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Cash Crop on the Wind Farm

Enhancing the Value of Wind-Generated Electricity

BY ARJUN MAKHIJANI

Peter Bickel, Aiyou Chen and Brice Smith are co-authors with Arjun Makhijani of the report on which this article is based.[1]

Severe energy-related problems are emerging in the United States on a number of fronts. They range from volatile and rising natural gas prices, to security issues associated with rising oil imports, to electricity blackouts that have affected vast regions sporadically since the late 1990s. At no time since the first energy crisis in 1973 has there been such a set of vulnerabilities that has emerged simultaneously.

Moreover, the energy system is now pushing up against problems not experienced before. A long drought in the West is creating more intense concerns and conflicts over water, and thermal power plants are a huge water consumer. There is now general agreement that emissions of carbon dioxide and other greenhouse gases due to human activities are playing a significant role in climate change. A large number of combined cycle power plants fueled with natural gas have been built in the past few years, but they are being affected by high and volatile natural gas prices.

The United States has not had an energy policy in place since the Carter administration, unless leaving it to large energy companies to supply whatever demand might arise is called an energy policy. Whatever the problems and defects of the Energy Plan published by the Task Force led by Vice-President Cheney,[2] it did have the merit of putting the energy issue in the center of the national political debate in the first part of 2001. But a variety of factors, including the terrorist attacks of September 11, 2001, and the Iraq war, as well as domestic differences over energy policy, have so far resulted in an impasse.

There is no single or simple answer to solve energy problems. Solutions must be coordinated on a number of fronts technically, geographically, economically, and politically. Many, including IEER, have covered these issues.[3] Efficiency, including mileage standards for cars, is one key. Transmission infrastructure is another. Insofar as supply is concerned, it appears clear that renewable sources of energy are a central part of the answer.

Among these, wind-generated electricity is possibly the most important for the short and medium term, because its costs have come down greatly and are now comparable, overall, to conventional generation (even without attributing the costs associated with climate change or nuclear proliferation to those sources). The U.S. wind energy resource is huge — about two-and-a-half times the total electricity generation of the United States, without taking into account off-shore resources. The annual potential is the same order of magnitude as the total oil production of all the members of the Organization of Petroleum Exporting Countries.

From an environmental perspective, utilizing the developable U.S. wind energy resource (excluding populated areas, national parks, etc.) can help greatly reduce U.S. greenhouse gas emissions arising from the use of fossil fuels, when combined with improving efficiency of energy use, and other measures. In addition, the use of wind energy can have a positive impact on water conservation.

But wind is not always predictable. The costs associated with this are central

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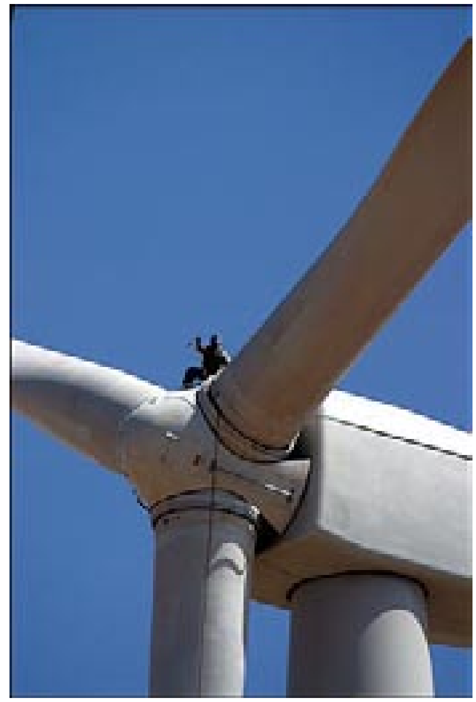

Crews construct a turbine at FPL Energy's New Mexico Wind Energy Center near Fort Sumner, New Mexico, in the summer of 2003. The facility opened in October 2003.

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to consideration of the value of wind-generated electricity to customers of electricity.

There is considerable literature on the *costs* of wind energy. A recent study that IEER produced with statisticians at the University of California-Berkeley, Peter Bickel and Aiyou Chen, added to such considerations by assessing the *prices* wind-generated electricity could fetch, given the uncertainty of future wind speed. The report, *Cash Crop on the Wind Farm*, focused on a windy site in New Mexico as a case study, and considered how wind speed forecasts, water conservation, reduction of natural gas price volatility, and reduction of carbon dioxide emissions might add up to enhance the value of wind energy.

> The U.S. wind energy resource is huge — about two-and-a-half times the total electricity generation of the United States, without taking into account off-shore resources.

The report is summarized here. References can be found in the report, which is available in its entirety on the IEER web site at www.ieer.org/reports/wind/cashcrop/index.html. The report was presented at the North American Energy Summit Western Governors' Association in Albuquerque, New Mexico, in April 2004.

Wind's potential

In the last decade and a half, a major new resource has become economically viable: energy from wind. The global land-based wind energy resource is several times the world's total electricity generation. The offshore resource potential may be even greater.

The United States is also well-endowed with wind energy in areas where it is developable. The top twelve states (of the lower 48) with high wind energy in areas with large farms and lands on which wind turbines can be built have a total potential of about 10 billion megawatt-hours (MWh), equivalent to roughly 2.6 times the total electricity generation of the United States. Figure 1 shows the details for these twelve states. This excludes offshore wind energy.

Wind energy development has been proceeding rapidly in the past few years. It is the fastest growing source of electricity. But this is from a small base. Total installed wind capacity in the United States at the end of 2003 was 6,370 megawatts (MW). This is far lower than the 28,440 MW of capacity in the European Union at the end of 2003. This is equivalent to the electricity consumption of 35 million people in the European Union and comprises 2.4 percent of the total EU electricity consumption.

In 2002 and again in 2003, Europe added almost as much wind capacity as the entire U.S. installed capacity. Wind energy meets less than half a percent of U.S. electricity demand. The present low level of U.S. use of wind is in stark contrast with its immense potential in economic, environmental, and security terms.

There are several reasons for the gap between promise and reality when it comes to wind energy. They include a lack of adequate transmission infrastructure, skewed rules for transmission and for integration of wind power into the electricity market, and the imperfect pricing structure for wind electricity. We will focus on the latter.

