Needs For and Alternatives To

APPENDIX 7.1

Emerging Energy Technology Review

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APPENDIX – 7.1
EMERGING ENERGY TECHNOLOGY REVIEW

1 Executive Summary

The emerging energy technologies studied and evaluated by Manitoba Hydro include wind, bio-energy, nuclear, solar photovoltaic, solar thermal, energy storage, hydrokinetic, and enhanced geothermal. Each technology is in a different stage of maturity: some are commercially available, while others are still in the research and development phase. Consideration was given to both utility-scale and customer-sited load displacement generation, as scale and site may present favourably for some specific applications.

As shown in Table 1, when compared on a levelized cost of electricity basis (Energy Costs), the near to mid-term technologies of wind, biomass, and nuclear provide the most potential and have lower levelized costs. Hydroelectric has been included in the table for general comparison. The Trend column indicates whether costs have been or are projected to rise, remain constant, or decline.

Table 1. Comparison of Installed and Per Unit energy costs based on utility scale generation in Manitoba

Technology	Installed Costs $/kW	Energy Costs $/MWh	Trend
Energy Storage	300 - 11,000	10 - 360	↓
Solar Photovoltaic	3,700 - 5,000	190 - 200	↓
Wind	1,600 - 7,600	60 - 210	↓
Biomass	2,000 - 5,800	100 - 150	↔
Solar Thermal	3,500 - 7,500	140 - 190	↔
Enhanced Geothermal	25,000 - 37,500	290 – 440	↑
Hydroelectric	3,800 - 21,000	60 – 290	↑
Hydrokinetic	7,000 - 9,500	160 – 620	↑
Nuclear	3,500 - 7,000	80 – 120	↑

Wind is potentially competitive on an energy basis, but cannot be relied on for meeting firm capacity requirements, which would require coupling wind with energy storage or other generation capacity resources. Biomass is attractive since it is dispatchable; however, emissions and fuel stock resource availability, as well as the potential for competition for biomass feedstocks from other industries must be considered. While nuclear has a long service life there are aspects of waste and fuel pricing, as well as of base load generation, that create challenges in implementation. Solar and energy storage costs continue to decline rapidly, which may present opportunities in the future. The intermittency of some renewable options also bears additional integration costs for integration into the existing electrical system.

Other technologies such as solar thermal are being further evaluated, and may be more suitable for heating loads than electricity generation over the long term. Enhanced geothermal has the potential to be competitive, but the resource uncertainty and high cost associated with drilling in Manitoba down to depths greater than 6 km makes further exploration of the concept challenging to undertake.

There are several varieties of small combined heat and power thermal technologies, some commercially available, while others still in the research and development phase. The electrical efficiencies of combined heat-and-power processes are low by nature because the primary output product is heat. Small thermal generation applications are attractive to industries and utilities that reject heat but which seek to improve efficiency.

This review compiles and summarizes information on emerging technologies obtained from research through demonstration projects, consultants reports, literature searches including peer reviewed papers and periodicals, as well as collaborations with academia and industry associations (locally and abroad).

Manitoba Hydro continues to study and monitor industry developments on an ongoing basis for options that have future commercial potential in Manitoba.

2 Introduction

This emerging energy technology review describes some of the key drivers affecting development, advancement and adoption/implementation of energy technologies and provides an overview of the current status of generation, storage and alternative emerging energy technologies and their potential applications in Manitoba.

Manitoba Hydro reviews energy sources and generation technologies on an ongoing basis as part of the resource planning process. There are number of staff dedicated to monitoring energy industry developments and maintaining current information on technologies. A multifaceted approach is undertaken, incorporating applied research obtained through demonstration projects and specific studies, participation in industry associations, and collaboration with academia, government agencies and industry, as well as research of peer-reviewed papers, periodicals and available literature.

2.1 Applied Research

Manitoba Hydro supports applied research activities, usually consisting of studies or testing equipment under Manitoba conditions, in an attempt to gauge the long-term potential and possible applications that could be realized in the future. Tapping into the innovations of others—without being a dedicated research & development organization—is accomplished through strategic alliances, research data acquisitions, and information networks. Undertaking small-scale demonstration projects with local entities such as the University of Manitoba or Red River College has proven to be a cost-effective way of obtaining information on the performance and economics of energy technologies. Collaborating has also helped in the development of local expertise and facilitated knowledge transfer through courses offered at educational institutions, such as the Renewable Energy Course at the University of Manitoba.

2.2 Industry Associations

Manitoba Hydro participates in a number of industry associations to collaborate on assessment and evaluation of emerging energy technologies, and to remain current on industry trends. Participating in industry associations can help leverage research efforts and knowledge across companies, especially regarding obtaining quality or proprietary information, and provides invaluable contacts with larger utilities that have greater experience and operating knowledge of non-hydroelectric based emerging energy systems.

A brief description of some of the key industry associations in which Manitoba Hydro maintains membership and actively participates can be found in the appendix Glossary—these include the Electric Power Research Institute, Inc. (EPRI), the Centre for Energy Advancement through Technological Innovation International Inc. (CEATI), the Utility Variable Integration Group (UVIG), the Canadian Wind Energy Association (CanWEA), Marine Renewables Canada (formally known as the Ocean Renewables Energy Group (OREG)), and the International Energy Association (IEA).

2.3 Collaborations

Manitoba Hydro maintains working relationships and collaborates with academia, industry and organizations, and government. Through these collaborations, Manitoba Hydro is able to explore a broader range of technologies and evaluate more effectively potential applications for implementation in Manitoba and the Manitoba Hydro system.

Some of the key agencies that Manitoba Hydro is supporting and/or collaborating with include:

- The Manitoba Hydro/Natural Sciences and Engineering Research Council of Canada (NSERC) Alternative Energy Research Chair at the University of Manitoba is Dr. Eric Bibeau. The Chair's objectives are to apply existing mathematical tools, develop models, validate against experimental field measurements, and disseminate the results. The Chair and graduate students have been active in research related to hydrokinetic turbines, bioenergy, icing of generation equipment, electric transportation, and solar energy.

- Red River Community College. Manitoba Hydro has undertaken several solar and electric transportation R&D demonstration projects. At the downtown campus a solar photovoltaic system was installed and at the Notre Dame campus a solar parabolic trough system was installed for evaluation. Red River has also performed a number of plug-in conversions and testing of Provincial fleet vehicles.
- Natural Resources Canada (NRCan). NRCan funds several Manitoba Hydro biomass and energy storage demonstrations through the Clean Energy Fund. Manitoba Hydro provides guidance and comments to several NRCan research activities. NRCan responsibilities include the Canadian Forest Service, Geological Survey of Canada, Electricity Resources Branch, Energy Technology and Programs Sector, Innovation and Energy Technology Sector, and Mineral and Metals Sector.
- The Institute of Electrical and Electronics Engineers (IEEE). IEEE is based in New York, New York and has more than 400,000 members in more than 160 countries. Manitoba Hydro participates in several IEEE standards working groups, such as the "Draft Guide for Electric-Sourced Trans Infrastructure".
- Conseil International des Grands Réseaux Électriques (CIGRÉ). CIGRÉ, based in Paris, France, focuses studies on technical, economic, environmental, and regulatory aspects of the electrical grid. Working groups of experts publish state-of-the-art technology summaries to initiate national and international standards work. Manitoba Hydro participates in several CIGRÉ working groups, such as the "Microgrids Evolution Roadmap".

3 Emerging Energy Technology Drivers

Globally, many drivers such as energy security, innovation, policy, potential impacts of climate change, pollution concerns from use of fossil fuels, as well as public demand for new clean renewable sources of electricity have fostered interest in emerging energy technologies. In some regions, government initiatives such as tax incentives, subsidies, renewable portfolio standards, and carbon credits, have incentivized the development of clean or renewable emerging energy technologies. While the use of these generation technologies has grown exponentially over the last few years and may continue to do so, they currently supply less than 3% of all required energy globally. Such rapid relative growth (largely incited by subsidies and mandatory renewable portfolio standards) may not be sustainable into the future due to factors such as perceived barriers of economics, material demands putting pressure on supply, and competing political agendas such as economic sustainability versus climate change.

In Canada and Manitoba the adoption and integration of these technologies have been significantly less than in the United States due to much lower electricity prices, much lower subsidies, less tax relief, and the availability of other renewable resources such as hydro-electric power.

The adoption of emerging energy technologies as a mainstream energy source, utility-scale or customer-sited, and their integration into systems over time, are expected to continue as installed costs decline; and as these technologies become more competitive and/or political or social influences drive market adoption.

A general description of some key drivers, including renewable energy policies, energy security, and technological advances, as well as a description of the local drivers in Manitoba, is provided in the following sections.

3.1 Renewable Energy Policies

Government policy can play a significant role in the advancement and adoption of emerging energy technologies. Some of the current policies that are in place for renewable energy projects across various jurisdictions are as follows:

- Renewable Portfolio Standards (RPS) – policies recommending or mandating that a province, state, or utility obtain a percentage of electricity from renewable resources.
- Subsidies/incentives which are paid to renewable power producers on a per kilowatt-hour (kWh) generated basis such as:
  - Eco-Energy Renewable Incentive (EERI) for Renewable Power and Renewable Heat – projects had to be commissioned before March 2011. $1.5 billion in incentives to encourage the development of 4,000 MW of new renewable generation in Canada.
  - Feed-In-Tariff (FIT) or Standard Offer Programs. The Province of Ontario offered 11 to 42 cents per kWh for renewable generation.
  - Renewable Energy Credits or Certificates (RECs) – sold or traded as an environmental commodity on the open market.
- Greenhouse Gas (GHG) emission reductions. Canada has made a commitment under the Copenhagen Accord of $1.2 billion in climate change financing to meet a target of reducing GHG emissions by 17% from 2005 levels by 2020.
- Income tax benefit of accelerated depreciation for renewable generating equipment, such as Class 43.1 Accelerated Depreciation, Capital Cost Allowance (CCA), and the Canadian Renewable and Conservation Expenses (CRCE).
- Property tax exemptions for some renewable energy projects.

- Federal and provincial green energy purchase policies. As a commitment to the 2002 Climate Change Plan for Canada, the federal government purchased renewable power from companies such as ENMAX, SaskPower, Maritime Electric, and Energy Ottawa.
- Incentives to promote the study of early adoption. To advance Canadian leadership in clean energy technologies the Clean Energy Fund is providing nearly $795 million to support research, development, and demonstration projects.

Policy and incentives for renewable technologies are common in areas of Europe and several US jurisdictions.

3.2 Energy Security

Energy security is the balancing of human survival and the availability of resources for consumption. The distribution of energy resources is not evenly balanced throughout the world, leading to vulnerabilities in supply in certain areas. Energy shortages have the ability to impact every aspect of society from transportation, and food production, to the health of the economy. As the worldwide need for energy continues to grow with the growing world population, increased competition for energy resources creates the potential for increased commodity price volatility.

A resource peak occurs when the maximum output flow rate of that particular resource is reached. Finite resources must eventually become exhausted if continuously consumed, no matter what the consumption rate. Replacement resources will need to be implemented if existing resources are exhausted. The notion that technology advancements will trump resource limits is prevalent in society.

3.3 Technological Advances

Technological advancements have the potential to introduce new energy technologies and increase the attractiveness of existing technologies.

For example, there have been numerous announcements and demonstrations from research laboratories related to technological advances, such as generation efficiency improvements, using nano-based materials. Nano technology means building new materials at the atomic level. Commercialization of nano-based materials is dependent on the large-scale manufacturing of materials on the atomic level, a technological feat that has yet to be achieved.

Improved efficiencies can potentially result by choosing different components, or by redesigning a system and utilizing new technologies. Such improvements could reduce waste or reduce wasted energy. Cogeneration, or combined heat and power, where both electricity and heat are generated simultaneously for use, would be another example of improved efficiency.

Additionally, for emerging intermittent renewables to become cost competitive with more traditional energy sources such as fossil fuels, nuclear, and hydro resources—outside of niche applications— will require the coupling of three elements: lower capital costs, energy portfolio diversification, and some form of energy storage.

3.4 Local Drivers in Manitoba

There are a number of drivers within Manitoba related to the adoption and advancement of emerging energy technologies. Some of these include:

- Manitoba Hydro promotes a number of energy conservation and Power Smart Programs, which includes efficiency improvements, rebates, and financing options, which can influence the adoption of new technologies.

- In August of 2008, Manitoba Hydro announced a new Bio-Energy Optimization Plan aimed to assist customers with reducing electricity purchases, fossil fuel purchases, and traditional waste disposal costs by converting biomass waste and by-products into fuel that produces useful heat and power. In addition to biomass, other renewable generation, such as from solar and wind could also qualify depending on certain scoring criteria (i.e. capacity factor, performance, risk). The plan offers incentives to qualifying customers to help offset project evaluation costs and the capital investment required to install a biomass-to-energy conversion system, other renewable systems, as well as assisting technical support.

- Manitoba Hydro has a Non Utility Generation (NUG) policy which sets the price for power purchases of less than 200 kW in size to the maximum Standard Residential Run-off Rate. Non utility generation can also be a cogeneration facility, which has a primary purpose of producing steam for industrial processes or heating, or it can be a stand-alone electricity generator. NUG power produced by a customer that is not surplus to the customer's needs is considered load displacement.

- The Province of Manitoba's emissions tax on coal came into effect in 2012, requiring anyone in Manitoba who purchases more than a tonne of coal to pay a tax ranging from $14.27 to $23.97 per tonne, depending on the type of coal.

- The provincial government's eight-year strategic plan, Tomorrow Now – Manitoba's Green Plan, highlights that "Manitoba's goal is to be one of the most sustainable places to live on earth". The five key priorities are entitled: Good for our economy good for our environment; changing our ways for a changing climate; safeguarding our water, air, and land; nurturing our living world; and simple personal choices big results.

4 Technologies

This section provides an overview of a number of emerging energy technologies including wind, bio-energy, nuclear, solar photovoltaic, solar thermal, energy storage, hydrokinetic and enhanced geothermal. Each technology is in a different stage of maturity; some are commercially available, while others are still in the research and development phase. Consideration has been given by Manitoba Hydro to both utility-scale and customer-sited load displacement generation, as scale and site may present favourably for some specific applications.

Table 2 presents the current range of installed and per-unit energy costs for various technologies and indicates the current or expected direction of changes in these costs into the future. While not discussed in this review, hydroelectric is included for comparison.

Table 2. Comparison of Installed capital cost and per unit energy costs based on utility scale generation in Manitoba

Technology	Installed Costs $/kW	Energy Costs $/MWh	Trend
Energy Storage	300 - 11,000	10 - 360	↓
Solar Photovoltaic	3,700 - 5,000	190 - 200	↓
Wind	1,600 - 7,600	60 - 210	↓
Biomass	2,000 - 5,800	100 - 150	↔
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Hydrokinetic	7,000 - 9,500	160 - 620	↑
Nuclear	3,500 - 7,000	80 - 120	↑

The following sections are structured to provide a brief description of the technology and current status, to present current trends in pricing and development, and to identify the potential for implementation of the technology in Manitoba.

4.1 Wind Power

4.1.1 Current Status

As of mid 2012, the global capacity of wind power installations has grown to nearly 250,000 MW. Currently, China is the world leader in installed wind power with over 62,000 MW, followed by the USA with just over 48,000 MW. Canada's wind power generation was just over 6,500 MW.

