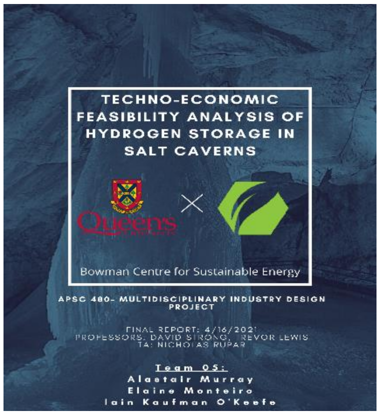
Sarnia Lambton Hydrogen - Project Proposal

Eliminate Hundreds of Thousands of Tonnes of CO2 Emissions

THEBOWMANCENTRE

Introduction



A pre-feasibility study to develop a concept to produce green hydrogen, store the product bulk hydrogen, and access an existing and readily expandible market has been completed for the Sarnia-Lambton region. This study, ***"Techno-Economic Analysis of Hydrogen Storage in Salt Caverns"*** © was conducted by Queen's University for the Bowman Centre for Sustainable Energy.

Sarnia-Lambton in Southwestern Ontario Canada was selected to host this proposed project since it is already a world scale hydrogen hub. The region has the expertise, world scale hydrogen manufacturing facilities, bulk hydrogen storage characteristics, access to developing national and international low carbon hydrogen markets plus an existing easily developed market for new production. The project would ***reduce GHGe emissions by between 200,000 and 400,000 tonnes per year.***

Proposed Project Deliverables (DG)

If built, this project would deliver the following.

- Reduce GHG emissions by between 200,000 and 400,000 tonnes per year.
- Enable hundreds of MWs of new renewable wind and solar energy supplies
- Commission and operate a world scale green hydrogen production, storage, and supply facility
- Demonstrate use of Canadian salt caverns for short, medium, and long-term hydrogen storage
- Serve as a massive grid scale energy storage 'battery' capable of supplying power to meet short term 'peaking' needs, days long power to back up renewables during protracted weather events, and demonstrate the concept for use as a seasonal scale energy storage system (Phase 2)
- As a battery, the system is expected to cost less than $200 Cdn/KW-hr compared to $400 Cdn/KW-hr for a state-of-the-art grid scale chemical battery[1].
- When used as a grid scale electricity battery, this project frees up lithium and other elements/metals for other energy storage applications, particularly mobile applications
- Provide off peak electrical load when electricity supply exceeds demand, i.e., flatten the curve
- Lower Ontario's already low electrical power system GHG intensity
- Make green hydrogen available to local industries to augment their existing grey hydrogen supplies
- Demonstrate the system and Sarnia-Lambton as a secure and reliable supply for emerging green hydrogen markets

RECOMMENDATION

The BCSE leadership team recommends a follow-up study be conducted with a view to building a facility based on the design and economic principles contained in the Queen's University study.

[1] https://electrek.co/2021/07/26/tesla-reveals-megapack-prices/

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Background

Nations around the world, including Canada, have agreed to decarbonize their economies[2]. Hydrogen is not the solution to decarbonizing all sectors of the global economy, but it will play an important role in selective economic sectors. Decarbonizing some economic sectors presents significant technical as well as economic challenges. Hydrogen is increasingly being promoted as a candidate solution to these more challenging sectors. These include long haul heavy transportation such as rail, heavy trucking, transoceanic shipping, and potentially long-haul aviation. Hydrogen also has a promising role in decarbonizing some industrial sectors, notably steel[3], petrochemical, and power generation.

