# TOPIC PAPER #14

# NON-BIO RENEWABLES

On July 18, 2007, The National Petroleum Council (NPC) in approving its report, *Facing the Hard Truths about Energy,* also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the Task Groups and their Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

**These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents but approved the publication of these materials as part of the study process.**

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached Topic Paper is one of 38 such working document used in the study analyses. Also included is a roster of the Subgroup that developed or submitted this paper. Appendix E of the final NPC report provides a complete list of the 38 Topic Papers and an abstract for each. The printed final report volume contains a CD that includes pdf files of all papers. These papers also can be viewed and downloaded from the report section of the NPC website (www.npc.org).

# NATIONAL PETROLEUM COUNCIL

## RENEWABLE SUBGROUP
## OF THE
## SUPPLY TASK GROUP
## OF THE
## NPC COMMITTEE ON GLOBAL OIL AND GAS

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# Renewable Energy Technologies

# Supply Task Group

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Date submitted: July 2007

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# I. Executive Summary

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## *A. General Overview*

Despite the expected rapid growth in wind and solar power, most accepted forecasts of future energy supplies suggest that the total contribution from new renewable energy installations will remain small for the next two decades. Although the potential contribution of solar and wind power, waves, tides, and geothermal energy is vast, the current cost of harnessing most of these sources is high, relative to energy from fossil fuels. However, that cost differential is now shrinking, from both directions. In the context of the NPC Study, this section addresses whether that differential is likely to become small enough for renewable energy to capture significant market share from conventional energy sources, and contribute meaningfully to the global energy mix in 2030.

Globally, hydropower already supplies as much energy as nuclear power, but its growth prospects appear limited, at least in the developed countries. While hydropower and geothermal energy have been used for decades, consumer and investor interest in the other "renewables" has historically tracked energy prices, peaking during the energy crisis of the 1970s, and again recently, as oil and natural gas prices increased to multiples of their long-term nominal averages. Environmental concerns have added important new drivers to this relationship, based on the minimal emissions of criteria pollutants and greenhouse gases from renewable resources. In addition, renewable energy is widely regarded as providing significant energy security benefits.

Although none of the renewable energy sources considered in this section produces liquid fuels that compete with petroleum products, they all generate electricity or heat that displaces natural gas or coal, which then becomes available for other uses. All these technologies have unique features, because they tap natural energy flows in different ways. Collectively, however, they have several common characteristics, in addition to producing mainly power, rather than fuels:

- High fixed costs of construction or fabrication and installation
- Low operating costs, with minimal fuel or feedstock expenses
- Economies of scale that have not been fully exploited

The latter point is particularly important for wind and solar power, which include manufactured components amenable to experience-curve effects and steady technology gains. The combination of these factors has driven the real levelized cost of wind power down by 85% and solar power by 80%, since 1980. With continued improvement, wind power and concentrated solar power appear likely to become economically competitive ($/kWh) with conventional power generation within a few years, while solar photovoltaic energy is expected to reach parity with retail power prices within the timeframe considered by the study. These milestones represent significant takeoff points for each of these technologies.

At the same time, the output of many of the new renewable energy sources is cyclic or intermittent, raising concerns about their integration into existing power networks. This problem is exacerbated by the remoteness of some of the best renewable energy locations from the markets they would serve, requiring new infrastructure that adds to their total cost of delivered electricity.

Until the key cost thresholds for renewables have been reached, regulatory policies will continue to have a large influence on the economics of renewable energy. A mix of tax incentives, subsidies, and mandates is making renewables much more attractive than they would be based on their actual costs. These vary from market to market but include the US production tax credit, state renewable portfolio standards, and EU feed-in tariffs. At the same time, greenhouse gas emission caps and their accompanying trading mechanisms, which are already in place in the EU and contemplated for the US, raise the effective cost of power derived from fossil fuels. After the experience of the US wind power market, which lived for years with the threat—and periodic reality—of the expiration of incentives, these regulations must be seen as consistent and durable, in order to achieve their maximum effect in promoting renewable energy.

Although emissions of criteria pollutants and greenhouse gases from renewable energy are quite low, even on a life-cycle basis, project developers are encountering a growing array of stakeholder concerns relating to other aspects of these technologies. Wind power has met opposition on noise, “flicker,” and its effect on viewscapes and on birds and bats. Solar power requires a substantial footprint, and even solar rooftops that minimize this are not universally appreciated. And while still growing in the developing world, large-scale hydropower is in retreat in some developed markets, with dams being removed to protect fish populations. As the scale of renewable energy deployment increases, and as population expands into formerly remote areas, developers will experience more conflicts of this type.

Excluding hydropower, renewable energy already contributes 38 GW of electrical generation globally, a figure that has been growing at 8.5% per year over the last five years. If these rates were sustained, these sources could provide up to 4% of global electricity by 2030. Where previously these sources collectively fell within the margins for error of most long-term energy forecasts, their growth is positioning them to influence both the future energy mix, and the market dynamics that drive it.

## *B. Policy Recommendations*

The results of three decades of renewable energy development, along with an understanding of the inherent attributes of these technologies, suggest several important guidelines for public policy that maximizes the contribution from these sources in the years ahead:

- Renewable energy will benefit most from a national strategy that addresses energy and environmental goals in a consistent, inter-connected way.
- Federal regulations and incentives should be technology-neutral, recognizing the regional diversity of our renewable resources. Coordination with state and local initiatives in this area is essential.
- Incentives for renewable energy should be sustained for periods long enough to stimulate strong, compound growth, rather than the boom-and-bust behavior associated with the Production Tax Credit in the past.
- Indirect measures to remove barriers to renewable energy, such as promoting transmission line access, grid inter-connections and other infrastructure, and national net-metering standards, may do as much to advance renewables as direct subsidies.

# II. Methodology

## *A. Introduction*

This report examines the potential of renewable energy to influence by direct and indirect substitution the global market for oil and the developing global market for natural gas. It identifies and quantifies the implications of this for US energy supply. For the purposes of this report, "renewable energy" excludes biofuels and biomass, which have been addressed by other teams, along with municipal solid waste (MSW.) We assess the level of development and the economic competitiveness of renewables as a whole, and of the specific technologies for tapping naturally-occurring energy sources, looking at both the production of renewable energy devices and the energy contribution of their expanding installed base. We also provide a high-level assessment of the potential of renewable energy to reduce global and US greenhouse gas emissions.

Renewable energy was an important source of power prior to the large-scale exploitation of hydrocarbons, but with the exception of hydroelectric power and geothermal energy, the current renewable energy technologies all owe their present level of development to research and incentives arising from the Energy Crisis of the 1970s. Renewables have advanced significantly since then, and the high energy prices of the last four years have stimulated further progress. Although many of these technologies require significant support from government entities in terms of incentives, tax credits, mandates and other policies, several are on the threshold of true commerciality, benefiting from "experience curve" effects and increased market pull resulting in further economies of scale.

There is a significant disconnect between government and industry projections of the likely market penetration of renewables over the next two decades. While this report cannot fully reconcile these differences, we will attempt to show where higher expectations may be warranted, and where technology, regulations, and infrastructure will tend to limit the growth of renewables. This is a critical issue, because the gap between the EIA's "reference case" projections and the outcome of sustaining recent growth rates for wind and solar power through 2030 would be large enough to affect projections of future natural gas demand in the electric power sector. The growing emphasis on reducing greenhouse gas emissions, both at the state and local level in the US and on the national and trans-national level elsewhere, adds another strong impetus to the development and deployment of these technologies.

## B. Scope

The purpose of this study is to determine the extent that renewable energy will contribute to the diversification of global energy sources by 2020 and 2030. The study examines the renewable energy sector in three primary segments, focusing first on the US, then globally and finally, where appropriate, addressing issues in the large developing countries.

As noted above, biomass and MSW were explicitly excluded, leaving all of the technologies for generating heat or electricity from renewable sources. This includes some, such as the various ocean power technologies, that although unlikely to contribute globally meaningful quantities of energy by 2030, still hold significant future potential.

DOE's definition, per the Office of Energy Efficiency and Renewable Energy (EERE) website:

> *Energy derived from resources that are regenerative or for all practical purposes can not be depleted. Types of renewable energy resources include moving water (hydro, tidal and wave power), thermal gradients in ocean water, biomass, geothermal energy, solar energy, and wind energy. Municipal solid waste (MSW) is also considered to be a renewable energy resource.* MSW is not covered in this study.

For the purposes of this study, "renewable energy" includes those technologies that convert a naturally-occurring primary energy flow into energy capable of performing useful work, by generating either electricity or high-grade heat, and rely on a resource that is either perpetually self-renewing or inexhaustible over many human lifetimes. This study explicitly excludes biofuels and biomass, which are both feedstock-based and still entail significant non-renewable inputs.

Specific examples include solar photovoltaic and solar thermal energy; hydroelectric power; wind, wave and tidal energy; geothermal energy; and ocean thermal energy. Historically, these energy flows have been tapped with varying degrees of success, but new technology is improving their conversion efficiency and increasing the scale at which they can operate. Although none of these technologies produces a direct substitute for petroleum products, their deployment displaces oil and natural gas from their use in generating electricity, steam and process heat.

In addition, the forms of renewable energy included above operate without any significant emissions of criteria pollutants or greenhouse gases, although their construction or fabrication may emit some quantity of either or both. All of these forms of renewable energy are location-specific, depending on resources that are unevenly distributed geographically and are often intermittent in nature, varying either unpredictably or according to daily and/or seasonal cycles.

From an investment project perspective, all of these renewables exhibit financial profiles similar to a hydroelectric dam, and should be compared to each other or to fossil fuel alternatives only on the basis of risk weighted, fully amortized economics. In particular:

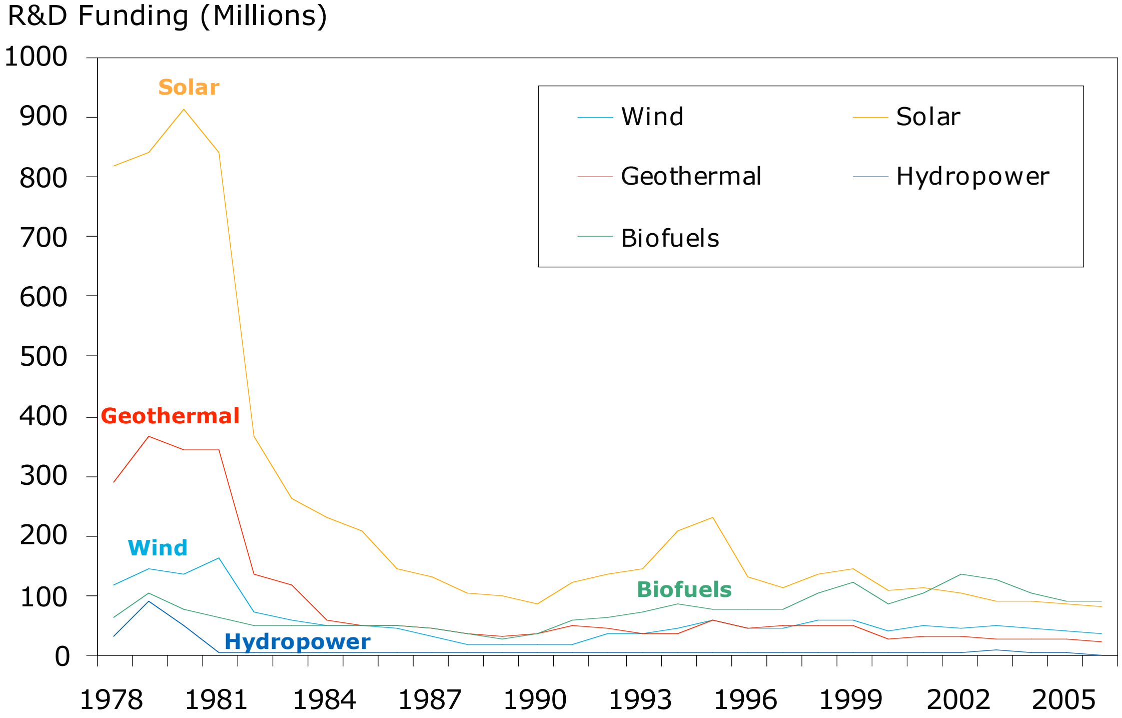
- Up-front investment in construction or fabrication and installation represents the bulk of project cost
- Operations incur minimal feedstock or fuel costs
- Ongoing variable costs are low, maintenance-type

# III. Findings

## A. History/Background

In 1972, prior to the first Energy Crisis, renewable energy consisted mainly of hydroelectric dams and geothermal installations, which together provided just over 6% of the world's total primary energy supply. The Oil Embargo of 1973-74 and the subsequent Iranian Revolution in 1979 fundamentally changed the global perception of energy, putting the long-term availability and secure supply of oil into question and increasing the attractiveness of alternatives, including renewables. Government and private R&D budgets for renewable energy increased significantly, as did incentives for investing in and exploiting renewable resources.

**U.S. R&D Funding for Selected Renewable Energy Technologies – 2006 Dollars**



*Source: EIA Renewable Energy 2000: Issues~Trends , Figure 1, Updated with DOE Budget Data for 2000 -2006*

As oil prices declined in the mid-1980s interest in renewable energy waned. Many governments scaled back their R&D efforts in this area, either as a share of overall government R&D funding or in absolute terms, comprising on average less than 8% of total government energy R&D from 1974-2003 (per IEA Renewables Information 2006.) Surprisingly, wind power, which has contributed the most to the recent growth of renewable power, received a smaller share of this funding than any major technology other than solar thermal power.

