Terry Thibodeau

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Municipality of the District of Digby

Grid capacity at Conway, Substation

For some time now the municipality has been involved in the greening of Digby County through myriad of efforts. For example, The introduction of a PACE (property assessed clean energy) or clean energy financing for energy efficient upgrades to homes. Another carbon reduction effort has been the conversion of 859 streetlights to LED. We have purchased 2 wind mills that we enjoy having a relation with NSP with providing NSP with clean wind power. Our region enjoys an abundance of natural resources which some people believe that our resources are among the most prevalent in the province. NSP will attest to that, the Digby Windfarm owned by NSP in Gullivers Cove is one of the best producing wind farms throught the province. However our main achilles heel for many aspirational goals is the inferior transmission grid (69kv) that extends from Tremont to Yarmouth. It has been playing havock with our ability to create the green environment that we feel that we can and should incorporate into our energy mix into the future. Here is a letter that we sent to the UARB expressing our concern over this lack of investment. We hope that it will help lead the discussion on future green projects for the region.

February 9, 2012

Clerk of the Board
Nova Scotia Utility and Review Board
Box 1692, Unit “M”
Halifax,
Nova Scotia.
B3J 3S3

Subject; Proposed Annual Capital Expenditure Plan (ACE Plan 2012) (NSPI)

Dear Sir/Madam;

Nova Scotia Power Inc., is applying for approval of its upcoming ACE Plan for the province. I am writing today to voice our concern regarding these expenditures with regards to the lack of emphasis being placed either on upgrades to our transmission line (69kv) in the Annapolis Valley or in investments to other areas of our grid system for improved efficiency.

Our grid system in Nova Scotia is antiquated and over time the upgrades in the system have been limited. It has been stated that the traditional North American grid system which we are part of, was conceived by Edison, designed by Eisenhower and installed by Nixon. This puts into perspective the nature of our archaic grid system in an era of modern technological advances both in hardware and in communications capabilities. Our region is actively pursuing the introduction of renewable energy technologies as a way to stimulate economic development in our region; a region facing difficult economic challenges, diminishing population and dwindling resources. In an effort to develop these opportunities in renewable energy developments, we engaged the services of Lockheed Martin to assess our ability to develop a CHP (combined heat and power) plant that would serve to generate electricity for the grid through the COMMFIT (community feed-in-tariff) program and to deliver inexpensive heat to several key facilities in Digby; namely the hospital, two schools, government buildings, an arena and private commercial properties. Not only would this investment allow these facilities to hedge against rising fuel costs in the future, but the overall reduction of GHG would be a significant benefit to the province as a whole.

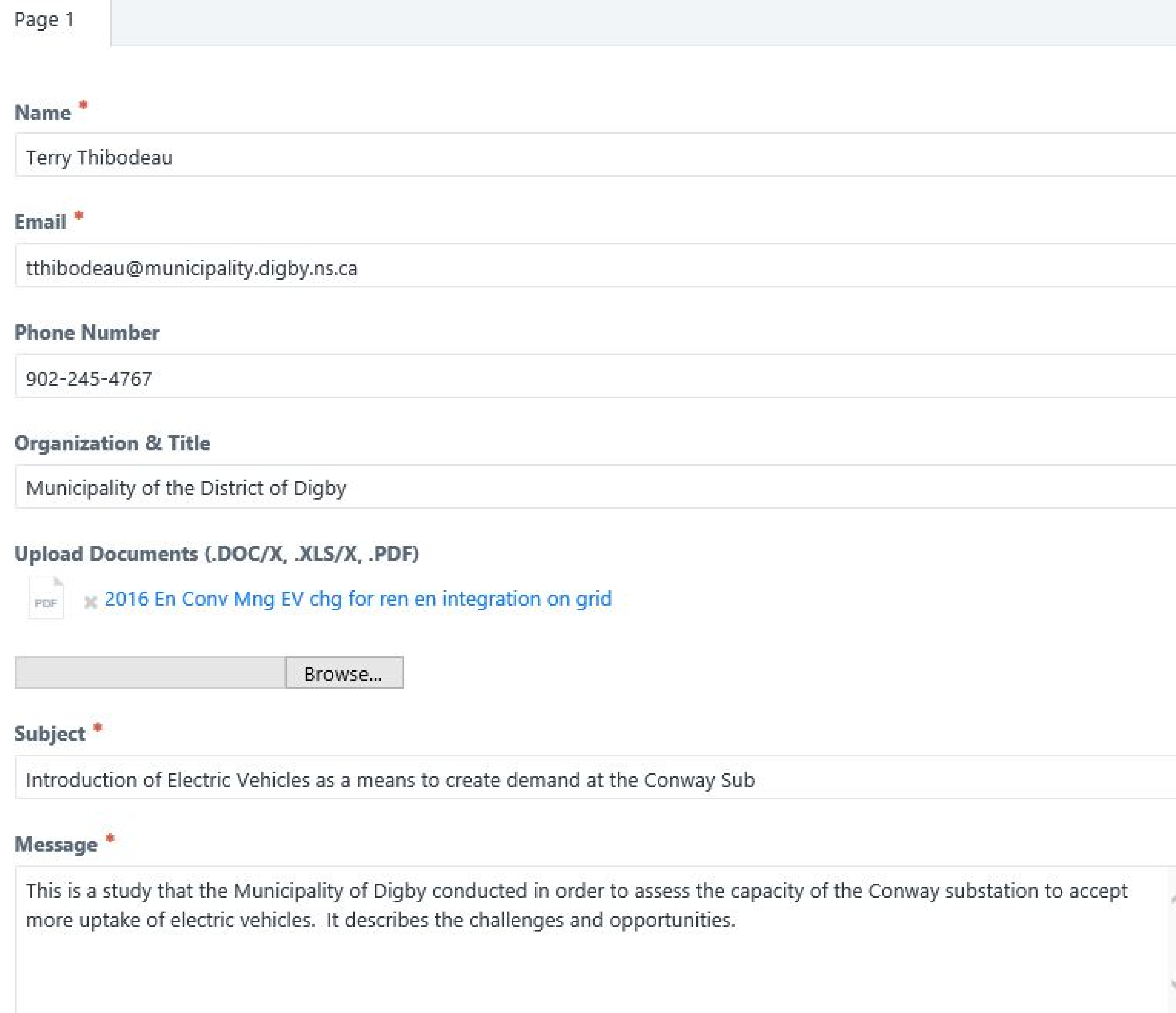
The consultants findings are summarized as follows; **“…there is significant risk that distribution interconnection may not be available, or that specialized interconnection equipment to mitigate the transmission impacts could be required in order to implement this project. It is not possible to further quantify the risk at this time”**. The consultants concluded that the current operational design of the transmission and distribution grid along with the age of the system has inherent flaws which prohibit the introduction of new electricity generating capacity coming from renewable energy projects including our efforts to establish a CHP plant.

The ability of the utility system to accommodate renewable energy technologies is very much driven by the degree of variability of these sources of energy and the utility's requirements to maintain reliability and voltages within mandated ranges. We are mindful that the rules and regulations that are in place are based on many years of operational experience and very difficult to change unless there are significant benefits. The variability of some renewable energy sources is often cited as the most challenging. Energy storage provides a way to overcome many of these challenges, but it still not very economical at this stage. Smart Grid technologies could also help with controlling voltage and redirecting power flows where possible. The requirement to regulate voltage in the future will be a deviation from the normal practice on the distribution system where only the utility has been allowed to do so, but the flicker and effects on voltage profiles on the feeders may ultimately lead to distributed voltage or reactive power flow control.

We are concerned as well, that as the province develops opportunities accruing from the Muskrat Falls project that it will see these investments as meeting its renewable energy targets established under the Environmental Goals and Prosperity Act and will serve to send a negative message to the utility about further upgrades to our valley transmission lines. **NO PLANNED INVESTMENT IN THE VALLEY REGION IS PROJECTED THIS YEAR NOR IN THE FORESEEABLE FUTURE**.   This is troubling from a municipal perspective given our attempts to create economic development through the introduction of renewable energy technologies in tidal, wind and biomass. Our wish is to see evidence that the utility is genuinely concerned about the same issues and that there is a willingness on their part to invest in the types of upgrades that would accommodate the introduction of renewable energy technologies in the future.

Sincerely

Terry Thibodeau
Coordinator
Renewable Energy and Climate Change



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Municipality of the District of Digby

Upload Documents (.DOC/X, .XLS/X, .PDF)

2016 En Conv Mng EV chg for ren en integration on grid

Subject *

Introduction of Electric Vehicles as a means to create demand at the Conway Sub

Message *

This is a study that the Municipality of Digby conducted in order to assess the capacity of the Conway substation to accept more uptake of electric vehicles. It describes the challenges and opportunities.

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Electric vehicle charging to support renewable energy integration in a capacity constrained electricity grid

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A B S T R A C T

Digby, Nova Scotia, is a largely rural area with a wealth of renewable energy resources, principally wind and tidal. Digby's electrical load is serviced by an aging 69 kV transmission line that often operates at the export capacity limit because of a local wind energy converter (WEC) field. This study examines the potential of smart charging of electric vehicles (EVs) to achieve two objectives: (1) add load so as to increase export capacity; (2) charge EVs using renewable energy.

Multiple survey instruments were used to determine transportation energy needs and travel timing. These were used to create EV charging load timeseries based on "convenience", "time-of-day", and idealized "smart" charging. These charging scenarios were evaluated in combination with high resolution data of generation at the wind field, electrical flow through the transmission system, and electricity load.

With a 10% adoption rate of EVs, time-of-day charging increased local renewable energy usage by 20% and enables marginal WEC upgrading. Smart charging increases charging by local renewable energy by 73%. More significantly, it adds 3 MW of load when power exports face constraints, allowing enough additional renewable electricity generation capacity to fully power those vehicles.

1. Introduction

The Municipality of Digby (Fig. 1, left) is embarking on an ambitious strategy to alter its energy consumption and production, for greater utilization of locally produced renewable energy. Transportation represents a major energy end-user, totalling 38% of all energy used in Nova Scotia [1]. This energy comes almost entirely in the form of gasoline and diesel. While Canada has significant fossil fuel resources, there is no petroleum production in Nova Scotia, so transportation fuels represent a significant economic trade deficit for the region. In contrast, Nova Scotia in general, and the Digby area in particular, have superb renewable energy resources consisting principally of wind and tidal flows [2,3]. Electric vehicles (EVs) which have greatly increased efficiency compared with internal combustion engines, thus represent an opportunity to not only vastly reduce energy consumption for transportation, but also to transition from imported fossil fuels to locally produced renewable energy.

The electrical transmission system of the area is shown in Fig. 1 (right). It consists of 69 kV lines servicing the Town of Digby via Conway Substation. Other 69 kV lines connect nearby communities and collect from small hydroelectric facilities inland. In 2010 a 30 MW wind energy converter (WEC) field, consisting of twenty GE 1.5 MW units, was commissioned on the Digby Neck, causing Digby to become a net exporter of electricity. This 30 MW wind field was sized to meet summertime transmission export limits when local loads are at their minimum. As a consequence, further development of renewable electricity generation is not permitted, absent one of three conditions: Either (1) the transmission system is upgraded to increase the export capacity, (2) renewable generation must be curtailed when transmission limits are reached, or (3) electrical load must be added locally, so that the additional power produced can be used locally and not contribute to overloading of the transmission system.

Option 1 is not being considered by the provincial electricity system manager in short or long term planning because it would be prohibitively expensive. Option 2, while not presently supported by the grid manager, is a reactive approach that is undesirable due to the loss in renewable energy caused by curtailment. It is under the premise of Option 3 that this study is conducted. The addition of EVs adds load to the local electricity network. By evaluating the time-dependent load of charging EVs and their interaction with existing loads and generation, this study will quantify the influence of EVs on the electricity grid for a local region, and the use of renewable electricity generation for powering those EVs.

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Nomenclature

EV	electric vehicle
TOD	time of day; electric rates that vary ($/kW h) on a fixed schedule
WEC	wind energy converter (wind turbine)

The use of energy storage and dispatchable load to manage variations in renewable energy output is a problem of nearly universal concern in utility management as non-dispatchable renewable energy sources become a significant contributor to total energy and grid instability [4–7]. Applying the possible grid management benefits of EV charging to achieve a specific grid management objective is of great interest to governments and utilities [8,9], so this case study, which benefits from well-defined grid constraints and precise grid loading data, may be of particular interest to policy makers.

The interaction of EVs that plug into the electrical system, and the electrical system itself rely entirely on an accurate understanding of when EVs are used, how much energy they consume when they are used, and when they are returned to a location where they can plug in and charge. The significance of the driving patterns is made doubly important when one considers three possible effects of EVs on the energy system [10]. One possibility is an undesirable evening peak in load that could occur if charging rates and timing are unconstrained, referred to here as “convenience charging”. The second is to respond to “time of day” (TOD) electricity rates with a charge timer, in which case an evening load peak is avoided and loads overnight are increased, but no more finely tailored benefits can be realized [11,12]. The third possibility is “smart charging”, which is managed by grid operator intelligence and real-time control, in which EV charging loads become a controllable resource providing valuable grid services.

Any charging strategies that are successful in reducing or controlling the export transmission loads could correspondingly permit increased local generation capacity. General Electric (GE), the manufacturer of the WECs in use at the wind field have developed a control software update titled WindBOOST, which increases the maximum power output by 10%, from 1.5 MW to 1.65 MW. This modification could be implemented at negligible cost, and would increase WEC field power capability to 33 MW, and annual average energy production by roughly 4% [13,14]. As an objective, this study investigates the potential of adding controlled EV charging, thus allowing the WindBOOST upgrade, with the intent that the added energy production would be sufficient to provide the necessary energy to charge the EVs, making them a net benefit to Nova Scotia’s grid.

2. Data sources/research methods

To conduct a thorough investigation of EVs and their impacts upon the electrical grid requires an understanding of the present transportation fleet in Digby with respect to both vehicle populations and vehicle use. Specifically, to understand the energy requirements of vehicles, it is necessary to know (1) how many vehicles of various types are in use in the area, (2) how much energy these vehicles use each day (how far they drive and how much fuel is consumed to do so), and (3) during what period of the day, and particularly when at the end of the working day, they are parked, indicating when vehicles would plug into the electricity grid. With those data and an assumed adoption rate of EVs, grid impacts can be estimated.

The following subsections describe the regions of analysis, the data sources related to vehicle populations in the area, the survey tools used to gather vehicle use information, and the data available on grid loading and renewable electricity generation.

2.1. Vehicle populations

The total vehicle population in Digby comes from Provincial vehicle registration data [15], however, the population served by

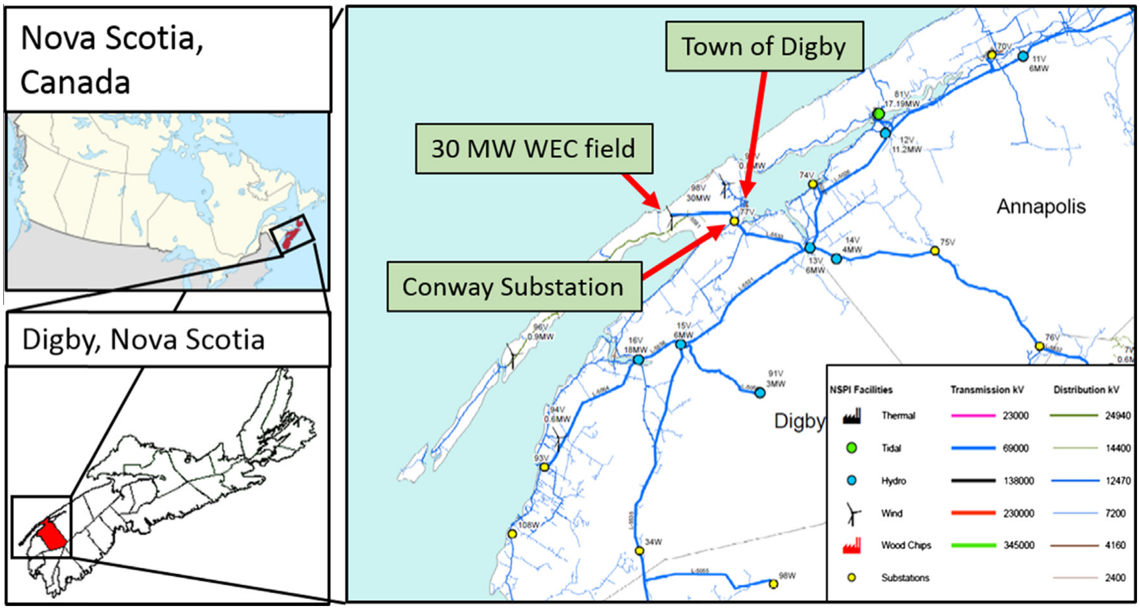

Fig. 1. Location of Digby (left) and transmission and distribution maps (right).

the Conway electrical substation (Fig. 1) does not correspond to a specific Provincial jurisdiction. The inferred population of vehicles must therefore be computed by scaling data from:

- The Town of Digby with an area of approximately 3 km^2 and a population of 2152.
- Digby County, consisting of the Town (above) and two Municipal Districts which combined have an area of approximately 2515 km^2 and a population of 18,036.

To establish the population served by Conway, estimates of Town and Municipal population were combined with a building count using satellite imagery. The resulting population estimate for the Conway service area is 9000 people. Table 1 groups the transportation fleet of Digby by vehicle type, lists how many of each type are registered in the Town and in the County, and gives the proportional vehicle population serviced by Conway Substation (Fig. 1, right), corresponding to this population estimate.

Table 1
Classes of vehicles, estimated numbers that operate in the regions of analysis in Digby.

Vehicle type	Digby Town (count)	Conway Area (estimate)	Digby County (count)
Population	2152	9000	18,036
Motorcycle	74	316	646
Small car	353	1275	2151
Medium car	347	1238	2053
Large car	247	884	1472
Van/SUV	131	504	921
Pickup	370	1577	3218
ATV	76	401	971
Bus (diesel)	0	9	38
School bus (diesel)	0	3	13
Freight van (diesel)	105	356	546

2.2. Vehicle use

To gather information on vehicle use, energy consumption, and the timing when EVs would be plugged-in, a variety of survey techniques were used.

To gather information on business vehicles, a selection of businesses in Digby County were interviewed by telephone. The selection of business types called for this study was made based on the perceived likelihood that they would have commercial vehicles (i.e. registered vehicles used exclusively or primarily by the business). Forty-seven business were interviewed by phone. Respondents were asked what business vehicles they used, how much they were used, and when during the day such use took place. Where specific information was not provided, average values for the vehicle type were used.

To gather the corresponding information about Digby area household vehicle use, both telephone and online survey methods were used. A total of 22 households were interviewed in depth in telephone surveys. In addition, there were 79 unique responses to an online survey that was promoted on the Municipality's web-site, and a newspaper advertisement.

2.3. Renewable generation and load

A variety of data concerning local, regional, and provincial electrical system conditions, including WEC field production, were available for this research, supplied by the provincial utility, Nova Scotia Power Inc. or its affiliates. The variables available to this research are shown in Table 2 (refer also to Fig. 1, right, for a map of electrical grid infrastructure). Note that for most of the system loading analysis, power transmitted on L5581 is used for the WEC field output, rather than the turbine data referred to in the first line of Table 2.

3. Analytical methods

In this section, the steps taken to transform the survey and energy system data into an impact analysis are described.

3.1. Annual electricity consumption of a Digby electric vehicle population

In order to determine the cumulative impacts of EVs in Digby, we assume an adoption rate corresponding uniformly to all vehicle classes of 10% (approximately 600 count). Although aggressive, it is attainable over the medium term given both local and provincial transportation electrification policies [16]. Regardless of technological advances and economies of scale of EVs to support consumer purchase, an adoption rate of 10% takes significant time because of the role-over time of the existing fleet.

These adoption rates do not take into account the differences in behaviors of commercial and private vehicle owners. Commercial vehicle owners may have the financial tools to amortize a high upfront cost and recoup it through operational savings, where private vehicle owners may not; however, private vehicle owners presently have a more comprehensive market and more local dealer engagement. Estimating how these aspects will play off against each other in the coming years is a challenge, so we have defaulted to the equal adoption assumption.

3.2. Electric vehicle charging scenarios

There are three scenarios of EV charging control that represent a range of technology and vehicle – grid interactivity. In this section they are described in the context of how they might operate in the Digby area.

3.2.1. Scenario: Convenience charging

The "convenience charging" case is conceptually similar to mobile phones, in that the vehicle is plugged in and charged right away upon reaching a charge station, without regard to the time of day or the effect on the grid. In this scenario, EVs are likely plugged in immediately upon arriving at a destination, typically home, and are charged until they are full. The control logic for this charging scenario is detailed in Fig. 2. The effect of this charging behavior would not be very different in Digby than in other regions where this scenario results in a charging load peak between 17 h and 19 h [17,18], unless there are systematic differences in the driving patterns of vehicles. The majority of EVs presently in Nova Scotia charge using convenience charging, because no provincial or utility policy exists to motivate any other behavior.

3.2.2. Scenario: Time of day charging

Nova Scotia has in place a "time of day" (TOD) residential electricity tariff, presently available to households with electric-thermal-storage. Three different rates are applied to electrical energy consumed at different times of the day, week, and year. The three rates represent a significant variation in price, especially during the winter peaking months of December through February, as illustrated in Fig. 3 [19].

While the rate structure shown in Fig. 3 is somewhat complex, for the purposes of this analysis the assumed response by EV drivers to this TOD charging scenario will be to delay charging through the use of a charge timer until after 23 h if possible,

Table 2
Digby electricity infrastructure measured data points and sampling rates.

