POTENTIAL OFF-GRID MARKETS FOR SMRS IN CANADA

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Abstract

Small modular reactors (SMRs), with less than 300 MW_e power capacity (~1000 MW_{th}), are being developed to improve the safety and economics of nuclear power, and to expand the application of nuclear power beyond large scale electricity grids. A key factor to improving the economics of SMRs is the ability to exploit the economies associated with replication. But in order to exploit these economies there must be a market with demands for a sufficient number of the produced SMRs. The purpose of this analysis is to estimate the market for SMRs for off-grid applications in Canada.

The potential market for SMRs in off-grid applications in Canada includes remote communities, remote mining projects, oil sands extraction and upgrading, cogeneration in a wide range of industries, and district energy systems. This study found that the potential market for off-grid SMRs in Canada consists of over 600 power plants, with a total power demand of 35 GW_e. Another important finding was that most of these power plants require an installed capacity of less than 5 MW_e.

Keywords:

Small Modular Reactors, Markets, Canada, Oil Sands, Mining, Cogeneration, District Energy

1 Introduction

Small modular reactors (SMRs), with less than 300 MW_e power capacity (~1000 MW_{th}), are being developed to improve the safety and economics of nuclear power, and to expand the application of nuclear power beyond large scale electricity grids. A key factor to improving the economics of SMRs is the ability to exploit the economies associated with replication. But in order to exploit these economies there must be a market with demands for a sufficient number of the produced SMRs. The purpose of this analysis is to identify the potential off-grid markets for SMRs in Canada in the time-frame of 2025, about the time that SMRs are expected to be ready for deployment. Here the term "off-grid" refers to an application in which the SMR must be placed close to the demand, but would not be connected to a large scale electricity grid.

There are two primary types of off-grid power demands that will be explored in this paper. One involves electricity generation in areas that are not currently connected to a large-scale electricity grid, and where connection to such a grid is infeasible or uneconomical. The other involves the generation of heat, the source of which must be close to the demand.

There are two aspects of the off-grid power demands that are important indicators of the market for SMRs: the magnitude of local power demands, and the number of sites requiring local power generation. Therefore the potential market for SMRs for off-grid power generation will be subdivided according to the magnitude of local power demands, where each sub-market is defined as the number of off-grid sites that require a given capacity of local power generation.

This market assessment will rely on publicly available literature and data. The identification of potential off-grid markets for SMRs in Canada first requires the identification of potential applications of SMRs, which will be presented in Section 2. Section 3 will then present the potential off-grid power demands in Canada in 2025. Section 4 will briefly discuss the potential use of SMRs to produce fuel for off-grid applications, and Section 5 provides some concluding remarks.

2 Target Applications of SMRs

An International Atomic Energy Agency (IAEA) report on SMRs includes 31 SMR designs as well as a description of their target applications [1]. Table 1 shows all of the target applications mentioned in the IAEA report, and the number of SMR designs that target each application. These numbers may be higher at the time of this publication due to the introduction of new SMR concepts after the drafting of this report. The most common target applications are desalination, locally generated electricity, process heat, and district heat, each of which will be discussed in further detail here.

Table 1. Target Applications of SMRs

Application	Number of SMR Designs
Local electricity	12
Desalination	15
District heat	10

Process heat	6
Steam	5
Oil sands	1
Off-shore oil	2
Marine propulsion	2

2.1 Locally Generated Electricity

The requirement for generating electricity locally stems from the isolation of the demand from a large scale electricity grid. There are two types of demands for locally generated electricity: community and resource extraction. The characteristics of each type of demand are quite different and present their own challenges with respect to the deployment of SMRs to meet these demands.

2.1.1 Off-grid Communities

Off-grid community power demands typically come from a relatively small locale of residential and commercial customers, which have an hourly variability that is similar to demands on large scale grids. This short-term variability in demand requires an electric power generating system that is capable of quickly changing its power output to match changes in demand, a process commonly referred to as “load following”. Therefore the design of a SMR power plant should take into account the load following capabilities of the SMRs, including energy storage capability if necessary.

2.1.2 Off-grid Resource Extraction

The main obstacles for deploying SMRs at resource extraction projects are the higher capital cost requirements relative to the incumbent fossil fuel-based power plants, and the compatibility between the SMR and project lifetimes. A SMR with a lifetime that exceeds the predicted lifetime of a project may not be an economical choice unless new customers for the power can be found when resource extraction operations cease, or the reactor is portable enough to be moved to a new location. The lifetime of the project may be affected by commodity prices, which affect its profitability. The higher upfront costs of deploying a SMR for a given project may increase the financial losses incurred if the project prematurely ceases operation due to a long-term drop in commodity prices.

Another potential obstacle relates to the increase in seismicity of a resource extraction site due to the extraction process, such as mineral mining [2]. The increased frequency of seismic events in close proximity to resource extraction operations should be accounted for in the SMR design. These design impacts may increase the cost of the SMRs.

2.2 Water Desalination

In many regions around the world, the supply of natural fresh water is, or will be in the near future, insufficient to meet local demands. With many of these regions being adjacent to sea-water bodies, a solution to insufficient natural fresh water resources is to desalinate sea water. A target market for some SMRs includes off-grid sites that can benefit from the desalination of seawater, although a Canadian market for desalination would likely be very small or non-existent due to the large abundance of fresh water.

2.3 Process Heat

Many different industrial processes use heat to produce the desired products. Due to the significant losses that occur during heat transport, it is recommended that the heat generator to be in close proximity to the demand, otherwise an upgrading facility is required to compensate for losses. This has resulted in most industrial facilities obtaining their required process heat from adjacent power plants. Many of these are cogeneration plants, meaning that they also generate electricity for the processing facility and for sale. Currently, most of these cogenerating facilities consume fossil fuels to produce power.