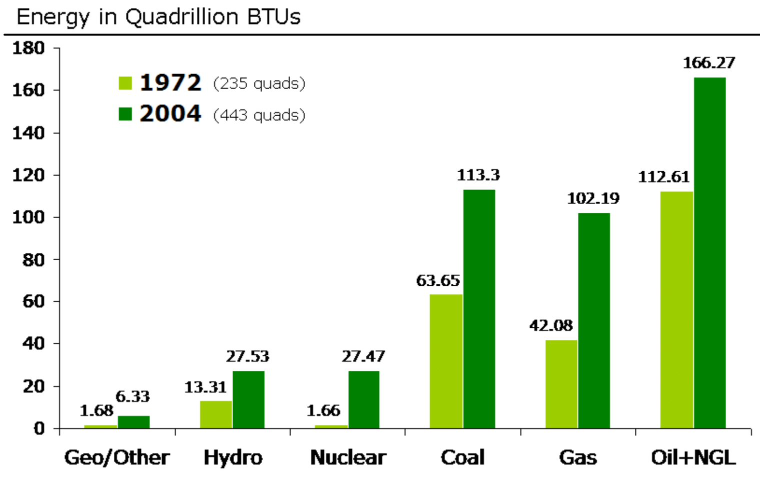
With the establishment of the United Nations Framework Convention on Climate Change at the Rio Conference on Environment and Development in 1992, renewable energy became more attractive for non-economic reasons, relating to its low greenhouse gas emissions. This has been particularly important within the European Union, where concerns about climate change have spawned a large renewable energy industry focused on wind and solar power. Despite the very visible growth in Europe, by 2004 non-hydroelectric renewable energy, including biofuels, still accounted for less than 1% of the global energy supply.

In addition to the economic challenges that all new technologies face when competing with established systems, most renewables have an extra hurdle to overcome. Unlike hydrocarbons, which provide energy in a concentrated and predictable form, wind and solar generation are by their nature intermittent, subject to cyclical or unpredictable variations that make their integration into existing energy infrastructure more challenging and decrease their net environmental benefit. In the last ten years, a variety of jurisdictions have established regulatory frameworks of incentives and mandates to help overcome these hurdles, such as the renewable portfolio standards for electricity generation in place in 23 states within the US.

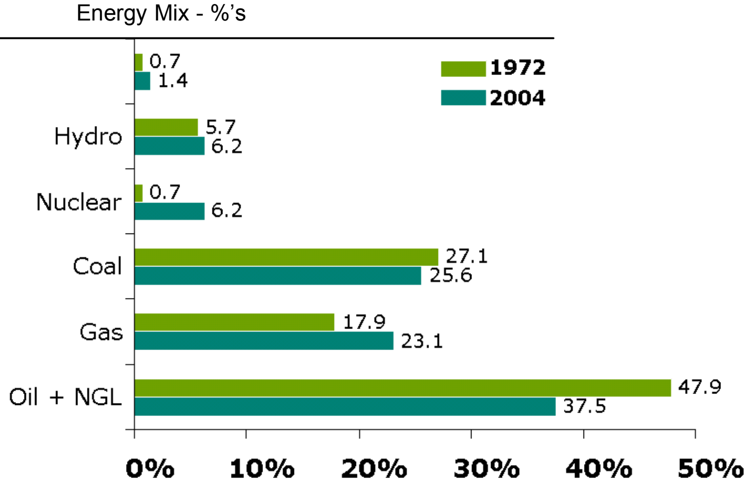
Today, non-hydroelectric renewable energy is on the threshold of materiality, accounting for more than half of planned 2007 additions to US electric generating capacity. Sustained growth will depend on four factors: continued technology development, continued improvement in capital and operating unit costs, (greater economies of scale,) the level and stability of government incentives, and the degree to which the price of fossil energy explicitly recognizes the cost of $CO_2$ emissions, by means of carbon taxes or cap-and-trade mechanisms. These factors will determine whether renewable energy remains a small but useful side-stream, or joins the mainstream of mid-21st century energy.

## *B. Current State*

The Energy Information Agency of the US Department of Energy has the task of compiling energy statistics on the domestic and global economies. The EIA's forecasts represent the official view of the federal government on future energy trends. When we compare their assessment of the global primary energy supply in 1972, the year before the Arab Oil Embargo, to that of 2004, we see that the energy mix has shifted significantly, while total energy production has increased by 89%, from 235 to 443 quadrillion BTUs (quads.) In particular, the relative share of oil has declined by one-fifth.



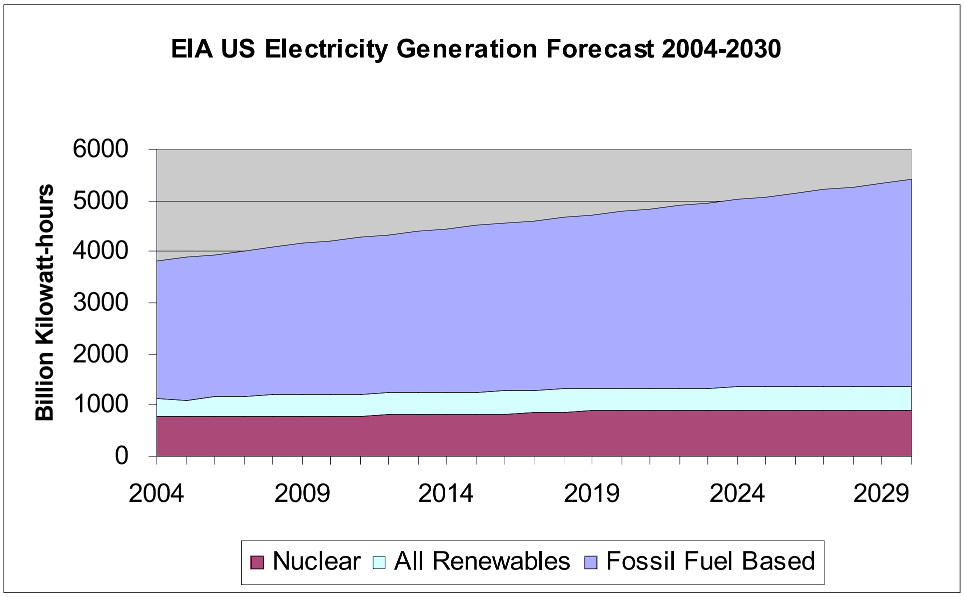
Source: EIA Annual Energy Review 2005, table 11.1 World Primary Energy Production by Source, 1970-2004



The changes in non-hydropower renewable energy over this period are scarcely noticeable, growing from less than 0.5 quads to 4 quads. When considering their potential future contribution, however, it is important to note that in the 1970s and 1980s petroleum yielded much of its global market share in power generation to natural gas and an earlier new technology, nuclear power, which grew by 1500%. Coal use also grew significantly, but at a slightly slower rate, on average, than overall energy consumption, while hydropower grew slightly ahead of total energy use.

## C. Future Trends (2020 & 2030)

The EIA's forecast projects that renewable energy will continue to grow over the next two decades, but on average no faster than the growth in overall electricity supply. In their view, total renewable energy, including hydropower, starts at 8.5% of US electricity generation, grows to 9.4% by 2020, and declines to 8.6% by 2030.



The EIA forecast assumes growth rates for non-hydro renewable energy that are inconsistent with recent trends, and significantly lower than the growth seen in 2005 and 2006. It also predicts that the growth of these renewables will stall at relatively low overall market penetration levels. Yet from 1990-2004, a period during which many of the current drivers of renewable energy development were still taking shape, wind power grew at a global rate of 24%, and solar power at 6%.

## D. Key Drivers

Although each of the specific renewable energy technologies has its own unique drivers, the entire renewables sector shares a set of common, global trends and uncertainties that will influence its development. Those with the greatest impact and uncertainty include:

- The cost and availability of natural gas
- The expansion and predictability of environmental regulations, including limits and charges on greenhouse gas emissions
- The global growth of electricity demand
- The pace of innovation in renewable energy, including improvements in reliability and continued reductions in per-unit costs, both capital and operating
- Development and deployment of enabling technologies, such as distribution infrastructure and energy storage
- The development of markets for the green attributes of renewable energy
- Energy security concerns

The interaction of these factors will determine whether renewable energy remains a small but useful side-stream, or joins the mainstream of 21st century energy supplies.

## E. Public Policy

Large-scale hydroelectricity and geothermal power are the only renewable generation sources that can currently compete on cost with conventional generation. The other technologies remain dependant on public policy to support their development, primarily in the form of incentives and mandates. Although conventional energy has been affected by various regulations during the last thirty years, many forms of renewable energy owe their very existence to subsidies or renewable portfolio standards, or at least their survival during periods when energy prices were low.

The renewable energy policy framework in the US is complex. Tax credits have been provided for renewable energy since the Energy Tax Act of 1978, with periodic extensions during the 1980s. These incentives were updated in the Energy Policy Act of 1992, though the wind energy production credit remained perpetually at risk of expiration. The Energy Policy Act of 2005 created a national target of 7.5% renewable energy by 2013, along with additional incentives and R&D funding for renewables. It also applied the inflation indexed Production Tax Credit of 1.9 cent/kWh to a broader range of technologies and extended it through 2017, but only for projects that would be on-line by the end of 2007. At the end of 2006, this deadline was extended through 2008. In spite of this greater focus, total federal spending on renewable energy was less than 0.1% of the total 2007 Federal budget.

Across the US, federal renewable energy policy and incentives are augmented by a variety of state and local initiatives. Twenty two states and the District of Columbia have enacted Renewable Portfolio Standards, requiring utilities to source targeted percentages of their electricity supply from renewables by a set date. Most of these mandate that10-20% of electricity supply come from renewables, as early as 2010 or as late as 2025. Comparing these state standards is complicated by their inconsistent treatment of large-scale hydroelectricity, the biggest current renewable electricity source. New York's 24% standard includes it; California's 20% target does not. In addition to financial incentives, state and local regulations cover a variety of issues that are important to the expansion of renewable energy, including interconnection, "net metering" standards, zoning and permitting.

Other governments have actively promoted renewable energy technologies as a response to rising energy prices and growing concern about climate change. Public policy in the European Union, in particular, has played a leading role in guiding the development and deployment of renewable energy. The new EU Energy Strategy, released in 2006, was intended to enhance energy security and provide an economically and environmentally sustainable energy future. The expansion of renewable energy is a key element of this strategy, which also integrates renewables into the EU Emissions Trading Scheme. Europeans see renewable energy not just as a way to address climate change and the EU's growing dependence on imported energy, but as a source of export earnings on renewable energy hardware, such as wind turbines and solar panels.

Specifically, the EU aims to generate 21% of its electricity from renewable sources by 2010, up from 14% in 2003, although the 2006 EU Green Paper on energy admits that it is likely to end up 1-2% short of this goal. It has a simultaneous target of reducing overall European greenhouse gas emissions by 20% by 2020, and the European Commission is debating a higher target. These policies are implemented within the EU's 25 countries by means of quotas and/or price supports—feed-in tariffs and "green certificates"—that enable renewables to compete with conventional power. Although this approach guarantees a strong market for renewable energy, it also creates distortions, such as the over-development of solar PV in Germany, by means of subsidies averaging 60 Euro-cents/kWh, even though Germany experiences half the average annual solar exposure of Spain.

Looking beyond the developed country markets, large developing countries such as China and India will have a significant influence on the expansion of renewable energy, because of the rapid growth of their economies and the enormous investment in electricity generation each must make. Renewables will capture an important segment of that market, assisted by government policies.

Growing out of earlier energy and development policies and the country's Five-Year-Plan process, China's Renewable Energy Law took effect in 2006. It targets increasing the country's renewable energy supply from 4% to 15% of the total by 2020, and it commits to investing $180 billion to make this happen. The law requires grid enterprises to buy the output of renewable power projects and includes price supports for renewables, which are partially recovered in the power price. Meeting the 15% target in the context of a planned 450 GW increase in total power generation—a figure that may significantly understate the quantity of new generation needed—could require up to 50 GW of new renewable power capacity from wind, solar, and biomass, and another 100 GW from large hydroelectric installations.

In India, the national government has funded renewable energy development since the 1980s, to promote energy security and sustainable development, and as a vehicle for rural electrification. A national renewable energy policy is being developed that builds upon the provisions of the Electricity Act 2003. At least six of the country's states have enacted renewable portfolio standards for power generation, and several have put in place "feed-in tariffs" for renewable power, similar to those used in Europe, along with capital cost subsidies and other incentives.

China, India and other developing countries are also eligible for renewable energy investments under the Kyoto Protocol's Clean Development Mechanism (CDM), which provides Certified Emissions Reductions (CERs) to third-country buyers. Nearly half of the CDM projects approved so far are for renewable energy.

## F. Conclusions

Other than for large-scale hydro-electricity and geothermal, which are now commercial:

- Unit costs have declined considerably since the 1970s, but renewable energy systems have not yet reached scales at which they can compete with conventional energy without subsidies or incentives, the required magnitude of which is different for each technology.
- Renewables are highly sensitive to government policy, which varies considerably from state to state and country to country.
    - Promoting the development and wide deployment of renewables requires policies that are consistent over long periods of time.
    - Technology leadership in renewables moves to those regions or countries that provide the most attractive and consistent policies.
- Optimal deployment of renewable energy technologies also depends on localized physical conditions.
    - The resources tapped by renewable energy technologies are unevenly distributed, varying by latitude, local climate, or proximity to flowing water, underground steam reservoirs or oceans.
    - Government policies that ignore these variations may result in inefficient deployment of renewable energy technology.
- Except where utilized for distributed power, some forms of renewable energy create challenges for local grid operators, because of their cyclic or intermittent output. This may require policy and technical upgrades to the grid such as net metering, real time grid management and energy storage.
- Renewable energy is attracting significant amounts of capital. Cumulative installations of several technologies, including wind and solar PV, are growing at very high rates, in excess of 25% per year globally.
- There is an apparent disconnect between high growth rates, which have been sustained for multiple years, and most official energy projections., which do not foresee renewables gaining meaningful market share against fossil fuels by 2030. This reflects a general view that renewables are “optional” or marginal.

## IV. Renewable Energy Technologies

The remainder of this report is devoted to detailed discussions of each of the key renewable energy technology areas, excluding biofuels, biomass and municipal solid waste. These technologies will be addressed in the following order:

Although these technologies share many characteristics, including relatively high initial costs offset by low ongoing expenses, they also exhibit important differences. Geothermal and solar thermal power compete primarily with grid-based conventional power, as does wind power, particularly as the scale of individual wind turbines and aggregated wind installations grows. Despite this similarity, each of these technologies fits into a different portion of the electric power dispatch curve, and thus competes with different conventional generators and fuels. Solar PV, on the other hand, looks equally applicable to grid or distributed power applications, including at the consumer level.

Some of the distinctions between these technologies derive from their intrinsic characteristics, while others are the result of the way that R&D funding and public policy have shaped their development. This makes comparing their future potential problematic, requiring assumptions about future regulatory environments, as well as the pace of technology development and cost reduction.

