Thunder Bay Community Energy and Emissions Plan

Supply and Constraints Analysis:

Local Renewable Energy and Biomass

October 15, 2020

PURPOSE OF THIS DOCUMENT

To provide a qualitative and quantitative analysis of the supply and constraints of renewable energy sources and biomass readily available to the city of Thunder Bay. The energy sources assessed include ground-mount and rooftop solar PV, utility-scale wind, and sustainable biomass (wet and woody). These energy sources are key elements of Thunder Bay's Community Energy and Emissions Plan.

Separate papers assess the related topics of their: 1) economic development potential, 2) capital and operational costs, and 3) implementation.

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Disclaimers

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This analysis includes strategic-level estimates of energy supply and constraints that should not be relied upon for design or other purposes without verification. The authors do not accept responsibility for the use of this analysis for any purpose other than that stated above, and do not accept responsibility to any third party for the use, in whole or in part, of the contents of this document. This analysis applies to the City of Thunder Bay and cannot be applied to other jurisdictions without analysis. Any use by the City of Thunder Bay, its sub-consultants or any third party, or any reliance on or decisions based on this document, are the responsibility of the user or third party.

Units of Measurement

<table>
<tr><th>Power
Used to describe the potential power of electricity resources (i.e. capacity)</th><th>Energy
A measure of energy actually used (or that will be used)</th><td rowspan="6">Watt vs. Watt-hour[1]

Electricity production and consumption are most commonly measured in kilowatt hours (kWh). A kilowatt-hour means kilowatt (1,000 watts) of electricity produced or consumed for one hour. One 50 watt light bulb left on for 20 hours consumes one kilowatt-hour of electricity (50 watts x 20 hours = 1,000 watt-hours = 1 kilowatt-hour).</td></tr>
<tr><td>kW (kilowatt, 1,000 watts)</td><td>kWh (1,000 watt-hours)</td></tr>
<tr><td>MW (megawatt, 1,000,000 watts)</td><td>MWh (1,000,000 watt-hours)</td></tr>
<tr><td>GW (gigawatt, 1,000,000,0000 watts)</td><td>GWh (1,000,000,0000 watt-hours)</td></tr>
<tr><td>TW (terawatt, 1,000,000,000,000 watts)</td><td>TWh (t1,000,000,000,000 watt-hours)</td></tr>
<tr><td>PW (petawatt, 1,000,000,000,000,000 watts)</td><td>PWh (1,000,000,000,000,000 watt-hours)</td></tr>
</table>

[1] "How is electricity measured?" n.d. European Wind Energy Association. Retrieved from: www.ewea.org/wind-energy-basics/faq/.

Scope of Analysis and Key Findings

This analysis is intended to substantiate and provide additional context to some of the key actions in Thunder Bay's Community Energy and Emissions Plans (CEEP), namely: the supply and constraints of key local renewable energy sources.

The city of Thunder Bay will need to take four key steps in order to decarbonize: 1) maximize energy efficiency; 2) then, switch as much as the remaining energy demand to fossil-free electricity; 3) where it is not feasible to use fossil-free electricity, switch to alternative fuel sources like hydrogen and biomass; as well as 4) minimize all emissions from the uncontrolled decay of organic waste in its landfill and composting facilities. These actions will likely also need to be complemented with the adoption of negative carbon technologies and sustainable forestry practices.

In Thunder Bay, local renewable energy production—from wind, solar and biomass—support several of these steps. It also has the potential to decrease reliance on central fossil fuel power plants. Ontario now has a mostly fossil-free electricity grid (in 2019, only 6% of electricity was supplied by natural gas or oil)[2]; however, this percentage is expected to increase through to 2040 due to a growing reliance on natural gas plants.[3] What's more, local renewable energy generation also provides local economic development benefits, such as jobs and lower energy bills (the latter are explored in a separate paper: 'Best Practice: Using a CEEP as an Economic Development Tool').

Based on the City's demographics projections, as well as future climate projections, we project that Thunder Bay will have a total energy demand of about 6.9 TWh (or 25 PJ) in 2050; however, this number would be significantly reduced in a low-carbon 2050 scenario where efficiency is maximized. If all the renewable energy supplies identified in this paper were leveraged, it could fulfill about four times Thunder Bay's projected business-as-planned demand, or a total of 30 TWh (108 PJ). There are limitations to installing all potential supply, including economics, provincial policies, public pushback, and technical and policy grid integration issues. As such, of the potential supply we have identified in this analysis, we have been conservative applying only a small portion (20%) of this total as a contribution to Thunder Bay's CEEP.

This supply and constraints analysis is focused on two major sources of local renewable energy: wind, and sun.
A supply and constraints analysis is also undertaken for biomass (wet and woody). Even though biomass is an emitting energy source, with proper care, certain sources can be harnessed with minimal GHG emissions[4] and air quality impacts.[5]

[2] IESO, 2019 Year in Review. Retrieved on Sept. 2, 2020, from: www.ieso.ca/en/Corporate-IESO/Media/Year-End-Data.
[3] IESO, Annual Planning Outlook (JAnuary 2020), Figure 32.
[4] IEA, Outlook for Biogas and Biomethane (2020), at 79.
[5] See generally: NRDC, A Pipe Dream or Climate Solution? The Opportunities And Limits Of Biogas And Synthetic Gas To Replace Fossil Gas (June 2020, Issue Brief 20-05-A). Retrieved from: www.nrdc.org/sites/default/files/pipe-dream-climate-solution-bio-synthetic-gas-ib.pdf.

Each of these energy sources are assessed for their projected supply within or near to the city boundary. Potential constraints to this supply (e.g. political, regulatory, technical, or financial) are also outlined.

Please note the rationale for not including the following renewable energy sources within this analysis:

- **Solar direct hot water:** Even though the collection efficiency (energy harvested per square area) of PV is less than that of a solar thermal system, when comparing the overall system capital and operational costs, the use of PV modules to provide hot water (through a simple resistive heating element) may now be as financially attractive as solar thermal collectors, and is more flexible to address different end uses as required.
- **Hydro:** Site-specific environmental assessments would be required for a meaningful analysis of hydro power supply for Thunder Bay.
- **Geothermal:** Any meaningful assessment of geothermal supply would require an additional geological survey. Geo-exchange as a cooling and heating source for electric heat pumps will be assessed in a separate memo on district energy.
- **Deep water cooling:** This technology will be assessed in a separate memo on district energy. Any meaningful assessment of potential deep water cooling supply would require the results of a separate hydrological study.

Table 1 - Summary of key renewable energy and biomass supply and constraints for Thunder Bay.

	Technology	Current Supply	Potential Additional Supply (2050)	Constraints
WIND	150 metre turbines	≈877 GWh	≈11,108 GWh	● available land area/competing land uses ● wind strength ● land slope ● need for community support ● economic case ● impact on biodiversity (habitat fragmentation) ● electricity system infrastructure

				• provincial electricity policy
	Offshore	none	≈11,493 GWh	• offshore wind moratorium
SOLAR	Roof mount	≈14 GWh	≈1,839 GWh	• roof strength • roof slope • financing • sharding • electrical grid management • provincial electricity policy
	Ground mount	≈162 GWh	≈6,815 GWh	• available land area/competing land uses • land slope • cost of land • cost to develop land • electrical grid management • provincial electricity policy
BIOMASS (wet)	Anaerobic digestion	≈ 60 GWh	none	• locating consistent wet biomass supply from private businesses • risk of methane leakage • nitrogen oxide (NOx) emissions during combustion; • need for carbon-free transportation of biomass
	Refined to RNG	none	≈ 26 GWh	
BIOMASS (woody)	Direct combustion	≈ 1,900 GWh	≈ 186 GWh	• locating sustainable woody biomass supply • need for carbon-free transportation of biomass • need to minimize CO2 and air particulate emissions from combustion
Total		3,013 GWh	31,467 GWh	

Electricity System Impacts from Electrification of Heating and Transportation

Despite significant improvements in energy efficiency, a net-zero carbon future will involve increased zero-emissions electricity demand. This is due to the fact that Ontario's electricity grid is expected to become more carbon-intensive out to 2050. There will be a need for additional renewable resources, which could be satisfied locally, primarily by wind and solar.

Because the wind is not always blowing and the sun is not always shining, balancing generation with demand with battery storage enables a more efficient use of these technologies. This minimizes how often the electricity system operator needs to balance these supplies with demand with the blunt and inefficient tool of curtailment (i.e. turning the resources down or off).[6]

In Ontario, the electricity system operator assumes that over the course of the year solar and wind installations will only be reliably available for about 15% and 30% of the time, respectively, due to their intermittency.[7]

If these solar installations were paired with back-up battery storage, we conservatively estimate curtailment could be reduced by 5% for both technologies.[8] In other words, by pairing wind and solar PV installation with batteries, the usable energy is increased. An additional or complementary strategy is to reduce curtailment by changing demand patterns, such as by charging car batteries overnight, as opposed to during peak electricity demand times.