The processes that have been targeted as potential demands for the heat generated by SMRs include oil sands extraction, hydrogen production, off-shore oil production, steel manufacturing, chemical production, and oil refining [1][3].

The compatibility of a given SMR to supply heat for a given process depends on the coolant outlet temperature of the SMR, where SMRs with higher outlet temperatures will be compatible with more processes. For example, a survey of process heat applications was conducted to identify applications that are compatible with high temperature gas-cooled reactors (HTGRs) [3]. The applications were subdivided into three temperature ranges: 250-500°C, 500-700°C, and 700-950°C. The lowest temperature range, which is comprised of the largest number of processes (16), includes in-situ bitumen extraction and various chemical processes (e.g., distillation, hydro cracking, and polymerization). Fewer processes (6) require temperatures in the mid-range, which include petroleum refining and chemical production processes (e.g., coking, catalytic cracking, catalytic reforming, and bitumen upgrading). The highest temperature range is required for the fewest processes (5). These high temperature processes include chemical production via steam cracking, hydrogen production processes (eg, steam methane reforming, and high temperature steam electrolysis), and metal production processes. If the outlet temperature of a given SMR design is not high enough for a given process then an auxiliary power source would need to be used to bring the temperature up to the process requirement.

The survey also took into account the power demands of typical facilities when determining the suitability of HTGRs. The thermal energy demand of a typical 200,000 barrel per day complex coking refinery is about 1100 MW_{th}. These demands include steam (5-8%), electricity (17-18%), and heat (75-77%), which depend on the refinery configuration.

With regards to oil sands operations, a 100,000 barrel per day in-situ extraction project requires 1271 MW_{th} of total power (99% of which is heat), surface mining requires 689 MW_{th} (46% of which is heat), hydrogen production via steam methane reforming requires 130 MW_{th} of total power (93% is heat and steam), and upgrading requires between 225 and 1065 MW_{th} of total power (22% and 35% of which is heat, respectively).

Another industry that was identified by the survey to have significant energy demands with process temperatures that are suitable for HTGRs is the metal industry. HTGRs would be suitable to provide electricity and heat to steal mills (295 MW_{th} plus 240 MW_e could support the production of 6.5 million tonnes of steel) and aluminum refining operations (317 MW_{th} plus 544 MW_e could support the production of 726 thousand tonnes of alumina).

As with electricity for off-grid resource extraction projects, consideration should be given to matching the lifetime and capacity of the project to the proposed SMR. For example, a higher power SMR will enable higher bitumen production but the oil sands deposits that are close enough to the SMR may become depleted prior to the end of the SMRs life [4]. Conversely, a lower power SMR may need to be replaced prior to depletion of the deposits. Matching the SMR capacity and lifetime to a given project would not be an issue if the SMR is near enough to a large scale electricity distribution grid or some other electric load to allow the distribution of excess generated electricity.

2.4 District Energy

District energy provides thermal power to multiple buildings for one or more of the following uses: heating, cooling, hot water, and electricity. As is the case for process heat applications, district energy requires that the power plant be located in close proximity to the demand. For off-grid communities, waste heat may be used for district heating, thus increasing the energy efficiency of the system relative to generating only electricity. District heating systems have been operating for decades in many countries around the world, including the US, Canada, and most European countries.

3 Potential SMR Markets in Canada

The assessment of the potential market for SMRs in Canada presented in this section is based on recent Canadian power generation data in off-grid applications. Specifically, as much as possible, the data for each individual power generation facility in Canada are aggregated in the form of a histogram.

3.1 Electricity for Canadian Off-grid Communities

The latest update on off-grid communities in Canada defines an off-grid community as a permanent or long-term settlement with at least ten dwellings that is not currently connected to the North-American electrical grid nor the piped natural gas network [5].

The long-term nature of this market, coupled with the fact that the number of off-grid communities in Canada is decreasing, means that the deployment of SMRs in this market would be either to replace or supplement the currently operating power plants. In particular, the latest update on off-grid communities in Canada identified a number of motivating factors for replacing diesel power generators in remote communities. Therefore the potential market for SMRs presented here encompasses current customers of diesel power plants, excluding any power plants that are designated as a backup power supply. The size of this market is estimated using data on current diesel power generators in off-grid communities in Canada. The primary source of data for this assessment is the Remote Communities Database [6].

The size of this market depends on the number and power generation capacity of the power plants, which are described in the following two sections.

3.1.1 Number of Power Plants

Of the 319 communities listed in the Remote Communities Database, there are partial data for 297 communities. While 211 communities are listed as primarily relying on fossil fuel (FF), only 186 communities have a listed power plant capacity in the database. There are off-grid communities in 10 of the 13 provinces and territories, as shown in Figure 1, with the three exceptional provinces being Nova Scotia, New Brunswick, and Prince Edward Island. Table 2 shows the number of such communities by province and territory, and their primary source of electricity. Most power plants, 96%, that serve off-grid communities in Canada consume fossil fuel (FF), with the remaining 4% using hydro-power. The communities that rely primarily on hydro-generated electricity also host a diesel power plant as a supplement to, or a backup for, the hydro-power plants. Of the 280 communities with active records in the database, 197 rely primarily on a local power plant that burns diesel fuel with a total nation-wide installed capacity of 337 MWe.