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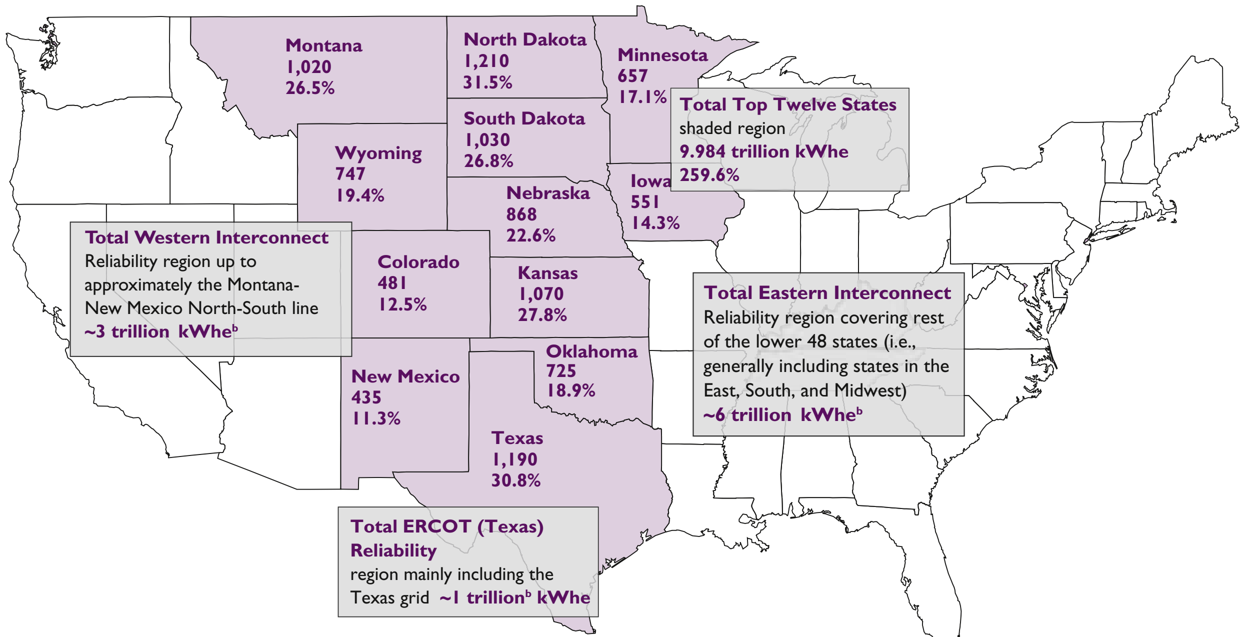
FIGURE 1. PHYSICAL WIND RESOURCE BASE IN THE TOP 12 STATES (CONTIGUOUS UNITED STATES)

Figures for each state are the annual electricity generation potential in billion kilowatt-hours electric (kWhe), followed by the corresponding percentage of total U.S. electricity generation in 2003.[a]



SOURCE: *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States.* Pacific Northwest Laboratory, 1991, as cited by American Wind Energy Association, online at www.awea.org/pubs/factsheets/WindEnergyAnUntappedResource.pdf.

NOTES: (a) Electricity generation in 2003 = 3846 billion kWh (kilowatt-hours). Source EIA. (b) The totals for the interconnected regions are approximate since the regions do not correspond exactly to state borders. ERCOT (Electric Reliability Council of Texas) includes most of Texas, but excludes a part of the Texas panhandle. Transmission is currently coordinated within the Interconnect regions.

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Pricing wind

The price of wind energy received by wind farm developers is based on the way that the value of wind energy is computed by its purchasers. Under current pricing formulas, wind energy developers often cannot meet their costs based on revenues from wind energy sales alone. The costs of wind-generated electricity, even at very favorable sites, are significantly higher than the prices that wind developers typically realize. The difference is made up by the federal tax credit, known as the Production Tax Credit,[4] and in some states a state tax credit. When the federal tax credit expires, as it did on December 31, 2003, development of new large-scale wind energy projects can grind to a halt. So far 2004 has been an essentially lost year for large-scale wind energy development in the United States. This is damaging the industry, the environment, and security.

Power purchase agreements generally provide revenues that are lower than those indicated by market considerations. In other words, wind-generated electricity should be commanding a considerably higher price, if the marketplace had a level playing field. Power purchase agreements also typically provide revenues to wind developers that are lower than the costs of production. As a result, the structure of wind energy pricing at present makes it difficult or impossible for wind energy developers to get financing for power plants unless the tax credit is in place.

The wind tax credit has wide support in Congress and is included in pending energy legislation. But the prospects for passage are uncertain at this writing, because the legislation contains many high cost and controversial subsidies to the fossil fuel and nuclear industries, at a time of high federal deficits. In states like New Mexico, the state tax credit can make up some of the difference. That may be enough to cover costs at the very best sites. The uncertainties around the federal tax credit are a major issue when it comes to the rate of development of wind energy in the United States.

The main technical goal of the IEER study was to develop a method for computing a practical *value of wind energy* that will enable wind developers to improve upon the avoided marginal cost pricing typical of large-scale wind farm power purchase agreements.

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A wind developer who can sell enough electricity to displace a new power plant that would otherwise have been built could, in principle, argue for being paid the full cost that the utility would have incurred if it went ahead and built the power plant. This cost is called full avoided cost. It is the total cost of generation of a unit of electricity, including capital costs, other fixed costs, and variable fuel and maintenance costs.

> Wind-generated electricity should be commanding a considerably higher price.

A typical full avoided cost for baseload coal power on this basis may be about $40 per MWh. Nuclear electricity prices are more variable, since capital costs of nuclear power plants, which dominate the total cost, have differed widely from one plant to the next. The full avoided cost for nuclear can range from $40 to $70 per MWh, when capital costs are included. Full avoided cost of combined cycle natural gas fired power plants, which are also used as baseload plants (though not in preference to coal or nuclear power plants if these have already been built), varies in the range of $30 to $50 or more, mainly according to the cost of fuel, which tends to dominate at prices above natural gas costs of $3 per million Btu (British thermal units). At the July 2004 spot market price of about $5.50 per million Btu, the full avoided cost for combined cycle natural gas fired power plants is about $50 per MWh. These costs are summarized in the table below.

SOURCE	FULL AVOIDED COST OF ELECTRICITY, PER MWh
Coal	About $40
Nuclear	$40 to $70
Combined cycle natural gas	$30 to $50 or more (currently about $50)

These full avoided costs must be understood in the context of the ability of these plants to provide electricity that can be scheduled—that is, the generating units that can be committed in advance by the Independent System Operators (apart from unforeseen and unscheduled outages, which are relatively rare). Wind energy cannot command full avoided costs because it is intermittent and somewhat unpredictable. In industry terms, it is not "dispatchable."[5]

Predicting the wind

But wind is not completely unpredictable. Future wind energy can be forecast with some level of confidence. The specifics depend on:

- how far in advance the forecast of wind speed is being made;
- the aggregate period of time for which the wind speed forecast is being made;
- the level of confidence with which we want to make the forecast—that is, how big an error (under-prediction or over-prediction) we are willing to tolerate, which depends on the cost of being wrong; and,
- the amount of wind speed data that exists for past time periods.

For instance, it is essentially impossible to forecast average wind speed a year or even a month ahead for a specific hour on a future day. The uncertainties around the average value will tend to be very large. By contrast, it will often be possible to make, with a reasonable degree of confidence, an estimate of average wind speed, say in July, or even for peak hours (6 A.M. to 10 P.M.) and all off-peak hours (10 P.M. to 6 A.M.) aggregated for that month, provided there are wind speed data that have been collected for a number of years.