Looking across these technology areas, we also see the degree to which the large scale and relatively low growth rate for hydropower still dominates consolidated measures of the renewables sector. If current growth rates can be sustained, however, wind power and both solar technologies could emerge from this shadow between now and 2030, with the potential to eventually eclipse hydropower in the long run.

**US Non-Biomass Renewable Electricity Contribution, 2006**

| | Net Generation (GWh)* | Growth Rate (2000-2006) | Equivalent Natural Gas (BCF/year)** |
|---|---:|:---:|---:|
| Wind | 25782 | 29% | 180 |
| Solar PV/Thermal | 505 | >30% (PV est. only) | 4 |
| Geothermal | 14842 | 0.9% | 104 |
| Hydropower | 288306 | 0.8% | 2018 |
| **Total** | **329435** | **1.8%** | **2306** |

*Source: EIA Monthly Energy Review April 2007, Table 7.2a

**Basis gas turbine alternative @ 7000 BTU/kWh

# V. Wind

## A. Technology Overview

The technology for capturing the energy contained in wind and turning it into electricity has advanced significantly since the 1970s, with wind turbines becoming larger, cheaper and more efficient. In a typical, modern, large-scale wind turbine, the kinetic energy in the wind is converted to rotational motion by the rotor – typically a three-bladed, upwind turbine. The rotor's motion is converted through a gearbox and series of shafts and a generator into electricity at medium voltage (a few hundred volts). The electricity flows to a transformer, which increases the voltage of the electric power to the distribution voltage (a few thousand volts). The distribution-voltage power flows through underground lines to a collection point where the power may be combined with other turbines. In many cases, the electricity is sent to nearby farms, residences and towns where it is used. Otherwise, the distribution-voltage power is sent to a substation where the voltage is stepped-up to transmission-voltage power (a few hundred thousand volts) and sent through transmission lines many miles to distant cities and factories.

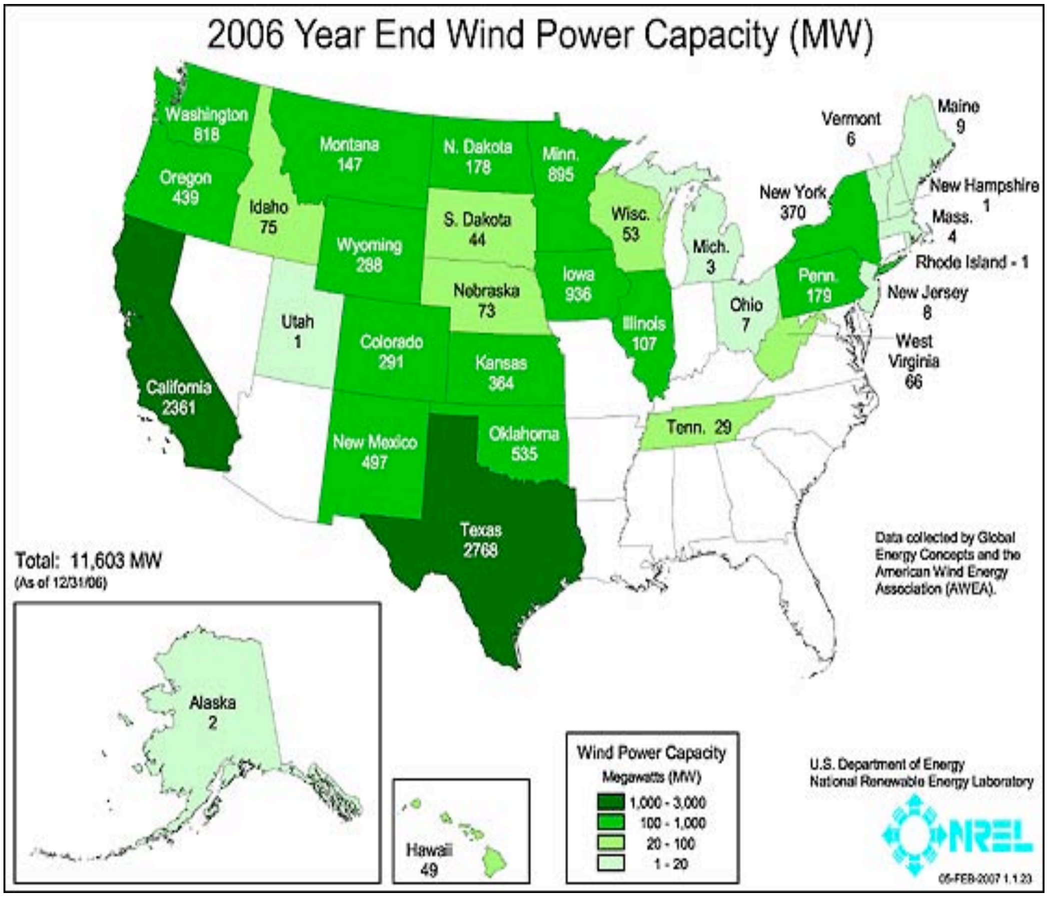
## B. Conclusions

- Wind power is growing rapidly and becoming an important source of energy globally
- It is commercially attractive in the US with current incentives
- Wind power is one of the more mature renewable energy sources. At current global energy prices and with further technology improvements, wind may soon compete economically without incentives.

## C. Key Drivers

- Wind generated electricity is eligible for the Production Tax Credit (PTC); the presence of this credit has been the key driver in wind investments in the US.
- Wind power is eligible for Clean Development Mechanism (CDM) credits
- Green E electricity certification and marketing is driving demand for renewable power sources
- As a domestic source of energy, wind power helps address energy security concerns
- Wind produces zero emissions and addresses concerns about greenhouse gas emissions related to energy production
- Steady technological advances in turbine technology and size have continue to expand the potential wind resource base
- Twenty-five percent of the US landmass has sufficient wind resources to produce electricity that can compete with conventional sources under current incentives

## D. Current Status



- In the U.S., 2,454 megawatts (MW) of new wind power generating capacity was added in 2006, boosting the total U.S. installed wind energy capacity by 27% to 11,603 MW.
- Annual investment of approximately $4 billion  In terms of capital spending for new power generation in the US during 2006, wind was second only to natural gas – for the second year in a row.
- Texas accounted for nearly a third of the new wind power installed in 2006, taking over the lead from California in cumulative installed capacity. Texas hosts the world's single largest operating wind farm, the 735-MW Horse Hollow Wind Energy Center, located in Nolan and Taylor counties.
- New utility-scale turbines were installed in a total of 20 states.

- The top five states in new installations were Texas (774 MW), Washington (428 MW), California (212 MW), New York (185 MW) and Minnesota (150 MW).

| Country | MW | Share of Global Wind Capacity | Renewable Portfolio Standard |
|---|---|---|---|
| Germany | 20,622 | 27.8% | |
| Spain | 11,615 | 15.6% | 15% by 2010 |
| United States | 11,603 | 15.6% | 22 state standards |
| India | 6,270 | 8.4% | 6 state standards |
| Denmark | 3,136 | 4.2% | 20% by 2010 |
| China | 2,604 | 3.5% | 15% by 2020 |
| Italy | 2,123 | 2.9% | |
| UK | 1,963 | 2.6% | |
| Portugal | 1,716 | 2.3% | |
| France | 1,567 | 2.1% | |
| Top 10 – Total | 63,217 | 85.2% | |
| Rest of World | 11,004 | | |
| World Total | 74,221 | | |

- Other countries with the highest total installed capacity are Germany (20,621 MW), Spain (11,615 MW), India (6,270 MW) and Denmark (3,136MW). There are now thirteen countries with over 1,000 MW of wind capacity.
- Globally, the US continued to lead in new capacity additions followed by Germany (2,233 MW), India (1,840 MW), Spain (1,587 MW), China (1,347 MW) and France (810 MW). France and China are gaining ground.
- Europe had 48,545 MW of installed capacity at the end of 2006, representing 65% of the global total. In 2006, the European wind capacity grew by 19%, producing approximately 100 TWh of electricity, equal to 3.3% of total EU electricity consumption in an average wind year.
- The worldwide growth rate of wind capacity is about 30% with new markets opening in countries throughout the world.
- Offshore wind continues to expand, and is realizing rapid growth in Europe, where national commitments to greenhouse gas reductions are driving

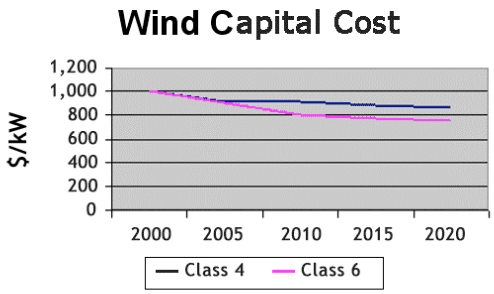
renewable energy development. In the northeastern United States, two of the country's first large offshore wind energy projects are currently involved in the planning and permitting process. Although there are significant opportunities for continuing wind energy development on land in some parts of the country, the future potential for offshore development may be even larger. The DOE estimates that offshore wind could support 900,000 MW, however much of the total capacity is unavailable due to environmental & other location concerns

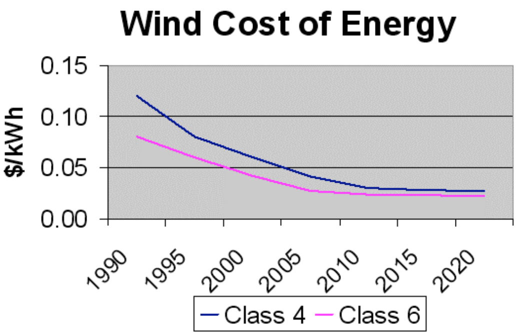
- Small wind, typically below 1 KW, has experienced major growth in the past decade. The market for small wind recently grew 35% in a single year and the industry has set ambitious growth targets continuing at 18-21% through 2010. The U.S. is a leading producer of small wind turbines, with one-third of the world market commanded by four U.S. producers. AWEA predicts continued growth in this market that has about 45 MW of installed capacity in small wind turbines domestically, and makes 50% of its sales in foreign markets.

## 1. Wind Power Costs

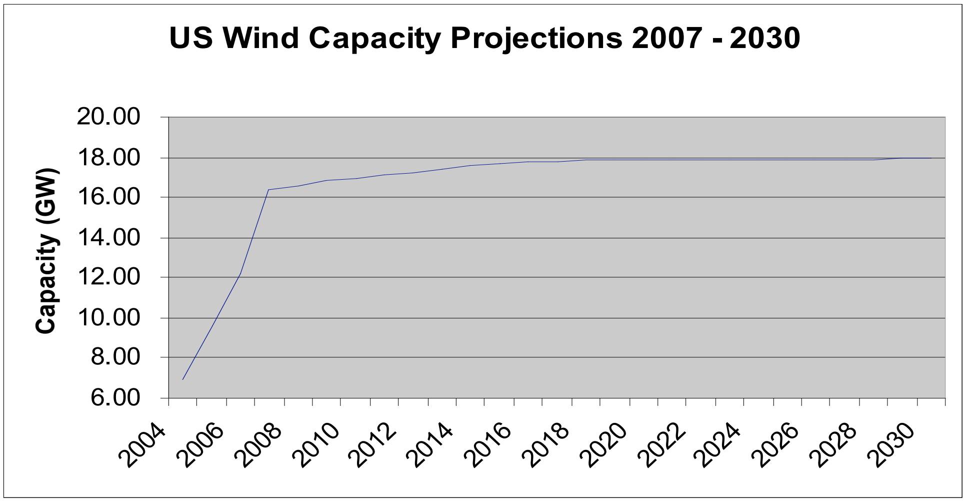
Wind technology is competitive today in grid connected power markets with support from the production tax credit, and in niche applications or markets that value non-cost attributes. Current performance is characterized by levelized costs of 4 to 5.5¢/kWh (depending on resource intensity and financing structure). Although wind costs have been projected to approach $800 to $1,100/kW installed capacity. The high level of demand and limited supply of turbines has driven costs to $1,800/kW.

The worldwide annual market growth rate for wind technology is about 30% with new markets opening in countries throughout the world. The increased domestic interest in environmentally responsible electric generation technology is reflected by new state energy policies (RPS) and in the success of "green marketing" of wind power across the country by providers.





## E. Future Projections (2020 & 2030)



*Source: EIA*

## F. Limitations

Wind power is currently unable to consistently generate power to the grid at cost lower than conventional generation sources. Although technology costs have declined over the past ten years and ongoing operation costs are relatively low, wind power installations still require higher initial investment per annual kWh than fossil-fueled alternatives.

The major challenge to using wind as a source of power is that the wind is intermittent and it does not always blow when electricity is needed. Good wind sites are often located in remote locations, far from cities where the electricity is needed. Wind resource development may compete with other uses for the land and those alternative uses may be more highly valued than electricity generation.

## 1. Technical

- **Intermittency of Wind**

  Wind can be highly variable from hour to hour, daily, seasonally and even annually. This variability presents substantial challenges to incorporating large amounts of wind power into a grid system, since to maintain grid stability, energy supply and demand must remain in balance. These challenges could be met by advances in enhanced grid management, energy storage technologies or hybrid wind applications

- **Supply chain issues**

  Demand for steel and other industrial commodities that make up components of turbines have driven up the capital cost wind projects substantially.

## 2. Footprint

- **Land/Space Requirements**

  Wind turbines require roughly 0.1 square kilometers of unobstructed land per megawatt of capacity. A 2 GW wind farm might have turbines spread out over an area of approximately 200 square kilometers

- **Birds and Bats**
  A well publicized concern of the dangers of turbines to bird and bat populations, with several documented problem locations. Special

consideration needs to given to siting particularly near migratory paths and nesting/rooking areas.

- **Visual, noise and other NIMBY complaints**
  The sheer size of many new turbines draws complaints from nearby residents and landowners. Additionally, the turbines give rise to noise complaints as well as complaints regarding “flicker" which is the alternating pattern of sun and shade caused by the rotating turbine.

## 3. Future Advances and New Technologies

- **Axial**
  Vertical axis wind turbines consist of a number of airfoils vertically mounted on a rotating shaft or framework. Unlike the more common type of generator which uses a propeller, the vertical axis turbine generator rotates around the vertical axis rather than the horizontal one. The vertical arrangement has several advantages, notably the generator can be placed at the ground for easy servicing, and the main supporting tower can be much lighter as much of the force on the tower is transmitted to the bottom. However, the increased force at the base is also the cause of many failures of this technology, causing the technology to remain commercially unproven.

