High Temperature ESPs for Geothermal Production: The Ideal Pump

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ABSTRACT

The need for a robust pumping system capable of operating in the challenging conditions presented in geothermal production wells has been identified as a critical piece of equipment for the advancement of geothermal energy utilization. In typical geothermal operations, establishing and maintaining a high production rate at high temperatures is critical to the economic viability of the project. Electrical Submersible Pumps (ESPs) have significant advantages over other commonly used pumping systems in geothermal operations, and have the potential to enhance the production of geothermal wells.

ESP systems are currently available that are capable of handling high operating temperatures; however, these systems are limited in their power output, reliability, and production rate. Conversely, higher power ESP systems are available; although, their allowable operating temperatures are significantly lower than their high temperature counterparts. There appears to be a technology gap marrying high operating temperatures with high power outputs that limits the value of ESPs in the geothermal industry. The design of an ESP system capable of meeting these requirements may be a significant market opportunity, and may spur the advancement of geothermal energy utilization. Many of the challenges posed by the high temperature conditions experienced in a geothermal production well have also been faced by ESP manufacturers designing systems for thermal Enhanced Oil Recovery (EOR).

This paper summarizes the current state of available high temperature ESPs, the typical artificial lift requirements for geothermal operations, and the ideal economic and technical parameters of
ESP systems for use in geothermal operations. Using this information, existing gaps in ESP capabilities for widespread adaption to the geothermal industry have also been highlighted.

1. Introduction
In order to advance the use of geothermal energy as a renewable resource worldwide it is critical to increase the economic viability of geothermal projects. A robust pumping system capable of operating under these challenging conditions has been identified as a critical piece of equipment for the advancement of geothermal energy production (Molloy (2009); Idaho National Laboratory (2006)). In geothermal production wells that require Artificial Lift (AL) the most common systems currently used in the industry are Line Shaft Pumps (LSPs). LSPs are reliable at high temperatures and are well proven for geothermal use; however, their design typically limits their power output (and therefore flowrate potential) and use in deep or deviated wells.

Electrical Submersible Pumps (ESPs) have been identified as the most promising alternative to LSPs for both hydrothermal systems and Enhanced Geothermal Systems (EGS) (Molloy (2009); Turnquist et al. (2013)). Recent advancements to ESP technology have focused on increasing the maximum operating temperature and system reliability in harsh environments, and have brought these systems closer to suitability in geothermal conditions. Despite these advancements, a significant technology gap remains between the capabilities of current ESPs and the "ideal" pump requirements of the geothermal industry.

The advancement of ESPs to become ideal AL systems for geothermal operations is not only a technical challenge, but an economical one as well. Current high temperature ESP systems were generally developed for thermal Enhanced Oil Recovery (EOR) operations, which differ in their operating requirements, but may follow a similar development strategy for geothermal energy production; suggesting that opportunities for information sharing between these industries currently exists.

2. High Temperature Artificial Lift Applications
2.1 Hydrothermal Operations
Hydrothermal resources naturally contain water, heat, and permeability, which are the main components required for geothermal energy production. Production wells for these hydrothermal resources can typically be categorized into either naturally flowing (artesian) or pumped (non-artesian) wells (Van't Spijker and Ungemach (2016); Sanyal (2005)). In either of these circumstances, the main components critical to maximizing energy generation are fluid production temperature and flowrate. Reservoir temperatures in geothermal systems typically vary from 150°C to 330°C (Dobson et al. (2017)). Reservoirs with higher temperatures (above 190°C) are generally associated with artesian wells (Sanyal (2005)) and do not require pumping systems; however, there are AL systems that operate in geothermal wells as hot as 220°C (Molloy (2009)). The nature of production fluids at these temperatures may also generate significant flow assurance issues, such as scaling or corrosion (Finger and Blankenship (2010)).
Production rates from wells in non-artesian hydrothermal systems vary greatly depending on the reservoir characteristics and setting depth of the pumping system. A flow rate of 60-80 L/s for AL systems in hydrothermal production wells has been a target in previous studies (Molloy (2009)); however rates of over 300 L/s have been achieved with AL systems. Another approach to characterizing the performance of AL systems (i.e. while taking other considerations such as setting depth into account) is to consider power output. Current LSP systems used in geothermal production wells have a maximum power output of approximately 1500 HP. The setting depth of AL systems is largely dictated by reservoir pressures, where a deeper setting depth will necessitate higher pumping power to maintain high flow rates, and eventually exceed the power capacity of LSPs.