In the same way, since there is some correlation between wind speed in the present hour and that in the previous hour, we can make an estimate of wind energy production in the next hour with some confidence (though significant errors will still tend to occur from time to time).

A basic determinant of the economic value of future wind energy is the degree of precision with which the forecast can be made. Improvements in wind forecasting can reduce the error and, hence, reduce the cost of adding wind capacity to a grid at a given level of penetration.

The statistical problem from the point of view of the wind energy seller is to develop an optimal strategy for offering hour-ahead or day-ahead sales. How much should be offered for sale, given uncertainty in future wind speed?

A statistical model that represents one reasonable strategy for optimization of sales on the spot market was developed for the IEER study. The model is described in detail in the box on the next page (for all of you econometrics wonks like us) .

Since wind can be forecast to a large extent for the next hour or next day, it can be offered for sale in advance. Because the seller cannot guarantee full delivery, she must be ready to compensate the buyer for the shortfall. The box describes how the seller and buyer would arrive at a reasonable contract. The buyer would not lose electricity in case of a shortfall, because all parties are drawing electricity from the grid. The buyer would

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be purchasing some from another source and would be billed by that source. The transactions are financial ones.

We can also think about seasonal wind energy contracts. Day-ahead wind speeds are much more difficult to predict with accuracy than wind speeds averaged over a whole season or a significant part of a season because seasonal weather patterns are driven by more predictable factors. If the contract is on an aggregate seasonal basis, the cost associated with advance contracting for wind-generated electricity (e.g., the cost to the wind electricity seller for non-windy days when windy days were predicted) will be low because the seller stands a very good chance of delivering the promised amount over the season. Further, shortfalls over a season can be made up with purchases of electricity on the spot market at suitable times. Seasonal contracts can be especially advantageous when a wind energy generator can offer to displace high price natural gas generation at the peak of summer or winter demand.

Case study: A windy site in New Mexico

We selected a site that enabled us to focus on the main problem we set out to solve: assessing how much value wind-generated electricity can have over and above avoided marginal cost. We therefore selected a site where:

- there are favorable winds;
- transmission corridors and infrastructure exist (without assessing its actual availability, since this is a methodological study rather than a study aimed at actual development of a particular site);
- road and rail infrastructure exist; and,
- the state government is favorable to wind energy development.

This last factor is a consideration, since state level policies can provide a crucial stimulus to wind power development, especially at a time when federal level

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THE MODEL

Professor Peter Bickel developed a statistical model to assess the cost of intermittent wind energy output from day to day or hour to hour. This is done by assuming that a fully developed market exists in which customers would demand firm supply. The wind farm operator makes a day-ahead or hour-ahead offer of electricity. We assume that the revenue realized for these sales is the average spot market price for the period in question. We assume that any shortfalls in supply are made up by purchasing electricity at the maximum spot market price for the same period. Finally, we also assume that the wind farm is integrated with a grid, which is suitably regulated to provide sufficient reserve capacity. The cost of shortfalls in meeting supply commitment in such an arrangement would be reimbursed after the fact to the purchaser. We do not deal with surpluses in generation in this draft of the model. Under these assumptions, the model can be developed as one that devises an optimal strategy for offering hour-ahead or day-ahead sales.

In this approach, the seller offers the electricity at the average price for the period (hour or day) prevailing on the spot market, and compensates the buyer at the maximum price for the same period in case of a shortfall in generation. The seller's optimization strategy for estimating the amount of wind-generated electricity to be offered is based on the ratio of the average price to the maximum price. If the ratio is close to one, he offers a large amount for sale, since the cost of being wrong is low. If the ratio is much less than one, he offers a small amount, since the cost of being wrong is high.

We want to examine the value that past knowledge of wind speed or power production has on gross income expected from wind energy sales by a utility generating wind energy.

The Four Corners hub is one of the major points of export of electricity westward from New Mexico. We do not have a long time series for wind data and assume, for the purposes of this illustration, that the wind data from the time period are sufficiently representative that they will not affect the broad quantitative conclusions of presented here.

The technical framework for the model is that a wind farm operator can commit to selling an amount of electricity in advance, based on his expectation of what the output of wind energy would be in the future period for which the commitment is being made and the cost of falling short. Any shortfalls in the commitment are met by purchases from the grid. This technical arrangement requires that an advance agreement be made that a wind farm operator will purchase grid electricity from some other entity that either has surplus capacity on line or is maintaining spinning reserve. This arrangement provides a form of insurance to the wind farm operator that he will be able to meet sales commitments even if the predicted wind does not materialize.

Having fitted the model, we can now use it to predict respectively, daily, hourly output in a given time frame—say, April 2000. The output on April 2 would be based on the output of April 1. Sales commitments are then based on the predicted day's (or hour's) maximum and average spot prices. Finally, total revenue for the month is calculated by adding up over days, respectively, hours for the month. These figures do not include any computation of revenue for excess production (more than sale commitment).

The results of this model provide an estimate of the net revenues that can be expected from a wind farm if the output is sold on the spot market, on a day-ahead or an hour-ahead basis. The model also can provide estimates of the cost to the wind farm operator of intermittent wind output, hence they also give an indication of the value of increasing the precision of the wind forecast.

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uncertainties are considerable. The site is a hypothetical wind farm located at New Mexico Site 604 in San Juan.

In considering spot market sales, we assume that the sales take place at the Four Corners hub in northwestern New Mexico, for which we have spot market data for the year 2003. The overall cost of wind electricity delivered to the Four Corners hub, where electricity is traded, is $44 per MWh.

Figure 2 shows the realized price, the cost, and the realized price plus the $10 per MWh New Mexico production tax credit. With the New Mexico production tax credit, the price realized is a little lower than the average cost. This shows that, in the example we have considered, wind energy sales may be able to realize nearly full cost on a spot market basis with the New Mexico production tax credit, but without the (now expired) federal tax credit.

We might summarize the actual situation at Four Corners as follows. While the Four Corners hub transmits a great deal of power that is generated in the area (several thousand megawatts of power plant capacity exist there) as well as power that traverses the hub, almost all of it is sold under longer term contracts between individual buyers and sellers who are simply using the transmission corridor, instead of being sold on the spot market. Four Corners cannot serve as the hub for large-scale spot sales of wind-generated electricity unless there is a far more developed spot market there— i.e. unless the volume of hourly sales is considerably higher.

This provides one indication that development of wind energy is still possible even without relying on the federal production tax credit, provided suitable markets exist. Of course, as we have seen, the Four Corners hub is not a suitable market as yet. Next we will consider sales of wind energy, in the context of a large commercial customer in New Mexico, the Chino Building in Santa Fe, where sales are regulated.

The Chino building is used by the State of New Mexico as an office building. We were provided with the building electricity use details for 2003 and the corresponding electricity prices by the person responsible for the utilities in the building.