Figure 1. A map showing the locations of remote communities in Canada [6]

Table 2. Fossil fuel Generation in Off-grid Communities in Canada by Province (Active Records Only)

Province / Territory	Number of Communities					
	Total Number	**Primary Diesel generation**	**Connected to Local Grid**	**Primary Renewable generation**	**Hybrid Diesel / Renewable**	**Other Primary FF**
Alberta	2	1	1	0	0	0
British Columbia	75	57	6	4	1	0
Manitoba	7	7	0	0	0	0
New Brunswick	0	0	0	0	0	0
Newfoundland and Labrador	29	26	1	0	1	0
Northwest Territories	37	21	8	4	0	2
Nova Scotia	0	0	0	0	0	0
Nunavut	25	25	0	0	0	0
Ontario	38	31	0	0	1	0
Prince Edward Island	0	0	0	0	0	0
Québec	45	24	20	1	0	0
Saskatchewan	1	1	0	0	0	0
Yukon	21	4	16	0	0	1
Total	**280**	**197**	**52**	**9**	**3**	**3**

There is some uncertainty as to the actual number of power plants that could be replaced with SMRs. Grid expansion over the 10+ years before SMRs are ready for deployment would reduce the number of communities that rely primarily on diesel power. The local diesel generators would likely be either decommissioned or relegated to the role of backup power generation, a role that may not suitable for SMRs.

3.1.2 Power Generation Capacity

An assessment of the scale of the power generation capacity of this market is made via an analysis of the histogram of power plants by capacity, which is shown in Figure 2.

This figure indicates that SMRs with electric power capacity of between 0.1 and 2 MW_e would be best suited for the bulk of the off-grid community market in Canada. This would likely be the case even if the power demands of communities grew buy a factor of 10, due to the ability to place multiple SMRs in a single power plant.

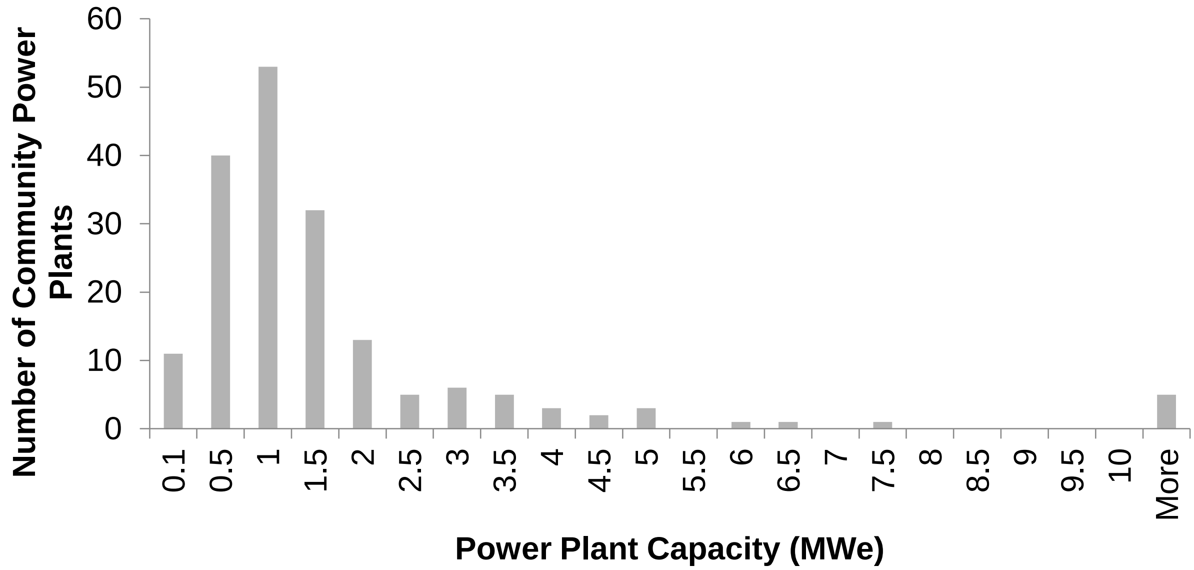

Figure 2. Histogram of current power plant capacity in Canadian off-grid communities

Since the total capacity of SMRs that may be installed in a community would depend on the peak and average electricity demand it would be informative to look at the relationship between installed capacity and demand data. On average, the installed capacity was more than double the peak power demands and quadruple the average annual power demands for those communities for which demand data were available. This excess capacity serves as backup and as a margin for future growth in peak demand. Assuming that it would be 10 years before an SMR is installed at a given community for which the current installed capacity is double that of peak demand, that the capacity of the SMR matches that of the current installed capacity, and that the SMR will operate for 30 years, then this SMR could support up to 1.7% average annual growth in peak demand and up to 3.5% average annual growth in total energy demands over its lifetime. It is also possible to install a smaller SMR that still exceeds current peak demand, and add another SMR if demand increases.

The relationship between installed capacity and the demand varies significantly across different communities. With peak and average demand data for 45 and 169 communities, respectively, the standard deviation of the ratio of installed capacity to peak and average demand is 0.9 and 3.0, respectively. This reinforces the need for community-specific assessments to gain a more accurate overall market assessment.

3.1.3 Uncertainty in the Remote Communities Market

There is significant uncertainty in what power generating capacity of SMRs would be suitable for a given community. This uncertainty stems from the following factors.

- Electricity demands in a community may grow significantly between now and when SMRs are ready for deployment, at which time the capacity of the SMRs installed in a community should be chosen taking into account future growth projections in energy demand over a planning horizon.
- The load following capabilities of a given SMR technology may have a significant effect on the maximum capacity that can be installed in a given community. These characteristics include minimum operating power level, and quick start-up capability. A SMR that is capable of operating at power levels that match the full range of demands of the community with capacity to spare would be well suited

for deployment as a stand-alone unit. If the power demands of a community fall below the minimum power level of a SMR then multiple smaller SMRs would need to be installed, each with a quick start-up capability.