In order to ensure increased renewable energy deployment and integration with the local grid, it will be necessary for the City to work in partnership with local utility Synergy North. Synergy North has already been an active player in the Independent Electricity System Operator (IESO) procurements and could continue to partner on projects and bid on procurement allocation.

The City of Thunder Bay, as one of the two shareholders of Synergy North, has an influence over renewable energy development in and around the city. This topic will be addressed in more detail in the CEEP Implementation Plan.

[6] Environmental Commissioner of Ontario, Making Connections: Straight Talk about Electricity in Ontario (2018) at 104.

[7] IESO, Ontario Planning Outlook (September 2016) at Table 2.

[8] Paul Denholm and Trieu Mai, Timescales of Energy Storage Needed for Reducing Renewable Energy Curtailment. Renewable Energy (2017) at 10.

WIND

Table 2 - Current and potential supply of wind generation within Thunder Bay and the surrounding region.

	As of March 31, 2020	Potential supply (150 meter turbines)	Major constraints
Wind energy	98.9 MW (Dorion)	1,268 MW* (onshore) 1,312 MW* (offshore)	● available land area/competing land uses ● wind strength ● land slope ● need for community support ● economic case ● electricity system infrastructure ● provincial electricity policy ● offshore wind moratorium
Total	**98.9 MW**	**2,580 MW**	

*assuming 25% curtailment (see text box)

As of today, Ontario has more than 5,000 MW of wind energy capacity installed, representing more than 12% of the province's electrical grid capacity.[9] When located in an area with an appropriate wind, wind is an ideal source of renewable energy because of its relatively low cost per unit of energy produced.[10] Wind energy prices are forecast to continue to decline as technology improves.[11]

Wind generation facilities can be developed where, at minimum, the following criteria are met:

1. Wind speeds match the wind turbine specifications; and,
2. The area,
   a. satisfies building set-back requirements,
   b. has (or can have) road access,
   c. has a compatible land use designation
   d. has or (can have) transmission line access, and

[9] IESO, Ontario's Supply Mix (as of June 2020). Retrieved from: ieso.ca/en/Learn/Ontario-Supply-Mix/Ontario-Energy-Capacity#:~:text=The%20current%20installed%20capacity%20on,within%20Ontario's%20local%20distribution%20systems..

[10] Lazard, Levelized Cost of Energy and Levelized Cost of Storage 2019 (Nov 2019). Retrieved from: www.lazard.com/perspective/lcoe2019/.

[11] International Renewable Energy Agency, The Power to Change: Solar and Wind Cost Reduction Potential to 2025 (June 2016).

e. has less than a 10% slope.

Some additional political and regulatory constraints are discussed below.

The size of the turbines and the setback requirements mean that turbines are usually sited in rural areas. Rural lands or lands away from city centres also have lower value and reduce the cost to install the towers. However, distance from the nearest transmission line creates additional costs and regulatory barriers. Ideally, local wind development should take place within 22 kilometres of the center of Thunder Bay. There are limited potential sites for wind developments within the Thunder Bay region.

Currently, the region in and around Thunder Bay is only home to one major wind generation facility, which is about 70 kilometres (km) east in the Township of Dorion, Ontario. The 43 towers near Dorion have a 98.9 MW capacity.[12] The Big Thunder Wind Project, which proposed 18 turbines (~27 MW) on the Nor'Wester Mountains on land owned by the City of Thunder Bay, adjacent to Fort William First Nation, was shelved in 2014. The main opposition to the project stated that there was insufficient consultation with Fort William First Nation.[13]

[12] "Greenwich wind farm project," n.d., The Canadian Business Journal. Retrieved September 2020 from: www.cbj.ca/greenwich_wind_farm_project_powering_change/.

[13] *Ibid.*

Supply

Average Wind Speeds

The taller the wind turbine, the more energy can be harnessed and the more economical the project.[14] Wind speeds increase with the height above the ground and, because there are fixed costs associated with wind turbine installation, wind turbines tend to be very tall, with main tower heights in the range of 80 to 130 metres (m), and blade lengths in the range of 40 to 60 m.[15] The analysis examines 150 m turbines, which require average wind speeds of 7.9–9 m/second (s) and are able to generate 4MW.

As shown in Figure 1, the region around Thunder Bay has potential for 150 metre turbine wind energy production in the mountains south of Thunder Bay, in the Fort William First Nation Reserve, and offshore. Wind speeds have been determined using data derived from the Global Wind Atlas.[16]

[14] Lazard, Levelized Cost of Energy and Levelized Cost of Storage 2019 (Nov 2019). Retrieved from: www.lazard.com/perspective/lcoe2019/.

[15] "Wind Power Pathway" 2017. Leidos Consulting. Retrieved from: documents.ottawa.ca/sites/documents/files/energy_evol_pathways_en.pdf

[16] Global Wind Atlas. Retrieved in September 2020 from: globalwindatlas.info/.

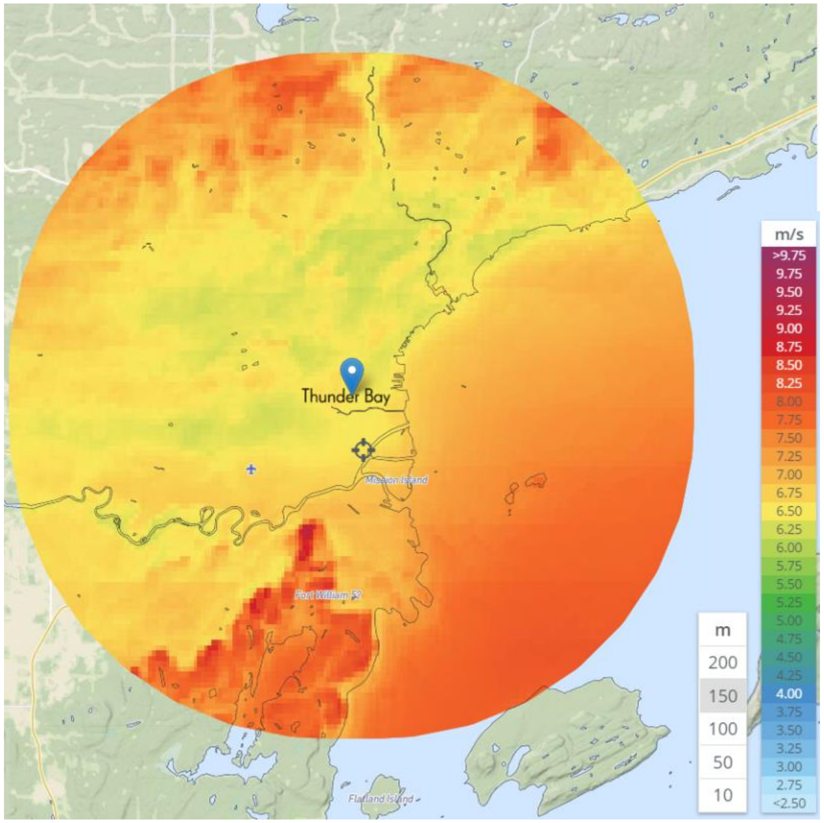

Figure 1 - Average wind speeds for the City of Thunder Bay and the surrounding 25km radius.[17]

The supply of wind energy in and around a 25 km radius of the City of Thunder Bay energy can be characterized as being medium to high capacity due to high winds in the mountainous areas, as well as near the shore of the lake, with the greatest capacity being offshore (see Figure 1).

Slope

Slopes of greater than 10% have been deemed too steep to support the construction of wind turbines.[18] Slope in Thunder Bay was determined using the HydroSHEDS digital elevation model.[19] All land with a majority slope greater than 10% have been removed from consideration.

Distance From Target

Wind farms require high voltage lines because of the magnitude of power produced at a farm. In addition, wind farms are typically developed within 10 to 40 km of an existing line. Projects are most frequently connected to 115 or 230 kilovolt (kV) lines.[20]

As there are no viable land patches within Thunder Bay proper, distances between viable land patches within the region and downtown Thunder Bay were calculated to estimate extra costs associated with building transmission lines to carry electricity from the outskirts to the city. Distances from each land patch to the nearest transmission lines were also calculated using utility line data from Ontario's Ministry of Natural Resources and Forestry.[21] The cost of building transmission lines ranges between $1,000 and $1,200 per meter.[22] Costs of transmission line construction to

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[17] Adapted from Global Wind Atlas, globalwindatlas.info/.

