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WIND ENERGY
An Analysis of its Potential Role in the Future Primary Energy Mix

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The author of this paper does not possess any professional knowledge of wind energy or other energy systems. However, as an interested observer of all aspects of the Problematique, he has for sometime noted that CACOR=s investigation of future energy options focused largely on fossil fuels and nuclear; renewable energy by comparison received only limited in-depth study. Through considerable reading, especially with respect to the reasons for the recent rapid growth of wind and solar photovoltaic energy, he gradually assembled a body of knowledge on renewable energy and its future prospects, the basis for this paper on wind energy.

Before publication of this report, and with particular reference to the above background, it was considered essential to have it critiqued by persons with *professional knowledge of energy systems. The author is appreciative of the assistance provided by CACOR members John Walsh, an engineer formerly with Natural Resources Canada, and Dr. E. P. Cockshutt of the Canadian Academy of Engineering. Additionally, Marc Chappell, an engineer retired from the National Research Council and a leading Canadian authority on wind energy, provided the author with extensive and detailed comment, and important revisions to an earlier draft of AWind Energy@ are based largely upon his observations and technical knowledge.*

Wind power, a new renewable energy source, is now achieving exceptional growth. Not only did wind energy=s annual world growth rate increase at an average of 25% during the decade of the 1990s, but this high level of growth increased to over 30% in 2000 and 2001. Germany maintained its world lead by adding an additional 1,890 megawatts in 2001 for a total installed capacity of 8,000 megawatts, while the United States was in second place with 4,258 megawatts, and added 1,694 megawatts in 2001, representing a 63% increase in a single year. Wind energy has not only greatly exceeded other primary energy growth rates during recent years but it has achieved significant cost declines, and further declines are anticipated. Admittedly, the above growth percentages apply to very low base levels compared to other primary energy sources. But if the present growth of wind power continues, an important change in the energy picture could emerge during the first few decades of the 21st century.

Interestingly, and despite the encouraging growth of wind energy with a minimum of tax incentives, subsidies and externalized costs(1), many if not most energy authorities continue to view renewable energy as assuming only a minor role in the primary energy mix during the early decades of the new century. There appears to be no real expectation that renewable energy, including wind, will reduce our present excessive dependency on fossil fuels, with their release of carbon dioxide into the atmosphere being the leading cause of global warming. This level of skepticism from widely accepted energy authorities cannot be ignored. An examination of the present energy outlook is therefore an essential first step in an analysis of the future role of wind in the primary energy mix.

A review of present conventional, or business-as-usual, global primary energy expectations is important for at least four reasons:

1. No primary energy source can be examined objectively in isolation from all other sources. Perspective on the total energy picture is necessary;

2. The magnitude of global energy requirements today is not only enormous but is increasing. A full appreciation of present day energy use, and the Aexpected@ direction of future trends, is critical to any valid analysis;

3. Business-as-usual projections will be less than realistic should key

assumptions be in error. Examples include: energy source constraints (resource depletion), new technological innovations (improved energy efficiency, micro power systems, etc.), or incorrect prediction of the rate and magnitude of global changes (global warming); and

4. Projections of future global energy requirements, based upon present conventional thinking, can provide a useful reference scenario for comparison with other scenarios based upon alternate energy policies and different assumptions.

It is beyond the scope of this paper to provide a comprehensive review of the present and future global energy picture based upon original data. Therefore, for the purposes of this analysis a brief abstract is recorded below of World Energy Outlook 2000, the biennial flagship publication of the International Energy Agency, based in Paris, France. WEO 2000 has been described by IEA as Aby far the most complete and sophisticated global energy model in the world@ and A the point of reference for the energy world.@