> **Steel on the Ground**
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> **To be clear, this proposal is not about studying options. Rather the recommendation is to complete the engineering design, procure land and equipment, develop a storage cavern, build, the facility, produce electricity for an existing peak price electricity market, and be ready for new decarbonization markets when they emerge.**

Canada is one of the world's largest hydrogen producers and Sarnia-Lambton is currently a hydrogen production and consumption hub. Hydrogen produced in this region, consistent with most hydrogen production in the world, uses fossil hydrocarbons as a feedstock, primarily natural gas. Hydrogen produced from natural gas results in about 10 tonnes of CO_2 emissions per tonne of hydrogen produced. Although large volumes of hydrogen are being produced in this region, it is consumed by local industries. However, the scale of hydrogen production in Sarnia-Lambton means the region is host to the skills, training, engineering, and safety pre-requisites for an expanded role in green hydrogen production. Plus, the region's geology is suitable for bulk hydrogen storage.

The conceptual design presents a low technical risk. Economic risk is mitigated by using the hydrogen to access a large existing local energy demand that could be satisfied by this project. Once proven, the project could tap into local hydrogen consumers that, ideally, could absorb, all the green hydrogen produced by the facility. If built, the facility would position the region as a world leader in 21st century green hydrogen production and use, show the world 'it can be done"; enable new renewable energy supplies, and facilitate decarbonization of difficult sectors.

Safety

Not unlike natural gas, propane, gasoline, jet fuel, diesel fuel, and other fuels, hydrogen is a potent energy carrier. And like those other fuels, industrial scale hydrogen has been produced, managed, stored, and used safely for about 100 years. The skills and experience required to safely host a new green hydrogen manufacturing and use sector are already present in Sarnia Lambton.

Jurisdictional Initiatives

Canada is moving forward with a world class hydrogen strategy, and it is up to regions and communities to leverage their strategic resources to take advantage of new opportunities afforded by green hydrogen. The Sarnia-Lambton region presents a unique opportunity to combine decades of industrial prowess with a skilled and willing population to usher in a new era of clean energy. Canada is looking to establish

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[2] The Paris Agreement | UNFCCC 2015.

[3] First Plant In Germany In Hydrogen-Based Steel Production Goes Into Operation - FuelCellsWorks

regional hydrogen hubs. Sarnia- Lambton's existing hydrogen production capacity, workforce skilled in hydrogen production, handling, safety, salt caverns and existing relationship with the petrochemical and energy industries all make this region an obvious choice for further low carbon hydrogen development.

Urgency

The Intergovernmental Panel on Climate Change interim report[4], released in early August 2021, was crystal clear in its message that we need to reduce GHG emissions dramatically, and soon. Failure to do so will lock in global average temperatures above 2°C. This will all but ensure ongoing and worsening severe weather events, climate related population migrations, unrest etc. From an environmental perspective, action is required; NOW. However, in addition to the hundreds of thousands of tonnes of avoided CO_2 emissions offered by this project, there is an urgency related to economic opportunity.

Jurisdictions in Canada and around the world are aggressively developing and tangibly advancing their published hydrogen strategies. These jurisdictions all seek to gain a head start on being global scale, low-carbon hydrogen producers. Most of these initiatives are being advanced in anticipation of a near future and growing market demand for low to zero carbon hydrogen. The initiative discussed here has a built-in market for green hydrogen and will be ready to supply the anticipated new markets as they emerge.

First movers will have a tactical and strategic advantage.

Time is of the essence.

Canada's Federal Hydrogen Strategy[5] document describes development of regional hydrogen hubs distributed across the country. Regions having characteristics amenable to a rapid buildout of hydrogen infrastructure are described in the Federal Strategy document. Alberta[6] and Quebec[7] along with cities within those provinces are seizing the moment and are already taking concrete steps to move forward. Both provinces are advancing their programs, each having tangible projects under development. So far, there are none in Ontario. This is notable as Ontario, particularly the Sarnia Lambton region, is already a hydrogen hub and ideally suited for expansion as a green hydrogen regional hub serving Eastern Canada and US markets.

The Project Proposal

The study scope included preliminary project design, region selection, economics, regulatory considerations, and community acceptance.