Category	Name	Detail	Variables	Sampling rate	Data collection period
Generation	WEC field	30 MW capacity	Wind speed, wind direction, ambient temperature, real power, etc.	10 min	Jan 2011–Dec 2013
Transmission	Line L-5581	Connects WEC field to Conway	Real power, reactive power	20 s	Jan 2014–Jun 2014
	Line L-5533	Connects Conway to Provincial grid			
Distribution	Distribution lines 301 302, 303	Connects Conway to Digby loads	3-phase currents		
Substation	Conway (77 V)	Transformer	Primary voltage	1 min	

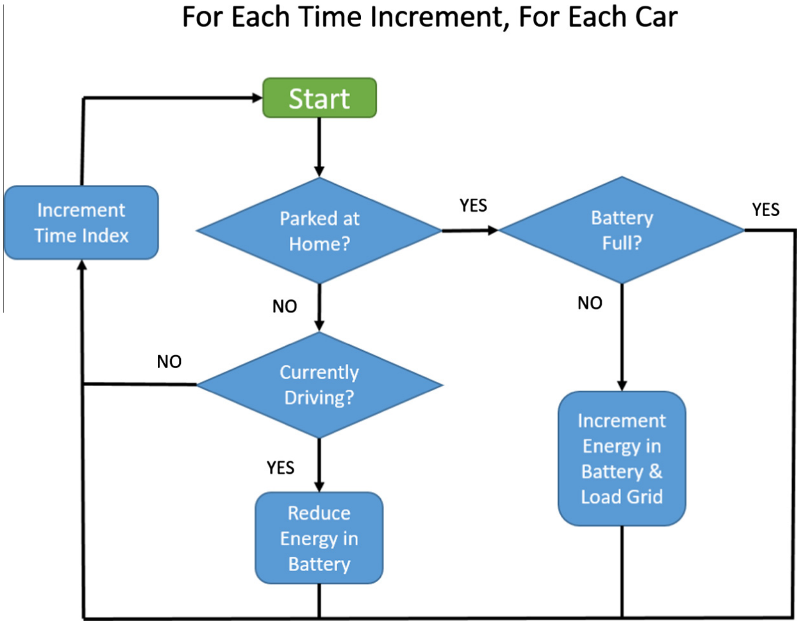

Fig. 2. Logic diagram for “Simple Charging” algorithm. The output is a load profile of each vehicle, which are then aggregated to become fleet charging loads.

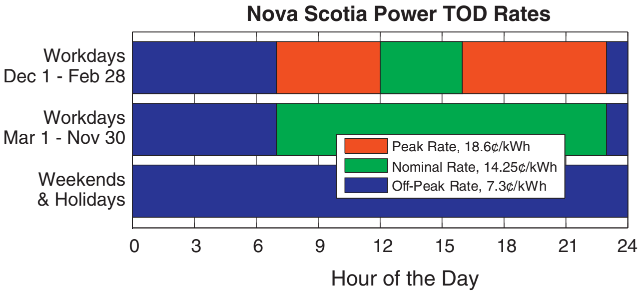

Fig. 3. Nova Scotia Power domestic service time-of-day electricity tariff schedule.

regardless of the day of the week, or the season of the year. While a more complex response is possible, it is unlikely that charge timing would differentiate between workdays and weekends, and so is uniformly applied for this study. The control logic for this charging scenario is detailed in Fig. 4. It is almost identical in structure to that used for simple charging, with the added test to insure charging does not take place during the day.

3.2.3. Scenario: Smart charging

In a “smart charging” scenario, the EV is responsive to conditions and constraints which exist on the electricity grid or in electricity markets. In Digby, the constraint of interest is power export on transmission line L-5533 (see Fig. 1). When the WEC field is at maximum generating capacity (30 MW), and the Digby load is low, the transmission line reaches its export limitation. With real-time monitoring, coupled with signalling, the net export on this transmission line could be used to signal EVs the preferred time to charge, and how fast to charge. When signalled, all the EVs with any flexible or discretionary charging capacity (i.e., those vehicles that are plugged in but not already charging) could begin charging, thereby increasing the Digby load and decreasing the net electricity export.

To model the effects of such a strategy, each 24 h period (noon to noon, so overnight discontinuities are avoided) was examined in isolation, and charging loads were added to periods when export power was at its highest for the period. The control logic for the smart charging scenario is detailed in Fig. 5. The logical structure of this scenario is significantly different from those of the previous two (Figs. 2 and 4), most notably because the unit of analysis is the 24 h period, rather than each vehicle. It should be noted that in the model as configured, a perfect response to this signal was used. In reality, any charging signal based on either a fixed schedule (TOD), or based on some real-time external signal, would only be a suggestion or a price difference, not a strict command. By default, when the vehicle requires charging for an imminent trip, charging will take place regardless of the grid impacts.

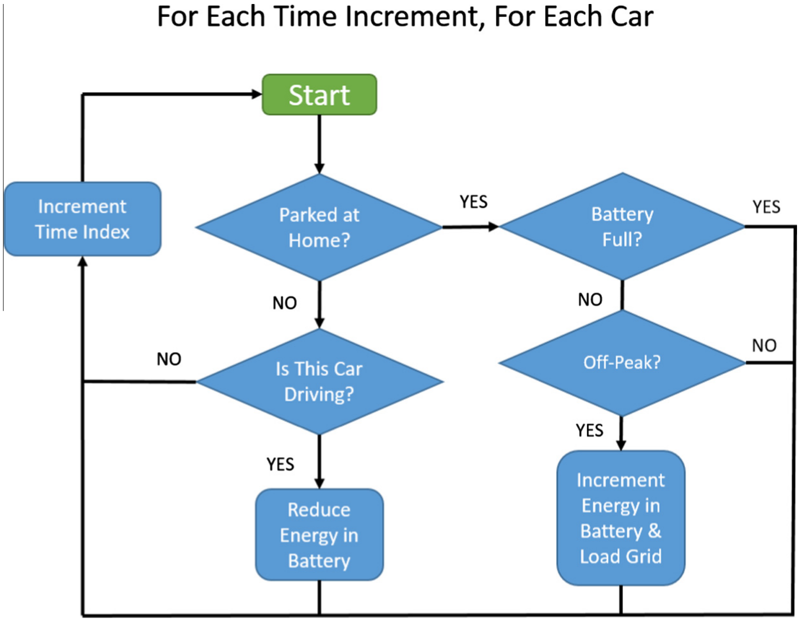

Fig. 4. Logic diagram for "TOD Charging" algorithm. Output is load profile of each vehicle, which are then aggregated to become fleet charging loads.

3.3. Creating load profiles

Based on the vehicle counts in Table 1 and coverage of the Conway Substation in Fig. 1, we assume 6000 vehicles exist in the area, and that the 10% adoption rate gives 600 EVs. Based on the survey of driving patterns, and vehicle class specific energy needs, Digby's EVs would need an average of 15 kW h per day, representing a fleet average of passenger and commercial vehicles. While this value is 2–3 times the daily energy needs assumed by some previous studies [9,20], this difference can be largely attributed to the assumption made here of proportional EV adoption across all vehicle classes, while those studies focused on small and mid-sized passenger cars.

The outputs of the vehicle use surveys were a set of individual vehicle use patterns and average daily energy needs on generic weekdays and generic weekend days. For each vehicle, these outputs were used to construct individual charging load profiles for convenience charging by drawing electrical load right away when returned to a home parking location, or for TOD charging by drawing load at 23 h if parked at home (refer to Section 3.2).

For the class of private vehicles and the class of business EVs, the average loads of all survey respondents' vehicles were proportioned equally to that of the total population of privately owned and commercial vehicles, respectively. Commercial and private charging load profiles were then multiplied by the presumed adoption fraction for each class (10% for both), and summed together to produce a regional vehicle fleet charging load for each day class, for each of the first two charging scenarios.

To produce a smart charging load profile, the sum of vehicle energy was used to 'fill' the points of greatest export power in each noon to noon 'day'. For example, at a historical export power peak of −25 MW, a modified peak export power of −24.99 MW was specified, and the difference in energy between an export power timeseries bottoming out on the modified peak and one following the historical data was computed. If that summed energy was less than the necessary driving energy for the fleet, then the modified peak export power was increased again to −24.98 MW. This process was iterated until the difference between the original and 'capped' export energy curves was equal to the energy needs of the EV fleet. This process is illustrated as a flow diagram in Fig. 5.

This methodology for smart charging could, in theory, require charging at any time, and possibly when a significant fraction of the fleet was not parked. However, this does not adversely affect the analytical results, because problematic peaks in power export

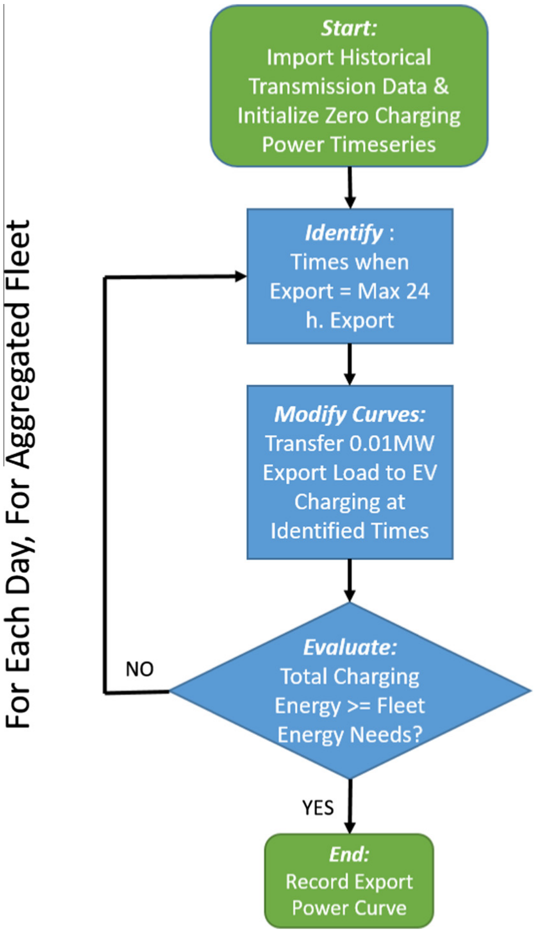

Fig. 5. Logic diagram for "Smart Charging" algorithm. Output is load profile of each 24 h period, which are then compiled in sequence to become fleet charging loads.

can only occur when *both* wind production is high *and* when local loads are low, and the later condition occurs only at night. Thus the test points for the system, the times at which the transmission system nears capacity limit, can only be at night when most vehicles are parked.

4. Results

In this section, the interactions and influence of EVs on the electric grid are discussed, with a focus on how they would relate to renewable electricity generation in Digby.

4.1. Description of existing conditions

Fig. 6 shows monthly average, and maximum and minimum electricity load in Digby, and generation at the WEC field. These data are from 2014, and 2012 through 2013 respectively, and it can be noted that only six months of data are available for Digby as the substation monitoring equipment was recently installed. These various years are not expected to affect the trending shown in Fig. 6.

In general, load in winter is higher than the load in summer, due to increased need for space- and water-heating, and increased need for artificial light as daylight hours recede. Similarly, winds are stronger in winter, and thus WEC field generated electricity follows a similar seasonal pattern. The WEC field generation averages 13 MW, while Digby averages roughly 8.8 MW of load, meaning the Digby region is an annual net exporter of electricity. Also shown on Fig. 6 are monthly maximum and minimum values as range bars about the averages. It can be seen that Digby's load can reach well above 18 MW, though only briefly, and can also drop to zero (during a power outage). The WEC field's output is continuously variable, achieving slightly more than its rated capacity of 30 MW and also becoming a small net load (<0 MW) within every month.

Of greater interest for EVs charging and grid management, Fig. 7 shows the hourly average load for each of six pairs of months, and shows how load and wind generation vary throughout the day. The different colored lines show different daily profiles characteristic of different seasons. From Fig. 7, the load in Digby (top), in both cold and warm months can be seen to drop by 2–3 MW overnight, with a minimum occurring between 2 h and 4 h. During the winter months, loads peaks twice daily, in the late morning and again in evening. This is characteristic of areas with electric heat that is often turned down at night when businesses are empty and people are asleep, and in homes during the day when people are at work.[1]

The hourly average electricity generation of 30 MW WEC field (Fig. 7, bottom) exhibits a different pattern. Wind turbine generation is typically higher during the night and lower during the day. This is especially apparent in Jul–Aug, when average wind output averages just over 5 MW (17% of nameplate capacity) at 12 h, and a peaks at 12 MW at 21–22 h. This is substantial variation considering it is an average over 120 days (two months for two years).

As Fig. 7 suggests, the probability of Digby exporting electricity, is a function of both the season and the time of day. This probability is more fully described in Fig. 8. Both heating loads and wind production increase during the winter, but the frequency of exporting power are more closely tied to the variations in WEC power output, so in colder months, exports are more common. Over the day, the negative correlation between load, which peaks during the day, and WEC output, which peaks at night, mean that exports are always 20–25% more likely at night.

Of course Figs. 7 and 8 represent general trends only, and at any given time of the year, the WEC field might be producing nothing, or might be at its maximum output of 30+ MW.

4.2. Impact of EV charging on the electricity grid

To illustrate the impacts of the three charging scenarios on the electricity grid we examine the first week of June, 2014, as shown in Fig. 9. During this period, Digby Load ([2]red, right axis) was quite low at 4–8 MW. The WEC field's generation (green, left axis) experienced both periods of low generation (such as June 3) and high generation (June 6). Consequently, Transmission Line L-5533 (blue, left axis) experiences periods of net import (positive values, e.g. June 3), and net export (negative values, e.g. June 6). The reader should note that export values approaching −26 MW are of concern because of transmission constraints.

In Fig. 10, the fleet charging load profiles described in Section 3.2 are plotted as a timeseries for the same week in June, 2014, along with the unmodified export power timeseries from Fig. 9. Charging loads for convenience charging (yellow), TOD charging (cyan) and ideal smart charging (magenta) are read on the right axis, while unmodified export power on L-5533 (blue) is read on the left axis to clearly illustrate times of concern for export.

Fig. 10 shows that convenience charging (yellow) adds about 2 MW of load quite consistently, with the load somewhat normally distributed around 17 h. This is the likely EV load scenario if no policy and/or tariff is put in place to encourage EVs to charge at specific times. The TOD charging scenario (cyan) will add over 4 MW of load (slightly less on weekends), which ramps up quickly every night beginning at 23 h. The smart charging scenario (magenta) can add as much as 6 MW of load (10 kW per vehicle), coordinated precisely with each day's peak exports on L-5533. It is evident that smart charging is highly variable in power, which will cause EVs to charge at various rates when signalled. It is likely that EV owners would be willing to accept such signals given an appropriate tariff or incentive, so long as they occurred overnight, thus having minimal impact on vehicle readiness for travel.

Note that, when the assumed smart charging logic is applied to June 3 (a low wind day) it causes the majority of the charging to occur in the morning when vehicles are likely in use. As previously stated, this unrealistic behavior is not problematic for the overall results, because such conditions, when local loads are not at their minimum, do not negatively impact the export transmission infrastructure.

Examining the loads within the local distribution area, the three charging algorithms result in significantly modified load profiles, shown in Fig. 11. This is an aggressive case (10% adoption rate) used to demonstrate the trends and impacts of EVs on the electricity grid.

The size of these changes to the local load profile is striking. The magnitude of these responses is due to the relative scales of variations in local load and variations in wind output. Convenience charging (yellow) adds significantly to the evening loads, causing the daily load variability to increase from about 4 MW (peak to trough) to 5 or 6 MW. TOD charging (cyan) adds load when they are low overnight, and it can be clearly identified that these start at 23 h with the drop in electricity cost. Load due to smart charging (magenta), is both inconsistent in timing, and abrupt, though Fig. 11 shows that it does exhibit some correspondence to charging at times of low load.

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[1] A comparison to Provincial load data suggest that Jul–Aug and Sep–Oct load curves would likely be similar to those of May–Jun, while the load curve for Nov–Dec would lie between those of Jan–Feb and Mar–Apr.

[2] For interpretation of color in Figs. 9–13, the reader is referred to the web version of this article.

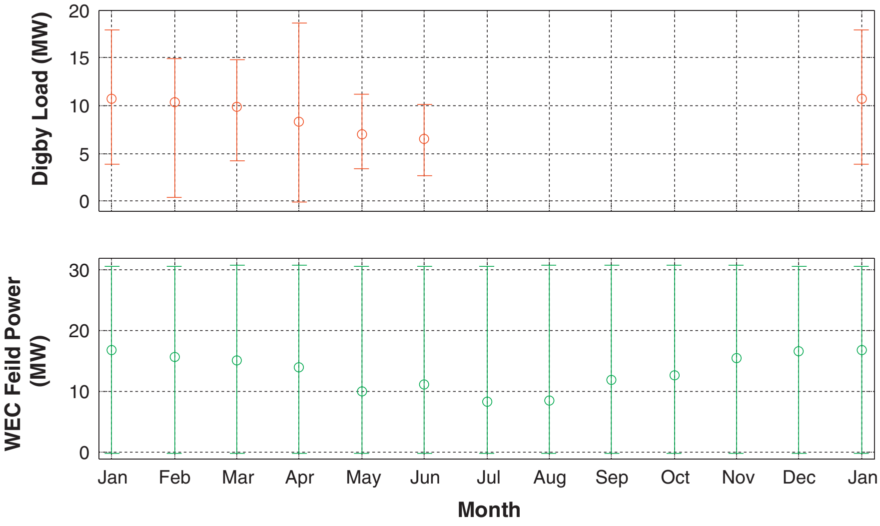

Fig. 6. Monthly average electricity power shown with 5 min maximum and minimum values as range bars for Digby load (top, red), and 30 MW WEC field generation (bottom, green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

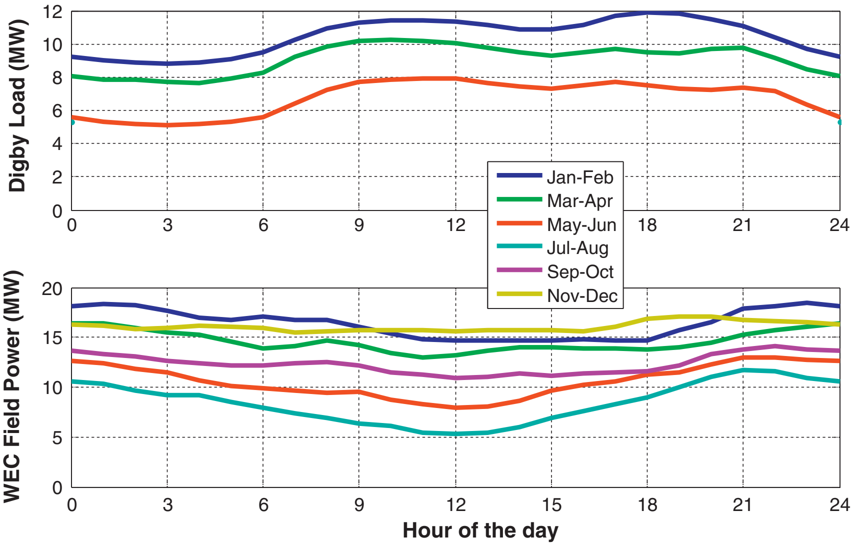

Fig. 7. Average electricity power as a function of month pairs (colored) for Digby load (top), and 30 MW WEC field generation (bottom). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

To determine how EVs might actually help provide load to address the grid constraint on Transmission L-5533, their influence is directly applied to L-5533 power to create a modified load time-series in Fig. 12.

In Fig. 12, it can be seen that convenience charging (yellow) does modify the L-5533 export. On June 4, it is not helpful, adding load when L-5533 was importing electricity already. On June 5 convenience charging happens to reduce relatively high exports, but not reduce the maximum exports of the day. TOD charging (cyan) also provides helpful load to modify L-5533. It reduced exports from −23 MW to −21 MW on June 5. It is also helpful on June 6. Smart charging (magenta) is seen in Fig. 12 to cause highly controlled load variation on L-5533. This can be noted by the horizontal magenta lines delineating modified exports. On June 5 it reduces export from −23 MW to −19 MW. On June 6 it reduces export from −24 MW to −22 MW. These modification occur precisely when required, as this is an idealized implementation.

To more broadly quantify the effects of charging algorithm, each was applied to every day during the first half of 2014, the period for which detailed generation output and transmission system data were available. The original export power curve and the three resulting modified export power curves were then sorted into

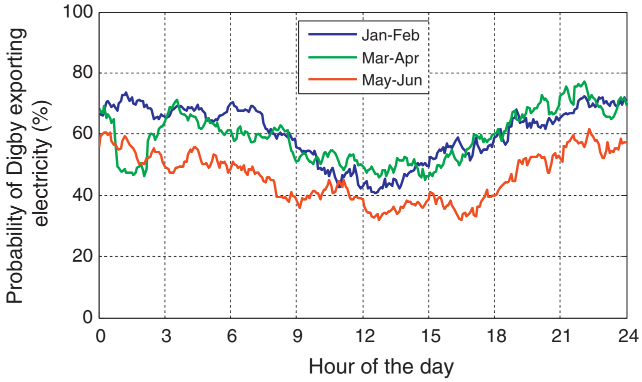

Fig. 8. Probability of Digby exporting electricity through the year.

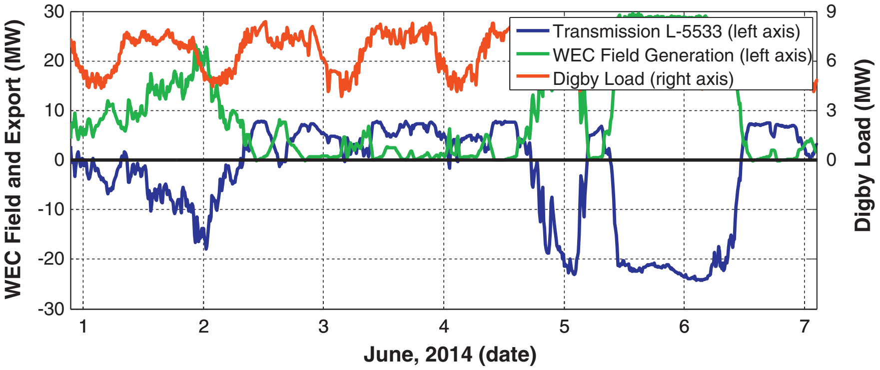

Fig. 9. Electricity flows of transmission, generation, and load in Digby in June.