[18] Rob Van Haaren and Vasilis Fthenakis, GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): Evaluating the case for New York State. *Renewable and Sustainable Energy Reviews*, 15:3332–3340 (2011).

[19] Bernhard Lehner et al., New global hydrography derived from spaceborne elevation data, Eos (Washington. DC), 89:93–94 (2008).

[20] Leidos Consulting Canada Inc, Pathway Study on Wind Power prepared for the City of Ottawa (October 2017), at 9.

[21] Government of Ontario, Geohub: Utility Line Data. n.d. Accessed August 2020, retrieved from: geohub.lio.gov.on.ca/datasets/mnrf::utility-line.

[22] Kirby Calvert et.al., Mapping Opportunities for Renewable Energy: A Guidebook (October 2019).

connect to downtown and to the nearest transmission line are included in the tables in **Appendix A.**

Area

Wind turbines greater than 100 m tall must typically be placed 7 hectares apart (.7km^2).[23]

Developing 20 MW, 50 MW, 100 MW, and 200 MW Farms

The proposed turbines each have a production capacity of 4 MW and require ~7 hectares (ha) of land. Thus, the smallest suggested wind farm of 20MW would require ~35 ha, a 50 MW farm would require ~90 ha, a 100 MW farm would require ~175 ha, and a 200 MW farm would require ~350 ha.

There are 32 land patches that meet slope, distance, and wind requirements that would support at minimum a 20 MW wind farm. If all of these sites were developed, the Thunder Bay region would be able to support roughly 1,690 MW in wind farms (see Figure 2 and **Appendix A**).

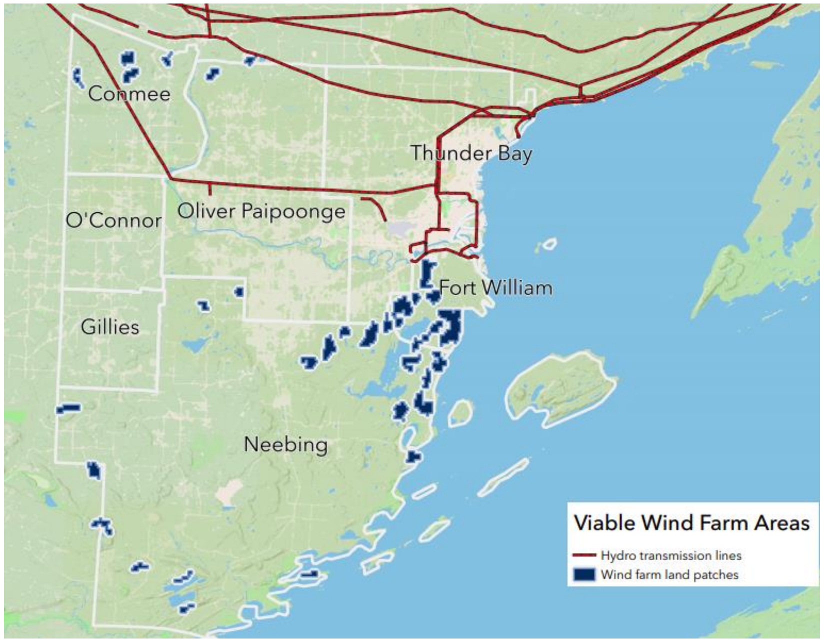

Figure 2 - Viable wind farm sites within the region of Thunder Bay (assuming 150 m wind turbines, minimum 20 MW installations).

Constraints

Environmental Impact Assessment and Consultation

Each site would require its own environmental impact assessment (EIA) and community consultation before construction. There have frequently been concerns and protests by local residents in the vicinity of wind farms, particularly in relation to perceived health impacts from low frequency sound from turbines. As of late 2018, municipalities have the right to oppose renewable energy projects

[23] UK Government, Draft PPS 18: Renewable Energy Annex 1 Wind Energy: Spacing of Turbines, n.d.. Accessed August 2020, Retrieved from: www.planningni.gov.uk/de/index/policy/planning_statements/pps18/pps18_annex1/pps18_annex1_wind/pps18_annex1_technology/pps18_annex1_spacing.htm.

in their jurisdiction.[24] Thunder Bay has experience with one failed wind farm near the city boundary in the Nor'wester mountains. Lack of proper community engagement has been cited as the reason for this project's failure.[25]

Offshore Wind Restrictions

Lake Superior has significant potential for offshore wind generation; however, offshore wind is currently prohibited by the Ontario Government.[26] The province's 2011 10-year offshore wind moratorium will be coming to an end soon, but it is unclear whether or not it will be extended.

Noise and Other Setbacks

The Province of Ontario prohibits the construction of wind turbines within 550-1,500 m of all noise receptors, including buildings like hospitals, homes, and malls.[27]

There are a few large patches of land in Thunder Bay that are set back at least 550 m from buildings and roads, but the wind speeds are insufficient to power turbines at a consistency that would make the 150 metre turbines viable. It is also important to note that wind turbines are not allowed within 30 metres of water (unless proponents can prove minimal impact) or permitted within 10 km of airports (though consultation can overcome this).[28]

Patches of land that meet distance and other requirements are situated outside of Thunder Bay proper, but within the Thunder Bay region.

Ontario's Market Renewal Program

Ontario's has a unique electricity market structure, which is still in design via the Market Renewal Program.[29] As it currently stands, utility-scale wind generation (the type being considered in this analysis) will not be able to access as many revenue sources within Ontario's electricity market as within other electricity markets. Therefore, according to energy consultants Power Advisory LLC, "Ontario-based wind generation presently cannot achieve its full potential to provide cost-effective supply and value of multiple electricity products to multiple buyers including electricity customers."[30]

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[24] Legislative Assembly of Ontario, Bill 34, Green Energy Repeal Act, 2018. Retrieved from: www.ola.org/en/legislative-business/bills/parliament-42/session-1/bill-34

[25] "Wind farm opposition garners First Nations support", May 30, 2013. CBC. Retrieved from: www.cbc.ca/news/canada/thunder-bay/wind-farm-opposition-garners-first-nation-s-support-1.1388970.

[26] "Canadian Wind Farm Database", n.d., Government of Canada. Retrieved September 2020, from: open.canada.ca/data/en/dataset/79fdad93-9025-49ad-ba16-c26d718cc070.

[27] Kirby Calvert et.al., Mapping Opportunities for Renewable Energy: A Guidebook (October 2019), at Table 12.

[28] Kirby Calvert et.al., Mapping Opportunities for Renewable Energy: A Guidebook (October 2019), at Table 8.

[29] See generally: IESO, Market Renewal, n.d.. Retrieved on Sept. 2, 2020 from: www.ieso.ca/en/Market-Renewal.

[30] Power advisory LLC, Whitepaper on Wind Energy and the Ontario Market, prepared for: Canadian Wind Energy Association (January 2020), at 38. Retrieved from: canwea.ca/wp-content/uploads/2020/01/Whitepaper-on-Wind-Energy-and-the-Ontario-Market_January-2020.pdf.

SOLAR

Table 3 - Current and potential supply of solar rooftop and ground-mount PV within the city boundary of Thunder Bay.

	As of March 31, 2020[31]	Potential supply	Major constraints
Solar rooftop	≈1.57 MW	90.54 MW (new + existing residential) 119.41 MW (new + existing commercial) **Subtotal = 209.95 MW**	• roof strength • roof slope • shading • financing • electrical grid management • provincial electricity policy
Solar ground mount	8.5 MW (airport) 10 MW (Fort William First Nation)	778 MW	• available land area/competing land use • land slope • cost of land • cost to develop land • electrical grid management; • provincial electricity policy
Total	**≈ 20 MW**	**≈ 987.95 MW**	

*assuming 10% curtailment (see text box)

As with wind turbines, solar photovoltaic (PV) technology is relatively mature. The province has more than 2,500 MW of capacity installed, representing more than 6% of the province's electrical grid capacity.[32]

[31] As reported by the IESO.
[32] IESO, Ontario's Supply Mix (as of June 2020). Retrieved from: ieso.ca/en/Learn/Ontario-Supply-Mix/Ontario-Energy-Capacity#:~:text=The%20current%20installed%20capacity%20on,within%20Ontario's%20local%20distribution%20systems..

Solar generation facilities (rooftop and ground-mount) can be developed at locations with:

- A minimum level of solar-radiation exposure (i.e. south facing); and
- Roof space, vacant land, or parking lots that could have solar panels built above.

