# ECONOMICS OF WIND ENERGY


3/16/2017

## INTRODUCTION

Wind energy capital costs have declined steadily. A typical cost for a typical onshore wind farms has reached around $1,000/kW of installed rated capacity, and for offshore wind farms about $ 1,600/kW. The corresponding electricity costs vary due to wind speed variations, locations and different institutional frameworks in different countries.

Wind power accounted for 5.6 percent of the USA electricity generating capacity in 2012, up from about 3 percent in 2011. Developers installed 13.1 GWs of wind capacity in 2012, surpassing natural gas power plant construction to become the largest new source of electricity. The growth is driven by tax incentives, utility demand, falling costs and better technology including taller towers and lighter blades.

The production tax credit incentive at 2.2 cents / kW.hr of energy production was extended for a year at the start of 2013. The rate was increased to 2.3 cents in April 2013 as an adjustment to the official inflation rate.

At low fossil fuel prices, wind energy has not generally been cost competitive with the thermal sources of electricity generation. The pattern of development of wind energy is largely dependent on the subsidies and support mechanisms provided by national governments.

However, wind energy prices are converging with those from the thermal sources, which have been steadily increasing as the fossil fuel resources are getting depleted both in individual nations and globally. It is not always simple to make objective comparisons, as there are few places where totally level playing fields exist.

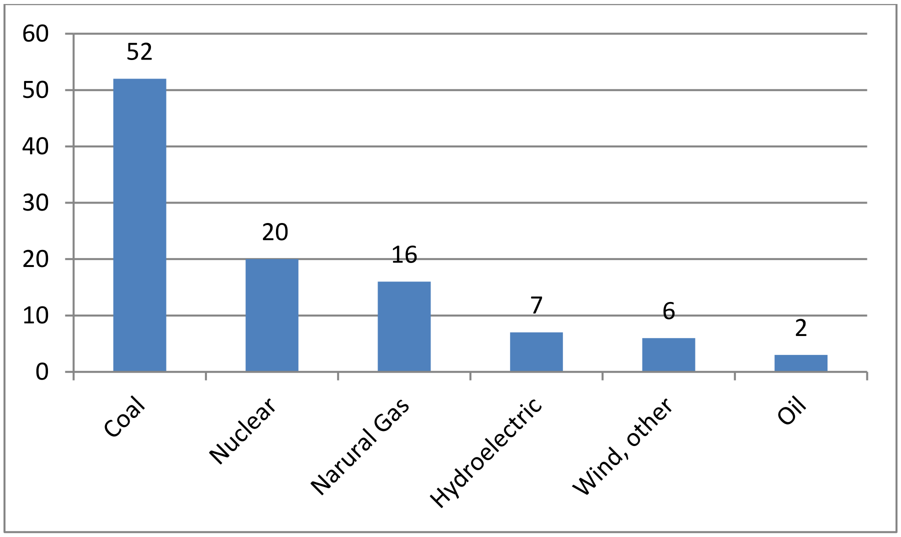


Figure 1. Share of electrical energy production in the USA.

## ECONOMIC CONSIDERATIONS

The big driver behind the growth in wind energy investment is the falling cost of wind-produced electricity. Over the last 20 years, the cost of generating electricity from utility-scale wind systems has dropped by more than 80 percent. When large-scale wind farms were first set up in the early 1980s, wind power was costing as much as 30 cents per kilowatt-hour (¢/kWhr) of the produced energy. Presently, new installations in the most favorable locations can produce electricity for less than 5 ¢/kWhr.

Higher fossil fuels such as oil, coal and natural gas prices are helping to make wind power more competitive. Even where wind power is still not able to compete head-on with cheaper power sources in some locations, it is getting close. At a natural gas price of $5-15 per million British Thermal Units (BTUs), wind energy becomes competitive even without the USA's Production Tax Credit (PTC) subsidy.

Continued investment will depend on whether energy prices of other sources will stay high. Developers of wind power installations are looking at a 20 to 30 year investment span. If natural gas prices fall over that period, a project that is now profitable could become uncompetitive a few years into the future.

## TRANSMISSION AND GRID ISSUES

Transmission costs are a major issue in wind energy development. Some of the best locations for generating wind energy are far distant from the consuming industrial and population centers. Some areas have a better, more reliable source of wind power than others. Although half the USA's installed wind power capacity is based in Texas and California, the greatest potential for wind generation can be found in areas where there is little demand for electrical power. For instance, there exists a significant amount of wind potential in North Dakota, but there are just not a lot of people or industries in North Dakota to consume the electrical power. The highest wind speeds exist in the remote and inaccessible Aleutian Islands in Alaska and necessitate an energy storage and conveyance medium such as hydrogen from water as a transportation fuel in fuel cells. A massive upgrade of the transmission lines nationwide through the national electrical power grid using High Voltage DC instead of High Voltage AC is needed to tap those distant sources.

Where water supplies are abundant, along seashores or internal lakes or rivers, the electricity produced could be used for extracting hydrogen from water through the electrolysis process. Hydrogen then can become the storage medium and energy carrier of wind energy. It would be conveyed or transmitted to the energy consumption sites possibly through the existing natural gas pipeline system which covers the USA.

Another alternative is to convert hydrogen with coal into methane gas, $CH_4$ that could be distributed through the existing natural gas distribution grid without significant modifications. Methane itself can be converted into methanol or methyl alcohol, $CH_3OH$ as a liquid transportation fuel.

In the long term, to reduce the electrical transmission losses, one can envision superconducting electrical transmission lines cooled with cryogenic hydrogen carrying simultaneously electricity and hydrogen from the wind energy production sites to the consumption sites. Such a visionary futuristic power transmission system could also provide the electrical power for a modern mass transit system using Magnetically-levitated

(Maglev) high speed trains transporting goods and people supplementing the current highway system in the USA.

## WIND ELECTRICITY COST AND PRICE

Data attributed to two USA sources: a Department of Energy projection for the period 2000-2005 and an analysis for the state of Oregon in 2000 shows a gap between wind and gas prices with wind larger than coal. Other USA data suggest that wind prices can be brought down to around 4 ¢/kW.hr in some locations.

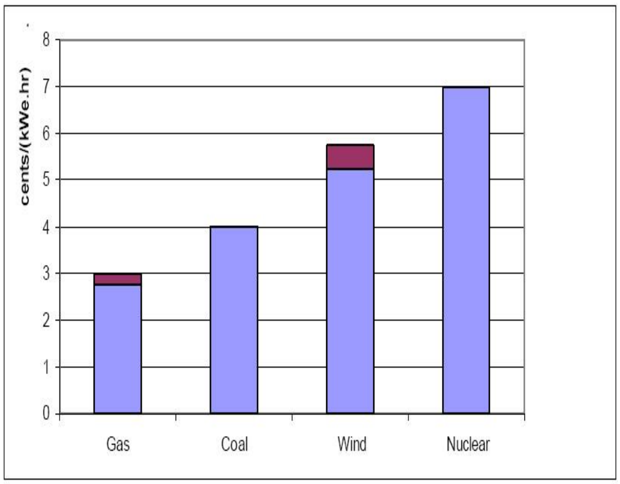


Figure 2. Electricity prices in ¢ / (kW.hr) in the USA over the period 2000-2005.

An important characteristic of wind energy production is that there is no such thing as a point price for wind energy. A linear relationship does not mathematically exist. This is so since the annual electricity production will vary largely depending on the amount of wind available at a given wind turbine site. Thus a single price for wind energy does not exist, but rather a price interval or range, depending on wind speeds.

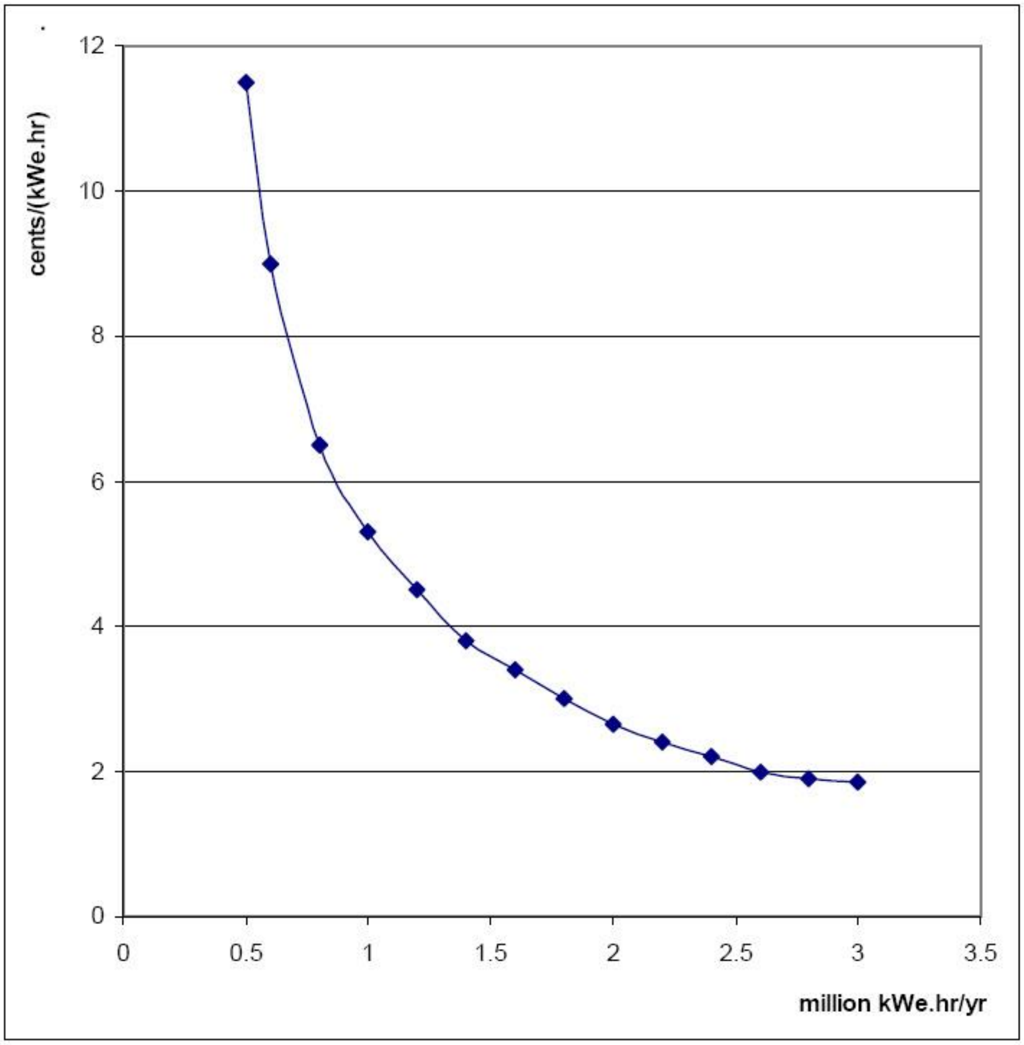


Figure 3. Cost of electricity for a 600 kW wind turbine as a function of its power output.

