

# Greenhouse Gas and Related Toxic Chemical Pollution Prevention

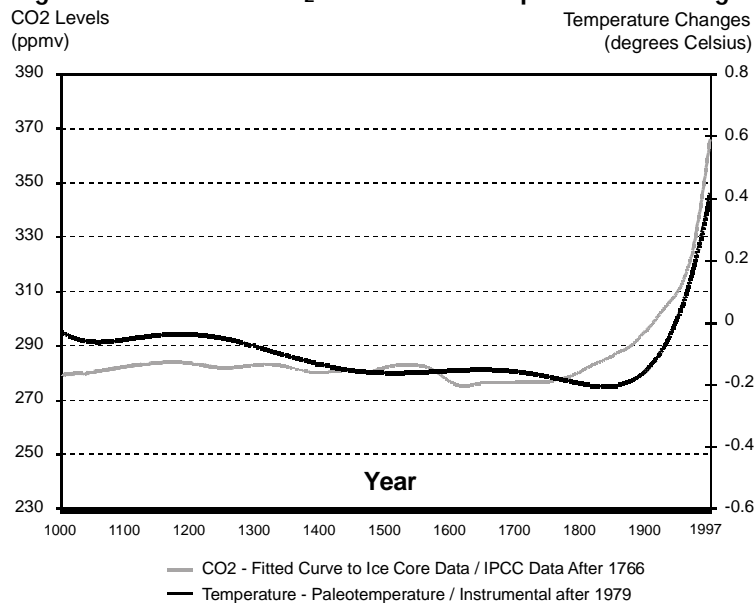
The Office of Environmental Assistance (OEA) is responsible for pollution prevention (P2) technical, financial and educational assistance and for evaluating state progress in P2. As data allow, this chapter of the *2002 Pollution Prevention Evaluation Report* evaluates progress and opportunities to reduce greenhouse gas and related toxic chemical emissions from Minnesota’s largest sources through using P2. The Minnesota Department of Commerce (MDC) is responsible for state energy planning and policy. The information presented here is supportive of the MDC State Energy Planning Report.<sup>1</sup>

There is significant concern that human activities that produce greenhouse gases (GHG) are affecting climate. The surface temperature of the earth is rapidly rising. Documented changes, such as the Arctic icepack losing 40 percent of its thickness in the last forty years, have occurred.<sup>9</sup> As sea temperatures and human-related activities have increased, more coral reefs have died in the past 20 years than in the previous 5,000.<sup>2</sup> The National Climatic Data Center reports that the eight hottest years on record have occurred since 1990.<sup>3</sup>

Most scientists working to understand this temperature change have concluded that it is being caused in part or largely by the human production of greenhouse gases. A two-mile-deep ice core in East Antarctica has revealed that there are now more greenhouse gases in Earth’s atmosphere than at any time in the past 420,000 years.<sup>4</sup> Based on continuation of current trends in emissions, the amount of warming forecast for the next century will be larger than anything found in the paleotemperature record (see figure) for an equivalent period of time. This warming will cause large geographical shifts of current climates, as well as changes in associated vegetation and sea level.

Figure 5-1 shows the observed changes in temperature and global atmospheric carbon dioxide (CO<sub>2</sub>) levels over time.

**Figure 5-1. Global CO<sub>2</sub> and mean temperature changes<sup>5</sup>**



# Global climate change initiatives

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As a result of concern about the impact of GHG, the United Nations Framework Convention on Climate Change (UNFCCC) was developed in the early 1990s. The stated goal of the convention is to avoid dangerous interference in the world's climate. As a party to the convention, the United States and 186 other nations pledged to implement policies to return their GHG emissions to 1990 levels by 2000. As of 2000, U.S. emissions exceeded their 1990s levels by 14 percent.<sup>9</sup>

In 1997, the Kyoto Protocol to the UNFCC was developed. If ratified, it would require developed countries to reduce their greenhouse gas emissions by an aggregate of 5 percent from 1990 levels by 2010. President Clinton signed the agreement in 1999. In 2001 in Germany, the European Union, Japan, Russia and other developed nations signaled their intent to adhere to this Protocol. If they carry through on their commitments, this will be sufficient to bring the Protocol into effect. The current U.S. Administration has announced its intention not to participate further in the development of the Protocol, will not submit it to the Senate for ratification, and will not support U.S. participation in the Protocol. Costs are cited as one reason not to participate. According to the U.S. Department of Energy's Energy Information Agency, with business as usual conditions, the United States will increase GHG emissions by an additional 30 percent by 2020 from 2000 levels.<sup>6</sup> Recently, concern has been expressed that U.S. non-participation might subject U.S. business to discriminatory trade practices and technological disadvantages.<sup>7</sup>

Many individual companies have voluntarily adopted their own GHG reduction targets for a variety of reasons, although common ones cited include the need for long-range investment strategies, economic competitiveness and integration of environmental concerns into corporate operations.<sup>8</sup> The chart below lists of some of those companies and their GHG reduction targets.

**Figure 5-2. Voluntary GHG reduction targets as identified by company**

<b>Company</b>	<b>Reduction target</b>
ABB	Reduce GHG emissions by 1% each year from 1998 through 2005.
Alcoa	Reduce GHG emissions by 25% from 1990 levels by 2001.
Baxter International	Reduce energy use and associated GHG emissions by 30% per unit of product value from 1996 by 2005.
BP	Reduce GHG emissions by 10% from 1990 levels by 2010.
Dupont	Reduce GHG emissions by 65% from 1990 levels by 2010.
Energy	Stabilize CO <sub>2</sub> emissions from U.S. power generating facilities at 2000 levels by 2005.
IBM	Reduce CO <sub>2</sub> emissions due to fuel and electricity use by an average of 4% from 1998 levels by 2004.
Intel	Reduce perfluorcarbon emissions by 10% from 1995 levels by 2010.
Ontario Power Generation	Stabilize CO <sub>2</sub> emissions at 1990 levels by 2000.
Rohm and Hass	Reduce energy consumption by 5% per pound of production from mid-1999 levels by year-end 2000.
Shell	Reduce GHG emissions by 10% from 1990 levels by 2002.
Toyota	Reduce energy consumption per unit of production by 15% from 2000 levels by 2005.

## Largest sources of Minnesota GHG emissions

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Energy production from fossil fuels for electricity and transportation are by far the largest sources of greenhouse gas emissions today. Eighty percent of Minnesota's GHG emissions come from fossil fuel combustion in electric utilities (37 million tons/yr.CO<sub>2</sub> equivalent) and in transportation (45 million tons/yr. CO<sub>2</sub> equivalent).<sup>9</sup> CO<sub>2</sub> emissions from Minnesota electric utilities are more than 4 times, and CO<sub>2</sub> emissions from transportation are more than 2.5 times, what they were 40 years ago. Total Minnesota GHG emissions are increasing at a rate of approximately 1.8 percent a year.<sup>9</sup>

# Utilities

Opportunities for pollution prevention are available for current generation and new generation capacity.

## Current generation

Approximately 95 percent of the electricity consumed in Minnesota is generated from coal and nuclear fuel.

### Coal

Power plants utilizing coal as fuel currently produce 75 percent of the electricity consumed in Minnesota and are substantial contributors to ozone, nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), particulate matter and GHG pollution. 2000 Toxic Release Inventory (TRI) data show that among reporting manufacturers, (excluding the Gopher Resources Corporation's battery recycling facility) electric utilities are responsible for the following total reported TRI air emissions.

Figure 5-3. Total TRI releases to air

Chemical	Pounds	Percent
Vanadium	8,871	100%
Hydrogen fluoride	226,035	98%
Molybdenum trioxide	300	95%
Mercury	1,484	85%
Nickel	12,628	79%
Barium	62,061	76%
Antimony	90	74%
Chromium	1,885	74%
Hydrochloric acid (aerosols only)	462,035	71%
Manganese	8,670	56%
Lead	1,110	37%
Ammonia	116,533	10%
Sulfuric acid (aerosols only)	183,975	10%
Zinc	6,461	10%
Dioxin	0.0065	0.5%

A common pulverized coal plant (with a 500 MW base load) generates 16,204 tons of SO<sub>2</sub>, 12,150 tons of NO<sub>x</sub> and 3.4 million tons of CO<sub>2</sub> per year.<sup>12</sup> Costs to supply electricity from Minnesota's current pulverized coal-fired plants will increase with plant retrofits or new construction. The table below compares the relative costs and reduction in emissions from primary pollution prevention alternatives.<sup>12</sup>

Figure 5-4. Comparison of P2 alternatives for a pulverized coal plant generating a 500 MW base load<sup>(b)</sup>

Pollution prevention option	Capital cost per KW	Percent reduction		
		SO <sub>2</sub>	NO <sub>x</sub>	CO <sub>2</sub>
Improve existing plant efficiency	low or no cost	5%	5%	5%
Convert to natural gas	\$400-600	99%	99%	70%
Convert to 90% coal/10% natural gas co-firing	small <sup>(a)</sup>	10%	small	5%
Convert to 80% coal/20% wood/bio co-firing	\$100-700	10%	small	20%
Convert to circulating fluidized coal bed	\$900-1,300	88%	93%	29%

<sup>(a)</sup> At 90% coal/10% n-gas, operating costs will increase 15% due to higher cost of natural gas.

