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Alaska's Renewable Energy Potential

Prepared by the Energy, Resources, and Nonproliferation Strategic Management Unit office for Senator Murkowski of Alaska

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Abstract

This paper delivers a brief survey of renewable energy technologies applicable to Alaska's climate, latitude, geography, and geology. We first identify Alaska's natural renewable energy resources and which renewable energy technologies would be most productive. We survey the current state of renewable energy technologies and research efforts within the U.S. and, where appropriate, internationally. We also present information on the current state of Alaska's renewable energy assets, incentives, and commercial enterprises. Finally, we describe places where research efforts at Sandia National Laboratories could assist the state of Alaska with its renewable energy technology investment efforts.

ACKNOWLEDGMENTS

This report was compiled from many sources. Where a specific report was directly quoted, the citation has been provided. However, the body of this report summarizes and describes research conducted worldwide. The description contained herein would not be possible absent the vast research efforts worldwide *and* the efforts of those people and organizations in making their results available to all.

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ACRONYMS

AC	alternating current
AEA	Alaska Energy Authority
BEOpt	Building Energy Optimization
BES	(DOE Office of) Basic Energy Sciences
BOS	balance of system
CETC	CANMET Energy Technology Centre
CRADA	cooperative research and development agreement
DC	direct current
DNR	Department of Natural Resources
DOE	U.S. Department of Energy
DWD	diagnostics-while-drilling
EER	energy-efficiency ratio
EERE	(DOE Office of) Energy Efficiency and Renewable Energy
EES	Electrical Energy Storage (research prog.)
GHG	greenhouse gas(es)
GVEA	Golden Valley Electric Association
IEA	International Energy Agency
INE	Institute of Northern Engineering
LBNL	Lawrence Berkeley National Laboratory
MOU	memorandum of understanding
NBB	National Biodiesel Board
NRBP	Northeast Regional Biomass Program
NREL	National Renewable Energy Lab
NWCC	National Wind Coordinating Committee
NWTC	National Wind Technology Center
OEDER	(DOE) Office of Electricity Delivery and Energy Reliability
PDC	polycrystalline diamond compact
PSEL	Photovoltaic Systems Evaluation Lab
R&D	research and development
RE	renewable energy
REAP	Renewable Energy Alaska Project
RFA	Renewable Fuels Association
SNAP	sustainable natural alternative power
STAR	sweep-twist adaptive rotor
TRNSYS	Transient System Simulation
UAF	University of Alaska–Fairbanks
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
VHP	Virtual Hydropower Prospector
WPA	Wind Powering America

Alaska's Renewable Energy Potential

Many renewable-energy (RE) resources can be grouped into five categories, based on the technology used to extract, capture, or exploit them. The categories are solar, wind, geothermal, biomass, and hydropower. For Alaska, the most applicable RE technologies are wind, geothermal, and hydropower (both inland/river hydropower and ocean/tidal power).

We have also identified leading institutions where RE research is underway today around the world and their general areas of specialty. This list could be used as a basis for developing a workshop on this topic and inviting some of the world's foremost researchers to Alaska.

Who Are the Research Leaders?

A large body of international research exists on RE and energy conservation in cold-climate areas. Because the German government significantly subsidizes RE and preferentially solar power (~40¢/kWh for 20 years), a great deal of funding is available for research there. Canada also has a well-developed research base in cold-climate RE and energy conservation. In the U.S., Sandia National Laboratories (Sandia) and the National Renewable Energy Laboratory (NREL) in Golden, Colorado, are recognized as national leaders in RE research.

What Are the Applicable Technologies?

The RE resource maps for Alaska at the U.S. Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE) program's Web site[†] do not show a large potential for solar power. Most of Alaska receives an annual average of 2000–3000 Whr/m^2 per day. Additionally, the long periods of dark or near dark further detract from this limited resource's annual reliability. The two methods for collecting solar *thermal* energy, light concentrators and using closed-loop water pipes, are not viable; the sun's energy at the Earth's surface is too weak to allow concentrators to be effective and the ambient temperature is too often too low to prevent the water pipes from freezing. Alaskans *can* exploit flat-panel photovoltaic solar collectors, but, given these systems' current costs and power-delivery densities, a stringent cost-benefit analysis would be necessary to determine their economic feasibility in any specific application.

What Alaska *does* possess is generous RE in the form of geothermal, wind, and hydropower resources that range from good to superb. Although Alaska's northern latitude and short growing season makes inland biomass sources scarce, much of Alaska along the coast is beginning to look at biomass for co-generation facilities.

The RE resources just identified are rich enough to be exploited not only on the small scale (i.e., by domestic dwellings or small buildings) but for large-scale electrical power generation. Because exploiting RE resources at both of these scales involves very different technologies, the next section of this paper will describe the domestic-dwelling size applications. Then, we will present information on the large-scale power generation technologies.

[†] http://apps1.eere.energy.gov/states/alternatives/resources_ak.cfm

Domestic/Small-Scale RE Power Generation and Consumption

Power Generation

The two largest energy usages in a typical home are electricity and heat (hot water and space heating). RE sources can address both of these energy paths. A study published in 2006[1] investigated five domestic-size RE configurations for cold climate regions (research was conducted at Hokkaido, Japan). They found that for regions with a climate similar to Alaska's, a system that uses photovoltaic panels for electrical generation and a heating/hot-water system that has

- a well-insulated electric water storage tank that services hot-water loads and
- a compact boiler/geothermal heat pump tank for room heating during the cold season

led to an ~28% reduction in greenhouse gas emissions. This system nearly completely eliminated the need for fuel oil.

Wind power is available to the typical Alaskan homeowner. Micro wind turbine technology is improving and more affordable. New microprocessor-based technology has increased performance, improved battery charging capability and unit reliability, and reduced "flutter" noise from the turbine blades. Statistics show the complementary nature of wind power and photovoltaics—wind speed often increases on cloudy days and after sunset.

Because of Alaska's large natural variation in elevation and abundance of river courses, micro hydropower is also feasible. Micro hydro installations are generally either free-flow generation where a turbine is immersed in the river flow or an engineered system where the water is diverted from the stream (weir) to flow through a pipe (penstock) to a turbine and then returned to the stream (tailrace). Free-flow turbines are less efficient, but more affordable because of the reduced infrastructure costs. Neither application would require a dam or reservoir. Implementing micro hydropower requires detailed site-specific measurements and plans.

Table 1. Information on Typical Domestic RE Technology Applicable to Alaska

Typical RE Technology	A Supplier	General Performance Characteristics	Typical Industry Costs
Photovoltaic panels	SunPower Corporation (San Jose, CA)	From 9%–14% of available solar energy is delivered as electrical power.	~$8–$11/W, installed
Geothermal heat pump	SunTeq Geo Distributors (central PA)	Heating: 3.3 EER[†], cooling: 14.1 EER	~$2,500 per ton of capacity (3 t/$7,500 for a typical home)
Micro wind turbine	Southwest Windpower (Flagstaff, AZ)	A turbine with a rated capacity of 400 W and a startup wind speed of 8 mph can produce an estimated 38 kWh per month at 12 mph.	~$600 for a unit with a rotor diameter of ~4'.
Micro hydro free-flow turbine	New Energy Corporation, Inc. (Calgary, Alberta, Canada)	A vertical-axis turbine with a rated capacity of 5 kW/h when immersed in a stream flow of 3 m/s.	~$28,000 for a turbine with 4 0.75 m rotor blades on a 1.5 m diam.

It should be noted that photovoltaic, wind-turbine, and micro-hydro technologies require significant support equipment (referred to as the balance of system [BOS]: power inverters, battery storage, power distribution [transmission lines], etc.). These BOS costs must be considered during evaluation to decide whether to purchase/install an RE power system.

[†] EER (energy-efficiency ratio): the ratio of the system's total heating/cooling capacity to electrical energy input.

Energy Conservation

Fossil-fuel-based energy systems often deliver higher specific energy and power content than RE technologies due to the fuel's intrinsic storage. Therefore, of equal importance with installing and using renewable, non-CO_2-emitting energy generation is energy conservation and the reduction of energy loss (increased efficiency).

Several modeling and simulation packages exist to help optimize a home's design to affordably reduce energy usage and increase conservation.[2] Included in these are the

- Transient System Simulation (TRNSYS) from the Solar Energy Laboratory at the University of Wisconsin,
- DOE2.2 Building Simulation Software developed by Lawrence Berkeley National Lab, and
- Building Energy Optimization (BEOpt) program developed by NREL.

These packages recommend constructing a superinsulated building envelope with two key features: a double-wall construction with a gap of at least 4" between the inner and outer wall[†] and roof trusses made with a "raised heel" that accommodates 2' of blown-in insulation. This truss design also permits longer roof overhangs—reducing passive solar heating in the summer.

These homes also used a solar water heating system (with a back-up tankless gas-fired system). In these case studies, the solar-heated water met over 60% of hot-water demand during the summer months.[3]

Alaska is home to the Cold Climate Housing Research Center (CCHRC)[‡] an industry-based, non-profit corporation dedicated to research that improves the durability, health, and affordability of shelter for people living in circumpolar regions around the globe. The CCHRC was created to facilitate the development, use, and testing of energy-efficient, durable, healthy, and cost-effective building technologies for Alaska and the world's cold-climate regions.

Alaska offers an excellent testing ground for cold-climate technologies and products. Its geography provides the full range of climatic conditions a researcher would encounter across the northern U.S.—from the windy, cool, wet weather in the northeastern and northwestern states to the very cold, snowy conditions across the northern plains and Rocky Mountain regions. In addition, Alaska's cold season lasts for six months or longer in any given year, allowing ample time for researchers to conduct experiments and evaluate housing performance.

In September 2006, the CCHRC opened a new research and testing facility, located on the campus of America's Arctic University at the on the University of Alaska–Fairbanks (UAF), providing space to expand research as well as work more closely with university students, faculty, and researchers. The research center was conceived and developed by members of the Alaska State Home Builders Association, representing more than 1,200 building industry firms and groups.

The CCHRC has conducted extensive research on energy conserving building materials and construction methods. CCHRC research is presented on their Web site and is too detailed and extensive to be repeated here. This paper discusses CCHRC in further detail in the section dedicated to Alaska's existing RE assets (please see page 38).

[†] This gap prevents the direct transfer of heat through the solid building members (wall studs).

[‡] http://www.cchrc.org/

Large-Scale Renewable Energy Power Generation Potential in Alaska

Geothermal Energy

Alaska has high-temperature geothermal resources that are suitable for electricity generation, as well as direct-use and heat-pump applications. The geologic and tectonic history of Alaska have produced substantial geothermal resources throughout the state. Recognized geothermal resources are concentrated in three regions:

1. within the "Ring of Fire," the volcanic arc that circles the Pacific and includes the Aleutian Islands, Alaska Peninsula, and Baranof Island;
2. a band of hot springs in central Alaska extending from the Seward Peninsula east to the Canadian border; and
3. near the Wrangell Mountains.

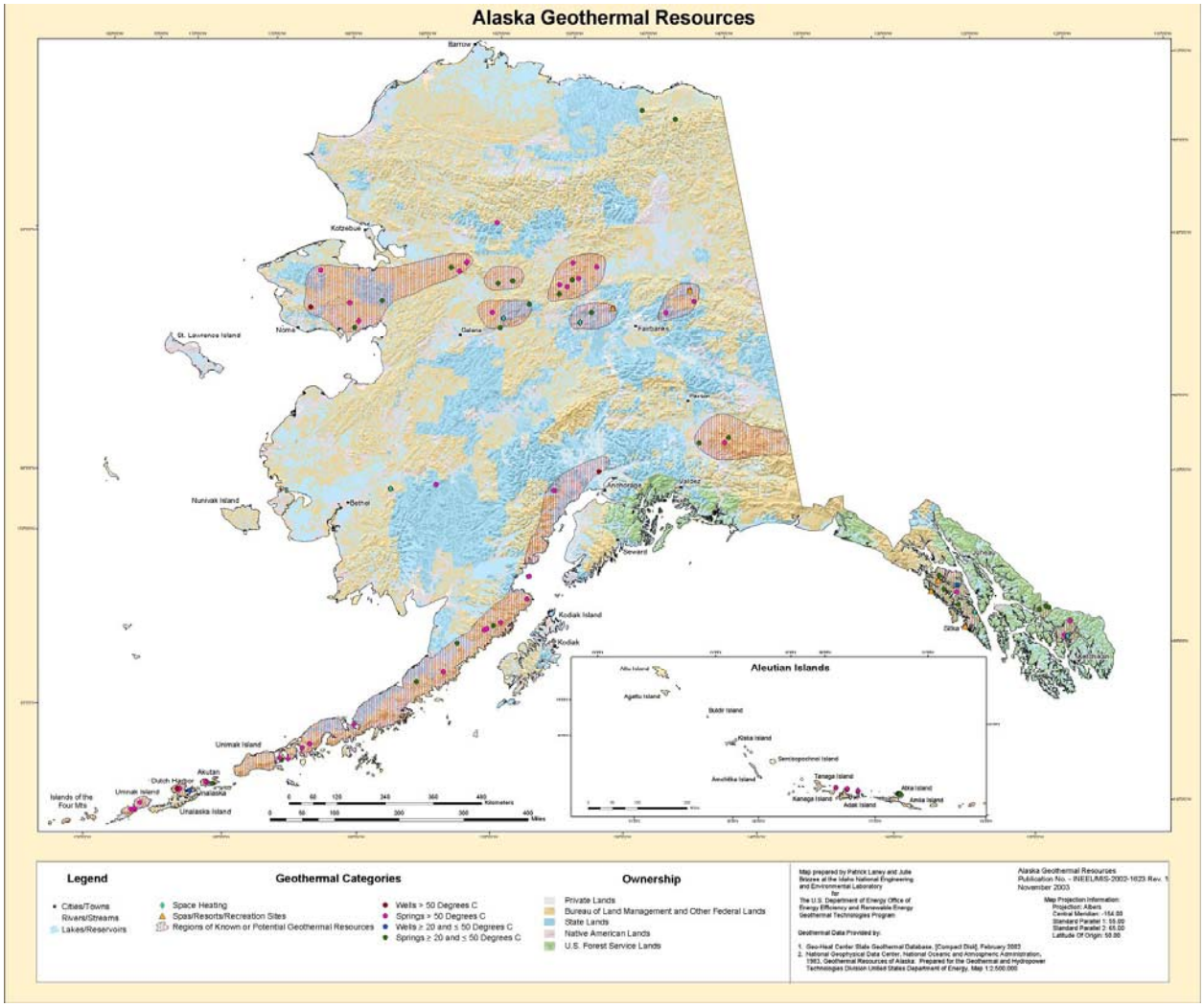

Figure 1. A geothermal-energy resource map for Alaska (source: AEA).

