Electrification through RF XL could Result in Zero-GHG Emissions for Oil Sands and Heavy Oil Producers

acceleware®

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The analysis presented in this whitepaper includes forward-looking information (as defined in Canadian securities legislation). This forward looking information used in the analysis takes the form of predictions that the effectiveness and efficiency of RF XL technology will be similar to levels indicated by experiments and simulations conducted to date by Acceleware Ltd. ("Acceleware", "AXE" or the "Corporation"); the anticipated economic performance of RF XL technology and state-of-the-art solar power generation; the expected capital and operating costs for RF XL in commercialization and solar power arrays; and the capital cost of the pad-based surface facility design.

These statements involve numerous assumptions about future economic conditions and courses of action and are therefore subject to various risks and uncertainties. Numerical assumptions used by Acceleware in the analysis and not mentioned in the body of the document are listed in Appendix 2. Additional risks and uncertainties include, but are not restricted to, the ability of Acceleware Ltd. ("Acceleware", "AXE" or the "Corporation") to fund its research and development ("R&D") activities, the timing of such R&D, the likelihood that the patent applications filed by the Corporation will be granted, that Acceleware will be able to commercialize the RF XL technology with the capital cost and operating cost characteristics expected, the future price and cost of producing heavy oil and bitumen, the availability of key components and the Corporation's ability to attract and retain key employees and defend itself against any future patent infringement claims.

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Electrification through RF XL could Result in Zero-GHG Emissions for Oil Sands and Heavy Oil Producers

1. Executive Summary

The effects and costs of climate change and other environmental factors are hastening a global energy transition in which the drive for the cleanest possible fuels is gaining momentum. It is becoming clear that environmental responsibility, sound economics and breakthrough technologies must be applied to the production of heavy oil and oil sands for both combustion and non-combustion uses. A high-tech method that can cleanly create valuable products from oil sands and heavy oil deposits could reinvigorate Canada's energy sector, and position Canada to be a leader in clean energy and high value products in a low-carbon future.

Global markets are searching for a method to reduce to zero the Scope 1 and to zero or near zero the Scope 2 greenhouse gas (GHG) emissions[1] associated with the production of hydrocarbons — whether for fossil fuels or for 'bitumen beyond combustion' (BBC) by-products, such as petrochemical feedstock for plastics, asphalt, carbon fibre, hydrogen and rare elements. Through electrification, Acceleware's RF XL enhanced oil recovery (EOR) technology is expected to be well equipped to lead the way. When applied in conjunction with a renewable energy source, RF XL is projected to deliver zero or near zero-GHG emissions heavy oil production at significantly lower capital and operating costs when compared to steam assisted gravity drainage (SAGD). By design, RF XL requires no external water, is quick to deploy and produce, and removes the requirement for steam distribution and produced water recovery systems, allowing for a much more compact surface footprint.

A zero-carbon means of producing heavy oil and the oil sands could play a vital role in helping to advance Alberta's position as an environmental, social and governance (ESG) leader in clean energy transition. To that end, this white paper provides a techno-economic analysis of the potential impact of deploying a local solar energy array to support a 5,000 bbl per day pad-based RF XL heavy oil project in Alberta, California and the Middle East. The goal is to demonstrate scenarios where transformative technologies and ideas could quickly and efficiently modernize the heavy oil and oil sands industry.

Combining RF XL with renewable power and pad-based surface facilities equals clean and lower cost production.

[1] *See https://ghgprotocol.org/sites/default/files/standards_supporting/FAQ.pdf for more information on Scope 1 and Scope 2 GHG emissions.*

Project Overview:

To demonstrate zero-GHG heavy oil production capabilities, we have opted to explore potential solar powered RF XL heavy oil production deployment scenarios. However, hydro-electricity, nuclear, geothermal or wind power could also be utilized to power RF XL and achieve zero-GHG emissions production.

In this document we discuss models of:

1. A solar powered RF XL example in Alberta designed to accommodate solar seasonality and leverage the ability to sell power to the grid.
2. California and Middle East examples that demonstrate the profitability of solar powered heavy oil projects in markets with higher solar production.

A typical SAGD project has a central processing facility (CPF) with all steam generation, water processing, and oil processing equipment. Well pads are constructed as satellites from that CPF, and are connected to it with pipelines and power lines. Although it could also be profitable to consider a renewable power source with a central processing facility (CPF) based RF XL deployment, all examples in this paper incorporate an innovative pad-based surface facility design that leverages the benefits of combining an RF XL platform with a local photovoltaic solar array. The pad-based design places all processing equipment at the pad, and moves those facilities from pad to pad over time. The scenarios provide capital cost savings and offer additional flexibility for projects at a 5,000 bbl/day to 10,000 bbl/day scale.

Acceleware has partnered with both Canadian Solar Inc. (CSI) and Scovan Engineering Ltd. (Scovan) for development of designs, as well as to incorporate current pricing estimates into the economic models for the photovoltaic solar array and the pad-based surface facility design.

RF XL enables zero Scope 1 and near zero Scope 2 GHG emissions heavy oil production.

Environmental Performance:

RF XL heavy oil production is an all-electric process and when deployed with a renewable power source such as solar it could result in zero-carbon emissions. In contrast with other thermal EOR techniques, additional anticipated environmental benefits applicable to any RF XL deployment regardless of power source are:

1. No external water is needed for production. RF XL heating requires only connate water from within the formation, cutting make-up water usage by an estimated 122 million litres per year for a typical 5,000 bbl/day project.
2. Land use is reduced by approximately 67 percent due to the elimination of steam generating facilities, the reduction in size of water processing facilities, and the elimination of steam pipeline connections to the CPF[2].

[2] *The considerable land use required by the renewable power sources such as solar, wind, or hydro require is not factored into the oil processing footprint reduction estimate.*

Economic Performance Expectations:

Combining RF XL with solar energy for heavy oil production is expected to be profitable in scenarios described within this white paper, largely because the capital cost per megawatt (MW) of solar power has decreased to a point where it is now competitive with other power sources. In Alberta, the ability to sell solar power to the grid provides economic benefits that can offset limitations resulting from seasonal changes and sunlight shortages in the winter. California and Middle East based projects, on the other hand, generate strong returns due to high levels of solar production and higher wellhead prices received for oil in those markets.

In each solar power deployment example, we have specified a grid-connection in addition to a solar array in order to a) support non-RF heating related processes during the night, thereby eliminating the need to invest in battery storage, and to b) incorporate the aforementioned electricity sale opportunity in Alberta. The pad-based facility design presented in this document involves extensive modularization as well as the ability to re-deploy processing facilities from pad to pad – both of which offer multiple potential cost benefits.

Economic highlights of the solar powered RF XL pad-based surface facility scenarios investigated herein include[3]:

1. The Alberta-based solar deployment scenarios would be profitable, and could generate internal rates of return (IRR) just under that generated by a pad-based, grid connected deployment scenario.
2. The ability to sell solar power to the grid would enable operators to maintain positive returns with an IRR of 12 percent for a 30-year project, even if the price of oil (WTI) drops to $20 USD for the last 15 years of the project, where the example of a non-solar pad-based project in Alberta shows a negative IRR.
3. Placing a solar powered, pad-based RF XL project in California or the Middle East is anticipated to provide very strong returns (IRR of 33 percent and 39 percent respectively), due to higher levels of solar production and the higher price for oil received in those markets.
4. The pad-based design could offer lower capital costs than a central processing facility approach for projects between 5,000 and 10,000 bbl/day.

Further economic benefits specific to the use of solar energy and the RF XL pad-based design are described in later sections of the white paper.

Acceleware's current pilot test is intended to validate RF XL's efficiency, production, operational costs and capital costs at commercial scale.

[3] *Unless otherwise shown, all amounts shown in the paper are in Canadian dollars, scenarios are based on a 30 year 5,000 bbl/day project, West Texas Intermediate (WTI) of $50 USD, Western Canadian Select (WCS) at $38 USD, and discount rate of 10%*

Background Information:

The intent of Acceleware's upcoming commercial-scale pilot test is to demonstrate that RF XL can produce oil at commercial scale while achieving and sustaining high levels of efficiency, consistent with multiple smaller-scale field tests and numerical simulations conducted to date. RF XL, once validated, can be expected to provide an immediate 25 percent reduction in GHG emissions for oil sands and heavy oil production when compared to SAGD, based on the current emissions intensity of the Alberta grid. That reduction would increase to 50 percent by 2030 when factoring in the current Alberta power grid emissions intensity reduction plan. When applied in conjunction with any one hundred percent renewable power source, zero-GHG emissions production can be anticipated. While the intermittent nature of many renewable power sources has, to date, posed barriers pertaining to heavy oil production, RF XL provides a technological foundation that can function with intermittent power.

In summary, we anticipate that once RF XL is commercialized, it will be possible to deliver efficient, zero-GHG heavy oil production via modern technologies and pricing, in various locations around the world.

Breakthrough technologies can provide global markets the capability of producing zero-carbon heavy oil.

2. RF XL Technology Overview

RF XL Background:

The RF XL system is an all-electric system designed to enhance bitumen and heavy-oil recovery, and can be deployed and become operational quickly. Basic components are presented in Figure 2.1. The system comprises (1) the electromagnetic (EM) energy converter, (2) a waveguide connecting the converter and the radiator, and (3) two radiator lines. The converter, deployed next to the wellhead at surface, produces an EM signal at a frequency range categorized as belonging to the radio frequency (RF) spectrum. The generated RF signal is carried to the radiator by a waveguide, comprising two coaxial lines. The coaxial lines are connected to two RF XL radiators, placed in the pay zone horizontally, approximately 4 – 6 m above the producing well.

Though it has many similarities to SAGD, RF XL modernizes operations.