Figure 3 shows how the cost of electricity produced by a typical wind turbine varies with its power output or its annual production of energy. From the graph, it can be inferred that as the energy produced per year is doubled, we can half the cost per kW.hr of the produced energy.

The data apply to a Danish built 0.6 MW wind turbine with a projected lifetime of 20 years, a capital investment of $585,000 including installation, an operation and maintenance cost of $6,750 per year; 5 percent/year real interest rate, and the annual turbine energy output taken from a power density curve using a Rayleigh wind distribution with a shape factor of 2.

One would have to modify the graph if the Operation and Maintenance (O&P) costs, which increase with turbine use, are taken into account. If the real rate of interest is 6 percent per year, rather than 5 percent per year, the costs would become 7.5 percent higher than shown in Fig. 4.

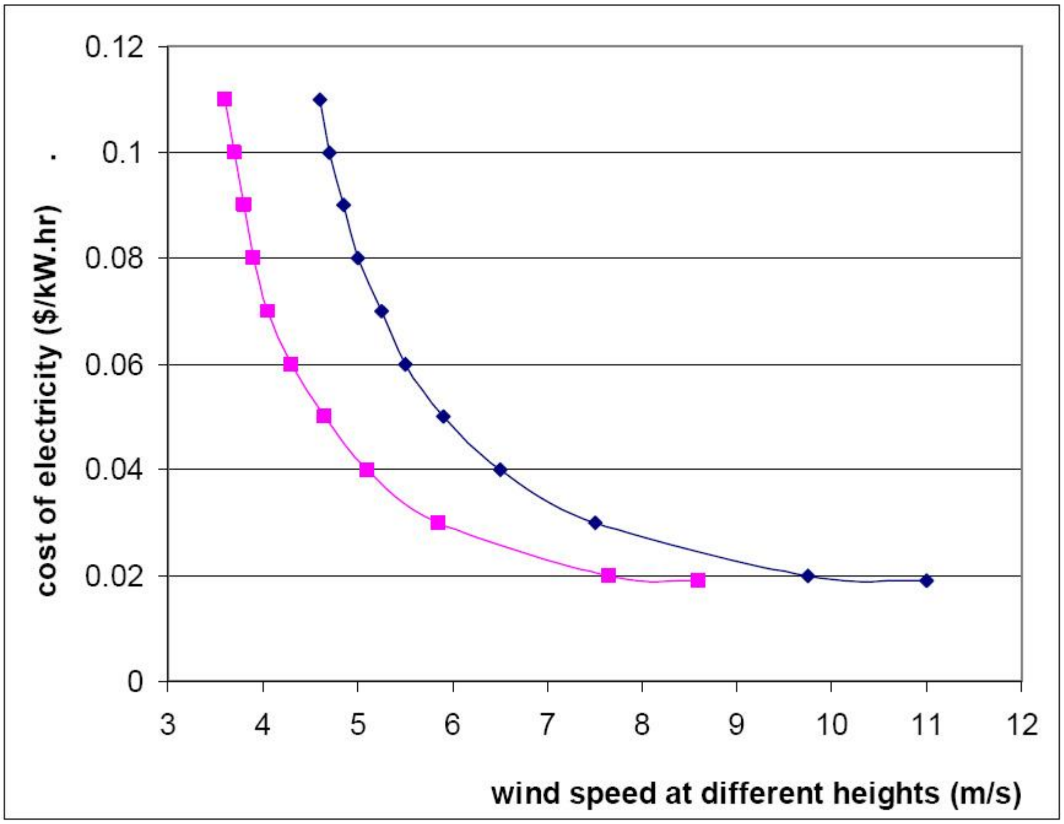


Figure 4. Cost of electricity at a 50 meters hub height (lower graph), and at the meteorological nominal 10 meters height (upper graph).

It must be noted that wind speeds at 50 meters hub height will be 28-35 percent higher, for roughness classes in the range 1-2, than the nominal 10 meters height used for meteorological observations and wind speed reporting at different locations. For instance, a wind speed of 5 m/s at 10 meter-height in the roughness class 1 will correspond to 6.5 m/s at a 50 meter hub height. It can be noticed that at high wind speeds above 9 m/s, the cost of electricity is about the same at the 10 or 50 meters heights (Fig. 4).

## WIND ENERGY COST ANALYSIS

In general, generation technologies, the cost of electricity is primarily affected by three main components:

1. Capital and Investment cost,
2. Operation and Maintenance (O&M) cost,
3. Fuel cost.

However, studies of the cost of wind energy and other renewable energy sources could become flawed because of a lack of understanding of both the technology and the economics involved. Misleading comparisons of costs of different energy technologies are common. It is misleading to think that the amount of funds needed to pay for the purchase a wind turbine is a cost or expenditure. Even the realized profit cannot be considered as a cost.

Specifically, the cost of electricity in wind power generation includes the following components:

1. Economic depreciation of the capital equipment,
2. Interest paid on the borrowed capital,
3. The operation and maintenance costs,
4. Taxes paid to local and federal authorities,
5. Government incentives and tax credits,
6. Royalties paid to land owners,
7. Payment for electricity used on a standby mode,
8. Energy storage components, if used,
9. The cost of wind as fuel is zero.

## LEVELIZED COST OF ELECTRICITY, LCOE

The Levelized Cost OF Electricity (LCOE) in electrical energy production can be defined as the present value of the price of the produced electrical energy in cents / kW.hr, considering the economical life of the plant and the costs incurred in the construction, operation and maintenance, and the fuel costs. Along this line, we can write for the generation cost over the construction and production periods:

$$LCOE = \frac{\left[\left(\sum_{t=-N}^{t=-1} \frac{I_t}{(1+i)^t}\right)\right]_{construction} + \left(\sum_{t=0}^{t=n-1} \frac{(F_t + O\&M_t - D_t + T_t)}{(1+i)^t}\right)_{production}}{\left(\sum_{t=0}^{t=n-1} \frac{G_t}{(1+i)^t}\right)_{production}} \qquad (1)$$

The fuel cost $F_t$ is zero in wind power generation, and the wind turbine is factory-assembled and directly delivered to the wind park site, resulting in a short construction period t in the range [-N, -1]. This results in the following form of Eqn. 1 for wind power generation, accounting for the intermittence factor IF, the Production Tax Credit $PTC_t$, the depreciation credit $D_t$, the tax levy $T_t$, and the royalties or land payments $R_t$:

$$LCOE_{wind} = \frac{\sum_{t=1}^{t=n} \frac{(I_t + O\&M_t - PTC_t - D_t + T_t + R_t)}{(1+i)^t}}{IF \sum_{t=1}^{t=n} P_t} \qquad (2)$$

where:

$LCOE$ = Generation Cost [cents/kW.hr]
$I_t$ = Investment made in year t [$]
$O\&M_t$ = Operation and Maintenance in year t [$]
$PTC_t$ = Production Tax Credit [$]
$D_t$ = Depreciation credit [$]
$T_t$ = Tax levy [$]
$R_t$ = Royalties or land rents [$]
$F_t$ = Fuel cost [$] = 0
$IF$ = Intermittence factor
$P_t$ = Electrical generation capacity in year t [kW.hr]
$G_t$ = Electrical energy generation in year t [kW.hr],
$G_t = IF \times P_t$
$n$ = Duration of the generation period [years]
$i$ = Discount rate

The Present Value Factor (PVF) is:

$$PVF = \frac{1}{(1+i)^t} \tag{3}$$

The LCOE is estimated over the lifetime of the energy-generating technology, typically 20 years for wind generators.

**DISCOUNT RATE**

The discount rate (i) is chosen depending on the cost and the source of the available capital, considering a balance between equity and debt financing and an estimate of the financial risks entailed in the project.

It is advisable to consider the effect of inflation, and consequently using the real interest rate instead.

**NET PRESENT VALUE**

The net present value of a project is the value of all payments, discounted back to the beginning of the investment.

For its estimation, the real rate of interest "r" defined as the sum of the discount rate i and the inflation rate s:

Real rate of interest = Discount rate + Inflation Rate

$$r = i + s \tag{4}$$

is used to evaluate future income and expenditures.

If the net present value is positive, the project has a real rate of return which is larger than the real rate of interest “r”. If the net present value is negative, the project has a lower rate of return.

The net present value is computed by taking the first yearly payment and dividing it by (1+r). The next payment is then divided by $(1+r)^2$, the third payment by $(1+r)^3$, and the n-th payment by $(1+r)^n$. Those terms are added together to the initial investment to estimate the net present value.

$$Net\ present\ value = \frac{P_1}{(1+r)^1} + \frac{P_2}{(1+r)^2} + ... + \frac{P_n}{(1+r)^n} \qquad (5)$$

## REAL RATE OF RETURN

The real rate of return is the real rate of interest “r” which makes the net present value of a project exactly zero. The real rate of return is a measure of the real interest rate earned on a given investment.

The computation of the real rate of return requires an iterative procedure to find the roots of the expression for the present value. One approach is to make a guess that is substituted into the equation. If the guess is too high, the net present value is negative. If the guess is too low, it becomes positive. The Newton-Raphson iteration method can make the iterative approach converge rapidly.

## ELECTRICITY COST PER UNIT ENERGY

The electricity cost per kW.hr is calculated by first estimating the sum of the total investment and the discounted value of operation and maintenance costs in all years. The result is discounted for all future electricity production: each year's electricity production is divided into $(1+r)^n$, where n is the project lifetime.

The income from electricity sales is subtracted from all non-zero amounts of payments at each year of the project period.

## DEPRECIATION COST

Depreciation is a term used in accounting, economics and finance to spread the cost of an asset over the span of several years. In simple terms, it can be said that depreciation is the reduction in the value of an asset or good due to usage, passage of time, wear and tear, technological outdating or obsolescence, depletion, inadequacy, rot, rust, decay or other such factors.

We cannot calculate the economic depreciation of an investment unless we know the income from the investment. Depreciation is defined as the decline in the capital value of the investment using the internal rate of return as the discounting factor. If the income from the investment is not known, the rate of return is not determined, thus one cannot calculate economic depreciation.

The tax depreciation or accounting depreciation is sometimes confused with economic depreciation.  However, tax or accounting depreciation is a set of mechanical rules which must not be used when the true cost of energy per kW.hr is sought.