2.2 Enhanced Geothermal Systems (EGS)

Energy production from EGS also requires the use of AL systems. Though this method of geothermal energy production is not yet widely used, ongoing projects such as the Frontier Observatory for Research in Geothermal Energy (FORGE) (FORGE (U.S. Department of Energy)) may spur the future advancement of EGS worldwide. This would further increase the demand for AL systems capable of operating in geothermal operations. Therefore, though EGS may not be currently widespread, it may be a significant future consideration for "ideal" AL systems.

As EGS facilities are high capital investments, the production requirements to make such a facility economically feasible are also higher than hydrothermal sources. Past studies have indicated that EGS production wells will need to be capable of producing fluid at temperatures of up to 300°C and rates in excess of 80 L/s (Turnquist et al. (2013); Qi et al. (2012)). As EGS production wells are typically drilled significantly deeper than hydrothermal systems, the resultant power requirements for AL systems would also be higher than that for hydrothermal systems (Turnquist et al. (2013)).

2.3 Thermal Enhanced Oil Recovery (EOR) Methods

Oil sands, such as those found in the provinces of Alberta and Saskatchewan in Western Canada, are hydrocarbon resources comprised of extremely viscous bitumen that require specialized methods of production compared to conventional oil reserves. To extract these hydrocarbon resources, operating companies with oil sands assets have developed a range of EOR methods such as surface mining and in-situ thermal production. In-situ thermal production requires the use of high temperature AL systems to effectively produce the hydrocarbon resource.

While there are a number of in-situ thermal production processes that have been developed by the oil and gas industry, two of the most common processes are Cyclic Steam Stimulation (CSS) and Steam Assisted Gravity Drainage (SAGD); where ESP systems are commonly used in both of these processes.

In the CSS process, high temperature saturated steam of up to 340°C (Graham et al. (2017)) is injected into the reservoir. The well is then shut-in to allow the steam to permeate (or “soak”) through as much of the reservoir as possible. After the steaming and soaking process, the condensed steam and reservoir fluids are produced through the same well. Production fluid temperature varies; however, the flow is typically controlled such that the wellhead temperature
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is maintained under 200°C (Ascanio et al. (2006)). Production flow rates for a typical CSS well also vary depending on the reservoir characteristics; however, the average CSS well in Alberta produced only 0.105 L/s in 2017 (AER (2018)). CSS wells may be vertical, directional or horizontal, depending on the operator's requirements. These wells are often drilled in rows or a set pattern to allow for continuous steam injection and fluid production from the same reservoir.

Alternatively, in SAGD, two wells are drilled in parallel and run horizontally through the reservoir, with the injection well positioned approximately five meters above the production well. The upper well in the pair injects saturated steam at up to 290°C, which creates a steam chamber in the reservoir and mobilizes the bitumen. The lower well in the pair is the production well, which collects the heated, mobilized bitumen so it can be pumped to surface. The downhole temperature that AL systems would be subjected to in SAGD operations may be in excess of 240°C (Graham et al. (2017)). Figure 1 shows a schematic of a SAGD process for reference.

As with CSS, SAGD production rates vary with well characteristics; however the average SAGD well in Alberta produced only 0.997 L/s in 2017 (AER (2018)). Similarly to CSS, SAGD well pairs may be pad-drilled near each other to maximize mobilization and production from a single reservoir.