In 2003 the DOE, Alaska Energy Authority (AEA), and its contractors completed an assessment of geothermal resources in the state. The assessment identified substantial resources near Chena Hot Springs, Unalaska, and Akutan. In 2006 Chena Hot Springs installed a 400 kW geothermal

power plant with the assistance of AEA's Denali Commission-funded Energy Cost Reduction program. The project eliminates the need for over 115,000 gallons of diesel fuel per year.

Despite Alaska's significant geothermal potential, the attributes of Alaska's geothermal resources remain poorly defined. AEA is involved in several task forces to better understand and develop these resources. These include

1. coordinating a statewide geothermal working group of industry, academic, and government officials interested in geothermal development;
2. participating in the DOE's Geopowering the West† program, which provides technical and financial support for western U.S. states; and
3. collaborating with the Alaska Department of Natural Resources (DNR) Division of Geological and Geophysical Surveys to compile geothermal data throughout Alaska.

Wind Energy

DOE EERE program's Web site shows Alaska has sufficient wind resources for large- and small-scale wind power. Much of this resource is available near the state's large population/industrial centers—making transmission from point of generation to consumer relatively inexpensive.

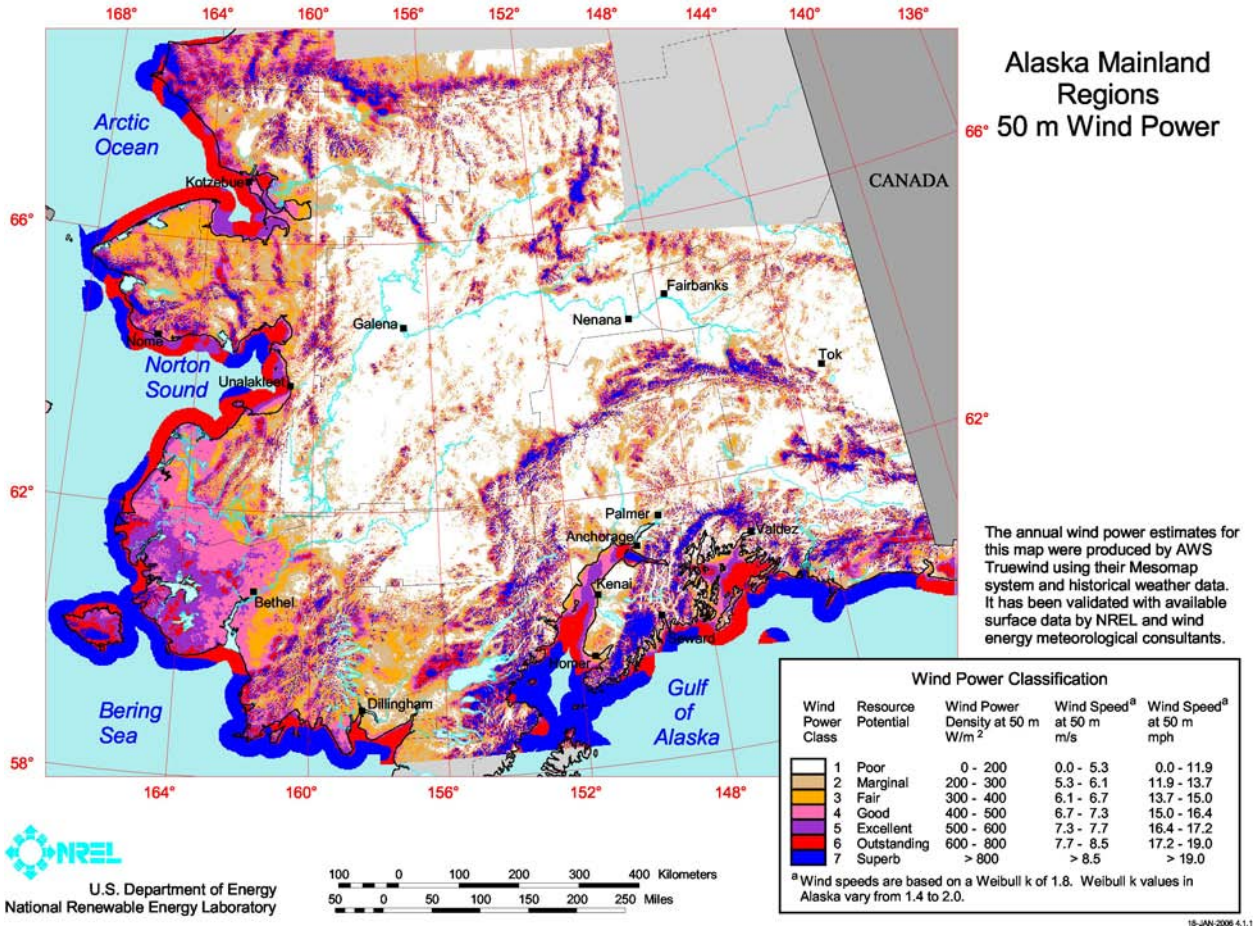

Figure 2. A wind-energy resource map for Alaska (source: NREL).

† http://www1.eere.energy.gov/geothermal/gpw/

Hydroelectric Energy

Alaska has a very good hydroelectric power resource as a percentage of the state's electricity generation. For additional resource information, please review Idaho National Laboratory's Virtual Hydropower Prospector† (VHP). VHP is a convenient geographic information system tool designed to assist in locating and assessing natural stream water energy resources in the U.S.

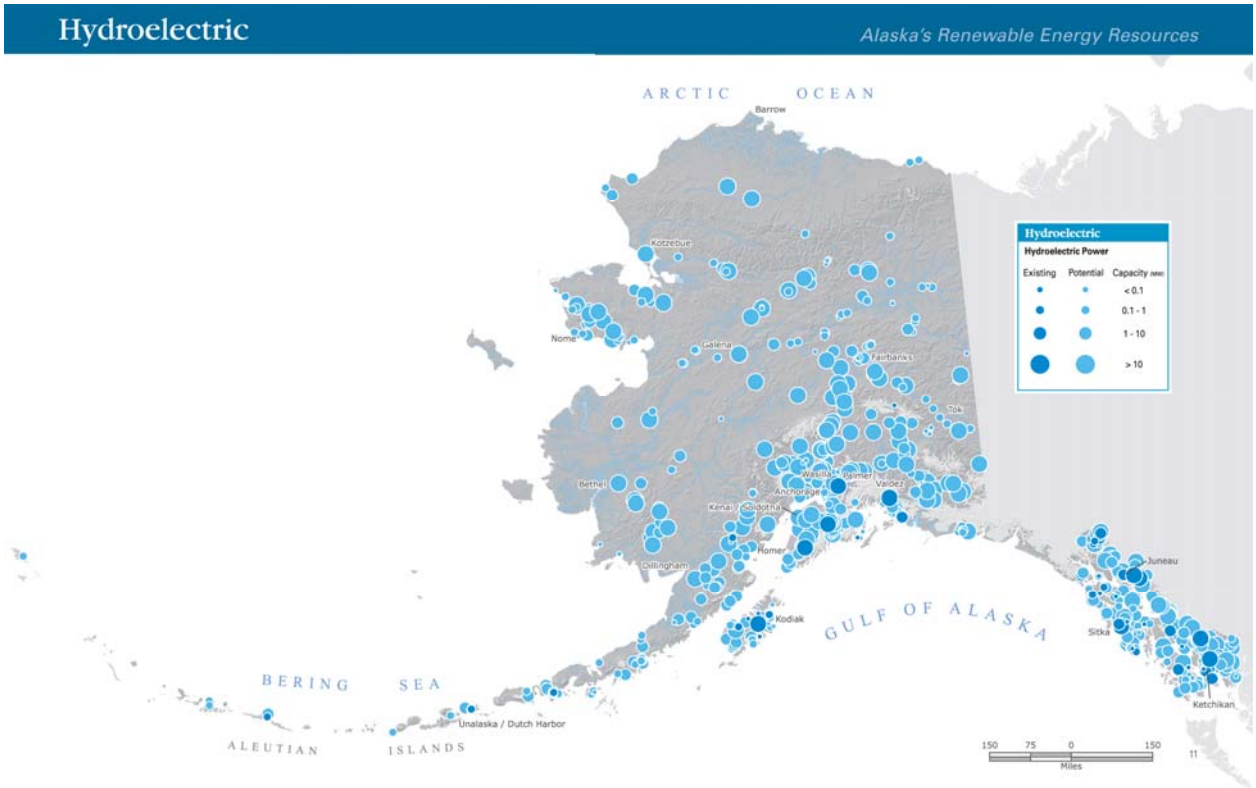

Figure 3. A hydropower-energy resource map for Alaska (source: AEA[4]).

In the 2004 report "Water Energy Resources of the United States"[5] the DOE EERE estimates that the power potential of the U.S. water energy resources is ~300,000 MW—corresponding to an annual energy production of 2,680,000 GWh. Of this potential, ~40,000 MW, corresponding to the ~80,000 MW capacity of existing hydroelectric plants, have been developed. Power potential in zones that exclude new hydropower development accounts for about 90,000 MW. This leaves ~170,000 MW of potential or ~60% of the total that *has not been developed* and is not excluded from development. This potential power corresponds to an annual energy production of 1,501,500 GWh.

The study shows that *over half of the power potential of the U.S.* resides in Alaska (29%) and the Pacific Northwest (26%); in particular, in the states of Alaska, Washington, Idaho, and Oregon. Nearly half of the available (untapped) power potential also resides in Alaska (26%) and the Pacific Northwest (23%).

† http://hydropower.inel.gov/prospector/index.shtml

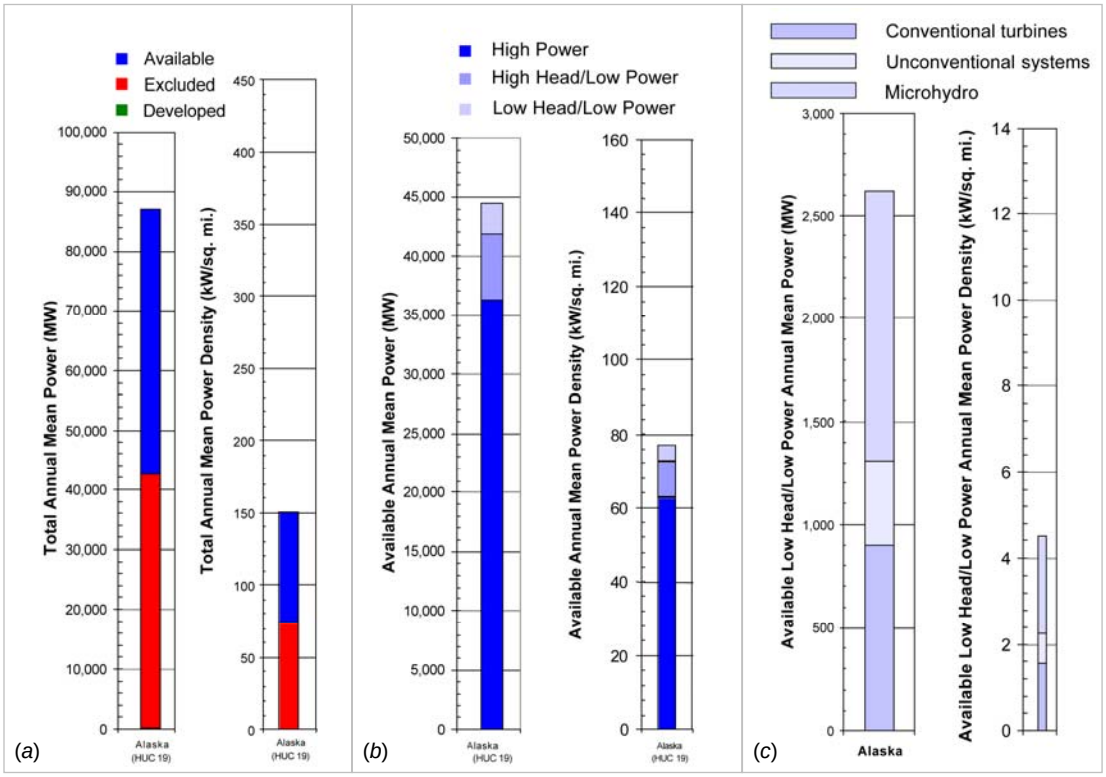

Figure 4. Alaska's hydropower potential. (*a*) Total power potential (*left*) and power potential density (*right*) of water resources in Alaska divided into developed, excluded (by law or treaty), and net constituents. (*b*) The power potential (*left*) and power potential density (*right*) of Alaska's available (from *a*) water energy resources divided into high power, high head/low power, and low head/low power constituents. (*c*) Alaska's available (from *a*) power potential (*left*) and power potential density (*right*) from low head/low power water energy sources divided into conventional turbines, unconventional systems, and microhydro constituents (source: DOE EERE[5]).

Approximately 90% of this available potential is composed of high power potential (≥1 MW), high head/low power (head ≥30 ft and <1 MW) potential, and part of the low head/low power (head <30 ft and <1 MW) potential that could be realized using conventional turbine technology. However, the conventional turbine technology would have to be incorporated into new system configurations and not require impoundments to be determined by future research and development (R&D).

The boundary between the high power and low power classes defined by hydraulic head and flow rate is shown graphically in Figure 5(a) below. The low head/low power class is defined by the following two criteria

- all power potential <100 kW (microhydro) and
- power potential ≥100 kW but <1 MW with hydraulic head <30 ft.

The low head/low power class shown in Figure 5(a) is divided into the operating envelopes of three classes of low head/low power technologies

- conventional turbines—power ≥100 kW, but <1 MW *and* hydraulic head <30 ft, but ≥8 ft
- unconventional systems—power ≥100 kW, but <1 MW *and* hydraulic head <8 ft.
- microhydro technologies—power <100 kW

These operating envelopes are shown graphically in Figure 5(b).

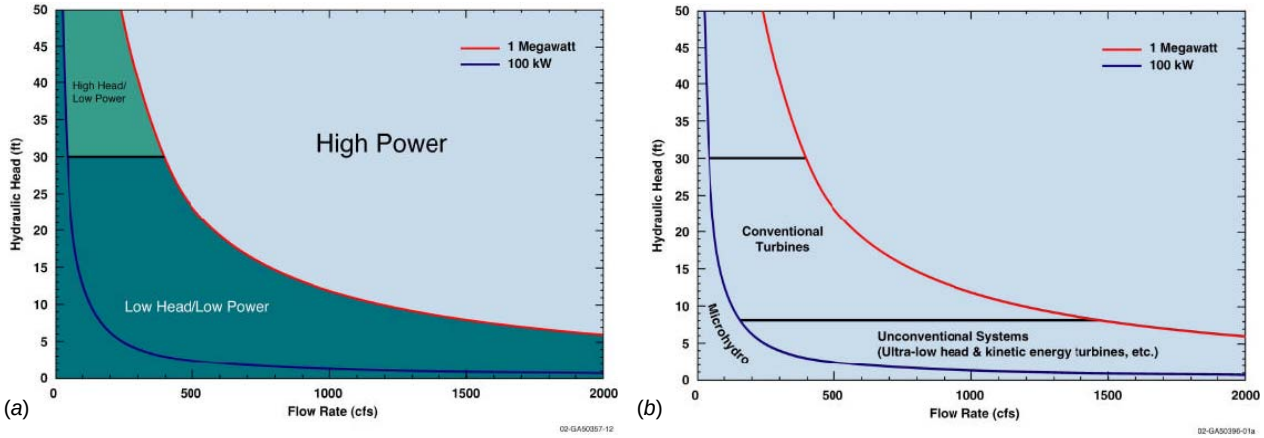

Figure 5. (a) Hydropower energy-collection regimes and (b) hydropower technologies that can capture that energy (source: DOE EERE[5]).