**STRAIGHT LINE DEPRECIATION**

Straight line depreciation is the simplest and most often used method in which we can estimate the real value of the asset at the end of the period during which it will be used to generate revenues, or its economic life.  It will expense a portion of the original cost in equal increments over the period.  The real value is an estimate of the value of the asset or good at the time it will be sold or disposed of.  It may be zero or even negative. Accordingly:

$$\text{Annual dedpreciation expense} = \frac{\text{Original cost-Real value}}{\text{Life span}}, \left[\frac{\$}{\text{year}}\right] \quad (6)$$

A linear depreciation of 2.5 percent per year over a 20 years lifetime of $585,000 turbine is shown in Fig. 5.

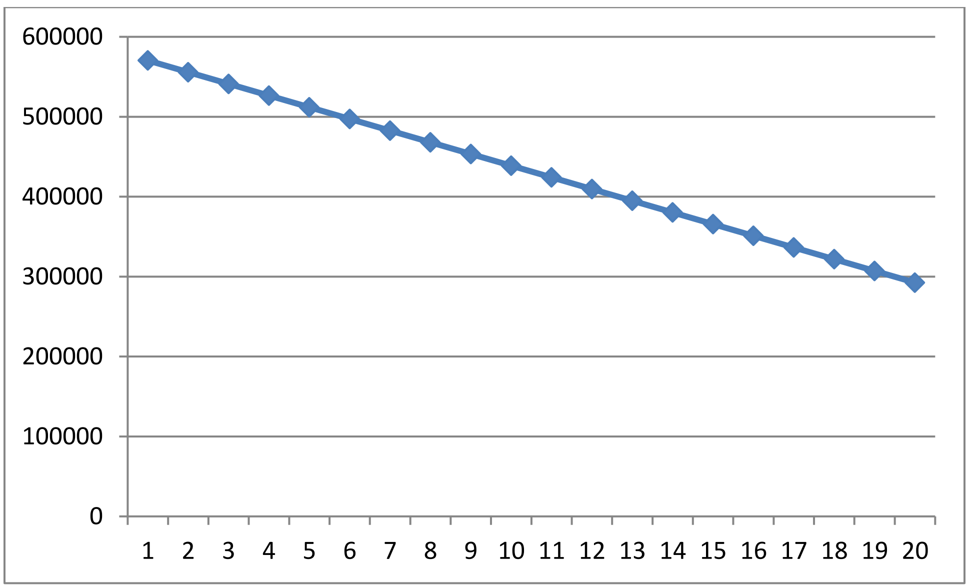


Figure 5. Straight line depreciation at 2.5 percent per year over a 20 years period for a wind turbine.

Table 1. Linear depreciation schedule over a 20 years useful lifetime**.**

| Linear depreciation | [percent of total cost/year] | [$/year] | Residual value[$] |
|---|---|---|---|
| Year 1 | 2.5 | 14625 | 570375 |
| Year 2 | 2.5 | 14625 | 555750 |
| Year 3 | 2.5 | 14625 | 541125 |

| | | | |
|---|---|---|---|
| Year 4 | 2.5 | 14625 | 526500 |
| Year 5 | 2.5 | 14625 | 511875 |
| Year 6 | 2.5 | 14625 | 497250 |
| Year 7 | 2.5 | 14625 | 482625 |
| Year 8 | 2.5 | 14625 | 468000 |
| Year 9 | 2.5 | 14625 | 453375 |
| Year 10 | 2.5 | 14625 | 438750 |
| Year 11 | 2.5 | 14625 | 424125 |
| Year 12 | 2.5 | 14625 | 409500 |
| Year 13 | 2.5 | 14625 | 394875 |
| Year 14 | 2.5 | 14625 | 380250 |
| Year 15 | 2.5 | 14625 | 365625 |
| Year 16 | 2.5 | 14625 | 351000 |
| Year 17 | 2.5 | 14625 | 336375 |
| Year 18 | 2.5 | 14625 | 321750 |
| Year 19 | 2.5 | 14625 | 307125 |
| Year 20 | 2.5 | 14625 | 292500 |

## PRICE AND COST CONCEPTS

The words: "cost" and "price" are sometimes mistakenly used as synonyms. The price of a product is determined by supply and demand for the product. Some people assume that the price of a product is somehow a result of adding a normal or reasonable profit to a cost, which is not necessarily the case; unless it is applied to a government controlled monopoly. Thus in general:

$$\begin{aligned} \text{Price} = \text{Cost} + \text{Profit} + \text{Taxes} + \text{Installation} + \text{Fuel} \\ + \text{Operation and maintenance} \\ - \text{Government incentives and tax credits} \\ + f(\text{scarcity}) \end{aligned} \quad (7)$$

A factor that is a function of the scarcity of wind resources at a given location, as well as the taxes paid, must be accounted for.

## WIND TURBINES PRICES

Wind turbine prices may vary due to transportation costs, different tower heights, different rotor diameters, different generators sizes and the grid connection costs.

To determine the prices of wind turbines, it is erroneous to divide the turnover in dollars by the volume or sales or MW to obtain the price of a turbine in $/MW:

$$\text{Price} \neq \frac{\text{Turnover}}{\text{Volume}}\left[\frac{\$}{\text{MW}}\right] \quad (8)$$

It must be realized that some of the manufacturers' deliveries are complete turnkey projects including planning, turbine nacelles, rotor blades, towers, foundations, transformers, switchgear and other installation costs including road building and power lines. The manufacturer sales figures also include service and sales of spare parts.

The manufacturers' sales include licensing income, but the corresponding rated power in MWs are not registered in the company accounts. Sales may vary significantly between markets for high wind turbines and low wind turbines. The prices of different types of turbines are quite different. The patterns of sales, types of turbines, and types of contracts vary significantly from year to year and depend on the different locations and markets.

The safest approach is to obtain the prices from the price lists and to consider the price in units of $\$/m^2$ of rotor swept area.

## PRODUCTIVITY AND COSTS

A unique aspect of wind energy production is that its productivity and costs depend on the price of electricity, and not vice versa as in other energy systems.

$$\begin{aligned} &\text{Cost} = f(\text{price of electricity}) \\ &\text{Price of electricity} \neq \text{Cost} \end{aligned} \tag{9}$$

The annual production per $m^2$ of rotor swept area in a location like Denmark tends to be significantly higher than in another location such as Germany. This has no relationship to the different wind resources. It is instead related to the different prices for electricity at the different locations. In Denmark it is not profitable to locate wind turbines in low wind areas, whereas it is profitable to use low wind areas in Germany due to the higher electricity prices.

Germany has a very high electricity price for renewable sources of electricity in terms of the tariff per kW.hr of energy delivered to the grid.

In Germany it is profitable to equip wind turbines with very tall towers. The high electricity price also makes it profitable to locate wind turbines in low wind areas. In that case, the most economic turbines will have larger rotor diameters relative to the generator size than in other areas of the world.

Wind turbines sold in the German market appear more expensive than they do in other markets; if one considers the price per kW of installed or rated power. However these are machines optimized for the German low wind sites. The price per square meter of rotor swept area located at a given hub height is what matters, not the price per kW of installed power.

## INSTALLATION COSTS

Another unique feature of wind energy is that a high cost of generating electricity is not necessarily a result of high installation cost. One incurs a high installation cost whenever a good wind resource is available and hence cheap generating costs are available in a remote area.

In Wales, UK, the installation costs tend to be high in the range of several hundred per cent higher than in Denmark, despite the very low electricity price. This is because there exists a substantial wind potential if the wind turbines are placed on top of the rounded Welch hills, due to the hill acceleration effect. It is profitable to build an expensive access road through the moors, and build expensive foundations in order to use the high potential wind areas.

High installation costs can be afforded, typically when a good wind resource exists since the power produced by a wind turbine is proportional to the cube of the wind speed.

The installation costs include the costs for extension of the electrical grid and the grid reinforcement. The costs of electrical cabling can be significant, affecting whether a wind farm is located next to an existing medium voltage power line or far from a power line.

Average installation costs cannot be used, since the electricity price per kW.hr delivered to the grid depends upon the distance to the grid. Installation costs may vary with the location, road construction and grid connection amounting to about 30 percent of the turbine cost.

### OPERATION AND MAINTENANCE

The operation and maintenance cost can be estimated as either a fixed amount per year or a percentage of the cost of the turbine. This could also include a service contract with the wind turbine manufacturer.

## WIND ENERGY AS A RESOURCE EXTRACTION TECHNOLOGY

There does not exist an average cost of wind energy like there is no average cost of oil. In Kuwait the average cost may be $5/barrel, but in Texas, it may be $60/barrel. The costs are different since it is more complex to extract oil from Texas than in Kuwait. We cannot average the cost of oil production in Kuwait and in Texas in order to find some average oil cost. Even if the market price of oil drops below 100 $/barrel, it may still be worthwhile to produce oil from Texas: what will matter in this case is not the average cost per barrel of oil but the marginal variable cost of extracting an extra barrel of oil.

## LOCATION EFFECT

One cannot use the statistics from a specific area to estimate the costs in another area. The cost of wind energy in Germany is high, because prices for electricity are high, and the cost of wind energy in the UK is low, because the price of electricity is low.

Few wind turbines will be installed if the price of electricity is low, because high wind sites are scarce, and sites which are profitable may not be found.

## PRICE PER SQUARE METER OF ROTOR SWEPT AREA

The price per kW of rated power is not a good guide to investment in wind energy project. What really matters is the price per square meter of rotor swept area.

This is analogous to farming where the price per acre of farmland is the relevant capital expenditure in addition to the price of the machinery and farm structures.

The price of a wind turbine per kW installed power is usually difficult to get hold of, and a very poor guide to cost developments. It is difficult to give a single figure for the price per kW of installed power, simply because the price of a turbine varies much more with its rotor diameter than with the rated power of its generator.

The reason is that the annual production depends much more on the rotor diameter than the generator size. The comparisons of average price per kW of installed power for different energy technologies are usually misleading, if wind power is considered.

**EXAMPLE**

The annual energy production from two wind turbines from the same manufacturer, both mounted on a 50 meters high tower can be compared. The first one is a high wind turbine, and the second one a universal wind turbine.