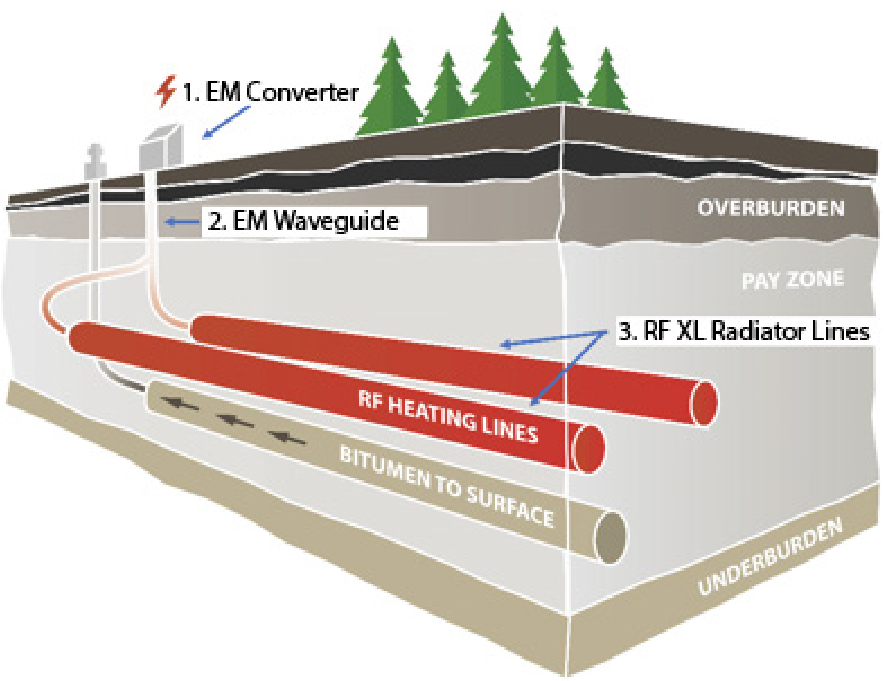

Figure 2.1: RF XL system

The components of the EM converter system are shown below in Figure 2.2. The AC power generator provides the electrical power needed for the system operation. This power can come from the standard power grid, a local power generation system, or a combination of both. The AC power is converted to DC power by a high-efficiency rectifier. The DC signal is fed to the RF converter which converts to the RF signal with a frequency between 10 kHz and 500 kHz. The RF energy is transmitted to two RF XL radiators which radiate it into the formation.

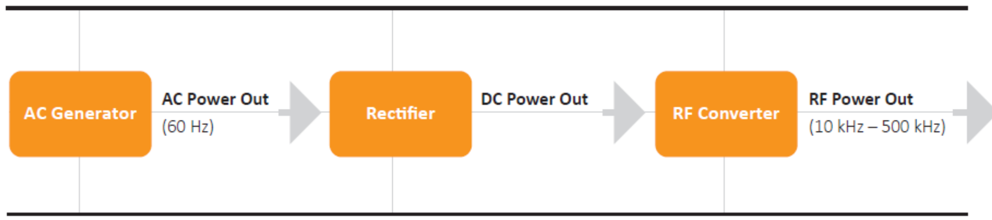

Figure 2.2: Components of the EM converter system

The amount of greenhouse gases emitted by an RF XL system depends on the type of AC power source used. If a renewable power source such as hydro, wind, nuclear, geothermal or solar is used, the GHG emissions associated with production can be reduced to zero.

Renewable power generation systems, like wind or solar, often operate intermittently. RF XL technology is designed for intermittent operation - the RF converter can be safely turned on or off without damage to the RF XL system, its subsurface components, or the heating process. As described below, if the RF XL system is able to deliver the same average amount of power per well per day as it would with constant power, the same volume of oil could still be produced from the well. In essence, by doubling the amount of power delivered into half as many hours, zero-GHG production at typical production rates can be achieved using renewable intermittent power sources.

Use of modernized technology means GHG emission levels can be almost eliminated since they depend on the type of AC power used.

Production Mechanics of RF XL:

Thermal recovery is an increasingly common method of extracting heavy oil and bitumen. There are several different forms of the technology, with SAGD and CSS (cyclic steam stimulations) being the primary technologies applied in Canada's Athabasca and Cold Lake deposits. Of these, SAGD is most similar to RF XL technology.

In the SAGD process, two horizontal wells are drilled - one a few meters above the other – with the upper well being where steam is continuously injected, heating and mobilizing the bitumen. The steam condenses at the steam chamber boundary and the steam condensate and mobilized bitumen drain due to gravity, where they are then produced by the collector well located at the base of the reservoir.

Like SAGD, RF XL uses parallel horizontal wells drilled near the base of the reservoir. The lower wellbore is drilled and completed like a typical SAGD producer. In place of an injection well, however, the specifically designed upper heating well is drilled with two horizontal laterals, forming an RF XL lossy transmission line[4].

[4] *Leaky wave transmission line, section 4, [Acceleware Whitepaper](), February 2019.*

Rather than injecting steam into the upper wells, RF energy is directly transmitted to the reservoir.

The RF XL process heats the water in the reservoir, similar to how an 'inside-out' microwave oven might heat. Steam is generated in-situ when connate water is vaporized by RF energy. The steam chamber will continually expand over the life of the well as energy is delivered into the reservoir. Due to the lossy nature of water in a liquid phase, steam will continue to be generated in-situ. Bitumen and steam are less lossy than liquid water, allowing the RF energy to penetrate further into the formation, beyond the desiccated region. Production is initially established at the heel and travels along the transmission lines to the toe. Bitumen or oil production from the lower wellbore will ramp up as the steam chamber continues to grow, initially along the length of the well, then vertically and laterally. A more comprehensive description of the RF XL heating and production process, along with the software used to complete reservoir simultions, can be found in the Acceleware whitepaper, published February 2019[5].

Like SAGD, the steam resulting from the RF energy creates a chamber that expands as energy continues to be delivered by the transmission lines. When steam condenses at the edge of the chamber, the steam condensate and mobilized bitumen drain due to gravity.

With RF XL, connate water turns to steam via RF energy - no fresh water is required.

[5] *How RF XL Can Profitably Produce Oil Sands and Heavy Oil with Low Environmental Impacts, Acceleware Whitepaper, February 2019.*

3. Heating Effectiveness using Intermittent Power

Background:

Intermittent renewable power sources such as solar and wind have typically not been considered reliable enough to support thermal oil recovery projects. The analysis presented in this whitepaper, however, demonstrates that an intermittent heating approach could generate the same production rates as continuous heating when applied in conjunction with RF XL's electrical EOR method.

SAGD/CSS vs RF XL:

Traditional thermal operations such as SAGD, CSS and others use steam as the vehicle to deliver heat to the reservoir, with optimum production resulting from continuous or multi-day cyclic (24/7) steam delivery. Steam generation and water treatment make up one-half to two-thirds of initial capital costs for these thermal projects. To allow for intermittent steam operations in these facilities, proportional upsizing would be required, which would increase both upfront capital costs as well as the environmental impacts of these projects. Turning equipment on and off daily would also pose personnel and process safety risks and be labour intensive, impacting reliability and maintenance costs for equipment. In essence, SAGD and CSS can not practically, nor economically operate via frequent intermittent heat sources such as solar or wind.

RF XL is designed for intermittent heating that is both efficient and effective - meaning that with minimal capital impact, a RF power source with proportionately more capacity can be installed on surface and run intermittently. The production rate and overall recovery from running a lower RF power source continuously or a higher source intermittently are unchanged. One can use solar power during the day to deliver the energy to the reservoir, stop heating during the night, and repeat the operations the next day.

Reservoir simulations completed by Acceleware for a heavy oil reservoir demonstrate that heating continuously for 24 hours at a given power of 2 MW (48 MWh), for example, has the same effect on the predicted oil rate as would heating only 12 hours at 4 MW (48 MWh). Figure 3.1 shows a heat map (plan view cross section through producer) of the same reservoir heated for 1,000 days in one case with 2 MW 24 hours a day, and in the other case with 4 MW for 12 hours a day. To provide another perspective on how similar the heating process results are between the continuous and intermittent cases explored here, figure 3.2 shows that the temperature in three different locations in the reservoir (the cell locations for figure 3.2 are shown in figure 3.1) is the same regardless of whether they are heated continuously or intermittently.

Fundamental differences due to electric production enable the use of intermittent power sources to support RF XL.

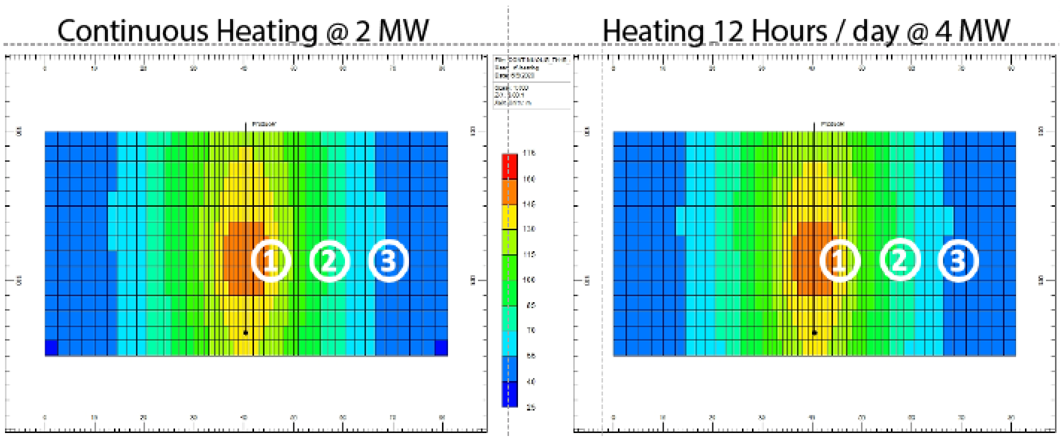

Figure 3.1: Heat map comparison of 2 MW continuous vs 4 MW 12 hours/day at 1,000 days and cell locations for Figure 3.2 temperature chart

