

Fuel Cell Power Plant Feasibility Analysis for Port Edwards, Wisconsin

Proposal for Port Edwards submitted jointly by:
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1.0 TERMS AND ACRONYMS

Term	Definition
AC	Alternating current
Capex	Capital expenditures
DC	Direct current
GJ	Gigajoule
GWh	Gigawatt hour
GWP	Global warming potentials
IRR	Internal Rate of Return
kV	Kilovolt
kVAC	Kilovolt alternating current
kW	Kilowatt
LHV	Lower heating value
MMBTU	One million British thermal units
MW	Megawatt
MWh	Megawatt hour
NG	Natural gas
Opex	Operating expense
PEM fuel cell	Proton exchange membrane fuel cell
SCF	Standard cubic feet
SGIP	Self-Generation Incentive Program
USD	United States dollar
VAC	Volts alternating current

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2.0 EXECUTIVE SUMMARY

Hydrogen fuel cells are widely believed to be one of the long-term solutions to future energy needs. One of the most significant barriers to widespread fuel cell commercialization has been developing economical and reliable sources of hydrogen. Port Edwards, Wisconsin is home to a chlor-alkali chemical plant that is owned and operated by ERCO Worldwide. One of this plant's by-products is hydrogen gas, which could be redeployed to provide clean electrical power from hydrogen fuel cells.

In many locations around the world, hydrogen from chemical plants is simply vented. However, after the significant upgrades at ERCO's Port Edwards chlor-alkali plant, all of the by-product hydrogen will be used to either make product or be burned to make process steam. As a result, any hydrogen diverted to make power at this site will require an alternate heat source to be supplied to the plant to maintain operation. In the near term, this source of heat would likely come from natural gas but could be substituted with biogas or steam from any source in the longer term. This would allow ERCO to redirect its hydrogen toward a higher value use in fuel cells. The electricity produced could either be sold back to the grid at a premium, or used within ERCO's facility to offset their electrical consumption. In the long term, there may be additional opportunities to utilize the fuel cell waste heat that would increase the power plant efficiency and reduce its carbon footprint. The proposed clean energy power plant would generate approximately 2MW of continuous zero or low emission electricity. Over a one-year period, a 2MW power plant would reduce the amount of CO₂ generated by at least 4,400 tonnes or the equivalent of 860 passenger cars.

The most significant remaining hurdle for the project is the lack of a clear business case that would provide an acceptable IRR and payback period. The fuel cell solution is most compelling from both an efficiency and environmental perspective. However, given that there is currently no feed-in tariff program or self-generation incentive program in the state of Wisconsin, and the industrial electric rates are relatively low, the fuel cell solution is currently challenging from an economic perspective.

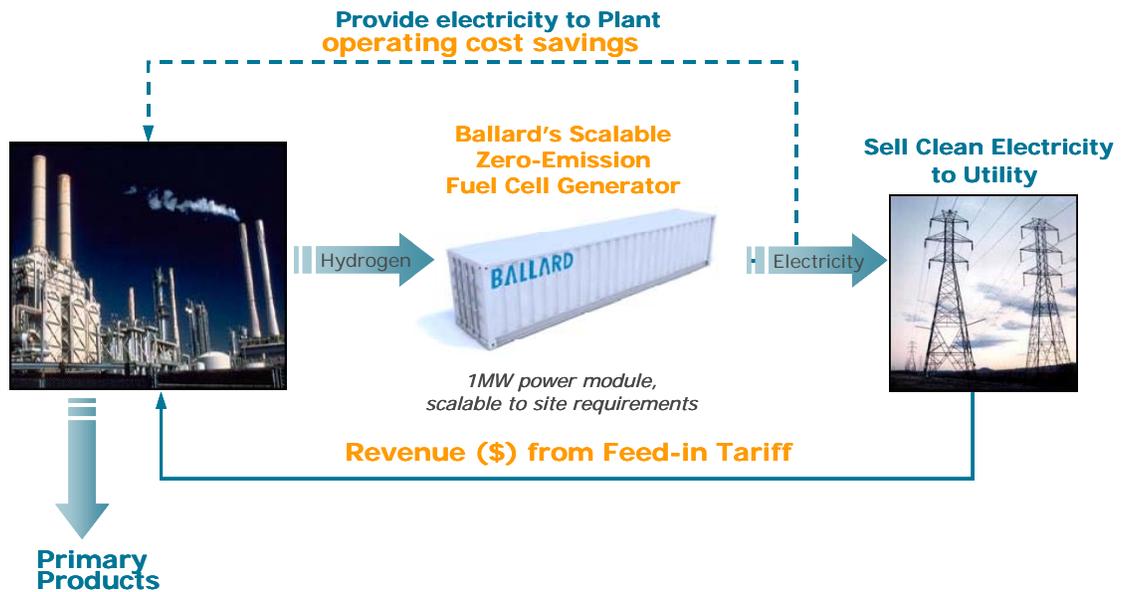
Ballard has found that the economics are very compelling in regions with feed-in tariff programs in place, such as Korea and Germany. In addition, California's self-generation incentive program (SGIP) reduces the payback times to less than 2 years and results in a IRR of >20% from the electricity cost savings. The overall recommendation of this report is, therefore, to suggest policy change in Wisconsin that will enable the adoption of clean energy solutions, such as the fuel cell generator.

3.0 PROJECT OVERVIEW

The concept described herein is intended to show the feasibility of a fuel cell generator at ERCO's chemical plant in Port Edwards. The generator is designed to provide constant power, either to the electrical grid or for self-consumption in the power plant, using by-product hydrogen from ERCO's chlor-alkali manufacturing process.

The concept of capturing waste hydrogen from chemical plants as the energy source for fuel cells has been around for some time, with plants in operation in several countries including Germany, the US, and Korea. The interest in this application has recently intensified as a result of increasing focus on clean energy production and energy independence by many countries around the world, enabled by compelling government feed-in tariff programs. Figure 1 below is an illustration of the application under consideration at ERCO's chlor-alkali plant. Ballard views this market as a promising commercial market for its hydrogen fuel cell products, and is actively pursuing deployments in a number of different international locations.

Figure 1: Fuel cell generator utilizing by-product waste hydrogen



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4.0 PRODUCT CONCEPT

4.1 Initial Sizing

The amount of electrical power that can be produced from the plant depends on the amount of hydrogen available. Currently, all of the hydrogen produced at the ERCO facility is either used in the production of product or burned to make process steam. As a result, any hydrogen diverted to a fuel cell power plant would have to be replaced with an alternate source of heat. This heat would most likely come from burning natural gas but it could just as easily come from biomass or steam piped in directly to the facility.

The exact amount of hydrogen available at the ERCO site is proprietary information. However, preliminary discussions with ERCO indicate that the Port Edwards plant would produce enough hydrogen to power a fuel cell power plant approximately 2MW in size. If the facility produced more or less hydrogen, the fuel cell generator could be tuned to produce more or less power accordingly. For the purposes of this feasibility study a power plant of 2MW is assumed.