2.4 Comparison of High Temperature Applications

It is apparent that while both hydrothermal and thermal EOR production have similar requirements for production fluid temperatures, the flow requirements are significantly different.
Geothermal energy production relies on significantly higher flow rates than in-situ thermal oil production to be economically viable. While EGS is not yet a widespread energy production method (like EOR or hydrothermal) it may be a significant resource in the future and also warrants consideration. Pumping requirements for EGS are even more demanding than those for hydrothermal systems, and serve as a further stretch goal for AL system development.

3. ESP System Overview

ESPs are used in a wide variety of conditions including conventional hydrocarbon production and thermal EOR methods. As such, ESP manufacturers have responded to this demand by creating multiple designs and configurations. For example, for relatively low operating temperatures (under 150°C) ESP systems with power capabilities extending beyond 2000 HP are available, while high temperature ESP systems capable of operating at temperatures in excess of 250°C are also available and used in the thermal EOR market.

3.1 Current Availability of High Temperature ESPs

For high operating temperatures, manufacturers offer high temperature ESP systems; however, their power output is typically limited. Table 1 shows a summary of some commercially available high temperature ESP systems with operating temperatures of 190°C or higher.

As shown in Table 1, high temperature ESP systems typically have maximum temperature, power, and flow rates that are consistent with the requirements of thermal EOR production.

3.2 Reliability of ESP systems

Aside from performance, reliability is another key consideration for any pumping system. ESP reliability can be affected by a wide range of factors, including: equipment sizing and selection, well inflow performance, operating temperature, solids, gas, and corrosion (Turnquist et al. (2010)). Typical ESP systems in the oil and gas industry may be expected to run for two to three years depending on their operating conditions. Some systems operate much longer but ESP systems subjected to high operating temperatures (i.e. during SAGD operations) generally have reduced run-life (Issa et al. (2011); Munro et al. (2016)).

Improving reliability continues to be a major focus of ESP research and development for both operators and manufacturers, and is a critical factor for improving the economics of ESPs in future applications. Some oil operators are actively targeting an ESP run-life in excess of 10 years; however, it has been noted that the cost and technology development challenges seem to increase exponentially with the requirements for increased reliability (Lastra (2017)). Some of the technical challenges seem to include temperature limitations of key materials (such as the motor winding insulation material), and designing all of the internal components for thermal cycling. Economic challenges include things such as the high research and development cost of developing new technology, as well as the misalignment of economic motivation that usually exists between manufacturers and operators.
3.3 Advantages and Disadvantages of ESPs as an Artificial Lift System

The design of ESPs provides a variety of strengths and weaknesses compared to other AL systems. Since LSPs are the most common form of AL in the geothermal industry they serve as a useful point of comparison and benchmark for ESPs. As shown below in Figure 2, one main difference is that in an ESP system the motor is located downhole beneath the pump; while in an LSP system the motor is located at surface and a shaft connects it to the downhole pump.

Table 1: Specifications of some Available High Temperature ESP Systems (Baker Hughes (2014a) and (2014b); Canadian Advanced ESP; Schlumberger (2011); Schlumberger (2016a) and (2016b))

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Pump Identification</th>
<th>Reported Maximum Flow Rate (L/s)</th>
<th>Reported Output Power at 60 Hz (HP)</th>
<th>Reported Maximum Operating Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker Hughes, a GE Company</td>
<td>400 Series CENtigrade™</td>
<td>0.257</td>
<td>156</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>500 Series CENtigrade™</td>
<td>0.257</td>
<td>264</td>
<td>275</td>
</tr>
<tr>
<td></td>
<td>Centrilift XP™ Extreme Temperature (ET)</td>
<td>0.147</td>
<td>330</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>Centrilift XP™ Ultra Temperature (UT)</td>
<td>0.147</td>
<td>240</td>
<td>250</td>
</tr>
<tr>
<td>Canadian Advanced ESP</td>
<td>CAESP ESP System</td>
<td>1.833</td>
<td>1500</td>
<td>190</td>
</tr>
<tr>
<td>Schlumberger</td>
<td>REDA Hotline Plus</td>
<td>0.990</td>
<td>257</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>REDA Hotline XTend / 562 Series</td>
<td>0.825</td>
<td>257</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>REDA Hotline XTend / SLIM Series</td>
<td>0.252</td>
<td>119</td>
<td>250</td>
</tr>
</tbody>
</table>
Some of the main advantages of using ESPs in geothermal energy production (Molloy (2009); Van't Spijker and Ungemach (2016)) includes the following:

