U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE & TECHNOLOGY
SUBCOMMITTEE ON ENERGY & ENVIRONMENT

HEARING CHARTER

The Advanced Geothermal Energy Research and Development Act of 2007, (H.R. 2304)
- and -
The Marine Renewable Energy Research and Development Act of 2007, (H.R. 2313)

Thursday, May 17, 2007
10:00 AM
2325 Rayburn House Office Building

Purpose

On Thursday, May 17, at 10:00 AM, the Energy & Environment Subcommittee of the House Committee on Science & Technology will hold a legislative hearing on two renewable energy bills.

H.R. 2304, introduced by Mr. McNerney of California, directs the Secretary of Energy to support research, development, demonstration, and commercial application of advanced technologies to locate and characterize geothermal resources and produce geothermal energy. The bill is co-sponsored by Mr. Gordon of Tennessee and Mr. Lampson of Texas.

H.R. 2313, introduced by Ms. Hooley of Oregon, directs the Secretary of Energy to support research, development, demonstration, and commercial application of technologies to produce electric power from renewable marine resources, including: waves, tidal flows, ocean currents, and thermal gradients.

Witnesses

- **Dr. Jefferson Tester** is the HP Meissner Professor of Chemical Engineering at the Massachusetts Institute of Technology. Dr. Tester is an internationally recognized expert in Enhanced Geothermal Systems and he served as chair of the MIT-led panel that produced the report: *The Future of Geothermal Energy*, released in January, 2007.

- **Mr. Paul Thomsen** is Public Policy Manager for Ormat Technologies, Inc., a leading provider of geothermal exploration, development, and power conversion technologies. Mr. Thomsen is responsible for Ormat's federal, state and local legislative programs. He is testifying today on behalf of both Ormat and the Geothermal Energy Association.

- **Dr. Annette von Jouannne** is a Professor in the School of Electrical Engineering and Computer Science at Oregon State University in Corvallis, Oregon. She specializes in Energy Systems, including power electronics and power systems, and she leads the Wave Energy program at OSU.

Witnesses (cont.)

- **Mr. Sean O'Neill** is President of the Ocean Renewable Energy Coalition (OREC), a trade association representing the marine renewable energy industry.

- **Mr. Nathanael Greene** is a Sr. Energy Policy Specialist with the Natural Resources Defense Council. His areas of expertise include utility regulation, renewable energy, energy taxes and energy efficiency.

Overarching Questions

The hearing will address the following overarching questions:

Geothermal

1. What is the current state of development of geothermal energy technologies? Are they mature? If not, what major research, development, and demonstration work remains to be done to increase their commercial viability?
2. What new opportunities might be created by the development of Enhanced Geothermal Systems?
3. What are the largest obstacles to the widespread commercial development of geothermal energy? How can these hurdles be addressed?
4. What is the appropriate role for the federal government in supporting RD&D in marine renewable energy technologies?
5. Are there environmental concerns associated with geothermal energy development? What are they? Can they be mitigated?
6. Does the bill under consideration – *The Advanced Geothermal Energy Research and Development Act of 2007* – address the most significant RD&D barriers to the widespread development of geothermal energy? How can the bill be improved?

Ocean Power

7. What is the state of development of marine power technologies? Are they mature? Does this assessment vary by resource (i.e. waves vs. tidal vs. currents vs. thermal)? If these technologies are not mature, what major research, development, and demonstration work remains to be done to make marine renewable energy technologies commercially viable?
8. What are the largest obstacles to the widespread commercial development of marine renewable energy? How can these hurdles be addressed?
9. What is the appropriate role for the federal government in supporting RD&D in marine renewable energy technologies?
10. Are there environmental concerns associated with marine renewable energy development? What are they? Can they be mitigated?
11. Does the bill under consideration – *The Marine Renewable Energy Research and Development Act of 2007* – address the most significant RD&D barriers to the widespread development of marine power technologies?

Overview of Geothermal Energy

Hydrothermal Systems

Geothermal energy is heat from the Earth's core that is trapped in the earth's crust. In locations where high temperatures coincide with naturally-occurring, underground, fluid-filled reservoirs, the resulting hot water or steam can be tapped and used either to generate electricity or for *direct use* (e.g. heating buildings, greenhouses, or aquaculture operations). Such locations are referred to as *hydrothermal* (hot water) resources, and they have been the focus of traditional geothermal energy development.

By tapping hydrothermal resources, the United States has become the world's largest producer of electric power from geothermal energy. About 2,800 megawatts (MW) of geothermal electrical generating capacity is connected to the grid in the United States; 8,000 MW of geothermal generating capacity is installed worldwide. Geothermal energy is currently the third largest source of renewably-generated grid power in the United States, behind hydropower and biomass. In 2003, it accounted for 7 percent of US electricity generated from renewable sources. The largest geothermal development in the world is at *The Geysers* in Northern California. This series of plants, which started to come online in 1960, has a cumulative capacity of over 850 MW and satisfies nearly 70 percent of the average electrical demand for the California North Coast region.