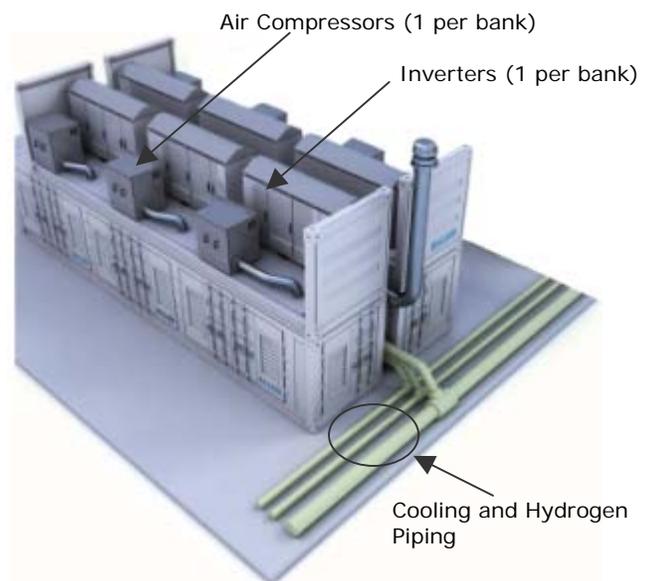
The power produced by the fuel cell power plant could either be used by the ERCO plant internally or could be exported back to the grid. Either option is feasible but the rate of return will differ depending on the value of the hydrogen, the value of the electricity and ownership of the power plant.

4.2 Product Architecture

Ballard is currently developing a scalable 1MW fuel cell generator that could be used at the Port Edwards facility. For this application, the 2MW power plant would consist of 2 x 1MW fuel cell generators and, depending on the exact system layout, at least one step up transformer and possibly a fuel purification module. If the power were to be used within the chemical plant, the voltage would likely be either stepped up to 480VAC or used as DC power directly. If the power were to be used on the grid, the voltage would have to be stepped up to 13.8kVAC. The fuel cell generator supplied by Ballard is based on an array of 2 x 1MW independent power modules, as shown in Figure 2.

The technology incorporated in the fuel cell stack and balance of plant has been well proven in multiple applications. Ballard's confidence in the performance, reliability, and durability of the generator is high. This confidence is reflected in the fact that Ballard sells the fuel cell generator with fixed service pricing for the first three years or 25,000 hours of operation. Availability of the power plant (defined as amount of time the fuel cell generator is available to provide 2MW net of power to the grid) is an important factor for both ERCO (impact on rate of return) and/or the power utility. Table 1 shows the high level specification for the fuel cell generator.

Figure 2: 2MW site layout



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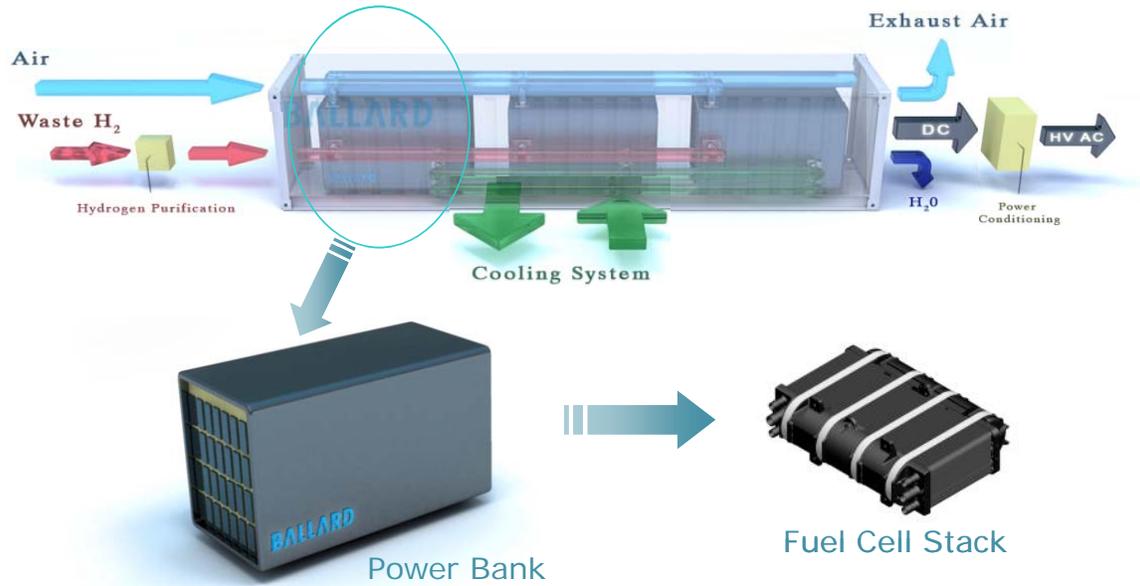
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Table 1: High-level fuel cell generator specification

Key Parameter / Attribute / Task	SI unit	Concept Value
Net power	kW	2,000
Gross power	kW	2,300
Total system efficiency (average, LHV, no waste heat utilization)	%	48
Fuel consumption (average)	kg/hour	135
Availability	%	>90
Service strategy	Hot-swappable banks	

Each 1MW module is comprised of 3 x 333kW banks that can be shut down independently for service and/or hot swap capability while the rest of the plant delivers uninterrupted power to the grid. Hot swap capability refers to the fact that individual banks can be shut down, replaced, and returned to service while the remainder of the plant continues to operate. The bank architecture is shown in Figure 3. Each bank comes equipped with its own air compressor and power conditioning (inverter) system. This independent bank design is a key feature of the platform to enable high plant availability. One of the key benefits of Ballard’s PEM fuel cell generator is the ability to start-up and shut-down rapidly, and to dynamically ramp power production according to the load requirements.

Figure 3: 1MW module containing three power banks



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4.3 Fuel Purification

Depending on the fuel quality, a purification module may also be provided with the fuel cell generator, in order to ensure that the hydrogen entering the fuel cell generator does not contain contaminants that impact either fuel cell lifetime or performance. Ballard has significant experience understanding which constituents, and at what levels, impact the efficiency and lifetime of the fuel cells. In order to contain costs, the approach is to reduce the constituents known to impact fuel cells to acceptable levels, while leaving other impurities in the stream that do not have a negative impact on fuel cell performance or lifetime.

In a typical chlor-alkali plant, the by-product hydrogen streams may also contain traces of chlorine, oxygen, and liquid water.

Chlorine attacks the fuel cell catalyst, negatively impacting performance, and therefore needs to be reduced to the parts-per-billion level. If the levels are too high, Ballard provides a packed tower scrubber, utilizing sodium hydroxide (caustic soda) or calcium oxide (caustic lime) as the scrubbing fluid. The captured chlorine would form disposable, non-volatile substances such as calcium and sodium hypochlorite.

Oxygen can create hot spots in the fuel cell, and needs to be reduced to <0.2% on a molar dry basis so it will not impact the fuel cell lifetime. If the oxygen levels in the fuel stream exceed 0.2%, Ballard would also provide a catalytic oxidizer to reduce the levels of oxygen. The oxygen present will react with hydrogen to form water. Catalytic oxidizers are quite simple devices that usually consist of a vessel containing catalyst in a fixed bed.

Although water is actually beneficial for PEM fuel cells, liquid water from outside sources is a concern because it tends to contain contaminants from its source. Therefore, water in the inlet stream will be cooled and removed to prevent the carry-over of contaminants into the fuel cell.

Preliminary discussions with ERCO indicate that the hydrogen from the Port Edwards facility will be exceptionally clean, once the plant updates are complete, and that no additional purification will be required. Any liquid water in the hydrogen steam could be removed at very little cost.

