved By
23-Mar-17	0	ED

Appendix R. Risk Assessment

RISK MANAGEMENT PLAN

R

Probability: The chance of the risk occurring

tion Unit — Impact: The effect on project objectives if the risk occurs

Risk Level: Probability x Impact

Date	RISK ANALYSIS														RISK EVALUATION			
	Probability				Impact						Risk Level							
identified	Rating	Scale	%	Value	Safety	Cost	Schedule	Impact to Site	Highest Impact	Value	Rating	Value	Scale	Risk Group	Impact if the risk occurs	Risk response strategy	Risk response owner	Action(s) to im
09 Mar 2017	4	High	70%	7	A	D	D	A	D	4	4D	28	High	Organization	Schedule delay and cost escalation	Mitigate	ERA / Site Host	Ensure that partic FEED
09 Mar 2017	1	Very Low	10%	1	A	D	D	A	D	4	1D	4	Low	Technology	Schedule delay and cost escalation	Accept	FCE	Detailed schedule
09 Mar 2017	3	Medium	50%	5	A	D	D	A	D	4	3D	20	High	Organization	Schedule delay and cost escalation as steering team would require additional funding if one or more of its members pulls out.	Mitigate	ERA / Site Host	Ensure that fundi
09 Mar 2017	1	Very Low	10%	1	A	D	D	A	D	4	1D	4	Low	Organization	Schedule delay and cost escalation as steering team would require additional funding if one of its members does not release funds.	Mitigate	ERA / Site Host	Contact Cenovus and confirm fundi
09 Mar 2017	2	Low	30%	3	A	D	A	C	D	4	2D	12	Medium	Technology	Operating costs escalation as impact to site would be new	Mitigate	FCE / Site Host	FCE will provide t cell technology ar monitoring will als
09 Mar 2017	3	Medium	50%	5	A	C	C	A	C	2	3C	10	Medium	Technology	Components of the fuel cell package may require replacement if reliability is not proven.	Accept	FCE / Site Host	Individual compor have been prover together for carbo
09 Mar 2017	3	Medium	50%	5	A	A	A	C	C	2	3C	10	Medium	Technology	Unable to determine if there are longer term site impacts with the fuel cell package.	Mitigate	FCE / Site Host	Testing time is cu time, if required, i ERA and Site Hos
09 Mar 2017	2	Low	30%	3	A	B	A	B	B	1	2B	3	Low	Technology	Fuel cell degrades and would require replacement.	Accept	FCE / Site Host	Low risk that there within the testing
09 Mar 2017	2	Low	30%	3	A	C	A	D	D	4	2D	12	Medium	Technology	Unable to interpret data gathered during test period. (ie. Lack of signals exchanged, lack of visibility of fuel cell operating parameters)	Mitigate	FCE / Site Host	Current design wi communication; h developed at a lat
09 Mar 2017	2	Low	30%	3	A	D	D	D	D	4	2D	12	Medium	Legal / Statutory	Unable to begin the next phase of the project	Mitigate	FCE / Site Host	NDA with FCE an before FEED
09 Mar 2017	1	Very Low	10%	1	A	A	C	A	C	2	1C	2	Low	Legal / Statutory	Schedule delay awaiting regulatory approval	Accept	Site Host	Both provinces ha for emmissions re
09 Mar 2017	1	Very Low	10%	1	A	A	A	A	A	0.5	1A	0.5	Low	Site Integration	Potential minor schedule and cost impact for the next phase of the project.	Mitigate	ERA / Site Host	CO2 product scop during FEED stag
09 Mar 2017	4	High	70%	7	B	C	C	B	C	2	4C	14	Medium	Site Integration	Schedule and cost impact while confirming specifications used for the demonstration unit.	Mitigate	FCE / Site Host	Since skid is a ter from oil and gas s be evaluated and
09 Mar 2017	1	Very Low	10%	1	A	B	A	D	D	4	1D	4	Low	Site Integration	CO2 product stream may be off-spec and impact the host site	Mitigate	FCE / Site Host	CO2 is separated Product quality is of product quality pressure / temper