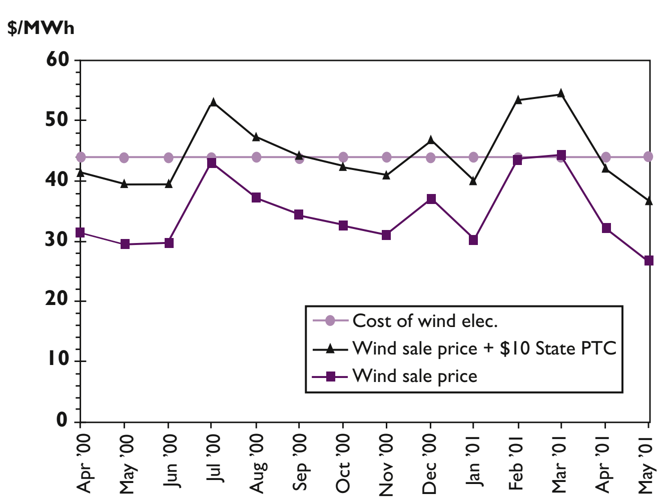
The curves in Figure 3 show the hypothetical purchase of energy by the Chino Building from a wind farm located at New Mexico Site 604. We assume that the average monthly capacity factors for July 1999 through June 2001 (circles) are the values for the wind farm for the year for which we are doing the calculations. For purposes of illustration, we assume that the contract with the wind farm would be arranged so that the wind farm supplies half the yearly total electricity used by the Chino building on a supply schedule that corresponds to the wind farm's monthly capacity factors. That is, the Chino building operators purchase a larger amount of electricity in the months of higher wind electricity generation and vice versa. Purchased power makes up the difference.

The wind pattern from this site is not very favorably matched to the Chino building demand, since it has a very high capacity factor in April, a month of low demand. The user could expect additional demand charges under such circumstances. Demand charges are fees charged by the utility for the peak electricity capacity usage by a consumer. It corresponds to the peak power demand, much like the peak horsepower demand on a car's engine during acceleration uphill, for instance.

In this case, the cost of electric utilities to the Chino building would not increase, even if half its electricity were supplied from wind farms. No subsidy from production tax credits is needed.

If wind electric capacity is assumed to be completely unpredictable, that is, if no credit is given for installed wind capacity, there would be a slight increase in the electricity bill (less than one percent). If there is an 80 percent credit for capacity (a very high upper limit), there would be a net savings of about two percent.

FIGURE 2. REALIZED SPOT MARKET PRICE WITH AND WITHOUT NEW MEXICO TAX CREDIT



Hypothetical realized prices from hour-ahead spot sales of wind-generated electricity on the Four Corners Hub, 2003 price data, 2000 and 2001 wind data. (PTC = production tax credit)

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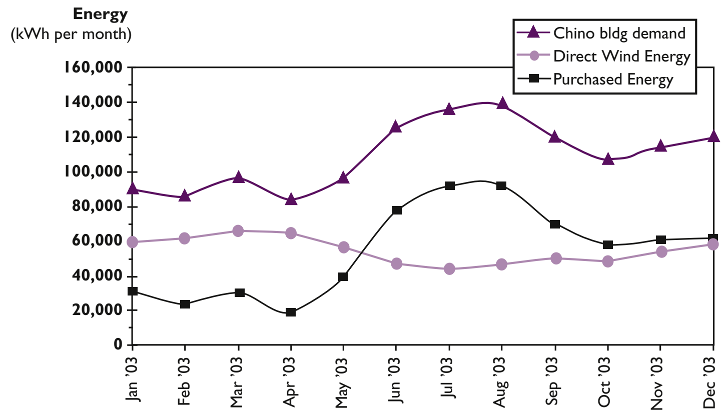
Greenhouse gas reductions

Wind energy has many other tangible benefits. New Mexico, for instance, could reduce the carbon dioxide (CO_2) emissions associated with supplying electricity to the Chino building by roughly 50 percent and still not significantly increase the building's energy bill.

As a first approximation, the reduction of purchased power by 50 percent would reduce the corresponding greenhouse gas emissions by about 50 percent also, since New Mexico electricity generation is mainly from coal-fired power plants. A more refined calculation may show a somewhat lower or higher reduction, depending on the actual mix of fuels that supplied the Chino building at various times in the year. If wind displaces nuclear generated electricity for part of the time, while increasing the relative share of fossil fuel generation in the purchased power mix, the CO_2 reduction would be less than 50 percent. If wind displaces coal preferentially, and increases the share of hydropower and nuclear, then the reduction would be larger than 50 percent. But in any event, it would be very substantial, and far greater than the proportions required under the Kyoto Protocol to be achieved by about 2010.

If carbon dioxide credits were traded in the United States as they are in Europe, the value of the reduction of CO_2 emissions would be between $2.25 to $4.50 per MWh in the case of displacing coal fired power plants and $0.75 to $1.50 in the case of natural gas fired combined cycle power plants.

FIGURE 3. ENERGY DEMAND VS. WIND AND PURCHASED SUPPLY (SITE 604)



Energy demand for the Chino building in Santa Fe owned by the state of New Mexico (triangles) as well as the postulated energy purchases from a 188 kW wind farm located at site 604 (circles) and the power purchased from other sources (squares). The average wind power purchased over the year is equal to 50 percent of the total annual demand.

Displacing natural gas

Factors such as high and volatile natural gas prices, the long lead times for building natural gas infrastructure, and security issues associated with liquid natural gas imports have raised the possibility that wind energy could be used to displace a part of the natural gas now used in electric generating plants. This can generate several different kinds of economic benefits:

- For the utility that has combined cycle natural gas capacity, it could be profitable to displace a part of it by wind-generated electricity.
- It could be very profitable to displace single stage peaking gas turbines, which are typically operated only for a few hundred hours per year, with wind energy.
- Wind capacity could provide a hedge against rising natural gas prices.
- High wind penetration into an electricity system could displace enough natural gas to help stabilize prices.
- Wind energy, when combined with efficiency improvements in heating and air-conditioning systems (notably earth source heat pumps) could displace large amounts of natural gas in the long term to make it available for displacing some petroleum use in vehicles.

Since wind-generated electricity is now far superior to single stage natural gas turbines, its use at peak times can be integrated with putting existing single stage turbines in appropriate standby modes to support wind capacity. This could be a low cost way of improving capacity credit for wind, since it does not require new natural gas turbine capacity to be built.

Single stage turbines can provide a very low cost backup capacity for wind. The gas turbines are cheap enough and gas is costly enough that it would pay to keep existing turbines idle and use wind generators, only starting up the gas turbines if the wind falls below expectations. Hence wind development can be coupled explicitly through contracts to displace natural gas use at peak times in single stage gas turbines. The avoided cost for generation and maintenance alone is on the order of $60 per MWh. This is also more or less economical in the case of combined cycle power plants, where the avoided costs are on the order of $50 per MWh at current natural gas prices.