The purpose of WEO 2000 was to provide IEA=s latest world energy projections from 1997 (the base year) to 2020, and to identify and discuss the main issues affecting demand and supply over that period. The report was based upon the following assumptions: C Global economic growth for the period would be more than 3%, close to the rate observed since 1990; C Population growth would continue but at a reduced rate; C Fossil fuel prices would remain unchanged until 2010, but would increase during the second decade of the projection; C Allowance was made for new policies and measures adopted by the Organization for Economic Cooperation and Development (OECD) countries, many resulting from commitments under the Kyoto Protocol; C Possible, potential or even likely future policy initiatives were excluded from the scenario. The conclusions of WEO 2000 included: C Primary world energy would increase at the rate of 2% per annum, or by 57% between 1997 and 2020; C World energy use and carbon dioxide emissions will increase steadily and will be significantly higher than required to meet commitments under the Kyoto Protocol. C Fossil fuels will account for 90% of the world=s primary energy mix by 2020, up slightly on 1997. In 2020 oil will represent 40%, natural gas 26% and coal 24% of the primary energy mix. Total oil consumption is projected to be 115 million barrels per day in 2020 compared to 75 million barrels per day in 1997, representing a 53% increase during the period. C The OECD consumption share will decline in favour of developing countries. The reliance on imported oil and gas of the main consuming regions, including the OECD and the dynamic Asian economies, will increase substantially. C World energy intensity (primary energy demand per unit of GDP) is expected to decline by 1.1% a year, equal to the historical rate since 1971. C Nuclear energy will remain unchanged during the 20 year period. Consumption of nuclear energy as a percentage of total energy declines from 7% to 5%. C Hydro power will increase by some 50% during the projection period. Over 50% of hydro=s increase will occur in developing countries, but hydro=s share of the total energy mix falls slightly; C The growth rate for non-hydro renewable energy, including wind, solar, geothermal, tide, wave energy and biomass, is expected to be 2.8% per annum but will increase to only 3% of the energy mix in 2020, compared to 2% at present. The IEA report states that renewables will Aremain expensive compared to fossil fuels.@ C World electricity power generation increases an average of 2.7% per year for the period through to 2020. Its share of primary energy use increases from 36% in 1997 to 38% in 2020. Coal maintains its position as the world=s largest source of electricity generation. Natural gas-fired generation increases by more than three-and-a-half times its present level, while the share of oil falls from 9% to 6% in 2020, and nuclear decreases from 17% to 9%. In the OECD area electricity generation from renewable energy doubles from 2% at present to 4% in 2020.

The IEA study mentions several uncertainties in their projections including macroeconomic conditions, supplies and costs of fossil fuels, environmental policies (e.g. climate change policies), the role of nuclear power, and developments in energy technology.

While the IEA report acknowledges uncertainties, there is reason to believe that their projections may be in error by a wide margin. The future is always difficult to predict and it is well to recall that oil represented only 2% of United States energy usage in 1900, and about 1% globally. There was not the slightest expectation at the time of the change in energy consumption which would occur during the early decades of the 20th century. The world is much more complex today than it was 100 years ago, a fact that makes it more difficult to predict the future with confidence. It is therefore entirely possible that the beginning of the 21st century may see a change in the energy mix of a similar magnitude. In fact there are at least three reasons to suspect that WEO 2000 will be as far removed from reality as conventional energy opinion was 100 years ago.

1. Petroleum Fuel Supply
The point of maximum production of any non renewable resource tends to coincide with the midpoint of the depletion of the resource. This view, first expressed by Dr. M. King Hubbert with respect to oil in the 1950s, explains that when the world reaches peak oil production (referred to as the Hubbert peak), the world will have used half of all the recoverable conventional oil that ever existed on the planet. To determine the date of peak production we need three numbers: our present rate of oil consumption, the rate consumption is increasing, and the total amount of oil (referred to as the Ultimate). The first two figures are known with reasonable accuracy but the third can only be estimated. Through the use of highly sophisticated studies, the best estimate of oil=s Ultimate ranges between 2.1 and 2.8 trillion barrels for all recoverable conventional oil. Based upon the above reasoning, and virtually all authorities on the world=s oil supply are agreed that the resource is finite, the Hubbert Peak will be reached before 2050, and a consensus of authoritative opinion indicates

that the Peak will occur between 2015 and 2020. One authority on this subject, CACOR=s John Walsh, expects the peak to occur in the 2017 to 2020 period(2). One approach to calculating the shortfall after the peak estimates a need for 8.2 million barrels of **non conventional** oil a day, or about 7% of total oil requirements, within a time frame of three years.