For this supply and constraints analysis, we begin our analysis with ground mounts in vacant land, which enable larger and more economical PV installations. Next, we analyze rooftops installations. Our recommendation is that the City undertake further analysis of these opportunities.

As of March 31, 2020, Thunder Bay is home to 15 solar PV generation facilities that are connected to the electricity grid. Two of these are ground mount (8.5 MW at the airport and 10 MW in Fort William First Nation), while the remaining 13 are rooftop facilities.

Supply (Ground Mount)

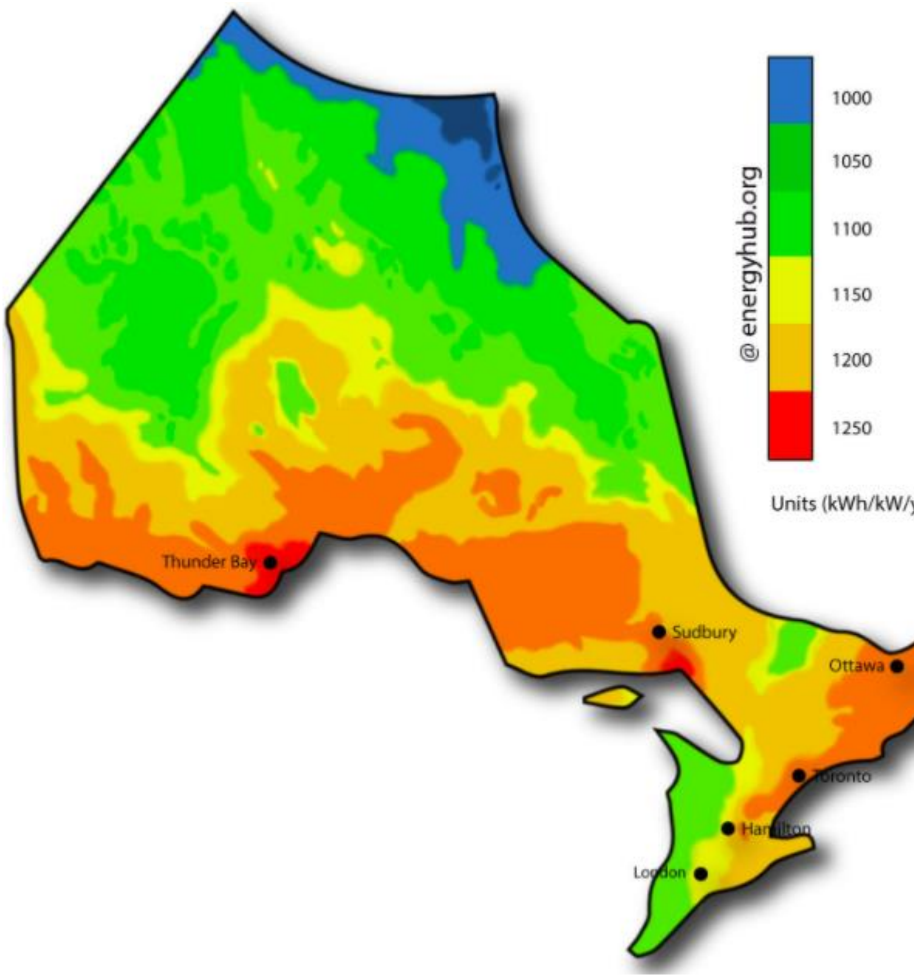
At least 4 hectares in available space is required to develop a 1 MW ground solar array, which we recommend as a minimum installation size to increase cost effectiveness.[33] Thunder Bay has ample vacant land to build ground solar arrays. In terms of solar radiation, Thunder Bay is considered to have relatively high sun exposure compared to other locations in Ontario (see Figure 3) and Canada.[34] Vacant south (S), south-east (SE), and south-west (SW) facing lands with a minimum area of 4 hectares have the potential to generate 778 MW of ground solar energy.

There are 147 viable land patches within Thunder Bay that would support a < 5 MW ground solar array (see Figure 4). Though they would be costlier to develop than larger solar arrays, they are still viable. There are 35 viable land patches that would support the development of ground solar arrays between 5 MW and 10 MW in capacity. There are 12 viable land patches that would support the development of ground solar arrays between 10 and 20 MW. There are 3 viable land patches that could support ground solar arrays of between 20 and 50 MW. In particular, there is a promising ground solar site on a slope just north of the Thunder Bay airport that faces S, SE, and SW that could serve as a promising site for a large installation. The site, which is ~150 ha, could support an installation of about 35–40 MW.

See Appendix B for a detailed list of potential sites for ground-mount solar arrays in the City of Thunder Bay.

[33] Kirby Calvert et.al., Mapping Opportunities for Renewable Energy: A Guidebook (October 2019) at 16.
[34] See NRCan, Photovoltaic potential and solar resource maps of Canada, n.d. Retrieved September 2020 from: www.nrcan.gc.ca/energy-efficiency/data-research-insights-energy-ef/buildings-innovation/solar-photovoltaic-energy-buildi/resources/photovoltaic-potential-and-solar-resource-maps-canada/18366.

Figure 3 - Average annual solar radiation across Ontario.[35]



[35] Energy Hub, Complete Guide For Solar Power Ontario 2020. Retrieved September 2020 from: www.energyhub.org/ontario/.

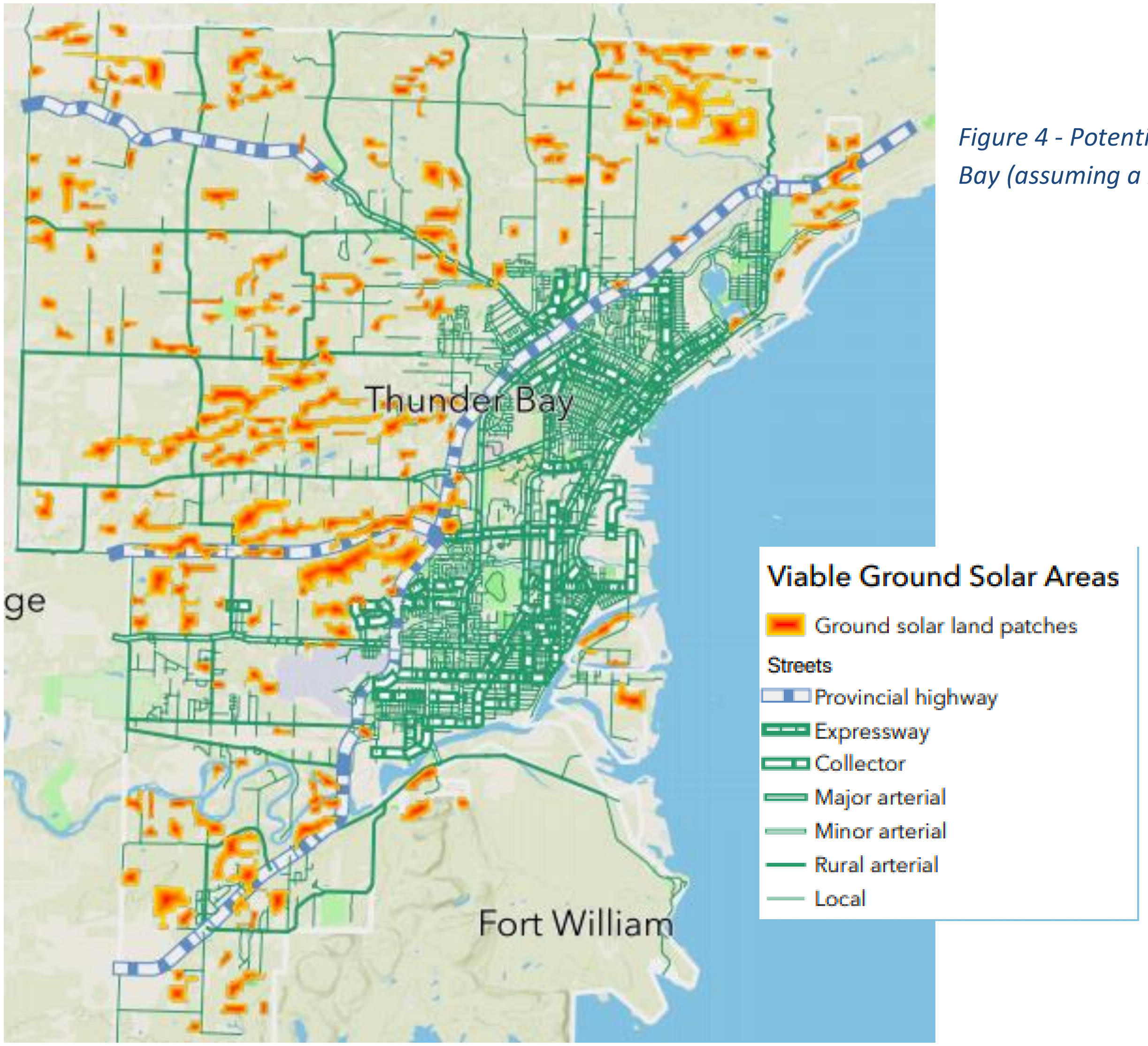


Figure 4 - Potential ground-mount solar PV sites in Thunder Bay (assuming a minimum 1 MW array).