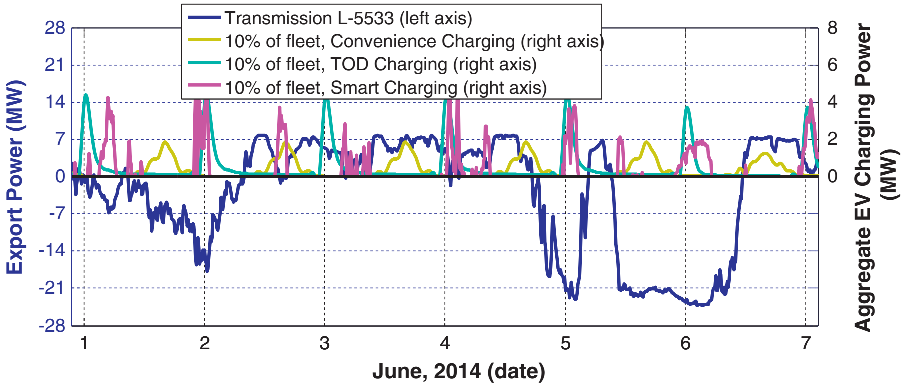

Fig. 10. Electricity profiles of convenience, TOD, and smart charging compared with unmodified Transmission L-5533 in June.

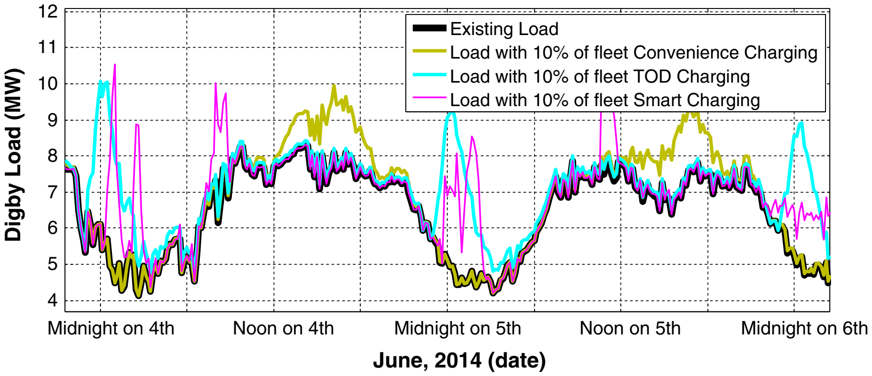

Fig. 11. Time-series plot of electricity demand on the distribution lines out of Conway substation (77 V) in the first week of June, 2014, given three possible EV charging scenarios being implemented by 10% of the vehicle fleet.

exceedance probability curves, which are presented in Fig. 13 in linear (left) and logarithmic (right) plots.

The plot on the left of Fig. 13 shows a broad range of export powers, and shows that all charging algorithms reduce the frequency of exports somewhat compared to the existing export exceedance probability (black line). However, export powers below about 23 MW are of no concern since they do not challenge the transmission capacity. In the right plot of Fig. 13 the same data are shown in greater detail, showing only exports between 22 MW and 27 MW, which correspond to exceedance probabilities of about 2% and less, and using a logarithmical distribution for the *y*-axis. From the right plot of Fig. 13, it is evident that convenience charging (yellow) has very little effect on the most challenging export conditions. In contrast, TOD charging (cyan) reduces the worst exports by about 0.6 MW, while Ideal Smart Charging (magenta) reduces the worst exports by 3 MW.

5. Discussion

Because of the high probability that Digby will be a net exporter of renewable energy at any given time (as shown in Fig. 8), any EV charging in Digby will often be using locally generated renewable electricity. Specifically, even using the convenience charging algorithm, about 49% of EVs' energy would be from local WEC output. Using the TOD charging strategy, this fraction is improved to 59%, as charging events are pushed to the overnight hours when exports are more likely (Fig. 8). Using real-time control to find each day's

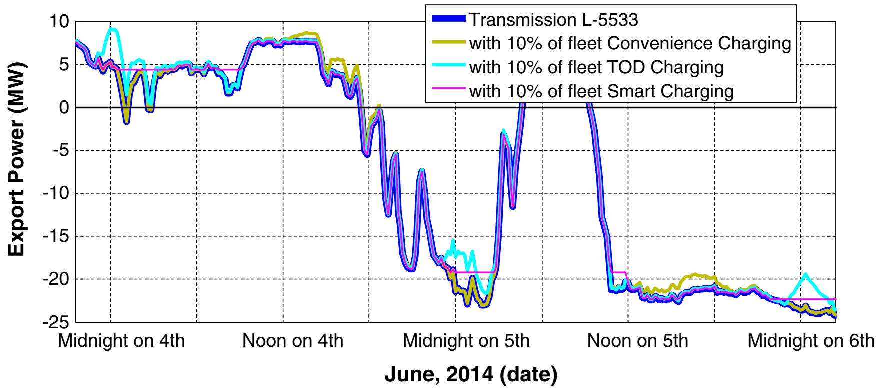

Fig. 12. Time-series plot of electricity exports out of the Digby Neck area in the first week of June, 2014. The unmodified line power (black line), and line power resulting from three EV charging algorithms are shown (green, red, and cyan). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

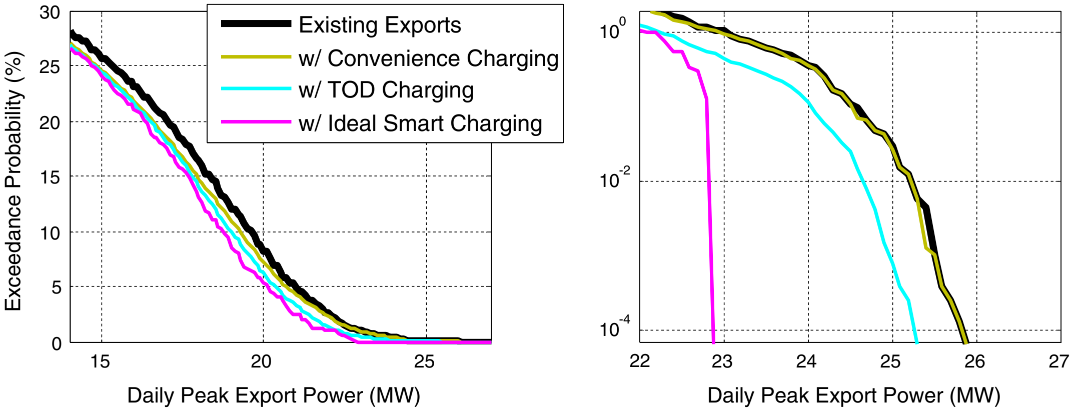

Fig. 13. Line 5533 export power, exceedance probability, showing effects of three charging strategies applied to 10% of Digby vehicle fleet.

period of peak export in the smart charging algorithm means that 85% of the time EVs would charge from local WEC-sourced power.

While these fractions make EVs seem attractive for local consumers, it is worth noting that any renewable electricity subtracted from the greater grid supply will require additional generation elsewhere [21]. Thus the greater question is whether any charging strategies can facilitate adding increased renewables to the grid, and whether such additional capacity can make up for the additional energy demand to power the EV fleet. This question can be answered from the preceding analysis, as shown in Fig. 14 and discussed below.

The TOD charging strategy, implemented for 10% of Digby's vehicle fleet, has been found to reduce export peaks by about 0.6 MW. At the same time, the fleet consumes about 9 MW h of electricity each day. In order for 0.6 MW of additional capacity to provide the annual energy to power such a fleet, it would need to have an annual capacity factor of about 62%. Thus the answer to the question of whether these additional cars can be powered from local renewable electricity is, unfortunately, 'no', unless an exceptionally good renewable resource, significantly better than the existing WEC field, can be found.

The smart charging strategy, in contrast, could free up 3 MW of export capacity. An additional renewable energy resource with an annual average capacity factor of just 12% would therefore fully power the fleet of smart charging vehicles. As has been discussed, the load profile derived from the smart charging scenario is idealized and could not fully be realized as it requires 100% participation, arbitrarily high charging power per vehicle, and vehicles to be plugged in and ready to accept charge precisely when needed.

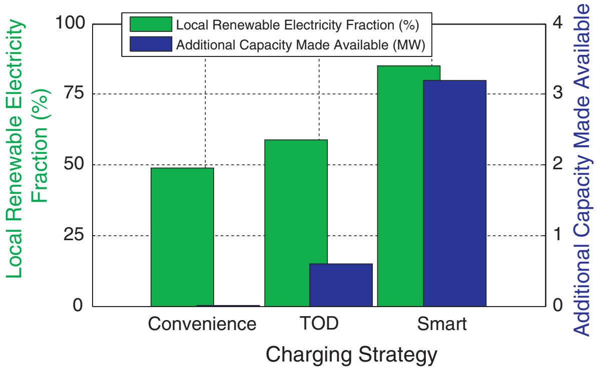

Fig. 14. Synopsys of effects of charging strategies.

Determining exactly how such an idealized algorithm would translate into a real world response is beyond the scope of this paper and would require an extremely detailed knowledge about not only drive cycles but about vehicle owners' responses to whatever incentive structure is put in place.

That being said, it seems reasonable to assume that the export attenuation resulting from real world smart charging would be more effective at the stated goal of capping export power than the convenience TOD response. If real world smart charging could attenuate export peaks by 1 MW (compared to 3 MW for ideal smart charging), and thereby free up 1 MW of transmission capacity to new generation, then that renewable resource would have to produce at 37% capacity factor to produce all of the 9 MW h/day needed by the vehicle fleet. Since the existing WEC produces at a similar capacity factor, this is a very favorable finding.

6. Conclusions

Digby is a region with abundant renewable energy resources, but has existing electricity grid constraints. Digby has articulated an ambitious goal to alter its energy consumption and production to better utilize locally produced renewable energy. Many such regions presently exist, and many more will develop given the ubiquity of renewable energy generation policy. Electric vehicles can support such policy as they reduce energy consumption for transportation, and can use locally generated electricity from renewable resources, while acting as controllable loads. The objective of this study was to determine the impact that EVs have on the electricity grid for various charging control strategies, and if this is complementary to renewable energy generation.

Three charging strategies were evaluated for their effect on the interaction between renewable electricity generation and export transmission constraints. Convenience charging (not signalled) will occur in absence of any policy or electricity tariff. This will add electricity load to Digby, but will do so at existing peak load periods (17 h) when export capacity is of no concern. The use of either time of day charging (scheduled) or smart charging (signalled) will incent drivers to charge overnight, or when additional load is most needed to alleviate electricity grid constraints.

Scheduled and signalled charging strategies would increase the fraction of transportation energy sourced from local renewable electricity generators from an already high 49% for convenience charging, to 59% for TOD charging, or 85% for smart charging. More importantly, these strategies were shown to be effective at addressing grid considerations: Using a 10% EV adoption rate, such charging algorithms could provide 0.6–3 MW of additional transmission capacity. This could enable new renewable energy generation, such as a negligible cost WEC field control strategy upgrade, that on an annualized basis could provide all the energy needed to power the vehicle fleet.

Acknowledgements

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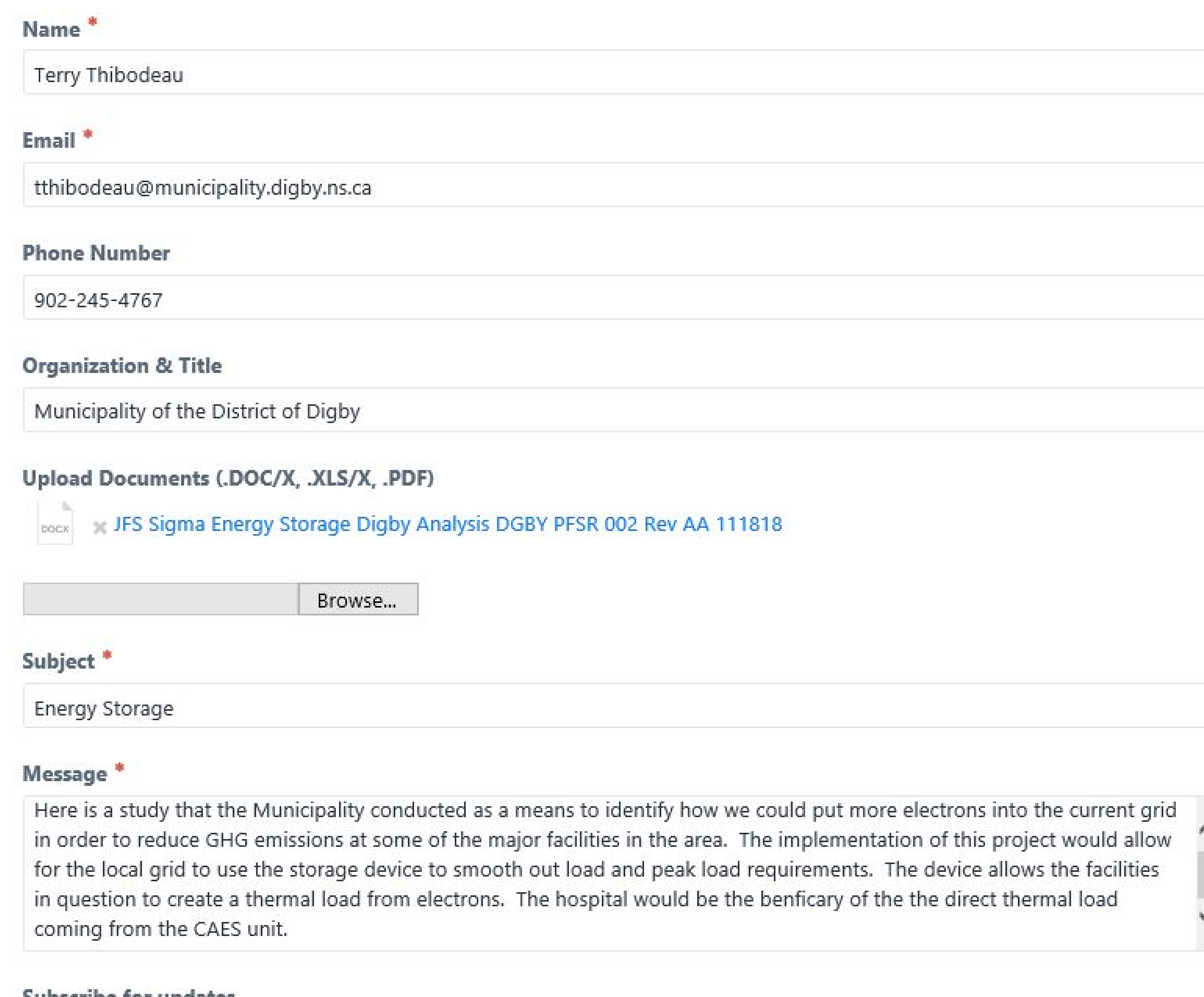

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Organization & Title

Municipality of the District of Digby

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JFS Sigma Energy Storage Digby Analysis DGBY PFSR 002 Rev AA 111818

Subject *

Energy Storage

Message *

Here is a study that the Municipality conducted as a means to identify how we could put more electrons into the current grid in order to reduce GHG emissions at some of the major facilities in the area. The implementation of this project would allow for the local grid to use the storage device to smooth out load and peak load requirements. The device allows the facilities in question to create a thermal load from electrons. The hospital would be the benficary of the the direct thermal load coming from the CAES unit.

1 Introduction

Sigma Energy Storage proposes a prefeasibility study to evaluate Digby's energy profile and identify solutions to maximize its renewable resources and minimize its fossil fuel consumption.

The Municipality of the District of Digby relies on the electrical energy from Nova Scotia grid and fuel oil for heating uses. Currently the municipality is considering to maximize the opportunities in renewable energy but these resources are non-dispatchable and they do not necessary follow grid demand Energy Storage System can offer dispatchable power solutions, which store electricity when it produced and regenerate when power is required.

On the other hand, Digby uses oil to heat several of its large facilities. Eight buildings, including the local Arena, Elementary and High Schools, RCMP, Hospital, Digby Lockup, Court House and Provincial building consume more than 370 m^3 of oil each year for heating. Thermal storage solution can store wind energy and delivers it to the buildings in form of heating services.

The goal of this project is to evaluate the fit and identify potential benefits of energy storage systems in balancing Digby's grid, optimizing the utilization of renewable resources, and assessing the impact of a thermal energy storage unit to provide low-cost heat to community buildings. The product will be a report detailing the potential of energy storage for Digby.

2 Municipality of the District of Digby

The Municipality of the District of Digby is located at the western end of the Annapolis Valley, Nova Scotia, on the southern coast of the Bay of Fundy. Situated between the District of Clare and Annapolis County, the Municipality encompasses Digby Neck, Long Island, Brier Island and the eastern half of Digby County (Figure 1) [1]. Digby is a great touristic destination. Nestled in a protected inlet off the Bay of Fundy, this area is known for its scallops, mild climate and daily ferry to Saint John, NB. Settled by United Empire Loyalists in 1783, it's now home to the largest fleet of scallop boats in the world [2].

2.1 Demographics

the Municipality of the District of Digby recorded a population (Figure 2) of 7,107 living in 3,264 of its 4,048 total private dwellings, a change of −4.8% from its 2011 population of 7,463. With a land area of 1,657.33 km^2, it had a population density of 4.3/km^2 in 2016 [3].

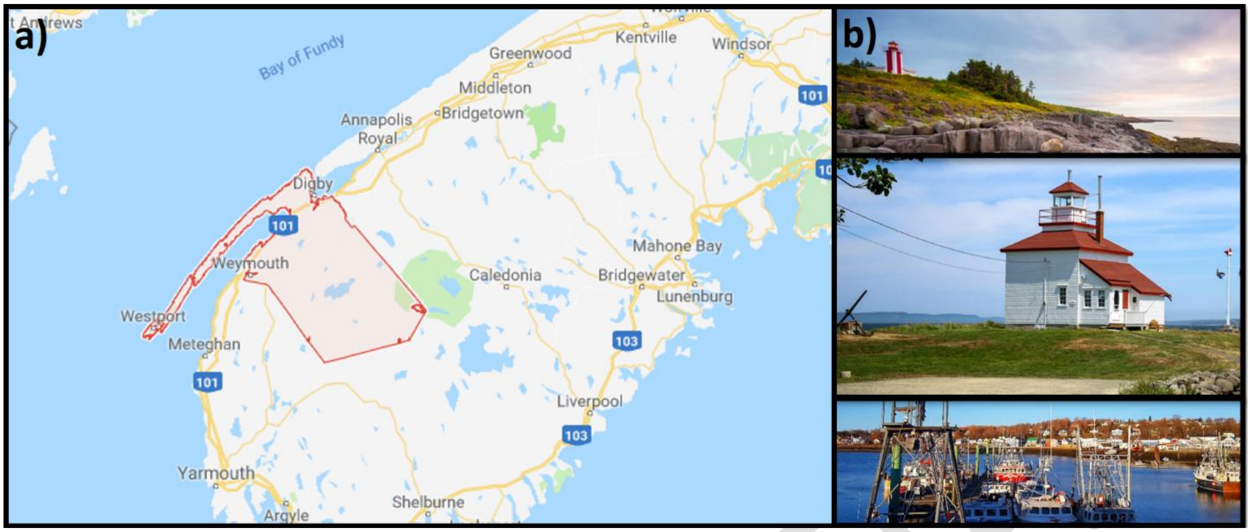


Figure 1. Municipality of the District of Digby location: **a)** Location [4]; **b)** Some tourist attractions [5].

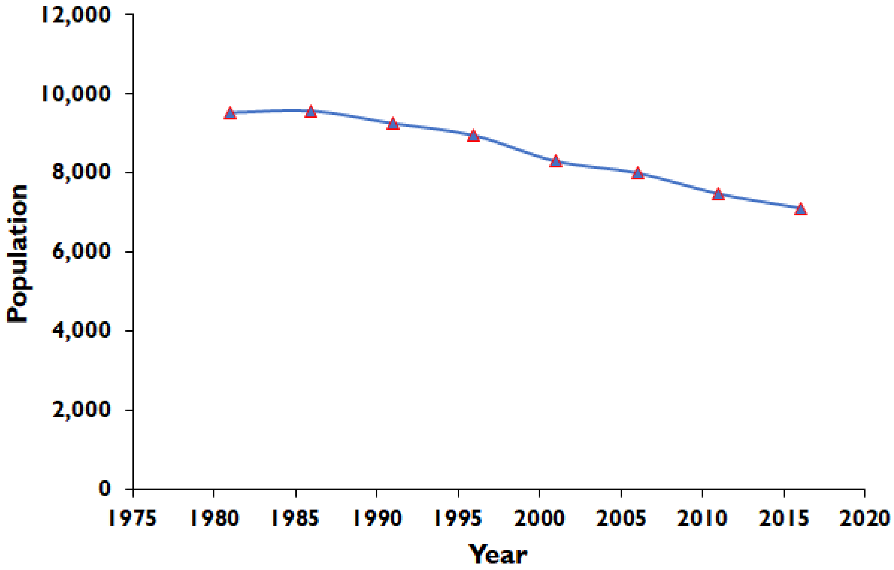


Figure 2. Municipality of the District of Digby Population from 1981 to 2016 [3]

The majority of people who leave the community are young people aged 20 to 30 years, resulting in an older community with a higher proportion of middle-aged and retired residents. Subsequently, the median age in the Municipality was 44 years in 2006, higher than the provincial median age of 41.8 and the Canadian median age of 39.5 [3].

2.2 Strategic Plan Overview

The Government of Canada has committed to transfer a portion of gas tax funds to municipalities. In 2005, the Province of Nova Scotia entered into a Gas Tax Agreement (GTA) with the Federal Government, under the New Deal for Cities and Communities. The Province then entered into Municipal Funding Agreements (MFA) with individual municipalities in order to deliver this federal funding to local governments and other appropriate recipients, for eligible environmentally sustainable municipal infrastructure and capacity building projects. As a part of these funding agreements, Nova Scotia municipalities are required to develop Integrated Community Sustainability Plans by 2010. Creating an Integrated Community Sustainability Plan (ICSP) is an important step in creating a more sustainable community. As part of the GTA, the Federal Government requires ICSPs to Integrate economic, environmental, social and cultural sustainability principles [1].

Related to the energy section, following goals have been included in the Municipality of the District of Digby Strategic Plan [6]:

- Maximizing the opportunities in renewable energy
- Reducing the carbon footprint
- Managing energy for a marketable Industrial Park

2.3 Possible Opportunities

The strategic goals defined by Municipality of the District of Digby the are based on the four pillars outlined in the municipality's Integrated Community Sustainability Plan (ICSP): Economic, Environment, Social/Community and Culture/Heritage [6]. These goals can be reached through specific plans such as building ecotourism and eco industrial park in the Municipality of the District of Digby.