<sup>(b)</sup> At 65% capacity factor, 30% thermal efficiency.

## **P2 options to reduce GHG and related toxic emissions due to energy generation**

### **Improve existing plant efficiency**

Based on experience at U.S. electric utilities, it appears possible to increase the efficiency of existing plants about 5 percent at low or no cost. If realized, a 5 percent improvement in plant efficiency would, at current rate of generation, result in a 5 percent reduction in CO<sub>2</sub> and other emissions.<sup>54</sup> Coal power plants operate under the air quality standards that were in place at the time of their construction. If gains in efficiency are obtained through improvements rather than repairs, the facility may be subject to the same air emission standards as a new facility. Meeting these standards may not be cost effective for the facility.

### **Natural gas**

Today's natural gas turbines are about 55 percent efficient<sup>10</sup> as compared to about 32 percent for pulverized coal facilities. When compared to coal, natural gas has very little mercury or sulfur and emits 30 times less SO<sub>2</sub>, 15 times less NO<sub>x</sub> and 3 times less CO<sub>2</sub> for the same amount of electricity generated. Price and supply are limiting factors for the use of natural gas.

Natural gas is an attractive fuel for power generation, and currently provides 1 percent of Minnesota's electrical generation capacity. The natural gas used in Minnesota is piped in from gas fields in the southern United States or in Ontario. Supply is dependent upon demand all along the pipelines and is limited in winter months. The cost of any needed increased security for gas pipelines is unknown at this time.<sup>11</sup>

### **Coal/natural gas co-firing**

Since natural gas contains only trace amounts of mercury and SO<sub>2</sub>, co-firing coal with 20 percent natural gas can reduce mercury and SO<sub>2</sub> emissions by up to 20 percent. Due to improved combustion efficiencies, CO<sub>2</sub> emissions are reduced by approximately 10 percent. Since natural gas historically costs more than twice the amount of coal, on a per million Btu basis, co-firing at a ratio of 80 percent coal and 20 percent natural gas would increase operating costs by approximately 20 percent.

### **Coal/wood/fiber co-firing**

Co-firing coal with up to 20 percent wood can reduce CO<sub>2</sub> emissions by 15 to 20 percent. If specifically grown wood or fiber rather than waste matter is used, care must be taken to assure that the net CO<sub>2</sub> produced through its production process is less than if pure coal were used.

Refuse-derived fuel (RDF) may also be burned with coal. Due to the amount of mercury contained in disposed products, incinerators which burn 100 percent RDF release two times more mercury per kilowatt hour than coal.<sup>12</sup> Reusing or recycling material is environmentally more beneficial than burning it as fuel. For example, twice the amount of CO<sub>2</sub> emissions is released producing virgin newspaper as compared to producing recycled newspaper.<sup>13</sup> Paper's use as a fuel, rather than to replace production of virgin paper, causes a significant net gain in greenhouse gases. Retrofitting existing coal-fired facilities to utilize biomass is expected to cost \$100 to \$700 per KW of biomass capacity.<sup>54</sup>

### **Fluidized coal bed**

There is no commercial experience with retrofitting pulverized coal to circulating fluidized bed. All retrofits thus far have been pilot-scale retrofits done under the DOE Clean Coal Technology Program with substantial federal subsidies. Initial evidence suggests that retrofit costs could be on the order of \$400 to \$500 per KW.

If commercialized costs are in this range, Minnesota's coal power plants could be converted from existing pulverized coal to circulating fluidized bed technology for approximately \$2 billion, twice that amount to convert to gasification technology.<sup>14</sup> Given that today's fluidized bed units are approximately 38 to 40 percent efficient as compared to 32 percent for pulverized coal, if conversion of all plants occurs, CO<sub>2</sub> emissions would decrease from approximately 37 million to 29 million tons a year, provided the quantity of coal burned remained constant.<sup>9</sup> Emissions of toxic metals such as mercury, barium, lead and chromium contained in coal are also an issue that must be considered. Electric utilities that exclusively burn coal as fuel are the largest source of mercury emissions in Minnesota, releasing approximately 1,500 pounds into the air in 2000.<sup>15</sup> National releases of mercury from all

coal-fired power plants are more than 40 tons per year.<sup>16</sup> Although research is underway, current technology is not available to remove the concentration of mercury found in electric utility stock gases.

## **Nuclear**

Nuclear fuel is currently Minnesota's second largest source of energy and provides approximately 20 percent of the electricity consumed in the state.<sup>12</sup> Minnesota's three nuclear power reactors (one in the city of Monticello and the other two on Prairie Island near Red Wing, Minnesota) have a total generation capacity of 1582 MW.<sup>17</sup> Although the facilities do not produce greenhouse gases, they do produce high and low-level nuclear waste. High-level nuclear waste must be safeguarded for 250,000 years.<sup>18</sup>

The wisdom of increasing the amount of nuclear waste in order to decrease greenhouse gases is controversial. Due to issues regarding security of nuclear reactors and their waste, public safety is of heightened concern.<sup>19</sup> The costs of increased safeguards, or how they will be paid for, have not yet been determined.<sup>20</sup> Due to a lack of a permanent storage facility for nuclear waste, the approximate \$2,200 per kilowatt cost for a new nuclear plant and the difficulty of siting new facilities, it is unlikely dependence upon nuclear power will increase in the foreseeable future.<sup>12</sup>

## **Opportunities for other fuels and new generation**

The remaining 5 percent of electricity consumed in Minnesota comes from hydro, wind, bioenergy and solar. Increase in their use represents the greatest pollution prevention potential to decrease greenhouse gases due to power generation. The 2001 Minnesota Energy Security and Reliability Act states that 10 percent of electricity generated in the state should be derived from renewable sources by 2015.

### **Hydro**

Hydro energy currently produces about 2.5 percent of the electricity consumed in Minnesota.<sup>21</sup> Xcel Energy annually imports about 5 million MWh of electricity from Manitoba Hydro. Manitoba Hydro has plans to build several more large hydroelectric facilities in Canada to serve Minnesota and other customers. The dams used to create the depth of water needed to drive high capacity water turbines result in flooding of adjacent land, produce a small amount of methane, disrupt aquatic environments, and decrease water quality.

Other than plans by Crown Hydro to build a 3.2 MW plant at St. Anthony Falls in Minneapolis,<sup>22</sup> no hydro projects are under permit review in Minnesota at this time. There are opportunities to install more efficient turbines in at least two existing hydro facilities in the state. Improvements have also been made to the design of mini-turbines for use in small, rapidly flowing, natural currents for site-specific generation.<sup>23</sup> New, low-flow turbines are also in development for commercial use. The Massachusetts Department of Environmental Protection successfully piloted the use of a Gorlov Helical turbine, which generates electricity from dam-free rivers and streams.<sup>24</sup>

### **Wind**

Wind turbines are used singularly or at large-scale wind-farms where wind energy is available. In Minnesota, wind power capacity has increased more than 200 percent since 1997<sup>25</sup> to 380 MW and provides for 1 percent of total electric use.<sup>12</sup> Wind power creates no GHG or toxic chemicals, does not deplete natural resources, and does not require mining. Hence, it is a preferred option for pollution prevention. Modern wind turbines can produce electricity for 4 to 6 cents a KWh, a cost comparable to new, modern coal-fired plants.<sup>26, 27</sup> Although wind alone cannot fill the need for all electricity consumed in the state, cost-effective opportunities currently exist to increase its contribution from the 1 percent presently in use to 10 percent.<sup>12, 28</sup>

### **Bioenergy: biogas, biomass and biodiesel**

Bioenergy produces electricity from the decomposition or combustion of organic material.

Biogas, or methane, is produced from the decomposition of most organic materials. Methane is a greenhouse gas; however, when burned as a fuel to create electricity, it causes no net gain in greenhouse gas emissions.