Although the United States is the world leader in hydrothermal development, significant potential remains untapped. The US Geological Survey (USGS) has estimated there to be 22,000 MW of hydrothermal resources sufficient for electrical power generation in the United States. However, many of these resources remain hidden and unconfirmed. H.R. 2304 contains provisions to support research and development of advanced technologies to assist in locating and characterizing hidden hydrothermal resources, and to encourage demonstration of advanced exploration technologies by the geothermal industry.

Enhanced (or Engineered) Geothermal Systems (EGS)

Enhanced Geothermal Systems (EGS) differ from hydrothermal systems in that they lack either a natural reservoir (i.e. the cracks and spaces in the rock through which fluid can circulate), the fluid to circulate through the reservoir, or both. In EGS development, sometimes referred to as "heat mining", an injection well is drilled to a depth where temperatures are sufficiently high; if necessary, a reservoir is created, or "cracked", in the rock by using one of various methods of applying pressure; and a fluid is introduced to circulate through the reservoir and absorb the heat. The fluid is extracted through a production well, the heat is extracted to run a geothermal power plant or for some direct use application, and the fluid is reinjected to start the loop all over again.

Although it has been the subject of preliminary investigations in the United States, Europe, and Australia, the EGS concept has yet to be demonstrated as commercially viable. However, experts familiar with the resource and the associated technologies believe the technical and economic hurdles are surmountable. In January, 2007, a panel led by the Massachusetts Institute of Technology produced a report entitled *The Future of Geothermal Energy*, which contained an updated assessment of EGS potential in the United States. The authors of the report estimated the nation's total EGS resource base to be "greater than 13 million quads or 130,000 times the current annual consumption of primary energy in the United States."[1] After accounting for the fact that the actual amount of recoverable energy will be much lower, due to technical and economic constraints, the authors conservatively estimate that two percent of the EGS resource could be economically recoverable – an amount that is still more than 2,000 times larger than all the primary energy consumed in the United States in 2005.[2] In other words, if the technological hurdles to EGS development can be overcome, the potential of the resource is enormous. H.R.2304 contains provisions to support research and development of advanced technologies to advance the commercial viability of EGS development, and to encourage demonstration of reservoir engineering and stimulation technologies by the geothermal industry.

Applications of Geothermal Energy

- *Electric power:* Geothermal power plants pump hot fluid (usually water or brine) from the earth and either use it to power a turbine directly, or run it through a heat exchanger to boil a secondary fluid into a gas, which then powers a turbine, to create electricity.

- *Direct use applications:* Geothermal water of at least 70°F can be used directly for heating homes or offices, growing plants in greenhouses, heating water for fish farming, and for other industrial uses. Some cities (e.g. Boise, Idaho) pipe geothermal hot water under roads and sidewalks to keep them clear of snow and ice. District heating applications use networks of piped hot water to heat buildings throughout a community.

Benefits of Geothermal Energy

- *Base load power:* Unlike most renewable energy sources, electric power from geothermal energy is available at a constant level, 24 hours a day. Because of this lack of intermittency, geothermal power may provide base load power production.

- *Pollution prevention*: A geothermal steam plant emits almost 50 times less carbon dioxide (CO2) than the average US coal power plant per kilowatt of electricity produced.[3] Every year, geothermal electricity plants prevent 4.1 million tons of CO2 emissions that coal-powered plants would have generated. A geothermal plant's cooling towers emit mostly water vapor, and emit no particulates, hydrogen sulfide, or nitrogen oxides. Plants that employ *binary* conversion technology emit only water vapor, and in very small amounts.

- *Jobs and security:* Geothermal energy can be produced domestically, thereby providing jobs for Americans and reducing security concerns associated with dependence on foreign sources of oil and natural gas. The large size of the resource, both in the United States and overseas, creates significant market opportunities for geothermal technology companies.

Cost

[1] *The Future of Geothermal Energy*; Massachusetts Institute of Technology, 2006; p. 1-15
[2] Ibid, p. 1-17
[3] According to the National Renewable Energy Lab, http://www.nrel.gov/geothermal/geoelectricity.html

Electricity from *The Geysers* sells for a wholesale price of $0.03 to $0.035 per kilowatt-hour (kWh), while electricity from newer geothermal plants (using lower temperature resources) costs between $0.05 and $0.08 wholesale per kWh. Wholesale prices for electricity produced from EGS reservoirs is likely to be higher in the initial stages of developing the technology, but projections by the MIT panel that produced *The Future of Geothermal Energy* anticipate that it would fall to a comparable level (i.e. $0.05 to $0.08 per kWh) by the time a 100MW of cumulative capacity have been developed in the United States, which amounts to bringing only a few EGS projects online.[4]

Direct use of geothermal resources is cost-competitive in many applications. For example, according to DOE, commercial greenhouses heated with geothermal resources, instead of traditional energy sources, average an 80 percent savings on fuel costs—about 5 to 8 percent of average total operating costs.