- **Higher Potential Power Outputs:** ESP systems currently exist with power outputs significantly higher than existing LSP systems. If high power output ESP systems could be married with high operating temperature ESPs these systems could significantly increase the potential of geothermal operations.

- **Greater Installation Depth:** Due to the need for the shaft between the surface motor and downhole pump, LSPs are typically limited to an installation depth of 600-700 m (Van't Spijker and Ungemach (2016); Molloy (2009); NREL (2014)). The use of ESPs would allow for greater well depths, which would be particularly important for EGS.

- **Installation in Deviated Wells:** Bending of the shaft causes reliability concerns for LSPs, and therefore LSPs are not installed in significantly deviated wells (typically not greater than 5°/100 ft). As ESPs use a downhole motor attached with a cable to surface, they can be installed in highly deviated and even horizontal wells as long as the ESP system is not
subjected to high levels of bending (the rule of thumb is less than 30°/100 ft) during installation, as this has been found to reduce the reliability of the systems (Radke (2016)).

- **Shorter Installation and Workover Time:** ESPs can typically be installed and removed from wells in shorter time frames than LSPs. As such, down production time is reduced when performing work over activities. Some oil operators have even set a development target of one day of ESP replacement time (Lastra (2017)) for their operations.

- **Reduction of Surface Facilities:** ESPs do not require some of the surface facilities that LSPs require, such as ancillary pumping systems, which helps to reduce the surface footprint of the AL system.

- **Lower Initial Cost:** ESP systems typically carry significantly lower initial costs due to the lack of need for additional equipment such as lineshaft and surface support systems. ESPs are also typically quicker to install, which further reduces the overall cost.

Conversely, some disadvantages of using ESPs over LSPs in geothermal production wells includes (Finger and Blankenship (2010); Molloy (2009); Turnquist et al. (2013)):

- **Unproven Technology:** High temperature ESP systems have been proven in thermal EOR applications and high flow ESP systems have been proven (such as in off-shore oil applications); however, these have not been done simultaneously. This technology would have to be proven under geothermal applications.

- **Reduced Serviceability:** In order to service an ESP component, the entire system must be pulled, while LSP motors can be serviced without pulling the downhole components.

- **Lower Reliability:** Most high temperature ESP systems are currently limited to a run-life of two to three years in EOR applications while LSP's may be expected to operate much longer. For example, a typical replacement period of an LSP in an EGS operation is approximately seven years (Pratiwi (2018)). Although some aspects of geothermal or EGS operation may help improve ESP reliability (operating with water will provide better motor cooling at equivalent rates) others may worsen it (thermal cycling is a significant problem for ESP's in EOR, and geothermal wells may be more prone to this).

4. **The Ideal Pump**

4.1 **Ideal Technical Specifications of Artificial Lift in Geothermal Energy Production**

A more robust pumping system has been identified by a number of sources as one of the critical components needed to advance geothermal energy production. As such, the requirements for an "ideal" AL system for widespread use in the geothermal industry has been investigated numerous times in the past (Molloy (2009); Turnquist et al. (2013); Finger and Blankenship (2010); Idaho National Laboratory (2006)). Although the specific performance criteria vary based on the geothermal production type and reservoir characteristics, the following criteria have typically been agreed upon (Molloy (2009); Turnquist et al. (2013)): 
• **High Operating Temperature:** AL systems for conventional geothermal production would be required to operate in fluid temperatures up to 220°C, while AL systems to be used in EGS applications would be required to operate in fluid temperatures up to 300°C.