Over a period of a few years, the value of wind-generated electricity as a hedge against natural gas price volatility might be a few dollars per MWh.

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Balancing the Energy System

Because the existence of wind at any specific future moment cannot be predicted, wind energy is "non-dispatchable." In other words, a wind power plant can deliver energy into the grid, but its availability cannot be relied upon in advance for a specific future period.

Despite wind's imperfect predictability, wind power plant capacity may be scheduled or sold ahead of time, say on a day-ahead or hour-ahead basis. However, there are costs associated with misestimation of future power generation.

In order to understand the nature of such costs, we must consider the various time-scales in the operation of a power system grid. A survey of studies on the impact and cost of the integration of wind energy into the grid (published by the National Renewable Energy Laboratory) has described this issue succinctly:

> Balancing the power system occurs over several time frames. Years in advance, for example, enough generation has to be planned and built so that there is sufficient capacity available to meet load requirements. Closer to real time, system operators forecast day-ahead load requirements and select which available generators can reliably meet the expected requirements at the lowest cost. Obtaining accurate forecasts from individual loads and generators is important, but only because collectively they constitute the aggregate forecast within a control area….
>
> Forecasting errors result in costs either because the system operator knows the forecast is unreliable and includes additional reserves in the mix of committed generation or because unforeseen errors result in the need to adjust the generation mix at the last minute. In either case, the resulting generation mix will be sub-optimal.[1]

PHOTO BY WARREN GRETZ COURTESY OF DOE/NREL

People at the base of a modern wind machine in northwestern Iowa.

Wind energy has two advantages in the longest time frame, which relates to adding capacity. Wind projects can be built relatively quickly and the incremental capacity additions can be kept small. Since power plants' long-term future load forecasts can be in error by large amounts, the long lead times (many years) for construction that are typical of coal and nuclear plants create risks that can be avoided by wind power plants.

> The long lead times for construction that are typical of coal and nuclear plants create risks that can be avoided by wind power plants.

However, there are two provisos to this statement. First, wind power cannot provide baseload capacity without costly energy storage, which could negate the advantage of short lead times.[2] Second, wind capacity additions can be made rapidly to the grid only if there is a well-developed transmission structure that connects high wind areas where the wind power plants need to be built with a regional grid. This grid should have enough capacity to carry large amounts of power. The transmission constraint is often a crucial one. With these two provisos, adding wind power plants to the grid can reduce risks from errors in long-term electricity forecasts.

There are three other time frames relevant to the energy system:

1. **Regulation:** The scale of this time frame is seconds to about 10 minutes. Adjustments in the power system in this time frame are made automatically by computer, in order to meet rapid fluctuations in demand, which are typically small relative to total demand. Rising demand in this time frame is met by power generating units that are online but not running at full capacity and by spinning reserve.

2. **Load following:** The scale of this time frame is ten minutes to several hours. This is the period over which significant changes to load can occur and must be met by the power system. Regulated utilities, which manage their own generation, transmission and distribution, have an integrated operation to ensure that there is sufficient capacity available to meet changing demand. Rising demand in this time frame is met by power generating units that are online but not running at full capacity, by spinning reserve, and by units that can be started up quickly, if necessary—typically single stage natural gas turbines or hydropower plants.
3. **Unit commitment:** This time frame involves commitment of specific units that require a relatively long time to start up and/or shut down (several hours, and sometimes longer). Since variations in electricity demand over a day and between seasons follow predictable patterns, unit commitment times are on the order of a day, several days, and according to season (so that maintenance of large units can be scheduled).

TRANSMISSION LINES AND WIND INTEGRATION

Transmission line capacity is a very major factor determining whether and how much wind can be developed in favorable areas. But there's more to it than that. The existence of a dense transmission system with sufficient capacity can increase the degree of wind penetration for a given integration cost. Even a strong distribution system can help. Much of Denmark's land-based wind capacity, for instance, does not go through a high voltage transmission system, but feeds directly into the distribution system, lowering energy losses and costs.

The term "transmission system" refers to the high-voltage long-distance part of the electrical grid, while "distribution system" refers to the local part of the grid, where the high voltage is progressively transformed into lower voltages and finally delivered to residential, commercial, and small industrial customers. Long distance electricity transmission is done at high voltages to reduce energy losses.

Wind already supplies 2.4 percent of Europe's electricity supply. Three regions in Europe have a wind penetration as high as 27 percent of capacity (Schleswig-Holstein in Germany, Jutland-Funen in Denmark, and Navarra in Spain). While we know of no detailed overall cost studies that have been done of this level of wind energy penetration, European utilities are in agreement with the political and social mandates that high wind energy is necessary to meet the goals of reducing carbon dioxide emissions. Cost estimates for future wind integration, that is, adding more wind farms to the grid, on top of this are not high.

A great deal of investment not only in wind farms, but also in infrastructure, especially transmission infrastructure, will be required before even a fraction of the physical resource base can be turned into a technical and economic reality in the U.S. energy system.

PHOTO BY WARREN GRETZ COURTESY OF DOE/NREL

Wind can be added rapidly to the electricity grid only if there is a well-developed transmission structure that connects a regional grid with high wind areas where wind power plants are built. This transmission constraint is often a crucial one.

Taken from Makhijani et al., Cash Crop on the Wind Farm, *prepared for a presentation at the Western Governors' Association North American Energy Summit, April 15–16, 2004. Online at www.ieer.org/reports/wind/cashcrop/index.html.*

1. Parsons, et al., *Grid Impacts of Wind Power: A Summary of Recent Studies in the United States.* Draft of paper presented at the European Wind Energy Conference, June 2003. Madrid, Spain. (Golden, CO: National Renewable Energy Laboratory, 2003).
2. Spatial diversity of wind power plants over very long distances connected on the same grid can alleviate a portion of this problem. Of course, this has its own issues with respect to large transmission investments and grid integration.

CASH CROP
FROM PAGE 7

Geographic diversity of wind farms

Credit for capacity can also be increased by geographic diversity and a sturdy transmission system. Large distances between areas with high wind potential can create very significant economic and reliability benefits. A European study[6] examined the correlation of winds and their effect on the grid. The study indicated that with sufficient geographic diversity, and a transmission system linking wind power plants (in this case a high voltage DC line was studied), wind capacity can be reliably integrated into the grid. In other words, geographically dispersing wind farms means that there is a higher chance that wind will be blowing in one place when it is not in another. In this sense, development of wind separated by large distances and connected by a sturdy transmission system can reduce the need for reserve capacity.

Integrating fuel cells into the mix

Fuel cells can stabilize the effective use of wind power for the consumer and open up options for cost optimization such as running them at full power during peak demand times and refilling the hydrogen reserves during off-peak hours.

Adding fuel cells considerably increases the costs of the system not only because of the high costs of the fuel cells but because of the energy losses associated with creating hydrogen from electricity and then electricity from hydrogen. These losses increase the installed wind energy capacity needed to supply a given load, such as the Chino building.