- The installation of energy storage capacity would reduce the required installed SMR capacity. This would allow the SMRs to operate at a higher power level than needed to meet current demands, with the excess energy stored and used to meet power demands that exceed the SMR capacity. The optimal combination of SMR and energy storage capacity would depend on the daily and seasonal demand characteristics of the community, and on the efficiency of the storage technology.
- Increased penetration of renewable power generators and energy storage capacity into this market by the time of SMR deployment would reduce the potential installed capacity for SMRs.
- The installation of SMRs may lead to the installation of electric heating systems to replace or supplement current diesel fuelled systems. This may increase the electricity demand by a significant amount depending on the relative amount of diesel consumed for heating. For example, in 2011 the three territories in Canada consumed 2.9 times the amount of diesel for heating as was consumed for electricity [7]. A community that consumes 1 and 2.9 units of diesel for electricity (30% efficiency) and heating (90% efficiency), respectively, will increase its electricity demand by a factor of almost 10 if all heating is provided electrically. Alternatively, a community may have a district heating system in place that could

draw thermal power from the SMRs. Such a system would likely require less thermal power than the equivalent electric power required for heating.

With such a high degree of uncertainty, establishing the sizes of SMRs that would fit this market would require the specification of scenarios and a detailed assessment for each community and SMR technology.

3.2 Oil Sands Extraction and Upgrading

Although most oil sands projects are located near a provincial electricity grid, these projects require a significant amount of thermal power for the bitumen extraction and upgrading processes. Currently, this thermal power is mostly generated via the burning of natural gas, but the resulting greenhouse gas emissions have prompted some analyses of deploying nuclear power in the oil sands [4].

The oil sands resources can be classified according to the method used to extract them: surface mining and in-situ extraction. Surface mining is for resources that are near ground level, and involves digging the bitumen ore out of the ground and transporting it to a processing facility to extract the bitumen. In-situ extraction is for resources that are too far underground to dig out. Instead, a deep well is drilled at the site and piping is installed for the purpose of injecting steam to melt the bitumen, which is then pumped to the surface. Figure 3 shows the forecasted bitumen production in Canada up to the year 2030 [8].

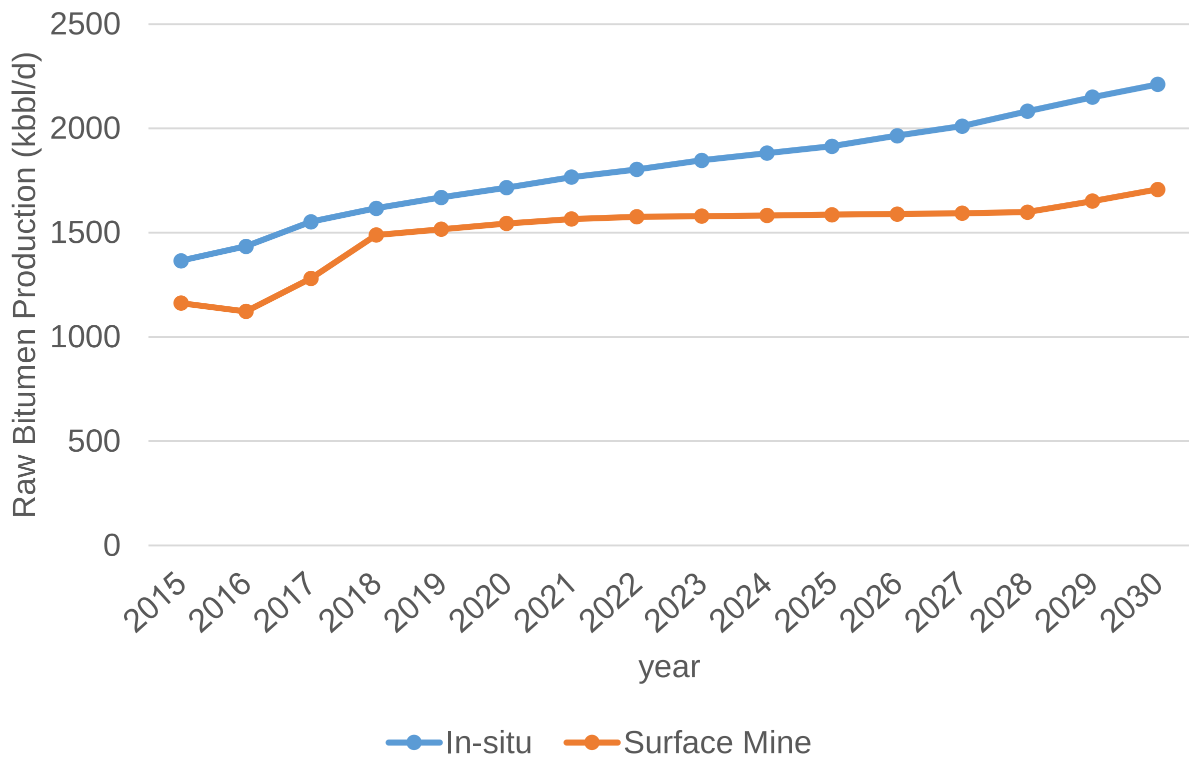

Figure 3. Forecasts of bitumen production in Canada [8]

The other major consumers of power in oil sands operations are the upgrading facilities. These facilities produce hydrogen using the steam methane reforming process, which is then used to upgrade the bitumen to synthetic crude.

3.2.1 Surface Extraction

There are currently seven oil sands surface mining projects operating in Canada [9] that produced an average of 1,162,000 barrel per day (bbl/d) of raw bitumen in 2015, and eight projects that have been approved but are not yet operational with a total capacity of 740,000 bbl/d [8]. According to the Canadian Association of Petroleum Producers (CAPP), the production of crude bitumen from surface oil sands extraction in Canada will grow by 420,000 bbl/d between the years 2015 and 2025, with most of this growth occurring prior to the year 2021 [8].