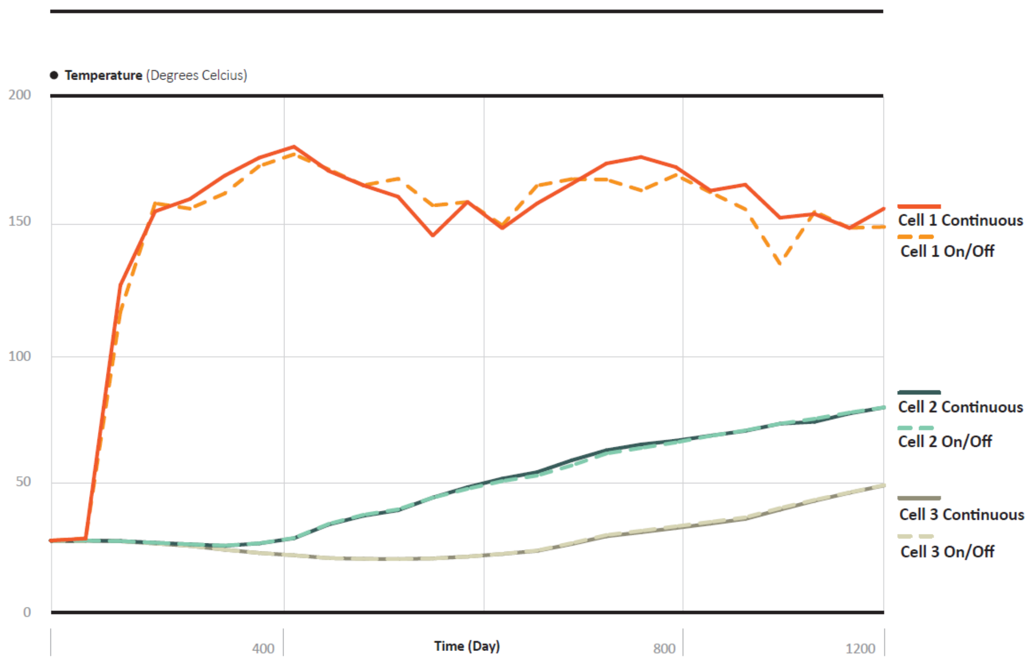

Figure 3.2: Temperature comparison for three locations in the reservoir over the life of the well

Figure 3.3 shows a comparison of the expected oil rate between RF XL heating at a continuous power rate of 2 MW and RF XL heating for only 12 hours at 4 MW every day. While the heat map and temperature charts show that the intermittent process could heat the reservoir to the same extent, these results predict that oil production is also equivalent for intermittent and continuous heating. The total energy delivered per day in both simulations is the same, 48 MWh. In this paper, all zero-GHG scenarios will apply 48 MWh of energy per day, delivered via 4 MW of power over 12 hours each day.

Intermittent power can heat the reservoir to the same level as continuous power.

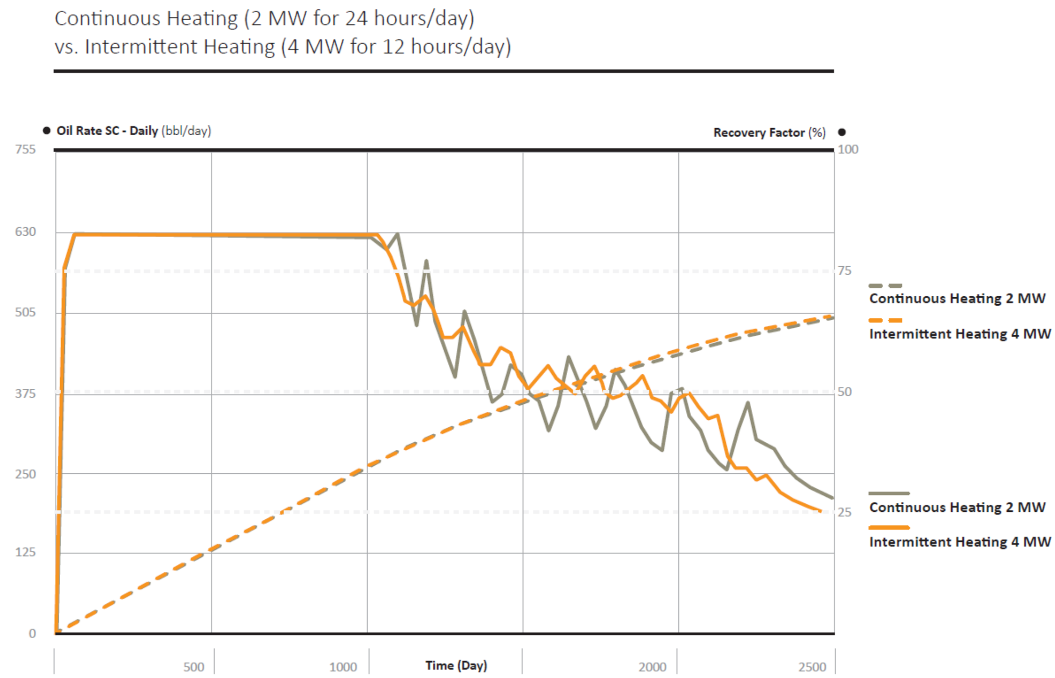

Figure 3.3: Oil rate Comparison: Continuous versus Intermittent Heating

The aforementioned use of intermittent heating cycles is effective when the reservoir retains injected energy. However, issues can arise at surface when produced fluids cool down and could solidify. Viscosity of the oil plays a significant role in handling requirements at surface. The chart below (figure 3.4) compares the anticipated reservoir temperature for both continuous and intermittent heating in two cells near the producer well over a 10 day period measured in 12 hour increments. The chart shows no more than a 1 Celsius drop in temperature drop in temperature during the 12 hour periods with no heating, demonstrating that the oil should stay hot and continue to flow through the night.

While cooling of the surface piping and thickening of the produced fluid can be alleviated through the use of insulation and electrical heat tracing, based on the simulation results it is not expected to be necessary to increase the amount of either of these components above what would be used in a thermal project with continuous heating.

Delivering the same total energy per day = the same overall temperature = the same production results.

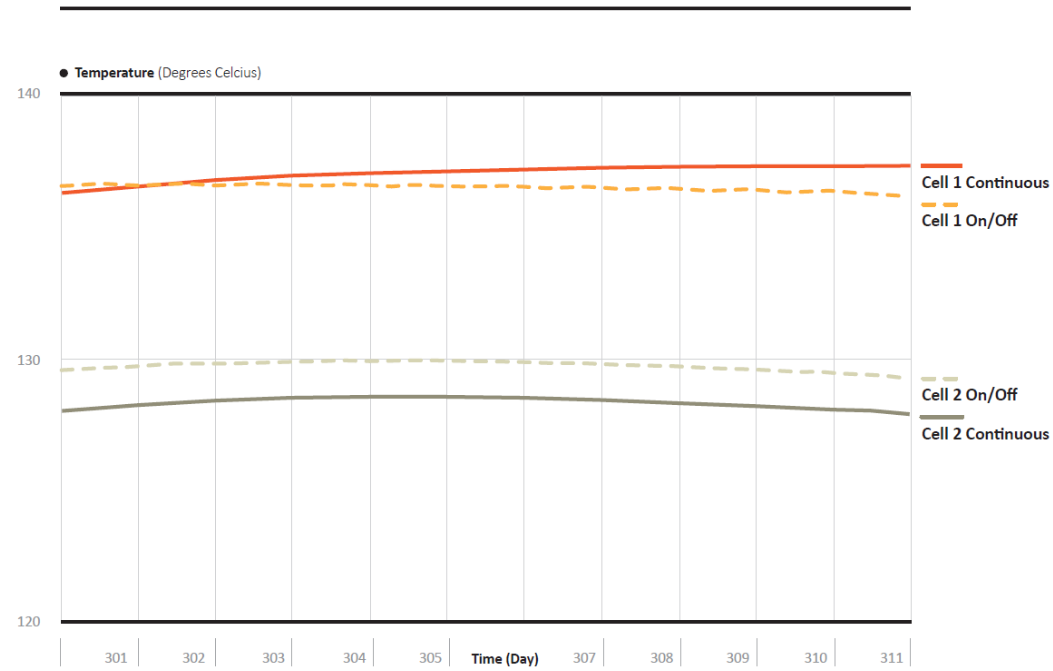

Figure 3.4: Temperature for continuous vs. intermittent heating at two locations in 12 hour increments

In summary, we believe the simulation results above demonstrate that it is viable to use intermittent renewable power in an RF XL project to achieve zero-GHG emissions from heavy oil and bitumen production. Delivering the same aggregate energy to the reservoir each day as would be delivered with continuous power should heat the reservoir to the same extent, and is expected to also produce the same amount of oil.

Simulation results demonstrate that RF XL plus intermittent renewable power can produce oil very effectively.

4. Solar Power Array Design and Cost Models

To achieve zero-GHG emissions from an RF XL production facility, a range of electricity sources were evaluated. First, consideration was given to traditional grid electricity. Two potential drawbacks were determined: (1) grid supply is not readily available at all target RF XL installation sites and (2) grid emissions intensities in most locations are too high to support zero-GHG production targets when used as the primary electricity supply source. Although geothermal and wind power could work in specific cases, solar is the most universally applicable for on-site zero-GHG electricity source. In addition, the production profile of solar power works well with RF XL's ability to utilize intermittent electricity supply.

On-site generation was considered with a focus on solar photovoltaics (PV), energy storage systems and conventional fossil-fuel-driven electrical generators. Although multiple renewable sources could be combined at site (such as wind and solar), this is typically impractical from the perspective of dispatch and grid connection sizing.

Photovoltaic solar was selected for this study due to flexibility and efficiencies.

Solar Photo Voltaic Design Considerations:

Solar PV all-in system costs have decreased while efficiencies have risen considerably over the last decade, making solar an economically viable option for on-site electricity production in relation to the cost of grid-supplied electricity. A particular advantage of the RF XL system is its ability to take large amounts of DC-coupled energy as generated from a solar PV system, lessening the need for an on-site generation system to offer constant electricity.

The output from a stand-alone solar PV system varies during each day, as well as seasonally. Some variation can be mitigated by oversizing the solar PV system - most commonly achieved by oversizing the DC components of the system. Although this results in the PV system effectively overshooting its target to avoid falling short, excess production could be stored on-site with an energy storage system or, as assumed in the Alberta scenarios in this paper, sold to the grid. The extent of seasonal variations in daily solar power generation in Alberta is shown below in figure 4.1.