Table 2. Comparison of energy production a high wind machine to that of a universal machine.

| | High-wind turbine | Universal wind turbine |
|---|---|---|
| Model | Vestas V39 | Vestas V47 |
| Nominal rated power | 0.60 MW | 0.66 MW |
| Relative rated power | 1 | 660/600 = 1.1 |
| Rotor diameter | 39 m | 47 m |
| Relative rotor area | 1 | 47/39 = 1.452 |
| Hub height | 50 m | 50 m |
| Relative energy production | 1 | 1.452 |
| Relative price of machine | 1 | 1.33 |
| Relative price per kW of installed capacity | 1 | 1.33/1.1 = 1.21 |
| Relative price per $m^2$ of rotor area | 1 | 1.33/1.452 = 0.916 |
| Relative price per kW.hr of energy produced | 1 | 1.33/1.452 = 0.916 |

The rotor area of the second turbine is 45.2 percent larger than the first turbine. The annual energy production from the second turbine with the larger rotor swept area is 45.2 percent higher than the first machine, despite the fact that the generator is only 10 percent larger.

If we assume that the price for the second turbine is 33 percent higher than for the first machine, the price per kW rated power increases by 21 percent. However, the price per unit rotor area and the price per kWhr of energy produced both decrease by 1 – 0.916 = 0.084 or 8.4 percent.

Modern wind turbines are increasingly being equipped with a pitch control system replacing stall control. The generator size can thus be varied more freely relative to the rotor size.

There exists a tendency to use larger rotor areas for a given generator size. This means that an overestimated development price is obtained when comparing the price per kW of installed power for old turbines to those of new turbines. The relevant price measure is the price per unit rotor swept area, not the price per kW of installed or rated power.

## INTERMITTENCE FACTOR

The Intermittence Factor (IF) or Capacity Factor for an energy generating technology is equal to the ratio of the annual energy production to the theoretical maximum energy production, if the generator were running at its rated electrical power all year.

$$Intermittence\ Factor \quad IF = \frac{\text{Annual energy production}}{\text{Rated maximum energy production}} \tag{10}$$

Depending on the wind statistics for a particular site, the ideal capacity factor for a wind turbine is in the range of 25-40 percent, because that capacity factor minimizes the cost per kW.hr of energy produced. An apparent paradox is that it is not desirable to increase the capacity factor for a wind turbine, as it would be for technologies where the fuel is not free.

Capacity factors will be very different for different turbines, but likewise the prices or costs of these turbines will be very different. Overall, what counts is the cost per kW.hr of energy produced, not the capacity or intermittence factor.

## LAND RENTS, ROYALTIES AND PROJECT PROFITABILITY

In wind energy production the land rents or royalties should depend on the profitability of a project and not vice versa.

$$\text{Royalties} = \text{f(Profitability)} \tag{11}$$

The compensation, land rents or royalties paid to land owners where the turbines are placed is sometimes treated as a cost of wind energy. In fact, it is only a minor share of the compensation which is a cost of the loss of crop on the area that can no longer be farmed; a possible nuisance compensation since the farmer has to make extra turns when plowing the fields underneath the wind turbines and he must be compensated for compaction and the damage to tiling from the heavy equipment access to the turbine site.

If the compensation exceeds what is paid to install a power line pylon, the excess is in fact an income transfer. This is a different matter economically: it is not a cost to society, but a transfer of income or profits from the wind turbine operator to the land owner. Such a profit transfer is called a land rent by economists. A rent payment does not transfer real resources from one use to another.

There is no standard compensation for placing a wind turbine on agricultural land. It depends on the quality of the site, the availability of the wind and the grid access nearby.

A land owner can bargain for a high compensation in a good location, since the turbine operator can afford to pay it due to the profitability of the site. If the site has low speed wind, and high installation costs, the compensation will be estimated closer to the nuisance value of the turbine.

## PROJECT LIFETIMES

The figure used for the design lifetime of a typical wind turbine is 20 years. With the low turbulence of offshore wind conditions leading to lower vibrations and fatigue stresses, it is likely that the turbines can last longer, from 25-30 years, provided that corrosion from salty conditions can be controlled.

Offshore foundations for oil installations are designed to last 50 years, and it may be possible to consider two generations of turbines to be built on the same foundations, with an overhaul repair at the midlife point after 25 years.

## BENCHMARK WIND TURBINE PRESENT VALUE COST ANALYSIS

An attempt is made at the estimation of a present value cost analysis for the cost of electricity over a 20 years turbine project duration. A benchmark problem is first presented to later accommodate sensitivity studies of the effects of other factors, such as the Production Tax Credit, depreciation and taxes.

### Investment

Expected lifetime = 20 years
Turbine rated power: 600 kW
Turbine cost: $450,000
Installation costs: 30 percent of turbine price = $450,000 x 0.30 = $135,000
Total turbine cost = Turbine cost + Installation cost
= $450,000 + $135,000
= $585,000

### Payments

The payments, including the initial payment, are used to calculate the net present value and the real rate of return over a 20 years project lifetime since this is the main economic aspect of the analysis.

The tax payments and credits and the depreciation credits are not considered for simplification but could be added for a more detailed analysis later. We consider that the capital is in the form of available invested funds: if the capital cost is all borrowed funds, then the interest payment on the loan or the bonds must be accounted for.

Operation and Maintenance: 1.5 percent of turbine price = 0.015 x 450,000 = 6,750 $/year.

Total expenditure = Total turbine cost + Operation and maintenance cost over expected lifetime
= $585,000 + $6,750 / year x 20 year

= $585,000 + $135,000
= $720,000

**Current income and expenditures per year**

Capacity factor: 28.54 percent = 0.2854.
Energy produced in a year: 600 x 365 x 24 x 0.2854 = 1,500,000 kWhr / year.
Price of electricity =$0.05 / kW.hr
Gross yearly income from electricity sale: 1,500,000 kWhr / yr at $0.05/kWhr = 1,500,000 x 0.05 = $75,000 / yr.
Net income stream per year: $75,000 – $6,750 = $68,250 /yr.

One can construct Table 3 over the 20 years useful lifetime of the turbine.

Table 3. Benchmark present value calculation for a 0.6 MW rated power wind turbine.

| Year n | Expenditures $ | Gross Income Stream $ | Net Income Stream $ | Present value factor $1/(1+r)^n$ r = 0.05 | Net present value of income stream $ |
|---|---|---|---|---|---|
| 0 | -585,000 | - | - | - | - |
| 1 | -6,750 | 75,000 | 68,250 | 0.9524 | 65,000 |
| 2 | -6,750 | 75,000 | 68,250 | 0.9070 | 61,903 |
| 3 | -6,750 | 75,000 | 68,250 | 0.8638 | 58,957 |
| 4 | -6,750 | 75,000 | 68,250 | 0.8227 | 56,149 |
| 5 | -6,750 | 75,000 | 68,250 | 0.7835 | 53,475 |
| 6 | -6,750 | 75,000 | 68,250 | 0.7462 | 50,929 |
| 7 | -6,750 | 75,000 | 68,250 | 0.7107 | 48,504 |
| 8 | -6,750 | 75,000 | 68,250 | 0.6768 | 46,194 |
| 9 | -6,750 | 75,000 | 68,250 | 0.6446 | 43,995 |
| 10 | -6,750 | 75,000 | 68,250 | 0.6139 | 41,899 |
| 11 | -6,750 | 75,000 | 68,250 | 0.5847 | 39,904 |
| 12 | -6,750 | 75,000 | 68,250 | 0.5568 | 38,004 |
| 13 | -6,750 | 75,000 | 68,250 | 0.5303 | 36,194 |
| 14 | -6,750 | 75,000 | 68,250 | 0.5051 | 34,471 |
| 15 | -6,750 | 75,000 | 68,250 | 0.4810 | 32,829 |
| 16 | -6,750 | 75,000 | 68,250 | 0.4581 | 31,266 |
| 17 | -6,750 | 75,000 | 68,250 | 0.4363 | 29,777 |
| 18 | -6,750 | 75,000 | 68,250 | 0.4155 | 28,359 |
| 19 | -6,750 | 75,000 | 68,250 | 0.3957 | 27,009 |
| 20 | -6,750 | 75,000 | 68,250 | 0.3769 | 25,723 |

| | | | | | |
|---|---|---|---|---|---|
| Total | -720,000 | 1,500,000 | 1,365,000 | - | 850,531.5 |

Net present value of income stream at r = 5 percent/yr real rate of interest: $850,531.5.

$$\text{Yearly net real rate of return} = \frac{\text{Net present value of income stream}}{\text{Total turbine cost}} \cdot \frac{1}{\text{Project lifetime}}$$

= ($850,531.5 / $585,000) / 20 years
= 0.072695
= 7.269 percent/year.

$$\text{Present value of electricity per kW.hr} = \frac{\text{Net present value of income stream}}{\text{Yearly energy production . Project lifetime}}$$

$$= \frac{\$850{,}531.5}{1{,}500{,}000 \frac{\text{kWhr}}{\text{year}} \text{ x } 20 \text{ years}}$$

= $0.02835105 / kWhr
= 2.84 cents / kWhr

## INCENTIVES, SUBSIDIES, PRODUCTION TAX CREDIT, PTC, INVESTMENT TAX CREDIT, ITC, RENEWABLE ENERGY PRODUCTION INCENTIVE (REPI)

The renewable energy Production Tax Credit (PTC), a credit of 2.3 cents per kilowatt-hour, is the primary federal incentive for wind energy and has been essential to the industry’s growth.

Since its establishment in 1992, the PTC has undergone a series of short-term extensions, and has been allowed to lapse in three different years: 1999, 2001 and 2003.

In February 2009, through the American Recovery and Reinvestment Act, Congress acted to provide a three-year extension of the PTC through December 31, 2012.

Wind project developers can choose to receive a 30 percent investment tax credit (ITC) in place of the PTC for facilities placed in service in 2009 and 2010, and also for facilities placed in service before 2013 if construction begins before the end of 2010. The ITC then qualifies to be converted to a grant from the Department of Treasury. The Treasury Department must pay the grant within 60 days of an application being submitted. This policy is designed to help the wind energy industry continue to finance projects during these challenging economic times.

In a measure taken by the USA Congress, a federal policy for promoting the development of renewable energy was initiated. The Production Tax Credit (PTC) provides a 2.3 cent per kilowatt.hour (kWhr) benefit for the first ten years of a renewable energy facility's operation. The PTC was set to expire on December 31, 2007, but due to the efforts of a coalition of clean energy supporters, it was extended as part of the Tax Relief and Health Care Act of 2006 (H.R. 6408). Strong growth in USA wind installations is consequently projected for as long as that tax incentive is available.

An incentive similar to the PTC is made available to public utilities; which do not pay taxes and therefore cannot benefit from a tax credit. The incentive is called the

Renewable Energy Production Incentive (REPI) and it consists of a direct payment to a public utility installing a wind plant that is equal to the PTC at 1.5 cents per kilowatt-hour, adjusted for inflation. Since the REPI involves the actual spending of federal funds, money must be "appropriated" or voted for it annually by the USA Congress. It is sometimes difficult to obtain full funding for REPI because of competing federal spending priorities.