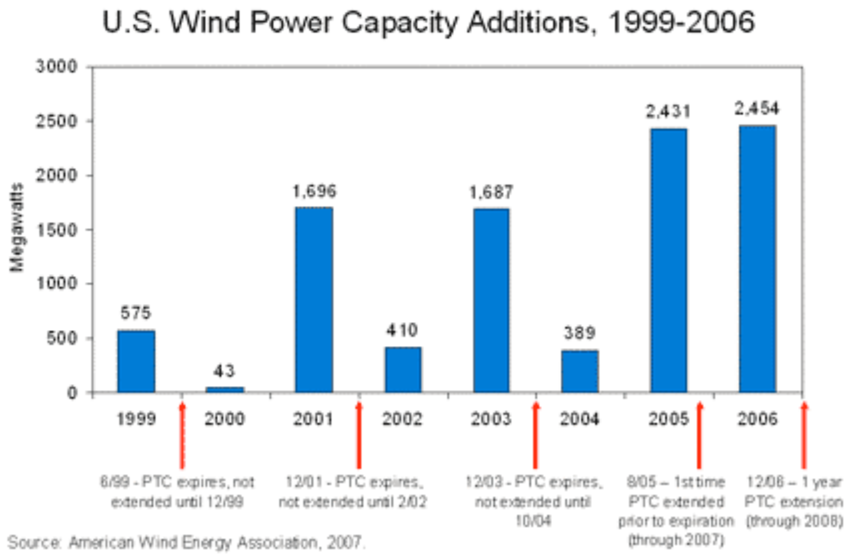
- **Airborne**
  Currently a concept technology using a tethered turbine aloft in the prevailing wind stream. An Ontario company, Magenn Power, Inc., is attempting to commercialize tethered aerial turbines suspended with helium. An Italian project called "Kitegen" uses a prototype vertical-axis wind turbine. The Kite Wind Generator (KWG) or KiteGen is claimed to eliminate all the static and dynamic problems that prevent the increase of the power (in terms of dimensions) obtainable from the traditional horizontal-axis wind turbine generators.

- **Low speed wind**

  The DOE has set a target to generate power from Class 4 winds at 3 cents/kwh for land based and 5 cents/kWh for offshore wind by 2012. This would significantly expand the area that would be able to sustain viable wind generation capacity. Technology improvements for low speed wind technology are needed in three principal areas:
  - Turbine rotor diameters must be larger to harvest the lower-energy winds from a larger inflow area without increasing the cost of the rotor.
  - Towers must be taller to take advantage of the increasing wind speed at greater heights.
  - Generation equipment and power electronics must be more efficient to accommodate sustained light wind operation at lower power levels without increasing electrical system costs.
- **Compressed-air energy storage (CAES)**

  A new storage technology being evaluated is compressed-air energy storage (CAES). CAES technology is designed to store wind power through compressed air. Air would be captured and stored in underground storage, such as caves or old wells. The air would then be released during peak or low wind periods. Demonstrations are underway in Alabama, Iowa and Germany.
- **Further turbine technology improvements**: GE has recently developed a 3.6MW turbine unit, other manufacturers are eyeing 5MW units that are allowing larger projects and provide greater economies of scale.

## *G. Relevant Public Policy*



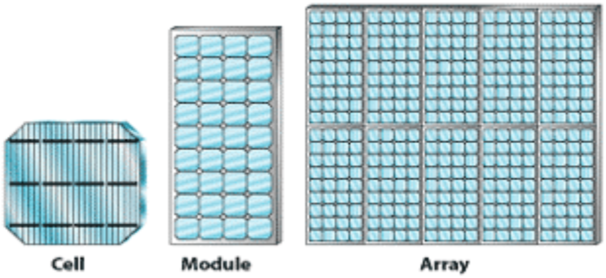
Source: American Wind Energy Association, 2007.

This chart from AWEA shows the “boom and bust” effect of the PTC on US wind capacity additions. Each expiration date of the credit has been followed by a precipitous decline in construction. Even today, meaningful increases in total generation capacity are dependent on the improved economics resulting from the credit. The current PTC has been extended through 2008. Without a further extension, past experience would predict a similar drop-off in growth.

# VI. Solar Photovoltaic (PV)

## *A. General Overview*

As with wind power, the technology for harnessing solar energy has progressed significantly in recent years. In general, solar power involves transferring the energy of the sun’s rays into a form capable of performing work, as either heat or electricity. For solar photovoltaic (PV) devices the transfer of energy takes place when light passes through a semiconductor most often made of polysilicon. Thin-film solar generates useable energy on the same theoretical platform of light transfer, but utilizes a layering process of semiconductors that are a few micrometers thick. Traditional PV is also categorized by the size in which the entire solar configuration is deployed: at a single cell level, a module level, and an array level; whereas thin-film solar material can be integrated with many traditional products such as roofing shingles, industrial glass, and military fabrics.



(Source: EERE-DOE)

(Thin-Film solar shingles by Uni-Solar)

## B. Conclusions

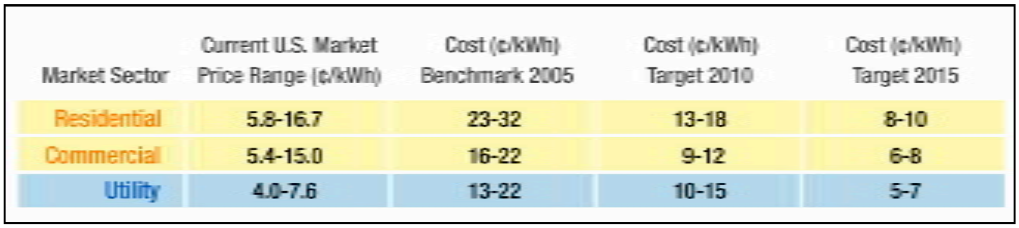
- The solar PV market will continue to expand, dependent upon government incentives, regulation of $CO_2$ emissions, and long-term power purchase agreements.
- In order to compete with conventional energy sources, R&D investment by the private and public sectors must address increasing the efficiency of solar PV cells, improving production processes, and reducing the effective cost per delivered kilowatt hour

## C. Key Drivers

- Production Tax Credits have been renewed through 2008
- Substantial amount of medium to high quality solar radiation sites in the Southwestern US on land that is otherwise largely non-productive.
- International, federal, and state initiatives providing financial incentives to produce solar power
- Reduced production costs are driving thin-film application expansion

## D. Current Status

- The solar PV market expanded at a record rate in 2005, manufacturing 1.7 gigawatts of capacity world wide and 150 megawatts of US based production, for a current year on year growth rate of 40%.
- The President's Fiscal Year (FY) 2007 budget requests $148 million for solar energy research, a $65 million (78%) increase over FY 2006.
- The solar industry in the U.S. provided 20,000 high tech jobs in 300 companies and is forecasted to employ 150,000 by 2020.
- Current cost per kilowatt is not competitive with traditional energy sources for utility applications. Subsidies and high retail power rates make solar PV installations more competitive for consumers in California and New Jersey.

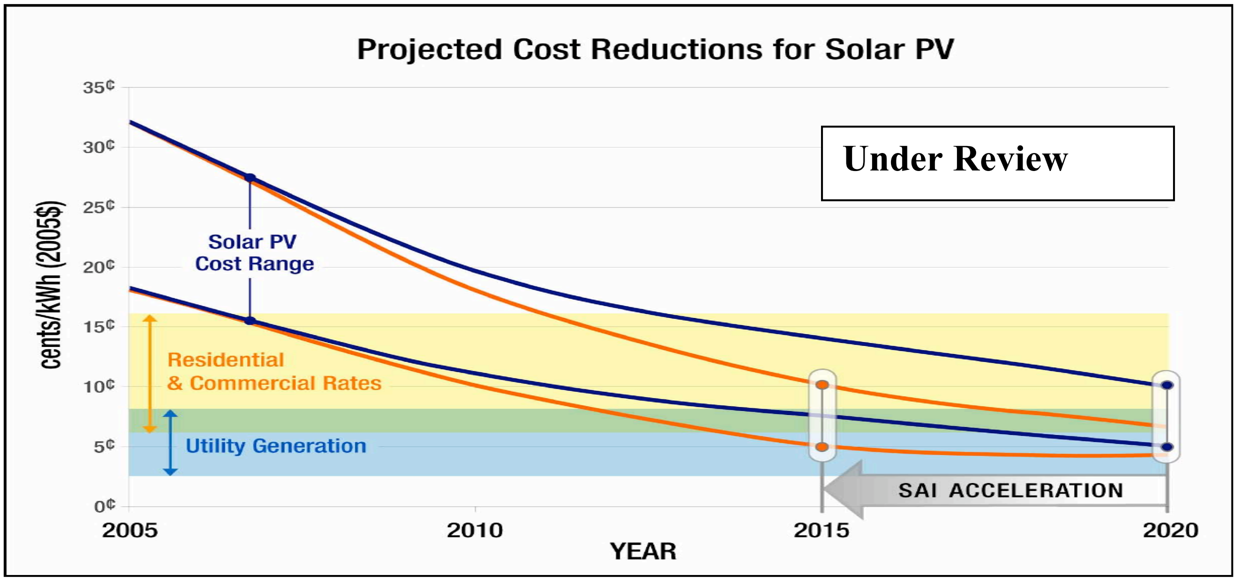


| Market Sector | Current U.S. Market Price Range (¢/kWh) | Cost (¢/kWh) Benchmark 2005 | Cost (¢/kWh) Target 2010 | Cost (¢/kWh) Target 2015 |
|---|---|---|---|---|
| Residential | 5.8-16.7 | 23-32 | 13-18 | 8-10 |
| Commercial | 5.4-15.0 | 16-22 | 9-12 | 6-8 |
| Utility | 4.0-7.6 | 13-22 | 10-15 | 5-7 |

Source: SAI

## *E. Future Projections*

- The solar market has nearly unlimited expansion potential, though the rate at which the sector actually grows is dependent upon tax incentives, supply chain constraints, and technology advances.
- The Solar America Initiative (SAI) has projected cost reductions based on sufficient R&D investments to bring PV generated to electricity to 8 to 12 cents kWh by 2015 and 6 to 8 cents kWh by 2030.

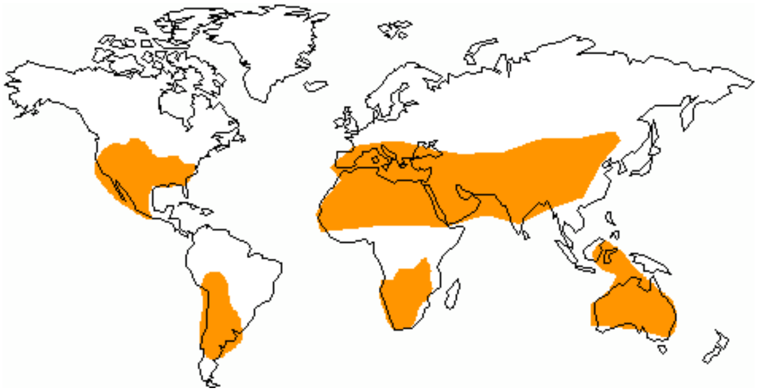


- SAI seeks to achieve projected deployed capacity between 5 and 10 GW by 2015.
- Industry analysis indicates that there is a sustained 25% year on year growth potential resulting in a 27 billion dollar market by 2020. Calculation based upon the most optimistic condition indicates that the PV sector could supply up to 10% of U.S. peak generation capacity by year 2030.

## *F. Limitations*

Despite the enormous potential of PV in the diversification of the global energy supply it is subject to many limitations. Sustained investment, technological advancement, and supply chain reliability are all uncertain. Physical limitations of climate, particularly cloud cover and latitude also restrict the utilization of solar PV in many areas of the world. . The greatest solar insolation is found in the lower latitudes of the world and are often concentrated in vast desert regions.

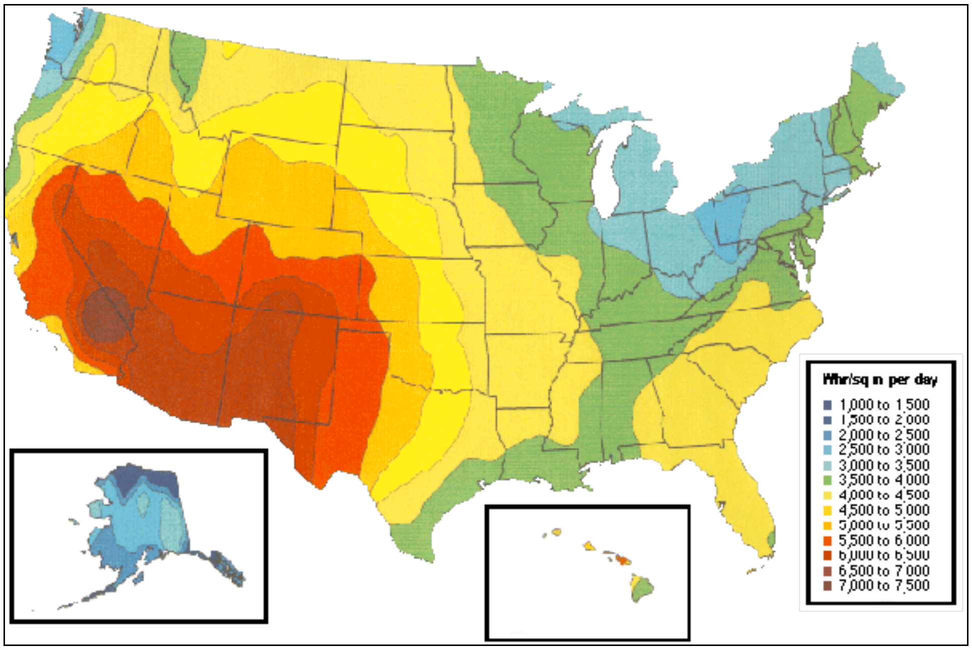
World solar radiation concentration



(source: Powerfromthesun.
http://www.powerfromthesun.net/chapter1/images/figure1_4.gif)

Solar installation and home mounted systems can be installed anywhere the sun shines, but achieving the maximum economic efficiency rating solar PV requires the highest levels of solar radiation, such as those found in the desert Southwest of the United States.