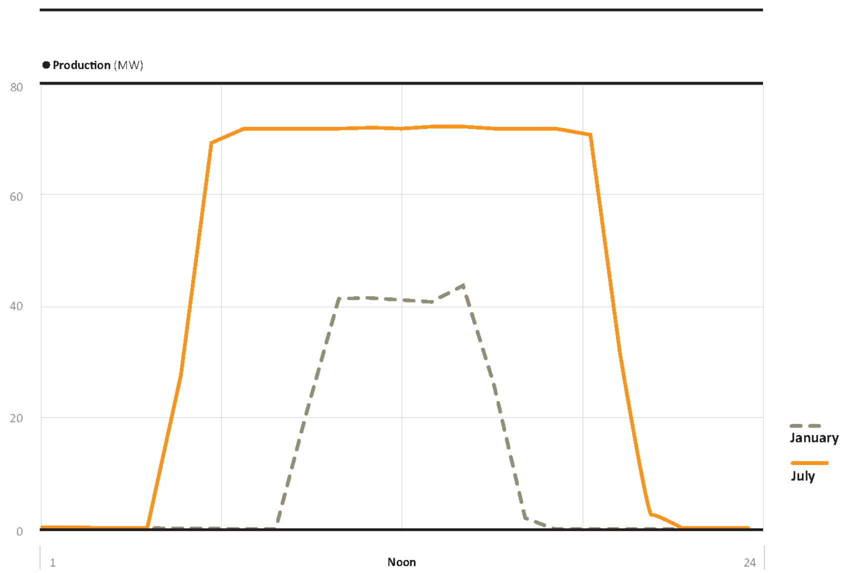

Figure 4.1: Seasonal daily power production comparison for Alberta

Seasonality of sunlight in Alberta requires a larger array to support total power needs in winter.

As sunlight intensity changes throughout the day, resulting in fluctuations in solar PV energy production, the RF XL system has some ability to withstand the resulting variations in electricity supply. Significant variation in solar PV production, however, could substantially lessen the annual production of the RF XL system, making some pairing of solar PV and at least one other supply (or energy storage) source more desirable than on-site solar PV energy production alone.

A range of energy storage systems were considered to store excess energy from the solar PV system to support RF XL operation during the nighttime and periods of low sunlight. While, like solar PV, the costs of energy storage have and continue to decrease considerably year-over-year, the capacity of an energy storage system required to support an oversized solar PV system and to provide on-site electricity supply with reduced fluctuation is considered too costly at this time to be a viable solution. Energy storage is likely to become a more viable solution as costs and performance continue to improve in coming years.

Consideration was also given to supplementing the solar power generation with conventional on-site fossil-fueled generation. Systems to integrate PV systems with dispatchable fossil-fuel sources are now prevalent, cost-effective and reliable. Inclusion of a fossil-fueled generator at site, however, works against the target for zero-carbon production from the RF XL facilities. While dispatchable fossil-fueled generators are technically and financially feasible, it is recommended that they be considered only for cases where grid-supplied electricity with a lower average emission intensity is not readily available.

It was concluded that on-site solar, supplemented with grid-sourced electricity at an average emissions intensity of 0.460 tonnes/MWh over the life of the project is the most feasible and cost-effective solution. By sourcing grid electricity, the option also becomes available to sell excess solar PV energy back to the grid, supporting achievement of the zero-GHG design target. The economic advantages in opting to operate the RF XL systems during periods of low pricing and to sell on-site solar generation at times of higher electricity market pricing were considered. This approach allows for: 1) the facility to offset all of its annual electricity consumption with renewable electricity production; and 2) the benefit of revenue diversity associated with electricity sales.

Solar PV Design and Performance:

The aforementioned solar PV design approach uses proven, commercially-available solar modules and racking. Where possible, RF XL loads would be served with DC supply from the solar PV arrays at 1,200 V, which can eliminate the need for excess inverter and rectifier capacities if there is no intention of selling the solar power to the grid. For AC loads, inverters have been sized for service from the solar PV system.

Consideration was given to the optimal sizing of the solar PV system. It was concluded that a 102 MW (peak DC capacity) system would provide for zero-carbon operation of the facility, including accounting for ancillary equipment consumption. It is also generally feasible to cost effectively export in the range of 100 MW to most existing transmission facilities with minimal system upgrades.

With this system sizing, the solar PV array would produce approximately 170,721 MWh in the first year of operation with around 140,000 MWh supporting the RF XL generators and the remainder serving the ancillary loads. This on-site generation therefore would meet the target of zero-GHG emissions for the combined facility. For the Alberta market, it was deemed most economical based on electricity market forecasts to generally sell solar electricity to grid at periods of favorable pricing and to source grid electricity to supply RF XL components during periods of off peak pricing. While RF XL can use a DC supply direct from the solar arrays, (reducing the amount of inverters and rectifiers required) the choice to sell all solar power to the grid for the Alberta means that equipment would be required regardless.

Connection to the grid can allow for excess solar power to be sold.

Economic Considerations - Solar:

A stand-alone solar PV system for the Alberta scenarios defined above is estimated to cost on average $1.20/watt (DC). The total installed capital cost for the PV system would be $122.7 million. The annual operational cost of on-site solar PV generation is low, estimated at $1.22 million in the first year of operation.

Installation cost savings are likely, given the solar PV system is planned for installation as part of the mobilization for constructing the RF XL facilities. The assumptions below were used to compare the financial performance of on-site generation. Construction of the solar PV system is estimated to take four months.

Economic Impact of Grid Connected Solar in Alberta:

Based on evaluating electricity market price forecasts, it is expected to be most profitable to export all on-site solar generation to grid during solar generation hours and to operate the RF XL equipment during off-peak hours using grid sourced electricity. This approach offers the added benefit of continuous planned operation of the RF XL system as compared to the potentially intermittent operation if run solely using solar electricity. The table (4.2) below compares the annual estimated cost of electricity used for RF XL to the value of solar generation sold to grid. It is clear based on review of the electricity price forecasts that in addition to meeting the zero-GHG emissions target, the on-site solar installation and grid connection also can improve the overall economics of a zero-GHG RF XL production project.

	Solar Power Generation	RF XL Power Needed
Total Energy in MWh	170,721	120,641
Power Cost in $/MWh	$ 67.76	$ 38.12
Gross Revenue (Cost) $MM	$ 12.2	$ (4.6)
Total Net Revenue	$ 7.6	

Table 4.2: Annual solar power generation and revenues vs RF XL grid power cost

Also in the Alberta-based example, the solar plant is designed to produce more power than is required for the RF XL process to ensure it can meet the full power required through the winter when production levels are lowest. By producing more total clean power than the RF project requires, this approach would create a carbon offset, or negative carbon heavy oil production.

Combining RF XL and solar power can allow operators to secure the lowest effective power cost by selling all available solar power to the grid at higher rates.

Regional Solar Comparison:

Although the open and competitive Alberta electricity market provides an ideal example of an RF XL oil production facility combined with on-site solar (capable of optimizing grid electricity sales, providing revenue diversity and improved oil market downside price protection), the relative value of solar improves with high solar irradiance and lower solar installation costs. To demonstrate these benefits, two other potential solar cases were compared to the Alberta case set out above. First a Bakersfield, California case was examined. Bakersfield is representative of a high irradiance continental US site in an oil producing region. Second, a Saudi Arabia solar case was considered in Eastern Ghawar, considered representative of a high irradiance, oil producing region of the Middle East. Table 4.3 below sets out the relative global horizontal irradiance (GHI) comparison of these three project locations.

Solar array costs per MW are lower in regions with higher solar irradiance.

Location	Type	MWdc	Meteonorm Annual GHI (W/m²)	Annual Energy (MWh)	GHI Delta vs Alberta (%)
Southern Alberta	single-axis tracker	100	1,400	167,000	
Bakersfield, California	single-axis tracker	100	1,894	214,142	28.2%
Eastern Ghawar, Saudi Arabia	single-axis tracker	100	2,117	235,422	41.0%

Table 4.3: Relative GHI and solar production for three project locations

Table 4.4 below sets out the relative anticipated capital costs of these three sample projects.

Location	Type	MWdc	Capex (USD, millions)	Capex vs Alberta (%)
Southern Alberta	single-axis tracker	100	$ 90.7	
Bakersfield, California	single-axis tracker	100	$ 82.4	-9.1%
Eastern Ghawar, Saudi Arabia	single-axis tracker	100	$ 65.9	-27.3%

Table 4.4: Capital cost for three sample projects of 100MWdc capacity at three locations

It is clear that the combination of higher solar irradiance and reduced capex can substantially improves the economic expectations of an RF XL powered by solar PV oil production project. The Eastern Ghawar, Saudi Arabia example shows substantial relative value improvements anticipated with higher irradiance and reduced installation costs.

In summary, while an RF XL oil and solar production approach is expected to be economical in Alberta, Canada, it would likely be even more so in the US and Middle East. For clarity, it has been assumed that in the California and Middle East scenarios, all power generated would be used for oil production, and so the size of the array can be scaled back to deliver only the power needed for the life of the project. Those locations are assumed to be grid connected such that the small amount of power required for nighttime operations of pumps and other processes can be supported by grid power, rather than adding the cost and complexity of battery storage. Battery storage in this case is uneconomical barring some specific capacity driver (it has to be off-grid, for example). This is true across all of the markets, however battery costs are falling rapidly, suggesting it may be worthwhile to review battery economics periodically.

Higher irradiance also allows for a smaller solar facility to support the 5,000 bbl/day RF XL project.

Table 4.5 below shows the actual power levels used for the economic models, and the associated anticipated capital cost for those solar arrays at the revised capacity levels.