Wind power is closer to becoming economic to mainstream energy sources than most other renewable energy resources. Most modern three-bladed turbines (1 to 3 MW) can achieve 39 to 42% efficiency. New revolutionary models have demonstrated the potential to achieve efficiencies in the 50% range, with the theoretical maximum approximately 59%.

Power is directly proportional to the swept area of the turbine rotor: a doubling in blade length would theoretically correspond to a quadrupling in power output. Additionally, the output power is extremely sensitive to the wind speed, which generally increases with hub height because of reduced friction from the earth's surface. As a result of the swept area and wind speed relations to output power, the general design trend of wind turbines is to increase the blade length and tower height. Logistical constraints of lifting and transporting components may ultimately limit the future evolution and advancement of land-based turbine designs.

Wind speed is the most important component affecting wind energy cost since power is proportional to the velocity cubed. Therefore, it is desirable to site a wind project where the average annual wind speed is as consistently high as possible, such that the largest amount of energy can be produced.

Currently, the limited ability to forecast wind accurately beyond a few hours into the future creates operational challenges. Improving the ability to forecast would greatly increase the effectiveness to wind resource could be incorporated into the integrated system.

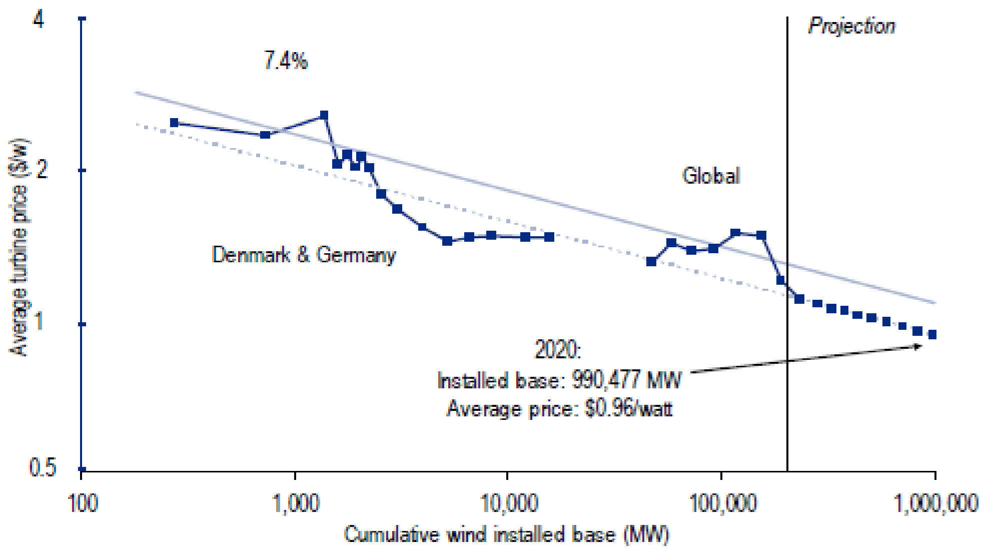
4.1.2 Trends

Efforts to improve the ability to forecast wind more accurately and to reduce the overall per-unit cost of energy cost through innovative designs and efficiency improvements are expected to increase the attractiveness of wind energy technologies over the next two decades.

Wind forecasting relies upon numerical weather prediction models, and improvements beyond the 12-hour forecast horizon depend on improving models. Statistical correction techniques provide the greatest opportunity to improve sub 12-hour forecast horizons. Growing trends include incorporating more regional and local weather data, remotely sensed sonar wind speed data, satellite weather data, and greater data resolution from hourly to minute intervals. Efforts are also being made to improve models through the use of computational learning systems, or advanced artificial intelligence methods.

Currently, there is a downward trend in turbine pricing as shown in Figure 1. The trend is driven by combination of factors, including technology improvements, utilities installing significant amounts of wind generation to meet government mandates, and overcapacity in the market largely to increased manufacturing in China.

Figure 1. Wind Turbine Trends Projected from 1972[1]



The levelized cost of energy (LCOE) of wind power is anticipated to continue to decline, at least on a global basis and within the fixed-wind resource class. Performance improvements associated with larger wind turbines and design advancements are expected to lower capital costs. An International Energy Agency (IEA) analysis projects a cost reduction in LCOE of about 20% to 30% by 2030 (based on $2011).[2] Cost of energy reductions are generally expected to be greater in the early years and then slow over time. Initial cost reductions range from 1% to 6% per year. By 2030, all but one study envisions cost reductions falling below 1% per year.

While wind power is regarded as commercially mature with a high confidence in cost, several technological improvements are still possible in regards to reducing the capital and O&M costs. Approximately 75% of the capital cost can be attributed to the wind turbine structure such as the blades, generator and tower components. Therefore, these areas present the greatest potential for capital cost reduction. However, the levelized

[1] CITI Research, Shale & Renewables: A Symbiotic Relationship, September 2012.

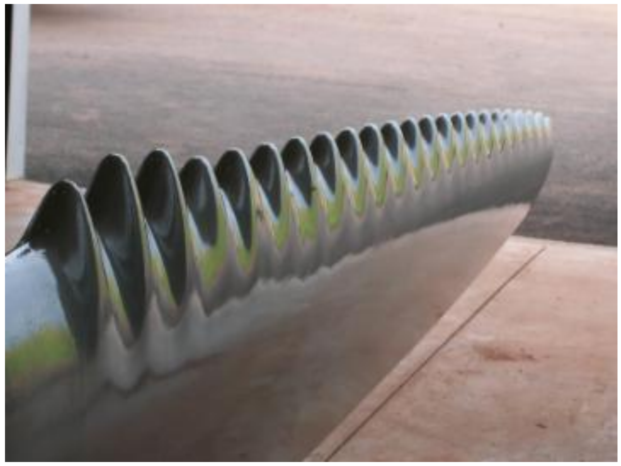
[2] IEA Wind Task 26 “The Past and Future Cost of Wind Energy”.

cost of energy is heavily tied to several commodities such as copper, petroleum-based resins, and rare earth elements, which are primarily produced by foreign economies.

Innovative Wind Turbine Generator (WTG) designs include gearless systems, in which the turbine rotor is directly linked to a low-speed direct drive generator. Gearbox failures account for approximately 7% of all component-related failures. Therefore, with the implementation of gearless systems, the expensive capital and maintenance cost of gearboxes can be eliminated. Advanced tower designs offer the potential for additional capital cost reduction. Hybrid towers are currently under development in which a significant portion of the tower section consists of pre-stressed concrete components. This could potentially reduce tower material costs, as well as the associated transportation costs required to move the tower to site.

The LCOE from wind power projects may be reduced by increasing the efficiency and improving operation of the system. Continued development of advanced sensing systems allow for more active control of rotor blades when a wind gust is sensed several hundred metres away. In addition, advanced developments in reinforced composites are allowing for the construction of longer and more aerodynamically efficient rotor blades. Rotor blades that mimic the serrated profile of humpback whale flippers, shown in Figure 2, can be adjusted to much steeper angles for improved performance where conventional blades would stall aerodynamically.

Figure 2. WHALEPOWER'S HUMPBACK INSPIRED TUBERCLE TECHNOLOGY[3]



General Electric (GE) is investigating a World War 1 era concept of using fabrics to reduce weight, applying it to wind turbine blades with the potential of reducing blade costs up to 40%. The blades could also be assembled on site, eliminating constraints related to manufacturing, assembly, and transportation.[4]

GE also offers a wind turbine with battery energy storage, providing the option of addressing short-term (15 to 60 minutes) mitigation of ramping, power peaks, and frequency regulation.

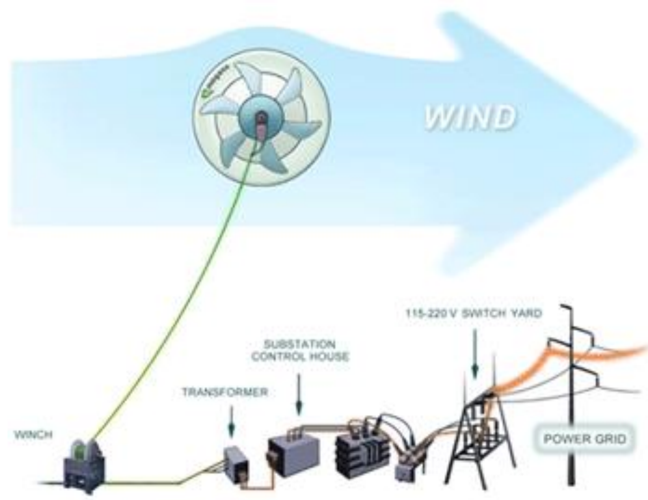
A number of companies are exploring the practicality of harnessing wind power from high altitudes that exceed a few hundred metres. Due to the reduced drag of the surface of the earth, average wind speed can reach up to 20 m/s, which results in a much higher energy density per unit area than conventional wind power at lower elevations. Magenn Power Inc. has developed an inflatable air rotor that can harness winds at altitudes of up to 300 m, and operate in wind speeds between 3 and 28 m/s, illustrated in Figure 3.

[3] Canadian Manufacturing, Whale of an Idea, November 2010.

[4] General Electric, GE Developing Wind Blades That Could Be the "Fabric" of our Clean Energy Future, November 2012.

Aerodynamically the rotor functions in a similar fashion as a cross-flow hydro-electric turbine and drives two generators that are attached on either side. The power generated is then transmitted to a transformer on the ground via a 300 m tether.

Figure 3. MAGENN AIR ROTOR SYSTEM FOR HARNESSING HIGH ALTITUDE WIND[5]



Additional advantages over conventional turbines include a reduced impact on bats and birds, fewer placement limitations, and potential capacity factors of up to 60%.[5] However, further development is still required to increase the capacity of units.

4.1.3 Manitoba Potential

Currently, the wind farms of St. Josephs and St. Leon are in operation in southern Manitoba and each has a Power Purchase Agreement (PPA) with Manitoba Hydro.

Wind generation is an intermittent resource with both seasonal and diurnal variability, typically producing more energy during off-peak periods, and has virtually no dependable capacity. As a result, some form of energy storage is required to provide firm capacity and dispatchability. In Manitoba Hydro's predominantly hydraulic system, utilizing hydro reservoirs to store wind generation or to time shift wind generation towards peak

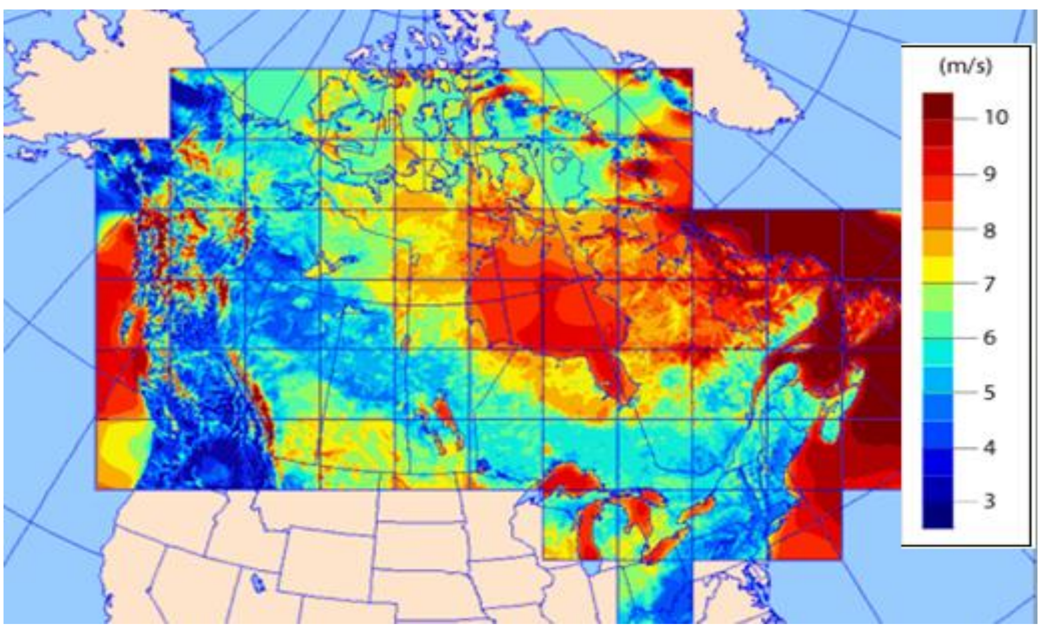
[5] Jason Colab, Magenn Wind Power Anywhere, Magenn Power Inc., 2010.

demand, comes with a cost against other possible revenue options available to hydro generation. Measures such as improved wind forecasting, wind ramp-up predictability, and sub-hourly scheduling can reduce associated integration costs for additional wind capacity.

There is a large potential wind resource of several GWs in Manitoba, with the best sites located in the southern edge of Manitoba, and in northern Manitoba near Hudson Bay. Potentially the wind resource over large open bodies of water also looks attractive, but the practicality of designing structures to survive ice movement remains a challenge.

Figure 4 shows a map of the Canadian wind resource, with average annual wind speeds at an 80 m height.

Figure 4. CANADA WIND RESOURCE AT 80 M HEIGHT[6]



[6] Canadian Wind Energy Atlas.

4.2 Biomass Energy

4.2.1 Current Status

Utilization of biomass as an energy source has been practiced for many thousands of years. Due to the resource's potentially sustainable nature, biomass energy for utility-scale generation has gained renewed interest in recent decades. Worldwide there is over 65,000 MW of installed capacity. Biomass is different from other renewable energy sources, such as wind and solar, as it is dispatchable but produces air emissions from combustion, and requires that a constant supply of fuel be collected and concentrated at a specific location. In the long term, bioenergy is a potential competitor to generation options in Manitoba. However, the cost to collect and process the biomass fuel is a limiting factor. Sources of biomass considered for use as fuel include crop residuals, forestry residuals, timber, animal wastes, and municipal solid waste.