The legislation extending the PTC provided a 1 year extension through December 31, 2008 of a 1.5 cent/kWhr credit, for wind, solar, geothermal, and “closed-loop” bioenergy facilities.

The $700 billion financial institutions bailout package bill passed by the USA Congress in September 2008 extended it another year to December 31, 2009. Any renewable energy system that is not installed and running by that time would not benefit from the PTC. This is negative toward the economics and the future investment of renewable energy systems.

The American Wind Energy Association estimated that the investment in renewable systems could fall by as much as 50 percent without the PTC in place. This would wreak havoc with the energy investment cycle and all but shut many projects down. Losing the PTC would strangle the vendor base, disrupt the work force and curtail future output.

According to the Union of Concerned Scientists (UCS), adjusted for inflation, the 1.5 cent/kWhr tax credit was valued at 1.9 cents/kWhr. Other technologies, such as “open-loop” biomass, incremental hydropower, small irrigation systems, landfill gas, and municipal solid waste (MSW), receive a lesser value tax credit.

This marks just the second time that the PTC was extended by Congress before it had been allowed to expire. In August 2005, a 2 year extension of the PTC was included in a large package of tax incentives in the Energy Policy Act of 2005 (H.R. 6). The PTC was set to expire at the end of 2005, and its extension was one of the main features for renewable energy in this energy bill.

From 1999 until 2004, the PTC had expired on three separate occasions. Originally enacted as part of the Energy Policy Act of 1992, the PTC, then targeted to support just wind and certain bioenergy resources, was first allowed to sunset on June 30, 1999. In December of 1999 the credit was extended until December 31, 2001. The PTC expired at the end of 2001, and it was not until March 2002 that the credit was extended for another two years. Congress allowed the PTC to expire for the third time at the end of 2003. From late 2003 through most of 2004 attempts to extend and expand the PTC were held hostage to the fossil fuel dominated comprehensive energy bill that ultimately failed to pass during the 108th Congress. In early October 2004, a 1 year extension retroactive back to January 1, 2004 of the PTC was included in a larger package of ‘high priority’ tax incentives for businesses signed by President George Bush. A second bill extending the PTC through 2005 and expanding the list of eligible renewable energy technologies was enacted just a few weeks later.

Combined with a growing number of states that have adopted renewable electricity standards, the PTC has been a major driver of wind power development over the last years. Unfortunately, the “on-again/off-again” status that has historically been associated with the PTC contributes to a boom-bust cycle of development that plagues the wind industry. The cycle begins with the wind industry experiencing strong growth in development around the country during the years leading up to the PTC’s expiration. Lapses in the PTC then cause a dramatic slowdown in the implementation of planned wind projects. When the PTC is restored, the wind power industry takes time to regain its footing, and then experiences strong growth until the tax credits expire. And so on.

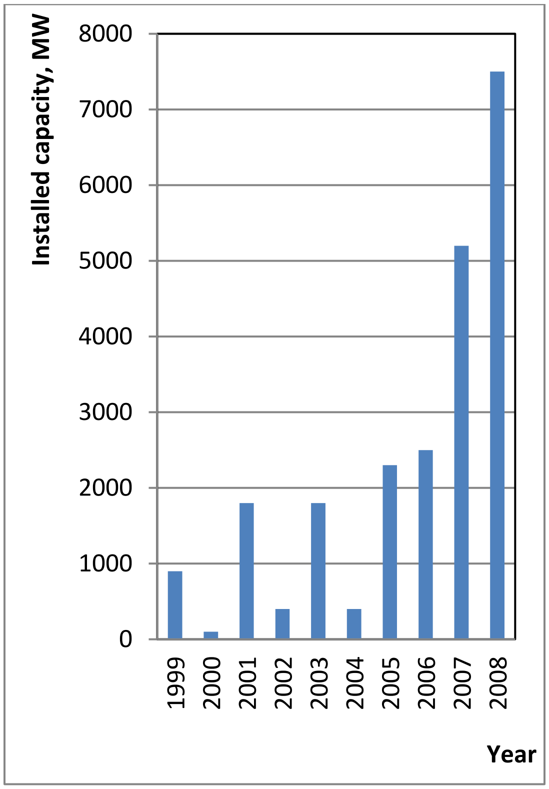


Figure 6. Effect of the Production Tax Credit (PTC) on the installed wind power capacity in the USA. A 93 percent, 73 percent and 77 percent drops occurred in 2000, 2002 and 2004 respectively upon temporary expiration then restarting of PTC. Source: American Wind Energy Association, AWEA.

The last lapse in the PTC at the end of 2003 came on the heels of a strong year in USA wind energy capacity growth. In 2003, the wind power industry added 1,687 megawatts (MW) of installed capacity; a 36 percent annual increase. With no PTC in place for most of 2004, USA wind development decreased dramatically to less than 400 MW; a 5 year low. With the PTC reinstated, 2005 marked the best year ever for USA wind energy development with 2,431 MW of capacity installed; a 43 percent increase over the previous record year established in 2001. With the PTC firmly in place, 2006 was another near record year in the USA wind industry. Wind power capacity grew by 2,454 MW; a 27 percent increase.

Extending the PTC beyond 2008 to 2012 allowed the wind industry to continue building on previous years' momentum, but it is insufficient for sustaining the long-term growth of renewable energy. The planning and permitting process for new wind facilities can take up to two years or longer to complete. As a result, many renewable energy developers that depend on the PTC to improve a facility's cost effectiveness may hesitate to start a new project due to the uncertainty that the credit will still be available to them when the project is completed.

The last extension of the PTC and ITC occurred in the FY16 Omnibus Appropriations Bill, passed on December 18, 2015, included a five-year extension and phase-down of the PTC, as well as the option to elect the investment tax credit for wind energy.

The PTC and ITC have driven more wind development– especially as utilities, Fortune 500 companies and municipalities seek more low-cost, clean renewable energy. The tax credits, extended through 2019, have begun phasing down by 20 percent each year beginning in 2017.

For the PTC (Sec. 301 of the bill), wind projects that started construction in 2015 and 2016 receive a full value PTC of 2.3 cents per kilowatt.hour. For projects that begin construction in 2017, the credit is at 80 percent of full value; in 2018, 60 percent PTC; and in 2019, 40 percent PTC.

Similarly, for the ITC election for wind energy (Sec. 302 of the bill), projects that started construction in 2015 and 2016 are eligible for a full 30 percent ITC; for 2017, a 24 percent ITC; for 2018, an 18 percent ITC; and in 2019, a 12 percent ITC.

## SECTION 1603 STIMULUS BILL GRANT PROGRAM

A prolific stimulus program has been the Section 1603 grant program. More than $7.8 billion were spent, $5 billion more than originally intended, to 3,160 applicants. The program allows developers of renewable energy facilities, including wind farms, to take a cash grant in lieu of the usual 30 percent investment tax credit. Originally intended to be over by the end of 2010, with a final price tag of $3 billion, the Section 1603 program got new life with a one-year extension into 2011.

Officially touted by the administration as a mega-job creator, it was viewed privately as a great way to funnel liquidity into a renewables industry suffering in the fall of 2008. The primary beneficiary, and the one most in need of cash injections, was the wind industry. More than $6 billion from the program, 77 percent, has gone to 133 large wind farms. While most of the funds available under Section 1603 went to large wind installations the list of recipients shows that the program had a much broader and deeper reach than some big cash handouts to the wind industry. The vast majority of projects, more than 3,000 of them, went to small businesses.

Included on the list are hundreds of unexpected recipients. Pet-related businesses, for instance, are well-represented. Places like DogBoy's Dog Ranch, a dog-boarding facility in Austin, Texas, which got a $23,948 grant for solar panels, or Pet Tender's Country Boarding Cattery, a cat-boarding place in rural Missouri, which received nearly $5,000 for a solar-thermal setup. A variety of other pet-boarding places, pet groomers, alpaca farms and sundry other animal businesses are on the list as well. There are pastry shops, doctor's offices and quilting shops. And there have even been a number of big retailers, including Walmart and Kohl's, that have collected millions in grants.

For some of these places, renewable energy might make some degree of sense, but none are businesses that stake their primary mission on renewables. For them to enter the renewables game, the barrier of entry to the market must have been lowered. Section 1603 lowered it for all of these places by at least 30 percent.

Even more important for the future of renewables is that as these grants have burrowed deep down into the market they have dragged a long tail of supporting infrastructure with them. Pockets of activity where experienced workers and supply chains are hardening into a permanent fixtures exist. Within 50 miles of York, Pennsylvania, there are dozens of recipients such as bologna manufacturers, steel fabricators, heating oil companies and chemical plants. The common thread among many of these recipients is that they have one or two relatively new companies that cater specifically to the financing and installation of small renewable systems. By the time the Section 1603 program officially gives its last dollar, probably sometime in late 2012, these companies will have had years of experience and business.

Section 1603 continued to give money, and new patterns are continuing to develop. Of the 16 fuel cell projects on the list, eight have received their money this year, including several Bloom Energy fuel cells. In the month of June 0f 2011, $482.5 million was given to 254 recipients, a pace in line with the previous five months. It is not hard to imagine that the final tally for this program might be north of $10 billion.

A report prepared by the State of Illinois alleged that the USA was eager to grant $8 million at developers for every wind job reported.

## EXAMPLE WIND TURBINE PRESENT VALUE COST ANALYSIS ACCOUNTING FOR THE PRODUCTION TAX CREDIT, PTC

We modify the calculation scheme for the benchmark, to study the effect of the Production Tax Credit, PTC, on the present value of the produced electrical energy.

**Payments**

Installation costs: 30 percent of turbine price = $450,000 x 0.30 = $135,000

Total turbine cost = Turbine cost + Installation cost
= $450,000 + $135,000
= $585,000

Operation and Maintenance: 1.5 percent of turbine price = 0.015 x 450,000 = 6,750 $/year.

Total expenditure = Total turbine cost + Operation and maintenance cost over expected lifetime
= $585,000 + $6,750 / year x 20 year
= $585,000 + $135,000
= $720,000

**Current income and expenditures per year**

Capacity factor: 28.54 percent = 0.2854.
Energy produced in a year: 600 x 365 x 24 x 0.2854 = 1,500,000 kWhr / year.
Gross yearly income from electricity sale: 1,500,000 kWhr / yr at $0.05/kWhr = 1,500,000

x 0.05 = $75,000 / yr.
Yearly income from Production Tax Credit (PTC) of 1.5 cent/kWhr = 1,500,000 x 0.015 = $22,500 / yr (Over first ten years of project).
Net income stream per year (first ten years): $75,000 – $6,750 + 22,500 = $90,750 /yr.
Net income stream per year (next ten years): $75,000 – $6,750 = $68,250 /yr.