In order to determine the costs of such a system, we assumed that the fuel cell system capital cost was $4 million per megawatt, including a few days of hydrogen storage and the electrolytic cells needed to create the hydrogen. With this assumption, the costs to supply the Chino building go up substantially—by over one-third for wind-generated electricity from Site 604.

Our analysis indicates that there are no real cost advantages to integrating fuel cells into the electricity system on a large scale at the present time. However, there are advantages to adopting policies that will integrate the use of renewable energy in buildings with a goal of eliminating the use of natural gas for space and water heating. This would free up natural gas to be used as an automotive fuel, displacing imported oil, improving security, and reducing CO_2 emissions. The use of fuel cells may have a significant role in creating such an energy system.

An energy system for the future

System-wide electricity planning in which wind power displaces some use of natural gas for electricity generation could help in a transition to a U.S. energy system that has far less carbon dioxide emissions, far less air pollution, and significantly less oil imports.

By combining the various elements—wind, fuel cells, efficiency with earth source heat pumps, and use of natural gas in cars—it will be possible to greatly reduce the use of natural gas for space and water heating in the commercial sector, freeing it up for use in transportation.[7] Even a one percent transfer of natural gas from commercial space heating to vehicles would result in a reduction of 80 million gallons of gasoline per year, equivalent to the annual use of gasoline by over 100,000 cars. This would correspond to a reduction of CO_2 emissions by over 300,000 metric tons per year, as well as reduction in urban air pollution, and the achievement of national security benefits from reduced oil imports.

There is evidently a significant investment cost to such a scheme. We have not done a detailed feasibility study that would optimize the various factors. However, our study of the Chino building without optimization indicates that the cost of achieving these goals, including on the order of 50 percent reduction in building greenhouse gas emissions, would be modest if viewed as a fraction of present cost of the services that energy provides, like heating, cooling, and lighting.

The main findings and recommendations of the IEER report on which this article is based begin on page 11.

1. This article is based on a report by Makhijani et al., *Cash Crop on the Wind Farm: A New Mexico Case Study of the Cost, Price, and Value of Wind-Generated Electricity*, prepared for a presentation at the Western Governors' Association North American Energy Summit, Albuquerque, New Mexico, April 15–16, 2004. Online at www.ieer.org/reports/wind/cashcrop/index.html. References can be found in the report.
2. For a critique of this plan, see SDA Volume 9 Number 4, August 2001. Online at www.ieer.org/sdafiles/vol_9/9-4/index.html.
3. See Arjun Makhijani, *Securing the Energy Future of the United States: Oil, Nuclear, and Electricity Vulnerabilities and a post-September 11, 2001 Roadmap for Action*, Institute for Energy and Environmental Research, Takoma Park, Maryland, November 2001. On the web at www.ieer.org/reports/energy/bushtoc.html
4. In 2003, this credit amounted to 1.8 cents per kilowatt-hour ($18 per MWh); it is available for the first ten years following the commissioning of the wind power plant, after which it expires.
5. Electric power grids require dispatchable capacity so that the generation can follow the changes in load over periods of minutes or hours. Baseload plants are capable of generating electricity 24 hours a day, 7 days a week. Because wind is not available all the time, it cannot provide baseload capacity.
6. Gregor Giebel, Niels Gylling Mortensen, and Gregor Czisch, *Effects of Large-Scale Distribution of Wind Energy in and Around Europe*, undated, but appears to be have been published in 2003. Online at www.iset.uni-kassel.de/abt/w3-w/projekte/Risoe200305.pdf and the associated Power Point presentation delivered at the Risø International Energy Conference: Energy Technologies for post Kyoto targets in the medium term, held at Risø National Laboratory, Denmark, 19 - 21 May 2003. Online at www.risoe.dk/konferencer/energyconf/presentations/giebel.pdf.
7. We have not explicitly addressed the issue of solar photovoltaic cells in place of or as a complement to this system. In desertic areas, solar cells can complement wind energy, especially in cases when wind speeds are low at peak times.

Findings and Recommendations

of the report Cash Crop on the Wind Farm

Main findings

1. **Wind electricity generated at very favorable locations in large wind farms is economical today.** Consumers would not see increases in electricity bills with far greater use of wind-generated electricity, even without taking any credit for avoided water use or greenhouse gas emissions.

Consumers would not see increases in electricity bills with far greater use of wind-generated electricity.

2. **U.S. wind energy resources are enormous and can accommodate much faster growth in wind-generated electricity.** The United States has the physical wind resource base to achieve high and economical penetration of wind capacity. The wind energy potential in the twelve windiest states of the continental United States is equal to about two-and-a-half times the entire electricity generation in the United States in 2003.

3. **A policy mandate is essential if high levels of wind integration are to be achieved in a reasonable time**. Three regions in Europe have already achieved 27 percent penetration of wind capacity. This is in part because there is a strong political and policy consensus in Europe, including from industry, that reduction of greenhouse gas emissions and increasing renewable energy use are essential. Today, states are in the leadership of renewable energy as well as in the area of reduction of U.S. greenhouse gas emissions, but in the absence of an economic and political mandate, such as a Renewable Portfolio Standard, wind energy development in the United States will lag far behind its potential.

4. **The transmission and institutional infrastructure needed for large-scale wind energy development is inadequate**. Wind energy development in the United States is lagging far behind Europe mainly because the transmission infrastructure and the economic and policy consensus to develop it exists in Europe to a far greater degree than in the United States.

5. **Prices of wind energy in typical Power Purchase Agreements (PPAs) appear to be considerably lower than the price that the same electricity would fetch if sold to the final consumer.** The average price of wind-generated electricity in many PPAs is in the \$25 to \$30 per megawatt-hour (MWh) range. However, the price that the final consumer could pay, *without an increase in electricity bills*, is considerably higher. In other words, the implicit final price of wind (after taking into account transmission and distribution costs and grid integration costs) is considerably higher than wind developers are receiving. This gap between final price and wind developer revenue increases the need for tax credits. If wind developers could actually recover the implicit price being charged, development of wind power could be greatly accelerated.

6. **With the right policies and with investments in wind and efficiency, a large reduction in greenhouse gas emissions is economically feasible.** Since wind energy does not emit carbon dioxide (CO_2), and since it is economical today, given the right conditions and policies, it follows that a large reduction in CO_2 emissions is possible without increases in electricity cost. This is currently being achieved in Europe. While credits for CO_2 reductions play a role in the United States, these are modest.

A large reduction in CO_2 emissions is possible without increases in electricity cost.

7. **Federal and state production tax credits are essential under present conditions.** In the absence of a national or uniform regional mandate and adequate transmission and other infrastructure for wind integration, federal and/or state production tax credits are essential for continued wind energy development.