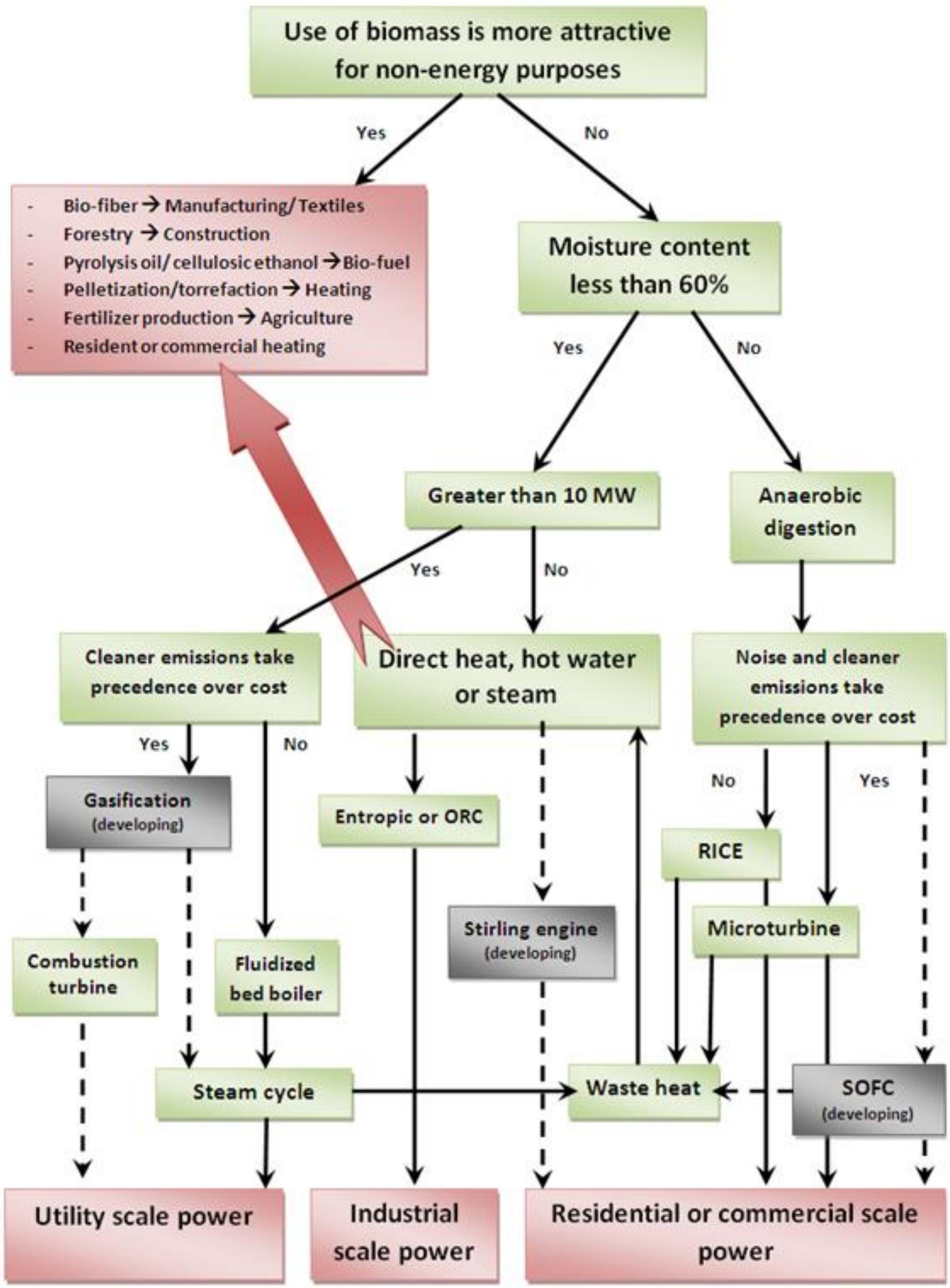
Conversion of biomass to electricity can be performed through a variety of technologies. Thermal combustion (e.g. steam-driven turbines) is the most mature electricity generation technology and is used in thermal power plants around the world. Thermo-chemical processes (e.g. gasification, torrefaction, and pyrolysis) are a less mature technology and generally focus on increasing the energy density of the biomass for transport. Finally, bio-chemical decomposition (e.g. anaerobic digestion) is useful for breaking down high moisture biomass into combustible biogas in systems called digesters.

A key factor affecting the sustainability of biomass generation is biomass availability and transportation to and storage or management at site. Crop residuals are baled using common farm equipment and can be easily transported to the generator, at which point partial or complete weather-proof storage facilities are required for long-term storage. Forestry residuals can be chipped or baled at source and transported with harvested timber. Using logs properly stored on site can reduce moisture content by up to 30%.

Ash generated from combustion of biomass can be disposed of in landfills, or potentially used as fertilizer or in industrial processes. Animal waste is often collected with straw from barns using conventional farm equipment and transported to site. On hog and dairy farms, manure is generally liquefied for easy gravity flow and pumped to storage tanks or into lagoons for holding.

Figure 5 illustrates a conversion technology decision path for biomass resources.

Figure 5. CONVERSION TECHNOLOGY DECISION PATHS FOR BIOMASS. ORC-ORGANIC RANKINE CYCLE, RICE-ROTATING INTERNAL COMBUSTION ENGINE, SOFC-SOLID OXIDE FUEL CELL



Currently, the magnitude of potential competition for biomass is largely unknown. Bio-fuel manufacturers, who produce cellulosic ethanol, consume considerable quantities of biomass in regions where they operate. Cellulosic ethanol is produced from non-edible parts of plants for which crop residuals and forestry biomass are highly suitable. Therefore, the bio-fuel industry may represent considerable competition to a biomass energy industry. Additionally, the bio-fibre industry has grown significantly in Manitoba in recent years and could potentially represent another major competitor to the development of biomass energy. However, poultry litter, animal manure and municipal solid wastes currently have no such competition.

4.2.2 Trends

Use of dedicated energy crops is a growing trend that explores the potential for crops, such as switchgrass, willow, and algae, to serve as biomass feedstock. Some researchers are studying the potential to increase unproductive or marginally productive land with energy crops and studying the environmental benefits of certain crops like cattails to remove excess nutrients from agricultural run offs to local waterways. Developing practical harvesting methods and equipment for energy crops is ongoing.

Energy crops are a form of biomass cultivated for the explicit purpose of energy or fuel production. Perennial grasses, woody crops, cattails and algae are the primary types of energy crops which are present in most of North America. Table 3 below illustrates the major energy crops and their expected advantages and disadvantages.

Table 3. Major energy crops and advantages/disadvantages of application in Manitoba[7]

	Type of Crop	Average Yield (tonnes/hectare)	Advantage / Disadvantages
Traditional Crops	Wheat Straw	1.8 to 2.4	Significant experience exists in collection of crops. Little room expansion in volume of production.
	Corn Stover	5.1	
	Flax Straw	1.2	
Perennial Crops	Switchgrass	3.9 to 20.7	Significant opportunities for growth in Manitoba climate. However, harvesting equipment is not locally available
	Miscanthus	6.3 to 48.3	
Woody Crops	Willow	7 to 10	
	Poplar	7 to 10	
Cattail	Cattails stock	14.7	Abundant, but difficult to harvest
Algae	Algae organisms	144 to 240	High energy yield per hectare. Extended winter prohibiting factor in Manitoba

While energy crops can produce significantly higher energy densities per hectare of land than traditional agricultural crops, dedicated energy crops are subject to the same seasonal and weather influences. Currently there is no established biomass generation industry in Manitoba and the potential for the adoption of energy crops in the future is uncertain.

In some parts of the world, there is an increasing interest in utilizing algae as a "fuel source" for heat, electricity, and other liquid fuels, since algae is renewable and replicates quickly. Algae can be harvested using a variety of techniques, including filtration screening and straining, sedimentation, flotation, and centrifugation. One group undertaking research in this area is the National Alliance for Advanced Biofuels and Bioproducts (NAABB), a consortium of universities, industry, and government.

As shown in Table 4, algae have the potential to produce significantly more energy per acre than traditional crops such as corn, canola, or soybean.

[7] Richard E. Grosshans, Cattail Biomass Harvesting in Manitoba, University of Manitoba, March 2011.

Table 4. OIL PRODUCTION OF VARIOUS SPECIES[7]

Feedstock	Yield (US Gallons of Oil/Acre/Yr)
Wheat	6-8
Corn	18
Soybeans	48
Safflower	83
Sunflower	102
Rapeseed (Canola)	127
Palm Oil	635
Micro-algae (Open Pond)	5,000-15,000

Despite the huge potential for algae to become a key fuel and energy feedstock in the future, major technical and economic barriers remain to large scale production of algae, which include:

- Invasive species risk (minimize cross-species contamination)
- Economics (need for the development of low-cost algae harvesting and dewatering techniques)
- Optimizing strain types for energy yield (certain strains are better for certain fuel types)
- Requires warm climates for continuous outdoor growth (minimum 17.8°C annual average) which includes areas such as the Southern portions of Florida, California, Texas, Arizona, Louisiana, Alabama, Georgia, South Carolina, Mississippi, and Hawaii.

4.2.3 Manitoba Potential

The greatest potential for biomass resources in Manitoba in the near term may be in displacing or managing waste streams in industrial processes or on farm operations, with electricity production another revenue option for Combined Heat and Power (CHP) applications.

Manitoba Hydro's bioenergy optimization program has a number of demonstration projects underway to implement 100 kW systems utilizing thermal chemical processes (pyrolysis oil, syngas, biochar) and bio chemical decomposition (biogas).

Landfill gas opportunities at the Brandon and Brady Road landfills are currently the only active landfills in Manitoba suitable for limited power generation opportunities. It is estimated that 8 MW of electricity and heat could be generated at a capacity factor in excess of 80%. Brady Road landfill near Winnipeg would constitute over 80% of this potential. Landfill gas collection can be performed with efficiencies of up to 70%. By flaring excess landfill gas, methane emissions in Manitoba could be reduced by 13,000 tonnes annually. In addition, odour within a few hundred metres of these sites would be largely reduced.

The environmental benefits of converting biomass into power include the enrichment of fertilizer properties after combustion, the elimination of pathogens and undesirable microorganisms through digestion, and the reduction of methane emissions into the atmosphere by landfill gas capture.

While the carbon dioxide produced from biomass combustion is eventually recaptured by plants, the harvest, collection and transportation systems rely almost completely on fossil fuels. Additional biomass combustion requires similar emissions mitigation systems as coal power plants as other hazardous air pollutants are released during combustion.[8]

[8] Thomas Walker, Biomass Sustainability and Carbon Policy Study, Manomet Center for Conservation Sciences, June 2010.

The majority of easily accessible biomass resources in Manitoba consist of agricultural residuals, forestry biomass, and animal and municipal solid wastes. The total potential of accessible biomass energy resources in Manitoba is estimated to be 4,800 GWh of electricity annually with a capacity of 630 MW, summarized in Table 5.

Table 5. MAXIMUM POTENTIAL BIOMASS RESOURCES IN MANITOBA

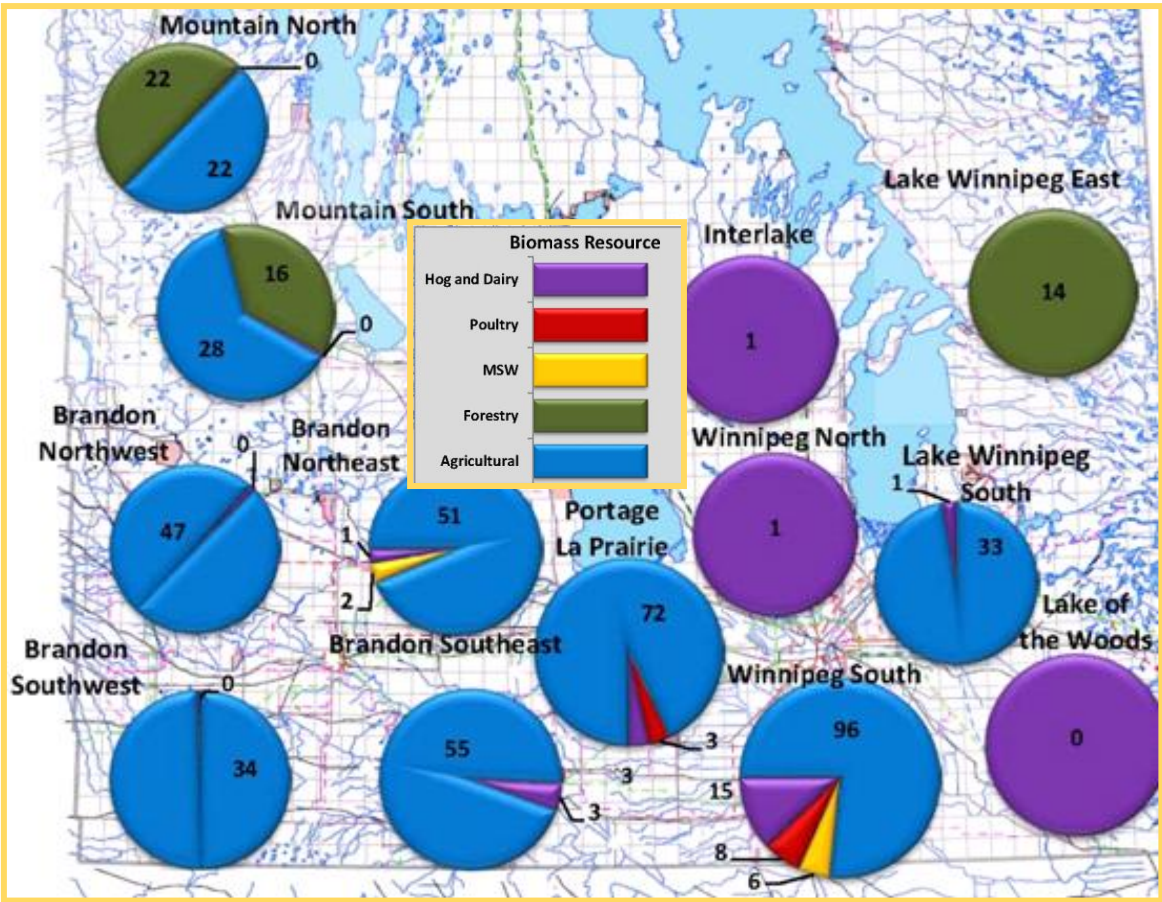
Type of Biomass	Maximum Potential		Fuel Cost ($/tonne)
	MW	GWh/yr	
Crop Residuals	495.0	3799	~65
Forestry Biomass	93.3	695	50 to 90
Hog & Dairy Manure	25.9	216	none
Poultry Litter	10.6	79	<20
MSW at Landfills	8.4	79	none
Total	633.20	4,868	

Biomass resources in Manitoba are widely distributed: approximately 40% of the biomass resources are located within 100 km of Winnipeg. The Manitoba Bio Energy potential is shown below in Figure 6, where each circle represents a 50 km radius and the value (s) in the circle indicates the potential in megawatt equivalents (MWe) for a particular resource (s).

Crop residuals represent almost 80% of the biomass energy potential and are located in the southern agricultural areas of the province—the highest concentration would be between Winnipeg and the US border. Forestry biomass represents approximately 14% of the total potential. The highest concentration exists around the Duck Mountain area (northwest of Dauphin). Over 70% of poultry litter is located within a 30-km radius of Steinbach; the remaining resources are near Portage La Prairie and southeast of Brandon. 60% of hog and dairy manure is located south of Winnipeg in the surrounding farms of

Steinbach and Morris. It is important to note that the distribution of resources was based on input from Rural Municipalities that meet a reporting threshold of having more than 100 dairy cows and greater than 1,900 hogs.

Figure 6. BIOMASS POTENTIAL IN MANITOBA BY RESOURCE AND GENERAL LOCATION (MWE)



It should be noted that biomass generation sized to individual farming or agricultural operations would likely be less than 5 MW of installed capacity, resulting in a levelized cost of electricity that would exceed utility scale energy costs.

4.3 Nuclear Power

4.3.1 Current Status

In 2012 over 370,000 MW of nuclear power was generated in 436 reactors worldwide, which constitute 13 to 14% of the world's electricity supply. Currently, 19 Canada Deuterium Uranium (CANDU) reactors are in operation in Canada, primarily in Ontario, and supply 15% of Canada's electricity, representing 13,553 MW with individual unit capacities ranging from 515 to 881 MW. Globally, unit sizes from 800 to 1,500 MW are typically being built today. Worldwide there are currently over 40 new nuclear plants under construction in 12 countries, which will add over 71,000 MW of new nuclear capacity.[9]

Nuclear power is far less sensitive to varying market fuel prices in comparison to other thermal plants fueled by coal, gas or biomass. This low sensitivity is due to the high energy density of uranium, which produces on average 40 GWh of electricity in power plants from 1 tonne of uranium, whereas an equivalent amount of energy would require over 18,000 tonnes of coal.