The above numbers of course refer to **world** petroleum supply. If individual countries are considered a very different picture emerges. The USA in fact reached its Hubert Peak in about 1970, over 30 years ago. Non OPEC countries, principally non middle east producers, are expected to reach their peak production before 2010, thus placing most of the industrialized world in a position of still greater dependency on OPEC oil.

It can thus be seen from the above discussion that reliance on oil to provide 40% of the world=s energy in 2020, an amount some 53% greater than 1997 production, is not only exceedingly uncertain but reliance on the IEA projections could prove dangerous.

2. Climate Change

Only two months after the International Energy Agency released its WEO projections in November, 2000, the Intergovernmental Panel on Climate Change released its latest report stating that average world temperatures are expected to rise between 1.4 to 5.8 degrees Celsius (or 2.5 to 10.4 degrees F) during this century, clearly a more serious threat to the planet than earlier calculations had indicated. The IPCC report warned that the increased levels of greenhouse gases in the atmosphere will bring more frequent droughts, heavier storms, rising oceans and heat waves.

Prior to the industrial revolution carbon dioxide in the atmosphere was about 280 parts per million (ppm); at the end of the 20th century it had increased to 370 ppm, with an average increase during the last two decades of 1.5 ppm/yr. These figures represent a 32% increase in carbon dioxide above the pre industrial era and 17% since 1958. It was earlier thought that the world may be able to tolerate carbon dioxide at double its pre industrial era level, or 560 ppm, but it now appears that the present level of 370 ppm may already exceed what may be acceptable. The IEA=s conclusion that carbon dioxide emissions will increase steadily, and will be significantly higher than required to meet commitments under the Kyoto Protocol, can be expected to meet with strong opposition from most countries.

The post Kyoto Protocol, agreed to by nearly all world countries (the U. S. excepted) on July 23 and 24, 2001, indicates that the participating nations will soon tighten their emission regulations, increase taxes on the consumption of fossil fuels, provide tax incentives to reward efforts to cut emissions, and develop cleaner energy technologies. The result of these measures will be to improve the competitiveness of non fossil fuel energy, including wind and other renewable technologies, and thus further contribute to placing in question the validity of the IEA projections.

3. Growing Competitive Advantage of Renewables

Quite apart from the above considerations, there is now evidence that the annual growth rate of non-hydro renewable energy will far exceed the 2.8% annual growth rate expected by the IEA. Not only does the growth rate of wind energy during recent years exceed by a wide margin the IEA percentage for renewables but it may soon become more cost competitive than thermal generating systems. Other renewable energy technologies, including solar, biomass, geothermal and wave energy are also achieving either significant growth rates or show promise of a major advance in the near future. As one example, and not unlike wind energy, solar photovoltaic has achieved an over 20 % growth rate since 1990.

With the above assumptions and conclusions of the IEA providing a background reference for global energy requirements and trends, based largely upon business-as-usual energy use expectations, present wind power growth and its promise during the period through to 2020 will be examined.

Wind Power

Although windmills were first introduced to pump water and grind grain in China and the Middle East over 2000 years ago, and were used for this and similar purposes until recent times, the new high-tech wind turbines of today were developed a mere 20 years ago. Unlike the windmills of old, the new wind machines are electricity generators, and the electricity they produce is usually fed to an electric grid to run a modern industrial economy. As stated at the beginning of this paper, wind energy generating capacity has grown rapidly since the new machines were first introduced in about 1980. Worldwide installed generating capacity, now in excess of 24,000 megawatts, has multiplied fourfold in the last five years, and there are indications that its growth rate is accelerating. While wind=s present electricity generation capacity is less than 1% of the world=s electricity needs, if its present rate of growth continues wind energy will occupy a significant place in the primary energy mix within a very few years.

Europe is in the forefront of wind energy. Denmark, the world leader in wind turbine technology, is now receiving 18% of its electricity from wind power. The northernmost state of Germany, Schleswig-Holstein, receives 19%, and Spain=s industrial state of Navara now gets 24% of its electricity from wind. The European Wind Energy Association, which recently increased its 2010 target for wind energy in Europe from 40,000 to 60,000 megawatts, estimates that wind could supply 10% of the **world=s** electricity by 2020. While Europe remains in the lead, other countries, particularly the USA, India, China, and Argentina, are now launching ambitious programs to increase their wind generating capacity(3).