The estimated, available, low head/low power potential of ~21,000 MW constitutes 13% of the total available potential. High head/low power potential adds another 26,000 MW (16% of the total); therefore, low-power potential is about 30% of the total available power potential.

Over 90% of available power potential could be realized using conventional turbines, but perhaps in new system configurations. However, nearly two-thirds (66%) of the low head/low power potential (»10% of total available potential) corresponds to technologies (unconventional systems and microhydro) that would require additional turbine and system configuration R&D; although, some units currently exist that could be put into service.

Ocean Energy

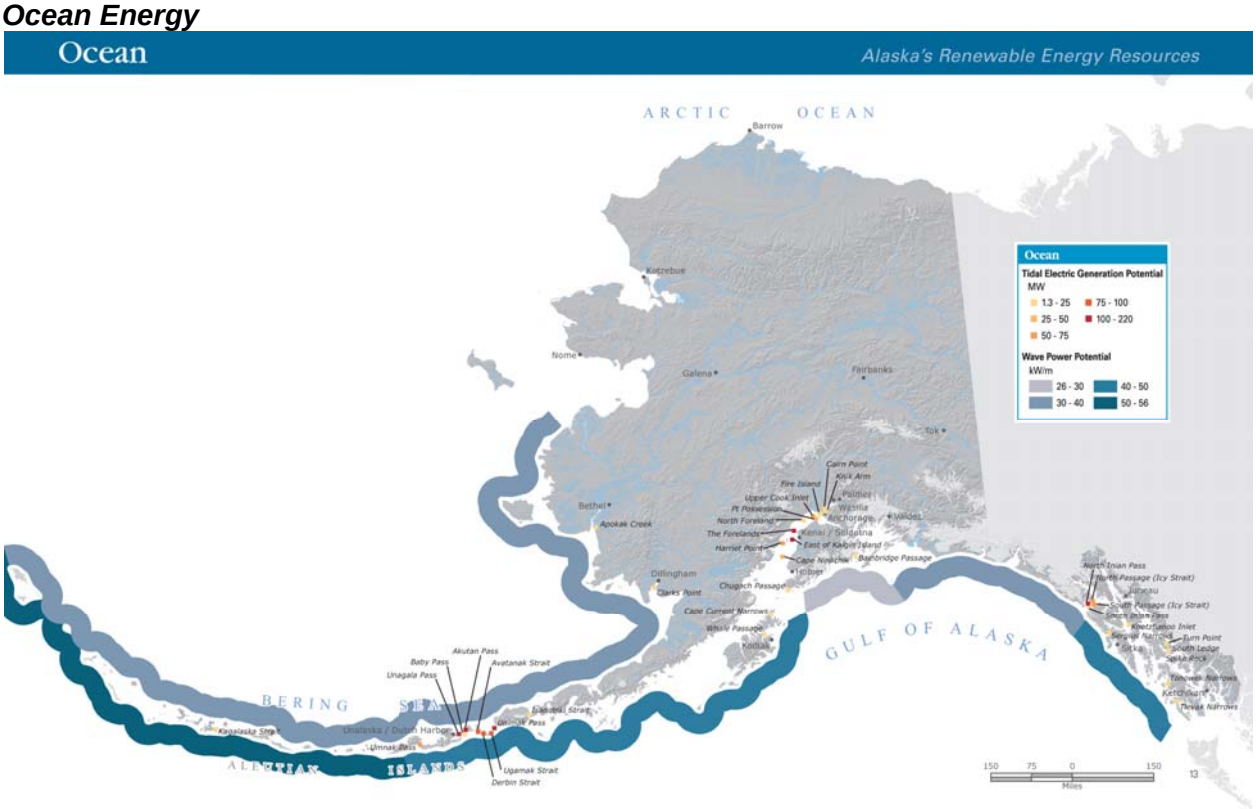

Figure 6. A ocean-energy resource map for Alaska (source: AEA[4]).

With its vast and highly indented coastline, Alaska can also exploit the tidal energy supplied by the Earth-Moon gravitational system. Alaska has many ideal candidate sites where strong tidal currents flow through geographically restricted channels—between islands, between islands and coastal features, or through undersea canyons or features. While tidal energy is intermittent—it is intermittent in a way that is precisely predictable. It could be regulated in tandem with river hydroelectric power sources to provide continuous reliable power.

Biomass Energy

According to the AEA, Alaska's most important biomass fuels are wood, sawmill wastes, fish byproducts, and municipal waste. AEA's Biomass Energy Program focuses on developing wood-fired systems that displace fuel oil for heating public facilities, demonstrating fish-oil biodiesel performance, and recovering energy from municipal solid waste. AEA is part of the Pacific Regional Biomass Energy Partnership, a state and federally supported effort that encourages bioenergy development in Alaska, Hawaii, Idaho, Montana, Oregon, and Washington.

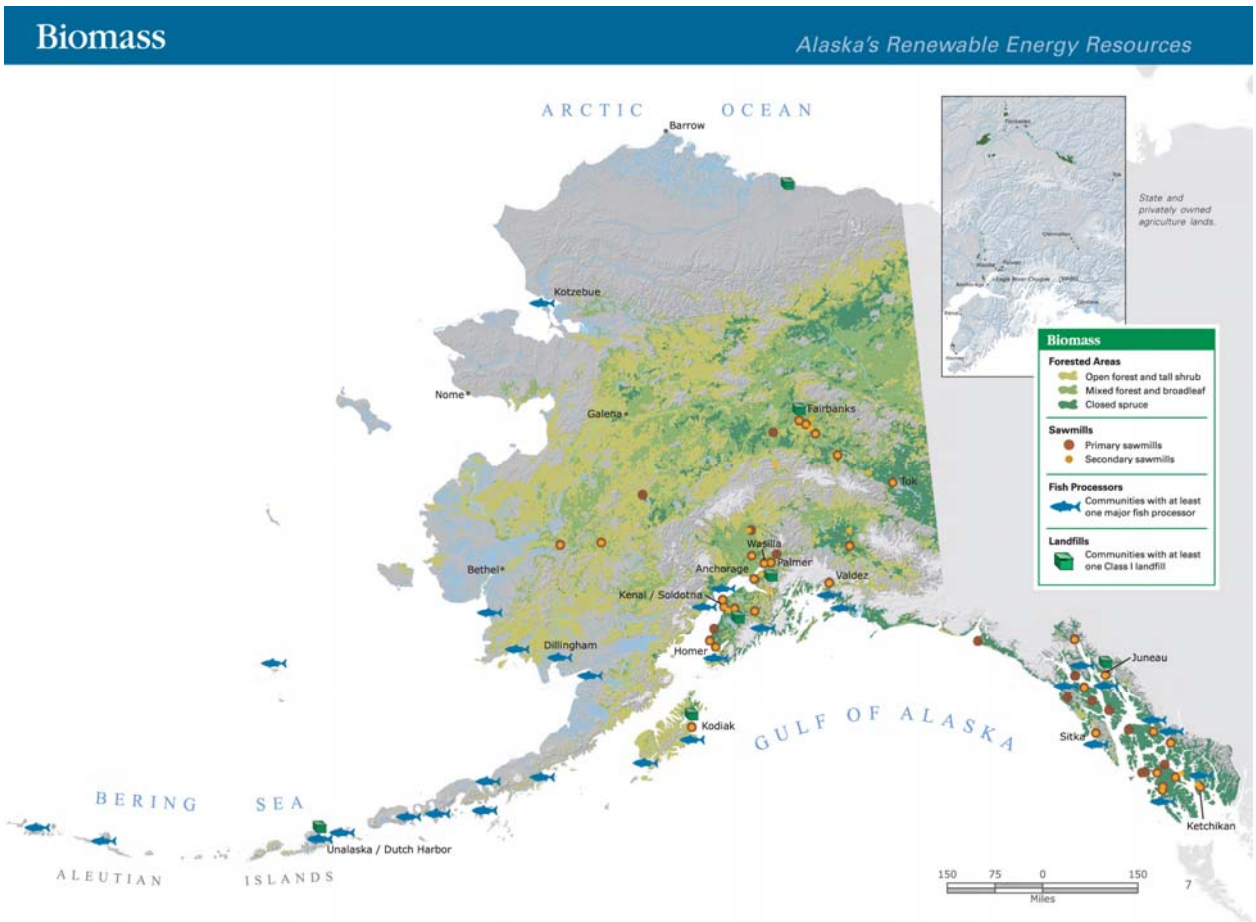

Figure 7. A biomass-energy resource map for Alaska (source: AEA[4]).

Wood remains an important RE source for Alaskans, with over 100,000 cords per year used for residential space heating statewide. Closure of the major pulp mills in Sitka and Ketchikan in the 1990s brought an end to large-scale wood-fired power generation in Alaska; however, recent increases in oil prices have raised interest in using sawdust and wood wastes as fuel for lumber drying, space heating, and small-scale power production. Alaska has also seen renewed interest

in converting low-value wood and wood wastes to liquid fuels such as ethanol. Under study in Ketchikan is a wood-waste to ethanol project.

Based on Alaska Wood Energy Development Task Group direction, AEA and the U.S. Forest Service (USFS) Region 10 are providing partial funding for the design of a wood-fired district heating system in Craig. If the project proceeds into construction, the facility will displace up to 36,000 gallons of fuel oil per year with local sawmill waste. AEA and USFS are also working with the Juneau Economic Development Council to conduct reconnaissance level feasibility assessments of wood heated facilities in other communities.

Fish Oil and Biodiesel

Shore-based and floating groundfish processors produce approximately 8 million gallons per year of fish oil as a byproduct of fish meal plants. Much of the oil is used in the process as boiler fuel for drying the fish meal or exported to Pacific rim markets for livestock and aquaculture feed supplements and other uses. In 2001, with the assistance of AEA and the Alaska Science and Technology Foundation, processor UniSea Inc. conducted successful tests of raw fish oil/diesel blends in a 2.2 MW 2-cycle Fairbanks Morse engine generator. Since then, the company has expanded the operation and used over two million gallons of 50:50 raw fish oil-diesel blend for power production between July 2002 and June 2004.

Biodiesel is an engine fuel manufactured from renewable sources, such as vegetable oils, re-cycled cooking greases or oils, or animal fats. Biodiesel is a U.S. EPA-approved substitute manu-factured to established industry standards. Currently AEA is working with UAF's Arctic Energy Technology Development Laboratory, Alaska Department of Environmental Conservation, and the National Park Service to test performance of biodiesel in generators at UAF and Denali National Park.

Municipal Waste

Alaskans generate approximately 650,000 tons of garbage per year. Currently there is no large-scale recovery of energy from burning unsorted garbage in Alaska. The Sitka Waste-to-Energy facility operated from 1985 to 2000 and provided heat to nearby Sheldon-Jackson College. Fair-banks Memorial Hospital operated a small onsite heat recovery incinerator from 1989 to 2001. Channel Sanitation's Juneau incinerators, under consideration for power production and heat recovery in the 1990s, halted operation in 2003 after a change in ownership.

Eielson Air Force Base, near Fairbanks, densifies paper separated from the local waste stream and co-fires the 4 cm^2 "cubes" at the base's coal-fired power plant. Beginning in 1997 the facility has produced 600–3000 tons per year of "refuse-derived fuel" providing 1% to 1.5% of the base's heat and power load. Co-firing densified paper at local power plants is a component of the AEA-assisted Fairbanks North Star Borough Solid Waste Plan's least-cost alternative. Conventional recycling of paper, around half of the waste stream, is economically marginal at best due to Fairbanks' distance from lower 48 markets.

Energy recovery from Anchorage landfill gas is viable, according to an assessment prepared for the Municipality of Anchorage Solid Waste Services with AEA assistance. The report estimates the landfill will produce an average energy equivalent of ~1.9 million gallons of diesel fuel per year over the next 10 years. The gas could be used to heat nearby military or school facilities, or

be converted to 2.5 MW of power, enough to supply 2,500 homes in the rail belt. Over the next 30 years, gas and energy output from the landfill is expected to more than double.

Science & Technology Research Efforts

Geothermal Energy

Worldwide geothermal usage is an estimated 15,000 MW of direct use (heating) and more than 8,000 MW of electricity-generating capacity. This generating capacity is about 0.4% of the world total installed generating capacity. The U.S. is the largest producer of geothermal electricity, followed by the Philippines, Mexico, Indonesia, Italy, Japan, and New Zealand.[†] Iceland is the largest *per capita* producer and user of geothermal energy.

Sandia is presently supporting DOE EERE Geothermal in working with Iceland. Iceland is moving forward from exploiting the geothermal to heat water, heat most of its buildings, and generate electricity. It has completed one pilot project and begun another to produce hydrogen fuel for fuel-cell vehicles from clean, geothermal energy. They hope to power all land vehicles and their fishing fleet (their main industry) by 2050. They are also beginning to make hydrocarbon fuels from the CO_2 that is released from the geothermal wells.

Australia and New Zealand also are focusing considerable efforts on exploiting their geothermal resources. Southern Australia is home to extremely large untapped geothermal resources, but no transmission lines exist to get the electricity to load centers, which are a great distance away.

World-wide geothermal research is vast and highly varied. The governments of the developed and much of the developing world support geothermal research. Most geothermal research in the U.S. is conducted in the national laboratory system and focused on large-scale electrical power generation.[6] The two largest programs are at Sandia (drilling) and Lawrence Berkeley National Laboratory (LBNL) (geoscience). The University of Nevada–Reno hosts the Great Basin Geothermal Energy Center which, in partnership with U.S. industry, conducts research toward establishing geothermal energy as a sustainable, environmentally sound, economically viable energy source in the western U.S. Smaller projects underway under the auspices of the DOE EERE program are

Idaho National Laboratory

- Mitigation of impact of off-design operation
- Power plant costing methodology
- Enhancement of air-cooled condensers
- Microbiological research
- Continual removal of noncondensable gases for binary power plant condensers
- Pipe coatings
- Geothermal process gas monitors

National Renewable Energy Laboratory

- Air-cooled condensers
- Component development for ammonia/water power cycles
- Plant performance enhancement and optimization
- Field-verification of small-scale geothermal power plants
- Direct use field verification
- Heat exchanger field tests

[†] International Geothermal Association, 2007

Lawrence Livermore National Laboratory

- Co-production of silica and other commodities from geothermal fluids
- Silica scale inhibition

Brookhaven National Laboratory

- High-performance coating materials
- Field demonstration and evaluation of lined heat exchanger tubes
- Geothermal silica recovery
- High-temperature polymeric elastomers
- Nondestructive testing of corrosion/erosion damage in piping systems

Wind Energy

Wind turbines are a mainstay of the RE market. As such, they are a constantly improving technology. Leading research involves transitioning from today's technology of turbine blades made of fiberglass to fiberglass/carbon-fiber construction. In addition, researchers are exploring how to improve the labor-intensive manufacturing process to reduce initial investment costs (and produce competitive U.S.-based jobs through advanced manufacturing techniques such as the DOE/Industry/State jointly funded project in Iowa by TPI Composites).