Location	Type	MWdc	Capex (USD, millions)	Capex vs Alberta (%)
Southern Alberta	single-axis tracker	100	$ 90.7	
Bakersfield, California	single-axis tracker	78	$ 64.3	-29%
Eastern Ghawar, Saudi Arabia	single-axis tracker	71	$ 46.8	-48%

Table 4.5: Actual solar capacity and capital cost for examples used in the analysis

5. Pad-based Surface Facility Design and Economics

The flexibility and scalability of an RF XL well-pad-based surface facility design helps to address several of the issues that may be limiting investment in SAGD, CCS, or steam and solvent assisted processes. By utilizing Acceleware's RF XL technology, surface facilities could be reduced in size and scope since there is no longer a requirement for a steam plant, and associated water treatment is also eliminated. A pad-based design would essentially allow for a modular heavy oil processing facility that is directly integrated with well pad infrastructure. Of significance, the equipment modules are designed to maximize the flexibility of the facility layout so that each component can be re-deployed and re-used at future installations.

The following sections further detail the expected benefits of an RF XL pad-based facility design.

RF XL reduces surface facility requirements and allows for re-deployable, modular, on-pad processing facilities.

Process Design Philosophy and Assumptions:

While completing the analysis of the RF XL well pads and processing facilities, the following process assumptions were made:

1. Each well pad will contain 8 to 10 RF XL well pairs.
2. Total oil production from each well pad will be approximately 5,000 bbl/day with peak rates up to 6,000 bbl/day.
3. Each well life cycle is 6 years after which surface equipment is moved to the next pad development.
4. Produced water disposal takes place locally through injection wells.
5. Primary power source to RF XL pad is from local utility power grid.
6. All power generated from solar power plant is exported to the grid during the day offsetting the power consumption of the RF XL converters and processing facilities.
7. RF XL converters are operated up to 12 hours per day during evenings and nights.

Figure 5.1 below illustrates the proposed equipment layout in an RF XL pad-based facility design.

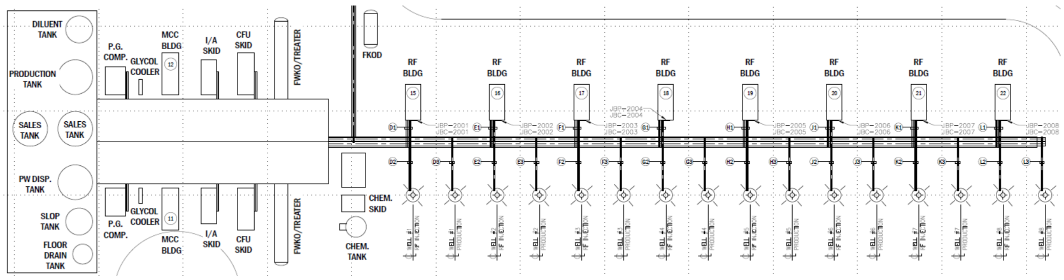

Figure 5.1: RF XL Pad-based Facility Design Plot Plan

The following sections provide additional details around the major process areas and the primary source of power in the RF XL pad-based design.

Well Pad Efficiency:

An RF XL well pad is expected to be more efficient than a traditional SAGD well pad, with the key difference being the source of thermal energy input to the oil reservoir, in this case RF XL's heating technology, rather than steam. As no steam is going to be created at surface, the overall produced emulsion volumes are reduced when compared to a traditional SAGD facility, and no additional water is being added to the reservoir. As a result, once the emulsion reaches surface, the size of the process piping can be smaller than a traditional thermal facility, reducing the overall environmental and emissions footprints and capital cost.

Processing Facilities:

Once the emulsion is transferred to the processing facility, the facility will operate in the same manner as a traditional thermal oil processing facility. The emulsion stream is cooled using glycol, and then the oil, water, and entrained gas that make up the emulsion stream is separated using a 3-phase free water knockout (FWKO)/ Treater processing vessel. From the FWKO/Treater vessel, the clean oil is cooled further and sent to storage where it can either be trucked out, or sent to a transfer station to be shipped via a pipeline.

As mentioned previously, the RF XL process does not require fresh water, so unlike a traditional thermal oil facility where produced water is supplemented with fresh water make-up and recycled in order to produce steam, RF XL technology would require no steam facilities.

Limiting surface facility requirements mean lower capex and material environmental benefits.

Power Distribution Design Philosophy:

Traditionally, utility power or on-site power generation such as natural gas or diesel generators are the primary source of power to the pad, though in some cases a combination of both is used for redundancy and emergency backup. The power is distributed to all buildings, modules, and electrical equipment on site through a main motor control centre (MCC) building that is located in a non-hazardous area of the pad.

Having a reliable power source is crucial to successful operation of a thermal reservoir and associated production facility, in particular at locations with extreme cold winter climate. Process equipment, building electric heaters, and lines which are heat traced require a dependable power source to avoid process interruptions and equipment freezing that could result in equipment damage. The design created for this project eliminates the need for on-site fuel gas power generators and provides a grid connection at the site as well as the solar array, providing high-reliability and zero emissions power for the pad operating loads.

On an RF XL well pad, each injection well would be equipped with a dedicated local RF electrical building that houses a 4MW RF XL Converter. Each building also consists of a local MCC, auxiliary transformer, and PLC panel with the ability to operate its designated injection and production well and manage it remotely through communication infrastructure. The production well pump and associated heat tracing for each well is fed from the local RF building, eliminating homerun cables and significantly reducing cable tray infrastructure and cost associated with tying in each well to the main pad MCC building. This design provides the ability to redeploy each RF building and associated wellhead electrical equipment to another location with minimal impact to existing infrastructure on the pad.

The power for the processing facility equipment will be fed from a single MCC building located in a non-hazardous area near the processing section of the pad. The MCC building for the RF XL well pad is much smaller than that of a traditional SAGD facility, as the size and number of equipment required at the processing facility is drastically reduced. This is because the electrical equipment associated with the production wells and piping is located within each individual RF electrical building. The MCC building is also powered through a dedicated AC feed from the utility grid.

A modular approach to power distribution maximizes the value of the surface facility by making it easier to operate, maintain, and move to another pad for continued production.

Economic Impact of the Pad-based Design:

A modular approach to well pad designs has resulted in the following benefits realized in traditional SAGD projects completed over the last 5 years:

1. Over 60 percent reduction in modular skid fabrication costs.
2. Over 40 percent reduction in on site construction costs.
3. A 50 percent reduction in on site installation timelines.

These results are shown graphically in Figure 5.2 below:

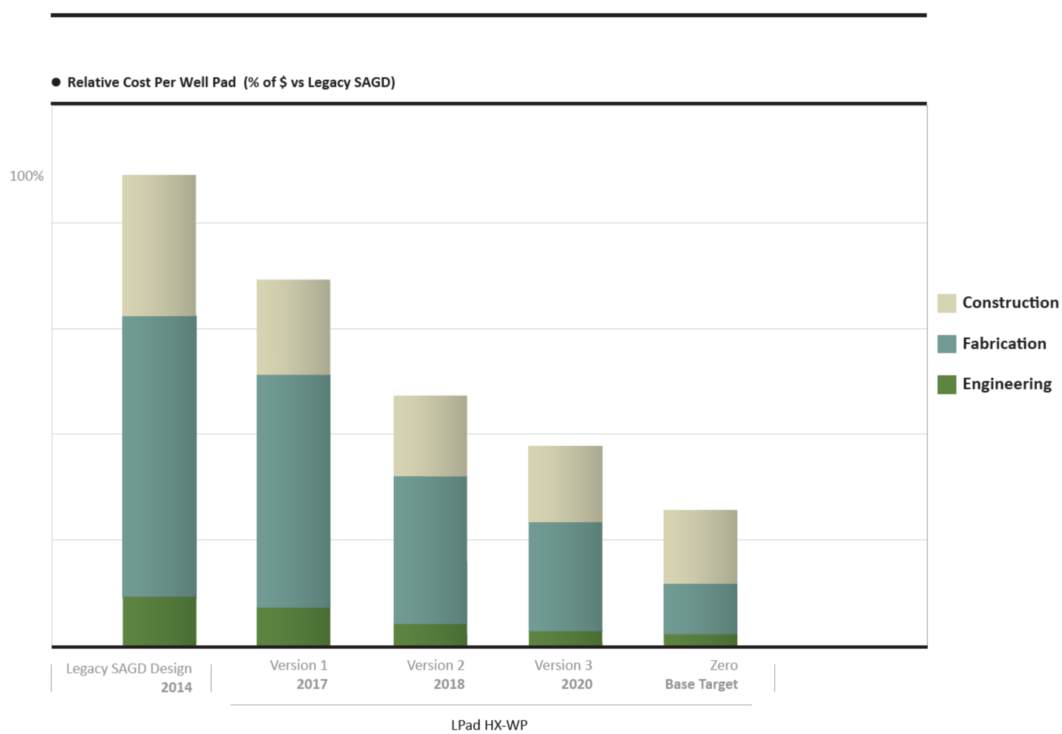

Figure 5.2: Relative Cost Impact of Modularization on Thermal Well Pads

The approach to engineering design and project execution that lead to the results in figure 5.2 are applied within the RF XL design. By taking advantage of the modularization and execution concepts already proven in the industry, Acceleware and Scovan can create a fit for purpose modular facility design that can be easily re-deployed to future well locations, reducing future capital expenses and execution timelines.

In addition to re-deployment opportunities, modularization improves timelines as well as costs.

Pad-based Capital Savings:

The RF XL pad-based design incorporates the same processing capabilities as a standard thermal oil facility. The surface facility capital costs used to complete this economic evaluation have been based on actual previous thermal project total installed costs. Major equipment costs have been factored, using oil production rate, to reflect the size required.

With the steam system eliminated from the process, the overall total volume of liquid produced by the wells should be reduced by 200 - 300 percent. As such, all the surface facility piping and equipment is smaller, further reducing the capital requirements of the RF XL pad-based design.

When compared to a traditional Alberta SAGD facility of similar size (5,000 bbls/day), the RF XL facilities design is projected to be 50 percent lower in up front capital cost. This correlates to a decrease in capital cost per flowing barrel of oil production by $17,276. Table 5.3 below highlights the estimate of the RF XL facility design compared to an equal sized greenfield SAGD development.