It must be acknowledged, however, that until recently the suggestion that wind energy has the potential to compete with conventional thermal generating systems, whether fossil fuel or nuclear, was often viewed with mild amusement by energy authorities. This attitude should not be surprising. As has occurred repeatedly in history, whether in science and technology or in other areas of human endeavour, major change of any kind is often greeted with skepticism, even ridicule. A new energy system is no exception. A response to doubts about wind energy=s potential requires an objective review of the appeal and special characteristics peculiar to wind power, an understanding of wind energy fundamentals, the technology of today=s advanced wind turbines, cost competitiveness with other technologies, and consideration of closely related technologies with particular reference to the rapid advance of the fuel cell as a successor to the internal combustion engine. Each of these areas of study help to explain wind energy=s recent growth momentum and will be discussed below.

Wind Energy=s Appeal and Special Characteristics Unlike fossil fuels and nuclear, the source of wind energy is free and inexhaustible. Wind energy by definition is not subject to any form of foreign control, interruptions in supply, shortages, or price fluctuations. A country=s energy security, therefore, to the extent it is based upon wind power, ceases to be a problem, a matter of great importance to countries like the United States which now imports just under 60% of its oil needs.

Also unlike other energy sources, prime wind sites are widely distributed throughout the world and there are few countries that do not possess land and/or offshore areas suitable for the installation of wind turbines. In the case of the United States, as one example, it is stated that wind farms located in the states of North Dakota, Kansas and Texas could generate all of the country=s electricity needs. It is probable that most wind farms on these and other mid west and western American states will be located on agriculture or ranch land, a highly compatible financial and geographic arrangement.

The wide distribution of winds availability makes possible small scale power sources, rather than large centralized thermal power plants. This characteristic of wind energy allows the power source to be located closer to the user of electricity, and thereby reduces the need for large scale electric grids. The reduced need for grids in turn means that transmission power losses are also reduced.

Still another advantage of wind energy systems is that they are modular and have rapid (less than a year) construction and development time periods. Generation capacity can therefore more accurately follow near-term demand-growth forecasts, rather than having to react to 10 to 15 year forecasts typical of the realization period for nuclear, fossil and large hydro installations.

Considerable savings in Ainterest during construction@ come from short lead times, and expenses related to over (or under) capacity are greatly reduced.

The reduced need for large scale electrical grids is a factor of great potential importance to rural village communities in many developing countries. There are today about two billion people in the developing world, a third of the world=s population, who do not have electricity, and most of this number are not in close proximity to an electric grid. Wind energy may therefore be able to provide a financially practical alternative for a large number of people to receive the benefits of electricity. For similar reasons, wind also has considerable appeal to island communities.

Also unlike other energy sources, the adverse effect of wind energy on the environment, human health and safety is minimal. By reducing the amount of carbon dioxide released into the atmosphere the threat of global warming is reduced. For example, a single 750 kilowatt wind turbine produces approximately two million kilowatt hours of electricity annually, the coal equivalent to the displacement of 1950 tons of carbon dioxide each year, or the amount absorbed by 650 acres of forest. It has also been calculated that a single 660 kilowatt wind turbine will displace the oil equivalent of 1,100 tons of carbon dioxide, six tons of sulphur dioxide and four tons of nitrogen dioxide.

Wind generated electricity also has a human safety benefit compared to other energy technologies. Injuries related to the operation of wind turbines are almost unknown.

There is evidence that wind energy, because it is more labour-intensive, has the advantage of creating more jobs than other electricity generating systems. For example, Germany, the present world leader with an installed capacity of 8000 megawatts (at the end of 2001), or close to 3% of the country=s total electricity generation, supports over 35,000 jobs in manufacturing, installing and operating wind turbines. Comparative numbers for coal are 80,000 jobs for 26% of Germany=s electricity generation while nuclear supports 38,000 jobs for 33% of the country=s electricity. The job advantage of wind generated electricity is therefore almost four to one compared to coal and ten to one compared to nuclear. In another example, the State of New York Energy Office states that 27% more jobs are created than coal generating plants and 66% more than a natural gas plant per kilowatt hour generated.