Nuclear power has been used to generate dependable and affordable utility scale power since the mid 1950s. However, nuclear power has drawn considerable public controversy over the past three decades in regards to radioactive waste management and perceived public safety issues. The Canadian-developed CANDU reactors have proven to be a safe, affordable, emissions-free source of baseload power since the 1960s and have been endorsed by the Canadian Nuclear Safety Commission (CNSC) in a post Fukushima incident market. Another major advantage of the CANDU reactor design is its fuel flexibility. CANDU reactors are capable of using both natural and enriched uranium. The

[9] World Nuclear Association

advantage of natural uranium is that it requires far less processing than enriched uranium and is effectively proliferation resistant. Additionally, CANDU reactors are capable of using spent fuel rods from other reactors which aids in the reduction of nuclear waste.

The concept of describing reactor designs by "generations" was proposed by the US Department of Energy as follows:

Generation I: "Gen I" reactors are the early prototypes, research reactors, and non-commercial reactors.

Generation II: "Gen II' reactors are the commercial reactors built from the 1960s up to the end of the 1990s which include the Pressurized Water Reactor (PWR), CANDU, Boiling Water Reactor (BWR), Advanced Gas-cooled Reactor (AGR), and the Vodo Vodyanoi Energetichesky Reactor (VVER).

Generation III: "Gen III" reactors are the development of Generation II designs which include evolutionary improvements such as fuel technology, thermal efficiency, and passive safety systems. Designs less than 300 MW are anticipated to be ready between 2020 and 2030.

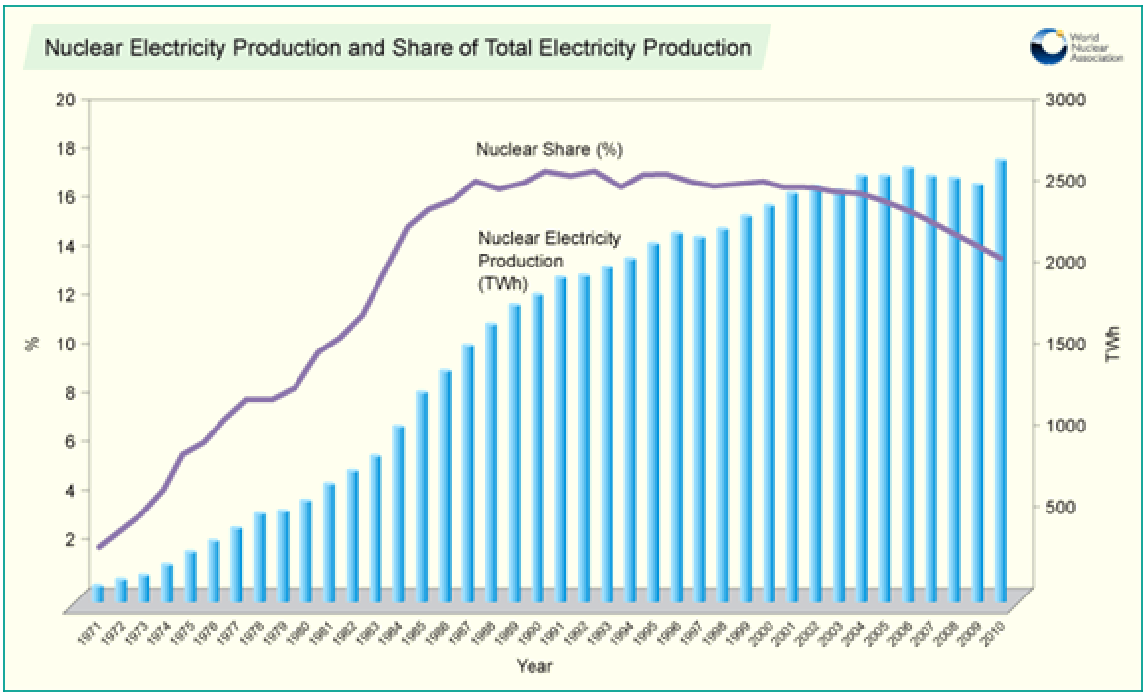
Generation IV: "Gen IV" reactors are designs currently being researched and not expected to be available commercially until after 2030, which include Very High Temperature Reactor (VHTR), Supercritical Water-cooled Reactor (SCWR), Molten Salt Reactor (MSR), Gas-cooled Fast Reactor (GFR), Sodium-cooled Fast Reactor (SFR), and Lead-cooled Fast Reactor (LFR).

Generation V: "Gen V" reactors are designs which are theoretically possible and include liquid core, gas core, fission fragment, and fusion reactors.

4.3.2 Trends

The nuclear power fleet greatly expanded during the 1970s and 1980s; however, this growth was tempered by events in 1979 and 1986: the Three Mile Island and Chernobyl reactor failures. The Chernobyl meltdown resulted in more worldwide aggressive safety measures, which further increased the capital costs associated with nuclear power plant construction. Since the mid 1980s, the portion of nuclear power as a part of total world electricity supply has decreased, illustrated in Figure 7.

Figure 7. NUCLEAR SHARE OF ELECTRICITY GENERATED IN THE WORLD SINCE 1971 [10]



In some parts of the world, strong public opposition currently exists against nuclear power following the Fukushima Dai-ichi meltdowns in 2011. Prior to 2011 Japan went from having 30% of electricity provided by nuclear generation to shutting down 52 reactors (51,914 MW) for safety checks; with an uncertain future, only two units are still

[10] Nuclear Power in the World Today, World Nuclear Association, April 2012.

in operation (2,360 MW). Recently five Japanese companies have submitted applications to restart 12 reactors. In Germany, strong opposition has influenced the government to mandate an exit from nuclear power by 2022, shutting down over 20,000 MW beginning in 2011. In contrast, almost 80% of electricity in France is currently produced from nuclear generation or approximately 65,000 MW. France also has one of the lower electricity costs in the European Union.

In February of 2012 the Nuclear Regulatory Commission (NRC) in the U.S. issued construction and operating licences for two new nuclear reactors (1,117 MW each) that will be operated by the utility Southern Company.[11] These will be the first nuclear reactors commissioned in the U.S. in approximately 30 years. Nuclear power is now being promoted as being the clean, secure, reliable, and affordable way of meeting America's growing energy needs.[12]

Since nuclear power is a non-renewable resource, long-term use is dependent on the availability of uranium fuel. At the current rate of consumption and pricing, over 100 years of currently known uranium reserves are reasonably assured, with additional potential in identified reserves. Any substitution of energy sources by nuclear power would accelerate exhaustion of these uranium fuel reserves.

Another potential nuclear fuel is thorium. Thorium is a fissionable material three to four times more abundant than uranium.[13] According to the U.S. Geological Survey, some of the largest thorium reserves are present in Australia, India, the U.S. and Canada.[14] Thorium was used in several experimental reactors during the 1970s, but has not yet been commercially introduced on its own. Since thorium reacts slower than uranium, a

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[11] Nuclear Energy Milestones, Southern Company, 2012.

[12] Nuclear Energy, The Next Generation, Southern Company, 2012.

[13] Thorium fuel cycle - Potential benefits and challenges, International Atomic Energy Agency, May 2005.

[14] Thorium, US Geological Survey, January 2007.

major challenge of a stand-alone thorium reactor is attaining a self-sustaining reaction. Other major advantages of thorium nuclear fuel are that it is intrinsically proliferation-resistant and has better thermophysical properties that would simplify reactor designs. Additionally, the use of thorium would result in 30 times less radiotoxic waste that is also simpler to handle than spent uranium fuel.

Small Modular Reactor (SMR) designs being explored by numerous companies are considered Gen III technologies that are essentially smaller-capacity versions of modern reactors (less than 300 MW in size). SMRs present the opportunity for reduced costs because they can be manufactured off-site and then shipped and assembled on site, which in turn reduces the construction time and costs of a nuclear power station. Not including design and licensing, it is estimated that a SMR power plant could potentially be constructed, following approvals, within two to three years rather than six to eight years required for a conventional reactor. Additionally, a power plant consisting of series of SMRs could be expanded with the addition of more SMRs over the plant's lifespan in order to more closely follow load growth. Furthermore, SMRs could also be integrated into an existing utility system more readily than conventional nuclear power units, which commonly exceed 1,000 MW in size. The projected timelines of SMRs generally range from 2025 to 2030; however, there is currently one plan in place to achieve an operational date for an SMR by 2022 at Tennessee Valley Authority's Clinch River site.[15]

Fast-reactor technologies have been demonstrated at small scales.[16] It is estimated that fast reactors could extend conventional known uranium reserves by a factor of 60 to 100, which would extend the usage of uranium fuels for a few hundred years based at current generation. Alternatively, the Nuclear Energy Agency in the U.S. theorizes that fast

[15] Marcum, Ed, TVA, B&W poised to put small modular reactors to the test, Knoxville News, April 2013.

[16] Fast Reactor Technology: A Path to Long-Term Energy Sustainability, American Nuclear Society, November 2005.

reactors could potentially extend this usage to over 3,000 years and beyond by using unconventional uranium reserves contained in seawater.[17] Of the six reactor types classified under Gen IV technology, very high temperature reactors and sodium fast reactors have been receiving the most research and development funding. These choices are primarily based on maturity and mitigation of waste disposal. However, Gen IV technologies still require significant development as they are currently not economically competitive.

Nuclear fusion reactions are currently known to be responsible for the energy produced inside the sun and stars throughout the universe. Developments are taking place around the world in an attempt to develop nuclear fusion reactors for power generation. Experimental fusion reactors have been built and have sustained fusion reactions from deuterium and tritium fuels for durations measured in seconds. In such fusion reactions, the nuclei of deuterium and tritium atoms fuse at incredibly high temperatures to produce large amounts of heat and electromagnetic energy with helium as a waste product. This energy can be used to produce steam for a turbine, such as in conventional thermal plants.

In 2007, the nations of the EU, India, Russia, China, South Korea, Japan and the U.S. signed an agreement to construct the International Thermonuclear Experimental Reactor (ITER), the world's largest experimental fusion reactor in Cadarache, France. ITER is a billion-dollar project designed to produce 500 MW for a duration of 1,000 s, which would consume about 0.5 g of deuterium-tritium fuel in the process. Construction of the facility has progressed and ITER is expected to be operational for experiments by 2020. Since the deuterium-tritium fusion reaction requires an operating temperature of about 40 million degrees Celsius, current technical challenges include heating and confinement of the thermonuclear plasma. Currently, the most successful demonstration of fusion for

[17] C. Tam, Technology Roadmap Nuclear Energy, Nuclear Energy Agency, International Energy Agency, 2010.

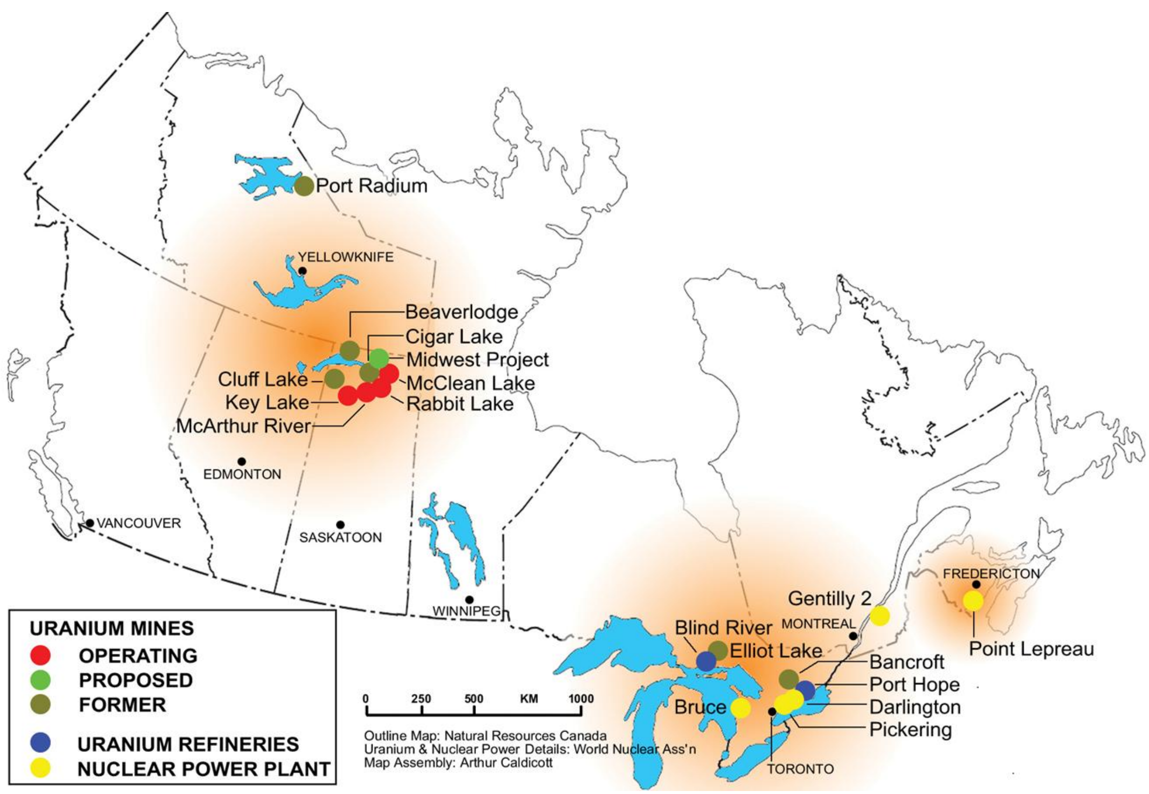
several seconds has been completed by a Tokamak reactor with a capacity of 16 MW. It is estimated that this technology will not be economical for a few decades.[18]

Advanced nuclear power technologies are currently emerging and present the potential for improved fuel flexibility, efficiency, waste reduction, and energy sustainability.

4.3.3 Manitoba Potential

Canada is one of the largest producers of uranium in the world, with known resources estimated at 572,000 tonnes. The largest uranium mine in the world is McArthur River, located in northern Saskatchewan, as shown in Figure 8. No potential uranium reserves have been identified in Manitoba at this time.