	RF XL	SAGD
Development Cost ($MM)	$ 88.6	$ 175
Cost per Flowing Barrel ($/bbl/d)	$ 17,724	$ 35,000
Percent Difference	-50%	-

Table 5.3: RF XL 5,000 bbl/day Pad-Based Facility vs. SAGD 5,000 bbl/day Facility

With a local fit for purpose RF electrical building design for each well, a significant capital cost savings can be realized with the reduction in major electrical equipment sizes, home run cables, cable tray infrastructure on the pipe rack modules, field electrical installation and a much smaller foot print for the process MCC building.

When considering the RF XL facility, the opportunity to redeploy capital equipment in the future provides a life cycle cost benefit when equipment can be re-purposed from produced reservoir to unproduced reservoir. Table 5.4 below provides an estimate of the capital requirements of installing a new RF XL pad-based facility compared to re-locating an existing facility design. The costs associated with the RF generation and facility electrical infrastructure are considered equal between cases and removed for clarity.

RF XL well pad facilities can reduce capex by an estimated 50 percent.

	Greenfield RF XL	RF XL Initial Relocation	RF XL Relocation
Civil Earthworks ($MM)	$ 2.5	$ 2.5	$ 2.5
Facility Equipment ($MM)	$ 35.6	$ 8.5	–
Teardown/Relocation ($MM)	–	$ 3.4	$ 5.8
New Site Construction ($MM)	$ 11.8	$ 11.8	$ 11.8
Total ($MM)	$ 49.9	$ 26.2	$ 20.1

Table 5.4: RF XL 5,000 bbl/day Facility Development vs. Relocation Costs

Pad-based Operating Cost Savings:

Within a typical SAGD facility, the water treatment and steam generation facilities are generally the most operationally cost intensive components of the facility. By removing these areas from the design, the facility natural gas consumption and greenhouse gas emissions are significantly reduced.

Because the steam generation facilities are removed, fuel gas consumption in the RF XL design is no longer required. For a 5,000 bbl/day SAGD facility with an SOR of 3.0, this equates to a potential savings of over $5.4 million a year. In addition to the operating savings, by removing the combustion of fuel gas from the facility, the design essentially eliminates the associated greenhouse gas emissions resulting in the removal of carbon taxes as an operating cost. This results in an additional $6.3 million in anticipated savings annually[6].

Furthermore, in the RF XL facility where the equivalent amount of electrical power consumed by the pad is generated by renewable source such as solar and then exported to the grid, the greenhouse gas emissions associated with the operation of the facility are expected to be reduced to zero, making the facility an environmental leader in recovering in situ heavy oil.

No steam generation facilities results in $5.4 million less per year in fuel gas consumption.

Re-deployment of Capital Equipment:

The Scovan approach to design and modularization allows for an owner to have the ability to deploy and re-deploy their capital equipment to locations based on how well reservoirs are producing, significantly improving the ability to re-deploy assets in the future. The compact facility modules have been designed to be standalone and have been structured to accommodate ease of lifting, as well as transportation. They have been strategically sized to prevent the need for any special permitting or restrictions in shipping times or high load corridors. Together with the turnkey RF XL electrical building, this design provides the owner flexibility in where the modules are located. An owner can re-locate a well pair module or RF electrical building to another well, or even another well pad, with minimal regulatory permitting or specialized transportation equipment.

[6] *These savings are based on a fuel gas cost of $2.5/GJ and a carbon tax of $50/tonne of CO2 emitted.*

The equipment foundation designs follow a modularization approach that allows for piled foundations to be installed in a new location and equipment simply moved and reset without any custom concrete or gravel foundation work. This reduces the time associated with capital equipment relocation, minimizing the time an asset is out of production during a re-location.

A clear advantage of the RF XL pad design is a modularized RF electrical building with local MCC and transformer that can supply power to each well electric submersible pump (ESP) and heat tracing loads. There is very little disassembly involved with the RF electrical building other than disconnecting cables such as incoming power feed, control system communication tie-in with the pad MCC building, and feeder cables to the ESP, heat tracing and any wellhead instrumentation. The building is on piles which can be removed upon cable disconnection and relocated to a new production site as required in a similar manner to the mechanical process skids. Cable trays designed and installed on pipe racks and skids come with splices at boundaries of skid edge, providing quick means for disconnection and relocation of cable trays on the skids minimizing reassembly time.

Modularization means that at blowdown, equipment can be re-deployed quickly and easily.

With the design considerations detailed above the disconnection and relocation can take place at an estimated 50 percent greater efficiency than when being installed. Once on site at the new location the re-assembly would have a similar schedule and cost to a greenfield facility, however, the estimated incremental equipment capital cost is greatly reduced. Furthermore, the time from commitment of capital to the initiation of cash flow is decreased in relocating an existing asset from a depleted reservoir to a new production area as no new long lead equipment needs to be procured.

The schedule can be shortened and schedule risk would also be mitigated as all major components would be available immediately upon relocation so assembly can be highly efficient. It is estimated the facility can be dismantled and prepared for shipment in 45 days and re-assembled on the new site in 90 days. This creates a 135-day window from shut in at the existing site to commissioning at the new site if all other site infrastructure is preinstalled before equipment relocation (civil, piles, drilling, etc.).

In order to ensure continued production during the transitions from one pad location to the next, the facility has been designed such that as the reservoir enters into the blowdown phase, the RF electrical equipment and 50 percent of the processing capacity equipment can be isolated and relocated while the declining reservoir continues to produce through the remaining facility components. During reservoir blowdown, the production volumes are expected to be less than 50 percent of the nameplate capacity of the facility which allows for any underutilized equipment to be relocated. Once the reservoir is depressured over a 9 - 12 month period, the remaining surface equipment can be relocated to the new development, bringing the total capacity of the new site location to the full 5,000 bbl/d. The operating strategy to support the efficient migration from one pad to the next is described in more detail in section 5.

Capital Intensity for Pad-Based Design vs Central Processing Facility:

Throughout the sections above, the potential benefits of the RF XL pad-based design have been discussed. They are intentionally modular so that they can be scaled or located in the best production areas. However, due to economies of scale, if a project is large enough to install multiple pads, at a certain point there will be economic advantages to centralizing the processing facilities. At this stage, it could be less capitally intense to purchase and install larger equipment at a central facility, rather than duplicating smaller process equipment at each well pad.

The economic evaluation completed for this section is based on the same design assumptions discussed in section 5 above, except that the well pads and processing facilities are to be located separately. As such, additional infrastructure such as a CPF lease, surface pipelines and roads are required. For the purposes of this evaluation, the following assumptions have been made:

1. Well pads are located approximately 2 km from the CPF (or each other).
2. Facility costs have been ratioed based on oil production capacity, and a factor of 0.7 has been used to account for economies of scale.
3. Well production declines have not been accounted for.
4. Similar to the facility costs, actual previous project costs have been utilized and factored to generate the estimated cost per km of surface pipelines.
5. For clarity, the costs do not account for the RF electrical infrastructure.

Figure 5.5 below details the estimated capital cost for both scenarios vs the number of well pads.

A pad-based design has lower capital cost than a CPF for up to two concurrent pads (max 10K bbl/day).

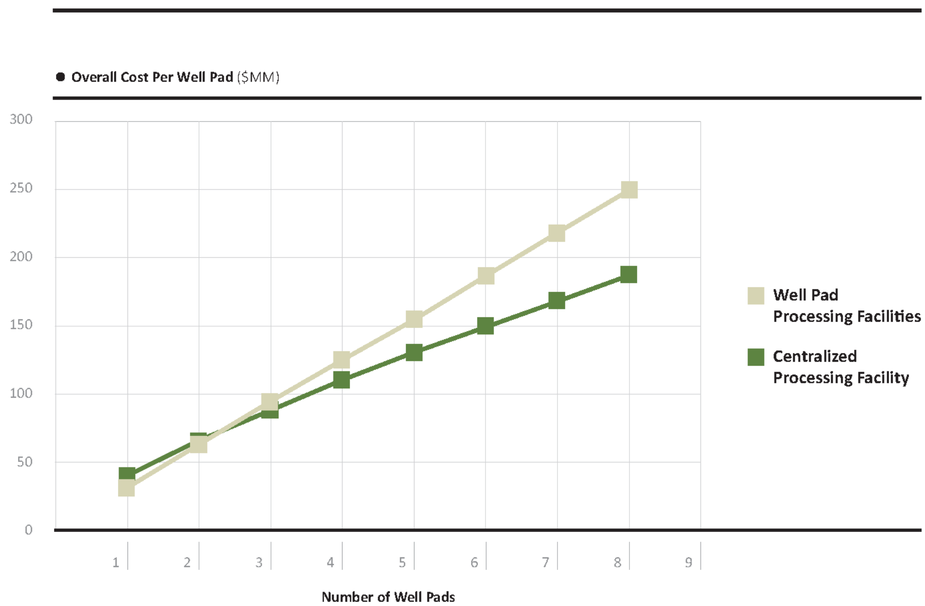

Figure 5.5: Cost Comparison of RF XL Vs. Central Processing Facilities for Multiple Well Pads

As the number of well pads increases, the results of the cost evaluation show that the cost advantage to centralize the processing facilities is expected to grow, despite requiring additional infrastructure to do so. Based on the results of the study, if three or more well pads are planned to operate simultaneously, it would be less capitally intense to utilize a centralized processing facility. This highlights the competitive advantage of the RF XL pad-based design in development areas that are not able to support larger scale multi-pad developments, or when operators are capital constrained.

A CPF based approach is more cost effective for three or more concurrent 5,000 bbl/day pads.

6. Solar Pad-Based RF XL Operating Plan

The use of the pad-based surface facility design should provide numerous economic, environmental, and operating advantages, though some operational adaptations are needed to optimize those results. Ensuring the design can support the 'leap-frog' approach - whereby, at reservoir blowdown some equipment will be re-deployed from the first pad to a second pad, and initial production at the second pad can begin before pad one has finished production - is critical.

Operations can be tailored to optimize economics when migrating from pad to pad.