Haubenschild Farms in Princeton, Minnesota uses an anaerobic digester to turn dairy farm manure waste into methane fuel to generate electricity to power the farm and 78 local homes.<sup>29</sup> Organic material such as manure is an ideal fuel source for anaerobic digesters due to its capacity to produce methane and low-odor, quality compost. It appears possible that Minnesota could create as much as 10 MW of power generating capacity by using farm-based anaerobic digestion.<sup>30</sup> Opportunities exist to increase the use of methane from animal waste and food waste as a means to generate electricity.<sup>22</sup> If specifically grown organic material rather than waste is used to create methane, care must be taken to assure that the net CO<sub>2</sub> produced through its production is less than if pure coal was used for fuel.

Cost-effective landfill sites in Minnesota have been developed to use methane to produce electricity. The Burnsville landfill uses internal combustion engine generators to produce about 25,000 MWh per year. The Pine Bend landfill in Inver Grove Heights uses gas turbines to generate 70,000 MWh per year.<sup>31</sup> Due to the corrosive properties of landfill gas, turbines may be more expensive to maintain than engines. The opportunities to increase generation from landfills are limited by their capacity to produce methane. Methane comprises approximately 50 percent of landfill gas.<sup>32</sup> Landfills are not nearly as efficient as anaerobic digesters when converting organic material to captured methane. Given this difference in efficiency, and due to the fact that landfill methane also includes impurities such as VOCs and, potentially, dimethyl mercury, organic material should not be intentionally landfilled for the primary purpose of producing methane. However, landfill gas should be recovered for energy where it already exists.

Biomass is wood, plants, or the organic component of municipal or industrial solid waste that is burned to produce energy. It may be co-fired with natural gas, oil or coal to generate electricity. Because it is made from vegetation, rather than a mined source of hydrocarbon, it is possible for biomass to cause no net increase in GHG. If specifically grown organic material rather than waste is used as fuel, care must be taken to assure that the net CO<sub>2</sub> produced through its use does not exceed emissions associated with the production and combustion of an energy equivalent amount of coal. This can be a problem if significant amounts of fuel are used in production and transport.

Minnesota currently burns about one-quarter of its municipal solid waste in high temperature combustors. There is about 128 MW of capacity in place. Due to the amount of mercury contained in products which wind up in the waste stream, incinerators which burn 100 percent refuse-derived fuel (RDF) or unprocessed MSW release two times more mercury than coal per kilowatt hour.<sup>12</sup> Due to the current economics of the solid waste industry, increased incineration of solid waste is not anticipated.

Wood and plant waste is currently co-fired with coal, natural gas and waste oil in some Minnesota industrial boilers, in the Hibbard facility in Duluth and in the Xcel Energy Allen King coal plant. Xcel Energy will contract for electricity from three biomass facilities (burning turkey litter waste, wood waste and whole trees) as a means to fulfill part of Prairie Island nuclear storage legislation.

Biodiesel is a renewable fuel produced from agricultural oil seed crops or made from waste cooking oil commonly used to fry food. Although nitrogen oxide emissions increase slightly, combustion of biodiesel made from waste or surplus material causes no net gain in CO<sub>2</sub>, and none of the carbon monoxide, sulfur or small particles created from petroleum-based diesel.<sup>33</sup> Although emissions' testing has largely occurred with automotive engines, emissions should be similar with diesel generators.<sup>12</sup> The question as to whether crops can be grown and processed to produce biodiesel, yet create no net gain in GHG, is unanswered at this time. Opportunities currently exist to increase use of biodiesel as a means to produce electricity, particularly for on-site generation.

Solar. In Minnesota, when compared to current pulverized coal plants, each KWh per year of photovoltaic (PV) electricity offsets up to 48 pounds of NO<sub>x</sub>, 52 pounds of SO<sub>2</sub>, and 19,900 pounds of CO<sub>2</sub>.<sup>34</sup> Although it produces energy from sunlight any time of year, solar energy is best suited to provide electricity during periods of highest demand—hot summer days. A recent study by the Department of Commerce shows that, for summer months, Minneapolis has a greater solar resource than Jacksonville, Florida.<sup>35</sup> Although used to power remote homes and buildings in Minnesota, there is presently less than 100 KW of grid-connected photovoltaic panels in the state. Xcel Energy's Solar Advantage Program estimates installed costs of \$8,500 per KW which equates to about 30 cents per KW when amortized over the 20-year life of the panels.<sup>12</sup> Xcel Energy awarded \$1.25

million from its Renewable Development Energy Fund to reduce installation costs of rooftop PV in Minnesota.<sup>22</sup> Given the funding opportunities currently enjoyed by other states, there is opportunity for Minnesota to add a significant amount of solar to its energy generation system.

Solar energy represents a technology with widespread potential applications and a growing niche market. Solar energy has great potential for decreased costs and increased efficiency, partly because of large photovoltaic initiatives by the federal government.<sup>36</sup> Funding through energy tariffs and state and federal grants helped develop 3.6 MW of solar energy capacity in the United States.<sup>37</sup> The Department of Energy (DOE) has a goal to facilitate installation of one million PV rooftops across the United States by 2010.<sup>38</sup> According to DOE, solar generating systems will contribute 10 percent of U.S. peak power generation by 2020—more if additional incentives are put in place.<sup>39</sup>

Payback periods for photovoltaic panels are decreasing steadily but are still too long for widespread use. With current funding and incentives, solar electricity is projected to become competitive for peak power on a per KWh cost basis by 2010.<sup>41</sup> Modern solar PV systems currently supply electricity for 15 to 25 cents per KWh.<sup>39</sup> In 2000, PV power grew by 30 percent in the United States and by 40 percent elsewhere in the world.

In response to the new efficiencies, increasing numbers of utilities are investing in PV solar distributed power generation.<sup>40</sup> SRP public power utility serving Phoenix made a commitment to spend \$29 million on solar and renewable energy without increasing costs to consumers.<sup>41</sup> Watts on Schools in Abilene, Texas, is a solar schools program with installations completed at 19 schools, generating an average of 6,266 KWh for each school and 119,045 KWh total.<sup>40</sup>

In California, on-site solar PV panels at the bus depot are being used to produce hydrogen for fuel cell zero-emission buses of SunLine Transit Agency, which provides mass transit service to the Palm Springs area.<sup>42</sup> The Sacramento Municipal Utility District is investing heavily in solar PV systems on private home and commercial roofs to meet peak energy demand.<sup>43</sup> In 2001, the citizens of San Francisco overwhelmingly passed a \$100 million bond issue to produce 70 MW of electricity from PV panels mounted on rooftops of public buildings within three years, almost doubling the solar power supply in the nation.<sup>44</sup>

Research and development drives high-tech industries; and in recent years, U.S. government funding of solar energy has not kept pace with that of other nations—particularly Germany and Japan. The U.S. share of world PV shipments has dropped dramatically, from approximately 50 percent to 30 percent, over the last three years.<sup>37</sup> Germany is scheduled to have 350 MW of solar power on-line in 2003. Japan currently has 192 MW of solar power generation, with an additional 3.4 MW to be on-line from a Sanyo Electric plant in 2004.<sup>45</sup>

Fuels cells use the physical properties of hydrogen and oxygen to produce electricity and pure water, and were originally developed to supply power needs of spacecraft. Fuel cells are well suited for distributed power generation. Units are available today for commercial use, but are still too expensive for widespread use. When hydrogen is produced from the electrolysis of water with power supplied by hydro, wind or solar, this technology provides pollution-free, renewable electricity. The nation's first pollution-free, self-standing and renewable (solar) energy fuel cell system was installed to provide electricity to Kahanu Garden, Maui, Hawaii in 2001. The \$150,000 cost of the system is substantially less expensive than the estimated \$200,000 to \$400,000 cost to connect to the Maui Electric Company grid. Long Island Power Authority is purchasing 28 pre-commercial natural gas fuel cell units to test and demonstrate efficacy of fuel cells for residential specific, distributed power generation.<sup>46</sup> The price for commercial residential units is expected to be \$3,000 in 2006.<sup>47</sup> Coleman's \$8,000 AirGen Fuel Cell is currently available for use as a readily portable, safe indoor, secondary power source, and is particularly useful for critical equipment power needs.<sup>48</sup>

## Storing electricity

A problem with intermittent sources of power such as wind and solar is that although they produce pollution-free energy when sufficient wind or sunlight is present, they produce none when it is not. However, solar PV systems would work well just about anywhere in Minnesota.<sup>35</sup> For wind, the limitation to significantly increasing its use in the state is a lack of transmission lines, not the resource.<sup>12</sup> An efficient way to store energy would mitigate the issues caused by intermittent and concentrated sources of solar and wind energy.