8. **Given natural gas prices of \$5 per million Btu or more, wind energy can economically displace natural gas generation on a marginal avoided cost basis.** The cost of wind-generated electricity at favorable locations, including \$3 per MWh for grid integration, ranges from \$38 to about \$45 per MWh for five New Mexico sites we looked at. The marginal avoided cost (that is, costs excluding capital and other fixed costs) for combined cycle plants is about \$38 to \$40 per MWh. Wind also provides the benefit of avoided water use (a few dollars per MWh) and as a hedge against natural gas price volatility (also a few dollars per MWh). Wind-generated electricity can displace duct-fired combined cycle electricity or peaking electricity from single-stage gas turbines even

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more economically, since the avoided costs in these cases are about $50 and $60 per MWh, respectively.

9. **Wind-generated electricity should get some credit for capacity and not only electricity generation.** Wind is not completely unpredictable. It can be estimated, with some error, on an hour-ahead, day-ahead, or seasonal basis. Statistical analyses can be used to plan wind capacity's availability in the grid. The size of the error, and hence costs, can be reduced by (a) improved forecasting, (b) diverse sources of wind energy supply geographically separated by large distances being integrated into the same grid, (c) a transmission infrastructure and grid integration arrangements. Greater capacity credit for a given level of cost and reliability can be achieved if new wind capacity is planned so as to reduce natural gas use for electricity generation.

10. **The economics of wind energy would improve if wind developers could realize a reasonable capacity credit.** In the examples we have studied, wind capacity credits could amount to $2 or $3 per MWh, which is a significant portion of the gap between the price in a PPA and the cost of wind energy (the difference being made up today by tax credits).

11. **Wind-generated electricity can be used to make natural gas available for vehicles (indirectly).** Earth source heat pumps, combined heat and power systems, and wind energy can be joined to eliminate the need for using natural gas for space and water heating in buildings. This natural gas, in turn, can be used in vehicles as compressed natural gas to displace gasoline and reduce oil imports. This type of arrangement would lead to significant CO_2 reductions both in buildings and in cars, as well as lower urban air pollution.

12. **Integrating fuel cells into the renewable energy mix will require improvements in fuel cell and hydrogen production efficiency as well as reduction in fuel cell costs.** Integrating hydrogen production and fuel cells into the electricity system as part of a strategy to increase renewable energy can help increase the capacity credit for wind. It is, however, not economical today due to high fuel cell costs and low overall efficiency of converting wind-generated electricity into hydrogen and fuel cell electricity.

Recommendations

1. **The Western Governors' Association (WGA) should formally adopt a renewable energy goal of 20 percent of electricity supply for the region.** Given that wind energy is both plentiful and, in the right circumstances, economical, a decision to get 20 percent of the region's electricity from renewables, with an emphasis on wind energy penetration, is highly desirable for reasons discussed in the findings. Each state would, of course, set its own regulations for enacting and achieving the 20 percent Renewable Portfolio Standard. The WGA should urge the National Governors' Association and the federal government to adopt the same Renewable Portfolio Standard.

2. **Wind energy development should be integrated with planning for reduction of natural gas price volatility.** Since wind-generated electricity costs at favorable sites are often lower than avoided costs of natural gas at current prices, regulatory bodies and independent system operators should examine the benefits of using wind-generated electricity to displace single stage gas turbine peaking unit use, including having some of the same units as standby units, as part of an overall approach for achieving high wind capacity penetration at modest cost. A regulatory framework for such integration needs to be created.

3. **The WGA should examine large scale wind energy integration in the entire region.** A committee should be set up to examine the technical and economic requirements of large-scale wind energy development in the Western Interconnect region, including diversity of supply and demand, the cost and financing of regional transmission lines, enhancing existing meteorological capabilities, benefits to the economy in terms of saving water, creation of financing mechanisms for infrastructure, integration of wind energy development with reduction of natural gas use, and policies that would result in cost internalization for CO_2 emissions and water use.

4. **New regulations are needed for equitable access to final consumers.** In states where electricity is regulated, rules to enable utilities to recover reasonable costs (including return on investment) can be created as part of the implementation of a Renewable Energy Standard. We estimate that if wind energy is developed at suitable sites, this is not likely to significantly affect the final cost of electricity to consumers.

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5. **Harmonized internalization of water and greenhouse gas emission costs should be carried out throughout regions.** An approach to cost internalization for CO_2 emissions and water use by thermal power plants would accelerate the development of wind power considerably. The price of wind-generated electricity in typical PPAs might increase on the order of $5 per MWh as a result.

6. **New Mexico should create a demonstration project to combine wind, fuel cells, solar photovoltaics, efficiency, and the use of compressed natural gas in motor vehicles.** This combination of measures holds large potential for both environmental and security benefits, but is not economical today. A demonstration project in which the benefits could be carefully assessed, along with the costs, would be of immense value in evaluating the prospects and difficulties of the road to a renewable energy future in which hydrogen, natural gas, and renewables are the main energy sources, while the use of oil is much reduced. While we did not study the question, it may be desirable to integrate some direct use of solar photovoltaic electricity into such a demonstration project, to assess reduction in peak loads on the grid and increased capacity credit for wind. New Mexico is well placed to provide leadership for such a project in the WGA and also the entire country since it has excellent scientific and technical resources available in the form of national laboratories, and NASA (at White Sands), and a state government that has already made the policy commitment to renewables and has much of the legal infrastructure in place.

PHOTO BY WARREN GRETZ COURTESY OF DOE/NREL

Cows and wind turbines at Buffalo Ridge in southwestern Minnesota.

The full report and presentation, *Cash Crop on the Wind Farm*, are online at www.ieer.org/reports/wind/cashcrop/index.html

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Dear Arjun

Dear Arjun: Is oil running out?

—Olive in Oklahoma City

In the 19th century, cooking with oils and fats was a luxury. Lately, vegetable oils and saturated fats have gotten a bad name. With all the rage being low-fat diets and such, it's unlikely that oil will… Oh, wait—you were asking about *oil*, sweet Texas tea, "black gold," the stuff used to fuel cars! Sorry about that. I must be hungry.

That kind of oil is our really high-carb diet, and it powers more than engines. For over a hundred years it's been driving various versions of a myth. Version 1: The world will soon run out of oil. Version 1.1: The world will soon run out of cheap oil. Version 6: Oil production will soon peak; rising demand will clash rapidly diminishing supply; prices will shoot up. Result: Economic catastrophe.

A century of growing world oil production and reserves and a hundred years of being wrong have not stopped the myth-makers. All resources are finite. But some are more finite than others.

There is a great deal of oil in the world. With an estimated one trillion barrels of ultimately recoverable reserves in Saudi Arabia alone, that's about 35 years of global consumption at present rates. One-fourth of that is proven reserves. Iraq has a hundred billion barrels of proven reserves and probably that much more in undeveloped areas. Persian Gulf proven reserves cost less than a nickel a gallon to pump out of the ground.

If the world had higher oil prices driven by true oil depletion, the world would quickly move to using natural gas, gasified coal, liquefied coal, even to hydrogen from wind energy. The hydrogen potential from wind energy in the 12 windiest states of the continental United States alone is of the same order of magnitude as the entire oil output of Organization of Petroleum Exporting Countries, and that includes the whole Persian Gulf region.