Operating procedures would be implemented to maximize total production from the project and minimize the duration of any periods of lower production associated with the shift from one pad to the next. The processing facility has been designed using two 2,500 bbl/day systems to support the peak production level of 6,000 bbl/day expected on each pad. The dual facilities will allow one of the two systems to be migrated to the next pad as production on the first pad begins to decline. The new pad can begin operating while relying on the single 2,500 bbl/day facility, and the old pad can finish producing using the other 2,500 bbl/day facility. Operating procedures that differ from typical thermal projects include the following activities which will occur once production begins to decline:

1. RF XL converters will be removed from the operating pad as production begins to decline and installed at the next pad to begin heating and production there.
2. At the same time, non-compressible gas (NCG) such as methane will be injected into the wells on the operating pad to maximize production from the heated reservoir once the RF XL units have been removed.

The timing and impact of this approach on production is indicated in figure 6.1 below which shows the original simulated production curve (maximum oil rate of 630 bbl/day, no injection of NCG and no removal of the power systems), compared to the new simulated curve with;

1. Oil production limited to 380 bbl/day max per well for 270 days to allow time for the second 2,500 bbl/day processing system to be transitioned from the previous pad.
2. Relaxed production limits during the plateau, resulting in a new peak of 756 bbl/day.
3. The addition of NCG injection and removal of the power system at 1,260 days.

The revised curve shows a recovery factor of 54 percent which is considered realistic for a thermal project in this hypothetical reservoir. Reservoir properties and details of operating conditions, well length, etc. are shown in Appendix 1.

4 MW Base Case Simulation vs. 4 MW Operating Case

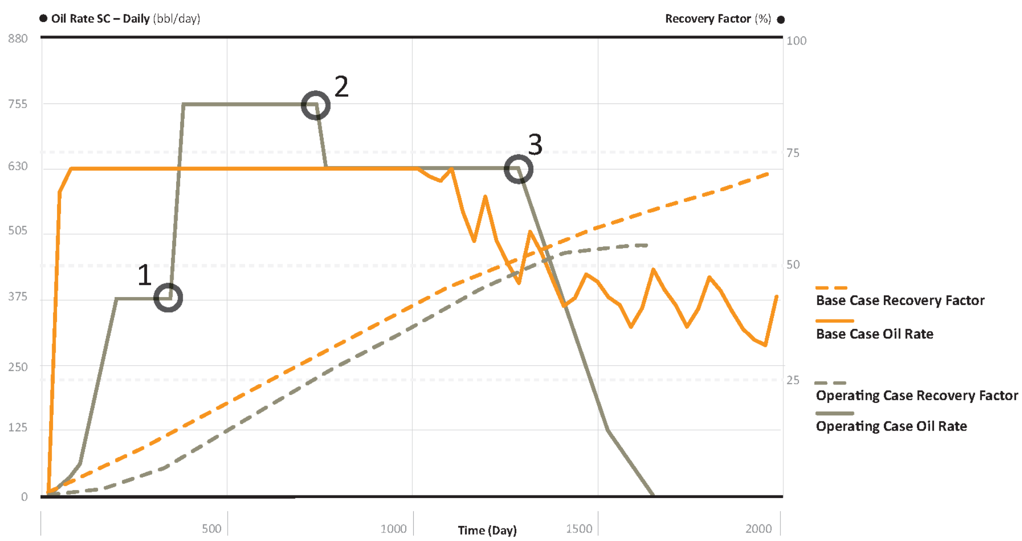

Figure 6.1: Adjusted production curve to accomodate pad-to-pad migration

To maximize efficiency and economic performance, the planned timing of well completion has also been managed to better fit within the maximum capacity of the dual 2,500 bbl/day processing system, as well as to account for the operational realities as components are being removed and reinstalled at the next pad. Figure 6.2 below shows the timing and number of wells drilled, along with total production compared to the capacity of the pad-based plant.

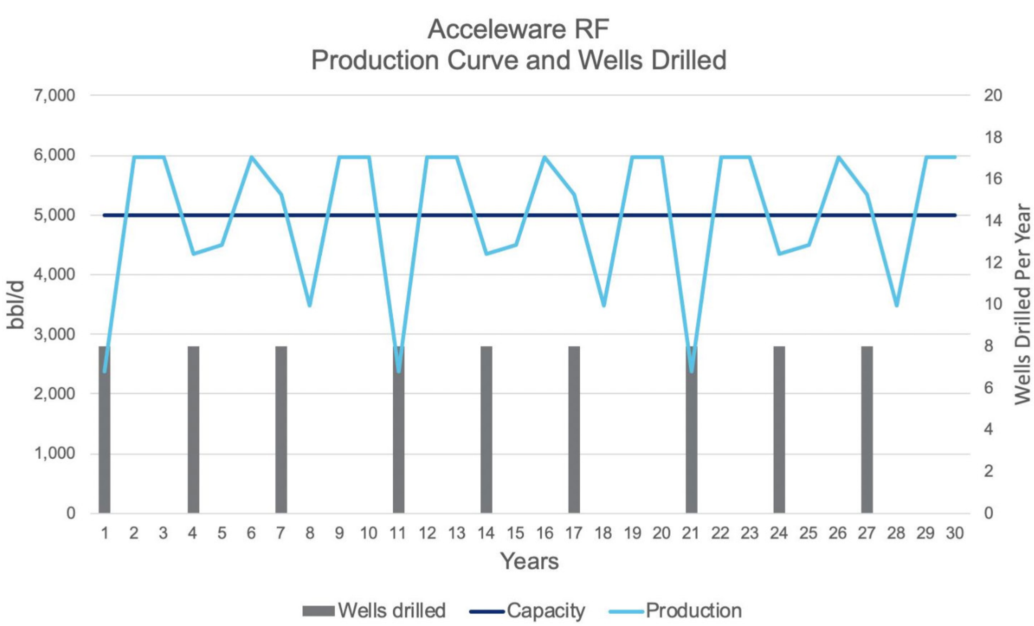

Figure 6.2: Project schedule for pad development and capacity utilization

Production volumes and drilling programs are managed to maximize the utilization of the capital assets.

7. Environmental and Economic Results

The potential to economically produce zero-GHG heavy oil makes RF XL's environmental impacts transformative, especially when paired with elimination of fresh water and reduced surface facility requirements. Expectations of material cost reductions, quick turnaround and the ability to easily re-deploy capital assets, make clean powered RF XL deployments a standout consideration for future reservoir production.

Zero emissions from production, no fresh water, a smaller footprint for the oil production facility, and low costs demonstrate strong ESG performance.

GHG Emissions Reduction and other Environmental Benefits:

An Alberta RF XL deployment relying only on grid power for production is expected to initially generate an approximate 25 percent reduction in carbon emissions compared to a natural gas fired SAGD project in the same reservoir, increasing to an estimated 50 percent as the Alberta grid retires coal-fired power plants to reduce emissions intensity by 2030. However, all solar powered deployment scenarios would operate at zero-GHG emissions for heating and production. The Alberta solar-powered RF XL scenarios studied herein would actually produce more zero emissions power than they consume, and so they could even create a negative carbon scenario or carbon offset opportunity. Solar plants for the California and Saudi Arabia scenarios, on the other hand, are designed to use all of the solar power generated in the RF heating process to achieve zero emissions production.

As is the case for RF XL in general, no external water would be required for the production process. A comparable 5,000 bbl/day SAGD project operating with a SOR of 3.0 would require 2.3 million litres of water per day, of which 14 percent or 334,000 litres per day is make-up water. As such, RF XL would reduce the requirement for make-up water by 122 million litres per year.

Removing steam distribution and produced water recovery systems results in a more compact module design and lower capacity processing equipment, resulting in a smaller facility footprint. Since the processing facility has been incorporated at the pad location as part of the design, the need for surface gathering pipelines is also removed. The smaller overall footprint would reduce the environmental disturbance associated with the development initially, and minimizes reclamation at the end of the project's life cycle.

Integrated Economic Model of a Pad-Based Solar Facility:

We compared five different pad-based scenarios as shown in table 7.1, the first three of which are Alberta based, and show the expected impact of using grid power versus solar, and the anticipated benefit of using long term debt to cover some of the capital cost of the solar plant. We have shown a scenario where a debt facility of $70 million is put in place on a 30 year term with 5 percent interest.

This low-interest debt is an option because of the perceived stability of the solar revenue stream resulting from selling power to the grid, which helps to improve the economic performance of the combined RF XL solar project. The table also shows California and Middle East solar scenarios.

Greenfield 5K bbl/day Project Location	Alberta A	Alberta B	Alberta C	California	Middle East
Power Source	grid	solar	solar	solar	solar
Leverage ($MM)	$ 0	$ 0	$ 70	$ 0	$ 0

Table 7.1: Pad-based project scenarios used in economic analysis

Table 7.2 shows details of the capital intensity and capital investment for each scenario. It clearly shows how the regional improvements in expected solar performance in California and the Middle East affect the capital intensity and (as shown in table 7.3) the economic performance. Details on the relative power capacity and capital cost of the solar array designed for each of the three locations are shown in table 4.5

Greenfield 5K bbl/day Project Location	Alberta A	Alberta B	Alberta C	California	Middle East
Initial Capital Intensity ($/bbl/d)	$ 17,724	$ 40,862	$ 28,554	$ 35,070	$ 31,255
Processing Equipment ($MM)	$ 51	$ 54	$ 54	$ 54	$ 54
RF XL Converters ($MM)	$ 20	$ 40	$ 40	$ 40	$ 40
Well Capital ($MM)	$ 51	$ 51	$ 51	$ 51	$ 51
Power Generation ($MM)	$ –	$123	$ 53	$ 86	$ 63
Total Capex ($MM)	$ 122	$ 268	$ 198	$ 231	$ 208

Table 7.2: Capital intensity per flowing barrel and project capital

The full set of economic assumptions related to oil prices for WTI and WCS, grid power costs in Alberta, interest rates, discount rates, etc. are shown in Appendix 2. The economic model for all of the pad-based scenarios captured in this paper rely on the same type curve and production profile as shown in figures 6.1 and 6.2.

Not only does deployment of solar power plus RF XL require less capex than SAGD, but it also reduces opex by 40 percent versus RF XL without solar, and 60 percent versus SAGD.