4.4 Site Layout

The 1MW fuel cell module is packaged in a standard 45 foot ISO container with the following dimensions:

Height	2.90 m (9.5 feet)
Width	2.44 m (8 feet)
Length	13.71 m (45 feet)

These dimensions do not include the air compressor and the power inverter modules. If desired, the air compressor and power conversion modules can be packaged in a separate ISO container for assembly and operation on the site. This second ISO container can be arranged beside or on top of the fuel cell generator. If required, the fuel processor is packaged on a separate skid.

The site layout is flexible depending on the requirement of the site. However, space needs to be provided for forklift service access (3m) on one side of each module as well as space for fluid piping (1m) to and from the modules.

Figure 4 below is a plan view of how the fuel cell generator could be arranged on the site but other variations are possible.

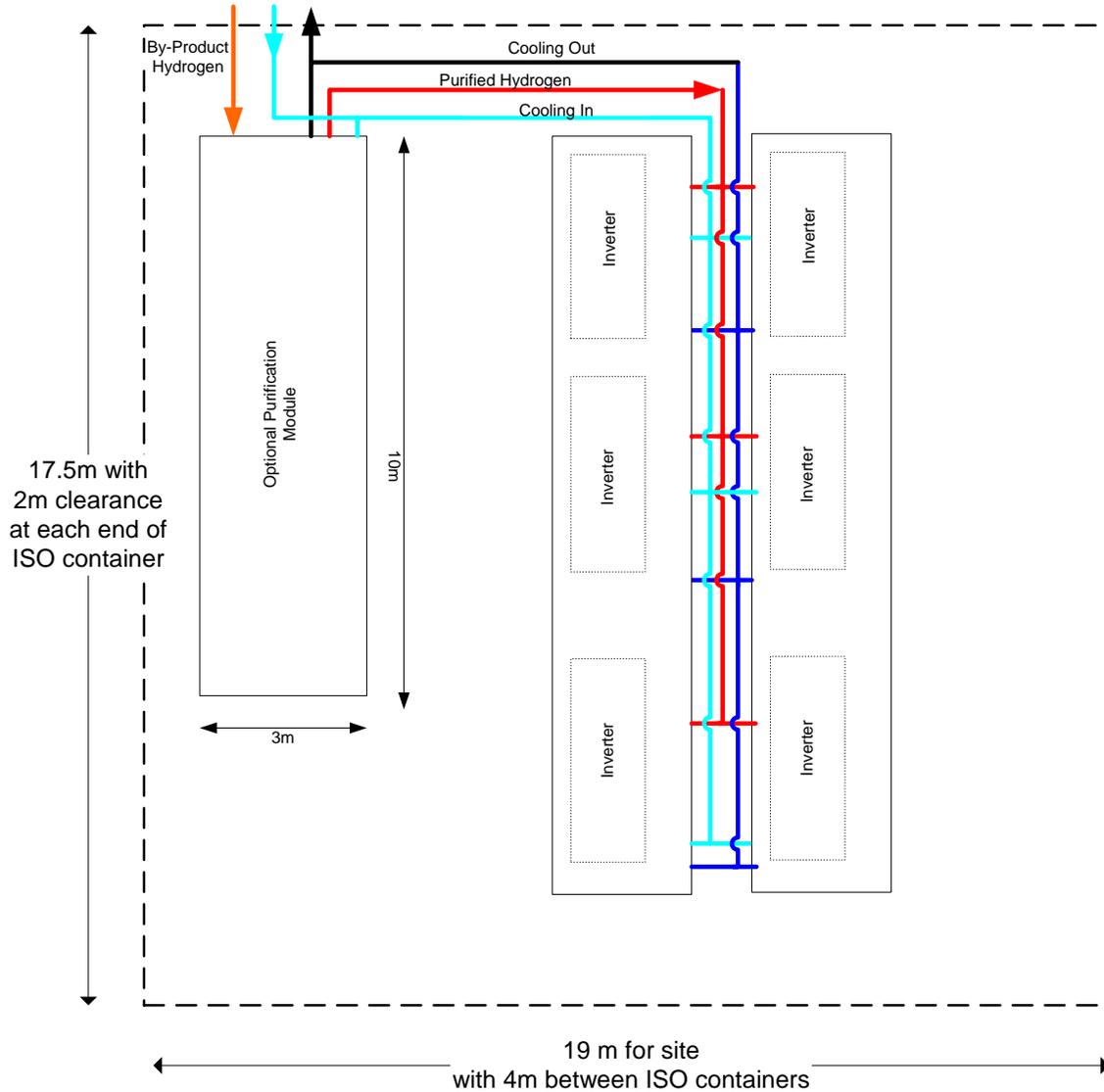


Figure 4: 2MW preliminary site layout

Each of the modules, as well as the optional purification skip, would be installed on a concrete pad. If the power plant were to be configured as above, the pad would be approximately 18m by 19m (59x62 feet).

Typically, each of the modules would be tested prior to shipping and installation at the site. Connections between the modules and fluid and electrical connections to the site would be the plant owners' responsibility.

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4.5 Fuel Cell Stack

The core technology in the generator is the fuel cell stack, Ballard's FCgen™-1300. The FCgen-1300 is a cost reduced derivative of the Mark1100 motive fuel cell stack, which is well proven in both car and bus applications. The platform also incorporates features from Ballard's FCgen™-1030 cogeneration stack and the FCvelocity™-9SSL fuel cell used in forklift applications. The FCgen-1300 maintains the same quality, reliability and durability features as the previous generation Mark1100 stack design but at a lower cost, and tailored to meet the requirements of the power generation market. The FCgen-1300 is made with advanced manufacturing processes that enable continuous (versus discrete) processing of the core membrane electrode assembly (MEA) technology; this is Ballard's first commercially available product manufactured on this new pilot line. As can be seen in Table 2, the majority of key materials and design elements are the same in both the Mark1100 and FCgen-1300 fuel cell stacks.

Table 2: Technology comparison between Mark1100 and FCgen-1300

Technologies	Mark1100	FCgen-1300
Catalyst	Same	Same
Cathode Loading	Nominal	Reduced
Anode Loading	Nominal	Reduced
Membrane	Same	Same
Plate Material	Molded	Molded – Cost Reduced
Operating Pressure	Nominal	Low
Cathode Seal Design	Standard	Cost Reduced
Anode Seal Design	Standard	Standard
Stack Hardware	Standard	Cost Reduced
MFG Process	Low Volume	High Volume

The performance of the FCgen-1300 has been validated through over 23,000 hours of rigorous design verification testing (408,000 cell hours) to date. This testing has validated the performance, robustness, durability, and efficiency of the fuel cell for this application. Figure 5 is a rendering of the FCgen-1300 fuel cell stack.

Figure 5: FCgen-1300 fuel cell stack



Several alternative fuel cell stack platforms were considered for this application. The FCgen-1300 was found to be the superior solution for the following reasons:

- Higher overall system efficiency
- Lower pressure operation, simplified air supply system, higher balance of plant reliability
- Primary product platform for stationary applications

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Although the power generation market requires long lifetime, the stresses to the fuel cell stack are much lower than Ballard's other markets, making it easier to achieve longer lifetime with the existing products. The key stressors are summarized in Table 3 below. Through lifetime testing, accelerated stress testing, and modeling, Ballard has demonstrated that the FCgen-1300 has the capability to achieve greater than 20,000 hours of continuous operation in this application before the main fuel cell component, the membrane electrode assembly (MEA), needs to be replaced.