Ecotourism is a form of tourism involving visiting fragile, pristine, and relatively undisturbed natural areas. It means responsible travel to natural areas, conserving the environment, and improving the well-being of the local people [7]. Natural resource management can be utilized as a specialized tool for the development of ecotourism [8]. Digby is rich in history and natural habitat, both of which can draw visitors and even new residents to the Municipality. Historical industries such as fishing and farming are supported by the area's wilderness and natural eco-systems, which also may attract tourists who enjoy the area's beauty and outdoor recreation opportunities. As part of the Southwest Nova Biosphere Reserve – a large region of South-western Nova Scotia spanning several counties where sustainable use, protection and enjoyment of natural resources are encouraged and fostered – the Municipality is going to promote the value of sustainability for the region [1]. Without the sustainable use of certain resources, they are destroyed, and floral and faunal species are becoming extinct. Ecotourism programs can be introduced for the conservation of these resources [9]. Using more renewable resources and managing the GHG emission can help the municipality to protect the environment and also to increase financial efficiency of the tourism industry in Digby.

An Eco Industrial Park (EIP) is a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaborating in the management of environmental and resource issues [10]. Following steps should be taken to create an EIP:

- Creating energy/material pooling and to help tackle the problem of local resource scarcity;
- Decreasing energy/material consumption and, as a consequence, the expenses for energy/material purchase;
- Reducing the cost of required energy/material
- Valorizing industrial energy/material waste;
- Decreasing environmental pollution [11].

Historically, the economy of the Municipality of the District of Digby has been tied to resource sectors of fishing, forestry and agriculture. Fur farming, particularly mink farming, is the largest contributor to the Municipality's agricultural industry. [1]. Currently the municipality is considering the growth of the industrial site located south of Highway 217 which is bounded by industrial lots, residential lots, and institutional uses [5]. At this time, the area is approximately 60% occupied. Creating an EIP can encourage other industries to move to this location because of low energy/materials cost and less environmental effects. More industrial investment leads to faster economic growth in the both short term and long run. It creates jobs especially for young generation and prevents population decline.

Figure 3 shows how the potential EIP and Ecotourism for the Municipality of the District of Digby align with the current strategic plan.

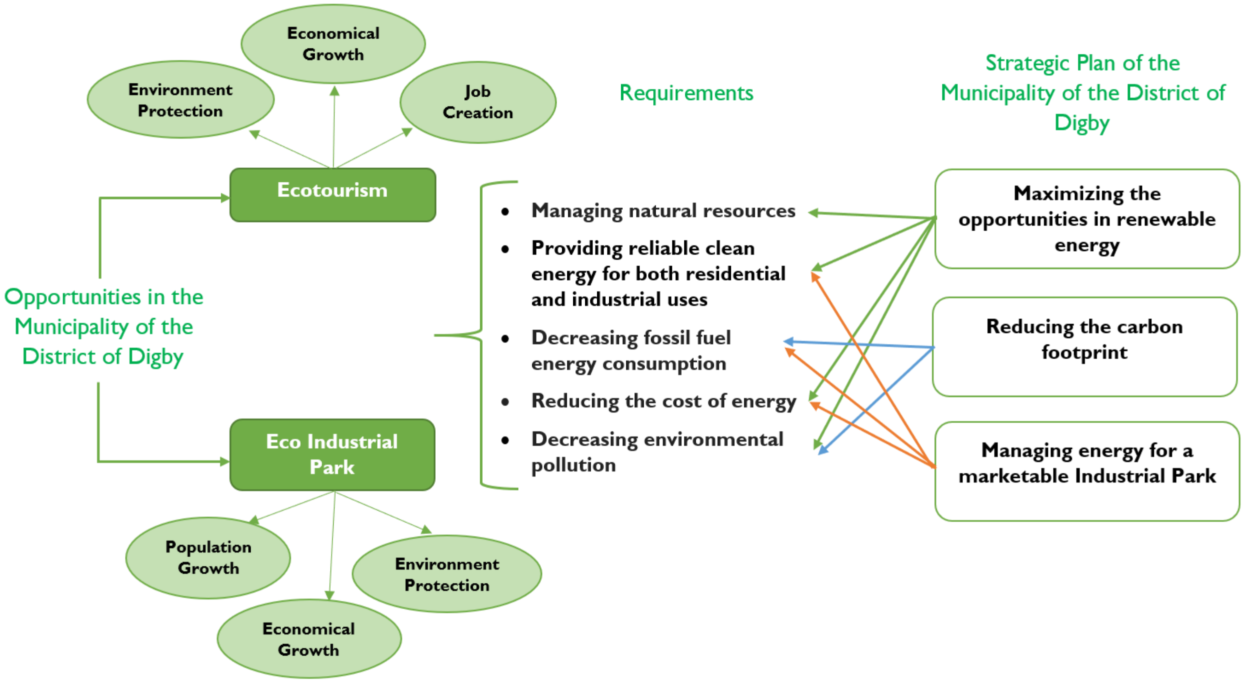


Figure 3. Opportunities along with the Digby strategic plan

The suitable location of the Municipality of the District of Digby (Figure 4) provide access to abundance of natural renewable resources such as Wind, Tidal, Hydropower, Biomass and Solar energy. Although no single resource can supply all the energy demand and the electricity from fossil fuels may continue to play a role but the municipality can reduce that role and create a diverse mix of energy resources. Renewables fit into the generation mix as do energy storages.

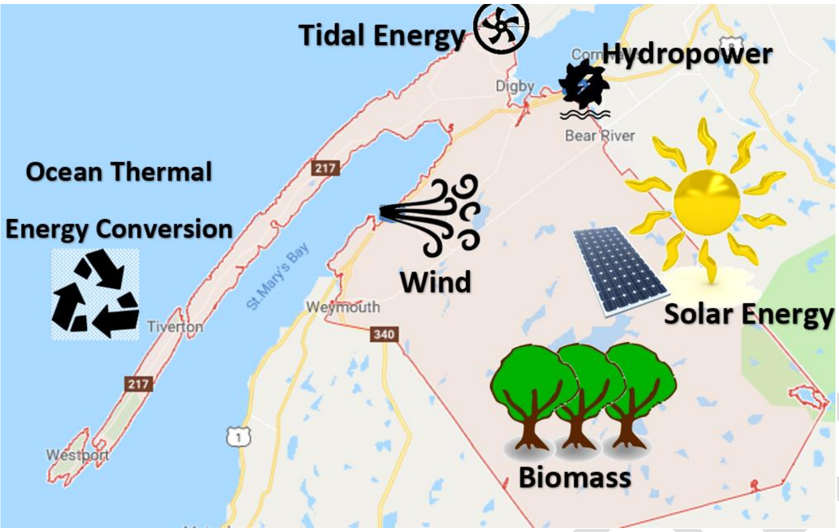


Figure 4. Available renewable resources in the municipality of the district of Digby

3 Ecotourism Opportunity

The district of Digby is rich in history and natural habitat, both of which draw visitors and new residents to the Municipality. Ecotourism which respect the area's wilderness and natural eco-systems, attracts more tourists who enjoy the area's beauty and outdoor recreation opportunities. To reach this goal, the Municipality of the District of Digby needs

(*i*) To reduce the fossil fuel consumption and GHG emissions. It can be achieved by providing clean energy from renewable sources to local facilities.

(*ii*) To reuse waste materials for energy generation. Recycling and processing waste wood and other waste materials from plants and animals to generate energy can support the local economy and a healthy environment.

3.1 Energy Demand Analysis

The large public buildings in the municipality use more energy than residential buildings, consuming about 80% of the total delivered energy. Energy is used in the high demand facilities for a wide range of purposes, such as heating and cooling, and lighting and air conditioning. There are eight high demand facilities in the municipality (Figure 5):

1. Hospital
2. Area Recreation Facility (Arena)
3. High School
4. Elementary School
5. RCMP Office
6. Courthouse
7. Digby Lock-up
8. Provincial Buildings

The average yearly electrical and heat demands for these facilities, based on Lockheed Martin study [12], are presented in Figure 6. Most of these facilities use Fuel oil for heating purposes but Arena uses Electric

Heat for main arena rink. The average yearly oil consumption for the eight facilities is presented in Figure 7. The yearly GHG emissions is presented in Figure 8. Only hospital and two schools produce more than 750 tonnes CO_2e each year.

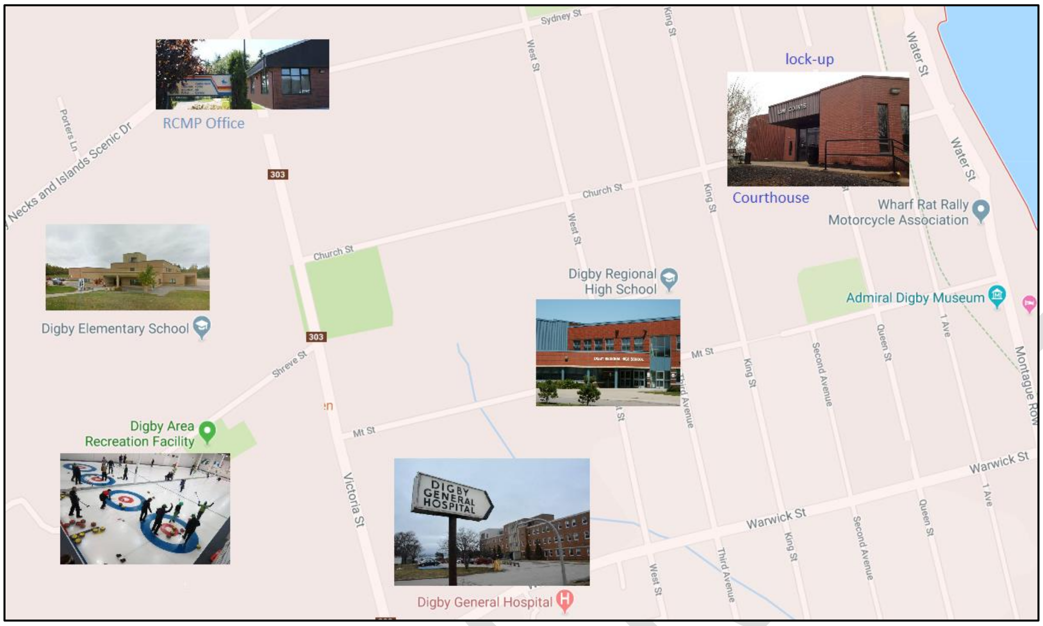


Figure 5. High demand facilities in the municipality

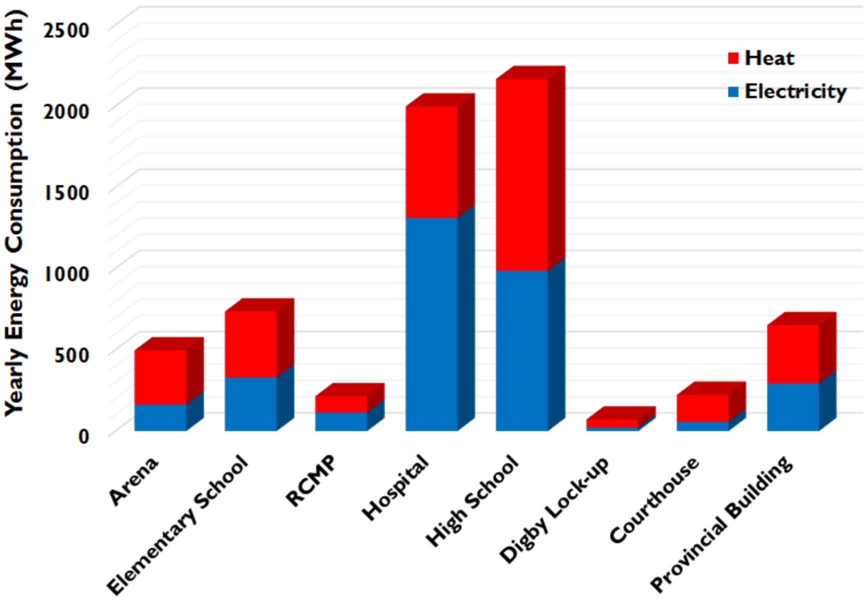


Figure 6. Average yearly demand for the high-demand facilities [12]

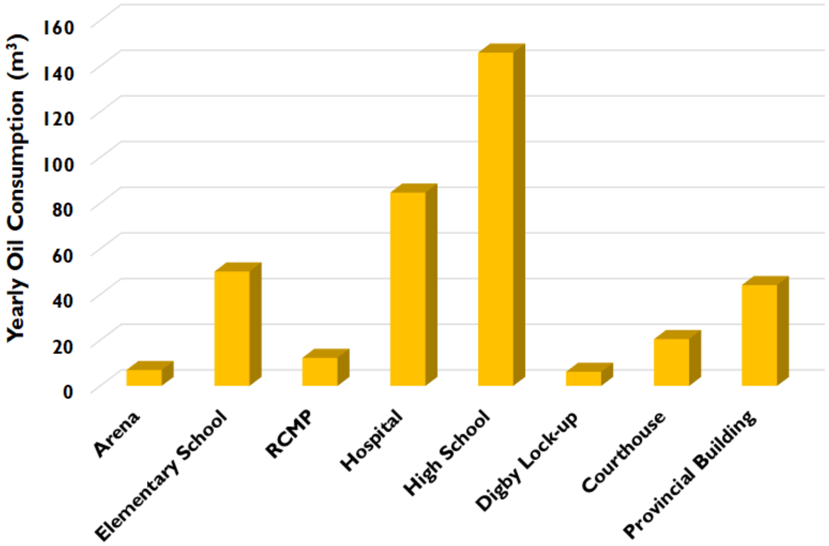


Figure 7. Average yearly oil consumption for the high-demand facilities [12]

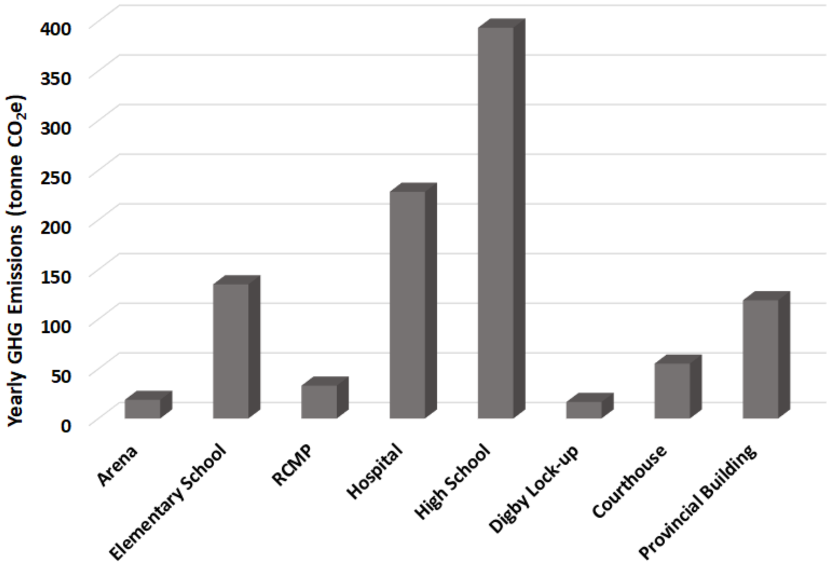


Figure 8. Average yearly GHG emissions from high-demand facilities

The two large facilities with the highest energy demand are the hospital and the high school with 1314 and 988-MWh annual electricity consumption and 85 and 146 m^3/year fuel oil consumption respectively. Digby General Hospital is located at 75 Warwick Street is open 24 hours a day, seven days a week. Its energy consumption peak hours are between 11 a.m. and 8 p.m. according to their official website [13]. The hospital's last ten-year energy consumptions, from Nova Scotia Power's data [14] shows an almost unchanging annual trend, as shown in Figure 9. Average energy daily consumption starts to grow in June, reaches a maximum sometime between mid-July and mid-August, and decreases until early October. It seems in the summer time; more electricity is used for cooling. The only exception was 2016 in which the maximum daily energy demand occurred in mid-March and relatively low demand was observed in the summer.

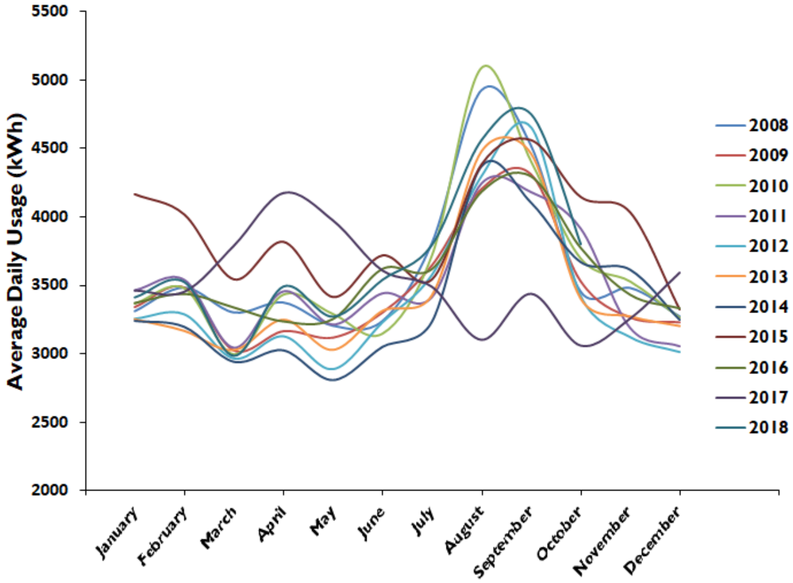


Figure 9. Average daily electricity consumption by the hospital over the last ten years

Digby Regional High School (DRHS) which is home to roughly under 500 students and staff, is located at 53 Mount St. DRHS is part of the Tri-County Regional School Board and is the only high school in the town of Digby. The average school day runs from 7:30 a.m. to 5 p.m. [15]. Average monthly energy consumption for the hospital and for the high school are presented in Figure 10. For both the hospital and the school have less heat demand during summer, from June to September. Since heat energy in hospital is also used for sterilization, autoclaves and ventilation processes [16], there are always a need for heat (Figure 10b). The highest monthly electricity consumption for the hospital (Figure 10a), happening in July and August because of cooling equipment [16], is around 137-147 MWh. The high school uses less electricity in May, probably because of no school days for all students. The minimum demand for the high school is 38 MWh in May and the peak demand is 98 MWh in February. The information presented in Figure 10 are used to design the energy storage for this facility.

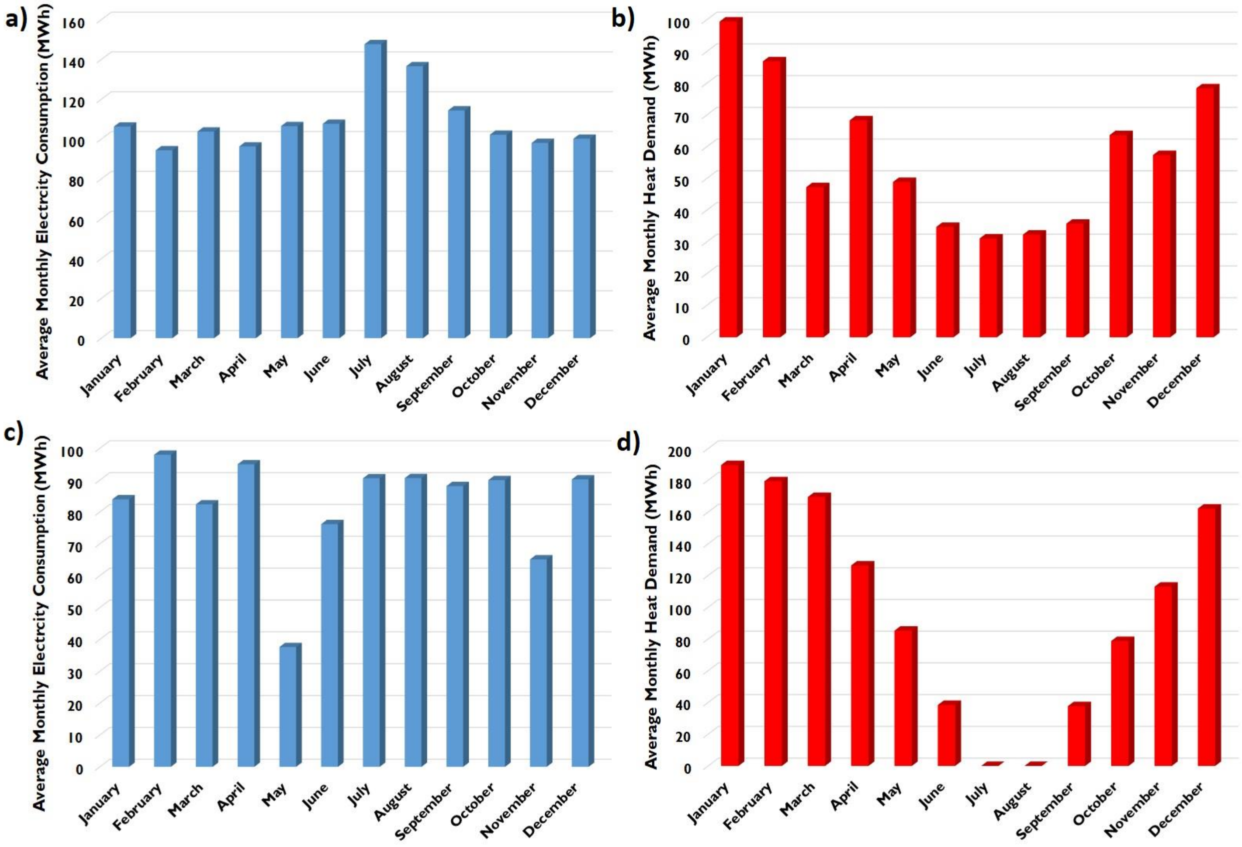


Figure 10. Average monthly energy consumption for Digby hospital: **a)** Electricity, **b)** Heat; and Average monthly energy consumption for Digby high school: **c)** Electricity, **d)** Heat [12]

3.2 Waste Materials and Biomass

The Municipality of the District of Digby has a organized process to manage waste materials disposal, recycling and compost [17]. Some of these waste materials that comes from plants and animals are considered as a renewable source of energy, called biomass. When biomass is burned, the chemical energy in biomass is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels. Some example of biomass, available in the local area, and their potential use are

(*i*) Wood and wood processing wastes: It is burned to heat buildings, to produce process heat in industry, and to generate electricity

(*ii*) Agricultural crops and waste materials: Can be used as a fuel or converted to liquid biofuels

(*iii*) Food, yard, and wood waste in garbage: It can be burned to generate electricity in power plants or converted to biogas in landfills

(*iv*) Animal manure and human sewage: It is converted to biogas, which can be burned as a fuel [18].