Date identified	Probability Rating	Probability Scale	Probability %	Probability Value	Impact Safety	Impact Cost	Impact Schedule	Impact to Site	Highest Impact	Impact Value	Risk Level Rating	Risk Level Value	Risk Level Scale	Risk Group	Impact if the risk occurs	Risk response strategy	Risk response owner	Action(s) to im…
09 Mar 2017	1	Very Low	10%	1	B	B	A	A	B	1	1B	1	Low	Site Integration	Higher than expected sulphur levels in natural gas may damage the fuel cell.	Mitigate	FCE / Site Host	Sulphur removal … design. NG samp… analysis to be do… of FEED phase.
09 Mar 2017	1	Very Low	10%	1	B	C	A	A	C	2	1C	2	Low	Site Integration	Higher than expected SO2 levels in flue gas may damage the fuel cell.	Mitigate	FCE / Site Host	Sorbent beds bei… Pre-FEED design… for SOx to be do… of FEED phase.
09 Mar 2017	3	Medium	50%	5	B	B	B	B	B	1	3B	5	Low	Legal / Statutory	Cost, schedule, safety and impact to site if equipment is not registered to suitable specifications.	Accept	FCE / Site Host	Individual electric… CSA. FCE indica… obtaining CSA-C… components. Ove… system including… Power Plant will n… worthwhile for a d…
09 Mar 2017	2	Low	30%	3	A	B	B	B	B	1	2B	3	Low	Site Integration	Interaction / designing with Saskpower may cause schedule, cost and site impacts.	Accept	FCE / Site Host	Initially thought to… now has incentive… Early engagemen… commencement o… their requirments… design.
09 Mar 2017	1	Very Low	10%	1	A	B	A	C	C	2	1C	2	Low	Site Integration	Flue gas composition / contaminants may change if other sources of fuel gas instead of natural gas are used at the host site.	Mitigate	FCE / Site Host	Flue Gas samplin… done to firm up d… phase.
09 Mar 2017	1	Very Low	10%	1	A	B	A	C	C	2	1C	2	Low	Site Integration	Site water quality is worse than what the water treatment skid in the FCE package was designed for	Mitigate	FCE / Site Host	Water compositio… other sources of … water sampling to… confirm the desig…
09 Mar 2017	2	Low	30%	3	B	B	A	B	B	1	2B	3	Low	Site Integration	Potential damage to equipment and loss of testing time.	Mitigate	FCE / Site Host	Ensure EHT to be… potential for freez…
09 Mar 2017	3	Medium	50%	5	A	A	A	A	A	0.5	3A	2.5	Low	Site Integration	Potential condensation of water out of flue gas resulting in operational issues. (additional draining required)	Mitigate	Site Host	Ensure all HT pip… follow site specific…
09 Mar 2017	1	Very Low	10%	1	A	B	A	A	B	1	1B	1	Low	Site Integration	Structural steel integrity would be in question	Mitigate	FCE / Site Host	Ensure all structu… temperature. LTC…
09 Mar 2017	3	Medium	50%	5	C	C	A	C	C	2	3C	10	Medium	Site Integration	Potential damange to aerial coolers or water coolers resulting in loss of testing time, maintenance costs and site impact.	Mitigate	FCE / Site Host	Site specific aeria… be followed durin…
09 Mar 2017	1	Very Low	10%	1	A	D	D	A	D	4	1D	4	Low	Technology	Stack is constructed not to FCE's specifications.	Mitigate	FCE	Stack warranty co… during the next pr…
09 Mar 2017	2	Low	30%	3	B	A	A	C	C	2	2C	6	Medium	Technology / Site Integration	Site operators are unfamiliar with fuel cell technology. Potenital safety and site impact.	Mitigate	FCE / Site Host	FCE will provide t… cell technology ar… monitoring will als…
09 Mar 2017	2	Low	30%	3	B	A	A	C	C	2	2C	6	Medium	Technology / Site Integration	Site operators are unfamiliar with fuel cell technology. Potenital safety and site impact.	Mitigate	FCE / Site Host	FCE will provide t… cell technology ar… monitoring will als…
09 Mar 2017	2	Low	30%	3	B	B	B	B	B	1	2B	3	Low	Organization	Schedule and cost impact while confirming specifications used for the demonstration unit.	Mitigate	FCE / Site Host	Final standards / … requirements. It s… temporary nature … with all site standa… Deviations will ha… the host site as re…
															Site operators are unfamiliar with fuel cell…			Emergency coord…