Table 3: Fuel cell stressors by application

Failure Mode	Stressors	Auto	Bus	Forklift	Dist Power
Transfer Leak	Cathode Potential	High	Medium	Low	Low
	Temperature	High	Medium	Low	Low
	Fenton's catalysts	High	Medium	Medium	Medium
	Gas Relative Humidity	High	Medium	Medium	Low
External Leak	Temperature	Medium	Medium	Low	Low
	Gas Pressure	Medium	Medium	Low	Low
Performance Degradation	Cathode Potential Cycling	High	Medium	Low	Low
	Anode Potential Cycling	High	Medium	Low	Low
	Air/Fuel Contamination	High	Medium	Low	Low
Cell Reversal	Fuel Stoich	High	Medium	Low	Low
	Liquid Water	High	Medium	Low	Low
	Relative Humidity	High	Medium	Low	Low

	Stressor has large effect on life
	Stressor has some effect on life
	Stressor has little effect on life

One of the key advantages of utilizing the FCgen-1300 as the building block for the distributed power generation market is that it is used in telecommunications backup power applications in India; the volume demand for this market will help to drive down the cost of the fuel cell stack for distributed power generation.

4.6 CODES AND STANDARDS

For stationary applications, the primary standard applied to the fuel cell generator is the ANSI/CSA FC 1-2004: Standard for Stationary Fuel Cell Power Systems. This detailed document represents industry-standard construction and performance requirements for fuel cell power generators, covering topics such as piping systems, hydrogen safety, electrical safety, ventilation, control algorithms, installation & operation, service & maintenance, and marking.

Where applicable, the generator is designed to comply with NFPA 496 - Standard for Purged and Pressurized Enclosures for Electrical Equipment, and NFPA 497 - Recommended Practice for the Classification of Flammable Liquids, Gases, and Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas.

The generator is intended to be installed in compliance with Local Codes & Standards, ANSI/NFPA 853 - Standard for the Installation of Stationary Fuel Cell Power Plants, and/or ANSI Z233.1 / NFPA 54 - National Fuel Gas Code.

5.0 FINANCIAL ANALYSIS

5.1 Market Potential

Worldwide, there is over 1,000MW of by-product hydrogen produced annually that can be converted into clean energy with fuel cells. This represents by-product hydrogen produced in the chlorine and sodium chlorate industries alone; there are additional sources of by-product hydrogen from styrene/ethylene production, steel production, and several other industrial processes that increase the size of the potential market for fuel cells.

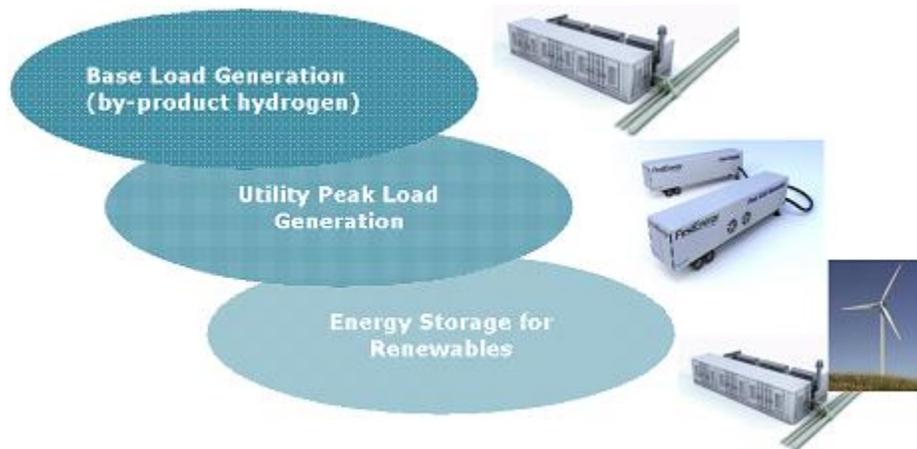
The Ballard PEM fuel cell technology is suitable for these markets as it is the best in class for converting by-product hydrogen into clean electricity. Ballard is the only PEM fuel cell manufacturer in the world that is able to produce multi-megawatt power using this technology. Reducing the initial capital cost of the fuel cell solution is key to gaining traction in the distributed power generation market. The volume resulting from a large-scale deployment of this nature would significantly reduce the cost of the fuel cell solution.

The cost of the generator depends largely on the size of individual installation (e.g. a 1MW installation is more expensive per kilowatt than a 6MW installation), and based on whether purification is required. In the longer term, Ballard is focused on reducing the capital cost of the fuel cell generator to make it a viable solution in regions that have high industrial electricity rates and no government feed-in tariff programs.

Ballard is in active discussions with companies around the world, in countries such as the United States, Germany, Korea, Spain, Denmark, and Japan, who are interested in fuel cell solutions for distributed power generation at chemical plants. Countries around the world have adopted a variety of incentives for the adoption of clean energy ranging from capital incentives to feed-in tariff programs, which enable this technology in those markets. The price paid by utilities to power producers using fuel cells ranges from \$0.15 USD/kWhr to \$0.28 USD/kWhr, thereby making fuel cell power generators commercially viable in those markets. Additionally, markets such as California offer a capital incentive of up to USD \$2,500/kW, in addition to the federally available tax credit of 30% towards the capital assets, making deployments of fuel cell technology feasible.

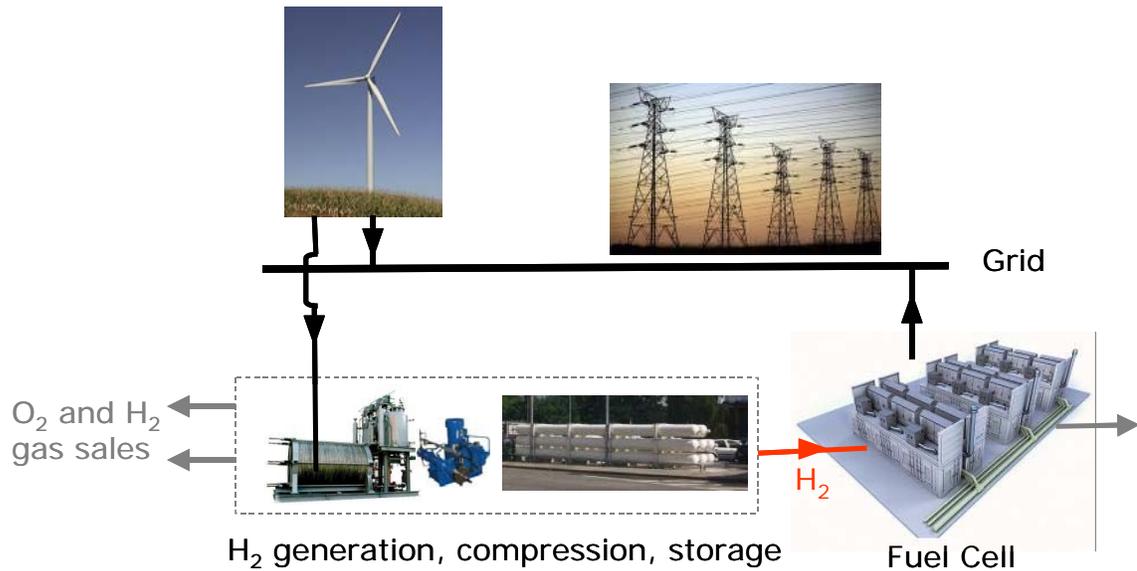
5.1.1 Alternative Applications of Technology

Ballard has recently entered into the distributed generation market, given the strong pull for megawatt scale fuel cell solutions that can produce zero emission power utilizing by-product hydrogen. The worldwide demand for clean power, supported by government policy initiatives, has made this a key market segment focus for Ballard. Ballard sees three different application areas for the 1MW scaleable distributed generation product: base load power production running on by-product hydrogen, peak load management running on stored hydrogen, and energy storage for renewable power sources such as wind and solar.