US solar radiation concentration



(Source: Arizona solar center)

The solar industry as a whole last year saw unprecedented private investment amounting to $378 million in 2006 compared to $242 million in 2005. This must be sustained for years to adequately fund emerging technologies, overcome the technological limitations of the current applications, and meet the cost-reduction and mass-production targets upon which current industry projections are based. If the technology anticipated in the projections is not realized, then the industry goals and projections will not be achieved.

Silicon shortages have been a major limitation to the production of silicon based solar cells. Industry analysis suggests that increased silicon production will be able to track the increasing demand in the long-term and achieve price stabilization, but this may not be the case for the specialized compounds used in the production of single crystalline thin film solar.

## 1. Footprint

Although there are multiple areas for optimal solar generation, physical limitations will also play a key role in the expansion of the PV solar sector.

Economic efficiency rates are dependant on optimal conditions and only a few locations meet the requirements of ambient temperature, insulation, and the amount of cloud cover. Utility scale PV installations cover vast tracts of land shading the area and transforming the environment from its natural state. The sheer amount of land that is needed for large-scale PV raises aesthetic concerns, as well. This “visual pollution” limitation may also be an inhibitor in the addition of PV modules on residential rooftops.

### 2. Future Advances

- **Thin Film Production:** Patented thin-film production methods have produced reliable test results in quality and stability. The replicability in the individual processes has the potential to transform the solar market in that mass production of consistent thin-film can be achieved.
- **Efficiency Ratings:** The efficiency limit of traditional PV cells has increased to approximately 40% and new advancements capitalizing on low level light could bring that level up to 45%. Typical PV cells currently marketed today have an efficiency rating of 10-22%.

## *G. Relevant Public Policy*

The future of the solar PV sector depends on public policy that provides strong reliable support and long term tax credit guaranties. Current policy operates on shorter timelines, such as the extension of the federal solar tax credit until the end of 2008. This is inhibiting the full valuation of solar projects and future investment. Individual States, predominately Western states, have created programs that provided incentives to adapt solar PV to residential areas. The California million solar roof top program and the Arizona has solar electric roadmap are just a few of the state driven initiatives to adapt solar PV.

# VII. Solar Thermal – Concentrated Solar Power (CSP)

## *A. General Overview*

In contrast to Solar Photovoltaic Energy, which turns sunlight directly into electricity, Concentrated Solar Power (CSP) employs mirrors to collect and focus the sun's rays to generate high temperature heat or steam that can be used to generate electricity. Sunlight is the most abundant renewable energy supply on Earth – only 1% of the Earth's desert area could produce more electricity than is currently provided by fossil fuels worldwide. CSP is not a new idea; the principle of concentrating the sun's energy in this way was understood by Archimedes in the 3rd century BC.

CSP technology generally falls into three types of concentrating systems: the parabolic troughs, parabolic dishes and central receiver or "power towers". The trough and tower technologies use the following basic components: concentrator (mirrors), receiver, transport/storage and power conversion. The concentrator captures the sunlight and focuses it on the receiver. A heat transfer fluid in the receiver absorbs the solar heat for storage or immediate routing through a heat exchanger to produce steam, which turns a conventional steam turbine to make electricity. The relative simplicity of these mechanical systems provides an important advantage over more complex technologies. The dish technology uses mirrors to concentrate and focus the solar energy on an individual receiver. The receiver absorbs the concentrated energy and converts it to heat, and transfers the heat to the engine/generator to produce electricity. The most common engine used in dish-engine systems is the Stirling engine.

## B. Conclusions

CSP, like other forms of renewable energy, is benefiting from increased concerns about the environment, energy prices and energy security. When augmented by thermal energy storage or hybridization with natural gas generating capacity, CSP is an attractive option to produce uninterruptible power for long periods, relative to other cyclic or intermittent renewables.

CSP is a relatively proven technology, and its different forms can meet the needs of a variety of locations and terrains. CSP projects have several advantages over other renewable energy sources, including their availability during peak demand periods (afternoon). Also, Trough and Tower projects can be designed to incorporate thermal storage, which extends their output beyond daylight hours.

Trough technology is the most mature CSP technology, with over 20 years of successful operations. Tower technology is not as advanced but holds similar promise, and may offer higher efficiency levels. Both technologies can also be hybridized and coupled with gas-fired turbines, to ensure a ratable electricity output during times when solar energy is insufficient. Thought not yet commercially proven, dish systems are perhaps the most versatile CSP design, due their wide scalability (kilowatts to gigawatts) and high level of efficiency.

## C. Key Drivers (Trough/Dish/Tower)

All types of CSP require arid regions, high intensity sunlight and minimal cloud cover. Most of the best locations for CSP are located within 35 degrees north/south of the equator. Desert environments are usually ideal candidates for trough and tower applications. Since CSP works best in dry climates, the availability of water may be a key decision variable in the design of the plant. Other drivers include:

- R&D to drive down costs.

- Construction costs will continue to decline as production ramps up and meaningful commercial volumes are achieved.
- Maintenance costs will continue to decline as more projects are completed and "learnings" are shared
- Proximity to transmission infrastructure and markets
- Regional economic growth, including electricity demand growth
- Government mandates and incentives, including renewable portfolio standards (RPS & PTC)
- Concerns about greenhouse gas emissions
- Alternative uses for the land

## *D. Types of CSP*

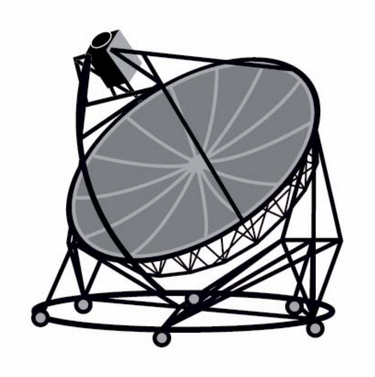
### 1. Trough

Solar trough plants are composed of parabolic trough-shaped reflectors, which concentrate sunlight onto receiving tubes that heat water (for direct steam generation) or another heat transfer fluid. The collector field is made up of parallel rows of solar collectors typically aligned from north to south. The collectors rotate to track the sun from east to west during the day (single tracking axis). Trough collectors are the most mature CSP technology.

The first patent for a parabolic trough design was issued in 1907. In the 1980s and early ’90s nine solar trough plants totaling 354 MW were constructed in California and formed the Solar Electric Generating Systems (SEGS). A favorable regulatory environment, coupled with tax incentives and off-take electricity agreements provided the economic stimulus to build these plants. Once the economic incentives were removed and the price of fossil fuels receded, no new CSP plants were built after 1991. However, the existing plants have been operating for the past 20 years and during that time they have reduced their levelized cost of energy produced from >$.25/kWh to $.10-.12/kWh today. The cost of energy from a new trough plant built today is estimated to $.12/kWh with a goal of reducing that to below $.09/kWh in the next five years.

## 2. Dish

Dish systems use parabolic dish-shaped mirrors to reflect and concentrate incoming sunlight on a receiver, which mechanically converts the concentrated heat into electricity. The Dish tracks the sun on two axes.



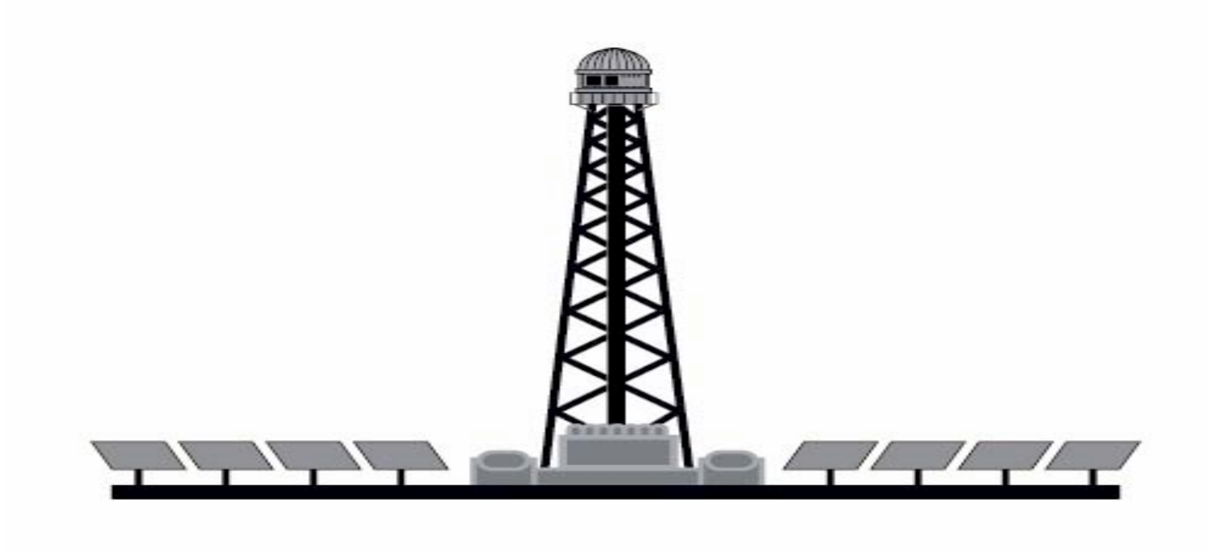
Dish systems are highly efficient and current designs have demonstrated high peak solar-to-electric conversion efficiency (29.4%).

Another unique characteristic of dish installations is their scalability. A single

location or terrain that is not suitable for other CSP applications. The challenge for dish/Stirling systems is the establishment of a reliability record (both for a better understanding of O&M costs and for eventual project finance). Lack of a reliability record should be mentioned. The current estimate for the cost of generating electricity from a dish/Stirling system is approximately $.49/kWh with the 5 year goal to reduce the cost by approximately 50%.

## 3. Power Tower

Tower systems employ many heliostats (reflecting mirrors) to concentrate sunlight on a central receiving tower, heating a transfer fluid that is ultimately used to make electricity via steam turbines. In the 1980's a number of small demonstration solar towers were built in Europe, Russia and Japan, and the US built a large demonstration solar tower in the Mojave Desert near Barstow, California. The project, named Solar One, was a 10 MW design which used 1,818 heliostats. The heat transfer fluid in the collection tower turned water into steam, which was converted to electricity by conventional steam generators. The current estimates of building a commercial-scale power tower today is about $.16/kWh.



In the mid 1990's Solar One was expanded into Solar Two. This project increased the number of heliostats, exchanged the oil based heat transfer fluid for molten salt, and incorporated a thermal storage reservoir for the salt.

These changes allowed Solar Two to produce electricity during daylight hours, while also charging the thermal storage system. The energy stored in the salt was used to continue producing electricity after sunset. These two demonstration projects advanced the tower technology and serve as the foundation for future plants.

## *E. Current Status*

CSP costs (trough and tower) today are estimated to be in the range of $.12 - .16/kWh, and continuing to approach the benchmark costs for fossil fuels. It is expected that within 5-10 years CSP will be competitive with electricity produced from fossil fuels, especially when the cost of greenhouse gas emissions is factored into the overall comparison.

- **Trough** – Recent US activity includes a 1 MW facility in Arizona and a 64 MW facility in Nevada.
- **Dish** – There have been several recent announcement to install between 800 – 1750 MW in California. However, to date, there are no dish commercial plants or large scale demonstrations in operation.
- **Tower** – The US built two demonstration projects in 1980s and ’90s. Capitalizing on high EU incentives for renewable energy, Spain has an active building program for tower projects. The 11 MW power tower, PS10 is a solar-only system with saturated water-steam heat storage which began operations in February 2007. SolarTres, a 15 MW power tower facility currently under construction, will use molten salt as its heat transfer fluid. The molten salt will provide 16 hours of heat energy storage which will enable the plant to produce 24 hours a day during the summer.

**Characteristics of Concentrating Solar Power Systems**

| System | Peak Efficiency | Annual Efficiency | Annual Capacity Factor |
|---|---|---|---|
| Trough | 21% | 10 to 12% (d)<br>14 to 18% (p) | 24% (d) |
| Power Tower | 23% | 14 to 19% (p) | 25 to 70% (p) |
| Dish/Engine | 29% | 18 to 23% (p) | 25% (p) |

(d) = demonstrated; (p) = projected; Annual Capacity Factor refers to the fraction of the year the technology can deliver solar energy at rated power.

**Source: Solarpaces**

## F. Future Projections (2020&2030)

Rapid growth is projected for all three CSP technologies, given their environmental profile, proven track record, scalability and flexibility in storing energy and/or operating in a hybrid mode to produce ratable deliveries of electricity, matched to peak daily demand. Because of these features and its relative simplicity, CSP could ultimately grow at faster rates than Solar PV, wind and ocean technologies. Once the market entry barriers are overcome and manufacturing/operating economies of scale are achieved, CSP technologies would also be competitive with conventional energy technologies that provide electricity/steam, and their growth could accelerate further.

## G. Limitations

### 1. Technical

Even though trough CSP has been in commercial operation for over 20 years, major improvements are still being made for trough, dish and tower technologies. The costs of CSP are expected to decrease and eventually approach the costs of making electricity from fossil fuels. The major risk for CSP is around market acceptance and the incubation process necessary for it to reach manufacturing economies of scale. Governmental policies and stable incentives are the key to CSP overcoming initial market hurdles and growing sufficiently to become competitive.

### 2. Footprint

CSP harnesses a clean, abundant source of energy that is available everywhere on the Earth.. For hybrid applications, emissions are produced when sunlight is not available and the fossil fuel back-up power source is used. Heat transfer fluids used in trough and tower technology are classified as non-hazardous in the U.S. The main environmental concerns revolve around the availability of water, especially if water is used as the heat transfer fluid, and the large acreage that solar facilities cover. A study in Texas showed that land requirements for producing electricity from parabolic trough CSP is less than other renewables (wind & biomass) and equivalent to oil. As with most renewable technologies there are physical environment requirements which provide advantages to geographic regions.

## *H. Future Advances*

- **Trough –** This is the most advanced CSP at the present time. There are several new plants being built around the world using this technology. Future advances are expected in the materials used to make the parabolic reflectors and the receiver tubes. Efficient thermal storage systems and hybridization, to ensure a reliable level of electricity, will be incorporated into most future plants. Also, there have been some limited demonstrations (DISS Project – Spain) that use water in the receptors to generate steam directly, which simplifies the heat exchange process and makes steam production more efficient. The steam produced can be used for electricity generation or other purposes. Additional advances may come with co-location of projects in order to minimize operating costs (i.e. solar parks).