Figure 8. URANIUM IN CANADA[19]

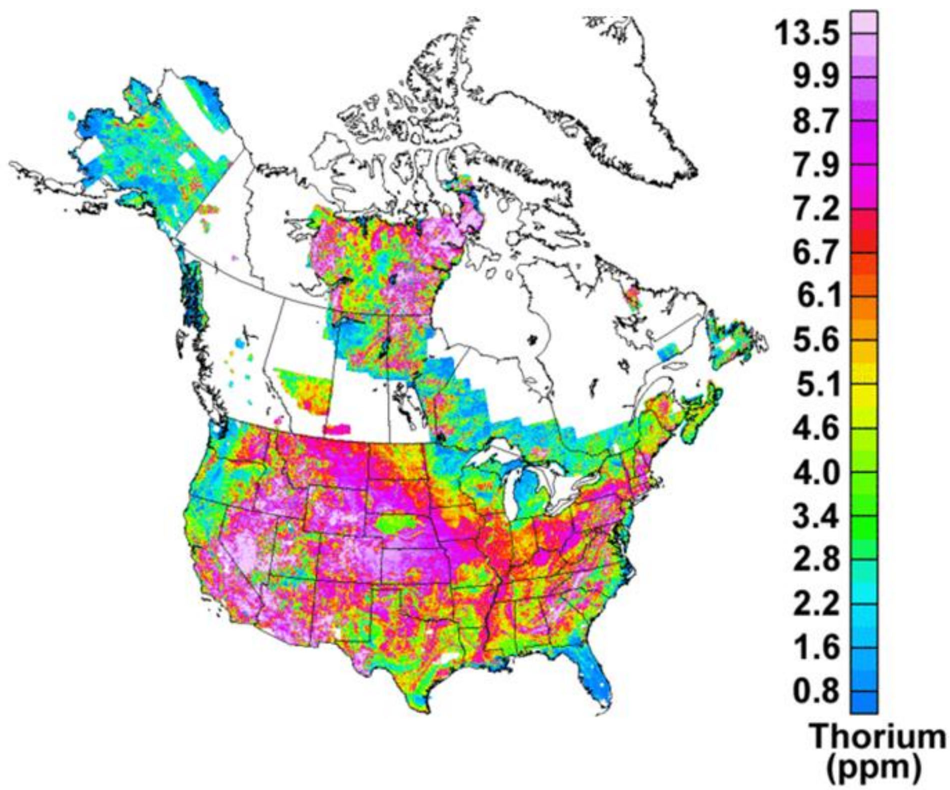


[18] P. K. Kaw, Fusion Energy using Tokamaks, Institute for Plasma Research, 2002.

[19] Tilman, On the Yellowcake Trail: History of Uranium Mining in Canada, Watershed Sentinel, July 2009

Thorium, a potential alternative to uranium, has worldwide reserves estimated at 5,385,000 tonnes, with the US at 434,000 tonnes, and Canada at 172,000 tonnes, shown in Figure 9. The most promising thorium resources in Canada appear in the territories and northern Manitoba.

Figure 9.THORIUM CONCENTRATIONS[20]



Technically, nuclear power plants are very similar to conventional thermal plants in regard to converting thermal energy to electricity. The night-time load trough in Manitoba typically varies from 600 to 900 MW, depending on the season. Incorporating large thermal baseload generation greater than 600 MW to the existing Manitoba system would be challenging.

[20] US Geological Survey 2005.

Siting a nuclear plant in Manitoba has some potential advantages, as Manitoba has the lowest provincial seismic hazards in Canada[21], and there is the potential for storing used nuclear fuel in the Canadian Shield region.

Atomic Energy of Canada Ltd (AECL) is decommissioning the Whiteshell Laboratories in Manitoba that operated from 1961 to 1997, where the development of underground dry storage containment facilities for used nuclear fuel was pioneered.

The town of Pinawa, Manitoba, has been promoting the development of a $6 billion (2007 $) nuclear power plant on the site of the AECL Whiteshell Laboratories[22].

4.4 Solar Photovoltaic Power

4.4.1 Current Status

There is currently more than 70,000 MW of solar photovoltaics (PV) installed worldwide. On a daily basis solar photovoltaics are considered intermittent resource options, being more variable than wind generation, but do offer some correlation to daily system peak electrical load. It is estimated that the upper atmosphere of the earth receives about 1,370 Watts of solar radiation per square meter, which can fluctuate slightly from year to year. The amount of solar radiation depends on time of day, geographical location, and cloud cover.

Due to low conversion efficiencies, and low capacity factor, solar photovoltaics are currently one of the most expensive renewable power technologies at a utility scale presently available. However, costs and efficiencies have both been improving rapidly,

[21] Greg Rzentkowski, CNSC Fukushima Task Force Report, Canadian Nuclear Safety Commission, October 2011.

[22] CBCNEWS, Manitoba should consider nuclear power: Pinawa mayor, December 2007.

partly driven by the US Department of Energy (DOE) funding efforts to reach grid parity by 2020 with the Sun Shot program.

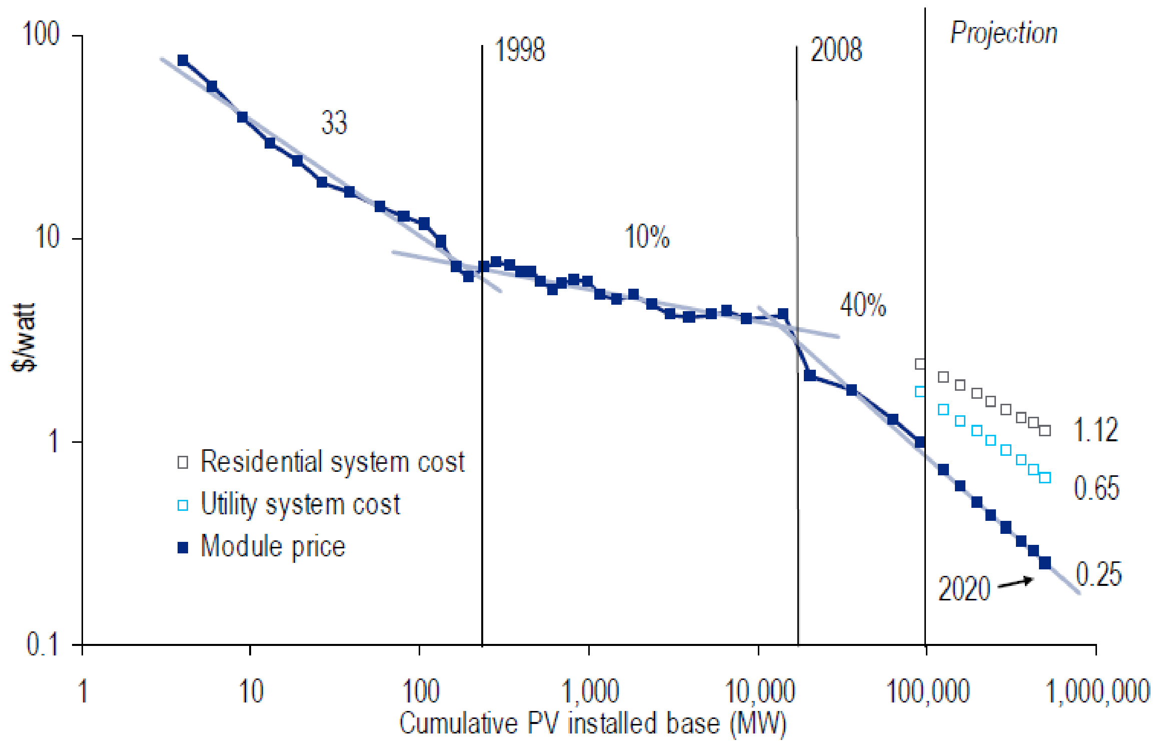
The asset life of a solar photovoltaic cell is between 25 and 30 years with the effectiveness decreasing about 1-2% per year, primarily from electron depletion. Solar photovoltaic systems are relatively low maintenance, only requiring cleaning, but may require limited simple mechanical maintenance if equipped for tracking the sun.

4.4.2 Trends

Modularity of photovoltaic systems provides the ability to expand and closely match the need for additional load. At present the cost competitiveness of solar photovoltaics with other conventional energy sources is the main barrier to continued growth.

Currently, there is a downward trend in pricing as shown in Figure 10, thought to be partially driven by overcapacity in the market largely due to increased manufacturing in China which accounts for over 60% of worldwide solar photovoltaic shipments.

Figure 10. **SOLAR PHOTOVOLTAIC INSTALLED COST PRICE TRENDS**[1]



As solar photovoltaic technology continues to evolve, significant cost reductions are expected as a result of improved power conversion efficiencies, development of low-cost cell fabrication processes, and increased cell production volume with attendant economies of scale. It is anticipated that adoption of universal standards will address interconnection requirements, ease the introduction of solar PV into the marketplace, and eliminate the complex and sometimes time consuming practices currently followed.

There are numerous solar photovoltaic technologies currently on the market, with efficiencies and performance improving over time.

Polysilicon, the dominant material used in most solar cells is expensive to process and there is competition for supply as polysilicon is also a key material that is used by the integrated circuit industry. Developers are looking at ways to reduce the amount of refined and processed silicon used, by experimenting with lenses to focus more sunlight onto a solar photovoltaic cell to increase the cell energy production and reduce the use of silicon. Many solar manufacturers have recently brought on new supplies of polysilicon that have helped drive down costs.

Crystalline silicon (c-Si) technologies are the largest deployed technologies in the marketplace, with typical commercial efficiencies in the range of 15 to 20%. Amorphous silicon (a-Si) is commonly referred to as thin film silicon, with efficiencies in the range of 8.5 to 10%. Other thin film technologies include cadmium telluride (CdTe), copper indium Selenide (CIS), and copper indium gallium Selenide (CIGS), with typical efficiencies in the range of 11 to 17%. In hot locations CdTe solar panels perform 2 to 5% better than silicon based panels. Cadmium (Cd) is a toxic element linked to a variety of human ailments, and has fallen under closer environmental scrutiny.

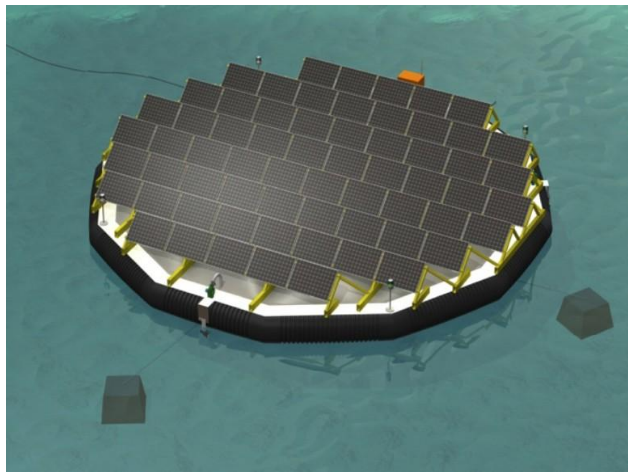
Gallium Arsenide (GaAs) has the highest range of efficiency, typically between 25 and 40%. Also known as multi-junction technology, each layer of GaAs can be chemically adjusted to absorb a different wavelength in the light spectrum. High cost and the ability to withstand harsh environments have seen the technology primarily utilized in space and concentrating solar applications. Concentrating systems utilize mirrors or lenses and can focus sunlight up to 500 times.

Hybrid materials, or HIT, for Heterojunction with Intrinsic Thin layer, combine both crystalline silicon and thin film technologies together. Efficiencies typically achieved are around 18%.

Many nano-technology based materials are currently under active research and development. Some of these technologies include dye sensitized inks, organic and inorganic cells, and quantum dot cells. Some of the cells being developed and tested in laboratories have demonstrated efficiencies upwards of 50%.

Solar photovoltaic arrays floating on water have been proposed by companies in India and Switzerland with prototypes expected to be tested shortly. The Swiss design, shown in Figure 11, is for 25 metre diameter islands, each with a 100 photo voltaic panels with the islands having the ability to rotate 220° to track the sun and maximize generation.

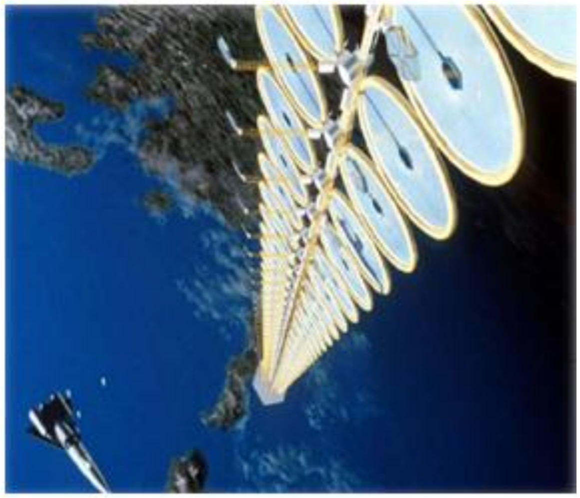
Figure 11. **FLOATING SOLAR ARRAY**[23]



The sun presents an enormous amount of energy that could potentially be tapped directly in the high atmosphere or outer space. Potentially, a space station of mirrors in orbit around the earth could focus solar rays and transmit their energy down to earth in the form of a laser beam. A conceptual space based solar system is illustrated in Figure 12 .

[23] Holloway, James, GIZMAG, Energy company to test floating solar islands, February 25,2013

Figure 12. CONCEPTUAL SPACE BASED SOLAR SYSTEM[24]



According to Solaren, a space-based system could capture between 4 and 8 times more energy per area than a system on the surface of earth. Additionally, the space based system would not be subject to intermittencies such as clouds and potentially night time. Pacific Gas and Electric has signed a Power Purchase Agreement with Solaren Corporation. The agreement contemplates the development of 200 MW of space solar power by 2016, with the ground receiving station in Fresno County.

Research is also being undertaken to develop artificial photosynthesis, or to mimic how living plant cells convert sunlight into energy. A protein from spinach identified as PS1 was found to convert sunlight into electrical energy with an efficiency of nearly 100 percent[25]. Work to develop the technology into a functioning solar cell is ongoing.

4.4.3 Manitoba Potential

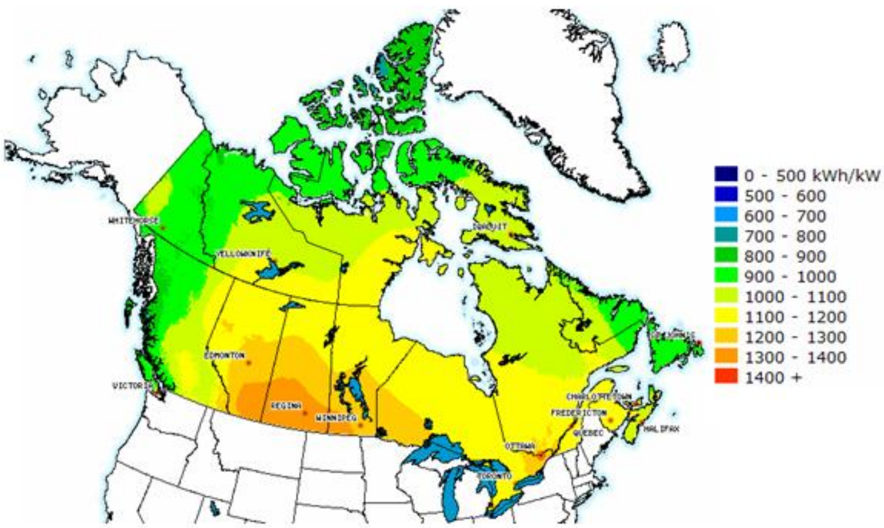
The energy productivity of photovoltaics is dependent on the amount and intensity of sunlight on the face of the solar panel, which varies by geographic location and weather (clouds). During times of little or no sunlight either connection to a grid, backup

[24] New JAXA Technology Concepts, Inhabitat, 2012.