Finally, it is important to note that world wind power is expected to grow to a $43.5 billion(5) industry by 2010, compared to $4 billion in 2000, representing an annual growth rate of over 40%.

Wind Energy Fundamentals

The kinetic power in wind is proportional to the cube of the wind speed, the area swept by the rotor blades, and the air density. However, the power curve of a typical utility-scale wind turbine does not follow the cubic relation over the full operating range of wind speed. Power output is controlled at or near the Arated@ value by altering the pitch of all or parts of the blades, or by clever aerodynamics which creates progressive stall along the blade length as wind speeds increase. The shape of the performance curve, the non-linear relation of kinetic power to wind speed, and the relative durations of wind above and below average wind speed, combine to make energy output approximately proportional to the square of average wind speed. This means, all other factors being equal, that a wind turbine at a site where the average wind speed is 5 meters per second (m/s) will produce about 56% more electrical energy than the same turbine when the average wind speed is 4 m/s. The speed of the wind, as well as the design of the turbine, is therefore critical to maximize the cost effectiveness of the generation of electricity from wind.

Another issue influencing wind energy output is the increase of wind speed with height. Wind speed increases in the earth=s boundary layer by 12% for every doubling of height. Since meteorological data quote wind speeds at a standard height of 10 meters, a turbine rotor at the top of an 80 meter tower, as one example, would produce double the energy output than it would at 10 meters.

Average annual wind speeds exceeding a minimum of 5 m/s (18 kilometers per hour) are required for cost effective wind turbines, and maximum electrical power output is achieved at 15 m/s (53 kilometers per hour). At very high wind speeds, e.g. 80 k/h, wind turbines are automatically shut down. These wind speed requirements mean that the geographic location of a wind turbine, or a wind farm, is of great importance to the achievement of cost effective wind energy.

Load factor, also called **capacity factor**, refers to the percentage of electrical energy generated by a power plant (wind turbine, thermal generator, etc.) compared to the net amount, or installed capacity, which could be generated if it was operating at its maximum power throughout the year. No electrical generation system achieves a load factor of 100% because of routine maintenance, unexpected breakdowns, insufficient water for hydro or wind for wind turbines, etc. Understandably, and as shown in the table below, wind energy because of its intermittent nature, has a lower load factor than most other energy technologies.

Energy System	**Load Factor**
Combined Cycle Gas Turbine	70-85%
Coal	65-85%
Nuclear Power	65-85%
Hydro	30-50%
Wind Energy	25-40%
Wave Power	25%

Although the load factor of wind energy is in the 25-40% range, wind turbines generally produce electricity for about 80 to 85% of the time. Since the wind speed will be below the maximum (and optimum) 15 m/s speed for much of the time, the calculated load factor is at a much lower level.

As explained earlier, wind generated electricity is usually fed into an electrical grid. An important question concerning wind energy relates to the effect its intermittent nature will have upon the reliability of the grid to deliver electricity to users when, and in the amounts, required. Most electrical grid systems depend upon energy generated by several sources and what is described as a **capacity credit** can be calculated for each. For example, the **capacity credit** of wind can be calculated by determining how much of the existing power generating capacity could be replaced by wind power, without any loss to the reliability of the system. For low levels of wind energy penetration into the grid (20% or less), the intermittent nature of wind is not a problem, and the capacity credit of wind is about the same as the installed capacity multiplied by the load factor. For levels of penetration above this percentage, reserve energy Aon demand@, usually referred to as **spinning reserve**, would have to be increased to meet possible maximum energy demand contingencies.

In terms of practical application, in the case of a wind farm with an installed capacity of 100 megawatts, a level of wind power penetration of 20% into the grid, and a calculated wind load factor of 30%, wind power would reduce the need for 30 megawatts of thermal generating capacity. This means that either existing thermal generating plants could be reduced by 30 megawatts or future construction of thermal generating plants could be reduced by this amount.