One of ongoing renewable project in Digby is the biomass project. The Southwest Eco Energy Ltd. facility outside of Weymouth, Digby County, uses biomass composed of mink farm waste and municipal green bin waste as feedstock to an Anaerobic Digester to produce biogas (Figure 11). The Municipality has a plan to use this biogas to generate electricity which can be exported onto the local grid, generating revenue under the COMFIT program. Such revenue could offset or lower property taxes in the future. Also, Université Sainte-Anne in Digby County uses renewable energy sources including a biomass furnace fueled by locally-sourced wood chips [19].

Figure 11. Digby mink farm (left) and the biomass facility based on biofuel produced from the mink farm [20,21]

Since the Municipality of the District of Digby has access to waste wood materials, an interesting option can be generating electricity though a biopower plant. The proposed process burns wood chips directly to produce high-pressure steam that drives a turbine generator to make electricity. The extra heat from the power plant is also used to heat local buildings. These combined heat and power (CHP) systems greatly increase overall energy efficiency to approximately 80%, from the standard biomass electricity-only systems with efficiencies of approximately 20%.

3.3 Energy Storage Systems

Energy storage is a dominant factor in renewable energy plants. It can mitigate power variations, enhances the system flexibility, and enables the storage and dispatching of the electricity generated by variable renewable energy sources. Both electrical and thermal energy storage system help the Municipality of the District of Digby provide a reliable and dispatchable energy to the residential and industrial buildings.

Electrical Energy storage systems provide a wide array of technological approaches to managing the power supply in order to create a more resilient energy infrastructure and bring cost savings to utilities and consumers [22]. There is a very wide variety of storage technologies for stationary applications, but no technology is suited to serve all applications. A comparison of storage technologies makes sense only with respect to a certain application. Comparison is very difficult anyway, because of the numerous parameters that define the technical and economical performance of a storage system. Therefore, it is necessary to use classification systems. Generally, the classification can be made based on the way energy is stored, e.g., mechanical, electrical, or chemical [23].

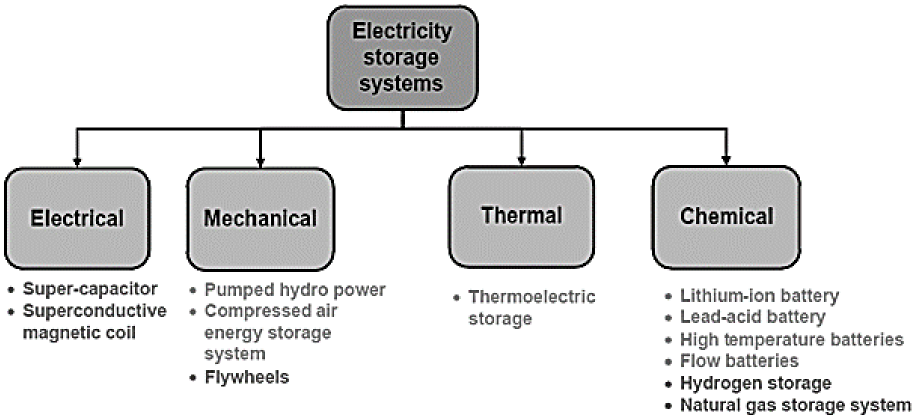


Figure 12. Classification of storage technologies [23].

Figure 12 shows the classification of electrical storage technologies. Below is a short description of the most developed systems:

- *Compressed Air Energy Storage*: utilizing compressed air to create a potent energy reserve
- *Solid State Batteries*: a range of electrochemical storage solutions, including advanced chemistry batteries and capacitors
- *Flow Batteries*: the energy is stored directly in the electrolyte solution for longer cycle life, and quick response times
- *Flywheels*: mechanical devices that harness rotational energy to deliver instantaneous electricity
- *Pumped Hydro-Power*: creating large-scale reservoirs of energy with water [22].

Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications [24]. Advantages of using TES in an energy system include an increase in overall efficiency and better reliability, and it can lead to better economics, reductions in investment and running costs, and less pollution of the environment, i.e., fewer GHG emissions [25]. TES combined with photovoltaic panels are industrially mature [26] and utilize a major part of the Sun's thermal energy during the day. During the low or no solar radiation hours, TES is charged using low cost electricity.

Different Types of the thermal energy storage are presented in Figure 13. Following characteristics can be used to choose an appropriate TES system:

- **Capacity** defines the energy stored in the system and depends on the storage process, the medium, and the size of the system;
- **Power** defines how fast the energy stored in the system can be discharged (and charged);
- **Efficiency** is the ratio of the energy provided to the user to the energy needed to charge the storage system. It accounts for the energy loss during the storage period and the charging/discharging cycle;
- **Storage period** defines how long the energy is stored and lasts hours to months (i.e., hours, days, weeks, and months for seasonal storage);
- **Charge and discharge time** defines how much time is needed to charge/discharge the system; and
- **Cost** refers to either capacity (¢/kWh) or power (¢/kW) of the storage system and depends on the capital and operation costs of the storage equipment and its lifetime [26].

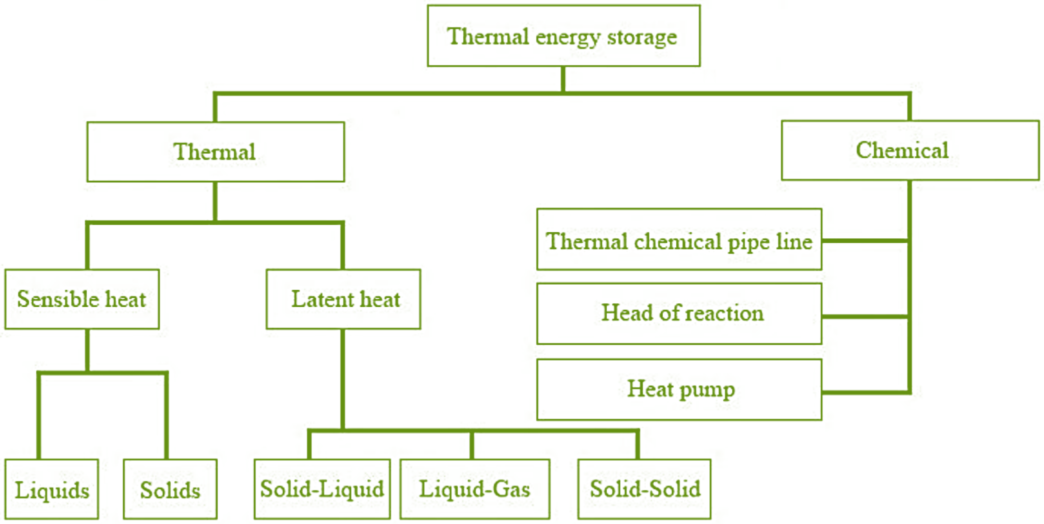


Figure 13. Types of solar thermal energy storage [24].

3.4 Grants and Financial Supports

Several Governmental foundations and programs support deployment of green energy production system across Canada such as NRCan, SDTC and provincial programs.

Natural Resources Canada (NRCan) seeks to enhance the responsible development and use of Canada's natural resources and the competitiveness of Canada's natural resources products. Clean Energy Innovation Program of NRCan focuses on renewable resources, smart grid and storage systems; reducing fossil fuel consumption; methane and VOC emission reduction; reducing greenhouse gas emissions in the building sector; and improving industrial efficiency [27].

Sustainable Development Technology Canada (SDTC) is a foundation created by the Government of Canada to support Canadian companies with the potential to become leaders in developing and demonstrating new environmental technologies that address climate change, clean air, clean water and clean soil [28].

Low Carbon Communities grant is a part of program that the Nova Scotia Department of Energy and Mines has designed to help communities to create long lasting greenhouse gas (GHG) reductions and to develop bright ideas for low-carbon, clean energy projects. Grants will be provided up to $75,000 up to $75,000 to a maximum of 75 per cent of project costs [29].

3.5 Recommended Solutions

The recommended solutions to achieve the goal of ecotourism, is based on the development of renewable energies align with energy storage systems. The main goal is to reduce fossil fuels consumption and to reduce GHG emissions. The recommended solutions can not only make good sense environmentally, but also economically.

3.5.1 PV-Thermal Energy Storage for Local Facilities

As a PV-thermal energy storage, buffer water storage tanks are good options for residential/small industries space heating applications. This system, presented in Figure 14, produces hot water for domestic needs to buffer variable rates of energy supply and demand [23]. The most common used PV-TES configurations are immersed tubes or immersed coils in the tank, backup external heater and a narrow annular jacket around the storage tank [24].

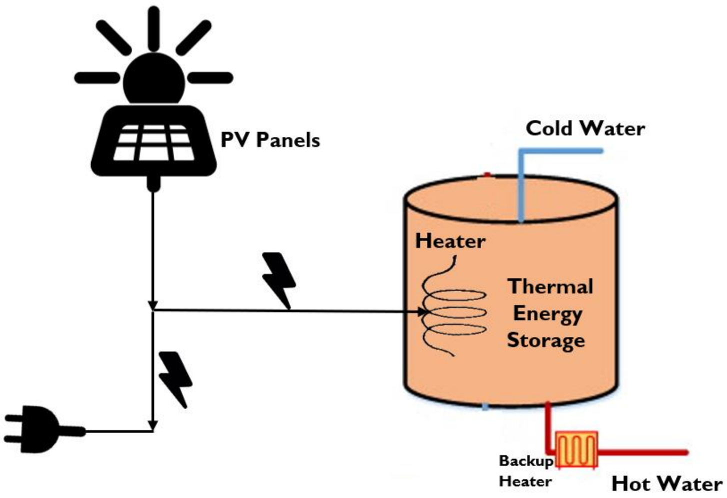


Figure 14. Typical schematic of a solar-thermal energy storage.

The proposed system uses water as the storage medium. At low–medium temperature, water is one of the best storage media: it has relatively high specific heat capacity, is chemically stable and is both widely available and cheap. Its main inconvenience is its limited temperature range (20–95°C) but, for building applications (our purpose), this is sufficient for space heating and domestic hot water production [23].

Ideas to improve water tank storage for solar systems providing both space heating and hot water production (so-called ‘solar combi-systems’) have been reviewed within the IEA ‘Solar Heating and Cooling’ (SHC) program in Task 32 ‘Advanced storage concepts for solar and low energy buildings’, Subtask D ‘Water tank solutions’ [25].

To conduct a technical and financial analysis for installing TES systems in eight large facilities, we considered following assumptions which are mainly realistic to optimistic:

- Space is available with no cost
- Electricity to be purchased from the grid at 12 ¢/kWh
- Cost of Fuel oil is $1.05/liter, escalated at 2% per year
- Cost of PV panels is $1.4/W including engineering and installation
- O&M cost is 2% of the total materials cost and increases at 2% per year
- Water is available at no cost
- The project is eligible for NS Low Carbon Communities Grant

This grant is a part of program that the Nova Scotia Department of Energy and Mines has designed to help communities to create long lasting greenhouse gas (GHG) reductions and to develop bright ideas for low-carbon, clean energy projects. Grants will be provided up to $75,000 [26].

Table 1 shows yearly cost and GHG emissions for the current installed heating system in eight high-demand facilities.

Table 1. Current heating systems

Facility	Fuel oil consumption	Fuel oil Energy cost	Heat Load	Current cost
	liters/year	$/kWh	kWh / year	K$ / year
Arena	**6955**	**$0.13**	**56259**	**7**
Elementary School	**50092**	**$0.13**	**405194**	**53**
RCMP	**12273**	**$0.13**	**99279**	**13**
Hospital	**84650**	**$0.13**	**684734**	**89**
High School	**145902**	**$0.13**	**1180201**	**153**
Digby Lock-up	**6158**	**$0.13**	**49812**	**6**
Court House	**20474**	**$0.13**	**165614**	**21**
Provincial Building	**44149**	**$0.13**	**357121**	**46**

The output power of PV panels is estimated based on the model described in appendix I. Installing 40 kW PV panels can generate 56 MWh energy per year. The systems were design to result in a positive net present value for the project after 4 to 5 years.

The financial and environmental benefits of installing a solar thermal energy storage for the high-demand facilities are presented in Table 2 and Figure 15.

Table 2. Financial and environmental benefits of solar thermal energy storage systems

Facility	S-TES Heat Generation	Fuel oil Saving	GHG reduction	Fuel cost saving	Net Benefit (subsidized)	Payback* (subsidized)
	kWh / year	liters / year	tonne/year	K$ / year	K$/year	years
Arena	**56259**	**7032**	**16**	**$7.30**	**$6.11**	**3.9**
Elementary School	**56400**	**7050**	**16**	**$7.32**	**$6.13**	**3.9**
RCMP	**56400**	**7050**	**16**	**$7.32**	**$6.13**	**3.9**
Hospital	**56400**	**7050**	**16**	**$7.32**	**$6.13**	**3.9**
High School	**56400**	**7050**	**16**	**$7.32**	**$6.13**	**3.9**
Digby Lock-up	**49812**	**6226**	**14**	**$6.47**	**$5.27**	**4.5**
Court House	**56400**	**7050**	**16**	**$7.32**	**$6.13**	**3.9**
Provincial Building	**56400**	**7050**	**16**	**$7.32**	**$6.13**	**3.9**

* Considering NS Low Carbon Communities Grant

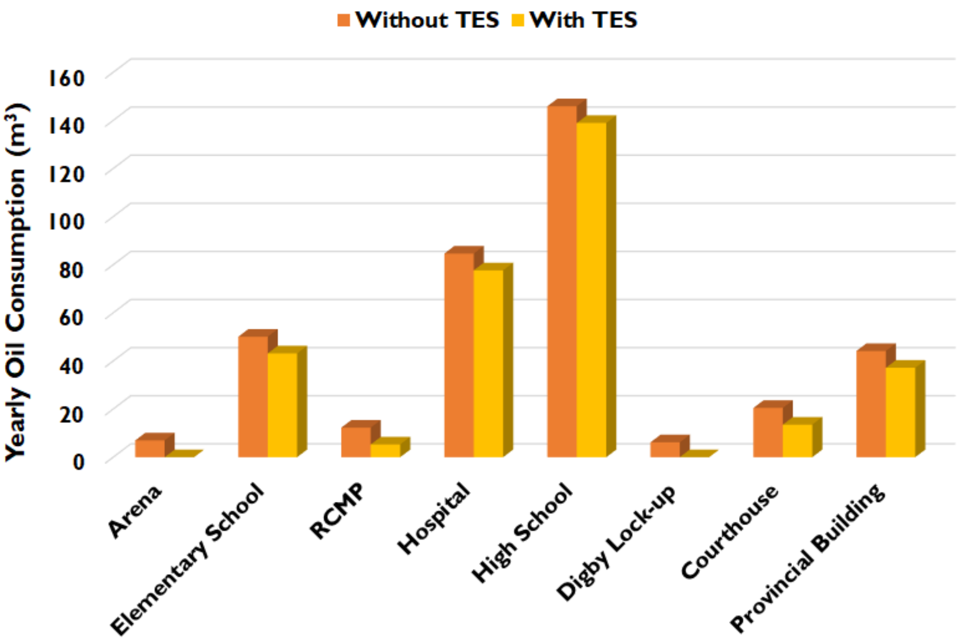


Figure 15. Yearly Oil consumption reduction for 40 kW PV panel

Figure 15 shows the difference between the yearly oil consumption with and without TES systems. Since the heat demand of hospital and schools are high, installing only 40 kW PV is not very effective. We did a more detailed techno-economical analysis for Digby General Hospital and Digby Regional High School. Heat consumption for the hospital and the high school are presented in Figure 10. Hourly and daily solar irradiation were calculated and used to size the appropriate solar thermal energy storage system for these two facilities. Considering 15 years payback period, the recommended design is presented in Table 3:

Table 3. Recommended design of solar thermal energy storage for the hospital and for the high school

Facility	PV Panel (kW)	TES (kWh)	Oil Saving (%)	GHG Reduction (tonne/y)	Payback Period (Years)
Hospital	485	**1500**	**52**	**100**	**15**
High School	350	**2000**	**22**	**71**	**15**

Figure 16 compares the heat generated by PV panels and heat demand for both the hospital and the high school. It can be seen that during the summer time, the heat generation is much more than the heat demand. One solution can be designing a multi-purpose system which can deliver also electricity, especially during the summer time. In that case, the module can deliver 194 MWh electricity per year for the hospital and 143 MWH for the high school (Table 4).

Table 4. Delivered energy by PV-TES system for the hospital and for the high school

Facility	Total Delivered Heat (MWh)	Total Delivered Electricity (MWh)
Hospital	358	194
High School	252	143

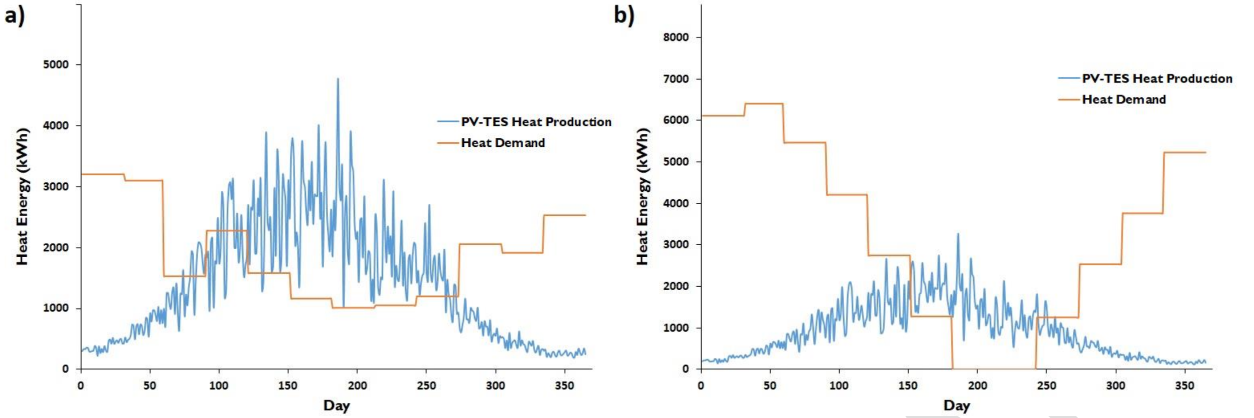


Figure 16. Annual Heat generation vs heat demand for **a)** Digby General Hospital; **b)** Digby Regional High School

The extra electricity can be used for cooling purposes. For example, during the summer time (mid-July to mid-August), PV-TES system can deliver around 114 MWh electricity for the hospital which is enough to run an 8000 BTU air conditioner in 42 rooms [30].

3.5.2 Biomass Direct Combustion System

Using available biomass resources in the Municipality of the District of Digby, we can obtain both heat and electricity at the same time. This combined heat and power system is illustrated in Figure 17. Steam turbines work on the principle of the Rankine cycle, which consists of a heat source (boiler) that converts water into high-pressure steam. A multistage turbine allows the high-pressure steam to expand, which lowers its pressure. The steam is then transported to a condenser, which is like a vacuum chamber and thus has negative pressure and converts, or condenses, the steam into water. Also, the steam can be transported to a distribution system that delivers steam at intermediate temperatures for different applications (district heating system) [31]. Seasonal heating requirements will impact the CHP system efficiency [32]. The condensate from the condenser or from the steam utilization system may return to the feed water pump, and the cycle continues. Cold water from the ocean or Bay of Fundy can be used to condensate the steam after the turbine which reduce the total capital cost of the system (Figure 17).

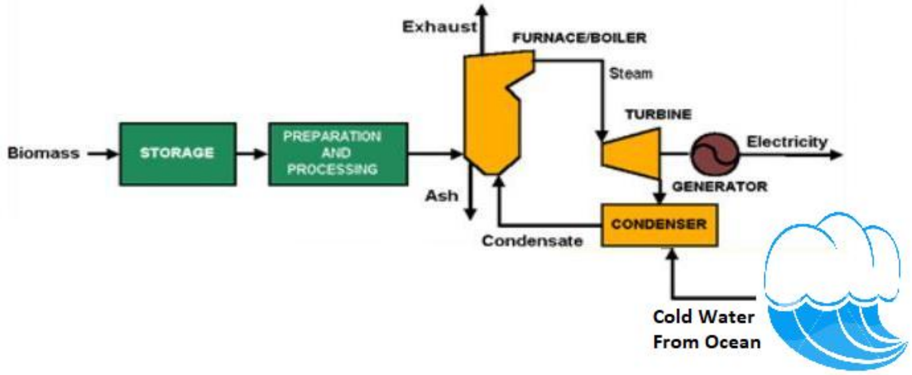


Figure 17. Biomass direct combustion system

A typical biomass energy generation system is made up of several key components. For a steam cycle, we consider the combination of the following items:

(i) Wood chip storage and handling equipment

(ii) Combustor / furnace

(iii) Boiler

(iv) Pumps

(v) Fans

(vi) Steam turbine

(vii) Generator

(viii) Condenser

Direct combustion systems feed a biomass feedstock into a combustor or furnace, where the wood chips are burned with excess air to heat water in a boiler to create steam. Steam from the boiler is then expanded through a steam turbine, which spins to run a generator and produce electricity [32].

To conduct a technical and financial analysis for a biomass energy generation system for the local facilities, we considered following assumptions:

- Space is available with no cost
- Cost of wood fuel is $35.0/tonnes, escalated at 2% per year
- Financing for 20 years at the interest rate of 6.5%
- O&M cost of the systems is 2% of the total materials cost and increases at 2% per year
- Electricity can be delivered to the large facilities (Hospital and High School)
- Heat can be delivered to both the large facilities and the residential buildings

Electrical demand for the hospital and the high school are presented in Figure 10. The average hourly demand for these large facilities is 345 kWh. Considering a 40% variance, the peak demand is estimated 482 kWh, so we designed a 500-kW system. The details are presented in Table 5.