	RISK ANALYSIS														RISK EVALUATION			
Date	Probability				Impact						Risk Level							
identified	Rating	Scale	%	Value	Safety	Cost	Schedule	Impact to Site	Highest Impact	Value	Rating	Value	Scale	**Risk Group**	Impact if the risk occurs	Risk response strategy	Risk response owner	Action(s) to im
09 Mar 2017									0	0				Organization				Note to steering c was conducted.
09 Mar 2017	2	Low	30%	3	A	A	B	B	B	1	2B	3	**Low**	Site Integration	Testing period could be impacted. Inability to validate data obtained in the demonstration.	Accept	FCE / Site Host	
09 Mar 2017									0	0				Site Integration				
12 Mar 2017	2	Low	30%	3	C	A	A	B	C	2	2C	6	**Medium**	Site Integration	Freezing issues with adjacent piping / structures and personnel.	Mitigate	FCE / Site Host	To be evaluated c Hazid reviews
12 Mar 2017	2	Low	30%	3	B	A	A	B	B	1	2B	3	**Low**	Site Integration	Potential safety issue with CO_2 venting during an upset.	Mitigate	FCE / Site Host	To be evaluated c Hazid reviews

Meeting: Project Risk Review
Date: March 9, 2017
Location: Jacobs Office, Edmonton, AB
Client: Alberta Innovates
Project No: EE060101
Project Name: MCFC-4CC 1.4MW Fuel Cell Demonstration Unit

List of Attendees

Name	Company	Comment
Gautam De	Jacobs	
Errol D'Souza	Jacobs	
Tan Le	Jacobs	
Candice Paton	Alberta Innovates	Called In
Linda Russell	Alberta Innovates	Called In
Dieter Lamprecht	Jacobs	Called In
Paul Torraville	Husky	Called In
Stephen Jolly	Fuel Cell Energy	Called In
Frank Dobek	Fuel Cell Energy	Called In
Gabriel Proulx	Shell	Called In
Daniel Burt	Suncor	Called In

JACOBS

PROJECT RISK ASSESSMENT - RISK PROBABILITY and IMPACT (P-I)

Safety	Cost	Schedule	Impact to Site	Risk Impact Level					
Total disability/ fatality or severe health problem	TIC increase > 10%	Extension of critical path > 8 months	Site Shutdown	E Very High	1E	2E	3E	4E	5E
Partial disability or major health problem	TIC increase 7 - 10%	Extension of critical path 4 - 8 months	Unit Shutdown	D High	1D	2D	3D	4D	5D
Lost time incident or potential health problem	TIC increase 1.5 - 7%	Extension of critical path 2 - 4 months	Localized Short Term Outage	C Medium	1C	2C	3C	4C	5C
First aid case, slight health problem	TIC increase 0.25 - 1,5%	Extension of critical path 1 - 2 months	Minor Impact to Unit	B Low	1B	2B	3B	4B	5B
No health or injury risks	TIC increase < 0.25%	Extension of critical path < 1 month	Minor Nuisance (More Maintenance)	A Very Low	1A	2A	3A	4A	5A

Project Objective

Risk Probability Level

1 Very Low	2 Low	3 Medium	4 High	5 Very High
10%	35%	50%	70%	90%
Event hardly heard of in the industry.	Event occurs in the industry, but doubtful.	Event occurs from time to time on the site	Event is expected to occur / occurs regularly on this site.	Event **will** occur at this site **annually** or more often.

Appendix S. Host Site Comments Resolution

Removed pages 170-177