Surface mining requires 6.9 kW_{th} to produce one bbl/d of bitumen [3].This means that a total of 20.2 GW_{th} of installed capacity will be required to achieve the forecasted production of 1,586,000 bbl/d in 2025 [8]. Exactly how many surface mining projects will be operating to make up the total production, and thus the maximum number of SMR power plants that could be built, is uncertain. The lower bound on the number of SMRs needed to meet these power requirements can be calculated using the maximum electrical output of SMRs of 300 MW_e, and assuming the thermal-electric efficiency to be 30%. In this case at least 21 SMRs with a capacity of 300 MW_e each would be able to meet the power requirements in 2025.

The choice of whether to build a SMR power plant will be project specific and will likely take into consideration the remaining lifetime of the project and the age of the existing power plants. For example, a project that has been operating for only a few years prior to 2025 will likely not benefit economically from the deployment of a SMR until either a capacity expansion has been implemented or the existing power plant is near its end of life.

3.2.2 In-situ Extraction

There are currently 31 oil sands in-situ extraction projects operating in Canada [9] that produced on average 1,365,000 bbl/d of raw bitumen in 2015, and 55 projects that have been approved but are not yet operational with a total capacity of 1,834,800 bbl/d [8]. By the year 2025, the bitumen production is forecasted to reach 1,914,000 bbl/d.

A typical in-situ extraction project requires 12.71 kW_{th} to produce 1 bbl/d of raw bitumen [3]. This study also states that in-situ extraction projects are typically installed in phases, each of which adds no more than 70,000 bbl/d of capacity. Assuming 30% thermal-electric efficiency, this corresponds to a 267 MWe (890 MW_{th}) SMR, 28 of which would be required to meet all of the power requirements for in-situ projects in Canada in the year 2025.

As was the case for surface mining projects, the choice of whether to build a SMR power plant will be project specific and will likely take into consideration the remaining lifetime of the project and the age of the existing power plants.

3.2.3 Hydrogen Production and Upgrading Facilities

There are currently five oil sands upgrading facilities operating in Canada that have a total processing capacity of 1,330,000 bbl/d of raw bitumen in 2015 [10], the names and capacities of which are shown in Table 3. The power requirements for each facility depend on the upgrading and hydrogen production processes, data that are not publicly available for all five facilities. While the production of raw bitumen is expected to grow, it is not so clear whether upgrading capacity will see similar growth. According to oil sands production statistics from the CAPP, the proportion of bitumen sent directly to market without upgrading has been increasing since 2013, although still relatively small. Bitumen that is sent directly to market is first diluted with lighter petroleum products to enable its transportation through pipelines. The installation of more upgrading capacity will depend on the price of synthetic crude, the main product of bitumen upgrading, relative to that of diluted bitumen, the difference in which must be higher than the cost of upgrading in order for upgrading to be economical. The increasing sale of diluted bitumen to refineries indicates that it is currently uneconomical to install new upgrading facilities in Canada. If these market conditions persist then it is likely that no new upgrading capacity will be installed and some of the existing upgrading capacity may be decommissioned due to rising operating costs of aging facilities. Conversely, a persistently high premium for synthetic crude will likely lead to the installation of more upgrading capacity to keep pace with bitumen production. It is in this latter case where SMRs may be installed to power the upgrading facilities, with a total capacity that should be no less than the bitumen production for the corresponding year: 3,500,000 bbl/d in 2025.

Table 3. Upgrading Facilities in Canada in 2015 [10]

	Capacity (kbbl/d)
Shell Scotford	255
Suncor Base	440
Syncrude Mildred Lake	407
CNOOC Long Lake	72
Canadian Natural Resources Ltd Horizon	156

The upgrading processes require between 2.25 kW_{th} and 10.65 kW_{th} to process one bbl/d of raw bitumen [3]. The upgrading of bitumen requires around 4 kg of hydrogen to process 1 bbl of bitumen [4], which may be produced at the upgrading site, or by an external producer and transported to the upgrader via a pipeline. The power required for hydrogen production depends on the process. Steam methane reforming, a commonly used method, requires 2.2 kW_{th} [3] to produce 4 kg of hydrogen per day. The total power required to produce hydrogen and upgrade 3,500,000 bbl/d, assuming a hydrogen production process with similar power requirements, is between 15.5 GW_{th} and 44.9 GW_{th}. This is equivalent to between 16 and 45 SMRs with 300 MW_e equivalent electric power and 30% efficiency.

3.2.4 Oilsands Extraction Economic Considerations

There are economic impacts on the size of the oil sands extraction and upgrading market that should be noted. The current low price of oil has prompted the Canadian Association of Petroleum producers to reduce their forecast for oil sands production [8], thus the potential production capacity that could use energy from SMRs depends on the price of oil. The price of natural gas also needs to be taken into consideration. With current natural gas prices being well below the breakeven price for deploying nuclear reactors [4], there would need to be a large increase in the price of natural gas just to render SMRs economically competitive with gas fired generators.

3.2.5 Efficiency and Waste Heat

Improvements in the efficiency of energy utilization may be achieved via the co-location of multiple processes at a given site, where waste heat from one process is used to reduce the energy requirements of another [4]. In this case the total power demands from oil sands extraction would be lower than stated above.