Bonnie Kitahata (@bonniekitahata) | Unsplash Photo
lightbulb.jpg (698×400) (bioctcommons.org)

Conceptually, the project involves using virtually carbon free electricity from the Ontario grid. Power would be purchased during off-peak times and at low off-peak prices. The power would energize banks of electrolyzers to produce pure hydrogen and pure oxygen. The system is designed to fill a salt cavern storage unit in eight hours. The stored green hydrogen would, initially, be used as a fuel to generate electricity during high electricity demand

4 Sixth Assessment Report — IPCC
5 The Hydrogen Strategy (nrcan.gc.ca)
6 Natural gas vision and strategy | Alberta.ca
7 Hydro-Québec's Strategic Plan 2020–2024 (hydroquebec.com)

and price periods. This would improve utilization of existing wind energy and reduce 'dumping' energy by Ontario's fleet of nuclear power stations.

The green hydrogen would be compressed and stored in an underground salt cavern similar in concept to natural gas storage caverns currently operated in Southwestern Ontario. The high purity and high value oxygen by-product would be compressed and sold into existing markets.

When electricity power demand rises, along with prices, the decompressed hydrogen would be routed to fuel cells where they would generate electricity and produce pure water to be reused in the process.

The electricity would be sold at peak power prices with revenues used to support the project

The pre-feasibility study scope evaluated the following components.

1. Clean Electricity and Grid Interconnects
2. Electrolysis of water to produce green hydrogen plus pure oxygen
3. Compressing the product gases, hydrogen to a storage cavern and oxygen to market
4. Design of a salt cavern for storing bulk green hydrogen
5. Recovering stored hydrogen from the cavern, decompression, and routing to fuel cells
6. Converting DC Power to AC Power, stepping up voltage and exporting to the Ontario grid
7. Proposal Economics
8. Value Proposition
9. Regulatory Considerations

Figure 1 (page 9) is a conceptual illustration of the first 6 components of the project proposal.

1. Clean Electricity and Grid Interconnects

At under 50kg CO_{2e}/MW-hr, the Ontario Grid distributes some of the lowest carbon intensity electricity in the world. During off-peak hours Ontario generated electricity is virtually carbon free. Sarnia-Lambton has access to the grid's 230kV transmission system and locally generated renewable electricity. Existing infrastructure can supply enough off-peak energy to power a project of this size. The feasibility study identified grid interface requirements including a new transformer station, power switchgear and related power infrastructure requirements.

Technology risk[8] for this component of the project is negligible.

2. Electrolysis

The feasibility study examined 3 electrolyzer technologies, Alkaline, Proton Exchange Membrane, and Solid Oxide Fuel Cell electrolyzers. That assessment led to a recommendation to proceed with proven and commercially available industrial scale PEM electrolyzers. Each PEM electrolyzer would be rated at 2 MWs[9]. Banks of electrolyzers would be connected in parallel to generate the green hydrogen production at design rates.

[8] Technology risk refers to potential for technology failure. Technology risk should not be confused with process safety.
9 Personal communication with Doug Duimering, Next Hydrogen Solutions Inc. Individual electrolyzers with capacities of up to 10 MW are in development. For purposes of this project proposal, proven 2MW units have been selected.

Hydrogen production rate was determined based on an optimization exercise that evaluated power price arbitrage opportunities opposite capital costs for plant equipment including a salt cavern[10].

The electrolysers use off peak electricity to produce two pure products, hydrogen and oxygen. The oxygen is an economically lucrative by-product to be sold into existing markets. When the hydrogen is used to generate electricity using fuel cells pure water is also produced. That water will be collected and used to supply the electrolysers which will reduce makeup water requirement to de minimis levels.

PEM electrolyser technology risk at the scale recommended by the study is considered low.

3. Compression

Following production, the hydrogen is compressed to allow storage in conventional geologic salt caverns. Compressor sizing, safeguarding, and compressor type were included in the study. Compressing the hydrogen will result in a temperature rise which creates an opportunity to recover the heat and store the energy for heating purposes or to supply heat to the hydrogen when decompressed.