Table 5. Recommended biomass direct combustion system for local facilities

Required Steam Turbine (kW)	500
Required Wood (38% moisture) (tonne/year)	1240
Deliverable Electrical Energy (MWh/y)	875
Deliverable Heat Energy (MWh/y)	2628
Installed cost (M$)	3.08
levelized cost of energy (¢/kWh)	8.5

Because of access to wood waste martials at low cost, our proposed system costs less than similar small-scale biomass electric plants (100 to 1500 kW) in the US (Table 6) [32]:

Table 6. Small-scale biomass electric plants (100 to 1500 kW) in the US

Installed cost per kW ($)	3000 to 4000
levelized cost of energy (¢/kWh)	8 to 15

The environmental benefits of the biomass direct combustion system are listed in Table 7. 2628 MWh heat energy can save 325 m^3 fuel oil each year. Also, the local facilities may consume less electricity from Nova Scotia Grid which is generated from a variety of sources including coal, pet coke, natural gas, oil [33]. The generation mix which can be seen in Figure 18 was used to estimate the reduction in the amount of coal and natural gas consumption.

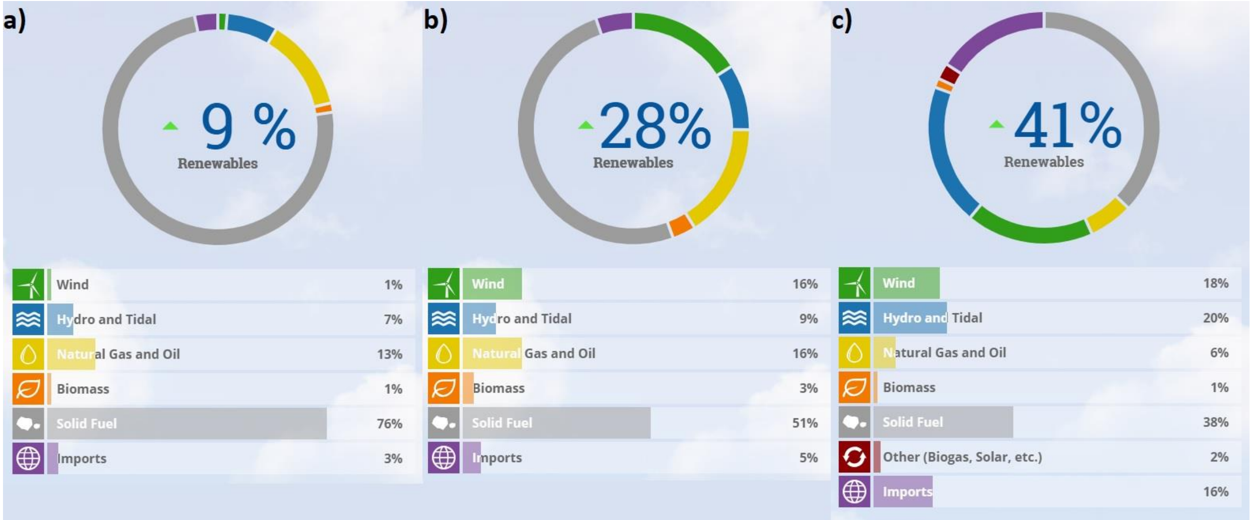


Figure 18. Nova Scotia Sources of Electricity: **a)** in 2007; **b)** 2018 Year-to-Date; **c)** 2020 Forecast.

Table 7. Environmental benefits of the 500-kW biomass direct combustion system

Coal Saving (tonne/year)	135-196
Natural Gas Saving ($10^3 m^3$/year)	17-43
Fuel Oil Saving (m^3/year)	325
GHG Emission Reduction (tonne/year)	1041-1211

Considering following assumptions:

- Cost of Fuel oil is $1.05/liter, escalated at 2% per year
- Cost of Coal is $0.078/kg, escalated at 2% per year
- Cost of Natural Gas is $0.154/$m^3$, escalated at 2% per year
- Carbon tax of $20 on every tonne of greenhouse gas emission starting in 2019, rising by $10 each year to $50 a tonne by 2022 [34].

We estimated the total revenue for both the Municipality of the District of Digby and Nova Scotia:

Table 8. Economical benefits of the 500-kW biomass direct combustion system

Revenue for the Municipality (k$/y)	356-534
Revenue for Nova Scotia (k$/y)	32-57

3.5.3 Energy Storage for Tidal Energy

Tidal Energy is classed as a renewable energy source, as the Earth uses the gravitational forces of both the moon and the sun every day to move vast quantities of water around the oceans and seas producing tides. Tidal energy, just like hydro energy transforms water in motion into a clean energy. The motion of the tidal water, driven by the pull of gravity, contains large amounts of kinetic energy in the form of strong tidal currents called tidal streams. The daily ebbing and flowing, back and forth of the ocean's tides along a coastline and into and out of small inlets, bays or coastal basins can generate considerable amount of energy [35].

The Bay of Fundy has the highest tides in the world (up to 16m), and holds the greatest potential for a tidal energy development in North America [36]. The tidal currents in the Bay of Fundy are fast, reaching 10 knots (5.1 m/s) at peak surface speed [37]. Oceanographers attribute it to tidal resonance resulting from a coincidence of timing: the time it takes a large wave to go from the mouth of the bay to the inner shore and back is practically the same as the time from one high tide to the next. During the 12.4-hour tidal period, 160 billion tonnes of water flow in and out of the bay [38]. The estimated total extractable energy is 2500 MW (out of about 7,000 megawatts of potential) without significant environmental effects [36]. Several sites have been identified in the Bay of Fundy as viable locations for tidal power generation projects including the Grand Passage (500 kW), Petit Passage (500 kW), and Digby Gut (1.95 MW). These specific projects have been accepted for COMFITs by Nova Scotia Power.

The predicted tide heights for the Digby Gut, 8.5 km away from the city of Digby, vary from the low of 2 meters to a high of 7.6 meters (see Figure 19). In addition to the daily period, the tides show a lunar monthly periodic behavior during which the maximum tide height varies between 7 and 7.6 meters.

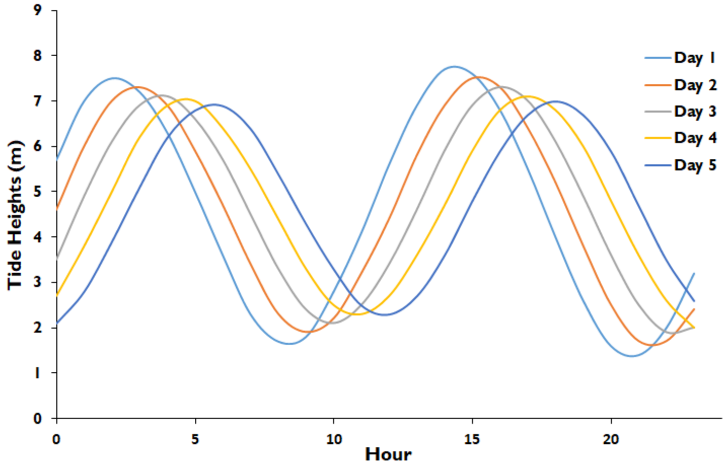


Figure 19. Predicted hourly heights [39]

Digby has been identified as the port of choice for tidal power development [40]. The Port of Digby is the most accessible, deep water, ice-free Bay of Fundy port in Nova Scotia. Its proximity to the Bay of Fundy's designated deployment area for tidal power development makes the Port a strong location for this emerging industry [41].

Figure 20. Placed turbine in the Bay of Fundy in 2009 [42]

Currently Fundy Tidal and Clean Current Power Systems Inc. have an agreement to test and demonstrate a 3.5-meter diameter 65kW tidal turbine. This turbine will take kinetic energy from the flowing tidal waters rather than water stored behind a dam to generate electricity. In-stream turbines pose less risk to the local ecosystem. The project of 1.95-megawatt tidal energy in Digby Gut was expected to last 12 months but it is not in service yet. Under the COMFIT program, Nova Scotia Power will buy energy produced from those turbines for the next 20 years at a price of 65.2 cents per kilowatt [36].

Since Tidal energy is non-dispatchable due to its fluctuating nature, an energy storage system can increase both the reliability and efficiency of the energy production system. A Hybrid thermal-compressed air energy storage (HT-CAES) System is an energy storage system based on air compression and air storage in high pressure tanks or geological underground voids (Figure 21). During operation, the available electricity is used to compress air into a high-pressure storage at pressures up to 75 bar. The heat produced during the compression cycle is stored using Thermal Energy Storage (TES), while the air is pressed into the air storage. When the stored energy is needed, this compressed air is used to generate power in a turbine while simultaneously recovering the heat from the thermal storage [43]. The opportunity of installing a compressed air energy storage technology for Nova Scotia Power has been investigated before by SNC-Lavalin [44].

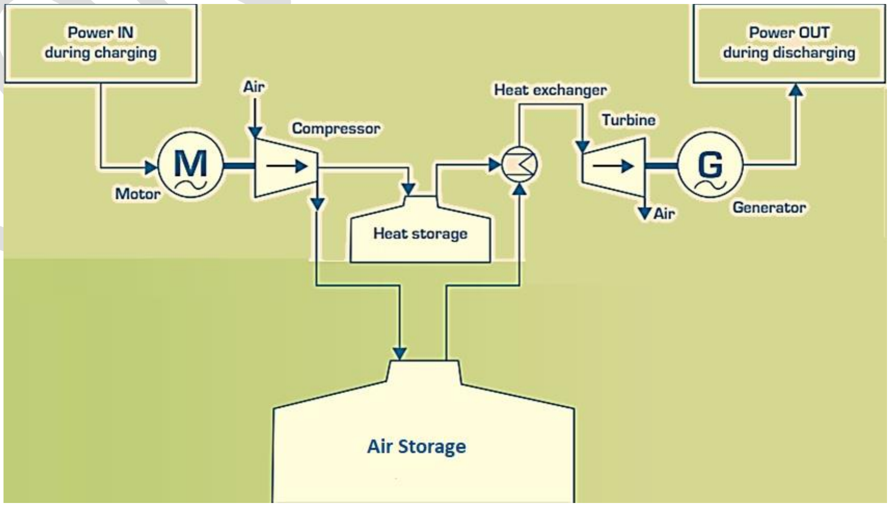


Figure 21. Hybrid thermal-compressed air energy storage (HT-CAES) [Adopted from Ref. [43]]

To design an appropriate energy storage system for available tidal projects, we considered following assumptions:

- Space is available with no cost
- Line restriction is 900 kW for Grand and Petit Passage
- Line restriction is 1950 kW for Digby Gut
- Electricity from Tidal is available to store at no cost
- The efficiency of HT-CAES system is 40%
- Charging and discharging are variable
- O&M cost of Tidal and HT-CAES systems is 2% of the total materials cost and increases at 2% per year

Th recommended HT-CAES systems for three locations are presented in Table 12. It can be seen that for small tidal turbines (500 kW), the contribution of the storage to total production is small but for the large tidal system (1.95 MW), the effect of HT-CAES is significant.

Table 9. Tidal energy system anchored with HT-CAES

Location		Grand/Petit Passage	Digby Gut
Nominal Power	kW	500	1950
Optimum Tidal Power	kW	644	2450
Turbo-Expander Power	kW	500	1950
Compressor Power	kW	550	2040
Storage Capacity	kWh	550	2040
Power Generation Improvement by HT-CAES	%	18.4	17.4
Additional Power Generation by HT-CAES	MWh/y	542	1988
Deliverable Heat Energy	MWh/y	677	2485
HT-CAES Operation	Hr./Month	90.4	85
Unit Cost	$ M	5.75	19.60
Payback Period	Years	13.8	13

Assuming the electricity produced by the combined system (Tidal - HT-CAES) will send directly to the grid, HT-CAES system can reduce the consumption of coal and natural gas and also GHG emissions. The generated heat will deliver to local users which reduces the fuel oil consumption. The economical and environmental benefit of the system are presented in Table 10. Installing an HT-CAES system in Grand or Petit Passage can reduce GHG emissions up to 294 tonne/year while generating revenue for both the Municipality of the District of Digby and Nova Scotia. For Digby Gut reduction in GHG emissions is 692-1079 tonne/year.

Table 10. Environmental and economical benefits of Tidal – HT-CAES system

Location	Grand/Petit Passage	Digby Gut
Coal Saving (tonne/year)	83-121	307-444
Natural Gas Saving (10^3m^3/year)	10.5-26	39-97
Fuel Oil Saving (m^3/year)	84	307
GHG Emission Reduction (tonne/year)	188-294	692-1079
Revenue for the Municipality (k$/y)	91-138	336-504
Revenue for Nova Scotia (k$/y)	19-35	71-128

3.5.4 Socio-economic benefits

Integrating renewables with energy storage into a microgrid results in short-term and long-term job creation. A job is equivalent to the resources required to employ 1 person for 12 months [45].

Construction, operation and the energy saving generated by the investment can create opportunities for workers (see Figure 22).

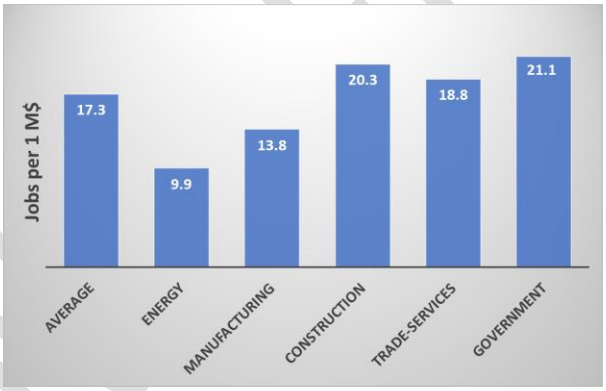


Figure 22. Jobs per million dollars of revenue by key sectors (Adopted from Ref.)

The number of jobs created during each phase of proposed systems is estimated from the money spent for manufacturing, engineering, construction, operation and maintenance of our system (direct jobs) and the costs saved by reduction in the energy price (indirect jobs). The number of jobs related to manufacturing is estimated from capital costs. For the engineering and construction phases, a portion of capital cost (usually 30%) is considered to estimate impact on job creation. The estimated number of jobs for the recommended systems are presented in table

Table 11. Total direct and indirect Jobs created for each recommended solution (person per year).

System	Manufacturing Phase	Construction Phase	Engineering Phase	Total Direct Jobs	Total Indirect Jobs

PV-TES for Hospital & High School	10	5	2	17	9
Biomass Direct Combustion System	14	8	6	28	23
Energy Storage for Tidal Energy (500 kW)	24	10	5	39	43
Energy Storage for Tidal Energy (1950 kW)	84	37	18	139	147

4 Eco Industrial Park Opportunity

Eco-industrial parks may offer the economical advantages of traditional industrial parks while also using resources more efficiently, improving productivity, supporting the achievement of eco-social goals, and lowering exposure to climate change risks. To reach this goal, the Municipality of the District of Digby needs to reduce the cost of energy by providing clean cheap energy from renewable sources to local industries.

4.1 Energy Demand Analysis

The industrial park is approximately 22 acres in area and is generally located south of Highway 217 and is bounded by industrial lots, residential lots, and institutional uses. At this time, the area is approximately 60% occupied. The remaining available lands (in yellow in Figure 23) total roughly 10 acres and are surrounded with streets that include municipal services including sanitary sewer, water distribution system, overhead electrical, and paved roads with roadside ditches and culverts for drainage [5]. Figure 7 shows our current knowledge of current industries located in this site.

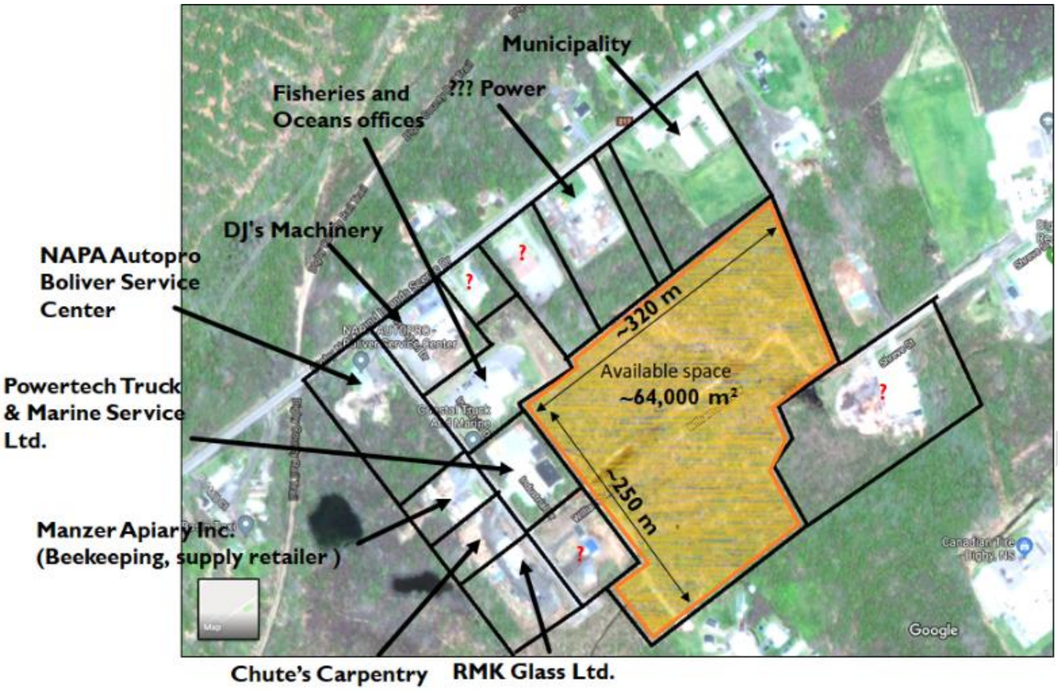


Figure 23. Municipality of Digby industrial park [5][46]

Assuming 8 working hours per day and 261 working days per year, we estimated the energy demand of the industrial park based on the type of industries. Table 12 shows our estimation of the energy consumption.

Table 12. The estimated energy demand for the industrial park

Energy Consumption (MWh/year)	Avg. Electricity Demand (kW)	Peak Electricity Demand (kW)
2577	788	2126

4.2 Recommended Solutions

The recommended solutions to achieve the goal of eco industrial park, is based on the development of biomass energies. The main goal is to reduce fossil fuels consumption and to reduce GHG emissions. The recommended solution can not only have environmental benefits, but also economically.

4.2.1 Clean Microgrid with Biomass CHP System

Using wood waste to generate electricity as well as heat (combined heat and power (CHP) system), is a suitable option for the industrial park which can run as a microgrid with zero carbon emission. Currently, more than 55% of NS grid electricity comes from coal which results in many tonnes GHG emissions each year. On the other hand, wood waste is technically a renewable energy resource because trees can be replanted after they're harvested. And because trees store carbon as they grow, replacement forests will gradually remove the carbon dioxide emitted when the previous trees were burned for energy. In this way, the whole process is carbon neutral, putting no net emissions into the atmosphere [47].

The advantage of the Clean microgrid system anchored with TES can be listed as follow:

- Has **abundant, dispatchable** energy capacity
- **Enables greater use of renewable power**
- Is stable and **dependable**
- Brings cost of electricity to **below grid average**
- **Reduces fuel oil** consumption and therefore
- **Reduces GHG emissions** and black soot
- Releases **no harmful chemicals** into the environment
- Captures and **redistributes waste heat**
- Lasts for **40+ years**
- **Pays for itself** and its replacement
- Directly creates **long-term** jobs for locals
- Provides energy stability to **encourage economic and social development**

To conduct a technical and financial analysis for a microgrid system for the industrial park, we considered following assumptions:

- Space is available with no cost
- Cost of Fuel oil is $1.05/liter, escalated at 2% per year
- Cost of Coal is $0.078/kg, escalated at 2% per year
- Cost of Natural Gas is $0.154/m^3, escalated at 2% per year
- Cost of wood fuel is $35.0/tonnes, escalated at 2% per year
- Cost of PV panels is $1.4 /W including engineering and installation
- O&M cost of the systems is 2% of the total materials cost and increases at 2% per year
- Carbon tax of $20 on every tonne of greenhouse gas emission starting in 2019, rising by $10 each year to $50 a tonne by 2022 [34]
- Financing for 20 years at the interest rate of 6.5%

Our optimization method aims to design a microgrid system including renewables to minimize the average energy cost while meeting the demand (Table 12). We assume that the peak demand occurs between 8 am to 4 pm and it is 2126 kW. The average daily demand is 788 kW. The details are presented in Table 13.

Table 13. Recommended biomass direct combustion system for the industrial park

Required Steam Turbine (kW)	2200
Required Wood (38% moisture) (tonne/year)	12846
Deliverable Electrical Energy (MWh/y)	7258
Deliverable Heat Energy (MWh/y)	21790
Installed cost (M$)	5.73
levelized cost of energy (¢/kWh)	7.2

Comparing Table 5 and Table 13 shows that levelized cost of energy cost intensity tends to decrease as the system size increases. Small systems have higher O&M costs per unit of energy generated and lower efficiencies than large systems [18].

Assuming the current electricity source for the industrial park is the NS grid and also local industries use fuel oil for heating purposes, the clean microgrid can reduce up to 3950 tonne GHG emissions each year while saving coal, natural gas and oil fuel (Table 14). Saving on fossil fuels and also carbon tax can bring revenue for both the Municipality of the District of Digby (up to $145k/year) and Nova Scotia Power (up to $4.2M/year) (Table 15).

Table 14. Environmental benefits of the 2.2 MW biomass direct combustion system

Coal Saving (tonne/year)	1121-1622
Natural Gas Saving ($10^3 m^3$/year)	142-353
Fuel Oil Saving (m^3/year)	2694
GHG Emission Reduction (tonne/year)	8363-9374

Table 15. Economical benefits of the 2.2 MW biomass direct combustion system

Revenue for the Municipality (M$/y)	2.5-4.2
Revenue for Nova Scotia (M$/y)	0.12-0.14

The energy cost for the next 20 years is shown in Figure 24. The residential energy price form NS power is higher than the energy production cost by the recommended microgrid. The cost of deliverable energy by the clean microgrid system is 7.2 ¢/kWh in 2019 which will reach to 8.9 ¢/kWh in 2038. Lower energy cost can encourage more industries to move to the industrial park.