Supply (Rooftop)

Unless a building is planning to be completely off grid, any rooftop solar PV will need to be connected to the grid according to Ontario's net metering program. This program essentially sends surplus electricity from onsite electricity generation back to the central grid and applies the value of that electricity to the building's electricity bill.

This analysis is limited to building rooftops. In a low-carbon scenario where more energy is generated locally, PV are projected to be installed on 50% of all pre-2016 buildings by 2030 (over 15,000 buildings). In this scenario, the PV systems would provide 50% of the electrical load of buildings.

Total potential rooftop area available for PV installation was estimated for all residential and non-residential buildings using total building counts and their footprint areas. While some roofs, particularly pitched roofs, are larger than their footprint areas, a 1:1 ratio between footprint and roof area was assumed, since overhangs are often not used due to their being less structurally stable to access for installation and maintenance. Eight percent of residential roofs and 63% of commercial roofs were assumed to be flat, while the remainder were assumed to be pitched.[36] Pitched footprint areas were multiplied by a factor of 1.051, assuming an average 18 degree slope angle.[37] Total roof area usable for PV installations for flat and pitched roofs was then determined, assuming 35% shading for flat roofs and 41.5% shading on pitched roofs caused by features such as chimneys, ventilation equipment, and building orientation.[38]

Developing Arrays

Residents of Thunder Bay have already installed solar arrays on top of their own roofs. For example, one single residential installation supports 46 solar panels.

Analysis suggests that if all available existing roofs in Thunder Bay were developed to their maximum, the city could support a total of 90.39 MW of capacity (61.22 MW on existing residential rooftops and 29.17 MW on existing commercial/industrial rooftops). New residential, commercial, and industrial rooftops projected in the city out to 2050 could provide an additional 34.92 MW of capacity (made up of 10.47 MW on new residential rooftops and 24.45 MW on new commercial/industrial rooftops).

Promising Buildings

There are a few large non-residential buildings that could prove to be useful places to start. For example, the Walmart Supercentre at 777 Memorial Drive and the nearby Real Canadian Superstore at 600 Harbour Expressway could support large installations.

Large urban big box stores have already expressed a desire to generate local power. Companies, such as Ikea, Canadian Tire, and Walmart, are adding energy sales to their business model.[39]

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[36] Paidipati, J., L. Frantzis, H. Sawyer, and A. Kuasch, "Rooftop Photovoltaics Market Penetration Scenarios", National Renewable Energy Laboratory (NREL), Golden, CO., 2008. Retrieved January 23, 2017, from www.nrel.gov/docs/fy08osti/42306.pdf; Denholm, Paul, and Robert Margolis. "Supply Curves for Rooftop Solar PV-Generated Electricity for the United States." National Renewable Energy Laboratory (NREL), Golden, CO., 2008. Retrieved January 23, 2017, from www.nrel.gov/docs/fy09osti/44073.pdf; Frantzis, Lisa, Shannon Graham, and Jay Paidipati. 2007, "California Rooftop Photovoltaic (PV) Resource Assessment and Growth Potential by County", Chicago: Navigant Consulting, CEC- 500-2007-048.

[37] Paidipati, J., *et al.* 2008.

[38] *Ibid.*

[39] Joshua Ostrof, "Rooftop Solar On Big Box Stores Could Power Millions Of Homes: Report", February 23, 2016. Huffington Post Canada. Retrieved from:

Constraints

Ontario's Market Renewal Program

Most energy planning falls within provincial jurisdiction. Grid-scale developments require contracts with the IESO to supply electricity to the grid. As it currently stands, it is unclear whether Ontario's Market Renewal Program will be favourable to utility-scale solar PV for the same reasons outlined for wind above.

Other constraints[40]

As with wind farms, EIAs will be required for solar developments. The Province of Ontario has also prohibited the development of PV farms on "prime agricultural land".[41]

https://www.huffingtonpost.ca/2016/02/23/rooftop-solar-big-box-stores_n_9292528.html.

[40] Kirby Calvert et.al., Mapping Opportunities for Renewable Energy: A Guidebook (October 2019), at 18.

[41] *Ibid.*

BIOMASS

Table 4 - Current and potential supply of wet and woody biomass within the city boundary of Thunder Bay.

	As of March 31, 2020	Potential additional supply (2050)	Constraints
Biomass (wet)	**≈ 60,000 MWh** 3.2 MW (landfill, biogas generator, grid connected) 600 kW (wastewater treatment, biogas CHP, grid connected)	**≈ 26,300 MWh** ≈ 9,400 MWh (diverted yard and food waste) ≈ 16,700 MWh (increased landfill gas capture) ≈ 170 MWh (meat processing plant & long-term care home)	● identifying potential sources of biomass ● processing the biomass in the most efficient system possible ● monitoring and minimizing leaks in the system ● monitoring and minimizing biogas combustion emissions ● ensuring the biomass is transported sustainably
Biomass (woody)	**≈ 1,900,000 MWh** (Resolute CHP system)	**≈ 186,000 MWh** (based on sources identified by the City)	● ensuring the source is sustainable ● ensuring the biomass is transported sustainably

Biomass is available in two general categories: wet and dry. This is a simple categorization based on the fact that each requires different types of technology to harness their energy. There are various different sources for each, but, for the purposes of this analysis, we have limited our analysis to major sources of existing GHG emissions in Thunder Bay's inventory (i.e. methane produced from the decay of organic matter in landfill and compost, and wastewater methane emissions), as well as additional sustainable sources identified by stakeholders and the City (i.e. sustainable forestry waste within close range of the city boundaries, as well as food waste from local businesses). The latter is an incomplete inventory of sustainable woody biomass or private sources of wet biomass; however, it gives a sense of what could be captured were a more comprehensive inventory undertaken.

The uncontrolled decay of organic waste is an important source of local low-carbon energy because it harnesses and transforms the potent GHG methane, which would otherwise be emitted into the atmosphere, into energy. Pound for pound, methane is about 86 times worse for climate change than carbon dioxide emissions during the next 20 years (which are critical for preventing dangerous levels of global warming), or 34 times worse under a 100-year time frame. (The latter is the equivalency used to calculate Thunder Bay's inventory.)

The controlled burning of forestry residue produces GHG emissions and no energy. It could however be combusted to produce energy, while the emissions could be minimized and potentially even captured.

Biomass is a source of energy with significantly lower emissions than any fossil fuel; however, it is not a zero-carbon source of energy. In order to achieve net-zero emissions, a community should first seek to minimize any uncontrolled decay or burning of organic waste via diversion from landfill and sustainable forestry practices. Second, the remaining biomass should be harnessed for power and stocks should be closely monitored in a way that minimizes emissions. Any remaining emissions should be captured and/or offset.[42]

Supply (Wet Biomass)

Wet biomass (e.g. organic waste in landfills or at wastewater treatment plants) can be processed into biogas via anaerobic digestion,[43] refined, then used in place of natural gas ("renewable natural gas" or "RNG"). RNG can be used within existing natural gas infrastructure and can be sold to the natural gas utility under long-term contracts.

It is important to note that RNG is neither truly "renewable" nor emissions-free energy. There is a high risk of leaks during methane processing and RNG combustion produces a small amount of indirect GHG emissions (namely NOx, which becomes ozone) with a negative impact on local air quality.

The business-as-planned energy and emissions model for Thunder Bay projects that, in 2050, approximately 65,000 tonnes of carbon dioxide equivalents will be emitted by decaying organic waste at the landfill, the composting facility, and the wastewater processing plant (applying the 100-year time frame and a generous efficiency assumption for the landfill gas capture system; see Table 5). Some amount of private sector organic waste may not be captured in this total, for example waste from food processing plants or institutions. Information provided by the City for just two such facilities (a meat processing plant and long-term care home) indicates an additional 185 tonnes a year of available food waste.