- **Dish –** Reflective materials are being studied for improvement, as are the ‘engines’ that collect the concentrated energy and produce electricity. Prototypes of this technology have been produced and tested, but commercial quantities have not yet been produced. Once dishes are made in large commercial quantities, the manufacturing costs are expected to decline.
- **Tower –** The science is being advanced through new designs, improvements to reflective materials, and thermal storage of energy during daylight periods to shift electricity production to nighttime. Hybridization may be important, depending on the need for a reliable flow of electricity when sunlight or stored energy is not available. Solar tower applications need to be large to be economical. These plants are not modular and therefore depend on size to reduce the effective cost of generating electricity. The heliostat field represents the largest single capital investment in a power tower project. Future advancements that reduce the cost to manufacture and operate this component, or extend its expected life, will help the growth of this technology.

## I. Relevant Public Policy

U.S. public policy towards CSP has not been consistent. During the late 1970s and 1980s, the government strongly promoted the development of CSP, as seen in the development of the 354 MW California project, which enjoyed favorable tax incentives and lucrative electric off-take contracts. After oil prices declined, the R&D and subsidies in this area disappeared and no new commercial projects were begun. As recently as the year 2000, a review of the DOE's renewable energy programs by the National Research Council recommended that the DOE "should limit or halt its R&D on power-tower and power-trough technologies, because further refinements to these concepts will not further their deployment.” Since 2004, with the price of fossil fuels escalating past $40/bbl, interest in renewable energy has revived. Multiple CSP projects are now being planned worldwide: U.S. - Nevada Solar One (64 MW – under construction), Spain, Iran, Algeria, Morocco, Egypt, India, Israel and South Africa. In the future, public policy may encourage CSP through the establishment of enterprise zones or solar parks, where multiple projects in close proximity would allow operators to achieve economies of scale and lower maintenance costs. In 2006 the Western Governors' Association adopted a 1,000-MW CSP initiative that is expected to lead to additional market growth in the U.S.

Permitting and siting large CSP plants in the U.S. is a costly and time-consuming process. Future renewables legislation may streamline and fast-track renewable projects that provide clean, safe energy.

# VIII. Geothermal

## *A. General Overview*

Unlike wind and solar power, which are driven directly or indirectly by the sun, geothermal energy extracts heat from the Earth. Geothermal reservoirs are found in "geothermal systems" which are regionally localized geologic settings where the Earth's naturally occurring heat flow is near enough to the surface to bring steam or hot water to the surface. The Earth's temperature varies widely, and geothermal energy is usable for a wide range of temperatures from room temperature to well over 300° F. For commercial use, a geothermal reservoir capable of providing hydrothermal (hot water and steam) resources is necessary; these reservoirs are generally classified as being either low temperature (<150°

C) or high temperature (>150° C). High temperature reservoirs are the ones suitable for, and sought out for commercial production of electricity. Examples of geothermal systems in the US include the Geysers Region in Northern California, the Imperial Valley in Southern California, and the Yellowstone Region in Idaho, Montana, and Wyoming.

## B. Conclusions

- Conventional geothermal is competitive in areas with readily accessible, naturally occurring steam
- The application of conventional geothermal can be advanced by leveraging existing O&G technologies (drilling, seismic, etc) to expand the amount of suitable areas
- Naturally occurring geothermal energy is a large, indigenous resource
- Provides continuous baseload resource

## C. Key Drivers

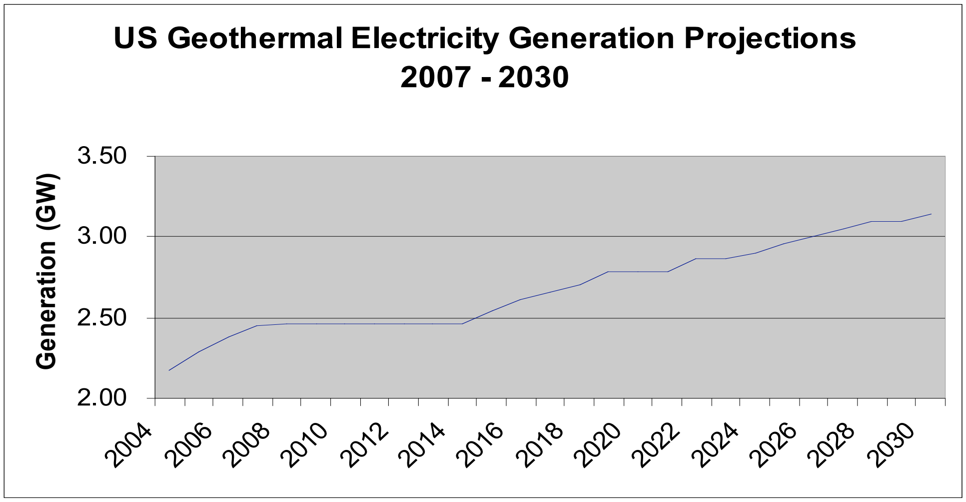
- Geothermal generated electricity is eligible for the Production Tax Credit (PTC), this credit was added with the 2005 Energy Policy Act
- As a domestic source of energy, geothermal power helps address energy security concerns
- Geothermal energy production produces minimal emissions and addresses greenhouse gas emissions concerns, related to energy production
- Eligible for Clean Development Mechanism (CDM) credits

## D. Current Status

- Limited to large scale conventional and local application heat pumps
- 8,932 MW installed in 24 countries
- US generated 2,200 MW (2,800 MW capacity) in 2005 – providing power to 4 million people

- No Enhanced Geothermal System (EGS) currently

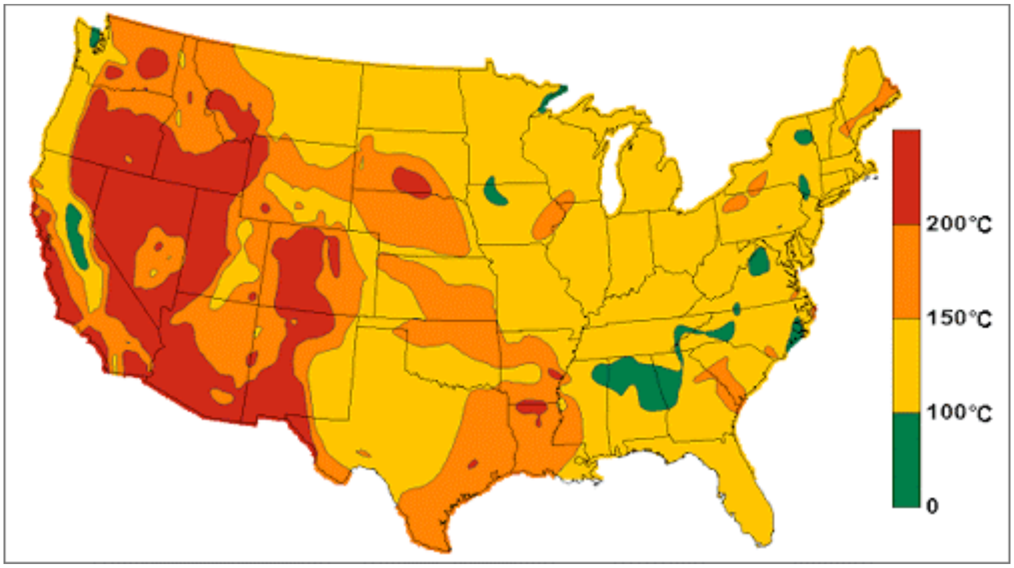
## E. Future Projections (2020&2030)



***Source: EIA***

Almost 1,500MW of new geothermal capacity are in the planning stages and could be developed in the United States. Development is planned in Alaska, Arizona, California, Hawaii, Idaho, Nevada, New Mexico, Oregon, and Utah.

**Geothermal Resources Map of the United States - 6km depth**



Source: DOE

## *F. Limitations*

### 1. Technical

- Project scale requires large up front cost
- 80% of exploratory wells are unsuccessful
- Handling lower temperatures
- Reservoirs have finite lives and must be managed carefully to prevent depletion
- Recent concerns have been raised about the "renewable" nature of geothermal energy. The Geysers project in California, one of the largest and oldest geothermal developments in the US, has experienced reduced steam generation over time, suggesting that the natural steam resource is being depleted. This depletion has been partially offset by reinjection of wastewater into the subsurface to produce the extra steam.

### 2. Footprint

- Limited remaining high grade geothermal resources
- Seismic issues
- Potential water contamination risk
- Some $CO_2$ emissions

## *G. Future Advances*

- Geothermal Energy Generation in Oil & Gas Settings
- Hot produced water, gas and/or oil in existing oil & gas (O&G) wells could be used for in-field generation of renewable power.
- There is also a potential for recovering heat from hot dry rock or even sedimentary basins using Enhanced Geothermal Systems (EGS). In the Permian Basin, 40-50% of the in-field O&G extraction cost (or about $4/BBL) is due to onsite power needs (pumping out oil, water reinjection for

water flood, etc). Onsite geothermal power, especially if coupled to any potential onsite thermal loads, may be able to extend the life of the wells. Cost viability would depend on:

- Current electricity rates for power delivered to the field
- Potential revenue from export of excess electricity if nearby grid connect is available
- Potential revenue from increased natural gas exports, i.e., gas that would otherwise be burned for producing onsite power

Ability to use existing O&G wells to avoid additional drilling costs

## 1. Future Technologies

- **Enhanced Geothermal Systems (EGS) or Hot Dry Rock**: EGS are engineered reservoirs created to extract heat energy from otherwise economically unproductive natural geothermal resources (hot dry rock). Water is injected through a subsurface fracture system and heated by contact with the rock and returns to the surface through production wells, just as in naturally occurring hydrothermal systems. This technology is being researched in the US, France, Australia, and elsewhere, yet none are economically viable or even near-commercial. The fracturing and stimulation techniques used in EGS are very similar to the technologies used in the oil and gas industry today to extend production.

  In the US, most conventional geothermal resources are found in the western states,however, there exist many potential geothermal resources in Gulf Coast and Mid-continent states that could be suitable for EGS.

- **Kalina System** A small demonstration power plant using the "Kalina" cycle operated as part of Iceland's Husavik GeoHeat Project. The Kalina cycle uses an ammonia-water mixed working fluid that claims higher efficiency. This system is not considered commercial and reports on the demonstration are not available.

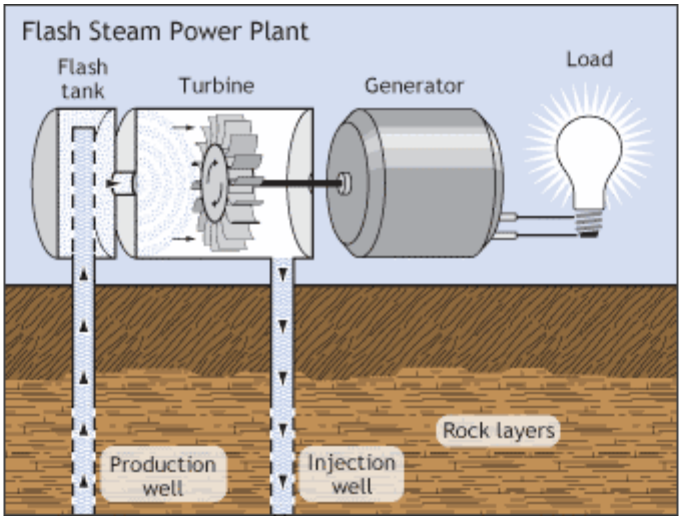
- **Rankine Cycle System**: The U.S. Department of Energy is proposing to demonstrate a remote geothermal power system at Chena Hot Springs in Alaska using the Rankine Cycle. In this system, a compressor/motor module is expected to be converted into a turbo generator by simply reversing the flow direction. This is a demonstration project, and this system is not considered commercial.

## *H. Relevant Public Policy*

- Although gaining recognition, often overlooked as a renewable resource
- Included in 2005 EPA for PTC and becoming part of state RPS
- EU overall target 20% renewables by 2020
- EU country target for renewables
- China 10% of capacity 60 GW and 5% primary by 2010, 10% primary by 2020

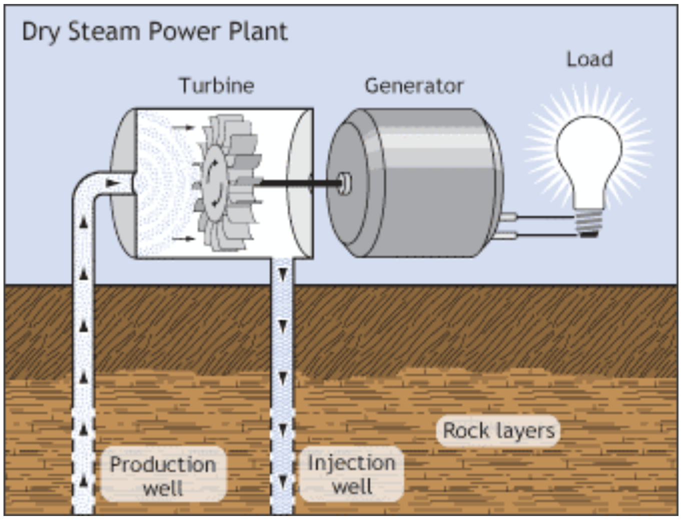
## *I. Current Geothermal Plant Technologies*

- **Flash Power Plant:** Flash steam plants are the most common type of geothermal power generation plants in operation today. They use water at temperatures greater than 360° F (182° C) that is pumped under high pressure to the generation equipment at the surface. Upon reaching the generation equipment the pressure is suddenly reduced, allowing some of the hot water to convert or “flash” into steam. This steam is then used to power the turbine/generator units to produce electricity. The remaining hot water not flashed into steam, and the water condensed from the steam is generally pumped back into the reservoir. An example of an area using the flash steam operation is the CalEnergy Navy I flash geothermal power plant at the Coso geothermal field.