• **High Flow Rates:** Higher flow rates help to maximize the energy production potential of a geothermal production well. In general, a flow rate of 80 L/s has been identified as a minimum target for AL systems in both hydrothermal production and EGS; however, higher flow rates would make the AL system more attractive to geothermal operators.

• **High Power Outputs:** Higher power outputs allow for the AL system to maintain production rates in a wide variety of applications, including deep wells. A minimum target of approximately 750 HP has been stated for hydrothermal systems, while significantly higher power outputs will likely be required for EGS. As with flow rate, higher power outputs will further increase the attractiveness of AL systems for geothermal operations.

• **Reliability:** Operational run-life is a key factor in AL system selection and can significantly impact the economic feasibility of geothermal production. A reliable run-life of three years has been identified as a minimum target for AL systems to be used in both hydrothermal production wells and EGS, with an ideal target of at least five years stated by some geothermal operators.

• **Deployable through Specific Wellbores Sizes:** To allow for retrofitting of current wells, and to minimize costs of new production wells, the AL system must be capable of being deployed in typical geothermal wellbores, which are usually 13-3/8" for conventional geothermal production wells and 10-3/4" for EGS.

### 4.2 Gaps between Ideal Specifications and Current ESP Systems

After comparing the current state of high temperature ESP systems to the ideal operating parameters of AL for geothermal energy production, it can be seen that while the maximum operating temperatures may be sufficient the output power (and associated flow rates) would not provide economically viable energy production. Higher power ESP systems are available but with much lower maximum operating temperatures than needed.

To provide the required flow rates, high temperature ESP systems would need to be married to their high flow rate counterparts, resulting in an ESP system capable of handling high production fluid temperatures; while at flow rates significantly higher than their current capabilities. Though there are technical challenges associated with this (e.g. the upsizing of the high temperature ESP motor likely chief among them) it would also take a strong economic drive to motivate ESP manufacturers to pursue this technology development.

Additionally, ESP reliability would need to be improved to match the ideal AL requirements for geothermal operations, where the challenging operating conditions of geothermal production wells may be expected to further reduce the reliability of these systems. Optimizing ESP technology for this purpose will likely require a comprehensive research and development plan that includes aspects of: simulation, laboratory-scale testing, pilot testing and field monitoring. Performance tracking systems, such as those used in the oil and gas industry for ESPs, may also
be utilized to help guide further development strategies and improve ESP reliability based on field data (Alhanati (2003)).

4.3 Economic Comparison for ESPs in the SAGD and Geothermal Industries

As recently as 10 years ago, the highest temperature ESP systems available to SAGD operators were limited to fluid temperatures in the range of 220°C. Despite this, the business case for developing a high temperature ESP for SAGD seems to have been strong enough to convince at least two manufactures to develop new technology. Following some level of internal research and development both Schlumberger and Baker Hughes were able to validate novel high temperature ESP systems rated for downhole temperatures greater than 250°C in 2010 and 2012 respectively (Noonan et al. (2009) and (2010); Waldner et al. (2012)).

Using publicly available data (AER (2018)) it is possible to coarsely estimate the "order of magnitude" of annual pump sales for ESPs in SAGD operations within Alberta in 2009 prior to the development of Schlumberger and Baker Hughes' new ESPs. The same data can also be used to further estimate the annual pump sales for SAGD and forecast how it may change over the next several years, neglecting the cost of installation. This information can be compared to an economic analysis previously completed for the geothermal industry (Molloy (2009)) that estimated the number of pumps and annual pump sales that could be expected for EGS and hydrothermal in 2020 for the "ideal" pump (noting this is for worldwide sales). To reflect the uncertainty in pricing that may exists for this "ideal" pump two different sensitivities are presented here: a “higher” cost ESP of $975K CAD (Molloy (2009)) and a “lower” cost ESP of $330K CAD, as estimated by the authors. Further assumptions can then be made to estimate how this business case may be expected to grow and change over several years. The results of this simple economic exercise are shown graphically in Figure 3 while the data and accompanying assumptions are detailed in Table 2.