Technology risk associated with hydrogen compression is low.

4. Hydrogen Storage – Salt Cavern

Storing hydrogen using conventional methods typical of other gaseous fuels is an expensive and complex engineering challenge for most regions in the world. But not in Sarnia-Lambton as the region overlays massive and deep underground salt beds. Deep underground caverns have been created to store a suite of materials. Regions outside Canada already safely store hydrogen in salt caverns[11].

The feasibility study examined development of dry as well as wet storage caverns and concluded that a conventional wet storage system, typical of systems already in use in the region, represented the lowest technical risk and lowest cost option. The study addressed solution mining a new well, brine disposal, brine pond, well stringers, pumps, instrumentation, safeguarding, and regulatory permitting.

The optimal well size for this initial project phase would be 30,000m^3 which is around the median salt cavern size in the region. This well capacity would store about 140 tonnes of gaseous hydrogen. Considering process efficiencies, the 30,000m^3 well could store and deliver about 4,000 MW-hrs of electricity to the grid. That power could be provided over a predetermined time and rate, e.g., 500MWs for an 8-hour peak demand and price period or when wind energy is unavailable.

Technology risk associated with salt cavern development and use for hydrogen storage is low to medium. Operating experience is expected to reduce the technology risk to low.

5. Recovering Stored Hydrogen – Fuel Cell

Hydrogen stored in a salt cavern will be under moderate pressure dictated by the depth of the cavern. Given the negligible density of hydrogen gas relative to brine, the closed in, or static, pressure at the well head will be essentially the pressure in the well. If the hydrogen is to be sold into the marketplace, rather than converted into electricity, then minor adjustments to the pressure will be required to meet the shipping method pressure specifications.

[10] A new salt cavern was a project design premise rather than re-purpose an existing cavern, which would be a less expensive and preferable option.

[11] H2 Storage in Salt Caverns, Energnet.eu., Hydrogen storage in salt caverns – pv magazine International (pv-magazine.com), Hydrogen Energy Storage - Energy Storage Association,

However, if the hydrogen is to be used as an energy carrier to produce electricity, then the pressure will need to be reduced. The least capital-intensive way to reduce the pressure would be to use a pressure control valve(s), or regulator. However, the high-pressure state of the hydrogen exiting the well presents an opportunity to recover some of the energy spent compressing the hydrogen for injection into the well. The pre-feasibility study uses a turbo-expander connected to a small electricity generator.

The study investigated several fuel cell technologies, a conventional hydrogen fueled gas turbine, and reciprocating engines as a means of releasing the energy stored in the hydrogen[12]. The study team performed an optimization study based on cost, commercial availability, scale, reliability, and performance of each technology. In the interest of minimizing capital requirements, the study team was asked by the BCSE to increase the 'weighting' for technologies that can switch between using electricity to produce hydrogen and then use hydrogen to generate electricity.

The result of the technology optimization exercise resulted in a recommendation to further examine reversable Proton Exchange Membrane units. Reversible PEM units can operate either as an electrolyzer or as a fuel cell. PEM electrolyzer/fuel cells capacities approaching about 1MW each and are currently commercially available. Increasing hydrogen fuel cell capacity is a very active applied research area with larger units expected to be available within the development life of this project. Given current technology, scaling to the 500 MW peak output rating could be achieved by stacking the required number of units. This is analogous to a 500MW wind farm using 200 X 2.5MW wind turbines.

Technology risk associated with a conventional pressure control valve(s) or a turbo-expander is negligible. Technology risk associated with PEM fuel cells at the recommended scale is low.

6. Converting DC Power to AC Power, Stepping Up Voltage and Export to Grid

The PEM fuel cells will produce DC power. That DC power will be routed to banks of invertors to convert it to AC Power and at a frequency suitable for synchronizing with the grid. The AC power will then go through a transformer station to step up the voltage to allow power to flow to the grid.