Table 4. Benchmark present value calculation for a 0.6 MW rated power wind turbine, accounting for the Production Tax Credit, PTC incentive.

| Year n | Expenditures $ | Gross Income Stream $ | Production Tax Credit (PTC) $ | Net Income Stream $ | Present value factor $1/(1+r)^n$ r = 0.05 | Net present value of income stream $ |
|---|---|---|---|---|---|---|
| 0 | -585,000 | - | - | - | - | - |
| 1 | -6,750 | 75,000 | 22,500 | 90,750 | 0.9524 | 86,430 |
| 2 | -6,750 | 75,000 | 22,500 | 90,750 | 0.9070 | 82,310 |
| 3 | -6,750 | 75,000 | 22,500 | 90,750 | 0.8638 | 78,390 |
| 4 | -6,750 | 75,000 | 22,500 | 90,750 | 0.8227 | 74,660 |
| 5 | -6,750 | 75,000 | 22,500 | 90,750 | 0.7835 | 71,103 |
| 6 | -6,750 | 75,000 | 22,500 | 90,750 | 0.7462 | 67,718 |
| 7 | -6,750 | 75,000 | 22,500 | 90,750 | 0.7107 | 64,496 |
| 8 | -6,750 | 75,000 | 22,500 | 90,750 | 0.6768 | 61,420 |
| 9 | -6,750 | 75,000 | 22,500 | 90,750 | 0.6446 | 58,497 |
| 10 | -6,750 | 75,000 | 22,500 | 90,750 | 0.6139 | 55,711 |
| 11 | -6,750 | 75,000 | - | 68,250 | 0.5847 | 39,904 |
| 12 | -6,750 | 75,000 | - | 68,250 | 0.5568 | 38,004 |
| 13 | -6,750 | 75,000 | - | 68,250 | 0.5303 | 36,194 |
| 14 | -6,750 | 75,000 | - | 68,250 | 0.5051 | 34,471 |
| 15 | -6,750 | 75,000 | - | 68,250 | 0.4810 | 32,829 |
| 16 | -6,750 | 75,000 | - | 68,250 | 0.4581 | 31,266 |
| 17 | -6,750 | 75,000 | - | 68,250 | 0.4363 | 29,777 |
| 18 | -6,750 | 75,000 | - | 68,250 | 0.4155 | 28,359 |
| 19 | -6,750 | 75,000 | - | 68,250 | 0.3957 | 27,009 |
| 20 | -6,750 | 75,000 | - | 68,250 | 0.3769 | 25,723 |
| Total | -720,000 | 1,500,000 | 225,000 | 1,590,000 | - | 1,024,271 |

The Production Tax Credit (PTC) pays fully 225,000 / 585,000 = 0.3846 or 38.46 percent of the initial cost of the turbine.

Net present value of income stream at r = 5 percent/yr real rate of interest: $1,024,271.

$$\text{Yearly net real rate of return.} = \frac{\text{Net present value of income stream}}{\text{Total turbine cost}} \cdot \frac{1}{\text{Project lifetime}}$$

= ($1,024,271 / $585,000) / 20 years
= 0.087545
= 8.75percent/year.

$$\text{Present value of electricity per kW.hr} = \frac{\text{Net present value of income stream}}{\text{Yearly energy production . Project lifetime}}$$

$$= \frac{\$1{,}024{,}271}{1{,}500{,}000\,\frac{\text{kWhr}}{\text{year}}\,\text{x}\,20\,\text{years}}$$

= $0.03414 / kWhr
= 3.41 cents / kWhr

Compared with the benchmark calculation, the Production Tax credit can be inferred to contribute a present value of:

3.41 – 2.84 = 0.57 cents / kWhr,

to the income stream from the produced electricity.

## ACCOUNTING FOR THE PRODUCTION TAX CREDIT, PTC, AS WELL AS DEPRECIATION AND TAXES

The owner of a wind power farm has to pay taxes for the incomes he is obtaining from the electricity sales. Assuming a 25 percent tax rate,

Tax payment per year = 0.25 x (75,003.12-6,750) = $17,063.28

However, if we consider the effect of depreciation, we can compute the net tax payment (net tax) as:

Net tax = tax payment –depreciation credit = 17,063.28 – 14,625 = $2,438.28

Then, the net income stream for the first 10 years is:

Net income = Gross income – expenditure – net tax +PTC

Net income = 75,003.12 – 6750 -2,438.28 + 22,500.93 = $101,815.776

Net present value of income stream at r = 5 % / year real rate of interest: $1,162,184.84

$$\text{Yearly net real rate of return.} = \frac{\text{Net present value of income stream}}{\text{Total turbine cost}} \cdot \frac{1}{\text{Project lifetime}}$$

= ($1.162184.84 / $585,000) / 20 years

= 0.099332

= 9.93percent/year.

$$\text{Present value of electricity per kW.hr} = \frac{\text{Net present value of income stream}}{\text{Yearly energy production . Project lifetime}}$$

$$= \frac{1{,}162{,}184.84}{585{,}000} \times \frac{1}{20} = 3.87\,\text{cents/kWhr}$$

Table 5. Benchmark present value calculation for a 0.6 MW rated power wind turbine, accounting for the Production Tax Credit, PTC incentive as well as depreciation and tax payments.

| Year | Expenditure | Gross income from electricity sale | Tax 25% Gross-Exp | Linear Depreciation 2.5 percent per year | Production Tax credit PTC | Net Taxes (Tax-Dep) | Net income | Present value factor | Net present value of income |
|---|---|---|---|---|---|---|---|---|---|
| 0 | -585000 | - | - | - | - | - | - | - | - |
| 1 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.952380952 | 96967.40571 |
| 2 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.907029478 | 92349.91020 |
| 3 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.863837599 | 87952.29543 |
| 4 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.822702475 | 83764.09089 |
| 5 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.783526166 | 79775.32466 |
| 6 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.746215397 | 75976.49967 |
| 7 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.71068133 | 72358.57112 |
| 8 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.676839362 | 68912.92487 |
| 9 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.644608916 | 65631.35702 |
| 10 | -6750 | 75003.12 | 17063.28 | 14625 | 22500.936 | 2438.28 | 101815.776 | 0.613913254 | 62506.05431 |
| 11 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.584679289 | 46373.74427 |
| 12 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.556837418 | 44165.47073 |
| 13 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.530321351 | 42062.35308 |
| 14 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.505067953 | 40059.38388 |
| 15 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.481017098 | 38151.79417 |
| 16 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.458111522 | 36335.04207 |
| 17 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.436296688 | 34604.80197 |
| 18 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.415520655 | 32956.95426 |
| 19 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.395733957 | 31387.57548 |
| 20 | -6750 | 75003.12 | 17063.28 | 14625 | 0 | 2438.28 | 79314.84 | 0.376889483 | 29892.92903 |
| **TOTAL** | **-720000** | **1500062.4** | **341265.6** | **292500** | **225009.36** | **48765.6** | **1811306.16** | **-** | **1162184.483** |

## SENSITIVITY ANALYSIS OF TAX RATE

The methodology described above can be implemented into an Excel spreadsheet. The present value of the electricity will vary according to the values of the different parameters. Such an estimation showing a variation in the tax rate is shown in Fig. 7. For a tax rate over the interval [0, 50] percent, the present value of the produced electricity varies over the range of [4.6, 3.2] cents/kW.hr.

Table 6. Excel Spreadsheet for present value calculation. Green cells indicate modifiable input data, whereas the gray cells indicate computational steps containing the mathematical formulae used in the economic evaluation.

| | | | |
|---|---|---|---|
| Wind Project | | | |
| **Construction stage** | | | |
| Capacity factor | 600 | [kW] | B3 |
| Investment cost | 750 | [$/kW] | B4 |
| Expected lifetime | 20 | [years] | B5 |
| Installation cost | 30 | [% of the investment cost] | B6 |
| O&M cost | 1.5 | [% of Investment cost / year] | B7 |
| Discount rate | 5 | [%/year] | B8 |
| Total turbine cost | 585000 | [$] | B9=+(B4*B3)+((B6/100)*B4*B3) |
| O&M cost | 6750 | [$/year] | B10=+(B7/100)*B4*B3 |
| Total expenditure | 720000 | [$] | B11=+B9+B10*B5 |
| | | | |
| **Operation stage** | | | |
| Capacity factor | 28.54 | [%] | B14 |
| Price of energy | 0.05 | [$/kWh] | B15 |
| Production Tax Credit | 1.5 | [c$/kWh] | B16 |
| Yearly income from PTC | 22500.936 | [$/year] | B17=+B16*B18/100 |
| Energy produced | 1500062.4 | [kWh/year] | B18=+B3*8760*B14/100 |
| Gross yearly income | 75003.12 | [$/year] | B19=+B18*B15 |
| Net yearly income | 68253.12 | [$/year] | B20=+B19-B10 |
| | | | |
| **Economics** | | | |
| Yearly net real rate of return | | 0.0993 | [1]<br>C23=+(O24/B9)/B5 |
| Yearly net real rate of return | | 9.933 | [%]<br>C24=+C23*100 |
| Present value of electricity | | 3.87379 | [c$/kWh]<br>C25=100*O24/(B18*B5) |
| Tax | | 25 | [%] |

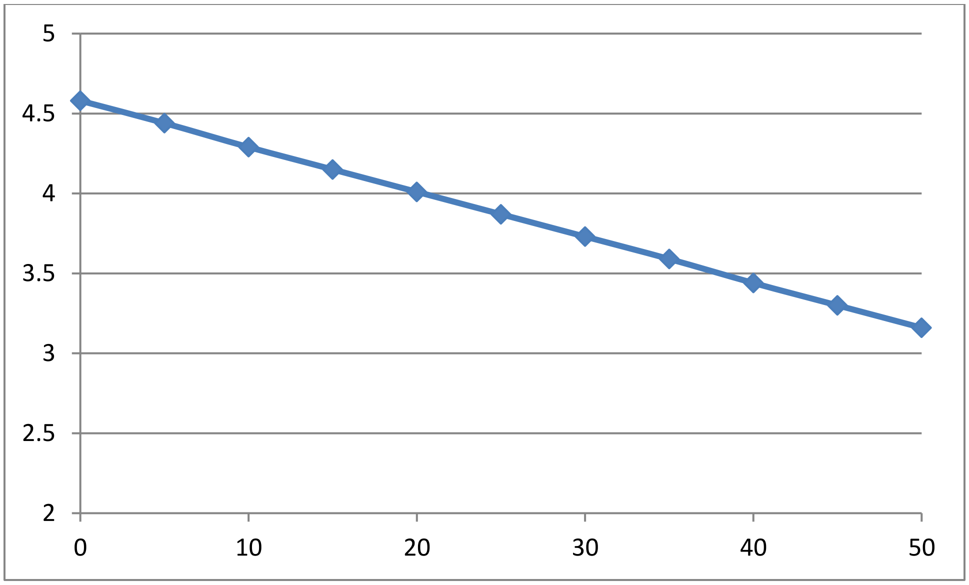


Figure 7. Sensitivity analysis of the present value of the income in cents/ kWhr depending on the tax rate percentage.