Once electrons are produced, they cannot be stored. Energy storage systems, such as using periods of surplus electricity to pump water up a hill or compress air so that their energy can be stored and used to regenerate electricity when needed, are being used. However, there are significant inefficiencies involved due to their need to move significant mass. Because it only involves moving electrons, using surplus electricity to produce hydrogen from water through electrolysis, and storing the hydrogen for later use in a fuel cell to produce electricity, is currently the most energy efficient way to store and utilize surplus electricity.<sup>49</sup>

The components are available in which rooftop solar panels or wind turbines could be used for electrolysis of water to produce hydrogen and oxygen. The hydrogen, in turn, would power a fuel cell to supply a constant source of electricity to a home and excess power to the grid.<sup>50</sup> Research and development of this technology is proceeding rapidly. When commercially cost-effective, which is estimated to be within 10 years, the technology will remedy major problems we currently face with traditional power generation.<sup>36</sup>

## Funding

Federal energy subsidies, some of which have been for pollution prevention, have played a major role in bringing particular electricity generation technologies to maturity. Using 1999 dollars, the historical total of ongoing subsidies are:<sup>51</sup>

- Hydro: Most significantly subsidized in the 1930s and 40s, with estimates ranging from \$1.6 to \$62 billion.
- Nuclear: Most significantly subsidized in the 1950s and 60s, with estimates ranging from \$61 to \$140 billion (does not include long-term nuclear waste storage costs).
- Coal, oil and natural gas: Estimated ongoing subsidies range from \$300 to \$410 billion.
- Wind and solar: Beginning in the 1970s, with estimates ranging from \$10 to \$23 billion.

Pollution prevention funding for coal has increased. Initiatives from the U.S. Department of Energy (DOE) and the coal industry are underway to increase the efficiency of coal-fired plants. The administration's budget requests \$2 billion over the next 10 years to supplement the approximately \$5 billion that has been spent developing more efficient ways to burn coal as a part of DOE's Clean Coal Technology Program.<sup>52</sup>

In 1999, out of a \$6 billion annual budget, the Department of Energy's outlays were approximately 50 percent for fossil fuels, 13 percent for ethanol, 11 percent for generation technology research, 10 percent for nuclear, 5 percent for geothermal, 5 percent for solar and wind, and 5 percent for energy conservation, with the balance going to end use.<sup>53</sup>

## Energy conservation and energy efficiency

Energy conservation is low cost and the most readily available pollution prevention action to reduce GHG from coal-fired utilities, because with more efficient use of electricity less coal need be burned.

The Minnesota Department of Commerce has identified the potential for about 1,000 MW equivalent of energy conservation that, by 2010, could be realized at costs of \$350 per KW or less.<sup>12</sup> From 1992 through 2000, Minnesota's Conservation Improvement Program saved approximately 1,300 MW for an average savings of \$343 per KW.<sup>12</sup> Recent national energy bottom-up engineering studies have concluded that 10 percent or more of all our GHG emissions could be avoided at zero costs through energy efficiency improvements.<sup>54</sup> Current conservation technologies, such as geothermal heat pumps that heat and cool buildings with 70 percent less energy than standard heating and cooling equipment, are underutilized.<sup>55</sup>

In 2001, the Minnesota Legislature passed the Energy Security and Reliability Act, which, in part, provides for public building energy conservation and sustainable building guidelines that will significantly improve the energy efficiency of state buildings. As a part of Minnesota's energy conservation program, utilities are also required to invest a percentage of their state revenue on conservation programs and have achieved significant results.<sup>56</sup> Power companies have achieved significant P2 through their participation in energy conservation programs.

Other states are increasing their use of energy conservation as a pollution prevention tool. The city of Seattle has one of the strongest green building policies in the country. All city buildings have to meet the U.S. Green Building Council's Silver LEED rating; and the city is committed to a 20 percent increase in the Seattle Energy Code, which goes beyond the National Energy Code Standard.<sup>57</sup>

## Summary

When the public sees OEA's working tabletop model of a solar-powered, hydrogen fuel cell running a fan motor, the feedback is consistent: "When can I get one for my house?" The public's desire to have a local, pollution-free energy source is strong. However, due to costs, such energy systems for buildings are currently very rare. Today, more than three-quarters of Minnesota's electricity is generated from combustion of fossil fuels. The contrast between the pollution-free vision of the future and the current need to release 37 million tons of CO<sub>2</sub> and related toxic chemicals per year for electricity could not be more pronounced.

Given the rapid changes occurring with power generation and storage technologies, many of which will be cost competitive in 10 years, prudent funding decisions are needed to assure that a non-disruptive transition to new pollution prevention technologies occurs in the most beneficial and timely manner. Decisions on power generation technologies made today will substantially impact the costs and environmental impacts due to them for the next 40 years, or longer.

To effectively reduce greenhouse gas and related toxic chemical emissions due to power generation, an orderly and coordinated increase in the use of P2 technologies is needed. The pace of the transition to these technologies will be determined by economic factors, commercialization of emerging technology, the support electricity generators have to make the transition to the new technologies, public will, and the policies of their elected representatives. To address environmental and long-term economic concerns, some states and nations are seriously considering their timing for a shift from a fossil fuel to a hydrogen fuel based economy.

Minnesotans should participate with such energy research and planning so that policymakers have the information they need to make the most beneficial policy and funding decisions.<sup>12,58</sup> Due to the long life of energy systems, the future sources of Minnesota's electricity and their resultant emissions are being formed today.

## OEA P2 actions and opportunities to reduce GHG and related toxic chemicals due to energy production

The following activities outline OEA efforts to reduce GHG emissions due to generation of electricity.

### Green building

As a part of OEA's Green Building Program, the OEA will provide Internet resources to:

- promote Energy Star labeled products: buildings, homes, heating and cooling equipment, high-efficiency motors and air compressors, major appliances, office equipment, lighting and consumer electronics.
- promote the use of energy efficiency auditors who examine existing and recommissioned buildings to eliminate energy waste.
- promote use of energy efficiency building design assistance offered through such efforts as Xcel Energy's Energy Assets Program and Energy Star Target Finder to improve architectural plans.
- promote use of the state's sales tax exemption for purchase of Energy Star lighting, photovoltaic devices, and high efficiency heat pumps, water heaters, and furnaces.
- link to Minnesota Department of Commerce web site resources that promote use of energy audits for residences and the construction of super-insulated homes with air-to-air heat exchangers to assure air quality.

### On-site technical assistance

OEA and MnTAP will research the feasibility of integrating energy efficiency into MnTAP on-site assistance, and provide additional measurements of pollution prevention.

### Design for the Environment (DfE)

As a part of the OEA's DfE activities, the OEA has joined expertise with the Energy Office of the Department of Commerce to develop a demonstration project to showcase solar panels and a small wind turbine to make hydrogen from water. Stored hydrogen will be used to power a fuel cell to produce an uninterrupted supply of

electricity. OEA will use grant funds, as available, to demonstrate this technology, provide measurable results, and educate the public on the exponential improvements that have been made to produce a local source of renewable, pollution-free electricity.

### Research hydrogen-based economy

The OEA will coordinate research and information with Minnesota Planning as a part of its 2002 initiative to investigate the costs, benefits and possible pathways for a transition to a hydrogen-based economy. Minnesota Planning will seek to develop a consensus among experts and stakeholders on what, if any, investments the state should make to prepare for such a transition.

## Transportation

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There are many methods to reduce greenhouse gas (GHG) from transportation. These include increasing use of such things as walkways, bikeways, mass transit, high-occupancy vehicles, telecommuting, high-efficiency vehicles, reduced highway speeds, tax incentives, improved traffic flow, policies to encourage vehicle maintenance, reduced city sprawl, increased vehicle occupancy, increased fuel economy, and low or no greenhouse gas producing fuels. The following pollution prevention opportunities describe only fuel changes which are being used to reduce GHG and toxic emissions from vehicles.

Greenhouse gas emissions from Minnesota's transportation sector are approximately 45 million CO<sub>2</sub> equivalent tons a year.<sup>9</sup> From 1998 through 2000, gasoline consumption increased 8 percent. The increase in consumption was due to a 2 percent increase in the number of miles driven per person, and a decrease of about 3 percent in the average number of miles per gallon.<sup>59</sup> In addition to causing the single largest source of GHG emissions in the state, on-road transportation results in the annual consumption of approximately 2,500 million gallons of gasoline which caused 9 million pounds of benzene emissions.<sup>60</sup> Benzene is of concern because long-term exposure to high levels can cause leukemia and damage the immune, reproductive and neurological systems.<sup>61</sup>

➤ *A 20-mpg gasoline vehicle releases about 11,500 pounds of CO<sub>2</sub> in an average 12,000-mile year.<sup>9</sup>*

### P2 options for vehicle fuels

There are five low or no-GHG emission fuels of primary interest for use in Minnesota vehicles: biodiesel, ethanol, natural gas, propane and hydrogen. In addition, it is possible to use these fuels more efficiently in electric-hybrid vehicles. These Ultra Low Emission Vehicles, as certified by the U.S. EPA, use some onboard fuel to generate electricity to power an electric motor which complements power from a high-efficiency internal combustion engine when additional power is needed.