The effort to allow wind turbines to capture as much of the wind's energy as possible has led to the investigation of innovative concepts such as

- modifying blade cross section design to capture wind energy more efficiently,
- embedding sensors and load-control devices during the manufacturing process to improve blades performance and alleviate fatigue loads, and
- developing computational fluid-dynamics tools to maximize structural and aerodynamic efficiency and fully understand the 3-D flow fields in which the turbines operate.

The *CANMET Energy Technology Centre* (CETC-Ottawa) is studying the effects of cold climate on power generation and operational safety of wind turbines. In the University of Manitoba's wind tunnel, severe icing events are simulated in order to study icing's effects on wind turbines. These experiments will contribute to the development of anti-icing and de-icing technologies to mitigate the effect of Canada's harsh climate on the performance of wind turbines. Also, *Clipper Windpower* has certified its wind turbines for cold climate operation.

Many large organizations coordinate wind-energy research. One of the largest is the International Energy Agency (IEA). Signatories of the IEA's Wind Agreement include

- Australia (Australian Wind Energy Assn.),
- Austria,
- Canada (Natural Resources Canada)
- Denmark (Danish Energy Authority),
- The European Wind Energy Assn. (EWEA),
- Finland (The National Technology Agence of Finland),
- Greece (The Ministry of Industry, Energy, & Technology),
- Mexico (Instituto de Investigaciones Electricas),
- Netherlands (The Netherlands Agency for Energy & the Environment),
- Norway (The Norwegian Water Resources & Energy Directorate and Enova SF),
- Portugal (Departmento de Energìas Renováveis),
- Sweden (Energimyndigheten),

- Germany (Federal Ministry for the Environment, Nature Conservation, & Nuclear Safety),
- Ireland (Irish Energy Center),
- Italy (CESI S.p.A. and ENEA Cassaccia),
- Japan,
- Korea (Ministry of Commerce, Industry, & Energy),
- Spain (Instituto de Energias Renovables of the Centro de Investigación; Energetica Medioambiental y Tecnologica),
- Switzerland (Swiss Federal Office of Energy),
- United Kingdom (Department of Trade & Industry),
- United States (The U.S. Department of Energy)

Most developed nations and many of the developing nations support wind-energy research. An exhaustive list is not possible in a short paper. Below, we describe the DOE EERE's Wind Energy program which supports a wide variety of research in partnership with major U.S. wind-energy companies. The companies and research institutions identified below could form the core list of researchers invited to a meeting in Alaska to discuss how to encourage exploration of Alaska's wind resources and expansion of its utilization.

By the end of 2006, the U.S. wind industry had become one of the fastest growing utility-scale energy resources in the nation. With a current annual growth rate of 27%, U.S. wind-energy capacity increased from 2,500 MW in 1996 to more than 11,500 MW at the end of 2006. The DOE Wind Program aims to significantly increase wind energy use—increasing and diversifying the domestic energy supply; boosting environmental benefits by avoiding pollutant emissions; and strengthening our infrastructure posture by increasing system reliability while reducing economic effects of fuel price or supply disruptions.

In May 2008, the DOE released a first-of-its kind report that examines the technical feasibility of harnessing wind power to provide up to 20% of the nation's total electricity needs by 2030. The report titled "20 Percent Wind Energy by 2030"[7] identifies requirements to achieve this goal including reducing the cost of wind technologies, siting new transmission infrastructure, and enhancing domestic manufacturing capability. Most notably, the report identifies opportunities for 7.6 cumulative gigatons of CO_2 to be avoided by 2030, saving 825 million metric tons in 2030 and every year thereafter if wind energy achieves 20% of the nation's electricity mix. As part of President Bush's Advanced Energy Initiative announced in 2006, clean, secure, and sustainable wind energy has the potential to play an increasingly important role in the nation's long-term energy strategy to make investments today to fundamentally change the way we power U.S. homes and businesses and to help reduce greenhouse gas emissions growth by 2025.

"DOE's wind report is a thorough look at America's wind resource, its industrial capabilities, and future energy prices, and confirms the viability and commercial maturity of wind as a major contributor to America's energy needs, now and in the future," said Assistant Secretary of Energy Efficiency and Renewable Energy for the DOE, Andy Karsner. "To dramatically reduce greenhouse gas emissions and enhance our energy security, clean power generation at the gigawatt-scale will be necessary, and will require us to take a comprehensive approach to scaling renewable wind power, streamlining siting and permitting processes, and expanding the domestic wind manufacturing base."

Prepared by the DOE and a broad cross section of stakeholders across industry, government, and three of DOE's national laboratories—NREL, LBNL, and Sandia, the report presents an in-depth analysis of the potential for wind in the U.S. and outlines a potential scenario to boost wind electric generation from its current production of 16.8 GW to 304 GW by 2030. For its technical report, DOE also drew on the expertise of the American Wind Energy Association and Black & Veatch engineering consultants and the report reflects input from more than fifty energy organizations and corporations.

The analysis concludes that reaching 20% wind energy will require enhanced transmission infrastructure, streamlined siting and permitting regimes, improved reliability and operability of wind systems, and increased U.S. wind manufacturing capacity.

The U.S. leads the world in new wind installations and has the potential to lead the world in total wind capacity by 2010. Last year, U.S. cumulative wind-energy capacity reached 22,613 MW—with nearly 6,000 MW of wind installed in 2008. Wind contributed to more than 30% of *new* U.S. generation capacity in 2007 (2008 statistics have not yet been released), making it the second largest source of new power generation in the nation—surpassed only by natural gas. The U.S. wind energy industry invested approximately $9B in new generating capacity in 2007, and has experienced a 30% annual growth rate in the last 5 years.

To expand wind energy's contribution to the nation, the DOE Wind Energy Program focuses its research on increasing the technical viability of wind systems and increasing the use of wind power in the marketplace. In the area of technology viability, the program is pursuing large wind technology, distributed wind technology, and supporting research and testing. To increase technology use, the program sponsors research into systems integration and technology acceptance.

Large Wind Technology

The performance goal for the large wind turbine research is to reduce the cost of electricity from large land-based wind systems in Class 4 winds (5.8 m/s at a height of 10 m) to 3.6 ¢/kWh by 2012 and 7 ¢/kWh for offshore systems in Class 6 (6.7 m/s at a height of 10 m) winds by 2014. Wind turbines are currently capable of producing electricity at 5–8 ¢/kWh in the Class 4 wind regimes that are broadly available across the United States, depending on many factors, including project financial structure. The program's strategy is to increase the commercial viability and deployment of wind energy by improving the reliability and performance of existing technology while setting the stage for future wind technologies advanced through applied research and market assessment.

Prototype Development

During the past two decades, the Wind Energy Program has worked with industry to develop a number of prototype technologies, many of which have become commercially viable products. One example is the *GE Wind Energy* 1.5-MW wind turbine. As of June 2008, GE had more than 8,500 of these machines installed worldwide. The design of GE's 1.5-MW machine is based on work conducted with GE and its predecessors (Zond and Enron). Since the early 1990s, the program worked with these companies to test components such as blades, generators, and control systems on the various generations of machines that led to GE's 1.5-MW workhorse. Another project that is demonstrating commercial success is the new 2.5-MW wind turbine manufactured

by Clipper Windpower. Clipper produced a prototype of its 2.5-MW Liberty wind turbine in 2005 after only three years of cooperative R&D work with the Wind Energy Program. By August 2008, Clipper had installed 205 of its 2.5-MW Liberty machines. Clipper is targeting another 300-plus wind turbines by year-end 2009 and will expand production further the following year. Clipper Windpower currently has sufficient plant capacity and equipment, a trained workforce, and processes in place to assemble more than 500 Liberty turbines annually, with potential for further capacity extensions.

Component Development

The program also works with industry partners to improve the performance and reliability of system components. *Knight & Carver's* Wind Blade Division in National City, California, worked with program researchers at *Sandia National Laboratories* to develop an innovative turbine blade that the company expects to increase energy capture by 5% to 10%. The most distinctive characteristic of the sweep twist adaptive rotor blade is a gently curved tip, which unlike the vast majority of blades in use, is specially designed to take maximum advantage of all wind speeds, including marginal speeds. The blade was tested for endurance at NREL in 2008.

Distributed Energy Systems (formerly Northern Power Systems) completed a successful partnership with the program to produce a modular, efficient power electronics package that can be scaled for use in a range of wind turbines, from small to multimegawatt systems. According to the company, the new converter improves wind turbine reliability, energy capture, and grid performance. Tests completed on the converter and the Distributed Energy Systems 1.5-MW direct-drive generator, also developed under the program, demonstrated high-quality power output.

To support the development of more reliable gearboxes, the program has worked with several companies to design and test innovative drivetrain concepts. Clipper Windpower's Liberty wind turbine incorporates a highly innovative multiple-drive-path gearbox that feeds four advanced permanent-magnet generators. *Global Energy Concepts* fabricated a 1.5-MW, single-stage drivetrain with a planetary gearbox and a medium-speed (190 rpm), permanent-magnet generator that shows potential for reducing tower-head weight and drivetrain costs. Northern Power Systems constructed a permanent-magnet generator with a novel power converter to allow variable-speed operation. The converter was chosen by the American Wind Energy Association for its 2006 Technical Achievement Award.

Genesis Corporation is testing a new tooth form for gearboxes that promises major improvements in power density while reducing the costs of these devices. The company completed the first round of testing with positive results and is now working to refine its design.

Distributed Wind Energy Technology

The Wind Energy Program goal for small, distributed wind-energy systems was to reduce the cost of energy to 10–15 ¢/kWh in a Class 3 wind resource from a 2002 baseline of 17–22 ¢/kWh. In 2007, the program met that goal through collaborative efforts with industry partners that included *Southwest Windpower*, *Windward Engineering*, *Abundant Renewable Energy*, and *Wetzel Engineering*, reducing the cost of electricity produced by residential-sized turbines (10 kW or less) to 9.9 ¢/kWh. Working with Distributed Energy Systems, *Composite Engineering*, Global Energy Concepts, *Princeton Power Systems*, and *TIAX*, the program reduced the cost of electric-

ity for business/industrial-sized machines (11–100 kW) to 10.7 ¢/kWh. In 2008, the program refocused its efforts on increasing the market for distributed wind systems to meet a growing demand for community-owned projects and local power generation.

To help industry provide consumers with more small wind turbine systems certified for safety and performance, the program launched an independent small wind test project in 2007. The primary objective of this activity is to test commercially available small wind turbine systems that have a high probability of success in the U.S. market over the next several years. The availability of reliable small wind turbines will support the program goal of increasing the number of small wind turbines installed in the U.S. five-fold by 2015.

The Wind Energy Program has worked with several small wind industry partners to develop and test commercially available award-winning small and mid-sized wind generation systems and components. In 2000, DOE's NREL received and R&D 100 Award for its contribution to the development of the Northern Power Systems (now, Distributed Energy Systems) NorthWind 100 wind turbine. The NorthWind 100 wind turbine is a state-of-the-art wind turbine designed for operation in remote, cold-climate conditions. By the end of 2007, 11 of these turbines had been installed and 10 more were sold and awaiting installation. Since then, they have reconfigured its 100-kW cold weather turbine for agricultural and community applications in temperate climates. The company began testing its new prototype at the NREL in 2007.

Southwest Windpower has been working with the program and researchers at NREL's *National Wind Technology Center* (NWTC) for the past several years to develop a 1.8 kW wind energy generator called the Skystream. In 2006, Southwest Windpower received *Popular Science* magazine's "Best of What's New" award for its new wind generator, and it was recognized by *Time* magazine as one of the "Best Inventions 2006." The new turbine has fully integrated electrical components, costs less, is easier to install, and has quieter operation. Since the company began commercial production of the Skystream in 2007, it has sold more than 1,000 units.

As part of its small wind components research, the Wind Energy Program conducted tests at the NWTC with Windward Engineering on its 4.25 kW Endurance wind turbine developed to demonstrate a furling control system. The company began commercial production of the unit in 2008.

Another component project completed in 2006 was the Princeton Power Systems 50-kW AC-AC converter. This new component has a higher conversion efficiency and produces excellent power quality, uses fewer components, and reduces cost.

Systems Integration

The goal of the systems integration activity is to complete program activities addressing electric power market rules, interconnection impacts, operating strategies, and system planning needed for wind energy to compete without disadvantage to serve the nation's energy needs by 2012.

As the need to stabilize national energy resources and electricity demands increases, more utilities are seriously evaluating wind power to provide a portion of their generation mix. At the same time, many utilities are expressing concerns about possible impacts on system operations when greater percentages of wind power are introduced into the electric power system. Their concerns, if not adequately addressed, could limit the development potential of wind power in this country.

Energy Storage

A key issue is that large penetrations of wind power will require energy-storage systems such as batteries, flywheels, compressed air, pumped hydro, etc. Appropriately sized energy storage mediates between variable generating sources and variable load demand.

The DOE Office of Science, Basic Energy Sciences (BES) hosted a joint basic-science R&D workshop in energy storage with the DOE's Office of Electricity Delivery and Energy Reliability (OEDER) which has resulted in an Electrical Energy Storage (EES) research program. (OEDER is responsible for the national power grid, technology applications, and applied R&D. BES is responsible for basic-science R&D. Sandia is the lead lab supporting Energy Storage Systems program within OEDER.)

The goal of the OEDER Energy Storage Systems program is to develop advanced energy-storage technologies and systems, in collaboration with industry, to increase the reliability, performance, and competitiveness of electric generation, transmission, and use in utility-tied and off-grid systems. The OEDER Energy Storage Systems program is working with BES to choose the research directions of the EES research program. The BES EES basic-research program sponsored a technology resource document, "Basic Research Needs for Electrical Energy Storage,"[8] which provided the groundwork for and served as a basis to inform the deliberation of basic-research discussions.

The panel on Chemical Energy Storage acknowledged that progressing to the higher energy and power densities required for future batteries will push materials to the edge of stability; yet these devices must be safe and reliable through thousands of rapid charge-discharge cycles. A major challenge for chemical energy storage is developing the ability to store more energy while maintaining stable electrode-electrolyte interfaces. The need to mitigate the volume and structural changes to the active electrode sites accompanying the charge-discharge cycle encourages exploration of nanoscale structures. Recent developments in nanostructured and multifunctional materials were singled out as having the potential to dramatically increase energy capacity and power densities. However, an understanding of nanoscale phenomena is needed to take full advantage of the unique chemistry and physics that can occur at the nanoscale. Further, an urgent need exists to develop a fundamental understanding of the interdependence of the electrolyte and electrode materials, especially with respect to controlling charge transfer from the electrode to the electrolyte. Combining the power of new computational capabilities and *in situ* analytical tools could open up entirely new avenues for designing novel multifunctional nanomaterials with the desired physical and chemical properties, leading to greatly enhanced performance.