Wind Turbine Technology

Today=s modern wind turbines were first developed in Denmark in the late 1970s and early 1980s(4), and about 60% of all turbines that were installed in 2000 were manufactured by Danish companies or licensed by them. The new horizontal axis machines had either two or three blades, rotor diameters ranged up to 65 meters and blades usually rotated at 15 to 50 revolutions per minute at either constant or variable speeds.

The early machines have been succeeded by the development of more advanced wind turbines, drawing heavily from aerospace technology. The new turbines have variable pitch blades and are able to maintain a relatively slow constant or variable speed through a new generation of electronic variable-speed drives to increase the turbine=s efficiency. The turbine equipment, including a braking mechanism, is coordinated by microprocessors. Sensors monitor the direction of the wind and a yaw mechanism turns the turbine to face the direction of the wind. Wind turbine towers range from 25 to 80 meters in height. The new machines are also much quieter than earlier models and it is understood that a normal speaking voice is sufficient for conversation directly underneath an operating turbine.

The capacity of wind turbines range from a few kilowatts to three megawatts. As discussed earlier, rated power output is proportional to the area swept by the rotor blades, hence to the square of rotor diameter. For this reason, the diameter of the area swept by the rotor blades is an important factor in determining energy output, and today there is a clear trend toward larger wind turbines in the 1 to 3 megawatt range. A l megawatt turbine is said to provide sufficient power for 300 average US households. In the United Kingdom a 600 kilowatt turbine is said to provide sufficient electrical energy for 375 households.

The reliability of European turbines is 98% or more, and downtime for scheduled maintenance is less than 1%. Apart from routine maintenance, the machines last for some 25 years without additional costs. The significant improvements in today=s wind turbines over the earlier models of some 20 years ago has greatly contributed to the dramatic fall in the cost of wind energy.

At one time concern was expressed about the energy used in manufacturing wind turbines relative to the value of the electricity generated. Recent studies in the United Kingdom indicate that the average wind farm will recover the energy manufacturing costs within three to five months, and during the turbines= lifetime it will produce over 30 times more energy than was used in its manufacture. Christopher Flavin, American co-author of Power Surge, has stated that Awind power pays back the energy investment in a year or two@. Marc Chappell, a Canadian wind energy authority, has stated if Apayback times@ include both emissions as well as energy payback, not an unreasonable assumption if the requirements of the Kyoto Protocol are to be met, a turbine with a 25 year life expectancy will produce about 100 times the cost of the energy used to manufacture and install it.

Wind Energy Cost Competitiveness
When the first utility-scale wind turbines were installed in the early 1980s, electricity generated from wind cost over 30 cents per kilowatt hour. Today=s state-of-the-art wind farms are now able to generate electricity at about 4 cents(5) per kilowatt hour, an enormous improvement in 20 years, and a price that is competitive with many thermal generating systems. Unlike fossil fuel and nuclear technologies, wind turbine generating costs are not subject to sudden fuel source price increases (wind is free!). Continuing technological improvements of wind turbines, as well as other factors discussed below which influence costs, indicates that wind generated electricity can be expected to decrease to the 2.5 to 3.5 cent range per kilowatt hour by as early as 2005. As stated earlier, the selection of wind favourable sites is a key factor in wind economics. The employment of wind meteorologists to conduct sound wind resource evaluations, as well as the siting of turbines for optimum wind energy efficiency (turbines must not shadow one other), is therefore of great

importance.

Another factor which contributes to the continuing reduction in the cost of electricity from wind is that the cost of wind turbines are getting cheaper as technology improves and the economies of scale are achieved through the mass production of components. Further, the trend toward larger wind machines reduces infrastructure costs since fewer turbines are needed for the same output.

Financing costs have long placed wind generated electricity at a cost disadvantage compared to conventional thermal generating systems. In part this difficulty is related to the common practice for wind farms to be owned and financed by private developers who do not have access to the more favourable interest rates available to public power utilities. Added to this problem is the fact that wind power is a new technology which has not acquired the same level of confidence in the financial community as the more conventional electrical generating plants. Some authorities state that the above financial considerations add as much as 30% to the cost of electricity generated from wind, compared to thermal generating systems. As wind power becomes more accepted by the public and the financial community, the present disadvantage related to financing costs can be expected to decrease in importance.