Earlier this year, Ballard entered into a contract with FirstEnergy, the USA's fifth largest investor-owned electric system, comprised of seven utility companies, to produce Ballard's first 1MW peak load management fuel cell system. Ultimately, once costs are further reduced through a number of large scale deployments, Ballard believes that the opportunities for energy storage for renewable wind and solar will further grow this market. The combined wind or solar and fuel cell systems are suitable for producing power in remote communities that currently rely on diesel generators for power production. shows a typical wind load management installation.

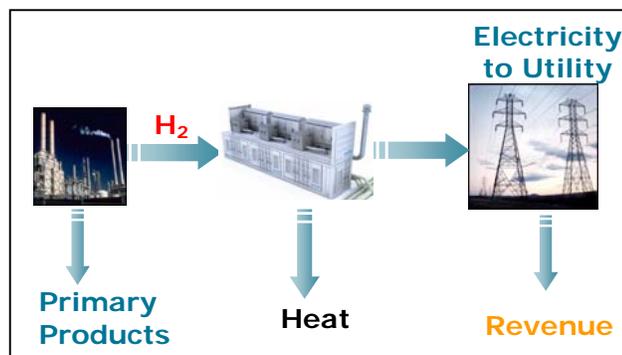
Figure 6: Wind load management installation



Ballard's PEM fuel cells, with dynamic load following and rapid start-up capabilities, can effectively be coupled with wind farms to provide an energy storage and power-on-demand solution. Electricity produced by the wind turbines at night or during off-peak hours can be used to generate hydrogen through electrolysis. A compression and storage system buffers the hydrogen, which is used to run the fuel cell during peak hours to provide stable, clean power on demand. Ballard's 1MW distributed power generation product offering can be scaled to the optimal size to maximize the revenue of the hybrid wind/fuel cell farm.

5.2 Port Edwards Facility Economic Modeling

Two ownership models are possible for this project. The first option sees the project wholly owned and operated by ERCO, with electricity produced consumed by the plant. The second involves a 3rd party owning and operating the fuel cell power plant by purchasing the hydrogen fuel from ERCO and selling the power to the electrical grid. A financial analysis has been conducted for both models.



Under current local market conditions in Wisconsin, both options are not likely to be economically viable. However, with appropriate incentives, both cases can be feasible. Key inputs to the value proposition model include: upfront capital costs, hydrogen value, electricity purchase rate, and incentives.

5.2.1 Capital Costs

The first option, where ERCO owns and operates the power plant, reduces the capital cost of installation relative to the second option. Many of the ancillary components (start up power, cooling, etc.) needed for the operation of the fuel cell are already installed at the plant and could be used for this application.

In the financial model, the following key estimates of the installed capital costs are assumed:

Fuel cell generator	\$2,000,000 USD/MW
DC/AC power converter	\$500,000 USD/MW
Step up transformer (480V-13.8kV)	\$150,000 USD/MW
Cooling system upgrades (3 rd party owner only)	\$70,000 USD/MW
Site preparation/concrete pad	\$10,000 USD/MW
Utility hook up (piping, electrical, controls)	\$125,000 USD/MW
Hydrogen piping (3 rd party owner only)	\$200,000 USD fixed
Miscellaneous	\$50,000 USD fixed

The total installed capital cost depends on how many of these items are relevant, based on where the power plant is installed and who owns the power plant. For the ERCO facility in Port Edwards, the chlorine and oxygen clean up and fuel pressurization will likely not be required.

5.2.2 Value on Electricity, Natural Gas, Hydrogen and Waste Heat

The value of hydrogen and electricity are key drivers in the economic model. The hydrogen represents the opportunity cost and the electricity represents the revenue. In many chemical plants around North America, by-product hydrogen is simply vented because there is no local use. In these cases, the opportunity cost of the hydrogen is zero and the business case is extremely favorable.

In the case of the Port Edward chlor-alkali plant, all of the hydrogen is used for making products or is burnt to make process steam. If the by-product hydrogen is redirected to a fuel cell power plant from the boilers, more natural gas must be used to offset the loss in heat value or an alternate supply of heat must be provided. In the short term, this additional heat would likely come from burning natural gas. The increased natural gas consumption is proportional to the ratio of lower heating values of natural gas and hydrogen. On a per megawatt basis, approximately 230 standard cubic meters per hour (or 8,086 SCF/hour) of natural gas would have to be consumed to offset the redirected hydrogen. If a 3rd party consumes the hydrogen, a 10% markup is assumed.

The value of the natural gas and electricity depends on the supply contracts negotiated between ERCO and the utilities, which are typically confidential. However, estimates can be made, based on publicly available information on industrial rates. In this report, the rate information used comes from the [Energy Information Agency \(EIA\)](#) for the months between April and September 2009. Here, the average natural gas price is listed at \$5.91 USD/1,000 SCF. Translating this to an equivalent heat value for hydrogen gives a value of \$0.73 USD/kg of hydrogen. In the event that an alternative heat source can be provided to ERCO, the value of the hydrogen decreases (potentially to zero). In the case where the waste heat from the fuel cell is used for heating or in an industrial process, the value of the waste heat is equivalent to the heat energy of natural gas or ~\$6.02 USD/GJ (\$5.71 USD/MMBTU or \$21.70 USD/MWh). Similarly, the electricity rate for industrial consumers in Wisconsin is ~\$68.40 USD/MWh (\$121 USD/MWh residential).

5.2.3 [Financial Assumptions](#)

Equally important in the financial modeling are the following factors and assumptions:

Internal rate of return period (IRR):	15 years
Annual escalation factor (electricity & natural gas rates):	1.5%
Availability of power:	90%

5.2.4 [Government Capital and Operating Incentives](#)

Like other green technologies (e.g. wind and solar), fuel cells need some form of economic stimulus in the near term to compete with established power generation technologies. Depending on the jurisdiction, a wide variety of capital and operating incentives are available. In Wisconsin, however, the only funding currently available for building the power plant is the Treasury Department's grant-in-lieu-of-tax credit program, whereby funding of 30% of capital expenditure is available within 60 days of the unit entering service. No operating incentives are currently available in Wisconsin.

Capital incentives allow green technologies such as wind, solar, or fuel cells to be purchased at sufficiently low cost so as to compete with conventional technologies. Operational incentives allow green technologies to produce power at a rate that can compete with conventional technologies. Depending on the specifics of a given location, the economics of a fuel cell power plant may require capex incentives, opex incentives, some mixture of both, or none at all.