The panel on Capacitive Storage recognized that, in general, electrochemical capacitors have higher power densities than batteries, as well as subsecond response times. However, energy storage densities are currently lower than they are for batteries and are insufficient for many applications. As with batteries, the need for higher energy densities requires new materials. Similarly, advances in electrolytes are needed to increase voltage and conductivity while ensuring stability. Understanding how materials store and transport charge at electrode-electrolyte interfaces is critically important and will require a fundamental understanding of charge transfer and transport mechanisms. The capability to synthesize nanostructured electrodes with tailored, high-surface-area architectures offers the potential for storing multiple charges at a single site, increasing

charge density. The addition of surface functionalities could also contribute to high and reproducible charge storage capabilities, as well as rapid charge-discharge functions. The design of new materials with tailored architectures optimized for effective capacitive charge storage will be catalyzed by new computational and analytical tools that can provide the needed foundation for the rational design of these multifunctional materials. These tools will also provide the molecular-level insights required to establish the physical and chemical criteria for attaining higher voltages, higher ionic conductivity, and wide electrochemical and thermal stability in electrolytes.

A third panel identified four cross-cutting research directions that were considered to be critical for meeting future technology needs in EES:

1. advances in characterization;
2. nanostructured materials;
3. innovations in electrolytes; and
4. theory, modeling, and simulation.

Energy from intermittent RE sources can also be stored in mechanical, rather than chemical, form. DOE laboratories are working to improve mechanical energy-storage options with research into flywheel or pumped storage—either compressing air or moving water uphill to reservoirs. In each case, electrical energy produced by the intermittent generator source at a time when it is not needed is converted into mechanical potential energy. When electrical demand rises, the stored potential energy is converted back to electricity and sent to the grid.

Grid Integration

Wind-energy researchers are assisting industry partners with a number of projects aimed at increasing utility understanding of integration issues and confidence in the reliability of new wind-turbine products. The DOE has a wind-turbine reliability program that is working with industry and the utilities to assess and increase the reliability of wind turbines and farms. Information and tools gained from the projects will be distributed through a national outreach effort to investor-owned utilities, electric cooperatives, public power organizations, and energy regulators to encourage the inclusion of wind power in generation portfolios and ensure the continued growth of the wind-energy industry.

The systems integration strategy is to assist regional electric system planning and operations personnel to make informed decisions about the integration of wind energy into their systems. The Wind Energy Program has identified six target research areas.

- Technology characterization and data collection
- Tools and methods development
- Application and implementation
- Integration of wind energy and hydropower technologies
- Wind energy and hydrogen production
- Wind energy and clean water

Technology Acceptance

To support the Advanced Energy Initiative objective to expand the use of wind energy, the Wind Energy Program strives to overcome near-term deployment barriers to wind by enhancing public acceptance, promoting supportive public policies, engaging key stakeholders, and addressing siting and environmental issues. In 1999, only 4 states had more than 100 MW of installed wind capacity. By the end of 2008, 21 states had more than 100 MW, with three more approaching that goal. The goal of this project is for 30 states to have 100 MW or more of wind installed by 2010.

The strategy of the Technology Acceptance effort is to build momentum for wind power's use across the U.S. Using a state-focused strategy for its efforts acknowledges the critical role in policymaking and incentive adoption that states have played in wind development to date. The primary program mechanisms for pursuing this activity are the Wind Powering America (WPA) program and the National Wind Coordinating Committee (NWCC).

WPA was established to identify wind-power barriers and options for overcoming them, primarily at the state level. A package of technical assistance and outreach activities is aimed at key user communities—farmers and ranchers, Native Americans, federal facility managers, rural electric cooperatives, and consumer-owned utilities. WPA works with these stakeholders and state and local officials to form state coalitions, or wind working groups, in conjunction with DOE's regional offices, to build the local presence required to accelerate wind power's widespread adoption.

The strategy of the NWCC, a U.S. consensus-based collaborative, is to establish dialogue among key stakeholders, and to support the development of environmentally, economically, and politically sustainable commercial markets for wind power. NWCC members include representatives from electric utilities and support organizations, state legislatures, state utility commissions, consumer advocacy offices, wind equipment suppliers and developers, green-power marketers, environmental organizations, agriculture and economic development organizations, and state and federal agencies.

Many institutional and informational barriers have slowed, and continue to slow, the adoption of wind power. The challenge for technology acceptance is to develop, disseminate, and support an appropriate mix of technical information and general outreach to states where there are strong wind resources yet little public or private momentum on wind energy as an option for development. Another challenge is to bring the wind-energy message to potential users of distributed wind technology. By reaching out to farmers, ranchers, Native Americans, and other state and local stakeholders, WPA can help build a state-level coalition. By building bridges to environmental and regulatory communities, the NWCC helps reduce barriers of interest at the nationally.

The Wind Energy Program's technology acceptance efforts complement the efforts being pursued under other elements of the program. This includes the Systems Integration activity, as both are aimed at reducing undue barriers to wind energy's use. The systems integration work targets some of the more technical barriers, while the technology acceptance efforts tend to address issues associated with state, local, and consumer-owned utility unfamiliarity with the technology and with the need for assistance in overcoming that unfamiliarity. The program is pursuing six specific themes under the technology acceptance activity.

- Outreach to state-based organizations
- Support for rural wind development
- Small-wind-energy outreach
- Institution building through utility partnerships
- Support Native American interest in wind power
- Use of wind power to meet federal loads

Supporting Research and Testing

Supporting research and testing provides funding to meet the needs of the large wind speed technology and distributed wind technology research activities by bringing specialized technical

expertise, comprehensive design and analysis tools, and unique testing facilities to bear on problems that industry will encounter in bringing new wind energy technology to the marketplace.

The strategy of the supporting research and testing effort is to use the research staffs of the NWTC and Sandia National Laboratories to perform wind-technology-specific research targeted to help industry improve the performance of components and fully integrated turbine systems. To that end, program researchers work closely with DOE and industry to define and prioritize those research activities that address their specific long- and short-term requirements. On occasion, program researchers may also contract with universities and other research organizations for supporting research and testing efforts.

NWTC and Sandia staffs provide extensive design review, analysis, and testing support for industry activities including systems analyses, component blade and drive train tests in NWTC facilities, and validation of turbine prototypes in the field. These activities are closely coupled and directly assist industry in achieving design goals with hardware that will meet international design certification standards. These support activities are performed under the auspices of cooperative research and development agreements (CRADAs) or as part of development subcontracts with industry. The following outlines the supporting research and testing research portfolio.

- Enabling research
  - Advanced rotor development
    - Blade development
    - Aerodynamic code development and validation
    - Aeroacoustics research and testing
  - Site specific design
    - Inflow characterization
    - Design load specification
  - Generator, drive train, and power electronics
  - Systems and controls
- Design review and analysis
- Testing support
  - Structural testing
  - Dynamometer testing
  - Field testing

A New Federal Agreement

In June 2008, the DOE signed an agreement with six leading wind turbine manufacturers to find ways to improve turbine design and production methods as the industry attempts to boost its contribution to the nation's electric supply. The agreement calls for a two-year collaboration to research methods to design and fabricate more reliable turbine components; reduce installation and operating costs; address environmental and technical issues; and to develop turbine certification, workforce and grid connection standards. Signatory companies included

- *GE Energy*,
- *Siemens Power Generation*,
- *Vestas Wind Systems*,
- *Clipper Turbine Works*,
- *Suzlon Energy*, and
- *Gamesa Corporation.*

Hydroelectric Energy

Hydropower is the most established of the RE technologies, providing more than 75% of the electricity generated by RE in the U.S. About 10% of all U.S. electricity is generated by hydropower. Hydropower offers significant advantages over other energy sources: it is a reliable,

domestic, renewable resource; it emits no harmful atmospheric emissions or greenhouse gases; and it has intrinsic storage which makes it dispatchable. Hydropower projects also provide other benefits, such as water supply, flood control, irrigation, navigation, and recreation.

The goal for the DOE EERE program's hydropower research is to maintain hydropower as an attractive electricity-producing option for the 21st century and increase electricity generation where available without adverse environmental effects (fish injury/mortality from turbine passage and changes to water quality/levels below dams). These increases in generation will be accomplished through a combination of advanced technology including new hardware (e.g., turbines, hydraulic controls, and facilities) to mitigate for environmental effects and operational improvements at the unit, plant, and reservoir systems levels. To develop advanced technology and operational improvements, the industry relies on aggressive R&D and support programs.

DOE's research promises to increase hydropower generation up to 10% at existing dams, while at the same time improving the environmental quality of U.S. rivers. In order to maintain and expand hydropower's contribution to the nation, the Hydropower Technology Program' research focuses on the two elements of its mission.

- Enhancing the technical viability of hydropower systems through
  - advanced hydropower technology and
  - supporting research and testing.
- Expanding the use of hydropower in the marketplace with
  - systems integration and technology acceptance and
  - systems engineering and analysis.

Advanced Hydropower Technology

The Advanced Hydropower Technology activity supports the development of technologies that will enable existing hydropower projects to generate more electricity with less environmental impact. This will be done by

1. developing new turbine systems that have improved overall performance;
2. developing new methods to optimize hydropower operations at the unit, plant, and reservoir system levels; and
3. conducting research to improve the effectiveness of the environmental mitigation practices required at hydropower projects.

The main objective of DOE's research into Advanced Hydropower Technology is to develop new system designs and operation modes that will enable both better environmental performance and competitive generation of electricity. While DOE does not own or operate hydropower projects, the products of DOE's research will allow hydropower projects to generate cleaner electricity. DOE-sponsored projects will develop and demonstrate new equipment and operational techniques that will optimize water-use efficiency, increase generation, and improve environmental performance and mitigation practices at existing plants.

When fully adopted, the products of DOE's research will enable up to a 10% increase in the hydropower generation at existing dams, with net benefits to the environmental quality of rivers in the U.S.

Three sets of research projects are being supported under Advanced Hydropower Technology:

- **Large Turbine Testing.** Evaluating a new generation of large turbines in the field to demonstrate that they are commercially viable; compatible with today's environmental standards; and capable of balancing environmental, technical, operational, and cost considerations.
- **Water Use/Operations Optimization.** Developing and demonstrating tools to improve how water is used within hydropower units, plants, and river systems with multiple hydropower facilities, to generate more electricity with less water and greater environmental benefits.
- **Improved Mitigation Practices.** Studying the benefits, costs, and overall effectiveness of environmental mitigation practices and developing guidance that will enable best-available technology to be used in hydro development and operation.

The Hydropower Program is pursuing four specific research activities under supporting research and testing:

- **Biological Design Criteria.** Performing laboratory studies of the biological response of fish to the physical stresses experienced during passage through turbines.
- **Computer and Physical Modeling.**
- **Instrumentation and Controls.** Developing new instruments and monitoring technologies to measure the physical conditions inside turbines in the field.
- **Environmental Analysis.** Applying advanced computational techniques to describe the full range of hydraulic environments in turbines under different operating conditions.

Two activities are being supported under Systems Integration and Technology Acceptance: hydropower integration with other renewables and outreach activities. Two activities are supported under Supporting Engineering and Analysis: low-head, low-power resource assessment and valuation of hydropower.

Run-of-the-River Hydropower

Run-of-the-river hydroelectricity is power generation where the kinetic energy in the natural flow and elevation drop of the water in a river is captured to generate electricity. The best candidates for this type of power generation are rivers with a steady, consistent flow all year round. Run-of-the-river power projects do not require a large impoundment of water, and so do not disrupt the natural environment as a dam would. The power project can be turbines immersed into the flow of the river's current (see Figure 8a–8c) or installed in a power station on shore (Figure 8d).

In a land-based run-of-the-river power-station, some of the water is diverted from a river (in such a way that aquatic life is kept in the main stream flow) and sent into a pipe called a penstock. The penstock feeds the water downhill to the power station's turbines. Because of the difference in elevation, potential energy from the water up river is transformed into kinetic energy as it flows down the penstock. After going through the generator turbines, the water leaves the power station and is returned to the river (tailrace) without altering the river's total flow or its water levels.

In this system, the turbines are securely mounted in the power house where they are optimized to maximize electricity generation and minimize wear and tear on the machinery. However, the system requires significant infrastructure costs and is difficult to expand without significant additional investment.

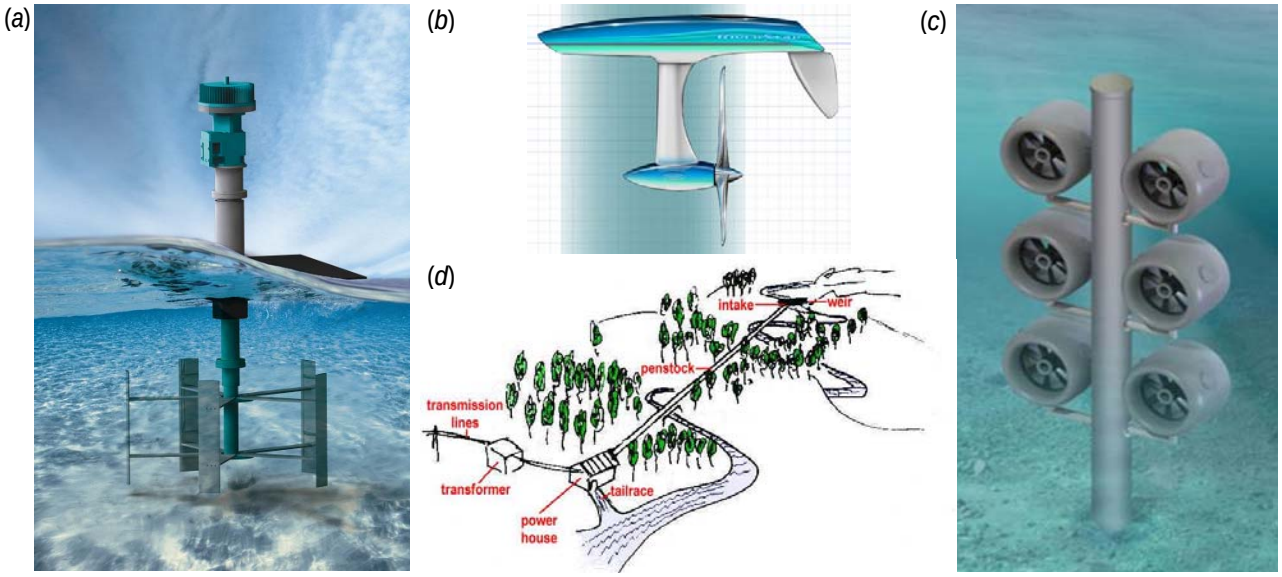

Figure 8. Typical run-of-the-river hydropower technologies are usually either free-flow turbines such as the (a) New Energy Corporation's EnCurrent vertical-axis turbine or (b) Bourne Energy's RiverStarMP 50 which operate in a floating/tethered configuration or (c) Free Flow Power's completely submersible turbine or (d) they require diverting a portion of the river's flow into an engineered system that extracts the energy in a turbine power house and returns the water to the stream.