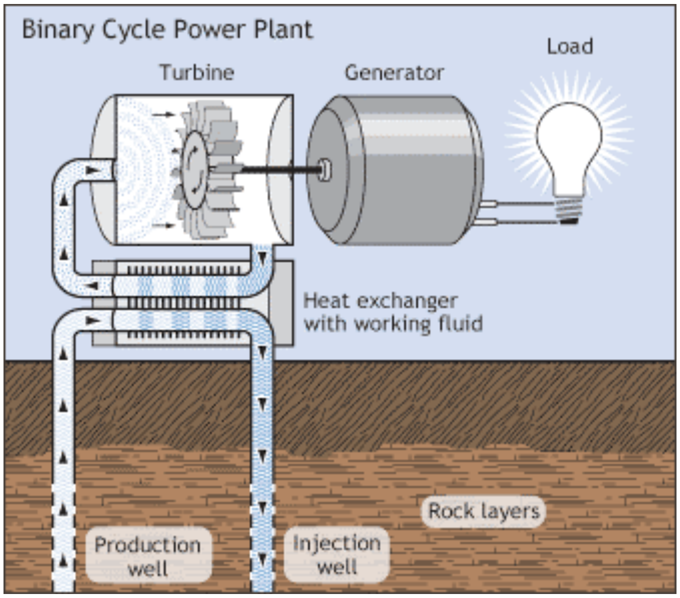
*(Source: DOE)*

- **Dry Steam Power Plant:** Power plants using dry steam systems were the first type of geothermal power generation plants built. They use the steam from the geothermal reservoir as it comes from wells, and route it directly through turbine/generator units to produce electricity. An example of a dry steam generation operation is at the Geysers in northern California.



*(Source: DOE)*

**Binary Cycle Power Plant:** Binary cycle geothermal power generation plants differ from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units. In the Binary system, the water from the geothermal reservoir is used to heat another "working fluid" which is vaporized and used to turn the turbine/generator units. The geothermal water, and the working fluid are each confined in separate circulating systems or closed loops and never come in contact with each other. The advantage of the binary cycle plant is that they can operate with lower temperature waters (225° F - 360° F), by using working fluids that have an even lower boiling point than water. They also produce no air emissions. An example of an area using a binary cycle power generation system is the Mammoth Pacific binary geothermal power plants at the Casa Diablo geothermal field.



*(Source: DOE)*

- **Flash/Binary Combined Cycle:** This type of plant, which uses a combination of flash and binary technology, has been used effectively to take advantage of the benefits of both technologies. In this type of plant, the flashed steam is first converted to electricity with a backpressure steam turbine, and the low-pressure steam exiting the backpressure turbine is condensed in a binary system.

- **Heat Pumps**

  Geothermal heat pumps (GHPs) use the Earth's huge energy storage capability to heat and cool buildings, and to provide hot water. GHPs use conventional vapor compression (refrigerant-based) heat pumps to extract the low-grade heat from the Earth for space heating. In summer, the process reverses and the Earth becomes a heat sink while providing space cooling. GHPs are used in all 50 U.S. states today, with great potential for near-term market growth and savings.

# IX. Ocean Power

## *A. General Overview*

While the potential of ocean energy is similar to that of other renewable sources, its current contribution is very small, reflecting its earlier stage of development. The Department of Energy (DOE) has classified ocean energy into three subcategories: tidal power, wave power, and thermal energy conversion. Each subcategory employs distinctly different technology and is subject to different specific restrictions pertaining to its development and deployment.

## *B. Conclusions*

Ocean energy and thermal energy conversion are still under development and need significant advancements in technology, pilot testing, and full scale deployment before this renewable energy sector can substantially add to the diversification of the energy supply. Sustained R&D investment and tax incentive inclusion are essential to providing a platform upon which the sector can develop and grow.

## C. *Key Drivers*

As with other renewable energy technologies, the ocean energy sector is driven by a combination of energy cost and environmental concerns. With 70% of the globe covered by water, and coastlines playing an important role in human habitation and commerce, tapping the enormous amount of thermal and kinetic energy in the world's oceans is very attractive. Ocean energy can provide large amounts of power, but more importantly it has the potential to deliver predictable and reliable service.

## D. *Current Status*

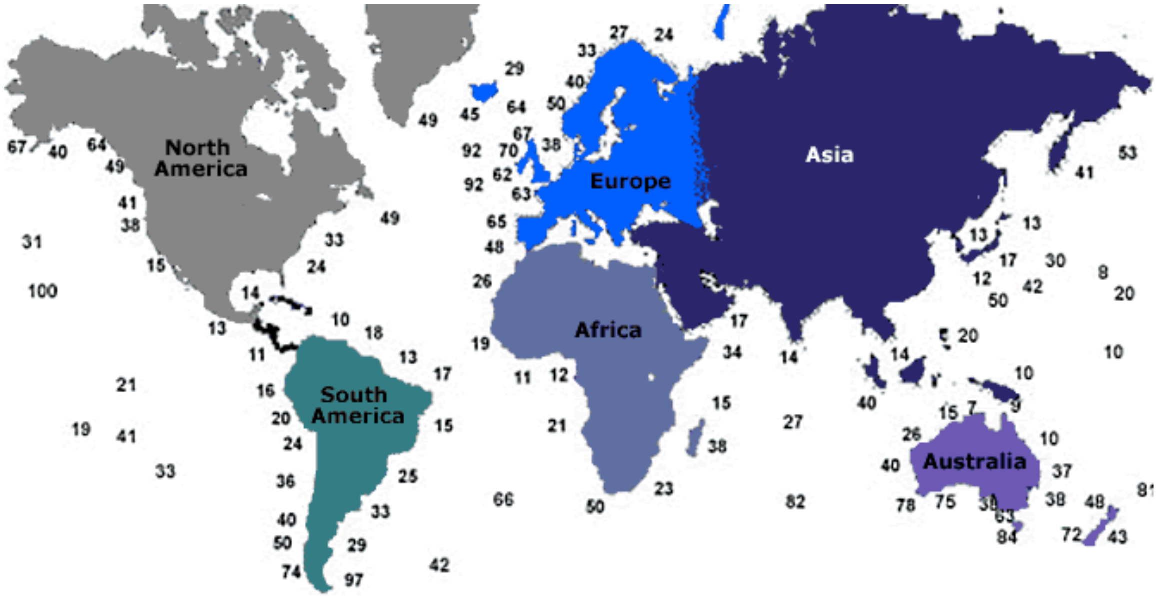
Ocean energy provided .0004% of the total renewable generation in 2004, nevertheless more recent developments have seen an increase in R&D spending, test project spending, and full scale model testing.

## E. *Limitations*

### 1. Technical

Ocean energy faces major technical hurdles ranging from design to optimal location availability. Currently, ocean power is most effective in a limited amount of the world's oceans due to specific physical conditions required by current generation models Offshore systems and some onshore systems are dependent upon wave height and the distance between each wave. Generally, the higher the waves and the greater the distance between the waves, the closer a system can come to maximum generation. Areas in which optimal conditions exist are limited and often in remote locations that require substantial transmission infrastructure improvement.

World map showing average wave power availability in KW/metre of wave front



*Source: Wave Energy paper. IMechE, 1991 and European Directory of Renewable Energy (Suppliers and Services) 1991*

Design improvements are also needed to maximize generation capacity and sustain long-term deployment. Limited amounts of data pertaining to sustainability have been collected due to the short deployment duration of current test models.

### 2. Footprint

Some models of ocean power energy devices create "visual pollution" in the deployment area. Due to the scarcity of deployments, environmental data on their long-term effects has not been collected. Grid connected deployments are also dependent on land based substations and transmission lines.

## *F. Future Advances*

Specific applications are being developed in the ocean energy sector, including sub-sea turbine farms, remote generation capabilities and inlet waterway generation. Early stage R&D is being conducted on multiple projects ranging from full-scale test models deployed off the coast of Scotland to wave tank scale design testing; as well as the first commercial sea based installation built off the coast of Portugal in late 2006.

## *G. Relevant Public Policy*

Ocean energy generation does not qualify for PTC credits. However ocean energy does qualify for a renewable energy production incentive (REPI) which provides a 1.9 cent/kWh incentive for state, local, and not for profit energy producers. Private, for profit energy producers do not qualify for the REPI in the United States.

## *H. Technologies Used in Wave Power*

Wave power technology is categorized into offshore and onshore generation systems that convert pressure fluctuations or kinetic energy from waves into useable energy.

### 1. Offshore Systems

Offshore systems are located in deep water and utilize the surge, heave, and sway movements of the waves to power pumps that generate electricity. Some offshore systems use hoses that are connected to floats that ride the upward and downward movement of the waves. The stretching and contracting of the hoses creates water pressure that is used to turn a turbine. Offshore systems include power generating buoys that float on the ocean surface, submerged buoys approximately 20 feet below the ocean's surface, and floating cylinder devices that produce energy using the motion of the waves to run electricity producing hydraulic motors.

(Source: Ocean Power Technologies)

(Source: AWS Ocean Energy)

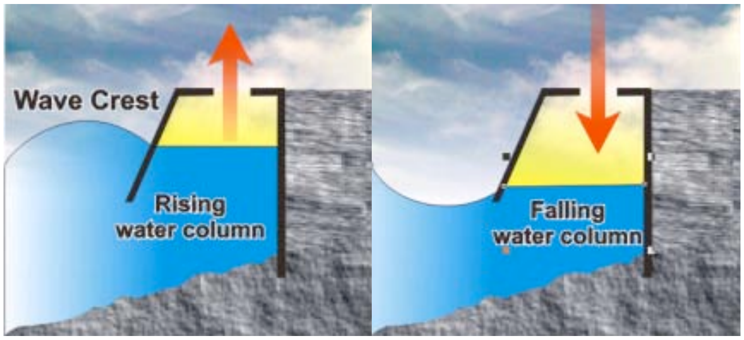
(Source: Ocean Power Delivery Systems)

## 2. Onshore Systems

Onshore systems are built close to the coast and utilize the power that is generated from the breaking waves.

## Oscillating water column

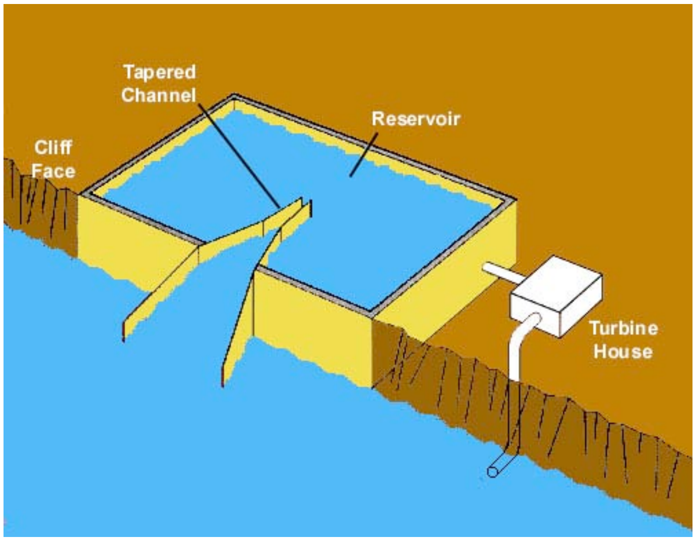
The oscillating water column consists of a partially submerged concrete or steel structure that has an opening to the sea below the waterline. It encloses a column of air above a column of water. As waves enter the air column, they cause the water column to rise and fall. This action alternately compresses and depressurizes the air column. As the wave retreats, the air is drawn back through the turbine as a result of the reduced air pressure on the ocean side of the turbine.(DOE)



(source: Oceanatlas.org)

## Tapchan

The “tapchan”, or tapered channel system, consists of a tapered channel, which feeds into a reservoir constructed on cliffs above sea level. The narrowing of the channel causes the waves to increase in height as they move toward the cliff face. The waves spill over the walls of the channel into the reservoir and the stored water is then fed through a turbine.(DOE)



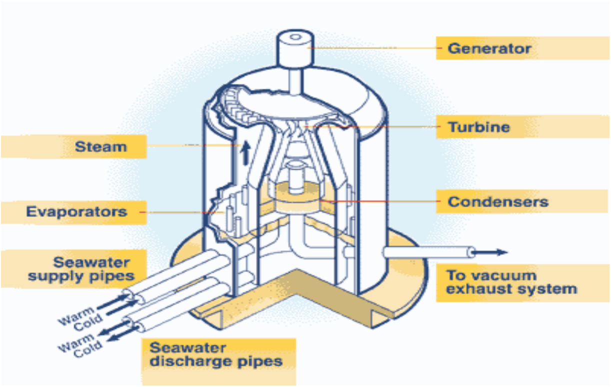
(source: Oceanatlas.org)

**Pendulor device**

The “pendulor” wave-power device consists of a rectangular box, which is open to the sea at one end. A flap is hinged over the opening and the action of the waves causes the flap to swing back and forth. The motion powers a hydraulic pump and a generator.(DOE)

## 3. Thermal Energy Conversion Technology

Thermal energy conversion capitalizes on the heat stored in the oceans to create electricity. Areas where the temperature difference between the warmer surface water and colder depths is around 36ºF produce the highest electricity generation. Most of the suitable areas for this type of development are located in tropical waters.(DOE)



### Closed-Cycle

These systems use fluid with a low-boiling point, usually ammonia or propane, to rotate a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo-generator. Cold deep-seawater—pumped through a second heat exchanger—condenses the vapor back into a liquid, which is then recycled through the system. (DOE)

### Open-Cycle

These systems use the tropical oceans' warm surface water to make electricity. When warm seawater is placed in a low-pressure container, it boils. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt behind in the low-pressure container, is almost pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water. (DOE)

## 4. Tidal Power

Tidal power consists of three different technology classifications: Barrage or dam technology, tidal fence technology, and tidal turbine technology. Each technology utilizes the flow of the ocean's tides to turn turbines.

## 5. Barrage or Dam

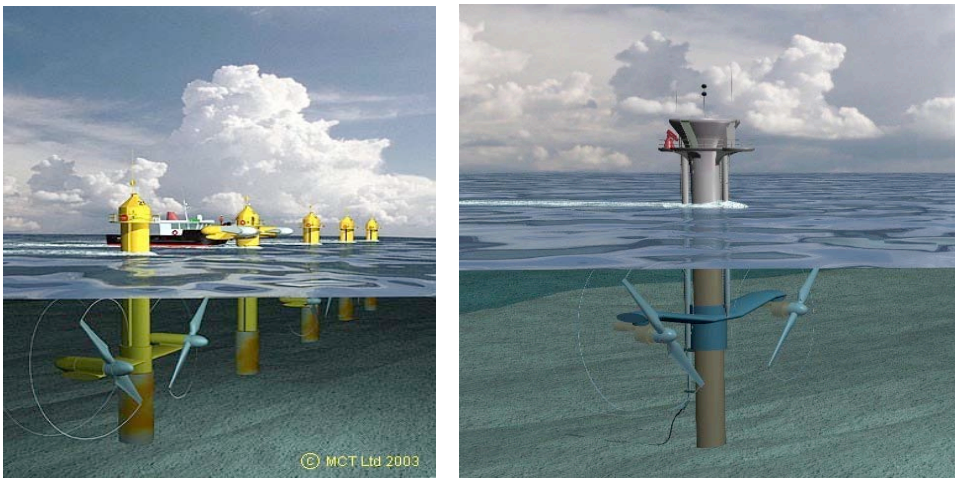
Barrage and Dam technology produces electricity when water is forced through turbines as tides advance and recede. Generation units are installed on dams and when a water differential is produced by the tides water is forced through turbines.