Technology risk associated with this component is negligible.

7. Proposal Economics

The feasibility study briefly considered emerging hydrogen markets, market prices, and revenues. However, those markets do not yet exist. Therefore, and as a hedge, the detailed economic analysis is based on electricity pricing opportunities. These include energy arbitrage, global adjustment mitigation, capacity services, and ancillary services. To be clear, this is a complex topic. Therefore, the report contains a rigorous evaluation of this component.

In addition to hydrogen derived revenues based on conversion to electricity, significant revenue will come from sale of pure, likely medical grade, oxygen. Until hydrogen as a gas becomes price competitive with natural gas, either due to dropping renewable electricity pricing and/or carbon taxes, project revenues will not be enough to attract private sector investors.

However, grid scale batteries to enable buildout of renewables required to decarbonize our economy are needed. This project competes well from an economic perspective with grid scale chemical batteries such as Tesla's Megapacks priced at a about 400$Cdn/KW-hr. Current battery technology enables 'peaking' response for a couple of hours at a few 10s of MWs for each hour. However, this project when

[12] The process produces a clean water which will be re-used in the process to minimizes 'make-up' water requirements.

used as a battery can supply 100s of MWs for 10s of hours at a capital cost of under 200Cdn $/KW-hr. Further, this project, performing as a battery, could bridge a long-term event, for example, no wind during a protracted weather event lasting for days. Li-ion batteries cannot perform that service.

Although this project presents very low technical risk, the cost to build such a facility cannot be justified using standard business economic decision criteria. If it did such facilities would already exist. Therefore, in addition to private sector investment, this project will need public or philanthropic funding to achieve an acceptable return on investment.

Gap funding, the difference between the amount a private sector investor(s) needs, and the amount required for a commercially viable project with utility grade ROI, is recognized by governments around the world. Including the Canadian government as well as some provinces. Part of the project scope will be to seek out and secure gap funding for the project.

8. Value Proposition "*H Two Prosperity*"

A world scale hydrogen project located in Sarnia Lambton would deliver skilled employment and facilitate expansion of renewable energy infrastructure. This project would enable research and development of hydrogen production, storage, and end use applications for export globally. With a strong focus on environmental, social and governance (ESG), this facility could be a model for societal partnership.

The ***H Two Prosperity*** concept is a vision where governments, Indigenous communities, society, institutions, and business build now for a prosperous future. That future involves seizing the economic opportunities afforded by a decarbonizing world economy; NOW, and to be a leader in an unfolding future. Regions across Canada offer a suite of characteristics unique to each region that can be configured to play an important role in decarbonizing difficult sectors of the economy for Canada and for the world. Appendix 1 lists key characteristics of Sarnia–Lambton. Taken together, these characteristics in one region is unique in Canada

The proposed green hydrogen production, storage, and use project would deliver the following.

Jobs, scaling current technologies to deliver the capacity envisioned by this proposal would create heavy industry scale employment levels. Skills requirement will be high; therefore, expect salaries to be high. Training infrastructure to provide the needed skills is currently available in this region. The capacity offered by Lambton College to train workers for the nascent but growing low carbon hydrogen industry sector is high enough to export a trained workforce to other hydrogen hubs across Canada.

Enabling Expansion of Renewable Energy Infrastructure, intermittent wind and solar power means the key to building out renewable energy capacity is predicated on energy storage. The proposed project is, in its essence, an energy storage battery. When built it would be larger than any chemical 'battery' in the world. Storing off peak energy and releasing that energy when the wind isn't blowing, when the sun isn't shining, when demand is high, enables further renewable energy development. Building more renewable energy capacity will create spin off jobs and new business opportunities.