For example, in a location where:

- 1) the hydrogen is currently vented,
- 2) the fuel cell generator can be installed at a minimum of additional expense, and
- 3) 80% of the waste heat is used

the generator can yield a rate of return of 10% IRR with industrial electricity rates as low as \$47 USD/MWh with no capex or opex incentives at all.

In Port Edwards, however, there are a number of factors that negatively affect the business case:

- 1) the industrial electricity rates are relatively low,
- 2) the hydrogen is fully utilized and must be replaced with natural gas at a cost, and
- 3) there is no use for the waste heat.

All of these factors combine to make the operating costs the most significant barrier to the economics.

Under the baseline assumptions, with the operational costs (including service and maintenance personnel, spare parts, and the cost of incremental natural gas consumed), the value of the electricity produced is more expensive than the industrial rate that it would be sold for. This is not surprising, as even conventional technologies used at a small scale would produce electricity at a higher cost than if it were produced at a large scale. As a result, distributed power in general requires higher electricity rates to be viable economically.

In the scope of the Port Edwards project, capital incentives help the project but cannot support the business case alone. Some form of operating incentive is required to make this project viable. This is also true for wind and solar power projects.

To model the effect of how a feed-in tariff program would affect the business case in Port Edwards, an operating incentive model similar to those in place in Korea, Germany and Spain can be used. Under these programs, local utilities enter into long-term power purchase agreements with independent power producers at contractually set rates for the duration of the agreement. Depending on the jurisdiction, the electricity produced can either be self consumed or exported to the back to the grid. These agreements are typically 15 to 25 years in duration, with rates indexed according to inflationary estimates as well as commodity prices of natural gas.

Depending on who owns and operates the power plant, a feed-in tariff rate of \$124-\$130 USD/MWh, would yield an IRR of approximately 15% and a five year payback. Although this is higher than the base industrial rate, it is only slightly more than the residential rate in Wisconsin (\$121 USD/MWh). Compared typical to wind (~\$225 USD/MWh) and solar (~\$400-\$500 USD/MWh) feed-in tariff rates, distributed fuel cell power generation feed-in tariff rates are relatively low, even in a location where the economics are not particularly favorable, while the power produced is more consistent. A 15% rate of return was assumed to be the minimum acceptable for a new technology. As the technology matures and becomes more commonplace, a lower rate of return may be acceptable.

5.2.5 Summary

Assuming 15% as the threshold IRR triggering investment in the project, it is clear that the baseline business cases are weak. Similarly obvious is the fact that the ERCO owner/operator base case is inherently stronger than the 3rd party base case across all scenarios. It is also possible to conclude that some form of opex incentive program would be required to make the business case economically feasible given the particulars of the Port Edwards site. Capex incentives would also help business case and would reduce the required feed-in tariff rate. The combination of capex and opex incentive programs produce a compelling project IRR that should stimulate local investment and job growth.

6.0 JOB CREATION

Although fuel cell stack technology (the power source) is only available from select vendors, the majority of balance-of-plant components that comprise the complete and system are standard and could be sourced locally, including the skilled labor required to conduct integration and final assembly. Skilled labor would also be required to maintain the power plant. It is estimated that during the installation phase between 3 to 10 temporary jobs will be created over the approximately three month installation and commissioning process and an additional 1 to 2 permanent jobs will be created for service and maintenance.

Additionally, indirect jobs would be created in Wisconsin if local component suppliers were used in the generator. It is estimated that 80% of the value of each project is comprised of components and labor readily available in the state of Wisconsin. Appendix B lists a preliminary list of Wisconsin based component suppliers that could be used in the project.

7.0 CARBON REDUCTION IMPACT

In many locations around the world, hydrogen from chemical plants is simply vented. When these sources of hydrogen are harnessed to provide electrical power from fuel cells, the power generated is truly zero emission and provides compelling environmental advantages.

However, after the upgrades at ERCO's Port Edwards chlor-alkali plant, all of the by-product hydrogen will be used to either make product or be burned to make process steam. As a result, any hydrogen diverted to make power at this site will require an alternate heat source to be supplied to the plant to maintain operation. This source of heat would likely be natural gas, however, biogas or steam from another source could just as easily be used.

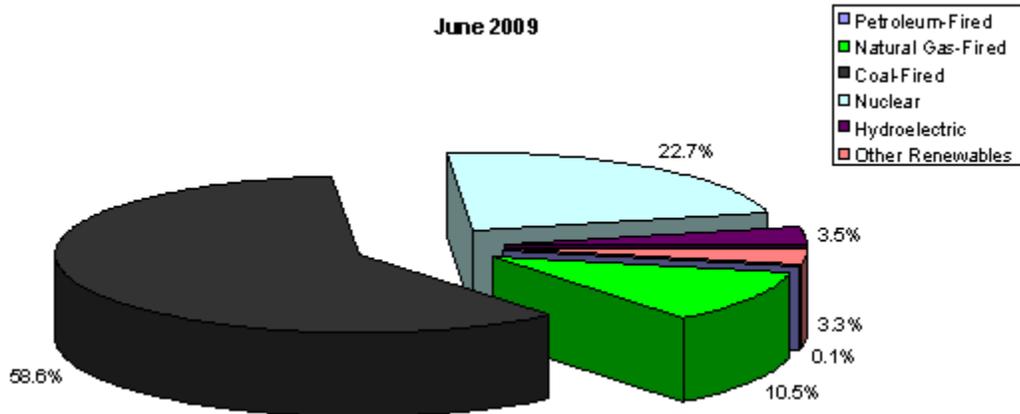
When natural gas is used to provide this additional heat, the fuel cell power plant cannot be considered zero emission, even though the fuel cell itself produces no emissions. There is, however, a significant reduction in the total greenhouse gas emissions from the project, even when additional natural gas is used to supplement ERCO's process steam requirements.

To calculate the reduction in greenhouse gas emissions resulting from the operation of the fuel cell power plant, one has to calculate the amount of greenhouse gases offset by the clean electricity from the fuel cell and the greenhouse gases produced by burning of incremental natural gas in the ERCO facility. The calculation of these emissions is the subject of the following sections.