![Figure 3: Economic Estimate for Annual ESP Sales ($M CAD / year) for SAGD and Geothermal Operators](image-url)
Table 2: Economic Estimate for Annual ESP Sales ($M CAD / year) for SAGD and Geothermal Operators

<table>
<thead>
<tr>
<th>Year</th>
<th>SAGD</th>
<th>EGS and Hydrothermal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Wells</td>
<td>“High” Cost ESP</td>
</tr>
<tr>
<td></td>
<td>Number of ESPs</td>
<td>ESP Cost (CAD$)</td>
</tr>
<tr>
<td>2007</td>
<td>226+</td>
<td>$600,000</td>
</tr>
<tr>
<td>2008</td>
<td>321+</td>
<td>$600,000</td>
</tr>
<tr>
<td>2009</td>
<td>446+</td>
<td>$600,000</td>
</tr>
<tr>
<td>2010</td>
<td>587+</td>
<td>$600,000</td>
</tr>
<tr>
<td>2011</td>
<td>691+</td>
<td>$600,000</td>
</tr>
<tr>
<td>2012</td>
<td>899+</td>
<td>$400,000</td>
</tr>
<tr>
<td>2013</td>
<td>1073+</td>
<td>$400,000</td>
</tr>
<tr>
<td>2014</td>
<td>1354+</td>
<td>$400,000</td>
</tr>
<tr>
<td>2015</td>
<td>1549+</td>
<td>$400,000</td>
</tr>
<tr>
<td>2016</td>
<td>1722+</td>
<td>$400,000</td>
</tr>
<tr>
<td>2017</td>
<td>1957+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2018</td>
<td>1981+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2019</td>
<td>2088+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2020</td>
<td>2211+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2021</td>
<td>2427+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2022</td>
<td>2613+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2023</td>
<td>2761+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2024</td>
<td>2870+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2025</td>
<td>2971+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2026</td>
<td>3039+</td>
<td>$300,000</td>
</tr>
<tr>
<td>2027</td>
<td>3088+</td>
<td>$300,000</td>
</tr>
</tbody>
</table>

1 In 2007, the maximum number of ESP's was estimated as the number of SAGD wells identified by the AER (AER (2018)); in each following year the maximum number of ESPs was estimated as the sum of all new SAGD wells plus a 50% replacement of the existing SAGD well population.
2 This number of SAGD wells was estimated by dividing the yearly SAGD production in Alberta by the current SAGD well productivity estimate (of 86.1 m^3/day) in 2017.
3 The number of SAGD wells in 2017 was provided by the AER (AER (2018)), although they note this is an estimate.
4 The number of SAGD wells starting in 2018 on was estimated by first estimating the likely SAGD production each year by assuming the levels of CSS and Primary Recovery in Alberta remain ~ flat (at 40 x10^3 m^3/day each) going-forward and all other total in-situ forecast by the AER (AER (2018)) can be associated with SAGD, which is already the most common form of thermal production. This SAGD production was then divided by the current SAGD well productivity estimate (of 86.1 m^3/day) in 2017 to estimate the number of new SAGD wells expected through to 2027.
5 For Sensitivity Case #1 the higher cost (and number) of an “ideal” ESP in 2020 for the EGS and Hydrothermal markets were estimated by Molloy (2009); and in each subsequent year the number of ESPs was assumed equal to all “new” geothermal wells plus a 50% replacement of the existing population, where the number of new wells was estimated to grow by 10% each year.
6 Annual ESP sales of USD$360M was estimate by Molloy (2009) and converted into CAD at the current exchange rate.
7 For Sensitivity Case #2 the “lower” cost of a suitable ESP in 2020 for EGS and Hydrothermal was estimated by the Authors.
This economic estimate is simplistic, and includes some significant error bands caused by broad assumptions (e.g. simplifying complex concepts like the growth expected in the SAGD and geothermal industries, the expected reliability of ESPs, and even the cost of the “ideal” ESP systems). Despite this, the results do provide some insight into the business case that was likely considered before two major ESP manufacturers chose to design and build high temperature ESPs for the SAGD operators in 2009. As shown in Table 2, the annual sales that could be expected for a new high temperature ESP in SAGD may have been about CAD$171 M/year in 2009. Carrying these calculations forward through to 2018, it is clear that SAGD has become much more prevalent in Alberta, as the market size for these ESPs has increased (doubled) and is only expected to increase (significantly) in the coming years. This is likely due to the significant benefits the use of ESPs has provided SAGD operators, including handling multi-phase flow, controllable operation over a wide range of rates, and reliability at least as high as many of the other AL options available for SAGD (Shang and Caridad (2017)). This seems to suggest that the development of new high temperature ESP technology has been beneficial for the manufacturers (and SAGD operators), despite the risks and challenges involved.