Issues

- *Subsidence and production declines:* At some geothermal power plants, energy production may gradually decline over time, through a loss of water/steam or declining water temperatures. If water or steam is removed from an underground reservoir, the land above the reservoir may slowly start to sink. Municipalities can inject their treated wastewater into the underground reservoir to replenish the hot water supply and avoid land subsidence. Newer geothermal plants tend to employ binary conversion technology, which reinjects the geofluid into the ground after extracting the heat, thereby replenishing the reservoir. Since almost no fluid is lost in these systems, reservoir depletion and subsidence are less significant concerns.

- *Induced seismicity*: Good hydrothermal resources usually coincide with areas of volcanic activity and so are almost always seismically active to begin with, and developing a geothermal resource can cause additional earthquakes. These induced quakes are usually small and imperceptible by humans, registering only 2 to 3 on the Richter scale. The process of developing EGS resources may also induce some seismic activity through the act of cracking the rock to create an underground reservoir. Experience to date suggests that the induced quakes from EGS development are also quite small, but this is an area that warrants further study. H.R. 2304 calls for the Secretary of Energy to study induced seismicity as a consequence of EGS development.

- *Water use*: Geothermal projects require access to water throughout development and operation. Water is used during well drilling, reservoir stimulation, and circulation. Cooling water is also used in most plants for condensing the hot working fluid after it has powered the turbine. In locations where water resources are in high demand, as in the western U.S., water use for geothermal projects requires careful management and conservation. Steps must also be taken to ensure that geothermal development does not contaminate groundwater and that noxious geofluids that are produced from deep wells are not disposed of on the surface.

[4] *The Future of Geothermal Energy*; Massachusetts Institute of Technology, 2006; p. 1-30.

Geothermal Energy Programs at DOE

The United States has been involved in geothermal energy R&D since the 1970s. The program reached a high point in FY 1980 with funding of approximately $150 million (1980 dollars). Since then, funding has gradually declined to its present level of $5 million (2007 dollars) in FY 2007.

Historically, many important technological advances have emerged from DOE-supported work at the national labs and US universities. The current geothermal program has allocated its FY 2007 budget of $5 million to support work on two EGS development projects, assess the potential of using hot water co-produced with oil and gas drilling to produce electricity, and to close down remaining program operations and establish an historical archive of the program.

In the Energy Policy Act of 2005, Section 931(a)(2)(C) included a broad authorization for research, development, demonstration, and commercial application programs for geothermal energy, with a focus on "developing improved technologies for reducing the costs of geothermal energy installations, including technologies for (i) improving detection of geothermal resources; (ii) decreasing drilling costs; (iii) decreasing maintenance costs through improved materials; (iv) increasing the potential for other revenue sources, such as mineral production; and (v) increasing the understanding of reservoir life cycle and management."

While broad-ranging, the EPACT authorization lacks specific provisions for cost-shared programs with industry partners (which have led to many advances in geothermal technology in the past and facilitated adoption of those advances by the private sector) and it makes no specific mention of developing Enhanced Geothermal Systems (EGS), an area of significant potential. Also, the authorization expires after FY 2009. Despite the authorization in EPACT '05, the administration requested zero dollars for geothermal programs at DOE for FY 2007 and FY 2008 and is currently making plans to shut down the geothermal program.

As justification for terminating the geothermal program, the Administration has claimed that geothermal technologies are mature – a claim disputed by geothermal researchers and the industry. Recent indications suggest DOE officials may be open to reexamining investment in geothermal R&D, particularly in light of the opportunities in Enhanced Geothermal Systems that were highlighted in the recent MIT report: *The Future of Geothermal Energy*.

Overview of Marine Renewable Energy

Marine Renewable Energy refers to energy that can be extracted from ocean water. (In some contexts the term may also encompass offshore wind developments, but that is beyond the scope of H.R. 2313 and this hearing.) For purposes of H.R. 2313, the marine renewable energy refers to energy derived from ocean waves, tidal flows, ocean currents, or ocean thermal gradients. Each is these is described in greater detail below.

Moving water contains a much higher energy concentration, measured in watts per meter (for waves) or watts per square meter (for tides and currents), than other renewable resources, such as wind and solar. This creates an opportunity to extract comparable amounts of energy with a smaller apparatus. The challenge lies in developing technologies to effectively and efficiently harness the energy contained in ocean movement or thermal gradients and use it to generate electric power, or for other purposes.