Table 7. Effect of tax rate on present value of electricity.

| Tax percentage | Present value of electricity |
|---|---|
| % | [cents/kWhr] |
| 0 | 4.58 |
| 5 | 4.44 |
| 10 | 4.29 |
| 15 | 4.15 |
| 20 | 4.01 |
| 25 | 3.87 |
| 30 | 3.73 |
| 35 | 3.59 |
| 40 | 3.44 |
| 45 | 3.3 |
| 50 | 3.16 |

## OFFSHORE WIND FARMS ECONOMICS

In 1997 the Danish electrical power companies and the Danish Energy agency finalized a plan for large scale investment in offshore wind energy in Danish waters. The plan implies that some 4,100 MW of wind power are to be installed offshore before the year 2030. Wind would by then supply some 50 per cent of Danish electricity consumption out of a total of 31 TWhr/year.

The most important consideration why offshore wind energy is becoming more economical is that the cost of building the foundations has significantly decreased. The estimated total investment, including the grid connections, required to install 1 MW of wind power offshore in Denmark is around 12 million Danish Korona (DKK), equivalent to 4 million German Marks (DEM), or $1.7 million / MW.

Since there is substantially more wind at sea than on land, the average cost of electricity at 5 percent real discount rate and a 20 years project lifetime is about 5 cents/kWhr including an operation and maintenance cost of 1 cent/kWhr.

## PROJECT LIFETIME

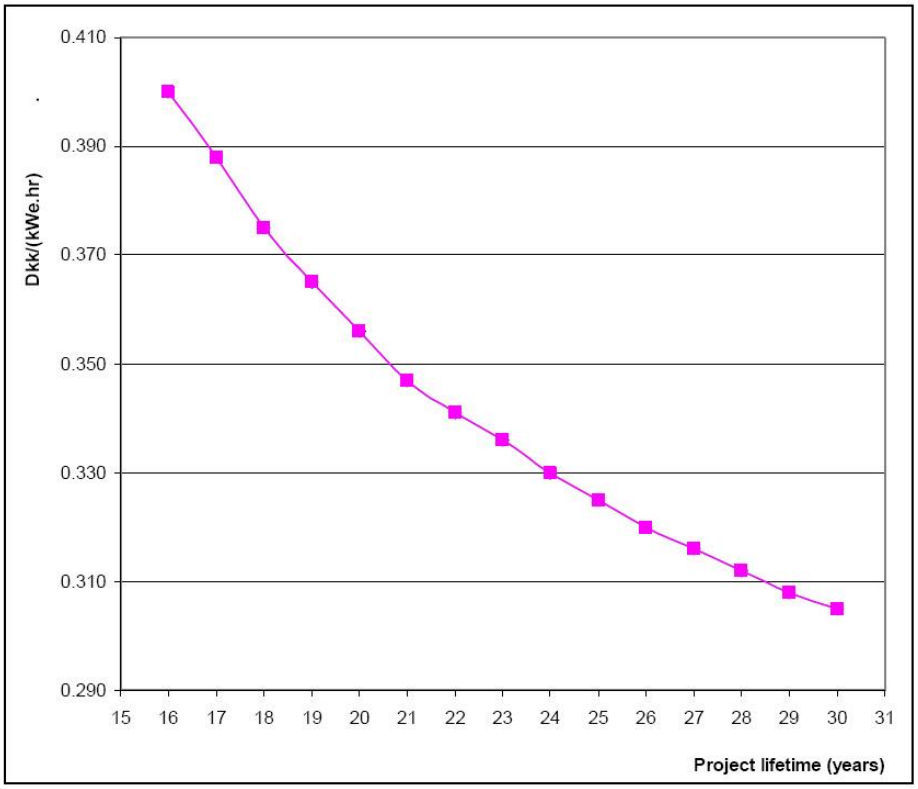


Figure 8. Dependence of the cost of electricity on the project lifetime.

One would think that turbines at sea would suffer corrosion from sea water leading to a shorter lifetime. However winds at sea have a lower turbulence than winds onshore leading to lower vibrations and resulting in a longer lifetime for turbines at sea. Assuming an extended project lifetime of 25 years instead of 20, this leads to costs that are 9 per cent lower.

Danish power companies have been optimizing their wind projects with a project lifetime of 50 years. They require a 50 year design lifetime for the foundations, towers, nacelle shells, and main shafts in the turbines.

If the turbines have a lifetime of 50 years, they will require an overhaul or refurbishment after 25 years. That should cost some extra 25 percent over the initial investment. This leads to a cost a cost of electricity of 0.283 dkk/kWhr, which is similar to the one for average onshore locations in Denmark.

## MANPOWER REQUIREMENTS

As of 1995, the wind industry employed some 30,000 people worldwide according to a study from the Danish Wind Industry Association. This includes both direct and indirect employment. Indirect employment includes the manpower involved in the manufacturing of the components for wind turbines, and those involved in their installation.

Table 8. Manpower allocation to different activities in the wind industry.

| Component | Number of persons | Percent |
|---|---|---|
| Turbine assembly | 3,600 | 41.9 |
| Rotor blades manufacture | 2,000 | 23.3 |
| Electronic controls | 700 | 8.1 |
| Brakes, hydraulic systems | 200 | 2.3 |
| Structural towers | 1,500 | 17.4 |
| Turbines installation | 300 | 3.5 |
| Other activities | 300 | 3.5 |
| Total | 8,600 | 100 |

Wind turbine production is thought to create about 50 per cent more jobs globally, since Danish manufacturers import many components such as gearboxes, generators, and hubs from other countries. Jobs are created when wind turbines are installed in other countries.

## FISHING INDUSTRY ANALOGY

Wind power production has unique characteristics that are different than other energy production systems. It bears up a close analogy to the fishing industry; in that to catch the fish that is available for free from the oceans, capital expenditures are needed to purchase a boat and the fishing nets, operational costs are needed to maintain the boat and its equipment in a running condition, human labor is needed to operate the boat, and then most important, markets are needed to sell the fish catch.

Similarly, to harvest the wind that is available for free from the air, capital expenditures are needed to purchase the wind turbine and the associated power conditioning and transmission equipment.

Operational costs are needed to maintain the turbine in a standby mode ready to catch the wind when it starts blowing, extracting power from the grid at a low level of 2-5 kW to operate its control and ventilation equipment. Human labor is needed for control and maintain the turbine components. Connection to the grid to sell the excess power produced is then needed when the wind blows favorably.

A unique characteristic of wind power production is that the cost incurred and the associated price that can be charged for the produced electricity are not constant and decrease as the total amount of wind electricity is increased.

Countries that have a history in the fishing industry, like Denmark have grasped this reality and have encouraged the individual and cooperatives ownership of wind turbines, much like the ownership fishing boats by individuals and small businesses, and provided them with a market for the product electricity by passing laws requiring the utility grid to purchase from them the product electricity. The system is so successful that Denmark has been exporting its surplus wind electricity to the European Union.

In contrast, under the antiquated protected utilities monopoly system in the USA, the concept of net-metering allows individuals to only get credit of their excess wind electricity production up to the amount of electricity that they purchase from the grid; and a lower price than the electricity purchased from the grid. Any credits for excess power production are forfeited by the utility at the end of the year.

This discourages the production and export of excess wind electricity, and other renewables, into the grid system, and amounts to an amateurish catch and release of the excess captured power, denying potential producers the benefit of being able to market their excess power production. Such a hurdle must be overcome for a sustainable and meaningful implementation of wind power production in the USA.

Consider the disadvantages and the unsolvable dilemma facing a potential solar power producer [1]:

> "Last year I looked into installing a photovoltaic system on my house here in southern California. Then I found out that I would have to sell any excess power back to Southern California Edison for less than Southern California Edison sells it to me.
>
> Plus I would have to use a special meter. I would not be permitted to install the equipment myself (although I am an industrial electrician with more than 20 years of experience), and I would have to pay an approved contractor for the system installation.
>
> Lastly, if there is a power credit at the end of the year (if I produce more power than I use), the credit is forfeited!
>
> Why bother?"

## DISCUSSION

Wind and other renewable sources of energy are creeping towards competitiveness and weaning out from subsidies, compared with traditional electricity generated from conventional fossil and nuclear power plants.

The depreciation period for conventional power plants, whether it is oil, coal, or natural gas is in general 20 years. These plants operate 8,000 hours per year at an average load of 80 percent; the capacity factor of the installed capacity is about 0.73 or 73 percent.

Each kW of installed capacity generates 365 x 24 x 0.73 = 6,394.8 or about 6,400 kWhr / year. If the investment per kW of installed capacity is on average $2,250 / kW; an investment per kWhr per year of 2,250 / 6,400 = $0.35 /kwhr.

We consider a small wind turbine with a nominal power of 2.5 kW, and an intermittence factor of 0.20 or 20 percent, and generating on average 2.5 x 365 x 24 x 0.20

= 4,380 kWhr / year. The investment per kW of installed capacity is about $1,000; each kW delivers 4,830 /2.5 = 1,752 kWhr/year; an investment of 1,000 / 1,752 = $0.571 / kWhr. The implication is that the financial burden of a small turbine per kWhr is 0.571 / 0.35 = 1.63, or 63 percent of those of a conventional power plant. What helps is the zero cost of the wind as fuel. The lower capacity or intermittence factor is balanced out by the lower capital cost.

It will always be argued that the fuel for a small wind turbine is free; there is not much maintenance required, nor personnel to run it. Its operational costs are minimal. A small wind turbine energy production does not need power lines to be delivered to the customer if they are already there in his backyard. No costs for the use of electricity networks and no grid losses are incurred. These could reach the 10 percent that conventional electricity looses during transport and distribution. No administrative or overhead costs are incurred. On average, the sale price of traditionally generated kWhrs is about 10 times the depreciation costs. If these factors are taken into account, the costs comparison between a small wind turbine kWhrs and conventionally generated electricity start converging toward each other.