The number of jobs created by deployment of a clean microgrid for the industrial park is presented in Table 16. In addition to people coming to invest in the industrial park, building and installing a clean microgrid can create 26 direct short term and 20 indirect long-term jobs.

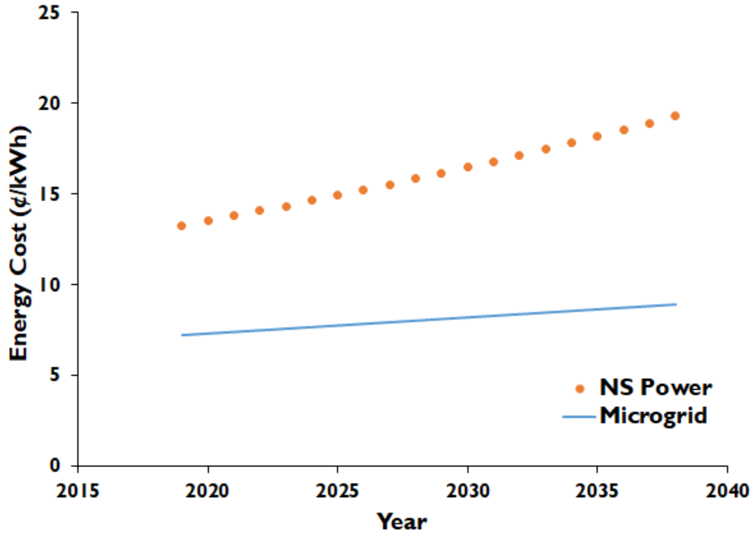


Figure 24. Microgrid energy cost versus energy price in NS

Table 16. Total direct and indirect Jobs created for each recommended solution (person per year).

System	Manufacturing Phase	Construction Phase	Engineering Phase	Total Direct Jobs	Total Indirect Jobs
Clean Microgrid	23	10	5	38	40

5 Other Possible Opportunities

5.1 An Electrical Port

5.2 Solar Energy

Solar energy, radiation from the Sun capable of producing heat, causing chemical reactions, or generating electricity [48]. Solar power is the conversion of sunlight into electricity, using photovoltaics (PV), or into heat using concentrated solar power (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect [49]. Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via photovoltaics into electricity. The efficiency of the solar cells used in a PV or CSP systems, in combination with latitude and climate, determines the annual energy output of the system [50].

The annual average energy production potential for PV solar panels in Canada is presented in Figure 25a. Digby County has some of the better photovoltaic potential in Nova Scotia (Figure 25b), and numerous residents have installed solar photovoltaic or solar thermal systems on their homes [51].

The solar map shows that Digby is located in the medium range: 1,100-1,200 kWh/kW/yr. It means that for example a PV power generation project of 100 kW will generate 1,10-1,20 MWh of solar energy per year. It is equivalent to an average capacity factor of 12.8% – 14%.

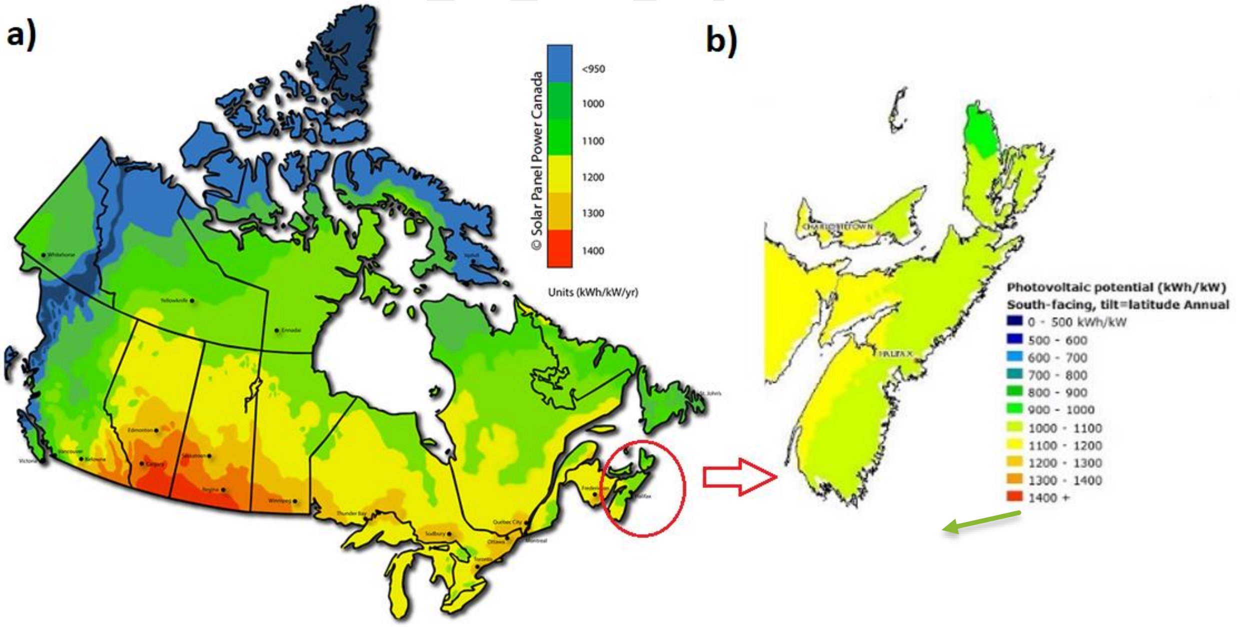


Figure 25. Annual average energy production potential for a solar panels in a) Canada [52] b) Nova Scotia (photo taken from www.nrcan.ca)

In the province's 2015 Electricity Plan: Our Electricity Future [53], Nova Scotia committed to introducing a new solar energy program. This program would help Nova Scotia move to a clean electricity system in a cost-effective way; while encouraging and enabling community participation in renewable energy generation [54].

However, installing a large capacity of PV panels especially for large facilities and the industrial park is an unexplored opportunity. The historical data for solar irradiation was available only in daily resolution [55]. To estimate the PV panel production, the hourly radiation was estimated to a second-order accuracy using the sunrise and sunset times [56]. Considering a typical 110 W PV panel, we estimate the yearly production for PV panels at Digby location (Figure 26). Assuming the cost of PV panels is $1.4/W including engineering and installation, the levelized cost of energy for PV panels is estimated as 9-10 ¢/kWh.

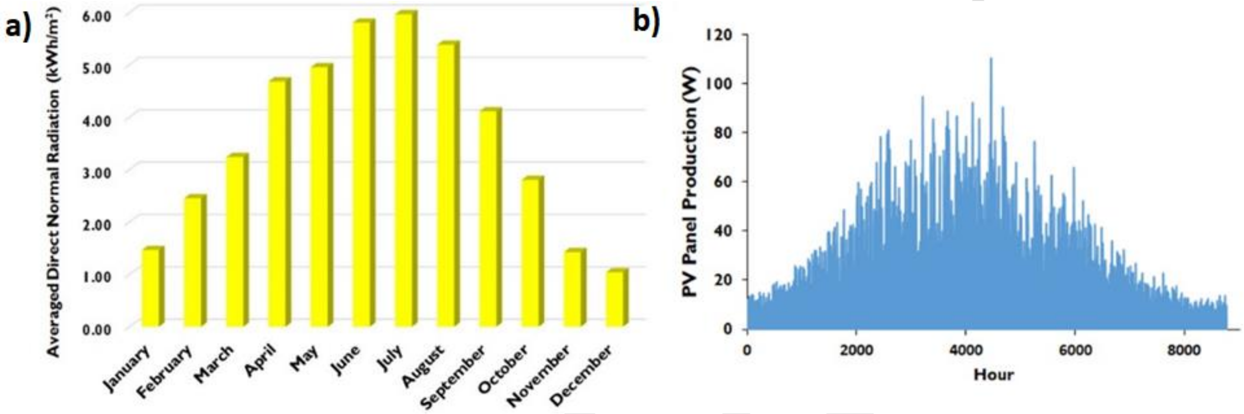


Figure 26. **a)** Average direct normal radiation for Digby over the last 10 years [57]; **b)** Hourly power output of a 110 W PV panel for over a year.

5.3 Ocean Thermal Energy Conversion (OTEC)

Ocean thermal energy conversion (OTEC) is a process for producing energy by harnessing the temperature differences (thermal gradients) between ocean surface waters and deep ocean waters. Energy from the sun heats the surface water of the ocean (here Bay Fundy). During summer day times, the surface water can be much warmer than deep water. In winter, the deep water is usually warmer than the surface water. Temperature differences of at least 25°C can be used to produce electricity using a thermoelectric module.

Alternatively, the cold deep water can be used as a cold source for an Organic Rankine Cycle (ORC) to produce electricity. Warm surface water is pumped through an evaporator containing a pressurized working fluid. The pressurized vaporized fluid drives a turbine-generator set to produce electricity. The fluid loses pressure in this process. Later, it is liquefied in a condenser cooled with the cold water pumped from deeper in the ocean [58].

The mean depth of the Bay of Fundy and Gulf of Maine is presented in Figure 27a [59]. The deepest spot in the study area is 366 meters, found in the middle of Georges Basin, but only 1.5% of the Gulf is deeper than 300 m. The closest deep spot to Digby is 200 m which is located in 60 km distance. Figure 20b shows how temperature decreases with increasing the ocean depth. The thermocline are layers of water where the temperature changes rapidly with depth [60].

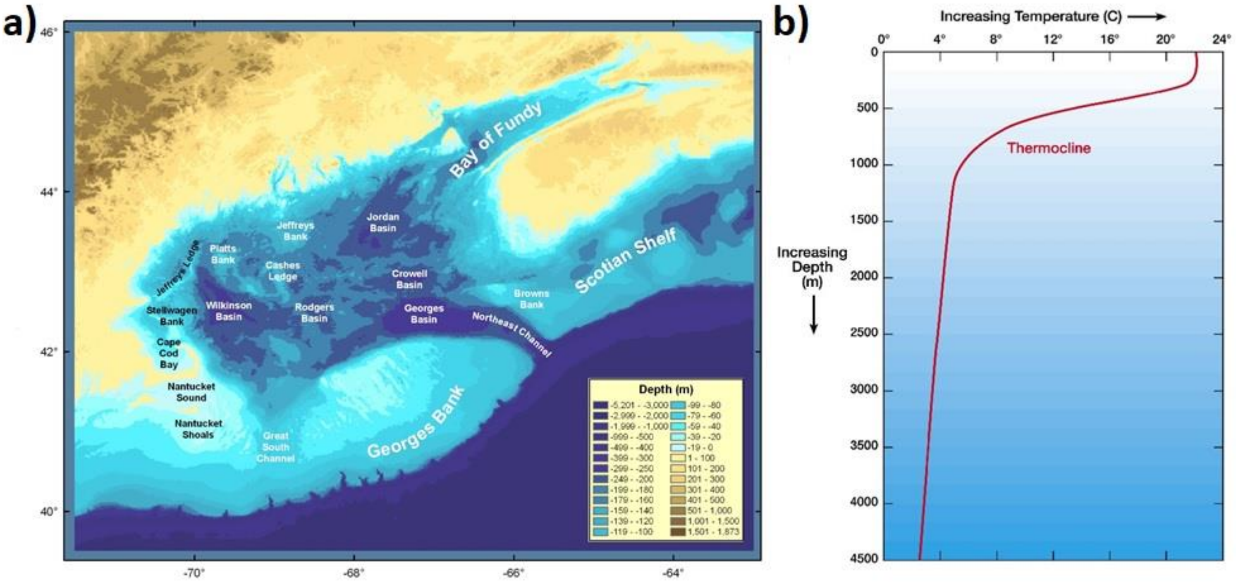


Figure 27. **a)** The mean depth of the Bay of Fundy and Gulf of Maine [59]; **b)** a typical temperature-depth ocean water profile [60].

Monthly average surface water temperature for Bay Fundy varies from -4°C in February to 17°C in August (see Figure 28a) [55]. Considering a typical Bismuth Telluride-based thermoelectric module [61] and the temperature 4 at the ocean depth as the cold source, we estimate the output power for 100 unit of 12-volt, 1.5 ampere thermoelectric power generator. The results are presented in Figure 28b. The generator efficiency was estimated around 1%. Although the natural power output and generation efficiency maybe very low, using a waste heat source at 300°C (such as biomass generator exhaust) can increase the efficiency to 40%.

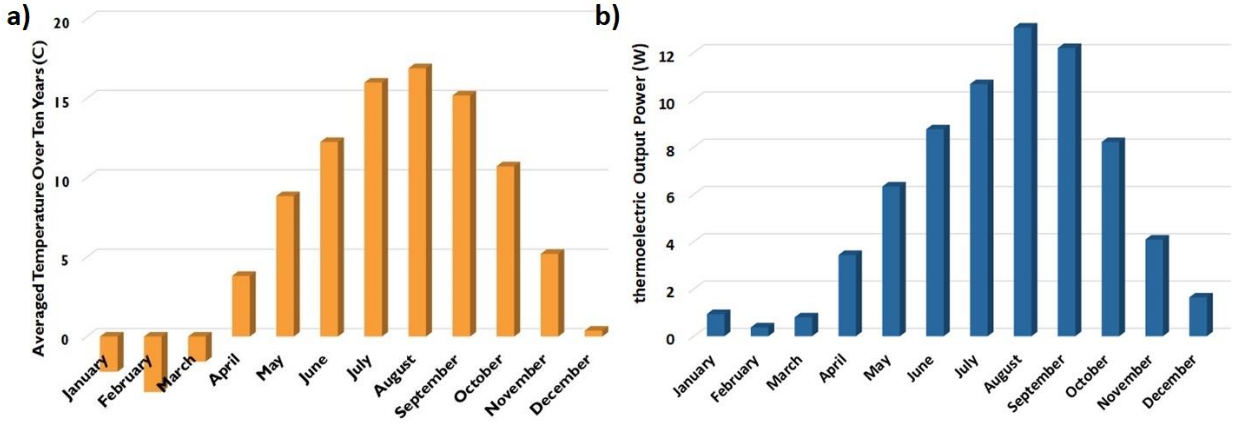


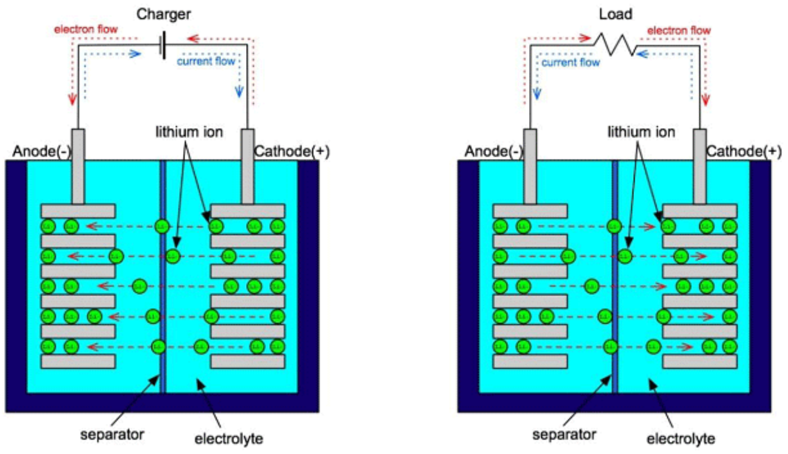
Figure 28. **a)** Average surface water temperature for Bay Fundy over the last 10 years; **b)** The output power for thermoelectric power generator.

5.4 Batteries

The largest battery energy storage systems use sodium–sulfur batteries, whereas the flow batteries and especially the vanadium redox flow batteries are used for smaller battery energy storage systems [62].

Li-ion batteries have been deployed in a wide range of energy-storage applications, ranging from energy-type batteries of a few kilowatt-hours in residential systems with rooftop photovoltaic arrays to multi-megawatt containerized batteries for the provision of grid ancillary services, but require some re-engineering for grid applications [62,63].

Figure 29 shows the charging and discharging process in Li-ion batteries. When the battery is charging up, the lithium oxide, positive electrode gives up some of its lithium ions, which move through the electrolyte to the negative, graphite electrode and remain there. When the battery is discharging, the lithium ions move back across the electrolyte to the positive electrode, producing the energy that powers the battery [64].



CHARGING

DISCHARGING

Figure 29.. Charging and discharging process in Li-ion batteries [65]

5.4.1 Life Cycle Analysis of CP-TES Compared to Batteries

To understand the relative impacts of a HT-CAES system compared to Li-ion batteries and conventional compressed air energy storage (CAES) we performed a Life Cycle Assessment (LCA). The analysis is conducted using OpenLCA software [66]. Each phase of the life-cycle has been considered (materials, construction, usage, and end-of-life phase) and the impacts are presented in four separate categories: Ecosystem Quality, Human Health, Resources and Climate Change. In all four categories, the HT-CAES system has the smallest environmental footprint (Figure 30).

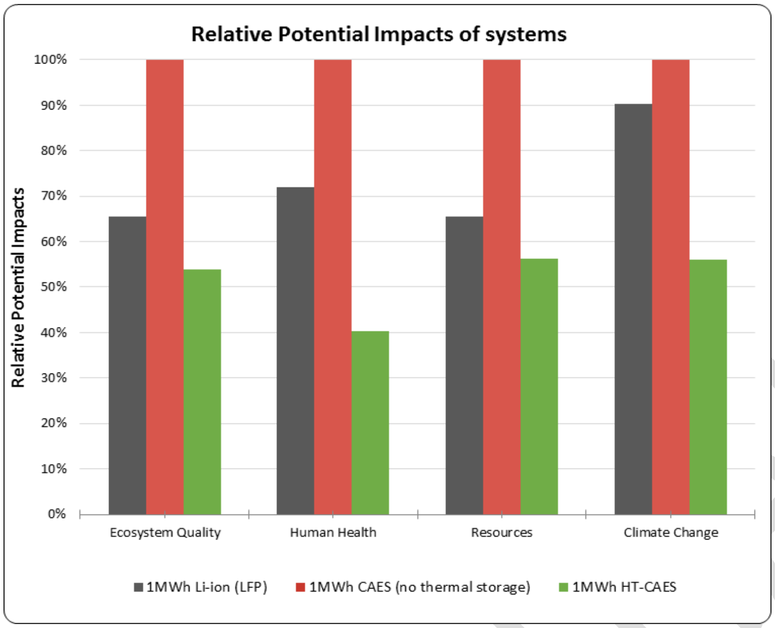


Figure 30: Life-cycle assessment comparison of CAES, Li-ion batteries, and HT-CAES

Compared to an equivalent Lithium-ion (Li-ion) battery storage system, an HT-CAES system reduces potential environmental impacts by 18% for ecosystem quality, 44% for human health, 14% for natural resources, and 38% for climate change. Comparison of HT-CAES system with an equivalent CAES system shows that environmental impacts of HT-CAES is lower: 46% for ecosystem quality (Terrestrial Ecotoxicity), 60% for human health (Ionizing Radiation & Respiratory Effects), 44% for natural resources (Non-Renewable & Mineral Extraction), and 44% for climate change.

5.4.2 Life Cycle Analysis of CP-TES Compared to Batteries

This life cycle analysis compares the environmental impacts of three energy storage technologies: $LiFePO_4$ Battery (Li-ion), Vanadium Redox Battery (VRB) and CP-TES. The study presents the impacts of each system for the delivery of 1 MWh. The dimensions of each system modelled have been scaled to fit this function (lifespan, materials, etc.) for comparison on the same basis. Each phase of the life cycle has been considered (materials, construction, usage, and end-of-life) and the impacts are presented in four separate categories: Ecosystem Quality, Human Health, Resources, and Climate Change. In all four categories, the CP-TES system is less damageable for the environment, as illustrated in Figure 31 and Table 17.

Overall, the Li-ion Battery presents the highest relative impacts, followed by VRB. This can mostly be attributed to the fact that many chemical components are required for them to function, requiring intensive mineral extraction and end-of-life landfilling that is harmful for both human health and the environment. This aspect is mostly visible in the Resources impact category. Another factor that plays against both battery storage options, but especially Li-ion, is their short lifespan. More batteries are required to accomplish the same task as one CP-TES system, so more extraction and landfilling of chemical materials is necessary to provide similar service. Additionally, Vanadium is extremely toxic and must be handled with extreme care. A major advantage for CP-TES system is the fact that minimal external electricity is required for the process. This reduces emissions during the usage phase.

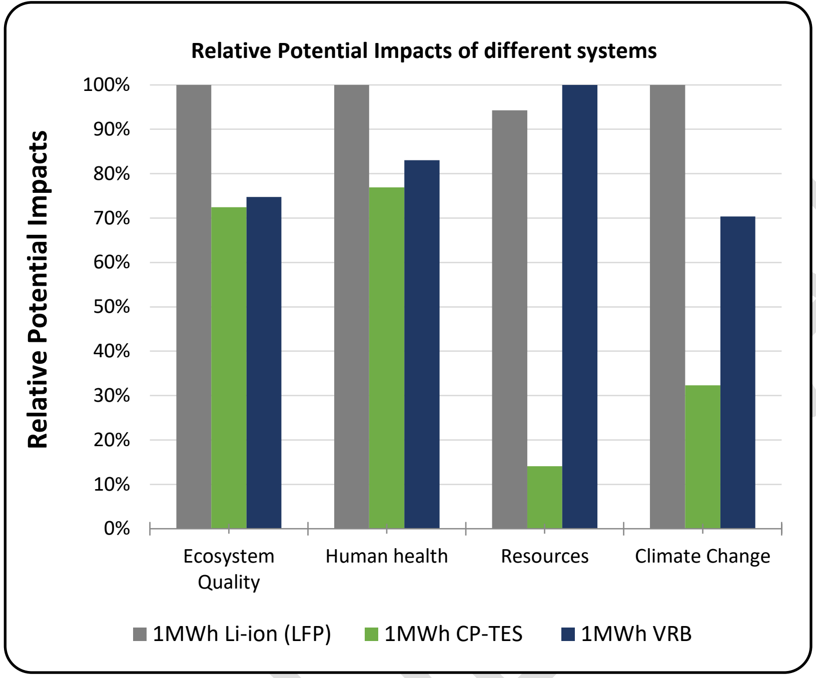


Figure 31 - Relative potential impacts for Li-ion battery, VRB, and the CP-TES.