3.3 Mineral Mining

In Canada there are over 1000 operating mines [11], but only 32 operating or proposed off-grid mines that rely on diesel power generators, the remainder are connected to electricity grids. The total power demands for these operating and proposed off-grid mines in Canada is 658 MW_e, with the minimum and maximum power requirements of 4

MW_e and 125 MW_e, respectively. As shown in Figure 4, the power requirements of 91% of these mines are between 5 MW_e and 30 MW_e. Due to the high degree of uncertainty with respect to the power requirements of projects operating in 2025 the data in Figure 4, which include proposed projects, are considered a rough estimate of the power requirements of off-grid mining projects that will be operating in 2025.

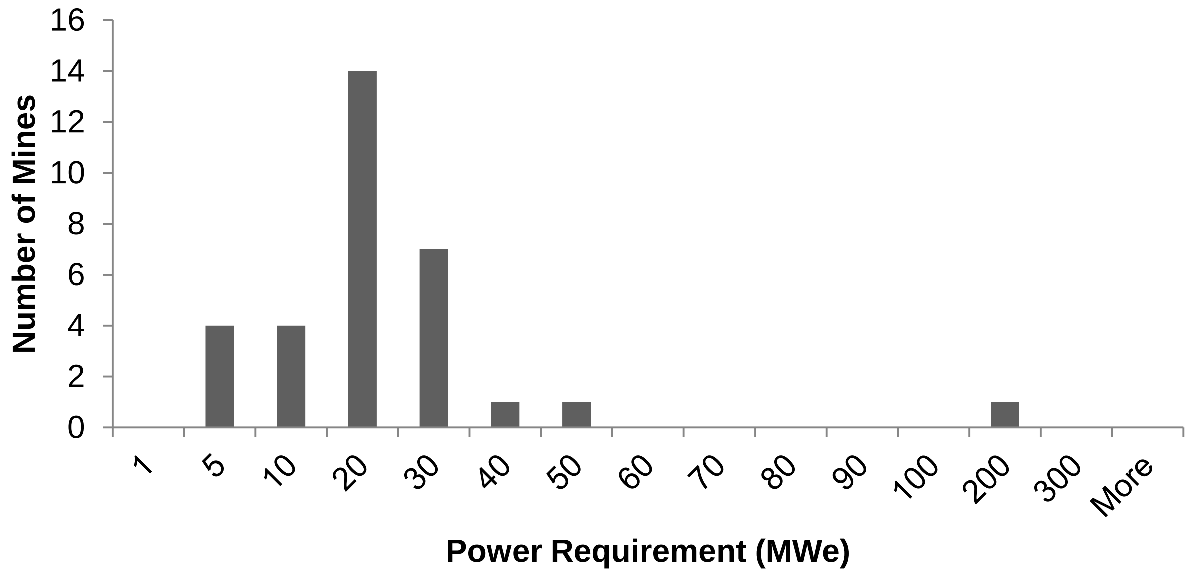

Figure 4. A histogram of power requirements of off-grid mines in Canada

The following describes the power requirements of the off-grid mining projects by province/territory.

Yukon Territory

In 2010, an average of 2.2 MW_e of power was required for off-grid industrial electricity in the Yukon Territory [12]. The Yukon Energy Corporation projected that the average power demand for off-grid mining projects in 2011 was 4.2 MW_e, and was expected to grow to a peak of 175.6 MW_e by the year 2020. After 2020 the average power demand was expected to drop to 124.2 MW_e by the year 2050. Complete data on the actual number of mining projects and the power requirement for each project could not be found. According to the Yukon Energy Corporation resource plan [12] there are five proposed mining projects located beyond the boundaries of potential grid expansion. Of these five, the power demands of only the Casino (125.0 MW_e [13]) and Mactung (12.5 MW_e [14]) projects were found.

Northwest Territories

According to the 2013 Northwest Territories power plan [15] there were four mines in operation in the Northwest Territories in 2013, with a total power demand of 61 MW_e. The plan also identifies six proposed mining projects that are at an advanced stage and have a reasonable likelihood of reaching operating status prior to 2020 (95 MW_e), for a total of 126 MW_e of electricity demand.

Nunavut

According to the 2013 Nunavut Economic Outlook report [16] there is one operating mining project (26.0 MW_e) in Nunavut and eight mining projects that are considered advanced with respect to their stage of development (164.7 MW_e), for a total of 190.7 MW_e of electricity requirements.

Quebec

There are two off grid mines currently operating (33.2 MW_e) and four proposed off-grid mining projects (48.6 MW_e) located in northern Quebec that will require 81.8 MW_e of electricity [17-22].

Newfoundland

There is one off-grid mine operating in Newfoundland with 25.0 MW_e installed generating capacity.

Ontario

There is a proposed off-grid mine in Northern Ontario that would require 22.0 MW_e [2]. The proximity of the proposed mine to off-grid communities would allow the power plant to sell any excess electricity to these communities. In order to fully meet the demands of these nearby communities an additional 7.0 MW_e would be required for a total of 29.0 MW_e [2].

3.4 Cogeneration Plants

According to the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC) database, there are 216 cogeneration plants in Canada, 185 for which there are publicly available capacity data [23] and which are not included in the remote communities and oil sands data. Of these power plants, 71 are known to be operating, 7 are not operating yet but will be in the future, and the status of the remaining plants are unknown but assumed to be operating. These power plants provide power for over 30 types of businesses, including paper manufacturing, hospitals, oil refining, chemical manufacturing, and gas extraction. A histogram of these power plants by electric power capacity, Figure 5, indicates that 70% of these power plants have capacities that are less than 30 MW_e, with the remainder roughly evenly spread up to 550 MW_e. According to the 2016 CIEEDAC report on cogeneration in Canada, cogeneration capacity has grown by 12% in between 2010 and 2015 [24]. Figure 5 also shows how much the number of cogeneration facilities would grow by the year 2025 assuming that this trend (i.e., 25% growth in 10 years) continues, and that the same growth occurs for each facility power range in the histogram (e.g., the number of cogeneration facilities with a capacity of less than 1 MW_e will grow at the same rate as the number of facilities with a capacity of between 1 MW_e and 5 MW_e). Although the capacity of an existing facility may be increased with the addition of generators, historically this has contributed only 7% of the growth in cogeneration capacity since the 1950s, therefore it is much more likely that future growth in cogeneration capacity will be mostly comprise of newly built power plants.