Operating Cost Overview:

Table 7.3 shows the operating cost per barrel expected for each scenario. The anticipated operating cost at the California and Middle East locations decreases marginally due to the reduced size and cost of the solar array required to generate the power required for the RF XL system. The grid powered deployment in Alberta is calculated using a power cost of $60.00/MWh which is an Acceleware estimate based on a long-term curtailed power purchase agreement.

Greenfield 5K bbl/day Project Location	Alberta A	Alberta B	Alberta C	California	Middle East
Power Opex ($/bbl)	4.62	0.91	0.91	0.71	0.47
Non-Power Opex ($/bbl)	4.01	4.01	4.01	4.01	4.01
Total Opex ($/bbl)	$ 8.62	$ 4.92	$ 4.92	$ 4.72	$ 4.48

Table 7.3: Operating cost breakdown

Economic Performance:

Table 7.4 shows the anticipated 30-year economic performance of all of deployment scenarios evaluated. Unless otherwise noted, the analysis uses a 10 percent discount rate. The full set of assumptions and commodity prices can be found in Appendix 2.

Utility projects typically provide an economic return rate of 7.5 – 10 percent, while heavy oil projects bring a higher level of risk and higher rates of return that are generally greater than 10 percent. The scenarios evaluated in this paper combine a heavy oil project with a solar power plant. We anticipate that these hybrid projects will provide a rate of return (and risk) that falls between the two stand-alone scenarios described above once the operating approach has been optimized to support the migration of production from one pad to the next.

In addition to the lower capital cost required to build the solar array in the California and Middle East scenarios, they also benefit from a higher oil price due to the expected absence of a 'differential' in those markets. The model assumes a $17 CAD ($12 USD) differential between WTI and WCS. The Alberta scenarios would see a price of ~ $50 CAD before transportation costs where the California and Middle East scenarios would receive $67 CAD ($50 USD) per barrel.

Greenfield 5K bbl/day Project Location	Alberta A	Alberta B	Alberta C	California	Middle East
IRR	17%	14%	14%	33%	39%
NPV ($MM) @ 10%	$ 33	$ 48	$ 79[7]	$ 229	$ 246

Table 7.4: NPV and IRR

[7] *The levered scenario uses a weighted average discount rate of 8.8%.*

RF XL plus solar is profitable in all examples at US$50 WTI.

To explore the full potential value of selling the solar power to the grid, an additional scenario exploring the impact of oil prices dropping to US$20 or lower in year 15 of the project was put together using the same designs and assumptions as the cases above. In this analysis, we focus on Alberta sites only since we have assumptions around the grid sales revenue from the solar plant in place. The results compare the estimated NPV and IRR for a grid-powered pad-based project with those for a pad-based solar project. While all of these scenarios would stop producing oil after the price drop, the ability to pivot and sell all power to the grid for the last 15 years of the project would provide a hedge against such a drop in commodity prices. While the grid powered project has an expected NPV of negative $5 million, the two solar powered scenarios salvage positive returns as shown in table 7.5. The effect of the hedge highlights the ability for RF XL to play an important role in the expected energy transition by allowing an operator to shift from oil production to electricity based on market conditions.

RF XL plus solar creates a hedge against oil price crashes.

Greenfield 5K bbl/day Project Location	**Alberta A**	**Alberta B**	**Alberta C**
IRR	n/a	12%	12%
NPV ($MM) @ 10%	$ (5)	$ 15	$ 38[8]

Table 7.5: NPV and IRR for Alberta scenarios with oil price (WTI) dropping to US$20 in year 15

In summary the potential economic impacts of incorporating a solar power source in an RF XL project would be:

1. Initial capital costs are $150 million higher compared to a grid power only scenario.
2. The perceived stability of the revenue stream from solar electricity could allow operators to secure lower cost debt for the project where a stand-alone heavy oil project would typically have to rely on equity and higher cost debt that in aggregate carry a higher weighted average cost of capital.
3. The very low operating cost for solar power provides a hedge against future increases in the cost of power which could impact rates of return in a grid power only scenario.
4. The solar power investment would provide a hedge against declines in the price of oil because it allows operators the flexibility to reduce or stop oil production and focus on electricity sales.

[8] *The levered scenario uses a weighted average discount rate of 8.8%.*

8. The Path to Zero-GHG Emissions Deployment

The examples presented in this white paper demonstrate scenarios where zero-GHG heavy oil production is both possible and profitable through modernized and transformative technology. The expectation is that industry will recognize the multiple benefits in pursuing zero emissions development and production of oil reserves via electrification, whether for fossil fuels while demand continues, or to support future production of clean hydrogen, asphalt, carbon fibre, or rare elements. The creation of a high-tech method that can cleanly create valuable products from oil sands and heavy oil deposits could reinvigorate Canada's energy sector, and position Canada to be a leader in clean energy and high value products in a low-carbon future.

While this paper shows a viable and profitable approach to produce heavy oil with zero emissions, the authors would like to acknowledge that there are a number of ways that the performance as described here could be improved in an actual deployment:

1. Additional optimization of the production rates and configuration of the pad-based design.
2. Pursuing a hybrid of solar and wind or other renewables sources in Alberta to increase the effective capacity factor and reduce the cost per MWh of renewable power for a project.
3. Achieving zero-GHG production at lower cost in Alberta through offsets by placing a solar (or wind/hydro/etc.) generation facility in an optimal area for production such as California or the Middle East.
4. Pursuing a larger scale (gigawatt) approach to renewable power for Alberta, supporting oil production during off peak periods and filling the growing need for clean power during peak periods.

Acceleware, Scovan, and Canadian Solar hope that this paper will help to stimulate discussion and facilitate the transition to a low-carbon future by showcasing several profitable zero-GHG-emissions heavy oil production examples. While these examples do not cover all the possible production scenarios in Alberta or other oil producing regions in the world, they show that zero-GHG production is a practical and profitable possibility in the immediate future.

RF XL technology can profitably provide zero or near zero-GHG emissions production of fossil fuels and by-products, such as petrochemical feedstock for plastics, asphalt, carbon fibre, hyrdogen, and rare elements.

Appendix 1

Reservoir Properties and Operating Conditions

Acceleware has completed numerous simulations over the past 10 years to predict oil production rates and energy efficiency levels when using RF XL to heat and produce from a wide range of heavy oil and oil sands deposits in Canada and around the world. The table below shows high level results for the amount of energy required per well to produce a commercial level of oil from reservoirs of different types (viscosities). The lower viscosity of heavy oil reservoirs compared to oil sand / bitumen deposits results in a lower amount of energy required to mobilize and produce the oil from those deposits.

Parameters	Oil Sand	Heavy Oil
Viscosity	> 1,000,000 cp	10,000 cp – 60,000 cp
Net Pay	10 – 30m	5 – 15m
Porosity	27 – 33%	27 – 35%
Permeability: Vertical	2 – 4D	2 – 4D
Permeability: Horizontal	3 – 5D	3 – 7D
Oil Saturation	0.7 – 0.85	0.7 – 0.85
Depth	>100m	>100m
Power Requirements/well	4 – 6 MW	2 – 4 MW

The comparatively lower power requirement for heavy oil reservoirs makes it easier to use intermittent power sources. The analysis for this paper is based on a heavy oil reservoir and RF XL well sets with the properties defined below.

Reservoir Properties	
Initial Viscosity	60,000 cp
Net Pay	15 meters
Porosity	34% average
Permeability: Vertical	3.25D average
Permeability: Horizontal	6.5D average
Oil Saturation	70% average
Depth	625 meters
Initial Pressure	4,500 kPa

Operating Conditions	
Horizontal well length	770 meters
Well spacing	81 meters
BHP in producer	500kPa
Max oil rate	750 bbl/day
Power injected	2 MW 12 hours a day (first 20 days) then 4 MW 12 hours a day (48 MW hours per day)

Appendix 2
Financial and Operating Assumptions

Units	Units	Value
1 GJ =	kWh	278
1 GJ =	MWh	0.278
1 kWh =	BTU	3409
1 m3 =	Bbl	6.2898
1 GJ =	BTU	947702
1 mcf =	mmBTU	1.037

Commodity Prices & Currency	Units	Value	Source
WTI	US$/bbl	$50.00	PSAC/FirstEnergy (avg 2017)
WTI-WCS	US$/bbl	$12.00	PSAC/FirstEnergy (avg 2017)
AECO Natural gas price	C$/mcf	$2.50	PSAC/FirstEnergy
AB Grid power price, 25 years, Curtailed	$/MWh	$60.00	Acceleware Estimate
1 USD =	CAD	$1.34	Bank of Canada

CO2 Intensities	Units	Value	Source
Average Alberta Grid (2021 Est.)	t/MWh	0.54	Source: IPPSSA
Average Alberta Grid (2030 Est.)	t/MWh	0.37	Source: IPPSSA
Nat Gas Combustion	Kg Co2 / mmBTU	53.12	EIA
Nat Gas Combustion	t/GJ	0.05	Acceleware Estimate

Operating Cost Savings	Units	Value	Source
Fuel Gas Consumption	GJ/m3 steam	2.5	Scovan
Facility Size	Bbl/day	5000	Scovan
Steam Oil Ratio for SAGD	SOR	3.0	Scovan
Steam generated for SAGD	m3/day	2385	Scovan
Fuel Gas Consumed for SAGD	GJ/day	5962	Scovan
Fuel Gas Cost Per Year for SAGD	$ CAD	$5,440,182	Scovan
Carbon Tax	$/tonne CO2	$50	Scovan
LHV Natural Gas	MJ/kg	47.1	Scovan
Amount of Natural Gas for SAGD	tonne/day	126.6	Scovan
Mole Weight of Natural Gas	Kg/mol	19	Scovan
CO_2 Emission	Kg CO2/kg CH4	2.75	Scovan
CO_2 Emission for SAGD	tonne/day	348	Scovan
Carbon Tax Cost for SAGD	$/year	$6,352,655	Scovan

Economic Modeling			
Discount Rate for IRR and NPV Calculations	%/year	10%	Acceleware
Interest Rate for Debt for Solar Capital Cost	%/year	5%	Acceleware
Weighted Average Discount Rate for Alberta Solar Project with Debt	%/year	8.8%	Acceleware