Set the Stage for Future, building the proposed project now would demonstrate to the world that the, largely Canadian, technology is available NOW. Using the stored hydrogen to generate electricity will serve as a hedge as well as a bridge to the future. Hydrogen, at current prices and on an energy unit basis (Joules or KW-hrs) is less expensive than gasoline jet fuel, or diesel fuel[13]. But infrastructure to use hydrogen as a fuel does not exist on a societal scale, YET. Building the proposed project would enable development of hydrogen fueled ships, large agricultural machinery, heavy and long-distance trucks, heavy construction equipment and difficult to decarbonize industries. This regional hydrogen hub would morph into a hydrogen R&D application development centre In Sarnia Lambton, because the green hydrogen supply would be available. R&D to design and build demonstration units will create jobs and new business opportunities.

Markets, the world is decarbonizing. This region has easy access to markets via rail, truck, marine, and potentially by re-purposing existing pipelines. Development of hydrogen export capacity to markets that will emerge as decarbonization proceeds will create jobs and new business opportunities.

Other jurisdictions around the world are not just talking about building green hydrogen production facilities, they are building such facilities. This region's hydrogen production experience, skills, receptive community, geology, coupled with ready access to markets represents a unique opportunity for Canada to catch up to other jurisdictions and become a 'first to market player' in this emerging industrial sector.

First movers will have a tactical and strategic advantage. Time is of the essence.

Equity is difficult to achieve by retrofitting contemporary societal expectations into past endeavors. We are embarking on a new industry sector and a 21st century that will be different than the last. Equity and fairness can be incorporated into development of a new industry sector and offers an opportunity to demonstrate leadership in Environmental, Social and Governance structures. The path to equity can be laid out at the outset of the proposed project development by involving local Aboriginal Communities, the public, local industries, educational institutions, and community leaders.