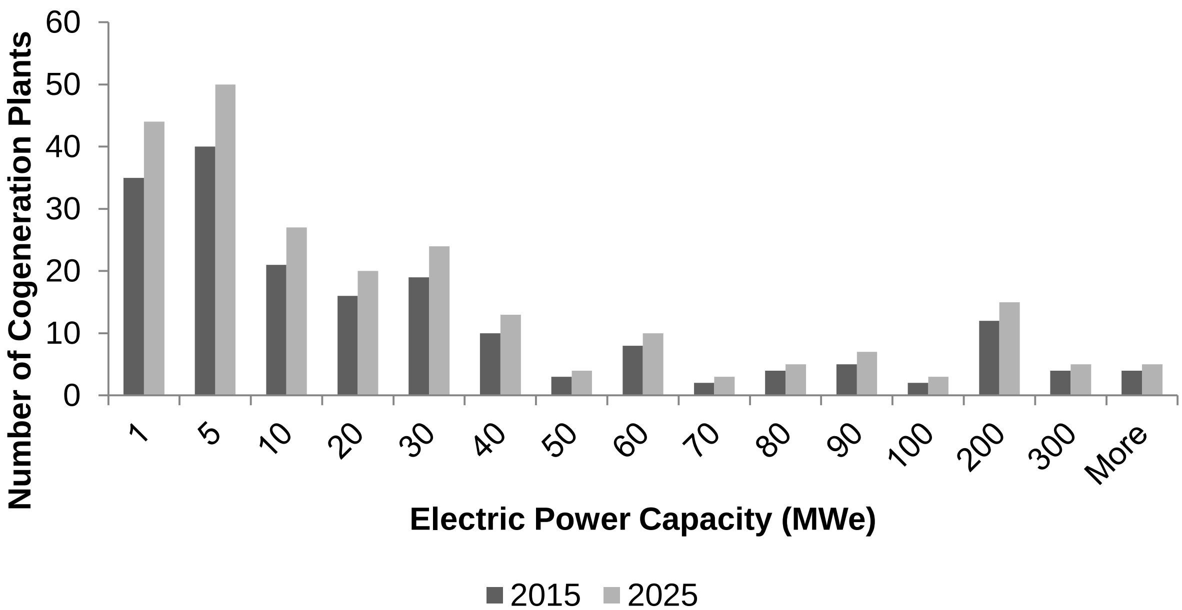

Figure 5. A histogram of cogeneration plants in Canada by electric power capacity

3.5 District Energy

According to Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC) database, there are 57 district energy systems operating in Canada, 47 for which there are publicly available capacity data [25] and which are not included in the remote communities, oil sands, or cogeneration facility data. A histogram of district energy systems, Figure 6, shows that 77% of these systems have a capacity less than the equivalent of 20 MW_e in 2015. Similar to Figure 5, Figure 6 also shows the projected power demands for the year 2025, assuming a continuation of the 4.5% growth in total installed capacity observed over the past 10 years, and all growth coming from the addition of new district energy systems.

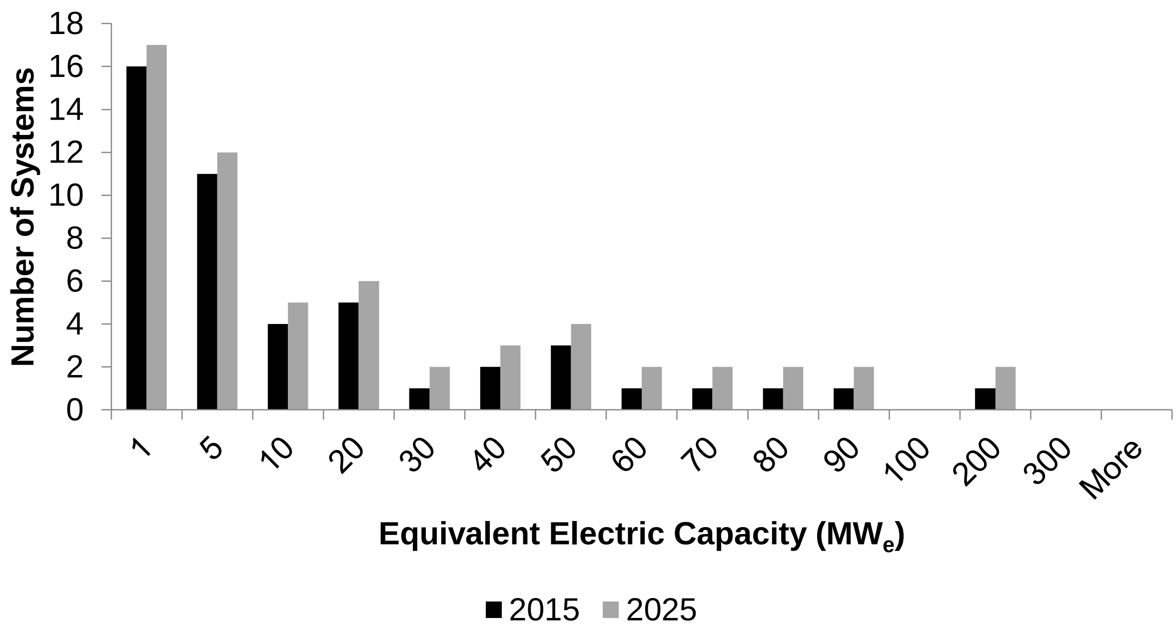

Figure 6. A histogram of district energy systems in Canada

3.6 Market Summary

Figure 7 shows the site power demands for remote communities, oil sands extraction projects, remote mines, cogeneration plants, and district energy systems. In total, the potential off-grid market for SMRs in Canada is comprised of over 600 sites for a total of over 35 GW_e. With respect to the number of sites, cogeneration and off-grid communities comprise the largest market with around 200 or more sites each. Oil sands extraction and upgrading operations have, by far, the highest total power demand (over 20 GW_e), which is over double the combined total of all other applications. The next highest total demand comes from cogeneration, with a total of nearly 10 GW_e.