In summary, compared to CP-TES process, a Li-ion solution causes more damage in the categories of Ecosystem Quality, Human Health, Resources and Climate Change by 39%, 30%, 671% and 312%, respectively.

Table 17- Comparison of the impacts of the Li-ion battery and the CP-TES

	1MWh Li-ion (LFP)	1MWh CP-TES	1MWh VRB
Ecosystem Quality	100%	72%	75%
Human health	100%	77%	83%
Resources	94%	14%	100%
Climate Change	100%	32%	70%

6 Conclusions

Energy storage is a valuable tool for reducing electric bills, making facilities resilient, and earning revenue, especially when it combined with renewable resources.

As a part of Nova Scotia Integrated Community Sustainability Plan (ICSP), Municipality of the District of Digby is committed to maximize the opportunities in renewable energy and to reduce its carbon footprint. These goals can be reached through specific plans such as building ecotourism and eco industrial park in the Municipality of the District of Digby.

Deploying renewable resources align with energy storage have a great economic and environmental benefits. By improving the overall efficiency of the grid, storage accelerates the broader adoption of renewable energy. The recommended solutions have no emissions, so it can be placed anywhere in a high-demand facility with no immediate environmental or air quality impacts. These solutions also provide low energy price to both residential and industrial costumers which improves the people quality of life and also attracts more business. More industrial investment leads to faster economic growth in the both short term and long run. It creates jobs especially for young generation and prevents population decline.

In this study we focused on four different systems as follows:

- PV-Thermal Energy Storage for Local Facilities

- Biomass Direct Combustion System

- Energy Storage for Tidal Energy

- Clean Microgrid with Biomass CHP System

The summary of technical and financial analyses for mentioned systems are presented in Table 18.

Table 18- Summary of the technical and financial analyses

Recommended System	**Goal**	**Environmental Benefits**	**Economical Benefits**	**Socio-economic benefits**
PV-Thermal Energy Storage for Local Facilities	Ecotourism	<u>For the hospital:</u> <u>52% fuel oil saving</u> 100 tonne/y <u>For the high school:</u> 22% fuel oil saving 71 tonne/y	Up to $52,500 for the hospital and up to $36,400 for the high school	17 person per year direct jobs and 9 person per year indirect job
Biomass Direct Combustion System	Ecotourism	Reduction Fossil fuel consumption: - Fuel oil (up to 325 m^3/year) - Coal (up to 196 tonne/year)	LCOE: 8.5 ¢/kWh Revenue for the Municipality: Up to $534,000 per year	28 person per year direct jobs and 23 person per year indirect job

		- Natural Gas (up to 43,000 m^3/year) - Reduce the GHG emissions (up to 1211 tonne/year)	Revenue for Nova Scotia: Up to $57,000 per year	
Energy Storage for Tidal Energy	Ecotourism	For Grand/Petit Passage: Reduction Fossil fuel consumption: - Fuel oil (up to 84 m^3/year) - Coal (up to 121 tonne/year) - Natural Gas (up to 26,000 m^3/year) - Reduce the GHG emissions (up to 294 tonne/year) For Digby Gut: Reduction Fossil fuel consumption: - Fuel oil (up to 307 m^3/year) - Coal (up to 444 tonne/year) - Natural Gas (up to 97,000 m^3/year) - Reduce the GHG emissions	For Grand/Petit Passage: Revenue for the Municipality: Up to $138,000 per year Revenue for Nova Scotia: Up to $35,000 per year For Digby Gut: Revenue for the Municipality: Up to $504,000 per year Revenue for Nova Scotia: Up to $128,000 per year	For Grand/Petit Passage: 39 person per year direct jobs and 43 person per year indirect job For Digby Gut: 139 person per year direct jobs and 147 person per year indirect job

		(up to 1079 tonne/year)		
Clean Microgrid with Biomass CHP System	Eco Industrial Park	Reduction Fossil fuel consumption: - Fuel oil (up to 2694 m^3/year) - Coal (up to 1622 tonne/year) - Natural Gas (up to 353,000 m^3/year) - Reduce the GHG emissions (up to 9374 tonne/year)	LCOE: 7.2 ¢/kWh Revenue for the Municipality: Up to $4.2M per year Revenue for Nova Scotia: Up to $0.14M per year	38 person per year direct jobs and 40 person per year indirect job

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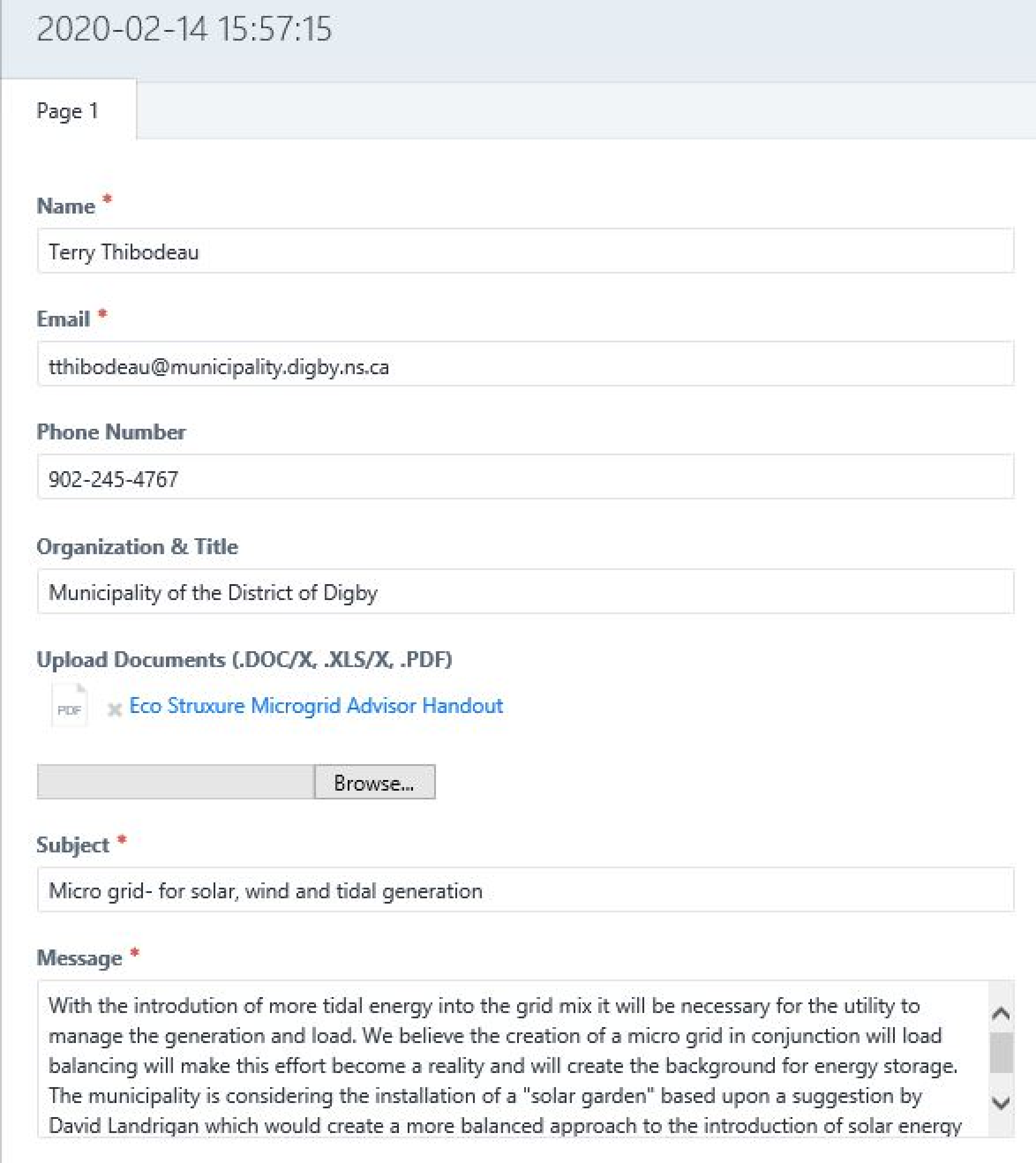

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Name *

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902-245-4767

Organization & Title

Municipality of the District of Digby

Upload Documents (.DOC/X, .XLS/X, .PDF)

Eco Struxure Microgrid Advisor Handout

Subject *

Micro grid- for solar, wind and tidal generation

Message *

With the introdution of more tidal energy into the grid mix it will be necessary for the utility to manage the generation and load. We believe the creation of a micro grid in conjunction will load balancing will make this effort become a reality and will create the background for energy storage. The municipality is considering the installation of a "solar garden" based upon a suggestion by David Landrigan which would create a more balanced approach to the introduction of solar energy

EcoStruxure™
Innovation At Every Level

EcoStruxure Microgrid Advisor

Connect, monitor, and control your facility's Distributed Energy Resources (DER) to optimize performance

Features

- Provides visibility and control to all of your DER in a single platform
  - Solar power
  - EV charging stations
  - Batteries
  - Wind energy
  - Back-up generators
  - HVAC systems
  - Lighting systems
  - Uninterruptible Power Supply (UPS)
  - Combined Heat and Power (CHP)
  - Utility metering
- Connects seamlessly to on-site DER to automatically forecast and optimize when to consume, produce, or store energy
- Guarantees system reliability and optimization – even if communication with the server is temporarily lost – through 48-hour advanced automatic default operation schedules

Benefits

- Single platform: connect, monitor, and control all DER from a single interface
- Demand control: shift and prioritize loads to avoid utility demand charges
- Storm hardening mode: leverage weather forecasts to reduce downtime
- Demand response: participate in utility programs to generate new revenue streams
- Tariff management: manage price through seasonal, day- and hour-ahead pricing
- Self-consumption: charge batteries with excess solar energy during peak periods
- Cyber secure platform: protect site and related data from external hacks

Distributed renewables and efficient on-site generation are changing the grid faster than ever before.

With EcoStruxure™ Microgrid Advisor, users can now take advantage of autonomous and dynamic control of energy production and consumption.

www.schneider-electric.us/microgrid

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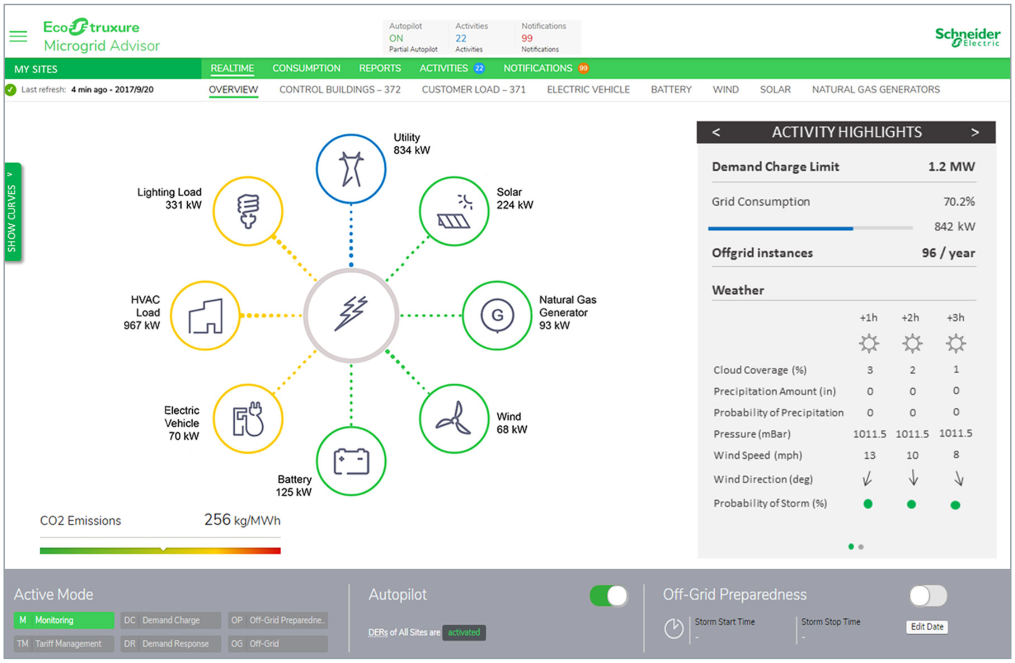
Access real-time DER system operation



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CO2 Emissions 256 kg/MWh

ACTIVITY HIGHLIGHTS

Demand Charge Limit 1.2 MW

Grid Consumption 70.2%

842 kW

Offgrid instances 96 / year

Weather

	+1h	+2h	+3h
Cloud Coverage (%)	3	2	1
Precipitation Amount (in)	0	0	0
Probability of Precipitation	0	0	0
Pressure (mBar)	1011.5	1011.5	1011.5
Wind Speed (mph)	13	10	8
Wind Direction (deg)	↙	↓	↘
Probability of Storm (%)	●	●	●

DERs of All Sites are activated

The cloud-based software platform enables you to monitor your power consumption, production, and energy usage by date. Export the data into an Excel™ file for a deeper analysis. Custom configurations and web services can be developed based upon your specific requirements.

Access and connectivity

Compatible devices and web browsers

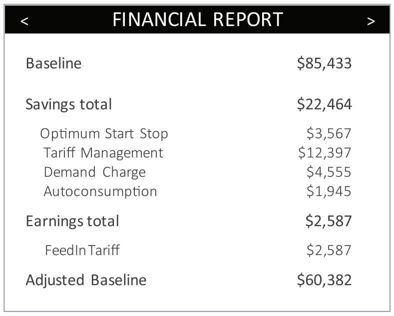
- Use your PC, tablet, or smartphone to stay informed of site conditions and usage
- Compatible with Chrome™, Firefox™, and Internet Explorer™ internet browsers

Third-party and DER database connectivity

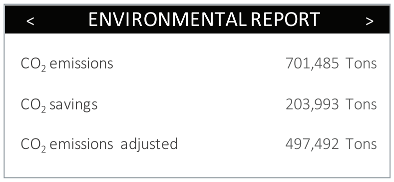
- Native OpenADR2.0 communication protocol seamlessly exchanges information, including utility information systems and commercial aggregators
- Standard web services API for cloud connectivity
- Communication with DER via
  - Modbus RTU
  - IP and LonWorks
  - TCP/IP, BACNet MSTP
  - HTTP/JSON

Connection to the hardware

- Secured connection through your on-site IT network (LAN) or dedicated ADSL lines
  - Cyber secure testing in white box mode using NIKTO, DIRBUSTER, SQLMAP, and BURP to secure EcoStruxure Microgrid Advisor from session hijacking, XSS, and SQL injection



< FINANCIAL REPORT >	
Baseline	$85,433
Savings total	$22,464
Optimum Start Stop	$3,567
Tariff Management	$12,397
Demand Charge	$4,555
Autoconsumption	$1,945
Earnings total	$2,587
FeedIn Tariff	$2,587
Adjusted Baseline	$60,382



< ENVIRONMENTAL REPORT >	
CO_2 emissions	701,485 Tons
CO_2 savings	203,993 Tons
CO_2 emissions adjusted	497,492 Tons

Provides real-time savings and earnings data (above) as well as CO_2 emissions (below).

To learn more about increasing your facility's efficiency, resiliency, and sustainability, visit www.schneider-electric.us/microgrid

Schneider Electric

800 Federal Street
Andover, MA 01810

www.schneider-electric.us/microgrid

October 2017

998-20080341_US

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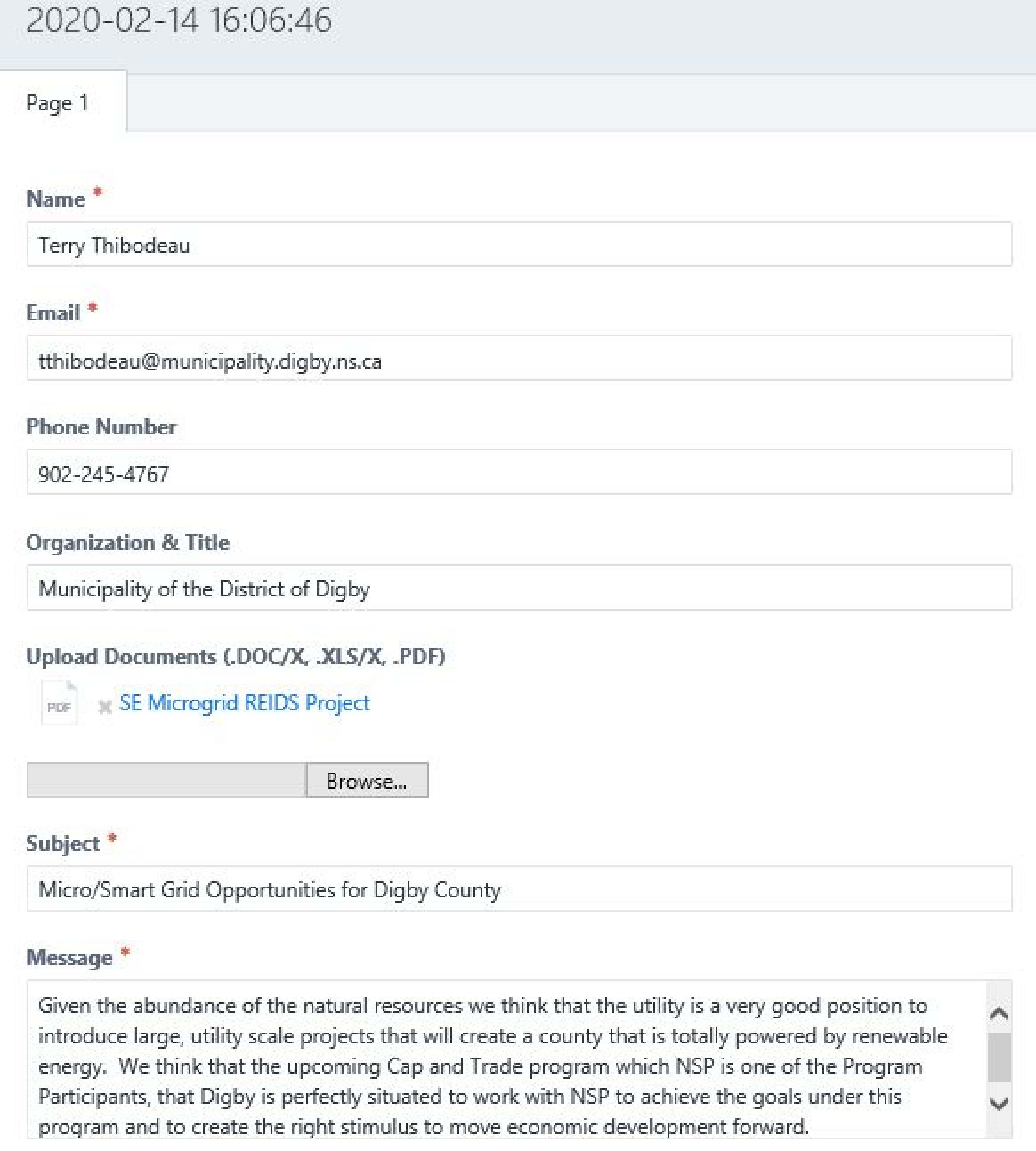

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SE Microgrid REIDS Project

Subject *

Micro/Smart Grid Opportunities for Digby County

Message *

Given the abundance of the natural resources we think that the utility is a very good position to introduce large, utility scale projects that will create a county that is totally powered by renewable energy. We think that the upcoming Cap and Trade program which NSP is one of the Program Participants, that Digby is perfectly situated to work with NSP to achieve the goals under this program and to create the right stimulus to move economic development forward.

Schneider Electric’s role

Development of the microgrid energy management system, to balance short-term loads

Engineering expertise

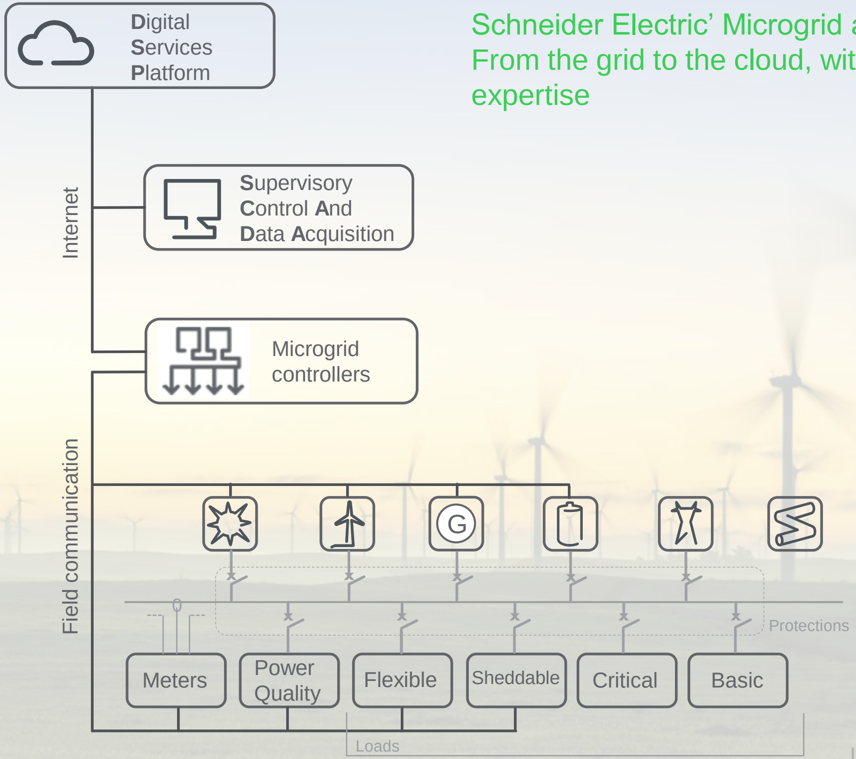
Cloud services
- Ancillary services
- Optimization Services
- Information Services

Supervision, HMI & Data Management
- Data Management
- Communication
- User and local Interfaces

Microgrid control
- Energy Management
- Power Management
- Control algorithms

Distributed Energy Resources
- Multi-fluid energies, heat & gas
- Electricity

Protections & Metering
- Protections
- Loads



Schneider Electric’ Microgrid architecture: From the grid to the cloud, with engineering expertise