We will run out environment long before we run out of oil and its equivalents. The capacity of Mother Nature to absorb all the technologically marvelous ways in which we can inject carbon dioxide in the atmosphere is already being overwhelmed. That's not a theoretical problem in the future. There is overwhelming scientific consensus that it is here already. Glaciers are melting, millions of acres of forest are dying, extreme climate events, like severe droughts and floods, are increasing in frequency.

Crying wolf about oil running out is a dangerous pastime. Panicky focus on this notion diverts attention from really serious problems associated with the entire modern energy system: the severity of global climate change, nuclear power security and accidents, plutonium-related proliferation problems, *and the problem of too much cheap oil in places that are not the centers of consumption*.

Too much cheap oil

Too much cheap oil is a principal factor in the world's energy and security problems. Oil in the Persian Gulf costs less than two dollars a 42-gallon barrel to get out of the ground. The present price of oil (August 2004) is about 35 to 40 dollars a barrel. The present proven reserves in the Persian Gulf are therefore a treasure trove of more than twenty trillion—yes, twenty *trillion*—dollars of royalties and profits. The additional potential reserves of oil in Iraq alone that have not been explored or developed may yield profits over time of more than 3 trillion dollars. Saudi Arabia is an even bigger prize.

Cheap oil in the Persian Gulf led multinational corporations and imperialists, starting with the British in Iran, then in Iraq, to go there in droves. Cheap oil and vast profits are still driving imperialism, war, and global warming.

The British wanted to control Persian Gulf oil resources first of all because they had converted their Navy from coal to oil in World War I. The Navy was essential to Britain maintaining its empire; Britain had plenty of coal, but no oil. It turned out that Persian Gulf oil was not only plentiful; it was cheap.

That oil has extracted a heavy environmental and security price, from global warming to the dead and maimed soldiers who have fought in the Middle Eastern sands for nearly a century—soldiers from India, soldiers from Britain, soldiers from the United States, and soldiers from the region itself. There has been more than one nuclear weapons crisis associated with Middle Eastern oil, including one in 1958 when the western client king of Iraq was overthrown in a coup. So one problem of the chronic Western addiction to cheap oil from the Middle East is a concomitant cozying up to fundamentalists as well as secular dictators (Saudi kings, the Shah of Iran, Saddam Hussein before 1990, etc).

In environmental and security terms, oil has not been cheap; it has been very, very costly. But we have found no effective way to constrain its use to reflect those costs. Using up the proven reserves of oil alone, to say nothing of the undiscovered and undeveloped reserves, would increase carbon dioxide concentrations in the atmosphere by nearly 30 percent. That would aggravate the climate change disaster that is already playing out. Moreover, panicking about running out of oil is giving a propaganda boost to nuclear power advocates and even advocates of the use of plutonium in nuclear reactors.

We will have reached the end of the rope environmentally long before oil can become depleted enough to become costly. In terms of security, too many lives have been lost over oil already. Finally, as I pointed out in the special issue of SDA (June 2003), even the dollar-dominated international monetary system has become tied to the way oil prices are set.

What's to be done?

If cheap oil is at the center of the world's security and environmental woes, what can we do about it? One simple answer, given by many, is to simply tax oil. European cars are more efficient than U.S. ones in large measure because of the stiff gasoline taxes in Europe. But this cannot be the center of the solution, in my opinion.

Taxation of oil is regressive. To have an impact on climate change, taxes would have to rise to punishing levels, and globally. This is unfair, unreasonable, and impractical, in part because so many have so little access to the services that oil provides. Further, the technology to vastly improve automobile efficiency is being kept off the market, partly by consumer decisions and partly by automobile companies. There's a vast gap between the available technology and the reality of low efficiency in the marketplace, even in Europe or Japan.

Audi, for instance, has made a commercial car that gets 80 miles to the gallon. It does not even involve hybrid engine technology. It's an advanced diesel. Volkswagen has made a car, very costly and not a practical passenger car at present, but it gets a whopping 265 miles per gallon. We need stringent efficiency standards for cars that will rise rapidly and inexorably, along with safety standards. Oil consumption can go down substantially, even with more travel.

It may also be reasonable to heavily tax inefficient cars, and unsafe cars, to discourage their manufacture and to use the taxes to promote renewable energy systems. Efforts to greatly increase transportation efficiency can be coupled with increased use of natural gas. Natural gas emits less carbon dioxide than oil or coal; it's compatible with fuel cells, which I believe should be in the center of much of the world's energy system in the future. That's because fuel cells can use hydrogen from renewable energy sources, like wind energy and solar energy. There's a good deal of natural gas in the world; it's better distributed than cheap oil. And it can provide a relatively smooth transition to a different energy world. But this can only be a partial answer because there are many competing uses for natural gas and prices have been rising (though they are far lower than gasoline prices).

The solutions to the problems of climate change and security that have become enmeshed in oil and transportation are going to be very difficult to accomplish. Let's focus on the real problems and the prospects for solving them. Obsessing about catastrophe because we will soon reach the peak of oil production or run out of cheap oil is diversionary at best. At worst it simply fuels the demand for more oil production or more nuclear energy production.

—Dr. Egghead

This column was taken from Arjun Makhijani's set of three radio commentaries, "Is Oil Running Out?," that aired on KUNM (Albuquerque) in January 2004. Listen to these, and many other IEER radio commentaries, on the web at www.ieer.org/radio/.

It pays to increase your jargon power with Dr. Egghead

Avoided cost

a. Amount of money one saves by using coupons at the grocery store.

b. What the oil, gas, and nuclear industries call government subsidies.

c. The cost to produce a unit of electricity that the utility does not incur because it purchases the electricity from another party (e.g., an independent power producer). Avoided cost is normally much less than the retail price.

Combined cycle power plant

a. A woody plant native to the American continent that grows along rivers and streams.

b. An energy-generating device powered by two stationary bicycles.

c. Natural gas-fired plant that uses internal combustion engines combined with steam turbines to generate electricity. The natural gas is burned in a gas turbine or reciprocating gas engine and the hot exhaust gases are used to produce steam which drives a steam turbine.

Answers: c, c, c, c, c

Independent System Operator

a. Another term for swing voter.

b. Slang for a smooth-talking lady's man.

c. Responsible for maintaining reliability of an electricity system, including its transmission grids in the context of deregulation.

Power purchase agreement

a. Any negotiation with Donald Trump or the like.

b. A large contribution to a political party.

c. Contract entered into by an electric utility with an independent power producer specifying terms and conditions under which the utility will purchase power from the independent generator.

Spot market

a. Grocery store that sells produce at bargain prices. Named for the blemishes that fruits and vegetables get when too ripe.

b. Place to buy puppy dogs.

c. Market in which electricity is bought or sold for delivery at a specified time and price in the near future. (Electricity spot market)

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