Biodiesel is a renewable fuel produced from agricultural oil seed crops or made from waste cooking oil commonly used to fry food. Its use as a fuel results in substantially reduced carbon monoxide and soot (particulate) emissions created by petroleum-based diesel fuel and requires no diesel engine modifications.

Hennepin County operates four heavy-duty trucks on B20, a mix of 20 percent biodiesel and 80 percent petroleum. The University of Minnesota Diesel Research Department operates one vehicle on 100 percent biodiesel. The Department of Commerce has received Department of Energy funding for a B20 school bus demonstration project. Other biodiesel users include the Minnesota Soybean Growers Association, U.S. Forest Service (International Falls), and the Department of Agriculture. Lower blends of biodiesel (B5, or 5 percent biodiesel) are being tested in MetroTransit buses. There are about a dozen greater Minnesota Cenex Cooperative service stations selling B2, a 2 percent biodiesel mix.

➤ *A 20-mpg diesel vehicle using B20 releases about 17% or 2,000 pounds less CO<sub>2</sub> per year than a comparative vehicle using regular diesel in an average 12,000-mile year.<sup>62</sup>*

Ethanol (ethyl alcohol) is a renewable fuel produced principally from agriculture corn crops at 14 facilities in Minnesota. Ethanol may also be produced from cheese whey, potatoes, brewery and wood—essentially any starch

or biomass material that can be broken down into fermentable sugars. Today, virtually all Minnesota gasoline is blended with ethanol—between 7.8 and 10 percent by volume. This is in accordance with the state’s oxygen requirement for gasoline (2.7 percent by weight) which is met with a 7.8 percent-by-volume ethanol fuel.

E85 (85 percent ethanol and 15 percent gasoline) fuel should only be used in Flexible Fuel Vehicles (FFVs). A number of popular FFVs are available today. There are presently 1,054 E85 FFVs in the Minnesota Department of Administration Travel Management Division’s fleet. Approximately 12,000 gallons of E85 fuel was pumped from the division’s bulk tank last year.<sup>63</sup> Minnesota has met and exceeded federal requirements for state use of alternative fuel vehicles.<sup>64</sup> Not including the CO<sub>2</sub> released during crop or fuel production, each gallon of E85 produces 77 percent less CO<sub>2</sub> than a gallon of gasoline when burned as fuel. There are approximately 70,000 E85 FFV owners in Minnesota, which leads the nation with 65 E85 fueling sites, making this fuel as convenient as gasoline for some FFV owners.<sup>21</sup> E85 use in the state is rising, from 75,000 gallons in 1999, to 320,000 gallons in 2000, to 550,000 gallons in 2001.

➤ *A 20-mpg E85 vehicle releases about 77 percent or 8,900 pounds less CO<sub>2</sub> and 85 percent less benzene per year than a 20-mpg vehicle using regular gasoline in an average 12,000-mile year.<sup>62</sup>*

Pollution prevention issues regarding biodiesel and ethanol

Large amounts of energy are required to grow and process ethanol and biodiesel feedstocks. If crops are farmed exclusively for use as fuel feedstocks rather than using waste or surplus crops to produce these fuels, special care must be taken to assure that the total CO<sub>2</sub> produced does not exceed emissions associated with the production and combustion of an energy equivalent amount of petroleum-based fuel.

The production technology for ethanol has undergone progressive improvement since 1980. Life-cycle GHG emission from ethanol production and use is currently about 20 percent less than those associated with gasoline.<sup>65</sup> With long-term technology development, ethanol life-cycle emissions are expected ultimately to be substantially less than for gasoline, as much as 40 percent per mile driven.<sup>66</sup> The use of grown crops decreases dependence on foreign sources of petroleum, and given that Minnesota imports all of its fossil fuel, there are potential economic and long-term reliability advantages for increased use of agricultural-based fuels.

Natural gas is a non-renewable fossil fuel. For equivalent vehicle miles traveled, natural gas releases 25 percent less GHG as compared to gasoline. There are more than 200 compressed natural gas (CNG) vehicles operating in Minnesota, primarily operated by natural gas utilities. Schwann’s Ice Cream and Leef Brothers Inc. also use CNG trucks for their deliveries. The Minnesota Valley Transit Authority has five CNG buses in service and plans to purchase six more. Pending funding approval, the Transit Authority has plans to purchase 31 additional CNG buses.<sup>21</sup>

In addition to reducing GHG emissions, CNG-fueled buses avoid the particulate emissions that are problematic with regular diesel buses. Particulate air pollution from regular diesel is a concern because it has been shown to significantly increase consequences of pre-existing cardiovascular or respiratory disease, pneumonia, pulmonary disease, and asthma attacks in at-risk populations.<sup>67</sup>

➤ *A 11-mpg bus fueled with natural gas releases about 5,200 pounds less CO<sub>2</sub> than a comparable bus using regular diesel in an average 12,000-mile year.<sup>62</sup>*

Propane. There are an estimated 1500 liquefied petroleum gas (LPG or propane) vehicles operating in Minnesota, mostly operated by centrally located fleet owners, such as Schwann’s Ice Cream and Leef Brothers laundry service trucks.

➤ *A 20-mpg vehicle fueled with propane releases about 10 percent or 1,150 pounds less CO<sub>2</sub> than a comparable vehicle using regular gasoline in an average 12,000-mile year.<sup>62</sup>*

Hybrid electric vehicles (HEVs) typically have a gasoline or diesel internal combustion engine and a battery powered electric engine in the same vehicle. Unlike the all-electric vehicles, which need electricity from power utilities, have limited range, and poor cold climate operation, HEVs have similar performance and greater range than gasoline combustion vehicles. The MPCA purchased two hybrid electric vehicles in 2001, a two-passenger Honda Insight (city 61/hwy 68 mpg) and a five passenger Toyota Prius (52city/45hwy mpg),<sup>68</sup> and they are meeting performance expectations.

➤ *A 50-mpg vehicle releases 60 percent less, or about 7,000 pounds less CO<sub>2</sub> and 60 percent less benzene, than a 20-mpg gasoline vehicle in an average, 12,000-mile year.<sup>9, 60</sup>*

Hydrogen is the most abundant element in the universe, is a very effective energy storage medium, is renewable, and burns clean. Adding just 5 percent to gasoline reduces NO<sub>x</sub> emissions by 30 percent.<sup>69</sup> Burning pure hydrogen produces only water and a minor amount of NO<sub>x</sub>. The goal of the U.S. Department of Energy is to use hydrogen to provide 10 percent of total U.S. energy consumption by 2025, which would reduce our dependence on oil imports by half. Cost remains the single largest obstacle. Current economics provide natural gas at \$3 per million Btu, gasoline at \$9 per million Btu, and hydrogen at \$30 per million Btu.<sup>69</sup>

Today, the U.S. safely uses about 3.2 trillion cubic feet of hydrogen a year, almost all of which is produced at oil refineries for use in fertilizers and petrochemicals. Hydrogen can be added to gasoline, ethanol, methanol, and natural gas to reduce pollution and increase the performance of internal combustion engines, which will probably be its initial widespread use.<sup>69</sup> As with natural gas or propane, internal combustion engines can be modified with existing technology to run on 100 percent hydrogen.<sup>49</sup>

Although existing engines can be modified to use hydrogen, substantial research is taking place on using fuel cell engines. Fuel cells use the physical properties of hydrogen and oxygen to produce electricity and pure water, and were originally developed to supply the power needs of U.S. spacecraft. They are used to power the space shuttle's electrical systems and the only by-product is pure water, which the crew uses as drinking water. Hydrogen-powered fuel cell engines are expected to reach efficiencies of 100 mpg with the same acceleration and performance as current vehicles in the long term.<sup>49</sup>

The automotive industry is investing heavily in the use of fuel cells for vehicles, although rather than using pure hydrogen, mainstream automotive and fuel industry thought currently favors "reforming," or extracting, hydrogen from gasoline as a next step, since a gasoline distribution network is currently in place. However, others within the industry consider methanol a better near-term choice, since it could use the same distribution network, but is more easily reformed and can be produced from natural gas, coal, or renewable biomass. Ethanol, because it is renewable and could also use the same distribution system, is advocated as another possibility. When hydrocarbon, versus pure hydrogen, fuels are used, CO<sub>2</sub> is released, but due to improved fuel efficiency, at levels 50 percent less than when burned in combustion engines. The first commercially available fuel cell automobiles, although expensive, will begin appearing in 2003.