[42] See generally: NRDC, A Pipe Dream or Climate Solution? The Opportunities And Limits Of Biogas And Synthetic Gas To Replace Fossil Gas (June 2020, Issue Brief 20-05-A). Retrieved from: www.nrdc.org/sites/default/files/pipe-dream-climate-solution-bio-synthetic-gas-ib.pdf.

[43] Anaerobic digestion involves microorganisms breaking down biodegradable material in the absence of oxygen.

Table 5 - 2016 and projected 2050 GHG emissions from the City of Thunder Bay's compost, landfill, and wastewater facilities.

	2016 (tonnes of GHG)	2050 (tonnes of GHG)
Compost	885	988
Landfill	44,971	62,535
Wastewater	1,695	1,900
Total	**47,551**	**65,423**

Landfill

The rate of methane generation at the Thunder Bay landfill is expected to grow out to 2050, despite growing diversion rates, because organic waste decays over 20 years. For an example based on an in-depth analysis completed for another Ontario-based city, existing waste will continue to decay and produce methane for decades (see Figure 5). The future levels of landfill gas emissions will depend on the amount and the composition of organic waste[44] already landfilled and landfilled in future years, as well as the efficiency with which those emissions are captured.

Thunder Bay currently has a landfill gas capture system in place. Landfill gas capture systems are not a complete solution to landfill GHG emissions. Landfill gas capture systems are leaky, generally capturing about 50% of all methane emissions produced.[45] The City has advised that their landfill gas capture system is only capturing 15% of the methane they estimate is being produced. The ideal solution for reducing methane in Thunder Bay's landfill is to both improve the efficiency of their landfill gas capture system and to divert the maximum amount of organic waste from the landfill to an anaerobic digester, where it could then be refined to RNG.

Even if the City were to start diverting 100% of organic waste tomorrow, there is likely to be more than enough methane produced at the landfill from existing waste to justify an investment in an energy generation equipment

The City should undertake further analysis to determine a long-term and integrated approach to organics management investment strategies, including detailed analysis of future levels of landfill gas generation.

[44] Primarily yard waste, food waste, and paper products.

[45] Riham Abdel Mohsen et. al., "Investigation of fugitive methane and gas collection efficiency in Halton landfill in Ontario, Canada", *Environmental Monitoring and Assessment*, 326 (2020) (Note: found the Halton Hills, Ontario landfill gas recovery system to have an 44% efficiency rate); Global Methane Initiative, International Best Practices Guide for LFGE Projects, Chapter 6 (2012), at 75 (assumes the maximum landfill gas capture efficiency rate in a dry climate to be 60% , and in a wet climate 50%); Sally Brown, "Greenhouse gas accounting for landfill diversion of food scraps and yard waste", *Journal of Compost Science and Utilization*, 24 (2016) 11-19 (The paper notes that the default efficiency used by the IPCC is 40% to 60%).

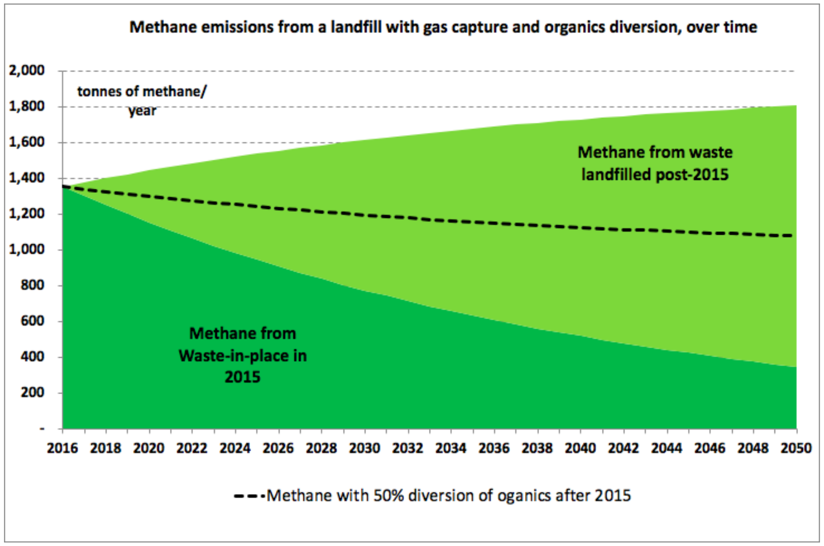

Figure 5 - Hypothetical methane emissions from a landfill with a gas capture system and 50% diversion rate (2016-2050).

Compost

Organic waste diverted from landfills and yard waste are sent to the City's composting facility. Composting significantly reduces methane emissions, but does not completely eliminate them. Inefficient composting processes can result in anaerobic (rather than aerobic) conditions, which produce methane and nitrous oxide. [46]

Wastewater Treatment Plant

Wastewater treatment plants process large amounts of the city's organic waste and treat them via anaerobic digestion. It is an increasingly well-established practice to capture the methane produced from this process for use as biogas within the facility (rather than flaring it). If there are sufficient quantities and the economics make sense, some plants further refine the gas into RNG and sell it back to the natural gas distributor for use outside the plant.

The Intergovernmental Panel on Climate Change (IPCC) recommends using a default assumption of 5% methane leakage rate for RNG processing facilities; however, if monitored and addressed, these can be minimized further.[47]

Some wastewater treatment plants have begun accepting wet organic waste from outside the facility, such as organics diverted from landfill.[48] This might be a good solution for Thunder Bay to consider for its organic waste.

Supply (Woody Biomass)

Thunder Bay is surrounded by forests and its economy has been built on them. Whether or not forests can also be a source of sustainable carbon-free energy is an interesting question.

Dry biomass (e.g. wood waste from construction or forestry) is either sent to landfill or, if it is waste from the forestry industry,

[46] Climate Action Reserve, Methane Avoidance From Composting (2009, Issue Paper), at 12-13. Retrieved from: faculty.washington.edu/slb/docs/CCAR_Composting_issue_paper.pdf; See also: IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol: 5, Chapter 4, at 4.4.

[47] IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol: 5, Chapter 4, at 4.4.

[48] See generally: Environmental Commissioner of Ontario, Every Drop Counts, Chapter 8: Energy from Sewage (2016/2017). Retrieved from: docs.assets.eco.on.ca/reports/energy/2016-2017/Every-Drop-Counts-08.pdf; See also Stratford Water Pollution Control Plant: Renewable Natural Gas (RNG) Facility. Retrieved September 2020 from: www.stratford.ca/en/inside-city-hall/renewable-natural-gas.aspx.

burned onsite.[49] However, it could be combusted to produce energy. Its combustion produces carbon dioxide and NO_x, and particulate matter, all of which should be minimized through system design (including through carbon capture) or, in the case of emissions, offset.

Ontario has sustainable forestry practices; however, sustainably harvested wood (i.e. from replanted trees) is not carbon-neutral. If a tree is harvested and burned for energy, the resulting carbon dioxide goes to the atmosphere immediately. If a tree is planted to replace the harvested one, this carbon dioxide will only be removed from the atmosphere over 60 or 70 years. Climate scientists have made it clear that the timing of emission reductions is important; reductions over the next decade are much more critical than reductions sixty years from now if the worst effects of global warming are to be avoided.[50] For this reason, only biomass that would otherwise be combusted should be used for energy.

The sources of woody biomass that have the most minimal impact on climate change are therefore urban wood waste diverted from landfill and forestry residuals diverted from open burning. Furthermore, the collection and transportation of biomass waste is expensive and can result in transportation emissions.

Available data from the provincial Natural Resources Information Portal (OMNRF)51 indicates that a significant amount of wood waste is burned annually within 50 km of the city in the Black Spruce Forest (≈ 2,500 slash burn piles) and the Dog River-Matawin Forest (≈ 2,200 slash and burn piles). In addition, about 60,000 green tonnes of wood residue are produced from Lakehead Forest, but not burned onsite.52 The energy potential of these three sources alone is 669,925.35 GJ/year, or 21.24MW of capacity. It is very likely that more sustainable woody biomass is available.

Constraints

Placement Within a City/Neighbourhood Feedback
Citizens generally do not like waste recovery plants in their neighbourhoods due to perceptions of pollution, increased vehicle traffic from delivery vehicles and potential reductions of property value. Thorough consultation is important; however, possible locations may be limited due to lack of City-owned land in industrial areas, as well as the logistics of getting waste to a plant and delivering energy back to the community. The wastewater treatment plant may resolve these constraints.

Reliability and Cost of Alternative Technologies
While anaerobic digestion of organic waste is widely practiced in Europe, its application to municipal organic waste in North America is relatively recent. There is even less experience with gasification technologies, which can extract greater energy from the waste than anaerobic digestion, but are more expensive than anaerobic digestion.