The recent trend toward the deregulation of the electrical supply, particularly in the United States and Canada, may also have important implications for renewable energy technologies. If electricity users receive an opportunity to choose a Agreen@ energy source such as wind, rather than conventional fossil fuel or nuclear energy generating sources, many will elect to do so even should the cost (excluding Aexternals@) may be marginally higher. Preliminary information indicates that providing citizens with a choice in selecting the source of their electricity is in fact beginning to have a positive influence on local wind energy growth rates.

Finally, and some contend the most serious obstacle to enabling wind generated electricity to compete on a level playing field with older conventional generating systems, is the many subsidies and tax advantages which today prop up fossil fuel and nuclear generation, benefits that are not available in the same measure to the newer energy technologies like wind. In fact, if fossil fuels were priced to reflect the harm done to human health and the environment, not only would it be necessary to remove present subsidies but a carbon tax would be levied on their use, and generation costs would exceed those for wind energy(1).

A careful analysis of the above considerations which impact on the competitiveness of wind energy, compared to the more conventional sources of energy, leaves little doubt that the cost advantages of wind will soon greatly increase its attractiveness as an alternative energy source. It is also only a matter of time before the costs of fossil fuels begin an inevitable increase related to their diminishing supply (even the IEA expects the increase to begin in 2010), thereby further enhancing the cost competitiveness of wind power.

Wind Power and Fuel Cell Technology

On January 9, 2002 the United States government announced that it had launched a partnership with domestic automakers to spur the growth of hydrogen fuel cells for the next generation of cars and trucks, and thereby not only lessen the country=s dependence upon foreign oil but reduce pollution. The new program is to include the development of a hydrogen refueling infrastructure. The U.S. government=s announcement is clearly a response to the decision by major automobile manufacturers to replace the internal combustion engine with the fuel cell for all forms of road transport. Both Daimler Chrysler and Honda plan to have fuel cell powered vehicles available in 2003. The replacement of oil with compressed or liquid hydrogen will have enormously implications for the economy of the US and all other industrial countries.

Today hydrogen comes largely from fossil fuels. There can be no doubt, however, that in the future most of the hydrogen requirement will be produced from the electrolysis of water and renewable energy will be the source of the required electrical energy. With the arrival of hydrogen as the principal energy carrier for road transport, and possibly other forms of transportation, additional support for an expansion of wind power seems certain. By converting wind generated electrical energy into hydrogen, to be used for road transport and other fuel cell purposes, the disadvantage of wind energy because of its fluctuating nature is greatly reduced.

It should also become feasible, with the further reduction in the cost of wind generated electricity, to produce hydrogen through the electrolysis of water for use as a standby fuel source C an energy storage medium C when wind or other intermittent energy sources are in short supply. Surplus wind power could in effect be stored as compressed or liquid hydrogen and used in fuel cells or gas turbines, thereby leveling supply requirements.

Conclusion

The growth rate of wind energy now exceeds all other energy technologies. Should its present growth continue for the next decade or more, and there is evidence that it will, electricity generated from wind could lead to a major change in the primary energy mix for many countries. The present 24,000 megawatts of installed capacity generated by wind represents a fraction of a percent of the world=s electricity needs. However, if it is assumed that the annual world growth of installed wind generated electricity will increase 20% annually (10% less than the growth rate of recent years), and the world=s need for electricity will increase at 2.7% annually (refer IEA estimate on page 3 above), Marc Chappell, an authority on wind energy and formerly with the National Research Council, has calculated that world wind energy penetration could reach 7.2% by 2020, a percentage almost double the IEA=s 2020 estimate for all non renewable energy. A table containing his calculations appears below.