### Tidal Fence

Tidal fence technology capitalizes on the movement of water into and out of a physical geographic feature such as a bay or between islands. Water moving into a bay during high tide is channeled into a turbine. The technology and be attached to the underneath of solid structures that submerged foundations such as bridges.

### Tidal Turbines

Tidal turbines function like wind turbines, but capitalize on ocean currents, mainly coastal, that mover under the ocean's surface. The blades of the turbine rotate as the flow of water produced by the tides pass over the turbine. The kinetic energy of the water currents are much great then that of air currents and theoretically produce more energy at much lower velocity.



Source: MCT Ltd 2003

# X. Hydropower

## A. General Overview

Over two thirds of the Earth's surface is covered by water. Hydroelectric power, which taps the energy of flowing and falling water, provides the world's fourth largest source of electricity, after coal, natural gas and nuclear, and its largest source of renewable electricity. It is the most mature of all energy technologies, since humanity has been using water to perform work for thousands of years, from ancient water wheels that ground grain to the first large-scale production of electricity in the 1880s. Currently hydropower supplies 88% of the total electricity generated from renewable sources. Developed nations have made extensive use (Norway at 99%) of this natural resource, while emerging areas such as Africa (at 7%) have only developed a small percentage of their potential. World-wide there is considerable potential to expand hydropower, especially in Africa, China, India and South America.

Because hydropower does not involve combustion, it emits no greenhouse gases, beyond the carbon dioxide from the production of concrete for dams. Large-scale hydropower projects provide additional benefits in the form of flood control, water supply, recreation and irrigation. Recently, however, the environmental and social impact of large-scale hydropower has received more attention, including its effect on animal habitats, downstream land usage, sedimentation, fish spawning, resettlement issues, flood defenses, riparian recreation, and water quality. The combination of these issues could limit the ultimate extent of hydropower utilization.

Hydropower captures energy directly from the currents or pressure changes resulting from flowing or falling water. The potential electricity generation from traditional hydro depends on the flow rate and the vertical fall of the water. Turbines convert the resulting water pressure into mechanical energy which in turn drives a generator that produces electricity. Hydropower is considered "firm" capacity, since the generating units can be started and stopped quickly to follow grid demand

There are three general types of hydropower facilities:

- **Impoundment** is the most common for a large facility. A dam is constructed to accumulate river water in a reservoir. Water is then released from the reservoir, flowing through turbines to generate electricity. The water flow rate can be controlled to match the production of electricity to demand.
- **Diversion,** which is commonly called "Run of River." Water is diverted from the main stream of a river to produce electricity and is then returned to the river, downstream.
- **Pumped Storage** is used when demand for electricity is low. Excess electrical capacity is used to pump water uphill to a holding reservoir.

During periods of high demand the water is returned to the main reservoir, generating electricity.

Hydropower projects fall into two main categories, by scale of operation:

**Large-scale Hydropower** – Dams of various sizes have been used to generate electricity since the late 19th century. In the U.S. between 1930-1970 federal and state governments sponsored the construction of many large, multi-purpose dams that provided water supply, flood control and electricity. Because most large U.S. hydropower plants have been fully depreciated, they provide the lowest cost renewable component of our current energy mix. Sites for new large-scale hydroelectric facilities are scarce in the US, and the costs are significant, though still competitive with other technologies. Over the life of a new facility, the cost is approximately $.03-$.04/kWh

**Small-scale Hydropower –** Modern, small-scale hydropower includes two different technologies that are often referred to as "Run of River": the "diversion" approach described above, and the newer 'Instream Energy Generation Technologies' (IEGT) that harness the natural movement of flowing water. Small-scale hydropower is one of the most cost-efficient and reliable energy technologies available for the production of electricity. Small hydro has high energy efficiency (70-90%) and a life expectancy of 50 or more years. Various sizes of installation are available. In general small hydro is usually considered to be installations that generate less than 10 MW. Recently smaller segments have emerged such as mini-hydro which is < than 1,000 kW and micro-hydro which is considered to be anything less than 100 kW. and can be matched to the application, with power output a function of the velocity of the water flow. Small-scale hydro has fewer of the problems associated with large hydro projects, largely because it stores little or no water, thus minimizing its impact on its surroundings. Under favorable conditions run-of-river hydropower costs can be as low as $.02/kWh, although they are generally in the range of $.04-.06/kWh.

## B. Conclusions

Hydropower is a mature, dependable and cost-effective technology that is available for immediate deployment. Given access to water and the right terrain, this is one of the cheapest long-term sources of renewable energy. Large hydro projects have high up-front environmental, engineering and construction costs, but these are offset by their long asset lives and low operating costs. Hydropower also provides the highest "energy payback" ratios (energy produced during its productive life divided by the energy required to build and maintain) of any power technology, over 200:1, compared to coal at 11:1, wind at 39:1 and solar photovoltaic at 9:1. Despite this, US electricity production from hydropower has been declining, due to changes in precipitation patterns and opposition to existing and planned hydropower installations on the basis of their environmental impacts, with several dams being decommissioned.

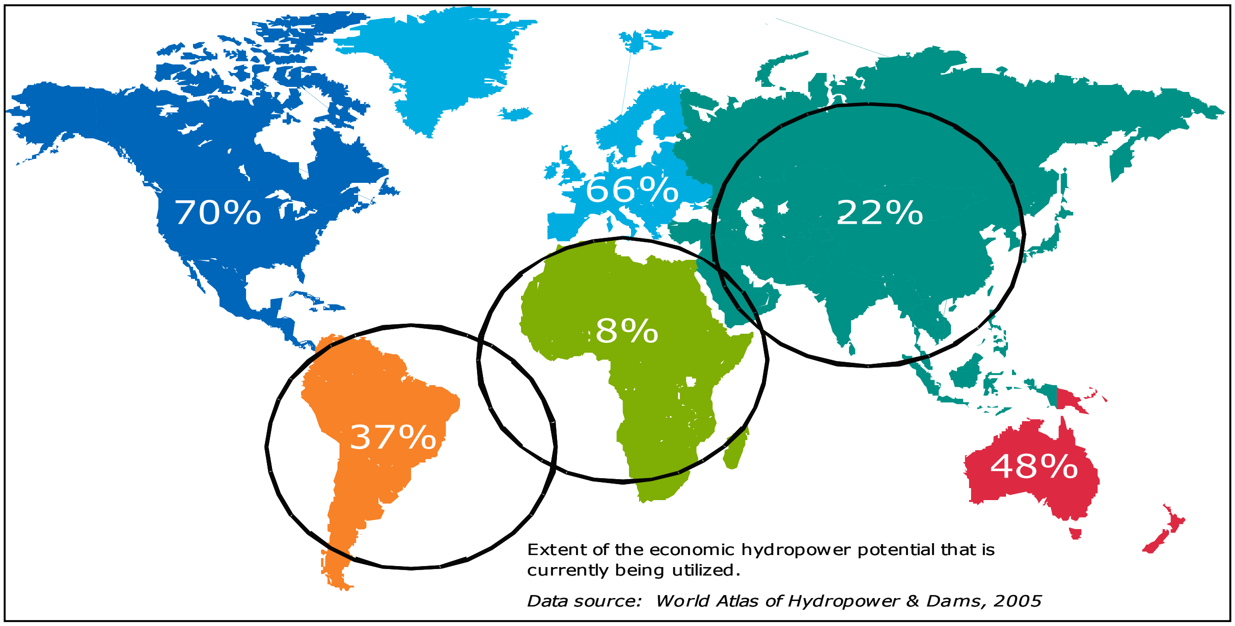
## C. Key Drivers

Water availability and topography (elevation) are the main factors in determining if a hydro application is feasible. Other drivers include:

- Regional economic growth, including electricity demand growth
- Available capacity of electric transmission infrastructure
- Government mandates and incentives, including renewable portfolio standards (RPS), if applicable to hydro
- Concerns about greenhouse gas emissions
- Social and environmental opposition to the impacts of hydropower
- Costs per kWh (O&M costs) relative to other technologies
- Energy security concerns
- Alternative uses for the land

## D. Current Status

U.S. hydropower generated 270 TW-hr of electricity from a capacity of 77.4 MW in 2005, accounting for 6.7% of net generation. Capacity has been decreasing due to recent weather conditions and the trend to decommission existing dams due to environmental concerns. Globally, India and China are each constructing significant quantities of large and small-scale hydropower, and the future growth in worldwide hydro capacity will be driven primarily by developing countries in Asia and Africa.



Extent of the economic hydropower potential that is currently being utilized.

*Data source: World Atlas of Hydropower & Dams, 2005*

## E. Future Projections (2020&2030)

Electricity production must grow to meet demand, especially in China and India. “Run of river” opportunities abound world-wide and will be an important area of hydroelectric growth for both developed and under-developed countries.

**Projected Regional Growth for Hydropower**

*Amounts in Gigawatts*

| | Installed | Under Construction | Planned | Total |
|---|---|---|---|---|
| Africa | 21 | 4 | 82 | 107 |
| Asia | 258 | 93 | 266 | 617 |
| Australasia | 13 | 0 | 0 | 13 |
| Europe | 170 | 3 | 13 | 186 |
| N/C America | 163 | 4 | 19 | 186 |
| S. America | 121 | 15 | 65 | 201 |
| **WORLD** | **746** | **119** | **445** | **1,310** |

**Key Points:**

* Africa and Asia are experiencing significant growth of >50%
* S. America is exeriencing moderate growth of appx. 40%
* Worlds hydro capacity is poised to increase by 75%
* Asia will be responsible for 64% of all future hydro growth
* Minimal future growth planned for developed countries

***Source: World Atlas of Hydropower & Dams- 2005***

US production of hydroelectricity will be relatively stagnant, as environmental concerns cause more dams to be decommissioned, and plans for new dams are put on hold. However, there is significant growth potential in the US from utilizing “run of river” hydro, upgrading existing hydropower facilities, and adding powerhouses to some of the 98% of US dams with no power component.

## *F. Limitations*

### 1. Technical

- **Dams: Although the technology is** mature, some older dams are being refitted with improved turbines that are more efficient and “fish friendly**.”**
- **“Run of River”:** A variety of small-scale technologies is available today. Standardization and increased demand should help to lower costs.

## 2. Footprint

The emerging challenge for building hydro projects is to balance social and environmental concerns throughout their planning, construction and operating phases. Construction of new dams in the U.S. is being deferred, and existing dams decommissioned due to environmental concerns. Large hydropower projects have been increasingly tied to negative ecological and socio-economic impacts, primarily fish populations and land use, Large-scale hydropower can impede fish spawning and migration, and it exposes fish to physical stresses, if they pass through the turbine.

Another example of environmental concerns is the degradation of the Sierra Nevada aquatic ecosystem – the state of California estimates that two-thirds of its native fish are extinct, endangered or in decline, with dams cited as a major factor. In addition, recent studies have reported that hydroelectric power plants in tropical regions may produce substantial amounts of methane and carbon dioxide, due to the decay of inundated plant material in an anaerobic environment. The gases are released into the atmosphere once the water is discharged from the dam.

- **Run of River** – Generally speaking the smaller "Run of River" projects have a higher level of public acceptance, since they cause few environmental problems and can adapt to meet local concerns.
- Both dams and Run of River can be affected by unusual weather. Too much rain may result in flooding and too little rain may result in the inability to produce electricity.

## *G. Future Advances*

The long-term growth of hydropower is tied to reducing its impact on the local environment.

- Large-scale Hydropower - Technology will slowly improve with the future refinement of turbines, especially in their impact on fish. New designs are focusing on reducing the amount of turbulence, pressure change and sheer that occur within the turbine, to reduce the mortality rate of fish passing through hydropower turbines from 5-15% to 2%.

- **Run of River –**The development of Instream Energy Generation Technology (IEGT) further reduces the modest footprint of run-of-river hydropower. IEGT systems can operate in rivers, canals, tidal areas and oceans, using water flowing in its natural pathway to turn a turbine. IEGT does not rely on conventional hydroelectric principles (impoundment, diversion of water, etc.) and its installations do not require large civil works. In general IEGT has few environmental drawbacks (i.e. turbines are fish friendly, no impact to the surrounding ecosystem). IEGT requires a strong, steady current velocity (5+ feet per second) and a minimum depth of 20 feet. Systems are anchored to the river bed but the turbines are positioned approximately 8 feet below the surface. Most IEGT turbines are designed to accommodate bi-directional flow depending on the application. Tests of this technology are currently underway (East River, NY). Future improvements will be focused on designing smaller units that can be used at shallower depths and units that can operate at reduced flow rates.

## *H. Relevant Public Policy*

Public policy towards hydropower is inconsistent and sometimes conflicted. Although generally included in most tallies of renewable energy, hydropower does not always count towards satisfying state Renewable Portfolio Standards, and until the Energy Policy Act of 2005, new hydro facilities did not qualify for the Renewable Energy Production Tax Credit. Rather than further exploiting this mature technology, dam operators are on the defensive, as environmentalists challenge their operations as detrimental to native water wildlife or the surrounding environment, sometimes successfully. Re-licensing of older facilities is no longer a foregone conclusion, as environmental groups are challenging the benefits provided by the dams with evidence of environmental and ecological damage.

Environmental concerns are impeding further hydropower development the United States, and current public policy appears inadequate to address the uncertainties and delays faced by developers in obtaining licenses and approvals. All of this increases the investment risk of this proven renewable energy technology. As the public perception of hydropower's net benefits declines, large projects and investment dollars within the U.S. are in short supply. Hydropower lost more than one-third of its production between 1995-2001.

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