By comparison, developing an ideal ESP that can operate at high fluid temperatures and deliver the rates and other requirements geothermal operators need will present new challenges for the ESP manufactures. One of the first questions that likely should be addressed before undertaking any new development is tied to the economics of the market. As the Lemelson meeting concluded (Molloy (2009)), the market demand for a new ESP strictly for EGS applications in North America is likely "...too little and too slow to warrant a commercialized pump." Fortunately, they also concluded that if an ESP vendor can develop a pump to produce hydrothermal resources (in the 190°C to 220°C range) the market demand did seem sizable. Furthermore, current EGS focused programs (such as FORGE) may increase future demand for these systems and improve on this business case.

Encouragingly, this simplistic economic estimate also seems to indicate that the expected annual sales for a suitable high temperature geothermal ESP may be in the “same ballpark” now as it was for an ESP for the SAGD operators back in 2009. As shown in Table 2 and Figure 3 the estimated annual sales potential varies significantly with the cost of the “ideal” ESP system” for example, anywhere between CAD$159.1 M/year and CAD$470 M/year in 2020. Although there are clearly significant differences in the economies of 2009 and 2018, the economics of this new technology development still compares favorably with this past business case for SAGD.

4.4 The Case for Collaboration

It should also be noted that both initial high temperature ESP vendors (Schlumberger and Baker Hughes) developed their new ESP systems with significant support from major SAGD operators. In 2009 through 2012 operators such as ConocoPhillips and Nexen played a key role in supporting the development of this new ESP technology. This included independent full-scale testing of both ESPs prior to full commercialization (Noonan et al. (2010) and Waldner et al. (2012)) to optimize and validate the systems.

Developing new technology is a significant challenge; however, the research and development strategy followed for the SAGD operators was proven successful for both vendors: internal development, full-scale independent testing, field pilots and finally full commercialization with field monitoring. This same development road-map (internal development and independent full-
scale testing to validate the technology) has been proposed by others (Molloy (2009)) in consideration of the best way to develop the ideal new pump needed by geothermal operators. It seems clear that ESP manufactures, geothermal operators, and research organizations should work collaboratively to develop an “ideal” pump.

5. Conclusions

- The ideal operating parameters for AL systems vary across high temperature applications for hydrothermal operations, EGS, and EOR. Despite this, high temperature ESPs have successfully been used in thermal EOR applications, and have often been identified as a high-potential alternative to current AL systems utilized in the geothermal industry.

- Commercial high temperature ESPs are available that can operate in geothermal production wells; however, the associated power outputs for these systems is often inadequate to provide the required flow rate for an economic geothermal facility.

- In order for ESP systems to match the specifications for the "ideal" geothermal pump, the ESP manufacturers would be tasked with combining their high temperature and high flow technologies, while also extending the run-life of their ESP systems. These goals present significant technical and economic challenges, and the ESP manufacturers will likely require the support of geothermal operators and independent research facilities to help them develop, optimize, and prove their new technology.

- The simple economic analysis presented in this paper shows that the potential market for an ESP manufacturer to develop a high temperature system for geothermal operators in the near-term (2020) is comparable to the ESP market in 2009 (just prior to the development of new high temperature ESPs for SAGD operators).

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