The production of hydrogen from the electrolysis of water by renewable energies such as hydro, wind or solar, provides pollution-free, renewable energy. Stuart Energy produces self-standing Hydrogen Fuelers<sup>70</sup> to produce pure hydrogen for fuel cell vehicles. Such a system is in use by SunLine Transit in California, which is using solar electric panels to produce renewable hydrogen for a hydrogen-powered fuel cell bus.<sup>71</sup> The company has also established the first public hydrogen fueling station.

➤ *No GHG or associated pollutants are created or released during the use of hydrogen in a fuel cell engine.*

#### The hydrogen economy

Significant progress is being made internationally in regard to hydrogen fuel. Iceland foresees an economic advantage to making a rapid transition away from fossil fuels to independent energy systems involving fuel cells. As a result, Iceland has made a commitment to be the first nation in the world to free itself from dependence on fossil fuels.<sup>72</sup> It will do so in stages. Renewable geothermal and hydroelectric energy will produce electrolytically generated hydrogen fuel from water. Due to a current lack of distribution infrastructure, the pure hydrogen will initially only be used to power the capitol city's fuel cell engine bus fleet. Hydrogen bound in methanol will be used as the near-term alternative to fossil fuel for private cars and fishing vessels because it can utilize the nation's existing fuel distribution system. Methanol fuel cell demonstration vehicles are operating in Japan and Germany.<sup>73</sup> Though not as ideal as pure hydrogen fuel, methanol fuel cell engines will emit very few of the toxic chemicals, nitrous oxide or sulfur dioxide caused by fossil fuels and will only emit one half the CO<sub>2</sub> per mile. Methanol was chosen because the metal industries of Iceland emit vast amounts of CO<sub>2</sub> and CO. These carbon oxides, currently released to the atmosphere, will be collected and then combined with the electrolytically produced hydrogen to produce the methanol. Iceland plans a full transition to a hydrogen-based economy within 30 years.

## Summary

Rapid changes are occurring with fuels and technologies for vehicles. In regard to P2 fuels, to effectively reduce greenhouse gas and toxic emissions, an orderly and coordinated decrease in the use of fossil fuels and increase in the use of low or no GHG and toxic chemical emitting fuels is needed. The pace of the U.S. transition will be determined by economic factors, the rate of commercialization of emerging technology, public will, and the policies of their elected representatives. To position the state to benefit from rapidly changing technology, Minnesotans should participate with research and funding opportunities regarding low or no emission fuels.<sup>12, 58</sup> This will ensure that policymakers have the information they need to make the most beneficial policy decisions.

## OEA P2 activities to reduce GHG and related toxic chemical emissions from transportation

### Vehicles

To reduce emissions from vehicles, the OEA will work with other state agencies to:

- Develop coordinated research that includes P2 for transportation.
- Recommend that when such vehicles meet transportation needs, state agencies lease or purchase passenger vehicles which get an equivalent of EPA city mileage rating of 45 mpg or greater; qualify as an Ultra Low Emission Vehicle; and is manufactured primarily for use on public streets, roads and highways and has at least four wheels. (There are only two now available, the Honda Insight and the Toyota Prius.)
- Coordinate with other agencies to research incentives such as state rebates, no sales tax, reduced license tab fees, or preferred parking to employees for passenger vehicles which get an equivalent of EPA city mileage rating of 45 mpg or greater, qualify as Ultra Low Emission Vehicle, and are manufactured primarily for use on public streets, roads and highways and have at least four wheels.
- Participate with community transportation planning through the OEA's sustainable communities activities.

### Research hydrogen-based economy

The OEA will coordinate research and information with Minnesota Planning as a part of its 2002 initiative to investigate the costs, benefits and possible pathways for a transition to a hydrogen-based economy. Minnesota Planning will seek to develop a consensus among experts and stakeholders on what, if any, investments the state should make to prepare for such a transition.

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<sup>1</sup> Minnesota Department of Commerce, *2001 State Energy Planning Report*, <http://www.commerce.state.mn.us/pages/Energy/MainEnergyPolicy.htm>

<sup>2</sup> Jackson, J., Scripps Institute of Oceanography, "Factors in the Decline of Coastal Ecosystems," *Science Magazine*, August 2001, 293: 1589-1591; Third Assessment Report of the Intergovernmental Panel on Climate Change, "Climate Change 2001: Impacts, Adaptation and Vulnerability." <http://www.ipcc.ch>.

<sup>3</sup> National Climatic Data Center, Asheville, N.C. <http://lwf.ncdc.noaa.gov/oa/climate/research/2001/preann2001/preann2001.html>.

<sup>4</sup> Smith, Rolf, National Geographic Society, "Antarctica," Vol. 2000, No. 6, December 2001.

<sup>5</sup> CO2 data: Intergovernmental Panel on Climate Change, "Climate Change 2001: The Scientific Basis," (Cambridge, UK: Cambridge University Press, 2001, <http://www.ipcc.ch/>. Temperature data: Crowley, T., "Causes of Climate Change Over the Past 1000 years," *Science*, 289 (2000): 270-277.

<sup>6</sup> U.S. Dept. of Energy, Energy Information Administration, "Annual Energy Outlook 2001," <http://www.eia.doe.gov/oiaf/aeo/index.html>

<sup>7</sup> Bodansky, Daniel, "Implications for U.S. Companies of Kyoto's Entry into Force without the United States," Pew Center for Global Climate Change, June 2001. <http://www.pewclimate.org/events/bodansky.cfm>.

<sup>8</sup> Margolick, M. and D Russell, Global Change Strategies International, Inc., "Solutions – Corporate Greenhouse Gas Reduction Targets," Pew Center on Global Climate Change, November 2001. <http://www.pewclimate.org>.

<sup>9</sup> Minnesota Pollution Control Agency, 2001 legislative report, *Air Quality in Minnesota: Problems and Approaches*, Appendix H, "Global Climate Change." <http://www.pca.state.mn.us/hot/legislature/reports/2001/airquality.html>.