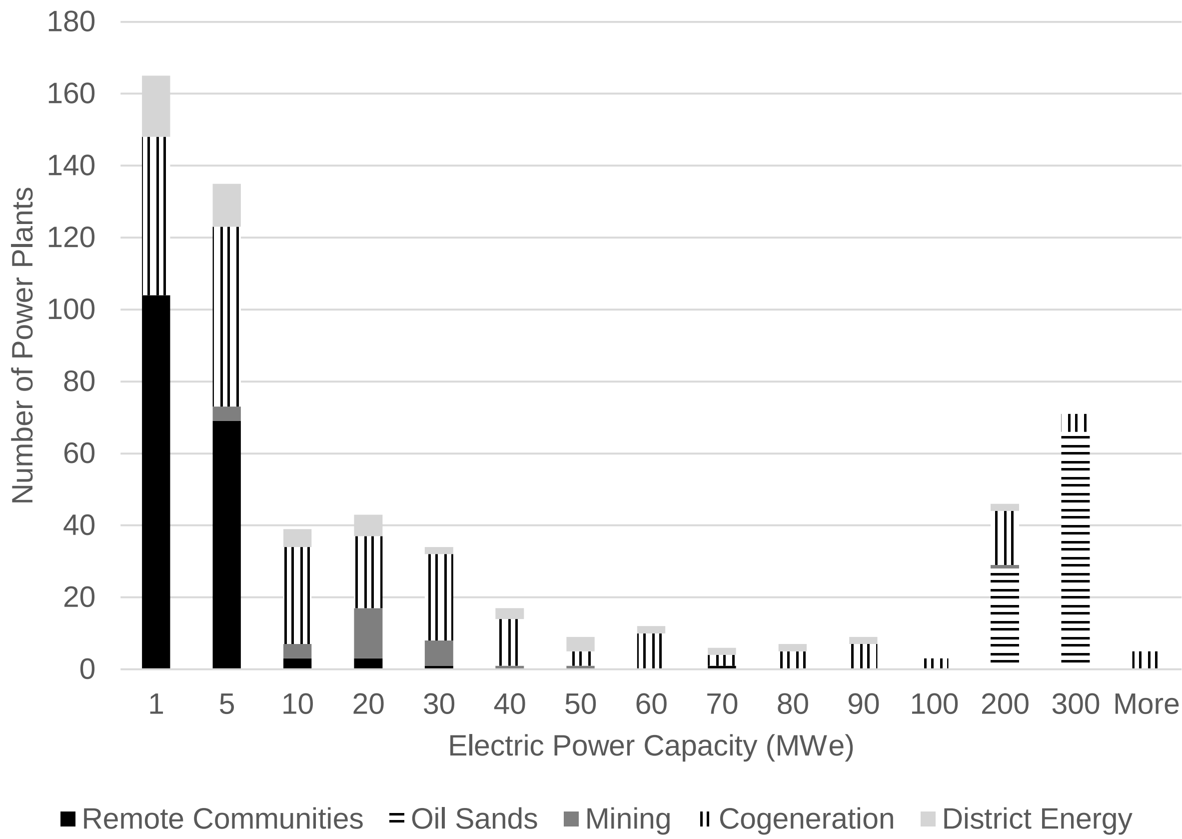

Figure 7. A histogram of the potential market for off-grid SMRs in Canada

4 Alternative Fuels for Off-grid Markets

Rather than installing SMRs at every site where power is needed, it may be more economical to install fewer, larger SMRs in central locations to produce fuel for these demands. This may be liquid synthetic fuel or hydrogen production from locally sourced feed materials. This synthetic fuel could be used to meet local fuel demand, with any excess fuel being transported to other sites. The potential advantages over on-site SMRs include the following:

- Better economics due to higher installed power at a given site (e.g., cost reductions through shared infrastructure).
- SMRs would not be required to operate in load following mode, improving economics.
- These SMRs may be placed at fewer sites and further from population centres, thus reducing the potential social and regulatory obstacles to siting nuclear power plants.

Such a system would not lead to significant improvement with regards to the transportation and storage of fuel at remote locations, except for the potential reduction in pollution if the SMR produced fuel is used to power the vehicles that transport the fuel.

5 Concluding Remarks

The potential market for SMRs in off-grid applications in Canada includes remote communities, remote mining projects, oil sands extraction and upgrading, cogeneration in a wide range of industries, and district energy systems. With over 600 sites, this potential market is quite large with respect to the number of sites. This market has a total power demand of 35 GW_e, although most of the sites require an installed capacity of less than 5 MW_e.

Due to incomplete data sets and uncertainties with respect to the state of power demands 10 years in the future, these results should be taken as a rough indication of the size of the potential market. Also, the results include sites with currently operating power plants, so the deployment of SMRs to these sites will be contingent on what role the existing power generators will have once the SMRs are installed. If they are to be taken out of service, then the deployment of SMRs may have to wait until the end of life of the existing generators.

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