In a free-flow run-of-the-river power generating system, an immersed turbine (or an interconnected string of turbines) is either secured to the river bed or suspended in the current from an anchored floating platform. This system requires less infrastructure cost than an engineered system and can be expanded as need demands or financing allows, but the turbines also capture the current's energy less efficiently. Most of these systems and prototypes employ low-RPM turbines that are specially designed to be safe for aquaculture.

Run-of-the-river power stations have little or no capacity for potential-energy storage; they depend on the consistent flow of the river past the power generating turbines. Also, because they cannot store the potential energy of the river, they cannot coordinate electricity generation to match consumer demand or be "timed" to complement other intermittent RE power sources.

Ocean Energy

Ocean Wave Power

Wave power devices extract energy directly from surface waves or from pressure fluctuations below the surface. RE analysts believe there is enough energy in the ocean waves to provide up to 2 TW of electricity.

Wave power cannot be harnessed everywhere. Wave-power rich areas of the world include the western coasts of Scotland, northern Canada, southern Africa, Australia, and the northeastern and northwestern coasts of the United States. In the Pacific Northwest alone, it is feasible that wave energy could produce 40–70 kW per meter of western coastline. The U.S. west coast is more than 1,600 kilometers long.

Wave energy can be converted into electricity through both offshore and onshore systems. Offshore systems are situated in deep water, typically of more than 40 m. Sophisticated mechanisms use the bobbing motion of the waves to power a pump that creates electricity. Other offshore

devices use hoses connected to floats that ride the waves. The rise and fall of the float stretches and relaxes the hose, which pressurizes the water, which, in turn, rotates a turbine.

Specially built seagoing vessels also capture the energy of offshore waves. These floating platforms create electricity by funneling waves through internal turbines and then back into the sea.

Built along shorelines, onshore wave power systems extract the energy in breaking waves. Onshore system technologies include

- **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 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.
- **Tapchan.** The tapchan 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.
- **Pendulor Device.** The pendulor 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.

In general, careful site selection is the key of minimizing the environmental impacts of wave power systems. Wave energy system planners can choose sites that preserve scenic shorefronts. They also can avoid areas where wave energy systems can significantly alter flow patterns of sediment on the ocean floor.

Economically, wave power systems have a hard time competing with traditional power sources. However, the costs to produce wave energy are coming down. Some European experts predict that wave power devices will find lucrative niche markets. Once built, they have low operation and maintenance costs because the energy they capture—motion of the seawater—is free.

Ocean Tidal Power

Typically, ocean or tidal power is harnessed in two ways. The most economical way is with turbines immersed in a fast-flowing tidal stream. Alaska has many ideal candidate sites where strong tidal currents flow through geographically restricted channels—between islands, between islands and coastal features, or through undersea canyons or features. Please see the report “Generation of Tidal Energy” for a detailed description of the current state of tidal-stream turbine technologies and their deployment around the world.

The second way to harness tidal energy is with a constructed barrier that briefly impounds the water and then releases the flow through the part of the structure that contains the generating turbines. Effectively a dam, the traditional structure is called a tidal barrage and is comprised of massive gravity-supported caissons emplaced with great care on a specially prepared site. The tidal barrage site geology must support the extreme weight of caissons that are large enough that their own weight enables them to withstand all of the challenges of the elements.

A newer method borrows construction techniques from the offshore oil & gas industry to build a pile-supported dam. Because the components are supported by piles driven into the underlying geology rather than their own massive weight, they can be much smaller, lighter, and less expensive. Please see the report "Hydroelectric Tidal Wing Dams" for a detailed description of this technology and its potential for application.

While tidal energy is intermittent—it is intermittent in a way that is precisely predictable. It could be regulated in tandem with river hydroelectric power sources to provide continuous reliable power (depending consumer load demands relative to potential energy supply, of course).

Biomass Energy

The total solar energy absorbed by Earth's atmosphere, oceans, and land masses is ~3,850,000 exajoules (EJ, an exajoule is one quintillion joules) per year.[9] This is more power in one hour than the world used in all of the year 2002.[10] The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's nonrenewable resources of coal, oil, natural gas, and mined uranium combined.[11] Photosynthesis captures approximately 3,000 EJ per year in biomass.[12] Biomass has been the primary source of energy for most of human history—in addition to being the only source of food.

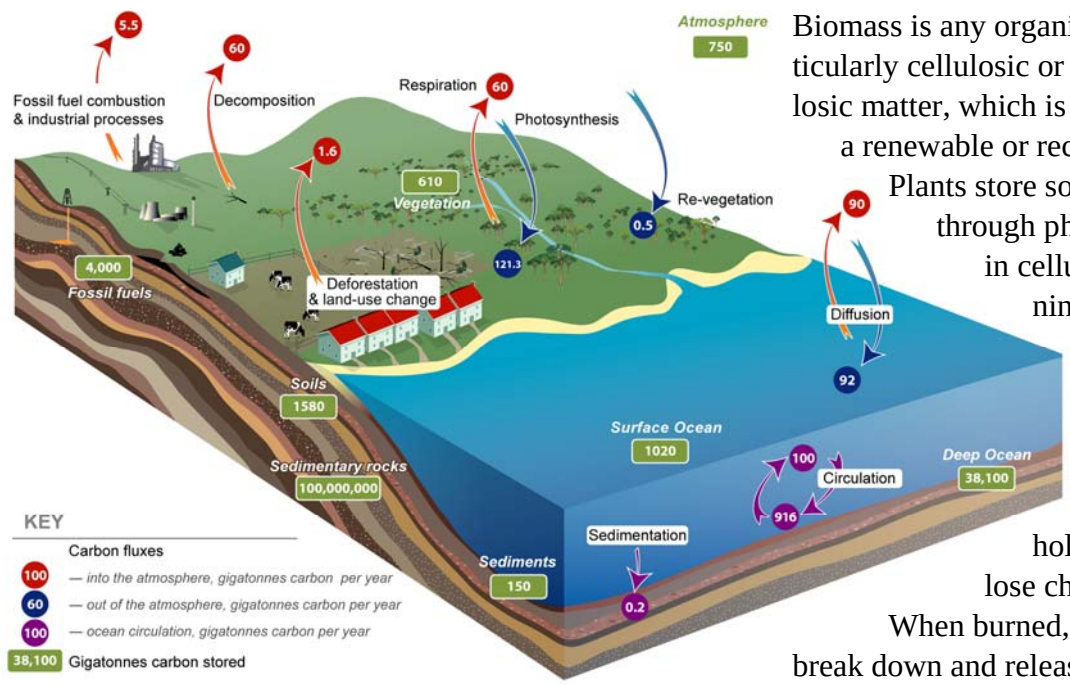

Figure 9. The carbon cycle (source: Cooperative Research Centre for Greenhouse Gas Technologies [Australia/New Zealand]).

Biomass is any organic matter, particularly cellulosic or lignocellulosic matter, which is available on a renewable or recurring basis. Plants store solar energy through photosynthesis in cellulose and lignin cells. Cellulose is a polymer; lignin is the substance, or "glue," that holds the cellulose chain together. When burned, these sugars break down and release energy exothermically, giving off heat, steam, and carbon dioxide.

Carbon dioxide is a naturally occurring gas. Plants collect and convert CO_2 to aid in photosynthesis. As plants or other matter decompose, or natural fires occur, CO_2 is released. Before the discovery and subsequent ever-increasing use of fossil fuels, the CO_2 cycle was approximately constant; roughly the same amount that was released through consumption/combustion was sequestered by new plant growth. This approximate CO_2 release/sequestration balance has since been lost. In the period since the Industrial Revolution, CO_2 levels in the atmosphere have risen from around 150 ppm to 330 ppm, and are expected to double before 2050.

Biomass (wood; crops, e.g., corn, soybeans, or nonfood energy crops) is considered a replenishable resource—it can be replaced without permanently depleting the Earth's natural resources. Some forms of bioenergy rely on waste from consumer, construction, landfill, industrial, or agricultural sources. These forms are considered renewable because they are produced on a continual basis, and using them is an effective way to put these (already produced) wastes to use.

Biomass can be processed to produce energy in the form of electricity transmitted through the grid, heat for direct use, and transportation fuels. Harnessing this energy through the production of advanced biofuels could meet much of the nation's annual transportation energy needs without producing *net* CO_2 emissions that contribute to global climate change.

The biofuels subsidies many Western nations originally supported were founded on the theory that plant-based fuels are carbon neutral, but their equation did not include greenhouse gas (GHG) or other emissions generated from fossil-fuel usage during cultivating, harvesting, or processing the crops into fuel. Nor does it cover the environmental cost of fertilizers and pesticides. The lifecycle energy inputs dictate how much final energy is needed to both satisfy the load and make up for the required energy inputs, while the lifecycle GHG emissions determine the effectiveness of the pathway as a GHG mitigation option. Such factors vary significantly from one biofuel feedstock to another. Increasing evidence shows total emissions and environmental damage from producing many biofuels thought to be "green" often outweigh their lower emissions (when compared with fossil fuels).

Land-use change has transient effects and is more difficult to quantify. Methane emissions from soil bacteria and nitrous oxide emissions from fertilizers change with the crop, but become constant relatively quickly. Changes in soil carbon from cultivating a new crop bring an exchange of carbon with the atmosphere over a period of several years until a new equilibrium is reached.

Once the biomass feedstock is produced, energy inputs and emissions associated with conversion into an energy carrier must also be counted in a consideration of the overall lifecycle from solar energy to energy carrier. These include process heat and any pumping or machinery-assisted mass transfer. The overall efficiency is then calculated by dividing the remaining available energy in the produced energy carrier by the original feedstock's available energy plus the work potential of any energy inputs. Fair comparisons between bioenergy and other conversion pathways can only be performed by considering all lifecycle inputs and emissions.

Governments are responding to these findings. Previously, they sought to encourage biofuel production with blanket incentives and mandates to plant crops and build refineries, as well as tax breaks for the energy (fuel and electricity) producers. Such policies led manufacturers to use the cheapest biomass, rather than biomass that has the fewest harmful effects on the environment. Those policies also produced unintended consequences, like the sale by farmers of food crops for use as biofuel, leading to staple-food price increases.

To address such problems, several countries—including Australia, Britain, France, Germany, The Netherlands, Switzerland, as well as parts of Canada[13]—are revising incentives for farmers, biofuel refiners, and distributors. They are requiring biofuels be certified as "sustainable," on the basis of their emissions reductions and the way the crops are grown, if it is to count toward the annual target of biofuels making up 5.75% of transportation fuel.[13] The manufacturers and sellers

will have to *quantify* their fuel's net effect on the environment before being eligible for subsidies or to count toward national biofuel quotas. Very few types of biofuel feedstock sources—like corn stalks—would qualify *automatically* for financial incentives. Food crops—sugar beets, rapeseed, and soy —will fall into a second category, in which producers will have to *prove* that their final biofuel product is environmentally beneficial, on numerous levels.

The next step for many countries is to factor in the broader environmental and social effects of feedstock cultivation, particularly for feedstocks imported from the developing world. The Netherlands announced that it would no longer subsidize the importation of palm oil, its major source of green electricity generation, after investigators showed that the product was grown on Asian plantations created from drained peat land, with disastrous environmental consequences.[13]

Around the globe, bioenergy is most commonly used for heating purposes; applications range in scale from cooking and home heating to industrial process heating. For example, some homeowners burn biomass fuels in wood stoves, while most pulp and paper mills burn wood wastes in large boilers. At these large facilities, bioenergy is often used for electricity generation as well. To generate electricity using bioenergy, the fuel is burned to produce steam that drives a turbine like those at fossil-fueled and nuclear power plants.

Today's bioenergy technology can be used to generate electricity while decreasing harmful emissions. However, individual bioenergy sources can have widely varying environmental effects. Advanced fuels and technologies are being developed that significantly reduce bioenergy emissions, positioning bioenergy as a key contributor to a sustainable energy future worldwide. Much current research focuses on the efficient conversion into fuels of lignocellulosic biomass, the most abundant organic material on the planet. Lignocellulose is a mixture of complex sugars and lignin, a noncarbohydrate polymer that provides strength and structure to plant cell walls. By extracting simple fermentable sugars from lignocellulose and producing biofuels from them, we can realize the potential of the most energy-efficient and environmentally sustainable fuel crops.[14]

Processing Bioenergy Waste Streams

It must be remembered that biomass energy systems generate waste streams just as conventional fossil energy systems. As with fossil energy systems, the energy to appropriately process the wastes that remain after the energy has been generated from the biomass and that waste's disposal requirements (e.g., landfills) must be taken into account in order to properly measure the success of the RE system with regard to the fossil energy system it replaces.

Japan is a significant example.[15] Its lack of significant domestic energy resources (traditional fossil fuels) in combination with very limited space for landfills has led to their development of an extensive solid-waste-combustion-for-energy industry. Environmental issues related to emissions from the waste-combustion facilities and leaching problems from the generated ash caused the government to investigate and invest in better air-pollution control technologies and methods to stabilize the ash. The Japanese research effort has developed a range of processes including high-temperature gasification (oxygen blown or plasma arc) with ash melting and specific plasma arc systems for melting ash from municipal solid waste combustion facilities.

A Nippon Steel process uses a fixed bed gasifier (not clear if pressurized), with enriched oxygen air injection in the melting section. Coke is added to the municipal solid waste (~50 kg/metric ton

municipal solid waste or 5% by weight) input feed which reacts with the oxygen and pyrolytic gases at the air injection and melting region. This is apparently done to help provide energy for full ash melting. Limestone is also added (~5% by weight of input) to provide some pH buffering of the melt. The producer gas is burned in conventional steam boilers from which heat and power are generated. Output materials include granulated slag (90 kg/metric ton input), recyclable iron (10 kg/metric ton input) and fly ash (~30 kg/metric ton input) which is sent to landfill. Mercury and heavy metals present in the waste are found in the fly ash and producer gas—requiring that these streams be managed appropriately before discharge.

As new bioenergy feedstocks and fuels are researched, developed, and demonstrated, system developers must ensure that the total system feedstocks, energy inputs, usable produced energy, and waste streams and waste processing requirements compare favorably with current methods.

Bioenergy Research in the U.S.

In June of 2007, the U.S. DOE chartered and funded ($375M) three bioenergy research centers:

- DOE BioEnergy Science Center led by Oak Ridge National Laboratory,
- Great Lakes BioEnergy Research Center led by the University of Wisconsin–Madison, and
- Joint BioEnergy Institute led by LBNL

to accelerate development of biofuels generated from plants and microbes. The nation must create the right mix of technologies, processes, and expertise to enable environmentally friendly biofuels production—a mission far beyond the scope of any single organization.