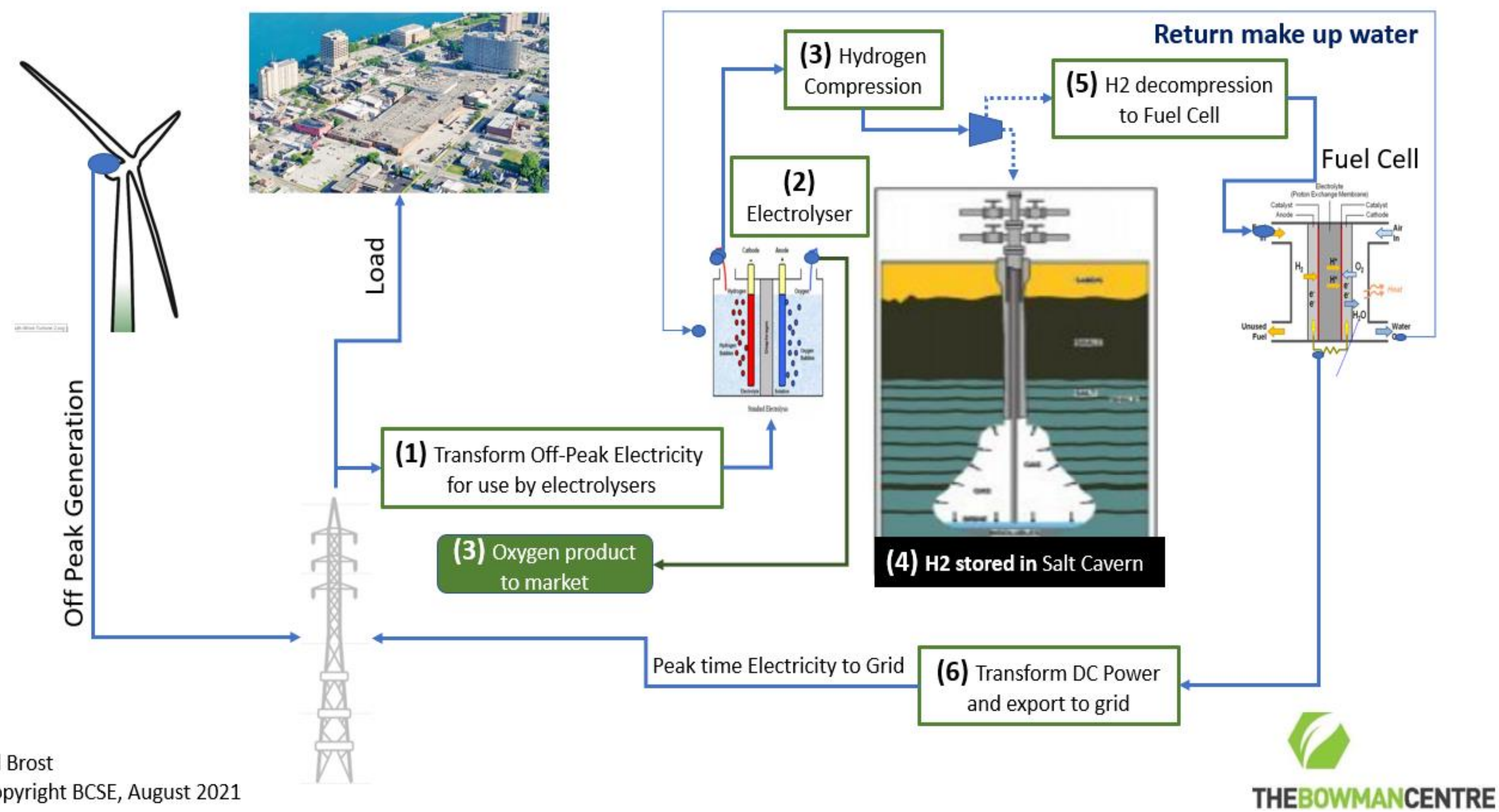
9. Regulatory Approvals

Regulatory processes for solution mining a new well are in place. Regulatory processes to permit construction of a facility as described in the pre-feasibility study are in place. Regulatory processes for drawing significant power from the grid as well as injecting power to the grid are well understood. These processes are identified in the pre-feasibility study report. Project developers need to use and follow those processes. Facility operators will need to comply with the terms and conditions in their regulatory permits and align with operational requirements of the IESO.

Regulatory approval of the proposed facility, like any proposal, is not guaranteed. But in this case, if the processes are followed, including Aboriginal Community consultation and stakeholder engagement processes are followed, risk of failure to receive required permits is low.

[13] Nation building projects | Bowman Centre for Sustainable Energy, 372347_a1e49c3376da48efa04928a08a02ce20.pdf (filesusr.com)

Figure 1 BCSE Hydrogen Storage and Power Generation Concept



Appendix 1

Sarnia – Lambton, Proposed Host Community

Sarnia-Lambton's existing industrial base has a massive appetite for hydrogen and therefore includes hydrogen production. Further, the region is within driving range of over 70% of the US market. And if that is not enough, this region has access to world-class rail and marine export facilities, enabling access to developing global hydrogen markets. This region not only has all the key technical, human capital, geographic, and market access prerequisites for a hydrogen hub in place, they are already in operation.

Sarnia – Lambton hydrogen hub enabling characteristics include:

- Receptive community
- Potential for aboriginal community involvement
- Access to water
- Access to a skilled labour market
- Access to potential heavy industrial customers for hydrogen
- Access to an underutilized low carbon electricity supply during off-peak hours
- Access to industrial scale design and fabrication consultants
- Experience with grid scale electricity production, high voltage, and high-power equipment
- Local experience with design, construction, and operation of salt caverns
- Experience in designing, building, operating, maintaining hydrogen production facilities
- Experience in safe handling of hydrogen
- Lambton College to design, develop and train workers for a new and expanding hydrogen economy
- Environmental consultants and First Nations communities to assess local and regional environmental and societal benefits and impacts
- Access to future hydrogen markets, via marine, rail/tunnel, highways
- Major project leadership and development skills, industrial and government
- Visionary and resolute regional leaders