Contractual Obligations and Jurisdictional Barriers
Contractual obligations and jurisdictional barriers present constraints to the practical availability of some private biomass

[49] See generally: Ontario Ministry of Natural Resources, Prescribed Burn Manual (May 2019).
[50] See generally: IPCC, Special Report: Global Warming of 1.5ºC (2018). Retrieved from: www.ipcc.ch/sr15/.
[51] Specifically, from the Forest Management Unit's annual reports.
[52] FMU Annual Report and Alum, M.B., Pulkki, R., & Shahi, C. (2012). Woody biomass availability for bioenergy production using forest depletion spatial data in northwestern Ontario. Can. J. For. Res., 42, 506-516.

sources and estimating waste-related energy options in Thunder Bay. Long-term “put or pay” contracts for organic waste constrain consideration of alternatives in the short term. In addition, it is unclear how much waste is generated by the institutional, commercial, and industrial sectors in Thunder Bay, as these are outside the management responsibility of the City.

Cost of Natural Gas

The relatively low cost of natural gas is a disincentive to invest in renewable natural gas. It serves as an incentive to invest in landfill gas utilization technologies that have high system efficiencies and net GHG reductions.

Transportation of Biomass

Potential GHG emissions from the transportation of biomass are a significant issue and need to be included in the net GHG impact of biomass as a source of energy. These emissions can be avoided or reduced by using RNG or electricity as a vehicle fuel.

Waste Composition and Generation Rates

With the exception of wastewater treatment sludge, which will grow with population, it is not clear that waste generation is growing significantly in Thunder Bay. In fact, it could decline. In assessing investment strategies for energy recovery from waste, it will be important to examine different scenarios for the future quantity and composition of the waste being generated

Summary

This high-level analysis indicates that Thunder Bay has a significant untapped renewable energy supply for wind and solar, and, to a much lesser extent, biomass. In fact, the potential energy supply exceeds the expected 2050 energy consumption for the city.

Each of these energy sources comes with its own set of unique restraints. For wind and solar, the most significant constraints are Ontario's electricity market and the grid’s capacity to effectively integrate these intermittent energy sources. Bearing these constraints in mind, a conservative percentage of wind and solar will be incorporated into Thunder Bay’s CEEP to achieve net-zero carbon emissions by 2050.

The urgency to address climate change is going to grow and it is therefore a reasonable assumption that some or all of these policy barriers to renewable electricity generation will be removed. Conversely, the policy barriers to the combustion of biomass will also increase, implying that a conservative or cautious approach to biomass is appropriate, while noting that that emerging strategies such as carbon capture and storage could mitigate the biogenic emissions resulting from the combustion of biomass.

Bearing these in mind, we make the following five observations that inform the development of the CEEP:

1. **Wind:** Thunder Bay’s potential wind energy supply is its most significant source of untapped renewable energy. Despite the increasing affordability of wind power, the combination of the offshore wind moratorium, Ontario’s uncertain electricity market, and public resistance, we recommend planning for a modest amount of the onshore wind potential we have identified: **250 MW** (about 20% of identified supply).

2. **Solar:** Despite Ontario’s uncertain electricity market, success with existing solar projects in the community, as well as the decreasing technology costs, we recommend planning for: **415 MW** (about 50% of identified supply).

3. **Biomass (wet):** Because of the importance of minimizing methane emissions at the landfill, increasing landfill gas capture to 80%, while simultaneously diverting as much organic waste as possible (from landfill, composting, and private businesses) from the landfill and compost, we recommend capturing all this identified potential methane as useful biogas or RNG (about **3 MW)**.

4. **Biomass (woody):** Any unavoidable forestry waste within the region of Thunder Bay being burned onsite should be considered for local energy use at the Resolute biomass CHP system which, according to our estimate has sufficient additional capacity (about **21 MW)** .

5. **Biomass (generally):** A comprehensive review of local sustainable biomass supply should be undertaken by the City.

Appendix A. 150 Metre Wind Turbine: Siting Locations and Costs

The following is a list of minimum 20 MW, 50 MW, 100 MW, and 200 MW, 150 metre wind turbine installation sites in the Thunder Bay region (about a 25 km radius from the city centre), as well as their related costs (to build transmission lines to connect them to the closest high voltage line and to the city's distribution network). Sources and details of these assumptions are outlined in the Wind section of the report.

Developing farms of 20 MW capacity

			Distance to town	**Cost to TB** ($ million)		**Distance to Hydro**	**Cost to Hydro** ($ million)	
Region	Hectares	Coord.	(km)	Low	High	(km)	Low	High
Oliver Paipoonge	53	48.517, -89.528	26.87	26.87	32.24	0.71	0.71	0.86
Conmee	53	48.515, -89.637	33.74	33.74	40.49	2.23	2.23	2.68
Conmee	69	48.497, -89.755	41.06	41.06	49.27	2.89	2.89	3.47
Oliver Paipoonge	79	48.504, -89.577	29.22	29.22	35.06	3.57	3.57	4.28
Fort William FN	63	48.313, -89.301	9.24	9.24	11.08	3.59	3.59	4.31
Neebing	74	48.282, -89.393	16.39	16.39	19.67	9.51	9.51	11.42
Neebing	53	48.314, -89.533	23.73	23.73	28.47	10.04	10.04	12.05
Neebing	53	48.301, -89.578	27.41	27.41	32.9	10.98	10.98	13.17
Neebing	58	48.068, -89.427	37.76	37.76	45.31	32.13	32.13	38.56
Neebing	67	48.07, -89.651	46.74	46.74	56.09	37.12	37.12	44.55
Neebing	53	48.062, -89.593	44.63	44.63	53.55	37.6	37.6	45.12
Neebing	53	48.035, -89.589	46.88	46.88	56.25	40.43	40.43	48.52

Developing farms of 50 MW capacity

Region	Hectares	Coord.	Distance to town (km)	Cost to TB ($ million)		Distance to Hydro (km)	Cost to Hydro ($ million)	
				Low	High		Low	High
Conmee	115	48.501, -89.686	36.36	36.36	43.64	1.65	1.65	1.98
Conmee	116	48.515, -89.69	37.26	37.26	44.71	2.26	2.26	2.71
Fort William FN	122	48.315, -89.276	8.1	8.1	9.72	3.83	3.83	4.59
Neebing	90	48.289, -89.337	12.94	12.94	15.53	6.64	6.64	7.97
Neebing	138	48.257, -89.305	14.88	14.88	17.86	9.82	9.82	11.78
Neebing	159	48.258, -89.268	14.01	14.01	16.82	10.08	10.08	12.09
Neebing	90	48.242, -89.283	15.91	15.91	19.1	11.54	11.54	13.85
Neebing	116	48.254, -89.437	20.93	20.93	25.12	14.04	14.04	16.84
Neebing	157	48.214, -89.316	19.65	19.65	23.58	14.64	14.64	17.57
Neebing	101	48.174, -89.298	23.57	23.57	28.28	19.06	19.06	22.8
Neebing	120	48.207, -89.752	43.37	43.37	52.04	24.54	24.54	29.45
Neebing	127	48.153, -89.715	44.09	44.09	52.91	29.28	29.28	35.14
Neebing	111	48.105, -89.701	46.58	46.58	55.9	34.05	34.05	40.86

Developing farms of 100 MW capacity

Region	Hectares	Coord	Distance to town (km)	Cost to TB ($ million)		Distance to Hydro (km)	Cost to Hydro ($ million)	
				Low	High		Low	High
Fort William FN	233	48.335, -89.287	6.69	6.69	8.03	1.56	1.56	1.87

Fort William FN	294	48.303, -89.318	10.92	10.92	13.11	4.84	4.84	5.81
Neebing	185	48.281, -89.284	11.81	11.81	14.17	7.25	7.25	8.7
Neebing	217	48.279, -89.359	14.85	14.85	17.82	8.33	8.33	9.99
Neebing	176	48.267, -89.413	18.6	18.6	22.32	11.73	11.73	14.08
Neebing	222	48.22, -89.287	18.4	18.4	22.08	13.99	13.99	16.79

Developing farms of 200 MW capacity

			Distance to town	**Cost to TB** ($ million)		**Distance to Hydro**	**Cost to Hydro** ($ million)	
Region	Hectares	Coord.	(km)	Low	High	(km)	Low	High
Fort William FN	476	48.29, -89.253	10.27	10.27	12.33	6.86	6.86	8.23

Appendix B. Ground-Mount Solar Array: Potential Sites

The following tables identify the coordinates, area, and size of solar PV ground-mount installation for viable land patches within Thunder Bay.