Multidisciplinary teams of top scientists from 18 of the nation's leading universities, 7 DOE national laboratories, at least 1 nonprofit organization, and a range of private companies support the three centers. The centers are located in geographically distinct areas and will use different plants both for laboratory research and for improving feedstock crops.

A major focus is on understanding how to re-engineer biological processes to develop new, more efficient methods for converting the cellulose in plant material into ethanol or other biofuels that serve as a substitute for gasoline. This research is critical because future biofuels production will require the use of feedstocks more diverse than corn, including cellulosic material such as agricultural residues, grasses, poplar trees, inedible plants, and nonedible crop portions.

The mission of the centers lies at the frontier between basic and applied science and maintains a focus on bioenergy applications. These centers aim to identify real steps toward practical solutions regarding the challenge of producing renewable, carbon-neutral energy. At the same time, the centers are grounded in basic research, pursuing alternative avenues and a range of high-risk, high-return approaches to finding solutions. To some degree, one key to the centers' success will be their ability to develop the more basic dimensions of their research to a point that can easily transition to applied research.

The centers address inherently interdisciplinary scientific problems requiring scientific expertise and technical capabilities spanning the physical and biological sciences, including genomics, microbial and plant biology, analytical chemistry, computational biology and bioinformatics, and engineering.

The DOE bioenergy research centers are by no means the only avenue for this research in the U.S. Many universities host their own research programs and initiatives. For example, the Uni-

versity of California–Davis has the Bioenergy Research Group, the University of Illinois has the Center for Advanced BioEnergy Research, and the University of Mississippi has the BioEnergy Research Laboratory.

In February 2007, global energy firm BP selected the University of California–Berkeley, in partnership with LBNL and the University of Illinois–Urbana-Champaign, to lead a $500M research effort to develop new sources of energy and reduce the impact of energy consumption on the environment. The funding created the Energy Biosciences Institute, which initially will focus its research on biotechnology to produce biofuels—turning plants and plant materials, including corn, field waste, switchgrass, and algae into transportation fuels.

Below is a short list of other bioenergy initiatives underway in the public and private sectors within the U.S.

- The *American Bioenergy Association* represents ethanol fuel producers, biomass power producers, chemical companies, utilities, farmers, equipment manufacturers, environmental groups, the forest products industry as well as nontraditional allies and partners who support the goals of promoting the economic and environmental benefits of biomass utilization.
- The U.S. Department of Agriculture's *Agricultural Research Service* maintains biofuels research programs for ethanol and biodiesel.
- NREL maintains technical information on biofuels conversion research conducted under DOE supervision from 1980 to the present in its *Biofuels Information Center*.
- The *Biomass Research and Development Initiative* is the multiagency effort to coordinate and accelerate all federal bio-based products and bioenergy R&D.
- The *Northeast Regional Biomass Program* (NRBP) evaluates biomass technologies and fuels and to provide objective, reliable information to consumers and policy leaders. The NRBP carries out its mission through an extensive network of local, state, and national government organizations, and partnerships with private industry.
- The DOE began the *Biomass Power Program* in 1991 to expand the use of RE from biomass.
- The *National Biodiesel Board* (NBB) established itself as the creator of the biodiesel market in the U.S. It is an integral part of the overall exchange of information for the biodiesel commercialization effort, which includes all feedstock providers, government agencies, customers, engine manufacturers, fuel providers, and other interested parties. NBB developed minimum quality standards and a system to register fuel suppliers assuring a high quality fuel supply and consumer confidence.
- The *Renewable Fuels Association* (RFA) is a national trade organization for the U.S. fuel ethanol industry. RFA has been working on behalf of the industry since 1981 to secure a strong marketplace for ethanol. As the "voice of the ethanol industry," the RFA is dedicated to the continued vitality and growth of ethanol in the fuel marketplace.

Internationally, the IEA (International Energy Agency) hosts *IEA Bioenergy* to improve cooperation and information exchange between countries that have national programs in bioenergy research, development, and deployment.

Solar Energy

Solar technology research primarily focuses on improving the percent efficiency of the solar collectors. Photovoltaic devices collect energy from roughly ⅓ of the visible-light spectrum. Different substrates collect the energy from different thirds. The most expensive photovoltaics (e.g., the ones on spacecraft and the Mars rovers—called multi-junction photovoltaics) use a combination of these substrates to capture energy from most of the spectrum. This technology is much more efficient, but are far from cost effective for consumer applications. NREL is working to develop substrates that can achieve the effects of multi-junction cells at economical costs.

Also, the BOS (balance of systems) accounts for as much as 50% of the cost of PV systems. Sandia is and has a long standing R&D effort in developing advanced inverters and integrated module designs. A solar-energy information exchange Web site[†] lists most of the leading solar research institutions world wide.

Table 2. Solar Energy Research Institutions and Their Areas of Research

Name, Location, Type of Institution	Research/Product Type
Florida Solar Energy Center Cocoa, Florida, USA (trade association, research institution)	Energy-efficient homes and buildings, solar water-heating systems, photovoltaic systems, and solar water-pumping systems
Institute of Energy Conversion University of Delaware, Newark, Delaware, USA (nonprofit organization, research organization)	Thin-film solar photovoltaic (PV) cells
National Renewable Energy Laboratory Golden, Colorado, USA (government research laboratory)	RE research, new technologies, and information
Sandia National Laboratories Photovoltaic Program Albuquerque, USA (nonprofit organization, government organization, research organization)	PV cells and PV modules/panels, concentrating solar (PV and thermal), inverters/controllers–balance-of-system components, component testing and evaluation
Renewable and Appropriate Energy Laboratory University of California, Berkeley, Berkeley, California, USA (research institution)	Solar and RE R&D
Schatz Energy Research Center Humboldt State University, Arcata, California, USA (nonprofit organization, research institution)	Fuel-cell test stands, fuel cells, solar-hydrogen power systems, and RE consulting services and feasibility studies
Institut für Solartechnik SPF (Solar Energy Lab) Rapperswil, Switzerland (research & testing laboratory)	Solar-thermal energy materials, components, collectors, and systems software
Institut für Thermodynamik und Wärmetechnik Stuttgart, Germany (research institution)	Solar-thermal energy systems
Institut für Solarenergieforschung GmbH Emmerthal, Germany (research institution)	PV cells and solar-thermal energy systems
Fraunhofer Institute for Solar Energy Systems Freiburg, Germany (research institution)	PV modules, PV systems, and solar-electric power systems
Ekomation Solar Energy Consultancy Rotterdam, Netherlands (independent consultancy, research, business intelligence, service)	PV systems, solar water-heating systems, PV modules, solar outdoor-lighting systems, and policy studies
Netherlands Energy Research Foundation Petten, The Netherlands (nonprofit organization, research institution)	Solar energy and wind energy
Centre for Energy Studies Dhaka, Bangladesh (research institution)	Research on RE systems and organizing training programs and seminars on energy-related issues

[†] http://energy.sourceguides.com/businesses/byP/solar/byB/research/research.shtml

Table 2. Solar Energy Research Institutions and Their Areas of Research

Name, Location, Type of Institution	Research/Product Type
Nimbkar Agricultural Research Institute Maharashtra, India (nonprofit organization, research institution)	Electric bicycles, wood stoves & furnaces, solar water-heating systems, energy-efficient lighting, biomass energy systems, and alternative fuel vehicles
Botswana Technology Centre Gaborone, Botswana (manufacturer)	PV fluorescent lights, solar lamps, PV street lighting, PV controllers, compressed soil blocks (using Kgalagadi Sand), PV testing services, solar hearing aid, and passive solar architectural designs
Centro de Investigación en Energía Morelos, Mexico (research institution, government organization)	PV systems designs for rural applications, solar water heating, low-temperature systems designs for domestic and industrial applications, solar drying systems for agriculture products, water treatment with high-temp. solar heating systems, thin films, & solar control coatings
New Energy and Industrial Technology Development Organization Tokyo, Japan (nonprofit organization, research institution, government organization)	PV, solar-thermal, wind, and other new energy technologies

What are Alaska's Existing Renewable-Energy Assets?

Incentives

Alaska residents and businesses can choose from a wide variety of federal- and state-sponsored incentives to take advantage of RE and energy-conservation technologies.

Table 3. State and Federal RE Investment Incentives for Alaska

	State of Alaska	Federal
Individual/Household Incentives	• Energy Efficiency Interest Rate Reduction Program • Golden Valley Electric Association (GVEA)—Builder $ense • GVEA—Sustainable Natural Alternative Power (SNAP) Program • Home Energy Rebate Program • Second Mortgage Program for Energy Conservation • Small Building Material Loan	• Residential energy-conservation subsidy • Residential energy-efficiency tax credit • Residential solar and fuel cell tax credit • U.S. DOE alternative fuels data center • Tribal energy program grant • USDA rural energy for America program (grants) • USDA rural energy for America program (loan guarantees) • Federal clean renewable energy bonds • Energy-efficient mortgages
Corporate/Municipal Incentives	• Renewable Energy Grant Recom-mendation Program • [Homeowners'] Association Loan Program • GVEA—Business $ense • Power Project Loan Fund	• Business energy tax credit • Energy-efficient new homes tax credit for home builders • Renewable electricity production tax credit • Energy-efficient commercial buildings tax deduction • Modified accelerated cost-recovery system + bonus deprecia-tion • Residential energy-conservation subsidy exclusion (corporate exemption)
Production Incentives	• GVEA—SNAP Program	• Renewable energy production incentive

Alaska Energy Authority Activities

Currently, AEA's Alternative Energy and Energy Efficiency (AEEE) program manages and funds 33 projects and initiatives totaling $31.5 million in state and federal funding. These projects seek to lower the cost of power and heat to Alaskan communities while maintaining system safety and reliability. AEA's AEEE programs promote

- use of RE resources and local sources of coal and natural gas alternatives to diesel-based power, heat, and fuel production and
- measures to improve efficiency of energy production and end use.

AEA publishes the biennial "Alternative Energy and Energy Efficiency Assistance Plan." This plan describes

- available funding and funding that AEA plans to request for alternative energy and energy efficiency assistance,
- types of assistance that AEA provides and plans to provide, and
- criteria for allocating funds.

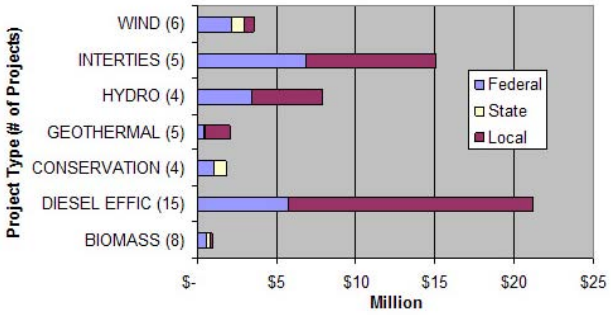

Figure 10. AEA AEEE projects listed by program.

AEA investments fund projects and initiatives in the following areas: biomass energy, diesel efficiency, end-use efficiency (conservation), geothermal energy, hydroelectric power, ocean and river energy, solar power, transmission and distribution (inter-ties), and wind energy.

Commercial/Nongovernmental Renewable Energy Activities in Alaska

Cold Climate Housing Research Center

The Cold Climate Housing Research Center (CCHRC)[†] is an industry-based, nonprofit corporation created to facilitate the development, use, and testing of energy-efficient, durable, healthy, and cost-effective building technologies for Alaska and the world's cold-climate regions. Ninety percent of CCHRC's charter members are general contractors from across the state. The Alaska professional building community is highly regarded as a national leader in energy-efficient housing design and construction, boasting the largest per capita builders' association in the nation.

The CCHRC research and testing facility is located on the campus of America's Arctic University at UAF (University of Alaska–Fairbanks). CCHRC and UAF share space and resources to advance the understanding and application of cold-climate housing principles—providing space to work more closely with students, faculty, and researchers at the university.

With its new facility, the CCHRC will enter into key research, product testing, and technology-transfer relationships with UAF and building scientists, building industry partners, and home building associations across the state and the nation. The facility provides space for CCHRC and its partners to carry out core research and product testing. It also provides classroom, library, meeting, and demonstration space to support technology-transfer agreements. CCHRC's Web

[†] http://www.cchrc.org/

site maintains detailed, extensive information on the results of their research into building envelopes, energy systems, foundations and their "green roof."

In October 2007, the Cold Climate Housing Research Center and UAF hosted the first of a series of international conferences on circumpolar housing and community infrastructure issues. This forum presented an opportunity for an international group of builders, architects, building scientists, and planners to discuss common challenges and exchange solutions for producing sustainable, appropriate, durable buildings, and infrastructure in the circumpolar north. The CCHRC plans to continue identifying pressing research needs in the field of northern building and infrastructure design and technology, as well as develop ongoing circumpolar partnerships.

Alaska Wood Energy Development Task Group

The Alaska Wood Energy Development Task Group is a coalition that is exploring opportunities to increase the use of wood for energy in Alaska. Since 2005, the task group has solicited statements of interest for thermal wood heat projects in Alaska. From 2005 to present, the task group has received and reviewed 79 statements of interest, selected 42 projects for further study, completed 34 site inspections and field reports, and completed 21 feasibility assessments. Two projects are in the design stage, and 3 projects are installed and operational.

The USDA Forest Service and AEA have been the lead agencies, providing expertise and the bulk of the funding. Juneau Economic Development Council provides the primary "point of contact," resource information, technical assistance, site reconnaissance, and pre-feasibility assessments. The Alaska Wood Energy Development Task Group is made up of the following partners:

- Alaska Energy Authority
- Alaska Village Initiatives
- Bureau of Indian Affairs
- Bureau of Land Management
- Denali Commission
- Division of Forestry, State of Alaska DNR
- Juneau Economic Development Council
- USDA Farm Service Agency
- USDA Rural Development
- National Renewable Energy Laboratory, DOE
- Pacific Northwest Research Station, USDA Forest Service
- State and Private Forestry, USDA Forest Service
- USDA Natural Resources Conservation Service
- University of Alaska–Fairbanks Cooperative Extension Service

Sustainable Energy Commission of the Alaska Peninsula

The Sustainable Energy Commission of the Alaska Peninsula (SECAP) is another group that has recently formed. SECAP has installed two grid-tied 10 kW Bergey wind systems at Port Heiden and Pilot Point.

Pacific Regional Biomass Energy Partnership

The Pacific Regional Biomass Energy Partnership is one of five regional programs supported by state energy offices or governors associations/regional energy boards/councils and the U.S. DOE. It encourages the development of bioenergy in the states of Alaska, Hawaii, Idaho, Montana, Oregon, and Washington. The DOE Western Regional Office manages the partnership and coordinates with the federal Biomass Program.