7.1 GHG from Electrical Sources in Wisconsin

Wisconsin, like the rest of the United States, has a mix of electrical generation sources. Wisconsin produced 5,031GWhs of electricity in the month of June 2009. Chart 1 below shows the breakdown of electrical generation in Wisconsin:

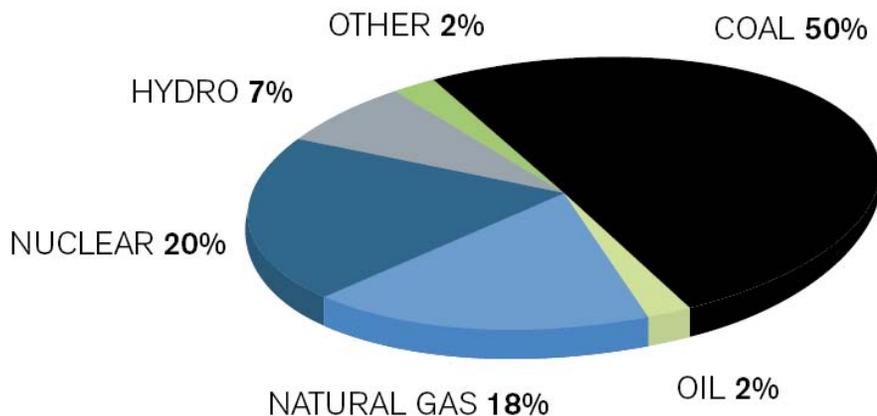
Chart 1: Breakdown of Wisconsin energy production



Sources: [Department of Energy, US Energy Information Administration](#)

In Wisconsin's energy landscape, coal fired power plants produce the most amount of electricity (at 59% of total production), followed by nuclear (23%), and natural gas (11%). Hydropower and other renewables represent only a small fraction of total production (3% each). This mix of energy production is similar to the larger US landscape shown in Chart 2 below:

Chart 2: Breakdown of US energy production



Source: 2002 Commission for Environmental Cooperation of North American "Power Plant Air Emissions"

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As shown in Appendix A, the weighted average CO₂ emissions per megawatt hour of electrical production in Wisconsin from coal and natural gas are 1.094 and 0.590 tonnes respectively. To get the weighted average emissions from all of Wisconsin's power plants, the entire mix of power production must be taken into account. Table 4 shows the mix of power produced in Wisconsin for the month of June 2009.

Table 4: **Wisconsin power generation distribution & CO₂ production for June 2009**

Wisconsin Power Generation Distribution & CO₂ Production

	Energy Production- June 2009 (thousands MWh) June 2009	GWP Equivalent CO ₂ Emissions (Tonnes/ MWh)	Total Equivalent GWP CO ₂ Emissions (Tonnes)	Percent of Total Power Production
<u>Total Net Electricity Generation</u>	5,031	N/A	3,543,572	
<u>Petroleum-Fired</u>	4	0.893	3,572	0.08%
<u>Natural Gas-Fired</u>	530	0.590	312,700	10.53%
<u>Coal-Fired</u>	2,950	1.094	3,227,300	58.64%
<u>Nuclear</u>	1,143	0	0	22.72%
<u>Hydroelectric</u>	175	0	0	3.48%
<u>Other Renewable</u>	164	0	0	3.26%

Average Equivalent CO₂ Emissions from Wisconsin Power Plants : **0.704 Tonnes/MWh**

Sources http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2emiss.pdf
http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_SWI_m.htm

Sources: Department of Energy, US Energy Information Administration

Combining the mix of CO₂ production from Wisconsin's power plants, gives a weighted average CO₂ production of the Wisconsin electric grid of 0.704 tonnes of CO₂ per MWh of electrical production. Neglected are the emissions associated with electrical transmission, transportation of feedstock, and the emissions associated with mining/drilling/refining of feedstock. Also neglected are the indirect greenhouse gas emissions from the power plant.

When clean hydrogen or unused hydrogen is available, all of these emissions can be offset. For a 2MW power plant, this translates to a CO₂ savings of over 11,000 tonnes of CO₂ annually.

7.2 Combustion Products of Natural Gas

The calculation of combustion products of natural gas is important, as the additional natural gas consumed by the ERCO facility will somewhat offset gains made by the zero emission electricity produced from the fuel cells. The exact emissions from the ERCO facility's natural gas boiler are not known at the time of this report. However, a reasonable amount of literature has been produced on the topic so accurate estimates can be made (as shown in Appendix A). On a per megawatt basis of electrical power generated, the electricity produced from the fuel cell power plant would effectively have a CO₂ footprint of 0.451 tonnes CO₂/MWh even though the fuel cell itself produces no emissions.

This assumes that all of the heat energy from the displaced hydrogen comes from natural gas and none of the waste heat is used. It should be noted that even under this worst-case scenario, considerable gains in CO₂ emissions per MWh could be realized. The fuel cell power plant would have 23% less emissions than if the natural gas were burned in Wisconsin's natural gas fired power plants and 36% less than Wisconsin's average energy production CO₂ footprint. This is because the efficiency of the fuel cell generator is higher than the average natural gas power plant in Wisconsin.

Similarly, if the waste heat from the fuel cell were to be used in a process that would otherwise use natural gas, such as district heating or industrial processes, the displaced natural gas would reduce the overall carbon footprint by the same amount as combustion process described above. For example, if 1MW of the waste heat could be utilized (~50% of available fuel cell heat), an additional reduction of ~0.226 tonnes of CO₂ emissions could be realized.

7.3 Net CO₂ Reductions from Fuel Cell Power Plant Operation

Given the average grid electricity in Wisconsin produces 0.704 equivalent tonnes of CO₂/MWh, the electrical power generated by the fuel cell power plant is relatively clean at 0.451 equivalent tonnes of CO₂/MWh. This holds true even if natural gas is used in place of the displaced hydrogen to run the power plant. This translates to a 36% reduction in CO₂ equivalent emissions relative to the Wisconsin average. Over a one-year period, a 2MW power plant would reduce the amount of GWP equivalent CO₂ generated by ~4,432 tonnes.

If an alternate supply of heat is used in the ERCO facility from bio-mass or from collocated industrial facilities, the potential to reduce emissions increases even further.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The fuel cell generator would be a strategic project for the state of Wisconsin, the utility, the hydrogen and fuel cell sector, and the chemical industry.

Benefits:

- 36% reduction in CO₂ emissions relative to Wisconsin's background CO₂ energy footprint.
- Showcase Wisconsin and the city of Port Edwards as leaders in clean energy and leaders in exporting this technology internationally
- Path forward for chemical industry to produce clean power and to be a contributor to reducing the carbon footprint
- New revenue stream to bolster plant competitiveness, particularly important in this time of excess chemical production capacity
- Economic stability and growth of jobs in Wisconsin
- Establish Wisconsin as part of the hydrogen economy and sector
- Compared to other clean energy solutions (i.e. solar and wind) fuel cells are lower physical footprint, less visibly obtrusive, provide higher predictability and availability, plus can be situated close to high demand locations (reducing transmission losses)

Like other green technologies, fuel cells need some form of economic stimulus in the near term to compete with established power generating technologies. Currently, this project is not economically feasible in Wisconsin and would require a change in state or federal incentive programs. With the hydrogen already fully utilized, some form of operating incentive would be required for the Port Edwards project. This could take the form of a feed-in tariff program or through displacing the burned hydrogen by providing an alternate heating source. If a feed-in tariff program were to be implemented, a minimum of \$124-\$130 USD/MW would be required to make the project economically feasible.

In the longer term, fuel cell generators such as the one proposed at Port Edwards, will be used not just for by-product hydrogen but to load level and peak shave the grid. This is particularly important as more renewable power comes online with less predictable electrical production.

9.0 APPENDIX A

9.1 Calculation of WI's CO₂ Production from Electrical Production

The actual emissions from each of Wisconsin's power plants are shown in Table 5, along with the total equivalent GWP CO₂ emissions. Sulphur dioxides, NO_x, and mercury emissions are also shown. Although these emissions are harmful to the environment and are closely monitored by the EPA, they do not influence the carbon footprint of a power plant as these emissions are not considered direct greenhouse gases. The data in Table 5 is from a 2002 study produced by the Commission for Environmental Cooperation of North America.