Developing ground solar arrays of <5 MW capacity

Hectares	Coordinates	MW
19.42	48.467, -89.421	4.9
19.65	48.46, -89.32	4.9
19.51	48.409, -89.418	4.9
19.08	48.352, -89.291	4.8
18.49	48.303, -89.368	4.6
17.48	48.497, -89.227	4.4
17.02	48.426, -89.346	4.3
17.29	48.384, -89.37	4.3
16.87	48.462, -89.272	4.2
16.42	48.484, -89.247	4.1
16.31	48.4, -89.345	4.1
16.58	48.383, -89.319	4.1
15.98	48.507, -89.235	4.0
16.14	48.396, -89.367	4.0
15.23	48.498, -89.218	3.8
14.68	48.455, -89.289	3.7
14.5	48.503, -89.302	3.6
14.06	48.328, -89.386	3.5
13.26	48.505, -89.348	3.3
13.08	48.488, -89.234	3.3
13.25	48.407, -89.284	3.3
13.36	48.39, -89.372	3.3
12.67	48.511, -89.412	3.2
12.77	48.422, -89.378	3.2
12.33	48.501, -89.351	3.1
12.52	48.48, -89.156	3.1
12.32	48.435, -89.286	3.1
12.12	48.35, -89.322	3.0
12.02	48.299, -89.35	3.0
11.51	48.504, -89.22	2.9
11.41	48.344, -89.385	2.9
11.74	48.338, -89.371	2.9
11.48	48.319, -89.367	2.9
10.74	48.429, -89.345	2.7
10.98	48.412, -89.397	2.7
10.68	48.384, -89.385	2.7

10.22	48.477, -89.425	2.6
10.37	48.347, -89.326	2.6
10.09	48.513, -89.193	2.5
10.04	48.503, -89.342	2.5
10.11	48.483, -89.331	2.5
9.95	48.422, -89.363	2.5
9.56	48.509, -89.292	2.4
9.53	48.485, -89.235	2.4
9.45	48.479, -89.163	2.4
9.2	48.504, -89.25	2.3
9.01	48.494, -89.154	2.3
9.17	48.449, -89.347	2.3
9.36	48.443, -89.327	2.3
9.28	48.344, -89.37	2.3
8.86	48.494, -89.161	2.2
9	48.484, -89.286	2.2
8.87	48.47, -89.405	2.2
8.71	48.38, -89.325	2.2
8.34	48.491, -89.313	2.1
8.3	48.451, -89.309	2.1
8.29	48.403, -89.304	2.1
8.24	48.39, -89.314	2.1

8.5	48.345, -89.32	2.1
8.06	48.503, -89.393	2.0
7.87	48.499, -89.36	2.0
8.09	48.469, -89.364	2.0
8.15	48.453, -89.419	2.0
7.82	48.433, -89.305	2.0
7.57	48.514, -89.398	1.9
7.66	48.504, -89.226	1.9
7.53	48.501, -89.226	1.9
7.78	48.486, -89.393	1.9
7.73	48.447, -89.414	1.9
7.46	48.404, -89.397	1.9
7.63	48.385, -89.348	1.9
7.13	48.513, -89.185	1.8
7.13	48.502, -89.359	1.8
7.08	48.487, -89.311	1.8
7.27	48.447, -89.328	1.8
7.02	48.374, -89.364	1.8
6.61	48.504, -89.4	1.7
6.75	48.502, -89.406	1.7
6.83	48.465, -89.309	1.7
7	48.455, -89.296	1.7

6.8	48.447, -89.398	1.7
7	48.422, -89.299	1.7
6.9	48.319, -89.346	1.7
6.41	48.475, -89.406	1.6
6.54	48.472, -89.249	1.6
6.59	48.465, -89.405	1.6
6.36	48.46, -89.294	1.6
6.26	48.455, -89.366	1.6
6.58	48.451, -89.365	1.6
6.49	48.454, -89.191	1.6
6.25	48.361, -89.309	1.6
6.39	48.295, -89.363	1.6
6.07	48.504, -89.425	1.5
6.2	48.499, -89.399	1.5
6.08	48.344, -89.38	1.5
5.44	48.505, -89.302	1.4
5.52	48.489, -89.251	1.4
5.76	48.485, -89.412	1.4
5.64	48.493, -89.221	1.4
5.53	48.468, -89.285	1.4
5.47	48.466, -89.295	1.4
5.53	48.462, -89.383	1.4

5.41	48.427, -89.284	1.4
5.5	48.419, -89.299	1.4
5.66	48.346, -89.277	1.4
5.01	48.511, -89.289	1.3
5.25	48.471, -89.424	1.3
5.14	48.466, -89.383	1.3
5.27	48.471, -89.17	1.3
5.12	48.464, -89.177	1.3
5.32	48.459, -89.329	1.3
5.16	48.456, -89.344	1.3
5.08	48.431, -89.288	1.3
5.37	48.43, -89.293	1.3
5.06	48.389, -89.386	1.3
5.16	48.361, -89.337	1.3
5.16	48.338, -89.38	1.3
5.2	48.31, -89.354	1.3
5.13	48.307, -89.369	1.3
4.96	48.514, -89.355	1.2
4.91	48.485, -89.426	1.2
4.9	48.489, -89.255	1.2
4.63	48.472, -89.266	1.2
4.79	48.472, -89.211	1.2

4.73	48.461, -89.23	1.2
4.64	48.453, -89.338	1.2
4.9	48.439, -89.328	1.2
4.74	48.418, -89.282	1.2
4.8	48.354, -89.35	1.2
4.77	48.352, -89.358	1.2
4.9	48.344, -89.325	1.2
4.41	48.498, -89.368	1.1
4.44	48.449, -89.392	1.1
4.6	48.442, -89.333	1.1
4.5	48.427, -89.318	1.1
4.49	48.412, -89.379	1.1
4.34	48.392, -89.332	1.1
4.3	48.392, -89.302	1.1
4.28	48.371, -89.359	1.1
4.35	48.378, -89.227	1.1
4.51	48.3, -89.341	1.1
4.02	48.499, -89.298	1.0
4.13	48.507, -89.299	1.0
4.06	48.49, -89.337	1.0
4.03	48.459, -89.351	1.0
4.05	48.395, -89.304	1.0
4.02	48.389, -89.359	1.0

Developing ground solar arrays of 5–10 MW capacity

Hectares	Coordinates	MW
39.05	48.327, -89.348	9.8
32.75	48.438, -89.336	8.2
32.73	48.433, -89.325	8.2
32.58	48.513, -89.21	8.1
32.33	48.479, -89.412	8.1
32.34	48.393, -89.38	8.1
30.2	48.424, -89.339	7.6
29.73	48.508, -89.357	7.4
29.31	48.34, -89.326	7.3
28.8	48.463, -89.349	7.2
28.45	48.37, -89.222	7.1
28.03	48.429, -89.303	7.0
28.16	48.385, -89.232	7.0
26	48.471, -89.292	6.5
25.86	48.408, -89.318	6.5
25.09	48.388, -89.322	6.3

24.43	48.406, -89.383	6.1
24.1	48.476, -89.289	6.0
24.09	48.42, -89.356	6.0
23.49	48.478, -89.363	5.9
23.21	48.445, -89.377	5.8
22.98	48.485, -89.293	5.7
22.76	48.305, -89.348	5.7
22.25	48.43, -89.362	5.6
21.93	48.34, -89.361	5.5
21.55	48.513, -89.418	5.4
21.4	48.492, -89.256	5.4
21.46	48.443, -89.343	5.4
21.05	48.371, -89.344	5.3
20.75	48.475, -89.164	5.2
20.86	48.453, -89.35	5.2
20.58	48.513, -89.235	5.1
20.39	48.464, -89.288	5.1
20.43	48.344, -89.292	5.1
20.29	48.324, -89.337	5.1

Developing solar arrays of 10–20 MW capacity

Hectares	Coordinates	MW
63.83	48.434, -89.355	16.0
52	48.408, -89.348	13.0
49.49	48.323, -89.373	12.4
48.41	48.422, -89.393	12.1
46.71	48.401, -89.372	11.7
46.56	48.506, -89.392	11.6
46.25	48.486, -89.16	11.6
46.35	48.334, -89.352	11.6

44.26	48.51, -89.212	11.1
44.51	48.429, -89.326	11.1
44.4	48.426, -89.366	11.1
44.34	48.405, -89.34	11.1

Developing solar farms of 20–50 MW capacity

Hectares	Coordinates	MW
163.01	48.499, -89.202	40.8
148.92	48.398, -89.314	37.2
82.3	48.409, -89.3	20.6