It must be admitted that the electricity from wind turbines is currently more expensive than traditional generation such as from coal or natural gas. However the future scarcity would bring cost increases as rising fuel costs, wage hikes, and environmental requirements will affect the costs of conventionally generated electricity, but not wind energy’s.

If one shares the view that the stock of fossil energy is finite and depletable, and that the first signs of shortage are already appearing on the horizon; then one is compelled to recognize the threat of international vicious competition for the control of the remaining supplies of fossil fuels. This makes a compelling case for wind energy.

# APPENDICES

# RENEWABLE ELECTRICITY PRODUCTION TAX CREDIT (PTC), INVESTMENT TAX CREDIT, ITC

| | |
|---|---|
| **Incentive Type:** | Corporate Tax Credit |
| **State:** | Federal |
| **Eligible Renewable/Other Technologies:** | Landfill Gas, Wind, Biomass, Hydroelectric, Geothermal Electric, Municipal Solid Waste, Hydrokinetic Power (i.e., Flowing Water), Anaerobic Digestion, Small Hydroelectric, Tidal Energy, Wave Energy, Ocean Thermal |
| **Applicable Sectors:** | Commercial, Industrial |
| **Amount:** | 2.1¢/kWh for wind, geothermal, closed-loop biomass; 1.1¢/kWh for other eligible technologies. Generally applies to first 10 years of operation. |
| **Eligible System Size:** | Marine and Hydrokinetic: Minimum capacity of 150 kW<br>Agricultural Livestock Waste: Minimum capacity of 150 kW |

| | |
|---|---|
| **Web Site:** | http://www.irs.gov/pub/irs-pdf/f8835.pdf |
| **Authority 1:** | 26 USC § 45 |
| **Date Enacted:** | 1992 (subsequently amended |

The American Recovery and Reinvestment Act of 2009 (H.R. 1) allows taxpayers eligible for the federal renewable electricity production tax credit (PTC) to take the federal business energy investment tax credit (ITC) or to receive a grant from the U.S. Treasury Department instead of taking the PTC for new installations. The new law also allows taxpayers eligible for the business ITC to receive a grant from the U.S. Treasury Department instead of taking the business ITC for new installations. The Treasury Department issued Notice 2009-52 in June 2009, giving limited guidance on how to take the federal business energy investment tax credit instead of the federal renewable electricity production tax credit. The Treasury Department will issue more extensive guidance at a later time.

The federal renewable electricity production tax credit (PTC) is a per-kilowatt-hour tax credit for electricity generated by qualified energy resources and sold by the taxpayer to an unrelated person during the taxable year. Originally enacted in 1992, the PTC has been renewed and expanded numerous times, most recently by H.R. 1424 (Div. B, Sec. 101 & 102) in October 2008 and again by H.R. 1 (Div. B, Section 1101 & 1102) in February 2009.

The October 2008 legislation extended the in-service deadlines for all qualifying renewable technologies; expanded the list of qualifying resources to include marine and hydrokinetic resources, such as wave, tidal, current and ocean thermal; and made changes to the definitions of several qualifying resources and facilities. The effective dates of these changes vary. Marine and hydrokinetic energy production is eligible as of the date the legislation was enacted (October 3, 2008), as is the incremental energy production associated with expansions of biomass facilities. A change in the definition of "trash facility" no longer requires that such facilities burn trash, and is also effective immediately. One further provision redefining the term "non-hydroelectric dam," took effect December 31, 2008.

The February 2009 legislation revised the credit by: (1) extending the in-service deadline for most eligible technologies by three years (two years for marine and hydrokinetic resources); and (2) allowing facilities that qualify for the PTC to opt instead to take the federal business energy investment credit (ITC) or an equivalent cash grant from the U.S. Department of Treasury. The ITC or grant for PTC-eligible technologies is generally equal to 30% of eligible costs.

The tax credit amount is 1.5¢/kWh in 1993 dollars (indexed for inflation) for some technologies, and half of that amount for others. The rules governing the PTC vary by resource and facility type. The table below outlines two of the most important characteristics of the tax credit -- in-service deadline and credit amount -- as they apply to different facilities. The table includes changes made by H.R. 1, in February 2009, and the inflation-adjusted credit amounts are current for the 2009 calendar year. (See the history section below for information on prior rules.)

| Resource Type | In-Service | Credit |
|---|---|---|

| | Deadline | Amount |
|---|---|---|
| Wind | December 31, 2012 | 2.1¢/kWh |
| Closed-Loop Biomass | December 31, 2013 | 2.1¢/kWh |
| Open-Loop Biomass | December 31, 2013 | 1.1¢/kWh |
| Geothermal Energy | December 31, 2013 | 2.1¢/kWh |
| Landfill Gas | December 31, 2013 | 1.1¢/kWh |
| Municipal Solid Waste | December 31, 2013 | 1.1¢/kWh |
| Qualified Hydroelectric | December 31, 2013 | 1.1¢/kWh |
| Marine and Hydrokinetic (150 kW or larger)** | December 31, 2013 | 1.1¢/kWh |

The duration of the credit is generally 10 years after the date the facility is placed in service, but there are two exceptions:

1. Open-loop biomass, geothermal, small irrigation hydro, landfill gas and municipal solid waste combustion facilities placed into service after October 22, 2004, and before enactment of the Energy Policy Act of 2005, on August 8, 2005, are only eligible for the credit for a five-year period.
2. Open-loop biomass facilities placed in service before October 22, 2004, are eligible for a five-year period beginning January 1, 2005.

In addition, the tax credit is reduced for projects that receive other federal tax credits, grants, tax-exempt financing, or subsidized energy financing. The credit is claimed by completing Form 8835, "Renewable Electricity Production Credit," and Form 3800, "General Business Credit."

As originally enacted by the Energy Policy Act of 1992, the PTC expired at the end of 2001, and was subsequently extended in March 2002 as part of the Job Creation and Worker Assistance Act of 2002 (H.R. 3090). The PTC then expired at the end of 2003 and was not renewed until October 2004, as part of H.R. 1308, the Working Families Tax Relief Act of 2004, which extended the credit through December 31, 2005. The Energy Policy Act of 2005 (H.R. 6) modified the credit and extended it through December 31, 2007. In December 2006, the PTC was extended for yet another year -- through December 31, 2008 -- by the Tax Relief and Health Care Act of 2006 (H.R. 6111).

The American Jobs Creation Act of 2004 (H.R. 4520), expanded the PTC to include additional eligible resources -- geothermal energy, open-loop biomass, solar energy, small irrigation power, landfill gas and municipal solid waste combustion -- in addition to the formerly eligible wind energy, closed-loop biomass, and poultry-waste energy resources. The Energy Policy Act of 2005 (EPAct 2005) further expanded the credit to certain hydropower facilities. As a result of EPAct 2005, solar facilities placed into service after December 31, 2005, are no longer eligible for this incentive. Solar facilities placed in-service during the roughly one-year window in which solar was eligible are permitted to take the full credit (i.e., 2.1¢/kWh) for five years.

Prior to H.R. 1, geothermal facilities were already eligible for a 10% tax credit under the energy ITC (26 USC § 48). However, the new legislation permits all PTC-eligible technologies, including geothermal electric facilities, to take a 30% tax credit (or grant) in lieu of the PTC. Recent guidance from the IRS regarding the Treasury grants in lieu of tax credits indicates that geothermal facilities that qualify for the PTC are eligible for either the 30% investment tax credit or the 10% tax credit, but not both. The window for the 30% tax credit runs through 2013, the in-service deadline for the PTC, while the 10% tax credit under the section 48 ITC does not have an expiration date.

H.R. 1424 added marine and hydrokinetic energy as eligible resources and removed "small irrigation power" as an eligible resource effective October 3, 2008. However, the definition of marine and hydrokinetic energy encompasses the resources that would have formerly been defined as small irrigation power facilities. Thus H.R. 1424 effectively extended the in-service deadline for small irrigation power facilities by 3 years, from the end of 2008 until the end of 2011 (since extended again through 2013).

## RENEWABLE ENERGY PRODUCTION INCENTIVE (REPI)

| | |
|---|---|
| **Incentive Type:** | Production Incentive |
| **State:** | Federal |
| **Eligible Renewable/Other Technologies:** | Solar Thermal Electric, Photovoltaics, Landfill Gas, Wind, Biomass, Geothermal Electric, Anaerobic Digestion, Tidal Energy, Wave Energy, Ocean Thermal |
| **Applicable Sectors:** | Local Government, State Government, Tribal Government, Municipal Utility, Rural Electric Cooperative, Native Corporations |
| **Amount:** | 2.1¢/kWh (subject to availability of annual appropriations in each federal fiscal year of operation) |
| **Terms:** | 10 years |
| **Web Site:** | http://apps1.eere.energy.gov/repi |
| **Authority 1:** | 42 USC § 13317 |
| **Date Enacted:** | 10/24/1992 (subsequently amended) |
| **Authority 2:** | 10 CFR 451 |

Established by the federal *Energy Policy Act of 1992*, the federal Renewable Energy Production Incentive (REPI) provides incentive payments for electricity generated and sold by new qualifying renewable energy facilities. Qualifying systems are eligible for annual incentive payments of 1.5¢ per kilowatt-hour in 1993 dollars (indexed for inflation) for the first 10-year period of their operation, *subject to the availability of annual appropriations in each federal fiscal year of operation.* REPI was designed to complement the federal renewable energy production tax credit (PTC), which is available only to businesses that pay federal corporate taxes.

Qualifying systems must generate electricity using solar, wind, geothermal (with certain restrictions), biomass (excluding municipal solid waste), landfill gas, livestock methane, or ocean resources (including tidal, wave, current and thermal). The production payment applies only to the electricity sold to another entity. Eligible electric production facilities include not-for-profit electrical cooperatives, public utilities, state governments and political subdivisions thereof, commonwealths, territories and possessions of the United States, the District of Columbia, Indian tribal governments or political subdivisions thereof, and Native Corporations.

Payments may be made only for electricity generated from an eligible facility first used before October 1, 2016. Appropriations have been *authorized* for fiscal years 2006 through fiscal year 2026. If there are insufficient appropriations to make full payments for electricity production from all qualified systems for a federal fiscal year, 60% of the appropriated funds for the fiscal year will be assigned to facilities that use solar, wind, ocean, geothermal or closed-loop biomass technologies; and 40% of the appropriated funds for the fiscal year will be assigned to other eligible projects. Funds will be awarded on a pro rata basis, if necessary.

## REFERENCES

1. Kenneth Johnson, “Plugging into the Sun,” National Geographic, Letters, p. 8, January 2010.