YEAR WIND ENERGY END	**WIND CAPACITY MW (+20%/yr)**	**WIND ENERGY PRODUCTION Twh**	**GLOBAL DEMAND Twh (+2.7%/yr) PENETRATION**	
1998		15,000		
2000	17,000	46.5	15,821	0.3%
2001	23,000	60	16,250	0.4%
2005	47,700	125	18,075	0.7%
2010	118,700	310	20,650	1.5%
2015	295,300	775	23,595	3.3%
2020	734,800	1,931	26,955	7.2%

How does the above projection compare with estimates from other sources? A recent estimate by the European Wind Energy Association states that 10% of the world=s electricity could be supplied by wind in 2020 (refer page 6 above). The American Wind Energy Association, as well as other American sources, estimate that with continued government encouragement wind energy will provide at least 6% of the nations electricity by 2020, the amount of electricity used by 25 million households. India, the third largest wind power producer after Europe and the United States, now has 1,500 megawatts of installed capacity and expects to exceed 10,000 megawatts in the next 10 years.

The above present and projected growth rates for wind energy are clearly related to the many advantages of wind power compared to other energy sources. They include:

a) The source of wind energy is free and inexhaustible. Wind energy by definition is not subject to any form of foreign control, interruptions in supply, shortages, or price fluctuations.

b) Prime wind sites are widely distributed throughout the world and there are few countries that do not possess wind land and/or offshore areas suitable for the installation of wind turbines. The wide distribution of winds availability makes possible small scale power sources, rather than large centralized thermal power plants.

c) The modular nature of wind energy systems, and the short time period required for their installation, enables a short-term response to changing market conditions with consequent savings of Ainterest during construction@ and Aover capacity@ costs.

d) Wind energy may be able to provide a financially practical alternative for a large number of people in the developing world to receive the benefits of electricity. Wind turbines may not only help solve the availability problem, but distribution costs may be greatly reduced.

e) Unlike other energy sources, the adverse effects of wind energy on the environment, human health and safety are minimal. By reducing the amount of carbon dioxide released into the atmosphere the threat of global warming is reduced.

f) Today=s state-of-the-art wind farms are now able to generate electricity at about 4 cents per kilowatt hour, an enormous improvement in 20 years, and a price that is competitive with many thermal generating systems. Unlike fossil fuel and nuclear technologies, wind turbine generating costs are not subject to sudden fuel source price increases. Continuing technological improvements of wind turbines, as well as other factors reviewed in this paper, indicate that wind generated electricity can be expected to decrease to the 2.5 to 3.5 cent range per kilowatt hour by as early as 2005.

g) It is also only a matter of time before the cost of fossil fuels begin an inevitable increase related to their diminishing supply, thereby further enhancing the cost competitiveness of wind power.

h) Wind energy, because of its labor intensive nature, has the advantage of creating more jobs per kilowatt hour generated than other electricity generating systems.

i) By converting wind generated electrical energy into hydrogen, to be used for road transport and other fuel cell purposes, the disadvantage of wind energy because of its fluctuating nature is greatly reduced. Surplus wind power could be stored as compressed or liquid hydrogen and used in fuel cells or gas turbines, thereby leveling supply requirements.

Notes

(1) The encouraging growth of wind energy has been achieved without significant subsidies and tax incentives. Cost savings related to Aexternalities@, i.e. global warming, environmental pollution, etc., give wind energy an undisputed advantage over fossil fuels.

(2) Refer page 3 of a paper by John Walsh published in the March 2002 issue of Proceedings.

(3) Canada=s installed capacity is at present only slightly over 200 megawatts. Its wind potential, however, is considerable and its present minor role in wind energy growth appears certain to change in the next decade.

(4) During the early 1980s the US, particularly the State of California, was also

a major player in the development of wind energy. US wind industry progress was erratic for a number of years, while Europe continued a steady advance. It is only recently that the US wind industry resumed its earlier momentum in the development of wind power.

(5) All cost figures contained in this report are in US currency.

References

The information and background data contained in this report came from a large number of sources. A partial list includes:

- American Wind Energy Association
- British Wind Energy Association
- Canadian Wind Energy Association
- Danish Wind Energy Association
- European Wind Energy Association
- German Wind Energy Association
- German Wind Energy Institute
- International Energy Agency
- Earth Policy Institute
- Union of Concerned Scientists
- World Resources Institute
- WorldWatch Institute (Includes various books and published reports)
- Intergovernmental Panel on Climate Change
- US Environmental Protection Agency
- US Department of Energy
- Various wind energy periodicals including ARenewable Energy World@ and AWind Energy Weekly@