Table 5: 2002 annual Wisconsin coal and natural gas power plant emissions

Plant Name	Primary Fuel	Capacity MW	Annual Generated Power MWh	Annual SO ₂ Emissions (tonnes)	Annual Hg Emissions (kg)	Annual CO ₂ Emissions (tonnes)	Annual NO _x Emissions (tonnes)	NO _x kg/MWh
Pleasant Prairie	coal	1,235	7,898,581	30,342	338	8,516,084	19,493	2.47
Columbia	coal	1,023	6,472,154	24,950	147	7,074,706	10,183	1.57
Edgewater (WI)	coal	770	4,786,914	15,817	92	4,935,895	7,939	1.66
Nelson Dewey	coal	200	1,172,335	14,250	36	1,284,668	4,796	4.09
Genoa	coal	346	2,203,168	13,650	32	1,819,196	4,036	1.83
Valley (WEPCO)	coal	275	1,147,954	13,323	21	1,612,962	2,976	2.59
South Oak Creek	coal	1,211	5,393,774	11,674	122	5,977,481	5,929	1.10
Weston	coal	565	3,202,588	10,698	72	3,649,498	5,677	1.77
Port Washington	coal	340	747,511	8,894	21	958,912	1,568	2.10
J P Madgett	coal	387	2,097,984	6,795	57	2,191,443	4,187	2.00
Alma	coal	181	690,029	6,607	9	740,346	2,719	3.94
Blount Street	coal	188	438,398	6,514	4	572,229	1,374	3.13
Pulliam	coal	410	2,349,544	6,261	37	2,886,951	7,463	3.18
Rock River	gas	294	279,656	8.26		167,059	410	1.47
Paris	gas	381	76,868	2.45		59,813	54	0.70
Whitewater Cogeneration	gas	315	731,388	1.81		317,460	50	0.07
Neenah Power Plant	gas	373	332,319	1.00		185,855	58	0.17
West Marinette	gas	167	95,106	0.54		102,000	58	0.61
DePere Energy Center	gas	187	139,865	0.45		90,453	67	0.48
RockGen Energy Center	gas	561	118,803	0.27		70,602	17	0.15
South Fond Du Lac	gas	344	40,155	0.18		66,674	38	0.94
Concord	gas	381	36,745	0.09		31,134	20	0.54
Germantown Power Plant	gas	330	39,922	0.09		23,989	8	0.20
Total Power (MWh)			40,491,761					

Average CO ₂ emissions from Wisconsin Coal Plants	1.094	Tonnes/MWh
Average CO ₂ emissions from Wisconsin Natural Plants	0.590	Tonnes/MWh

Source: Commission for Environmental Cooperation of North America "2002 North American Power Plant Emissions"

Neglected are the emissions associated with electrical transmission losses, transportation of feedstock, and mining/drilling/refining of feedstock.

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9.2 Combustion Products of Natural Gas

Combustion of natural gas, like the combustion of coal, produces a variety of emissions but CO₂ is the main greenhouse gas emission. In properly tuned boilers, nearly all the fuel carbon (99.9%) in natural gas is converted to CO₂ during the combustion process. This conversion is relatively independent of boiler or combustor type. A typical boiler of the size required at the ERCO facility will produce 120,000lbs of CO₂ per 10⁶ SCFNG (Source: Environmental Protection Agency: "AP 42 Fifth Edition Compilation of Air Pollutant Emission Factors", Volume 1: Stationary Point and Area Sources).

Over the lifetime of the fuel cell power plant, the average consumption of hydrogen will be approximately 67.5 kg/MWh. Consequently, additional natural gas will need to be consumed in the boilers. The amount of additional natural gas will be based on the ratio of natural gas and hydrogen lower heating value energy contents. The energy content of 1kg of hydrogen equates to ~3.48m³ (123 SCF) natural gas. On a per megawatt basis of electrical power generated, this translates to approximately 234 standard cubic meters/hour (or 8,300 SCF/hour) of natural gas that must be consumed to offset the redirected hydrogen. This will result in an additional 996 lbs/MWh or 0.451 tonnes/MWh of CO₂ emissions. Therefore, the electricity produced the power plant will effectively have a CO₂ footprint of 0.451 tonnes CO₂/MWh, even though the fuel cell itself produces no emissions.

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10.0 APPENDIX B

- **Aprilaire/Research Products**

<http://www.aprilaire.com/>

- **Badger Transformer Company**

<http://www.badgertransformer.com/about.html>

Badger Transformer Company is a specialist in the designing and manufacturing of electromagnetic products.

- **Cooper Power Systems**

<http://www.cooperpower.com/AboutUs/overview.asp>

Cooper Power Systems manufactures equipment, components and systems for distributing and managing electrical energy. Their products are used by electric utility companies in bringing electric power to homes, industries, businesses, and institutions throughout the world.

Cooper Power Systems, with its combination of McGraw-Edison, Kyle, RTE and Kearney product lines, provides an unequaled array of products for substation, overhead, underground and in-plant medium voltage distribution systems.

Products include single-phase and three-phase overhead and pad-mounted transformers, power capacitors, voltage regulators, air-break disconnect switches, reclosers, switches, fault interrupters, sectionalizers, fuses, arresters, cable accessories, transformer components, entrance/terminating equipment, tools and grounding equipment, fault indicators, protective relays, distribution automation equipment, power systems analysis software, and specialty transformer fluids.

- **DRS Technologies (Power and Control Technologies)**

<http://www.drs.com/>

- **Eaton**

<http://www.eaton.com>

- **Johnson Controls**

<http://www.johnsoncontrols.com>

- **Magnetek**

<http://www.magnetek.com/overview.htm>

Specializes in the development, manufacture and marketing of digital power and motion control systems for material handling, people-moving, alternative energy and mining applications. Their power control systems serve the needs of selected niches of traditional and emerging commercial markets that are becoming increasingly dependent on "smart" power.

- **Modine**

<http://www3.modine.com/v2portal/modine.portal>

- **Next Step Energy**

<http://www.nextstepenergy.com/html/default.shtml>

Next Step Energy, LLC., based in Western Wisconsin, specializes in radiant heating and renewable energy applications. They design and install custom space heating, domestic hot water and electric power systems. They are also a dealer of many radiant heating and renewable energy products, energy efficient appliances and backup generators.

- **Synergizedsolar**

<http://www.synergizedsolar.com/>

Synergized Solar is a source for solar products, training, and design services.

- **Transformers Inc. / Coil Trans**

<http://www.transformersinc.com/mission.htm>

Transformers Inc. specializes in custom-made transformer bobbins and toroids built to customer specifications. They can produce a single prototype or an entire production run working within a customer's delivery requirements.

Transformers Inc. can help to design or engineer requirements from blueprint or re-engineered designs, providing cost effective solutions for any production.

- **TSI Power Corporation**

<http://www.tsipower.com/>

TSI Power engineers and manufactures power protection products for wireless, telecom, security and industrial applications.

- **Zahn**

<http://www.zahninc.com/>

US manufacturer of DC/DC converters, DC converters, step up or step-down converters, DC motor controls, servo amplifiers, DC amplifiers, pure DC or chopper motor controls, all by PWM.

- **List of Inverters companies in Wisconsin**

<http://energy.sourceguides.com/businesses/byGeo/US/byS/WI/byP/invert/invert.shtml>