[25] Szondy, David, GIZMAG, Spinach protein boots efficiency of “biohybrid solar cells, September 6,2012.

generation, or use of a storage system, would be required to provide power. The southern portions of the Province of Alberta, Saskatchewan, and Manitoba have the best solar resources in Canada, 1,300-1,400 kWh/kW (or 5 kWh per square meter per day), as shown below in Figure 13.

Figure 13. CANADIAN SOLAR RESOURCE[26]



In Manitoba, even with peak sunlight available, every 230 W of electrical load would require one square meter of photovoltaic cells. Cities such as Brandon or Winnipeg that are located within good solar resources could have the photovoltaic farm located near their urban load centres. The solar photovoltaic rooftop potential of Winnipeg has been estimated to be greater than 3,000 MW.

Manitoba Hydro supported the installation of a 12.7 kW solar photovoltaic glass vertical wall at the Red River College downtown campus in January 2003. Monitoring data indicates this facility has an average annual capacity factor of 8%, with vertical installed systems peaking during the winter months.

[26] Natural Resources Canada, PV potential and insolation.

4.5 Solar Thermal

4.5.1 Current Status

Concentrated Solar Power (CSP) is an intermittent power source, commonly combined with thermal storage in order to improve operations. Current trends indicate that the economics of CSP are improving as technological developments are made in regards to lower cost collectors and innovative power cycles.

Global installed capacity of CSP is over 2,300 MW, with a few thousand MW of additional projects in the planning stage. By 2050, the International Energy Association (IEA) forecasts that CSP could meet approximately 10% of the world's energy needs[27]. For example, Solar Millennium and Chevron are currently developing the Blythe Power Project in southern California. This project will have a total capacity of 1,000 MW and has received approval from the US Department of Energy.

CSP technologies incorporate two primary components which include a reflective surface that can track the sun's movement, and a heat transfer fluid which transports the thermal energy to a power cycle. In addition, all these CSP systems have excellent scalability as they are inherently modular. Current CSP technologies are estimated to degrade at a rate of 0.5%/yr, primarily from material weathering, and have a lifespan of 30 years.

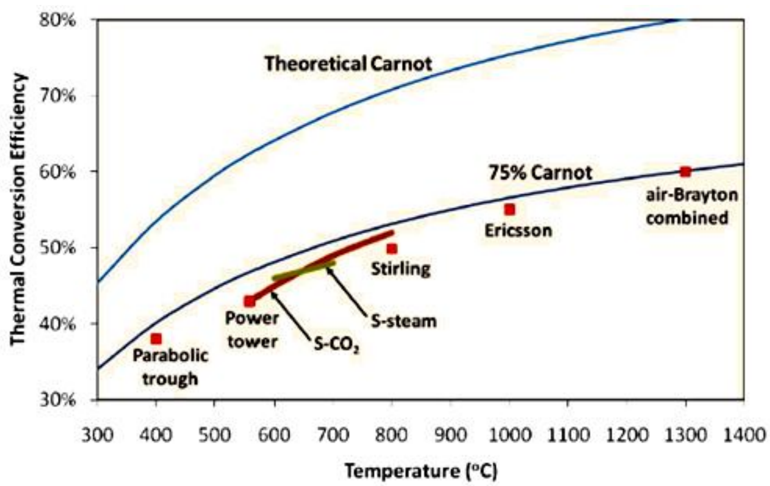
[27] Tanaka et al, Technology Roadmap Concentrating Solar Power, International Energy Agency (IEA), 2010.

The most developed utility scale solar thermal technologies consist of concentrating the sun's rays onto a smaller area to heat a working fluid. The most common technologies include:

- Parabolic dish/Stirling engine systems
- Power tower systems
- Parabolic trough systems
- Linear concentrator systems

A Carnot cycle is the theoretical maximum, or most efficient cycle for converting thermal energy into work. Typical conversion efficiencies of solar thermal technologies are shown below in Figure 14.

Figure 14. RELATIVE ENERGY CONVERSION EFFICIENCIES OF MAJOR SOLAR THERMAL TECHNOLOGIES [28]



[28] Glatzmaier, Summary Report for Concentrating Solar Power Thermal Storage Workshop, National Renewable Energy Laboratory, August 2011.

4.5.2 Trends

Parabolic troughs are currently the most reliable and lowest risk solar thermal technology for near-term deployment. Longer term cost projections of troughs will likely be higher than other solar thermal electric technologies, due to having lower solar concentration and lower temperatures (when compared to power towers or dish systems).

More solar thermal technologies are operating as hybrid plants integrated with biomass, gas turbine, or coal boiler systems, effectively increasing dispatchability and minimizing grid integration issues. Worldwide there are currently eight solar thermal hybrid plants in operation with at least another eleven being planned.

Use of CO_2 as a thermal working fluid is also advancing. Further development of the supercritical CO_2 Brayton cycle may prove to significantly reduce the cost of solar thermal projects since CO_2 turbines are four to six times more compact than conventional Rankin cycle turbo machinery. S-CO_2 Brayton cycles have also been found to be less corrosive to turbo machinery at higher temperatures as the CO_2 has better materials characteristics with stainless steel than does steam.[29]

CSP plants also require no fuel which could potentially contaminate the environment; however, current CSP systems require either oil or molten salt as a heat transfer fluid. The potential leakage of the oil is a concern for environmental contamination. The American Society of Mechanical Engineers is currently conducting research into the usage of direct steam generation. This would involve producing steam directly in the collector system. In conventional systems steam is produced through a series of heat exchangers near the power turbine. A direct steam system would reduce the risk of fire, environmental contamination, capital costs, and heat losses.

[29] Steven Wright, Mighty Mite, Barber Nichols Inc., January 2012.

Missouri-based Matt Bellue and Ben Cooper have built a prototype internal combustion engine that runs on water and solar heated oil greater than 200°C. This means no fossil fuels or steam plant would be required for electricity generation. Hot oil would be injected into the cylinders where a few droplets of water would be introduced creating steam. Missouri State University and the Missouri University of Science and Technology are assisting with development and testing of the prototype.[30]

4.5.3 Manitoba Potential

In cold weather climates like Manitoba, harnessing solar thermal energy for heating purposes may be more attractive than using solar thermal energy for electricity generation.

Manitoba Hydro is currently working with Red River College (RRC) and the University of Manitoba to establish a R&D solar trough field at RRC. The solar trough project was commissioned in May 2012 to investigate the suitability of CSP in southern Manitoba. Future phases of the project may include testing of thermal storage systems, and power generation from leftover heat. From these results Manitoba Hydro will be able to analyze and assess the issues and operational aspects of solar thermal under Winnipeg climate conditions.

Direct Normal Irradiance (DNI) is a measure of solar energy intensity that strikes a given area over time. Manitoba receives between 1800 and 2400 kWh/m^2-yr which is approximately 75% of the DNI achieved in California. Large scale solar thermal plants occupy a large footprint of about 2 to 4 hectares per MW in California. Given the lower DNI available in Manitoba, a 1,000 MW CSP plant would occupy between 33 to 38 km^2 (13 and 15 square miles) of landscape. This represents a large footprint and implies that there would be significant land use implications on a utility scale.

[30] Gizmag, HydroICE project developing a solar-powered combustion engine, 22 November, 2012.

4.6 Energy Storage

4.6.1 Current Status

Use of energy storage technologies allows utilities to manage an increasing variable load of intermittent renewable generation sources, face costs associated with upgrading aging infrastructure, and prevent financial damages caused by outages. There is currently over 100 GW of energy storage installed worldwide, with 99% being pumped hydro storage (i.e. pumping water from tailrace to forebay).

Energy storage can refer to chemical, thermal, or mechanical means of storing energy for future use, with the future being anything from nanoseconds to days. Uses for energy storage can include numerous applications, including everything from enhancing power quality (quickly provide power to the grid to stabilize supply voltage), frequency regulation (smoothing cyclic supply), ramping (meet rapid increases in load), shifting the delivery of energy from off-peak to on-peak times (or load leveling, storing excess generating capacity during times of low demand for use during peak demand hours), and deferring system upgrades (grid improvements and new transmission capacity). There is a trend toward increasing energy storage to improve grid robustness and energy supply management.

Energy storage is an option for maintaining power quality and grid stability in utility systems that have an increasingly large portion of intermittent renewable energy by firming or shaping the supply. Continued decreasing costs in high energy battery storage may make the combination of energy storage options, and intermittent renewable generation, more competitive in the future. Additionally, thermal energy storage may become suitable for waste heat and solar thermal applications.

Electrical energy storage technologies include pumped hydro, batteries, flywheels, compressed air, capacitors, superconducting coils, thermal, and fuel cells. None except reservoir ponding are currently economic on a utility scale application in Manitoba.

In addition to electrical energy storage, thermal energy storage can include numerous materials such as rock, concrete, sand, water, and phase change materials. Phase change materials refer to materials that store heat while changing states, perhaps from a solid to liquid form for example.

Like electrical energy storage, thermal energy storage can also be utilized to mitigate the intermittency of renewable energy resources. In solar thermal projects, phase change materials are most commonly used to absorb large quantities of heat. Commonly, mixtures of salts are used in these applications, which melt during operation. Molten salt, or saltpeter (60% sodium nitrate and 40% potassium nitrate), is being used as thermal energy storage for solar tower or solar trough systems. Salt has a melting temperature of 238°C, and can be heated up to 565°C to drive a steam turbine. Molten salt in the liquid state has a similar viscosity and appearance as water. Molten salt can be stored in insulated hot thermal storage tanks, allowing a solar thermal to electricity plant to produce electricity 24 hours a day. Some thermal storage tanks are very well insulated and can store thermal energy up to one week. Currently many solar thermal generating stations with thermal storage have storage capabilities in the 6 to 12 hour range.

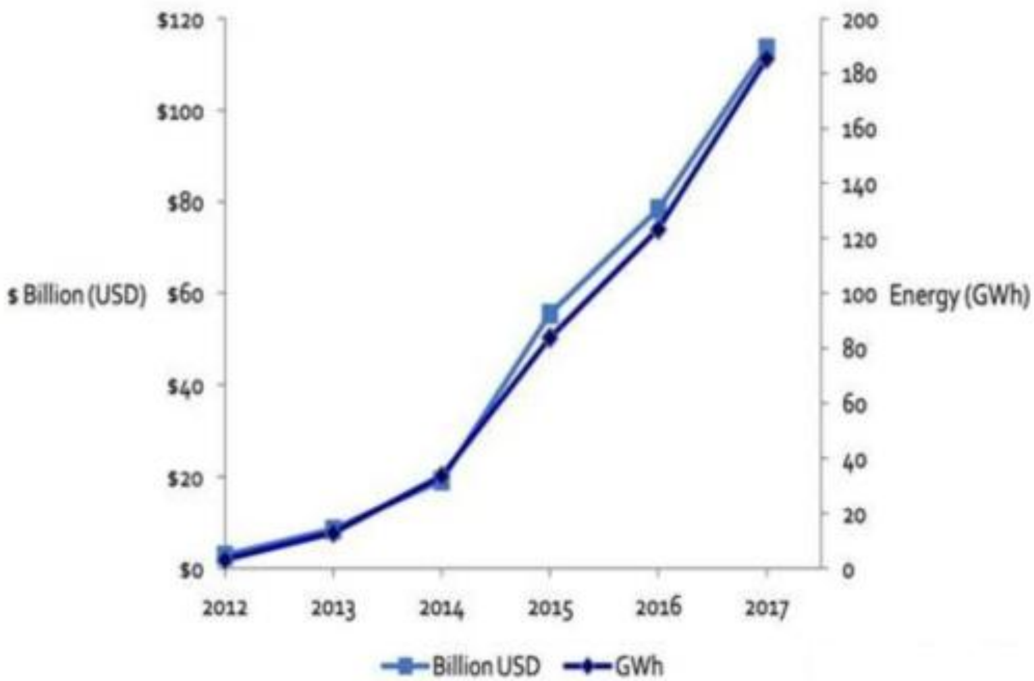
4.6.2 Trends

Although there is regulatory uncertainty and many unproven technologies, there is a growing market of opportunity for energy storage. It has been estimated that only about 2% of electricity supply worldwide leverages the use of energy storage.

Demand for portable electronics has been driving advancements for battery technology, the need to increase energy density, reduce size, and lower costs through economies of scale. This has also spawned auto manufacturers to incorporate batteries to displace the use of fossil fuels. There are potentially an unlimited number of materials that could be utilized in battery chemistries.

Figure 15 below illustrates the forecasted demand for global grid storage from 2012 to 2017, reaching over $110 billion, or 185 GWh, or 52 GW of capacity.

Figure 15. **FORECASTING GLOBAL DEMAND FOR GRID STORAGE** [31]



According to a recent industry survey, 65% of respondents felt cost was the biggest challenge facing the adoption of energy storage, followed by 14% who cited deployability, 7% who cited lack of industry standards, 7% software, and unspecified concerns.[32]

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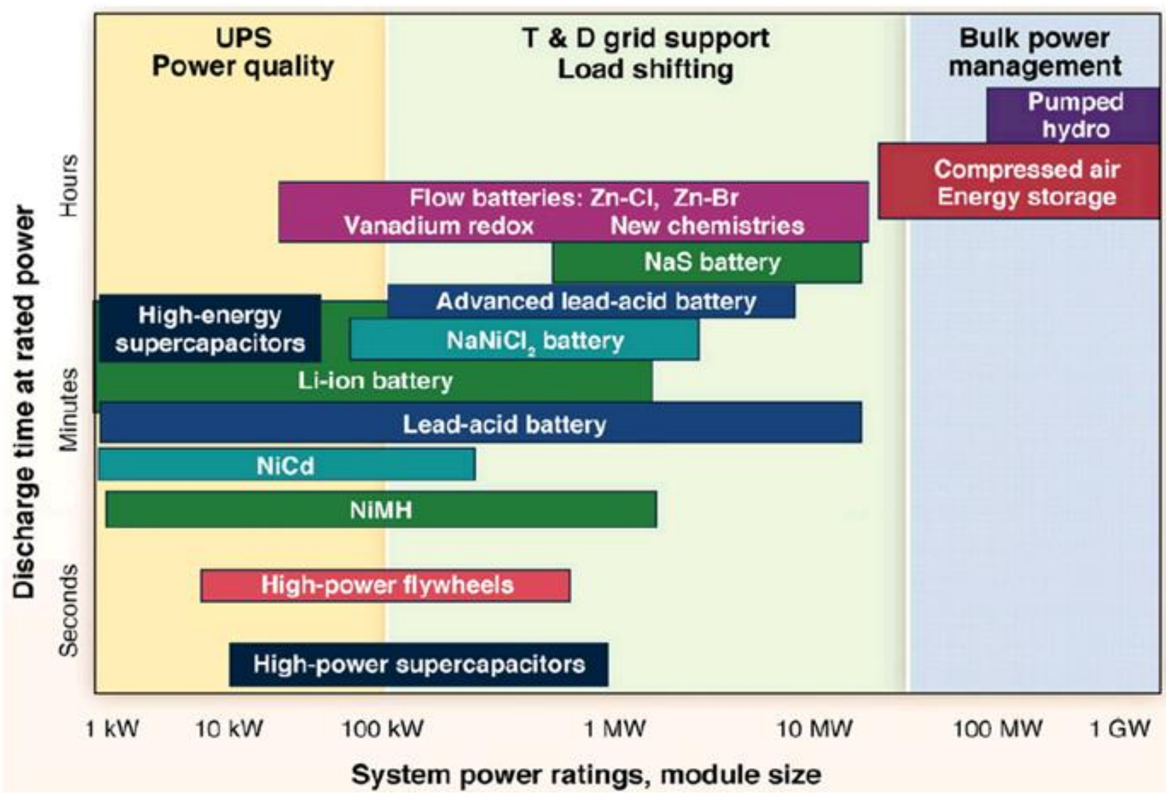
[31] Lux Research, Smart Grid and Grid Storage Intelligence, June 2012.