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- <sup>10</sup> Siemens-Westinghouse sells 7 combined cycle turbine models with a range of efficiency of, at a low end, of 51% and at a high, of 58%. <http://www.siemenswestinghouse.com/en/plantrating/index.cfm>
- <sup>11</sup> Wiest, Ron, Minnesota Office of Pipeline Safety, "Minnesota Pipeline Operators Told to Increase Security," Minneapolis *Star Tribune*, 9/14/01.
- <sup>12</sup> Minnesota Department of Commerce, "Draft Energy Planning Report," 2001, <http://www.commerce.state.mn.us>.
- <sup>13</sup> Minnesota Office of Environmental Assistance, "Municipal Solid Waste Management and its Impact on Resource Conservation and Greenhouse Gas Emissions." <http://www.moea.state.mn.us>.
- <sup>14</sup> Lynch, George, U.S. Department of Energy, Office of Coal & Power Systems, FE-22. Based on demonstration projects, the estimated costs for converting or "repowering" an existing pulverized coal plant to circulating fluidized bed (CFB) technology are \$400-\$450/KW. These costs are rough estimates, but are reflective of the projects. When the technology is converted to CFB, the original fuel feedstock may be changed to a cheaper opportunity fuel, i.e. pet coke, to take advantage of the CFB's fuel flexibility. A good example of a CFB repowering project is Southern Illinois Power Cooperative's (SIPC) 120 MW repowering of a PC plant near Marion, Illinois with Foster Wheeler Energy Corporation (FWEC) CFB technology. Estimated cost from pilot projects to convert PC to integrated gasification combined cycle (IGCC) is \$750-800/KW. Conversion to IGCC requires purchase of a gas-fired turbine, gasifier island, oxygen plant, and syngas cleaning system for sulfur removal, and fuel preparation and feed system. Primary savings will come from the existing coal receiving, handling and storage equipment; continued use of steam turbine which will be coupled to new gas-fired turbine; cyclones and ESP; and instrumentation and controls. <http://www.fe.doe.gov/>. Minnesota coal power plant KW capacity is available from Minnesota Department of Commerce, *Minnesota Utility Data Book*, which provides KW capacity ratings. <http://www.commerce.state.mn.us/pages/Energy/MainData.htm>. The estimate is calculated by multiplying the conversion cost per KW by the KW capacity for each plant.
- <sup>15</sup> Minnesota Pollution Control Agency (MPCA), 2001 legislative report, *Air Quality in Minnesota: Problems and Approaches*, Appendix G, "Mercury." <http://www.pca.state.mn.us/hot/legislature/reports/2001/airquality.html>.
- <sup>16</sup> U.S. EPA, Utilities, mercury information at <http://www.epa.gov/mercury/>. Actions—Utility Air Toxics Determination Facts, December 2000. Also EPA study of air toxics emissions from electric utility power plants at <http://www.epa.gov/ttn/atw/combust/utiltox/utoxpg.html>.
- <sup>17</sup> U.S. Nuclear Regulatory Commission, general information and permitted nuclear reactors; <http://www.nrc.gov/>.
- <sup>18</sup> For energy planning and strategies, see Minnesota Department of Commerce, "Draft Energy Planning Report." <http://www.commerce.state.mn.us>.
- <sup>19</sup> U.S. Nuclear Regulatory Commission, "NRC Reacts to Terrorist Attacks," publication No. 01-12, 9/21/01; and Massachusetts Rep. Edward Markey, U.S. House Energy and Commerce Committee, 9/21/01 press release.
- <sup>20</sup> "Nuclear plants get extra help with security – sheriffs worry about budgets," Minneapolis *Star Tribune* 11/2/01.
- <sup>21</sup> Minnesota Department of Commerce, "Energy Policy and Conservation Report 2000." <http://www.commerce.state.mn.us/pages/Energy/MainEnergyPolicy.htm>.
- <sup>22</sup> Lupo, John, Renewable Energy Fund Manager, Xcel Energy. "Xcel funds renewable energy projects," Annual distributions from above-ground storage of nuclear waste assessments: \$5.1 M for Crown Hydro; total of \$1.78 M for methane digesters; total of \$1.25 M for solar; and \$.75M for wind. *Pioneer Press*, 11/7/2001.
- <sup>23</sup> An Internet search for micro-hydro turbines showed the following sites: Jade Mountain Micro-hydro Electric Power features micro-hydro electric systems from Harris, Aquair, Microset, and for pelton wheel turbines <http://www.jademountain.com/hydro.html>; Fords MTM L.L.C, features micro-hydro electric systems from Harris, ES and D, and Aquair <http://www.fords-mtm.com/alt-engy/hydro.htm>; Water Turbine.com features micro-hydro Nautilus and Neptune systems <http://www.waterturbine.com/>.
- <sup>24</sup> Massachusetts Department of Environmental Protection, Bureau of Policy and Planning, Innovative Technology, tested a four Gorlov Turbine, 5 KW system which supplies power for a 14-room hotel. <http://www.state.ma.us/dep/bspt/it/ithome.htm>.
- <sup>25</sup> Minnesota Environmental Quality Board, Wind Energy Section. EQB oversees power plant siting. Information on both pending and permitted wind energy projects; <http://www.mnplan.state.mn.us/eqb/wind/projects.html>.
- <sup>26</sup> Jacobson, Mark and Gilbert Masters, Department of Civil and Environmental Engineering, Stanford University, "Energy: Exploiting Wind versus Coal," *Science* 2001. August 24; 293:1438; <http://www.sciencemag.org/>.
- <sup>27</sup> McGowan, Jon G. and Stephen R. Connors, "Windpower: A Turn of the Century Review," Annual Reviews, *Energy Environment*, 2000. 25:pp147-197.
- <sup>28</sup> Governor Jesse Ventura stated that 10% of the state's total electric power should come from wind power in the near future. Upper Midwest Renewable Energy and Agriculture Summit, St. Paul, Minn., Feb. 4, 2002.

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- <sup>34</sup> U.S. Dept. of Energy, "Form EIA-906 Database Monthly Utility Power Plant Database," Generation. <http://www.eia.doe.gov/cneaf/electricity/page/eia906u.html>. U.S. EPA, Air Emissions Data, Minnesota Coal Power Plants, <http://www.epa.gov/air/data/sources.html>.
- <sup>35</sup> Minnesota Dept. of Commerce, Energy: Modern Technology—Solar, <http://www.commerce.state.mn.us/pages/Energy/ModTech/solarmain.htm>.
- <sup>36</sup> Schmitz, Gary, spokesman for U.S. DOE National Renewable Energy Laboratory, Golden, CO; <http://www.eren.doe.gov/>.
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- <sup>39</sup> U.S. Dept. of Energy Photovoltaics Program, Publications: "The U.S. Photovoltaic Roadmap." <http://www.eren.doe.gov/pv/onlineind.html>.
- <sup>40</sup> Austin Energy made a "commitment to help drive down the cost of producing solar power and bring clean, renewable solar energy to Austin and other American communities" <http://www.austinenergy.com/solar-explorer/>.
- <sup>41</sup> Solar Electric Power Association, News and Publications, <http://www.solarelectricpower.org>.
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- <sup>45</sup> Walcott, Barbara, *Mechanical Engineering*, October 2001, "Solar Gains," pp. 66-67. <http://www.memagazine.org/>.
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- <sup>55</sup> U.S. EPA Office of Air and Radiation, “Space Conditioning: The Next Frontier,” April 1993, p. ES-5, publication number 430-R-93-004. Additional information available from GeoExchange, <http://www.ghpc.org>
- <sup>56</sup> State law requires regulated electric utilities to invest 1.5% of their state revenues in Conservation Improvement Programs, CIP, (except Xcel Energy, which must invest 2 percent). Regulated gas utilities are required to invest 0.5% of their state revenues into conservation programs. Cooperative and municipal utilities are required to invest 0.5% of their revenues in conservation programs. The cost of CIP programs is billed back to customers of these utilities. <http://www.commerce.state.mn.us/pages/Energy/MainCIP.htm>. Energy Assets Xcel Energy CIP Program participants are saving an estimated total of \$14 million annually in energy costs. The program has reduced peak electric demand by 54 megawatts, enough electricity to power approximately 54,000 homes. <http://www.commerce.state.mn.us/pages/NewsReleases/Releases2001/News011011.htm>.
- <sup>57</sup> This web site contains all of Seattle’s ordinances and resolutions. The following ordinances were referenced for this section; 120253, 30359,30280,113795,30144. <http://clerk.ci.seattle.wa.us/~public/leghome.htm>.
- <sup>58</sup> Minnesota Planning will coordinate an investigation in 2002 of the costs, benefits and possible pathways for a transition to a hydrogen-based economy, and will seek to develop a consensus among experts and stakeholders on what, if any, investments the state should make to prepare for such a transition.
- <sup>59</sup> Minnesota Pollution Control Agency, “Automobile and Heavy Duty Vehicle VMT, Fuel Consumption and Mileage” data sheet.
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- <sup>62</sup> Calculation update, P. Ciborowski, 11/2001, Minnesota Pollution Control Agency, 2001 legislative report, *Air Quality in Minnesota: Problems and Approaches*, Appendix H, “Global Climate Change.” <http://www.pca.state.mn.us/hot/legislature/reports/2001/airquality.html>.
- <sup>63</sup> Morse, Tim; Minnesota Department of Administration Travel Management Division, October 2001.
- <sup>64</sup> In 1992 the federal government sought to decrease dependence on foreign oil through passing the Energy Policy Act (EPAAct). The Act requires states to purchase 75% of their light duty vehicle acquisitions, destined for metropolitan areas, to be able run on alternative fuel. The State of Minnesota has exceeded this requirement.
- <sup>65</sup> Wang, M. C and D. Santini, Argon National Laboratory, Center for Transportation Research, Energy Division, “Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions,” January 1999.
- <sup>66</sup> U.S. DOE, Transportation Data Book, ORNL-6958, Sept. 1999, “Fuel-cycled energy use and GHG emissions for passenger cars. <http://www.ott.doe.gov>.
- <sup>67</sup> Minnesota Pollution Control Agency, 2001 legislative report, *Air Quality in Minnesota: Problems and Approaches*, Appendix B, “Particulate Matter.” <http://www.pca.state.mn.us/hot/legislature/reports/2001/airquality.html>.
- <sup>68</sup> U.S. EPA, Fuel Economy Ratings; <http://www.fueleconomy.gov>.
- <sup>69</sup> U.S. Department of Energy, Hydrogen Information Network, Hydrogen the Fuel of the Future. <http://www.eren.doe.gov/hydrogen/basics.html>. Other hydrogen sites: <http://www.tcorp.com/nha/h2.htm>.
- <sup>70</sup> Stuart Energy—Hydrogen Bus Fueller supplies on-site, hydrogen fuelers for such transit companies as Coast Mountain Transit, Vancouver; Montreal Urban Transit Authority; University of California, Los Angeles; Xerox Corporation, Los Angeles; and SunLine Transit, Palm Springs for their fuel cell buses. <http://www.stuartenergy.com>.
- <sup>71</sup> SunLine Transit Agency web site, Hydrogen—fuel cells. [www.sunline.org/education/education\\_middle.html](http://www.sunline.org/education/education_middle.html).
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<sup>72</sup> Sigfusson, T. I. and B. Arnason, Science Institute, University of Iceland, Reykjavik, “New Perspectives for Renewable Energy in Iceland,” also published as “Iceland, A Future Hydrogen Economy,” *Renewable Energy Focus*, July/August 2000.