The partnership's major purpose is to encourage the deployment of biomass energy technologies. For example, the partnership has worked to develop biodiesel and ethanol production throughout the region. The partnership also has supported biopower development through the testing and demonstration of the anoxic gas flotation process for dairies that use a flush system to handle manure. In addition, the partnership produces and distributes reliable information on potential biomass energy technologies.

The mission of the partnership is to encourage the use and development of biomass energy technologies that are technically feasible and cost effective. They work to provide technology transfer, remove barriers to biomass energy production, and promote its benefits. They provide information and technical assistance to improve the regional environment and economies. The DOE Western Regional Office and each state bring strengths and expertise to the partnership. In addition, the partnership has developed a network of other experts. The range of expertise includes: biodiesel, ethanol, anaerobic digestion and biopower, bioproducts, resource assessments, and policy and siting.

Renewable Energy Alaska Project

The Renewable Energy Alaska Project (REAP)[†] is a coalition of small and large electric utilities and utility interests, environmental groups, consumer groups, businesses, and Alaska Native interests with the goal of increasing RE production in Alaska. REAP's mission is "to facilitate the increased development of RE in Alaska through collaboration, education and training, and advocacy." A nonprofit organization, REAP hosted their *4th Annual Renewable Energy Fair* at the Memorial Block at Delaney Park in August 2008. Their Web site promises to offer a complete list of Alaska RE manufacturing, design, and sales firms in the future. Below is a list of commercial firms we were able to assemble during our research on Alaska which exemplifies some of Alaska's RE expertise.

Table 4. Alaskan Commercial Firms Who Manufacture/Design RE Systems

Name, Location, Type of Company	Research/Product Type
Manufacturing	
Durotest Lighting, Anchorage Manufacturer, distributor	Energy efficient lighting, light bulbs & tubes
Polar Wire Products, Inc., Anchorage Manufacturer, retail sales, wholesale supplier	Backup power systems, flooded lead acid batteries, battery cables, DC-to-AC power inverters, hybrid power systems, photovoltaic systems
Design	
ABS Alaskan, Inc., Fairbanks Design, project development services, retail sales, wholesale supplier, installation, maintenance and repair services, recycling services	Wind energy systems (small), DC lighting, RE system batteries, photovoltaic systems, lead-acid batteries, DC-to-AC power inverters, remote power systems, AC-to-DC power converters, hybrid energy systems, battery charge controllers
Arctic Technical Services, Fairbanks System design and retail sales	Photovoltaic systems, air heating systems, air filtering and purification systems, flooded lead-acid batteries, battery connectors, solar tracking systems, efficient oil boilers and heaters, Toyotoves, Quadra-Fire woodstoves, Excell chimney & components, Kyocera solar panels, frames and components, Outback and Trace inverters and controllers, misc. solar components

[†] http://www.alaskarenewableenergy.org/

Table 4. Alaskan Commercial Firms Who Manufacture/Design RE Systems

Name, Location, Type of Company	Research/Product Type
***Design** (cont'd)*	
Remote Power Inc., Fairbanks System design and service, retail sales, installation, troubleshooting, and repair of off-grid power systems	Outback PS2 power systems; Outback, Trace, Xantrex, and Exel-ech inverters; photovoltaic modules; wind turbines; propane refrigerators; DC appliances; Staber washing machines; Concorde batteries; Ecofans; meters; and MPPT controllers
Renewable Energy Systems, Anchorage Consulting, design, engineering, project devel-opment services, site survey and assessment services, retail sales, contractor services, con-struction, installation, maintenance, and repair services	DC-to-AC power inverters, wind turbines (small), deep cycle batteries, wind energy systems (small), and solar energy systems
Solar-Alaska, Fairbanks System design, wholesale supplier, retail sales, installation, and service	Photovoltaic and hybrid power systems
Susitna Energy Systems, Anchorage Consulting, design, retail sales, and installation	Photovoltaic modules, wind generators, hydro generators, energy efficiency oil & propane heaters, high-efficiency appliances, TOYO oil heaters, on demand water heaters, satellite telephones, and cell phone boosters
The Mobile Homestead, Sitka Retail sales	Photovoltaic systems, energy-efficient appliances, battery compo-nents, hydro energy system components (small), composting sys-tems, solar water heating systems

What Can Sandia Do to Help?

Because Sandia has ongoing R&D in renewable-, fossil-, and nuclear-energy systems as well as grid integration, we provide a unique capability to perform systems analysis, design, and engi-neering in the transition of the electric power and transportation infrastructures heavily dependent upon fossil energy sources to a dependence upon more sustainable energy resources. Sandia could contribute to Alaska's developing its RE utilization by applying Sandia's recognized excel-lence in systems analysis and engineering to evaluating your RE potential. This could be applied on both the domestic and community power-generation scales.

Sandia has an memorandum of understanding (MOU) with AEA. We can support their $100M request for proposals for RE integration through the UAF. Sandia is working on an MOU and CRADA with the UAF Institute of Northern Engineering (INE) to help them develop capabilities to support AEA and the utilities, companies, and others in the energy areas. We are picking a first site, likely to be Kodiak, with INE to begin developing capabilities. Sandia is working with the UAF International Arctic Research Center on climate change modeling and monitoring in con-junction with our atmospheric radiation monitoring site in Barrow.

Sandia can increase its partnership with industry, academic, and government resources within Alaska to help them meet the needs of their industry/utilities as they change their energy/tran-sportation infrastructures to meet the needs of the state's electricity-consuming customers.

Geothermal Energy

Sandia's focuses its geothermal systems work on expanding the nation's use of geothermal power. The Geothermal Research Department develops technology aimed at reducing the cost of geothermal energy. The majority of our work focuses on improving key elements of well construction technology: hard-rock drill bits, high-temperature electronics, real-time drilling diagnostics, methods for detecting and controlling lost circulation, and geothermal systems analysis. We work closely with both the geothermal and oil & gas industries and participate in a variety of other drilling-related projects.

Drill Bits

Our most significant contribution has been our research into the development of the polycrystalline diamond compact (PDC) drill bit. Sandia researchers conducted the finite-element modeling analyses, diamond bonding research, cutter testing, bit design/analysis, and laboratory and field testing under CRADAs with industry partners. Sandia catalyzed the development of PDC bits in the drilling industry. They now drill over 60% of borehole footage world wide—a $1.5B industry where the bits also save the industry billions annually because of the extended life of the bits themselves.

Telemetry, Electronics, and Diagnostics

One of the most difficult elements of drilling is knowing what is happening at the point where the bit is cutting the borehole—hundreds or thousands of feet below the surface. To stabilize the drill string (the pipe that drives the bit), mud is pumped into the hole. For some time, the industry has used pulses in that mud to act as a conduit for data—at a rate of 2–5 bits per second. Sandia's geothermal programs dealt with the basic physics issues of wave propagation through the drill pipe and the engineering and applications codes to develop an acoustic telemetry system that has increased the data transmission rate ten-fold (20–50 bits/s).

By definition, geothermal drilling is a high-temperature endeavor—problematic for downhole electronics needed for drilling, logging, and monitoring of geothermal wells. Sandia has become the *de facto* "UL Labs" for testing high-temperature electronic components as well complete downhole tools, seals, batteries, fiber optics, and sensors. Our geothermal scientists work with all major manufacturers to analyze component and equipment failures and provide solutions. We have developed new tools and fabrication methods based on Sandia's capabilities from the weapons programs and supplied prototypes to industry for manufacture. We recently began a joint industry partnership to develop standards and test high-temperature batteries that the oil & gas and geothermal industries need.

Understanding the environment at the bit during the drilling process is important to increasing the rate that holes can be drilled as well increasing the reliability of drilling systems. Sandia developed a diagnostics-while-drilling (DWD) system to understand this drilling process. The DWD system provides the driller and engineers real-time data of the downhole environment and is capable of operating at geothermal temperatures.

Drilling Dynamics Systems Modeling

Dynamic dysfunctions during drilling are among the leading causes of nonproductive time on a drilling site. The drill bit, drill string, and the local geology interact in a complex way that can

induce a variety of vibration-related problems—resulting in a low rate of penetration and/or bit and tool failure. If the bit fails, the drill string must be “tripped” to replace it—a process that can exceed a million dollars in some situations.

With a combination of unique software and hardware Sandia has developed a drilling dynamics simulator to evaluate arbitrarily long drill strings in a laboratory environment. Once validated, our drilling dynamics simulator will

- identify deficiencies in drill-bit designs and help manufacturers improve bit and tool performance before a company is committed to expensive field drilling,
- improve the industry’s capability for predicting vibrations,
- validate development of hardware and software for downhole tools that combat vibration, and
- develop best practices for mitigating vibration.

Controlling Lost Circulation

During a drilling operation, a drilling fluid is circulated through the drill string and up the borehole to stabilize the borehole, clean cuttings from the hole, and cool and lubricate the bit. As the borehole is extended, it breaches a wide variety of geological formations that exhibit varying degrees of permeability and may contain fractures, faults, or voids. The drilling fluid can be lost from the borehole into the surrounding rock formations. This loss of drilling fluid increases the expense of the drilling operations as the lost fluid volume must be replaced and can cause drilling problems ranging from borehole instabilities to the drill string sticking in the borehole. Sandia has worked on technologies to reduce problems of lost circulation—solutions ranging from the development and testing of high-temperature polymers in borehole grouts to drillable packers (mechanical seals).

Water Systems Research

As water moves through a geothermal system, it has a tendency to coat the inner surfaces of pipes, tanks, and boreholes with a scaly residue. Eventually these system components will become occluded and must be replaced—an expensive process for the above-ground components. The boreholes could only be replaced by drilling new ones. Sandia’s water systems researchers are developing a high-capacity, nanometer-scale filtration membrane to reduce the system water’s total dissolved solids and remove scale-forming constituents. This new membrane will also facilitate the use of nonpotable, brackish aquifers for the system water for power generation plants—easing the increasing strain on limited potable water sources.

Wind Energy

Materials and Manufacturing

Wind-turbine blades constitute a significant portion of the cost of a modern, utility-scale, wind turbine. These blades are comprised of relatively low-cost composite materials and current manufacturing processes are very labor-intensive. To facilitate incorporating larger blade designs into new turbines, Sandia studies composite materials and manufacturing processes targeted at developing innovations that will help reduce the nonlinear growth in blade weight. The objective of this effort is to provide innovations in materials, manufacturing processes, and embedded sensor technologies. Sandia scientists are also working with DOE Wind Program, TPI Composites, and

the State of Iowa to build a new, highly automated wind-turbine-blade manufacturing facility (GE blades). It may be possible to do something similar in Alaska.

Innovative Concepts

As wind turbines become larger and heavier, blades that incorporate small load-control devices (similar to but smaller than flaps on an airplane wing) and embedded sensors to alleviate fatigue loads offer the potential for significant weight savings. Efforts are focused in three primary areas: (1) analysis of the aerodynamic performance, (2) development of advanced controls, and (3) calculation of the maximum potential cost of energy reductions that can be reasonably achieved through reductions in fatigue loading. These are leading edge sources of R&D for university programs and advanced technology development companies.

Aerodynamic Tools and Aeroacoustics

Sandia continues to develop and utilize computational fluid dynamics codes to improve our understanding of the highly 3-D flow fields under which wind turbine rotors operate. By leveraging the high-performance computing capability of Sandia, these tools provide the necessary information needed to develop the next generation of wind turbine blades that maximize both structural and aerodynamic efficiency. Additionally, Sandia will continue to develop aeroacoustics emission and propagation prediction codes that provide the capability to estimate the noise characteristics of wind turbine rotors. As part of that effort, the aerodynamic performance and acoustic emissions of a rotor with blunt trailing edge airfoils will be compared to those of a similar rotor with conventional airfoils and the effects of various blunt trailing edge treatments on these characteristics will be investigated. This comparison effort is supported by wind tunnel tests to compare the measured noise generation and propagation of a traditional sharp trailing edge airfoil and a structurally efficient flatback airfoil.

Design Tools and System Modeling

Sandia will continue its efforts to develop computational tools to significantly improve the structural and aeroelastic analysis capability available to the wind industry. These analytical capabilities may be used to guide the design of new blades as well as to verify/improve the design of existing blades. The validity of the tools will be demonstrated by continuing a comprehensive design, analysis, build, test, and validation program. A major focus is on better integration of the structural analysis and aeroelastic codes. We hope to reduce design time and produce better and more efficient designs for future wind-turbine hardware.

System Performance and Blade Testing

Full-scale testing of prototype wind turbine blades is vital to asses the structural and aerodynamic performance of advanced concepts. Recently, Sandia has developed three advanced blade designs which are in the process of being evaluated by a series of structural and aerodynamic tests. Sandia will continue to conduct both laboratory and field testing of advanced blades in the future, and provide the necessary results to industry to ensure the viability of the unique features of the designs. Additionally, results from the blade testing provide the critical information needed to validate and improve our design codes.

Biomass/Biofuels

Sandia performs extensive R&D in biofuels. We participate in JBEI and have over a dozen research efforts, funded by LDRD and other sources including significant DARPA funding, to develop fuel-source alternatives to corn and other commercially valuable crops.

In the San Francisco Bay Area, LBNL, Sandia , and Lawrence Livermore National Laboratory; major public and private universities; industry; and federal agencies joined together to create JBEI, the Joint BioEnergy Institute, whose mission is to develop basic science and technology to create environmentally friendly biofuels using plant biomass and microbes. JBEI is centrally situated among JBEI's six institutional partners. It is organized along the lines of a biotech company whose goal is to achieve significant scientific progress within the next five years. JBEI will focus its effort in three key areas: feedstock production, deconstruction, and fuels synthesis. JBEI will apply crosscutting technologies in computational tools, systems and synthetic biology tools, and advanced imaging in a multipronged approach for biomass-to-biofuel solutions in addition to discovery-driven benefits for biohydrogen research, solar-to-fuel initiatives, and broader DOE programs.

Sandia is open to opportunities to form new joint R&D opportunities to expand the research base that is addressing biomass/biofuels technical issues.

Solar Energy

Sandia has decades of research experience in solar energy which is split between photovoltaics (highly useful in Alaska) and solar concentrators (not commercially viable at Alaska's lattitude). We have long been a leader in photovoltaic research. Our Photovoltaic Laboratories work with the photovoltaic industry and energy users to accelerate the commercial use of photovoltaic energy systems and aid in understanding and improving the performance of those systems.

Our Photovoltaic Systems Evaluation Laboratory (PSEL) provides expertise and test support within several facilities and outdoor sites for evaluating PV and other distributed energy hardware. It includes the following capabilities:

- PV systems evaluations and optimization;
- field testing of arrays and systems in collaboration with system integrators;
- performance testing for modules, arrays, power inverters, charge controllers, and batteries;
- diagnosis of module reliability issues with manufacturing consultation;
- complete performance characterization of PV cells and photo sensors;
- calibration of PV reference cells, reference modules, and solar instruments;
- performance measurements on multiple, interacting distributed energy sources; and
- on-site education and training on the attributes and limitations of photovoltaic and other distributed energy systems.

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