[32] IEEE, Power Systems of the Future: The Case for Energy Storage, Distributed Generation, and Microgrids, November 2012.

For operational uses, one must consider whether its use is for capacity, energy, or a combination of both, and the time frame requirements of seconds, minutes, or hours, plus market considerations and regulations. Potential operational uses for storage systems are shown below, in Figure 16.

Figure 16. OPERATIONAL USES FOR STORAGE SYSTEMS[33]



It is uncertain at this time if energy storage will be cost competitive with conventional solutions for energy related challenges in the foreseeable future. Many predict steep downward cost curves due to expanding manufacturing volume. However, cost reduction paths are yet unproven, with balance of plant typically the largest cost component.

Electricity storage technologies cover a wide spectrum of applications, ranging from fast high power management applications through to slow high energy management

[33] Koritarov, Vladimir, Grid-Scale Energy Storage Presentation, March 2013.

applications, often at a trade-off to each other. This spectrum covers energy discharges from a fraction of a second in high power applications to hours or days in high energy applications. The high power end of this spectrum includes power quality and uninterrupted power supply applications, where electricity storage technologies, such as capacitors and flywheels are used, while the high energy end of this spectrum includes long term energy management applications such as load levelling and peak shaving, where electricity storage technologies such as pumped hydro, compressed air, and flow batteries are used. In the middle of the spectrum are a range of applications where stored energy is required in minutes rather than seconds or hours, such as spinning reserve applications. Ongoing research is blurring the distinction between traditionally power oriented technologies such as capacitors increasingly taking on the characteristics (and the chemistries) of each other.

A higher degree of confidence in cost can be expected from more mature technologies such as pumped hydro and Compressed Air Energy Storage (CAES). Although, high energy battery costs have fallen 30% since 2009 and continue to decrease, further economic improvements can still be made to improve competiveness with conventional utility technologies. High energy battery types typically include lithium ion, metal air, sodium sulphur, nickel cadmium, nickel metal hydride, and advanced lead acid.

The Zhangbei National Energy Storage and Transmission Demonstration Project marks China's first big move into energy storage, and will be rated at 20 MW (or 95 MWh) when completed, using batteries with a lithium ion iron phosphate chemistry, and may be expanded up to 36 MW.[34] Also included in the project are 100 MW of wind generation and 40 MW of solar photovoltaic generation. Wind power has grown rapidly in China with grid operators struggling to integrate wind on a predominately coal fired system (over 75% of China's electricity). With some regions in China curtailing up to 25% of the wind

[34] Green Tech Media, How China Will Impact the Grid Scale Energy Storage Market, July 30, 2012.

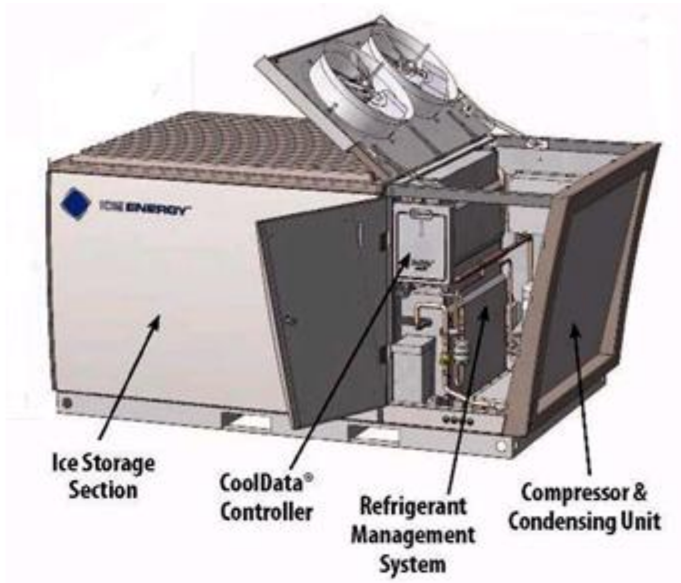
generation produced, there is a growing demand to install energy storage to capture lost wind energy.

Ontario Power Generation is working with Temporal Power to install 5 MW of flywheels at an installed cost estimated at $8 million. [35] With growing wind and solar capacity being installed on the grid, the flywheel facility will counter balance minute by minute voltage variations, spinning up to 11,500 revolutions per minute.

Ice Energy, a company based in Windsor Colorado, offers a hybrid air conditioner, the Ice Bear 30, as shown below in Figure 17, for residential and commercial applications that can be utilized for peak electric demand shifting. Water is frozen in an insulated storage tank each night when demand is lower. During the day the system provides cooling by circulating chilled refrigerant from the storage tank. A conventional HVAC system operates during off-peak hours to create ice. Thermal storage capacity is estimated at 360,000 BTU with a water tank capacity of 475 US gallons. The system can provide up to 7 kW peak reduction or 35 kWh of peak electric demand shifting.

[35] Spear, John, Renewable energy: Flywheels could boost Ontario's power grid, Toronto Star, May 10, 2013.

Figure 17. ICE BEAR 30 HYBRID AIR CONDITIONER[36]



4.6.3 Manitoba Potential

Currently, Manitoba Hydro is working with Electrovaya and the Manitoba HVDC Research Centre to evaluate the feasibility of utilizing repurposed electric vehicle batteries. During the life-cycle of a plug-in electric vehicle, batteries undergo several thousand cycles of charging and discharging. It is expected that 80% of the battery life will remain at the end of a vehicle's 10 year life. Potentially, these batteries can be repurposed for a second life in stationary utility scale applications.

Currently, there are no permanent fuel cell applications in Manitoba. However, fuel cell technologies could potentially be used in a similar industrial fashion in Manitoba as Gills Onions LLC in California. Specific applications could include digested biogas from organic waste products. These could include on farm digested biomass waste products such as crop residuals and hog manure. Also, digested potato wastes from Simplot in Portage la Prairie could provide a renewable energy resource through fuel cells. Similarly, power

[36] Ice Energy, Glendale, California

generation from landfill gas at the Brandon and Brady Road Landfills may be a possibility. However, given the lack of experience, short lifespan, and high cost of the fuel cell system in comparison to RICEs, the introduction of fuel cells in Manitoba is unlikely without significant incentives, typically for mandated requirements for advanced emission or noise control. Additionally, utility scale implementation of fuel cells using natural gas as a fuel source for Manitoba Hydro is highly unlikely, in comparison to the lower cost of natural gas fired simple or combined cycle combustion turbines.

Further research and development of thermal storage systems is needed in order to determine their feasibility and relevance in Manitoba.

The adoption of advanced metering and smart grid related technologies over time could potentially improve efficiency and reliability of the Manitoba grid, and may also enable more cost effective integration of intermittent renewables and energy storage devices.

4.7 Hydrokinetic

4.7.1 Current Status

The theoretical Canadian hydrokinetic resource potential is estimated at 750 GW, with the Manitoba resource potential estimated at 63 GW. The practicality of harnessing the hydrokinetic resource potential will naturally depend on continuing technology development, the remoteness of location, and the distance from the nearest serviceable load.

Currently, the most advanced hydrokinetic turbines are found between the prototype and commercial stages of development. This is also reflected in the installed capacity of hydrokinetic power. As of November 2011, the installed worldwide capacity of hydrokinetic systems was about 300 kW, with about 130 kW in the US. It is estimated that the total capacity of hydrokinetic turbines will be 500 MW by 2025, at which point hydrokinetic turbines will potentially be produced in large commercial volumes.

Hydrokinetic turbines generate power by directly harnessing the in-stream flow speed of a river. As water moves through the turbine a torque is imparted on the blades which drive the hub of the turbine similar to that of a wind turbine. The hub is connected to a drive train which serves to power an electrical generator. A variety of different configurations are possible for hydrokinetic turbines. The most common types are illustrated in Figure 18 and 0.

Figure 18. MOST COMMON DESIGNS OF HORIZONTAL AXIS HYDROKINETIC TURBINES. HYDRO GREEN'S TURBINE (LEFT) AND VERDANT POWER HORIZONTAL AXIS TURBINE (RIGHT)

Figure 19. MOST COMMON DESIGNS OF VERTICAL AXIS HYDROKINETIC TURBINES. NEW ENERGY DARRIEUS TURBINE (LEFT) AND LUCID ENERGY CROSS-FLOW HELICAL VERTICAL TURBINE (RIGHT) ERROR! BOOKMARK NOT DEFINED.ERROR! BOOKMARK NOT DEFINED.

Kinetic turbines are highly susceptible to large woody debris or ice flows which can be carried downstream during periods of high water flows. Therefore, it is likely that hydrokinetic turbines installed in Manitoba would be completely submerged and anchored to the river bottom rather than being installed on floating structures permanently. Additionally, the rocky bottom of many rivers in Manitoba's Canadian Shield is highly suitable for securing anchors for hydrokinetic applications.

Hydrokinetic turbines can potentially extract comparable amounts of energy in comparison to utility scale wind turbines which are physically much larger, because water is about 1,000 times as dense as air. A number of modifications can be made to a hydrokinetic turbine in order to maximize its power factor. Surrounding the horizontal axis turbine rotors in a shroud is highly effective for increasing the power output. Results have demonstrated that a shroud significantly increases the volumetric flow through the turbine as shown in Hydro Green's shrouded turbine design in Figure 18. However, the addition of a shroud dramatically increased the drag on the turbine assembly, thus requiring stronger supports and anchors. Although, both of these characteristics are economically oppositional, it is likely that the incorporation of an optimized shroud on a kinetic turbine would increase the overall economics of such a system.

4.7.2 Trends

The Marine Renewable Energy Roadmap has a vision to develop Canada's technologies and expertise related to wave, tidal, and river current resources.[37] Targets of installed generating capacity of 75 MW by 2016, 250 MW by 2020, and 2,000 MW by 2030 have been made. Federal and Provincial governments have already supported $75 million towards marine renewable development and $100 million will be invested towards the

[37] Charting the Course: Canada's Marine Renewable Energy Technology Roadmap, October, 2011.

first phase of Nova Scotia's Fundy Ocean Research Centre for Energy. Hydro Québec has a long term goal of installing up to 200 MW of hydrokinetic capacity.

Rivers that discharge fresh water into bodies of salt water release enormous amounts of energy, as the fresh water is salinated. It is estimated that between 1600 and 1700 TWh could be feasibly generated annually worldwide from fresh water salination.[38] This energy can be harnessed by osmotic power technologies which take advantage of the potential energy of a salinity gradient between fresh and salt water. Pressure Retarded Osmosis (PRO) is one suitable technology. In PRO, a pressure is exerted as salt moves through an osmotic membrane into fresh water. This pressure can correspond to a head of water of up to 120 m. This water pressure can then be harnessed by a hydro electric turbine and be converted into electricity. If this PRO technology was applied at the Nelson River in Manitoba which has an average flow rate 2066 m^3/s,[39] this would correspond to a capacity of approximately 2,000 MW. Alternatively, osmotic power can also be harnessed through Reverse Electrodialysis (RED) which functions in a similar fashion to a fuel cell.

Both PRO and RED are suitable for baseload power and would experience the same seasonality issues as conventional hydro power. However, PRO is more likely to be utilized as the energy density per unit area of the membrane is approximately 80% higher than RED. Statkraft plans to construct a 2 MW pilot plant by 2017 and a 25 MW demonstration plant shortly after 2020. Significant development in cleaning the osmotic membranes and overcoming technical challenges in plant construction are still required, as osmotic power is currently prohibitively expensive.

Hydro Québec announced a partnership with Statkraft in November 2012 to accelerate research and development on osmotic power.

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[38] Werner Kofod Nielsen, Progress in the Development of Osmotic Power, Statkraft Pure Energy, 2011.

[39] James March, Nelson River, The Canadian Encyclopedia, 2012.

4.7.3 Manitoba Potential

Rivers and tidal currents contain a significant amount of energy and can be harnessed without the application of dams as used in conventional hydro power. Hydrokinetic turbines generate power in a similar manner as wind turbines. Currently, Manitoba Hydro is studying the applicability and resource potential of hydrokinetic power within the province. Hydrokinetic turbine technologies require further development before economical and durable turbines can be deployed on a utility scale.

The University of Manitoba has endeavoured to research and develop hydrokinetic turbines for rivers at which flow speeds are in excess of 3 m/s, for application in low impact, district energy systems. Figure 20 shows an eight foot, 60 kW horizontal turbine was selected for testing near the Pointe du Bois GS in Manitoba.

Figure 20. 60 KW HYDROKINETIC TURBINE TESTED AT POINTE DU BOIS [40]

The University of Manitoba conducted similar tests at Pointe du Bois with two additional turbines that included a 5 and 25 kW vertical axis turbines from New Energy as shown in Figure 20. Since the 5 kW turbine was tested in winter, the floating structure was subject to frazil ice and ice flow conditions. This demonstrated that ice mitigation would be a major concern for future deployment of hydrokinetic turbines in Manitoba.

[40] Bibeau, In-Stream River Technology Status in Cold Climates, University of Manitoba, July 2010.

Unfortunately, stream flow conditions in 2011 were lower than expected which prevented the testing of the 60 kW turbine to its full potential.

The University of Manitoba is developing a Canadian hydrokinetic turbine test centre. This facility will provide a national resource for hydrokinetic turbine testing for a number of potential new technologies and deployment schemes.

4.8 Enhanced Geothermal Systems

4.8.1 Current Status

Approximately 1% of the heat stored in the upper 10 km of the Earth's crust is estimated to be 500 times the energy stored in worldwide known oil and gas reservoirs. The implementation of geothermal projects has been rising significantly following two decades of sluggish growth. Currently, more than 11,200 MW of geothermal power capacity has been installed worldwide with thousands of MW in development. Even considering the drop in world energy prices in 2008 and 2009, it is anticipated that by 2020, the installed geothermal capacity will exceed 30,000 MW worldwide. This trend includes the United States, where the portion of geothermal generation is expected to double within the next 5 years. While tapping geothermal is possible everywhere in the world, it is most economic in regions with the potential for volcanic activity, such as Iceland, which harnesses over 1,000 MW of geothermal power.

The downhole, water temperatures drawn from the production well are in most cases subcritical range from 150° to 200°, and lower than the temperatures injected into a steam turbine in a coal, gas or nuclear plant, and therefore, the efficiency of geothermal power plants is lower. In comparison to other thermal power plants, an EGS is expected to operate for a nearly equal length of time (20 to 30 years), after which heat outflow of the production well would drop. Heat outflow would recover within 50 to 100 years of closure. Most geothermal power plants located in geothermally favourable areas in the world today have an average capacity of 50 MW; however, plants have been constructed with capacities up to 180 MW. Similar to other thermal plants, EGS is winter peaking, suitable for base load purposes with capacity factors over 90%, and may be scalable up to 1,000 MW.