<sup>73</sup> Mazda is public road testing “Premacy FC-EV,” a methanol fuel cell vehicle based on the Mazda Premacy; <http://www.mazda.com> search for Premacy FC-EV. Daimler-Benz is piloting use of a similar methanol fuel cell system in its Mercedes NECAR III. Methanol was chosen over gasoline and diesel because of its higher efficiency level and potential as renewable fuel; <http://www.mercedes-benz.com/e/default.htm> search for NECAR III.

## Pollution-free Electricity

Renewable energy sources such as wind and solar produce pollution-free power, but the flow of electricity from wind turbines or photovoltaic panels is intermittent. Energy is only provided when the wind blows or the sun shines. But how can you store energy from intermittent sources so it can be available at any time?

### Renewable hydrogen power

Hydrogen can store energy efficiently. When electricity is applied to water molecules ( $H_2O$ ), you can separate the hydrogen (H) from the oxygen (O) atoms so that the hydrogen can be stored for later use.

A **fuel cell** uses hydrogen as a power source to create electricity through a simple electrochemical process. The only by-products from the fuel cell are breathable oxygen, drinkable water and some heat.

- a. Through a simple chemical reaction, a “proton exchange membrane” removes an electron from a hydrogen atom.

- b. The freed electron travels through a wire to power any electrical device.
- c. The hydrogen atom, minus one electron, is released to the air, where it combines with an oxygen atom to form pure water.

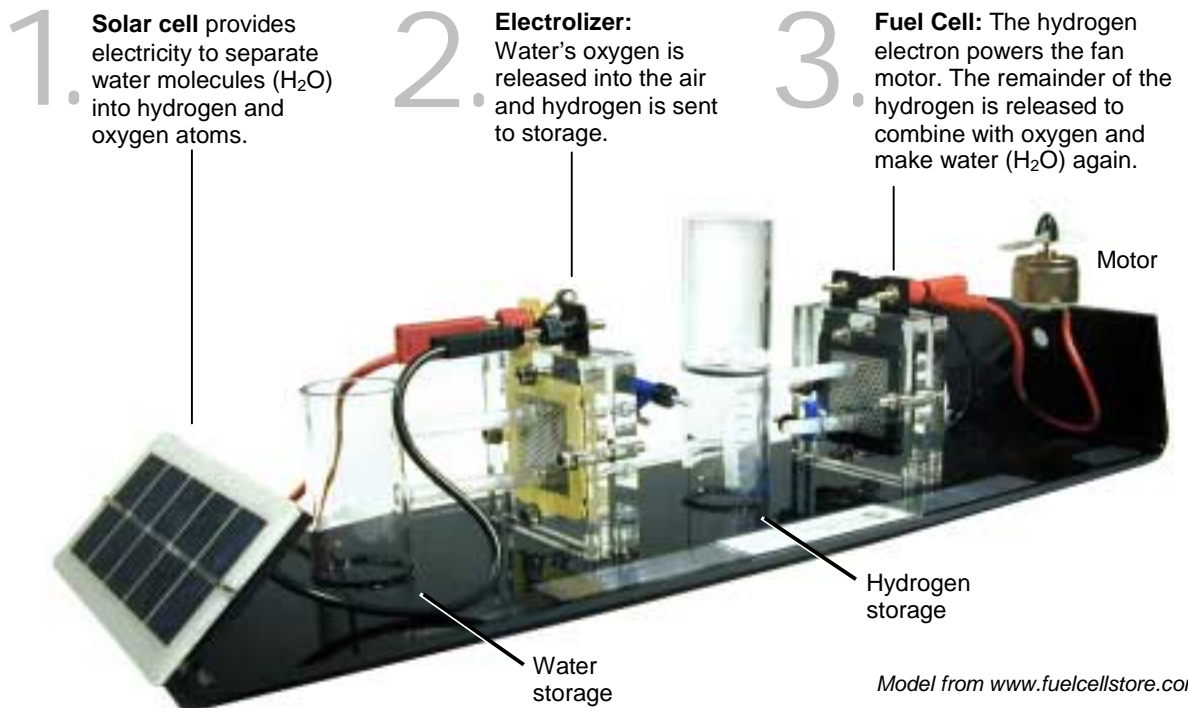
### Other hydrogen sources

Fuel cells can run on any source of hydrogen, including hydrocarbons: natural gas, methanol or gasoline. These non-renewable fuels must first be run through a converter to separate the hydrogen.

This conversion process does create some air pollution. However, a hydrocarbon-powered fuel cell generates only half of the greenhouse gases compared to when hydrocarbons are burned in internal combustion engines.

Natural-gas-powered fuel cells that are not dependent upon power plants to generate electricity are in use today. Although economic factors have kept this technology from being widely applied, its use is increasing in powering homes and buildings.

## How does a renewable, hydrogen-powered fuel cell system work?



Model from [www.fuelcellstore.com](http://www.fuelcellstore.com).



Minnesota  
Office of  
Environmental  
Assistance

[www.moea.state.mn.us](http://www.moea.state.mn.us)

520 Lafayette Rd. N.  
Second floor  
St. Paul, MN  
55155-4100

Ph: 651-296-3417  
800-657-3843  
Fax: 651-215-0246

## Hydrogen-based home energy system

Although several years away from mass market, buildings similar to this one are moving from the drawing board to reality.

In this design, rooftop solar cells provide the electricity to separate water into oxygen and hydrogen. The hydrogen is stored in underground tanks for use in the fuel cell, which would provide uninterrupted electricity for the home.



*Reprinted with permission from U.S. Department of Energy  
National Renewable Energy Laboratory.*

Is hydrogen a safe fuel? Experience has shown that risks are similar to using other flammable gases such as propane or natural gas. Today, more than 3.2 trillion cubic feet of hydrogen are used safely in the U.S.

### Other uses for fuel cells

In addition to power generation for homes and offices, fuel cells are being adapted for other uses.

Motorola, for instance, has a cell phone prototype that is powered by a methanol fuel cell. The methanol cartridges will last up to ten times longer than a rechargeable battery.

Electrolux Corporation is experimenting with fuel cells in common appliances such as vacuum cleaners. Other manufacturers are experimenting with putting them in electric bicycles.

In early 2002, the Bush administration announced that it was replacing a program to develop high-mileage gasoline/electric hybrid vehicles with one to develop hydrogen-powered fuel cell vehicles. Cost-competitive fuel cell vehicles are expected within ten years.

## A hydrogen economy

In the United States, interest in making a transition to a hydrogen-based energy system is growing because it would free the U.S. from the costs of dependence on foreign sources of fuel. In addition to environmental benefits, the improved economic and national security offered through use of hydrogen versus fossil fuels are increasingly recognized as in the best national interest.

On the international front, Iceland declared it will be the first nation in the world to convert to a hydrogen-based economy. With no fossil fuel reserves and abundant geothermal and hydro energy, Iceland will use electricity produced from these renewable sources to separate hydrogen and oxygen from water.

Buses will use the hydrogen directly; and fuel cells in cars, trucks and ships will use liquid methanol made by combining hydrogen with existing carbon dioxide. Existing fueling stations can be used.

The government plans to make Iceland a net exporter of hydrogen with a goal of becoming a "Kuwait of the new energy economy."

### For more information

Fuel Cells 2000 provides extensive information on fuel cells, from the basics to monthly technology updates: [www.fuelcells.org](http://www.fuelcells.org)

Plugpower is a supplier of pre-commercial, natural-gas-powered fuel cells for residential use. [www.plugpower.com](http://www.plugpower.com)

Educational desktop models of solar-powered fuel cells, manufactured in Germany, are available through their U.S. distributor, The Fuel Cell Store: [www.fuelcellstore.com](http://www.fuelcellstore.com).

Environmental benefits of fuel cells are discussed in the greenhouse gases section of the OEA's 2002 *Pollution Prevention Evaluation Report*: [www.moea.state.mn.us/berc/p2evaluation2002.cfm](http://www.moea.state.mn.us/berc/p2evaluation2002.cfm)