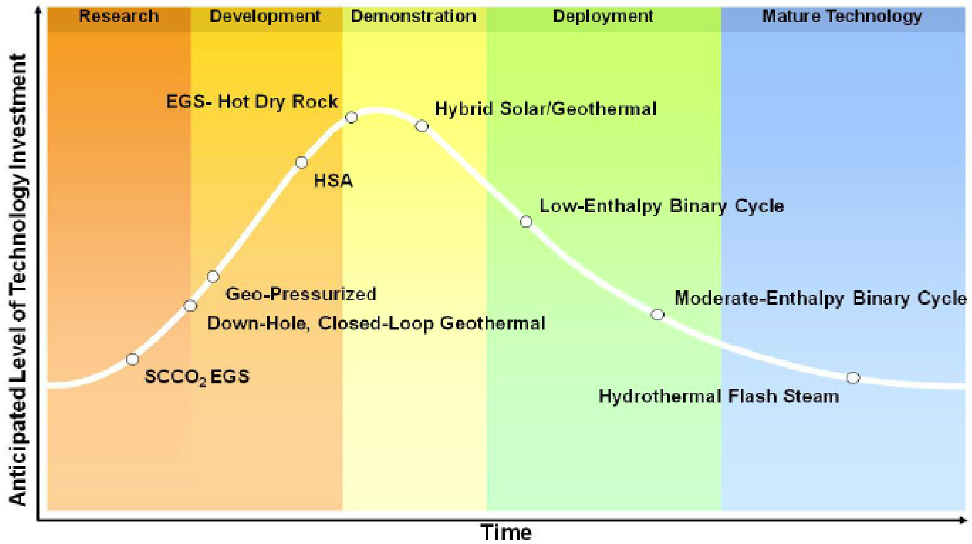
The feasibility and deployment of Enhanced Geothermal Systems (EGS) is largely dependent on a number of trends, which include improvements in drilling technologies, enhancements in the identification of geothermal resources, and the hybridization with other forms of thermal energy.

4.8.2 Trends

In order to facilitate good flow around the injection and production wells, the rock strata around the wells may be stimulated through hydraulic fracturing (i.e. “fracking”) after drilling of the wells. Fracking can greatly improve flow rate yields through the wells and thus improve heat extraction by the power plant. Fracking also allows the geothermal resource to be used more efficiently. Water drawn from open loop EGS systems contains dissolved gases and carries them to the surface. The primary emissions include hydrogen sulphide (H_2S) and ammonia (NH_3) in open-loop cooling systems.

Hybridized EGS systems are currently in the development phase, but could potentially prove to be more economic, than a standalone EGS electricity generator. This hybridization includes augmenting a solar, biomass or fossil fuel thermal plant with EGS. Figure 21 illustrates the Grubb curve, understanding the cost of bringing a technology from concept to implementation.

Figure 21. MATURITY OF GEOTHERMAL TECHNOLOGIES



The cost associated with well drilling increases exponentially with depth. Current drilling technologies limit the availability of EGS as they significantly impact the economics of such systems. Three developing drilling technologies in the R&D state but not widely deployed have the potential to cut drilling costs in half by reducing the tendency of equipment to fail and increase the speed of drilling. These developing drilling methods accomplish this by avoiding any direct contact with the rock, such as through grinding and crushing rock utilized in conventional drilling technologies. These new techniques include hydrothermal flame spallation, chemically enhanced drilling, and metal shot abrasive-assisted drilling. Additionally, newer and advanced methods such as directional and horizontal drilling currently used in shale gas extraction from much deeper depths are highly compatible with developing geothermal resources.

In some cases inactive oil and gas wells have been utilized for taping into geothermal resources, which negates the cost of developing a geothermal well field. However, the diameter to which oil and gas wells are drilled may not facilitate optimum performance of an EGS. On average, a geothermal well will cost 30% more than an oil and gas well drilled to the same depth up to 3 km. Typically oil and gas wells have borehole diameters in the range of 6 to 8.5 inches, whereas EGS wells are typically in the range of 8.5 to 12.25 inches.[41]

As geothermal resources are not distributed evenly throughout the world, prediction and measurement of geothermal gradients and ground temperatures is central to successful EGS development.

4.8.3 Manitoba Potential

Electric and thermal energy derived from renewable deep well geothermal sources in the earth's crust (2-10 km deep) are being more seriously examined worldwide. Areas, such as those found in south-western Manitoba, can be enhanced through hydraulic stimulation (drilling and pumping water) such that the enhancement increases the water flow rate to geothermally active regions. These systems could also be used to pump heat from within the earth for use in district heating systems.

Currently, the Province of Manitoba offers incentives for installations of geothermal heat pump systems. These systems differ from EGS in that they are much closer to the surface rather than drawing heat from 2 to 10 km depths like EGS. The geothermal heat pump systems also represent a residential scale capacity, rather than a utility scale like EGS.

A study examined the availability within 0.5 to 10 km depths in the Williston sedimentary basin, which intersects the southwest portion of Manitoba. The study demonstrated that temperature gradients within this sedimentary basin are about 20^{o}C/km, and are much steeper than the gradients which exist in the relatively cooler Manitoba Precambrian shield. The geothermal resources in southwestern Manitoba have the potential to produce 100 kg/s at 150^{o}C from a 6 km depth, which is equivalent to a generating capacity of approximately 40 MW thermal (or 4 MW electric). Shallower regions in the range of 2 to 3 km in Manitoba could produce 10 kg/s at 80^{o}C, which would be equivalent

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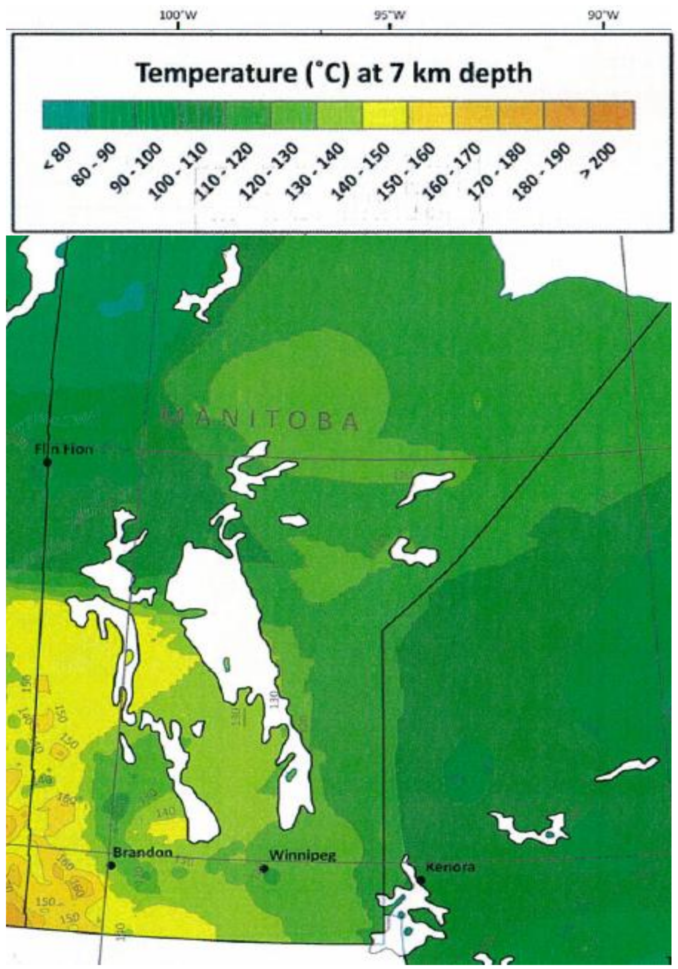
[41] Beswick, Status of Technology for Deep Borehole Disposal, April 2008.

to only 2 MW thermal in peak regions. The potential temperatures at a 7 km depth have been estimated for Manitoba and are shown in Figure 22.

Figure 22. ESTIMATED TEMPERATURES AT 7KM DEPTH



5 Summary and Observations

The cost of many generation and energy storage technologies are expected to decline over the next couple of decades, often based on a combination of increased manufacturing and technology advancements. It remains to be seen if projected cost reductions can be implemented to significantly reduce the balance of plant component (typically the civil and electrical works and related labour), often a significant component related to any installed cost of generation.

Since most other renewables such as wind and solar, are intermittent, there is a need for some form of energy storage to allow the electricity to be dispatchable, or generation capacity from other resources would be jointly required. If emerging energy technologies are being compared against resources such as hydro electric generation, they need to be comparable to the long service life, resource predictability, and dispatchability offered by a hydroelectric resource.

Many potential technology developments are based on nano based materials, or building new materials at the atomic level. Commercialization of nano based materials is dependent on being able to have large scale manufacturing of materials on the atomic level, a technological feat that has yet to be achieved.

Renewable generation technologies are often dependent on some sort of subsidy to be viable. Government policy often creates and drives the industry, resulting in a "boom and bust" cycle as changes in government and policy are inevitable over time. Given the global economy, effects of foreign decisions and actions by their local industries and companies can significantly impact domestic markets, sometimes resulting in the financial failure of domestic companies unable to effectively compete fairly.

Manitoba Hydro continues to undertake applied demonstration projects and resource assessments to continue evaluating emerging energy technologies as they evolve, and how they perform under Manitoba conditions. Participation in the industry associations that track, evaluate, and test various emerging energy technologies has proven to be an effective way to leverage research funds, share industry knowledge, and remain current on emerging technology trends.

6 Glossary of Abbreviations

AECL – Atomic Energy of Canada

AGR – Advanced Gas-cooled Reactor

a-Si – Amorphous Silicon

BTU – British Thermal Unit

BWR – Boiling Water Reactor

CAES – Compressed Air Energy Storage

CANDU – Canada Deuterium Uranium

CanWEA – Canadian Wind Energy Association was established in 1984 as a non-profit trade association to promote development and policy of wind energy in Canada. CanWEA has a goal to meet 20% of Canada's domestic electricity demand with wind energy by 2025. CanWEA has over 400 members.

CCA – Capital Cost Allowance

Cd – Cadnium

CdTe – Cadnium Telluride

CEA – Canadian Electric Association

CEATI – Centre for Energy Advancement trough Technological Innovation roots date back to 1891, with the founding of the Canadian Electric Association (CEA), which formally initiated an R&D program in 1974. CEA Technologies Inc. was separated from CEA in 1996 to allow global expansion, and become known as CEATI in 2008. CEATI is a user-driven technology solutions exchange and development program for utilities. The vision of the Strategic Options Interest Group (SOIG) is to assess, evaluate, and demonstrate sustainable power generation and other distributed energy technologies. CEATI has over 700 participant utilities from 14 countries.

CHP – Combined Heat and Power

CIGRÉ - Conseil International des Grands Réseaux Électriques

CIGS – Copper Indium Gallium Selenide

CIS – Copper Indium Selenide

CND – Canadian Dollars

CNSC – Canadian Nuclear Safety Commission

c-Si – Crystalline Silicon

CRCE – Canadian Renewable and Conservation Expenses

CSP – Concentrated Solar Power

EERC – Energy and Environmental Research Center

EERI – Eco-Energy Renewable Incentive

EGS – Enhanced Geothermal System

EPA – Environmental Protection Agency

EPRI - Electric Power Research Institute was established in 1973 as an independent, non-profit organization to bring together experts from academia and industry, as well as a team of scientists and engineers to address challenges in electricity generation, environmental impacts, government policy, economic analysis, and to drive long term research and development while supporting research in emerging technologies. EPRI membership includes utilities from over 40 different countries around the world.

FIT – Feed-In-Tariff

GaAs – Gallium Arsenide

GE – General Electric

GFR – Gas-cooled Fast Reactor

GHG – Green House Gas

GJ – Giga Joule

GS – Generating Station

GW – Giga Watt

GW.h – Giga Watt Hour

HHV – Higher Heating Value

HIT – Heterojunction with Intrinsic Thin layer

HVDC – High Voltage Direct Current

Hz - Hertz

IEA – International Energy Association was originally founded in response to the 1973 oil crisis, to help countries deal with disruptions in oil supply. Today the main areas of focus include energy security, economic development, environmental awareness, and worldwide engagement. IEA has 28 member countries. The IEA Wind Task 25 main objective is to analyze and further develop the methodology to assess the impact of wind power on power systems, being undertaken by 16 member countries including Canada.

IEEE – Institute of Electrical and Electronics Engineers

IRENA – International Renewable Energy Agency

ITER – International Thermonuclear Experimental Reactor

kV – kilo Volt

kW – kilo Watt

kW_e - kilo Watt electric

kW_{th} - kilo Watt thermal

kWh – kilo Watt Hour

LCOE – Levelized Cost Of Electricity

LFG – Landfill Gas

LFR – Lead-cooled fast reactor

LHV – Lower Heating Value

Li-ion – Lithium ion

LLC – Limited Liability Company

LOCA – Loss Of Coolant Accident

LPG – Liquefied Petroleum Gas

m – metre

m/s – metres per second

MESO Map – Mesoscale Atmospheric Stimulation System

MIT – Massachusetts Institute of Technology

MJ – Mega Joule

MSR – Molten Salt Reactor

MW – Mega Watt

MW_e - Mega Watt electric

MW_{th} - Mega Watt thermal

MW.h – Mega Watt Hour

NAABB – National Alliance for Advanced Biofuels and Bioproducts

$NaNiCl_2$ – Sodium Nickel Chlorine

NaS – Sodium Sulfur

Ni-Cd – Nickel Cadmium

NiMH – Nickel Metal Hydride

NRC – Nuclear Regulatory Commission

NRCan – Natural Resources Canada

NREL – National Renewable Energy Laboratory

NSERC – Natural Sciences and Engineering Research Council of Canada

NUG – Non Utility Generation

O&M – Operation & Maintenance

ORC – Organic Rankine Cycle

OREG – Ocean Renewables Energy Group , now known as Marine Renewables Canada, was established in 2004. The goal is to ensure Canada is a leader in providing marine energy solutions to a global market, bringing together industry, academia, and government. Work is being undertaken to implement and realize the Canadian Marine Renewable Energy Technology Roadmap. Marine Renewables Canada has over 60 members.

PHEV- Plug-in Hybrid Electric Vehicle

PPA - Power Purchase Agreement

PRO – Pressure Retarded Osmosis

PWR - Pressurized Water Reactor

REC – Renewable Energy Credit or Certificate

RED – Reverse Electrodialysis

RICE – Rotating Internal Combustion Engine

RPS – Renewable Portfolio Standard

SCWR – Supercritical Water-cooled Reactor

SFR – Sodium-cooled Fast Reactor

SMR – Small Modular Reactor

SNL – Sandia National Labs

SOIG – Strategic Options Interest Group

SPL – Spruce Products Limited

R&D – Research and Development

RICE – Rotating Internal Combustion Engine

UVIG – Utility Variable Integration Group, previously known as UWIG was established in 1989 for critical analysis of wind technology for utility applications. The mission of UVIG is to accelerate the development and application of good engineering and operational practices supporting the appropriate integration of variable generation into the electric system. UVIG has over 150 members from around the world.

UWIG – Utility Wind Integration Group

VHTR – Very High Temperature Reactor

WTG - Wind Turbine Generator

Zn Cl – Zinc Chlorine Redox

Zn Br – Zinc Bromine Redox