Their potential debated for many years, marine renewable energy technologies appear to be on the verge of a technological breakthrough. Prototypes or small demonstration installations have recently been hooked into the power grid in Australia, Portugal, the United Kingdom, and the United States. H.R. 2313 would support technology research and development to ensure that US companies are competitive in this emerging global market, and that emerging technologies are developed in an environmentally sensitive way.

- ***Waves:*** Ocean waves are really a super concentrated form of solar energy. The sun makes the wind blow, and the wind blowing across the ocean surface creates waves. Waves may travel unimpeded through the ocean for thousands of miles, accruing significant amounts of mechanical energy. Wave power devices extract energy directly from surface waves or from pressure fluctuations below the surface.

  According to a study by the Electric Power Research Institute (EPRI),[5] the total annual wave energy resource in the United States is approximately 2,300 TWh per year (2,300 terawatt hours = 2,300 billion kilowatt hours). If we were to harness 24% of that resource, at 50% efficiency, it would generate an amount of electricity roughly comparable to all of our current output from hydroelectric sources (~270 TWh per year, or approximately 7% of current US electricity generation[6]).

  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, DOE estimates that wave energy could produce 40–70 kilowatts (kW) per meter (3.3 feet) of western coastline.[7]

  Wave energy can be converted into electricity through either offshore and onshore systems. Offshore systems are situated in deep water, typically between 40 and 70 meters (131 and

[5] EPRI Offshore Wave Power Feasibility Demonstration Project, Final Report; http://www.epri.com/oceanenergy/attachments/wave/reports/009_Final_Report_RB_Rev_2_092205.pdf
[6] Energy Information Administration, http://www.eia.doe.gov/fuelelectric.html
[7] http://www.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50009

230 feet). Most offshore systems take the form either of a *single point absorber*, which is a vertical buoy design, similar in appearance to a navigation buoy, or an *attenuator*, which is a long, segmented tube that generates energy as waves flow along its length, flexing the adjacent segments against one another and powering hydraulic pumps inside.

Onshore wave energy systems are situated on the shoreline and exposed to oncoming waves. *Oscillating water column* designs enclose a column of air above a column of water. As waves enter the air column, they cause the water column to rise and fall, alternately compressing and depressurizing the air column, which powers a turbine. The *tapchan*, or tapered channel system, consists of a tapered channel, which feeds into a reservoir constructed on cliffs above sea level. The narrowing of the channel causes the waves to increase in height as they move toward the cliff face. The waves spill over the walls of the channel into the reservoir and the stored water is then fed through a turbine. *Pendulor* devices consist 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, powering a hydraulic pump and a generator.

- *Tidal Flows:* Tides are controlled primarily by the moon, and so can legitimately be thought of as lunar power. As the tides rise and fall twice each day, they create tidal currents in coastal locations with fairly narrow passages. Good examples include San Francisco's Golden Gate, the Tacoma Narrows in Washington's Puget Sound, and coastal areas of Alaska and Maine. Technologies of various designs may be used to harness these flows.

  Many tidal turbines look like wind turbines, and engineers of tidal technologies have been able to draw on many of the lessons learned from 30 years of wind-turbine development. They may be arrayed underwater in rows, anchored to the sea floor. Because the energy in moving water is so much more concentrated than the energy in moving air, the turbines can be much smaller than wind turbines and still generate comparable amounts of electricity. The turbines function best where coastal currents run at between 3.6 and 4.9 knots (4 and 5.5 mph). In currents of that speed, a 15-meter (49.2-feet) diameter tidal turbine can generate as much energy as a 60-meter (197-feet) diameter wind turbine. Ideal locations for tidal turbine arrays are close to shore in water depths of 20–30 meters (65.5–98.5 feet).

- *Currents:* Ocean currents are similar to tidal flows, but significantly larger. As an example, the energy contained in the Gulf Stream current in the Atlantic Ocean is equivalent to approximately 30 times the energy contained in all the rivers on Earth.

  The only area in the United States where ocean currents come close enough to land to make potential power extraction attractive at this time is in South Florida, where the Gulf Stream swings in close to shore. It is envisioned that undersea turbines, similar to those being developed to harness tidal flows, might be deployed to tap into this massive current.

- *Ocean Thermal Energy Conversion (OTEC):* Thermal gradients are the only marine renewable energy resource addressed in this bill that is not based on moving water. Instead, thermal technologies use the difference in temperature between deep and shallow waters to run a heat engine. This temperature difference contains a vast amount of solar energy. If extraction could be done profitably, the resource is virtually limitless.

OTEC works best when the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (36°F), conditions that exist in tropical coastal areas. To bring the cold water to the surface, OTEC plants require a large diameter intake pipe, which is submerged a mile or more into the ocean's depths. Heat is extracted from warm surface water

Applications of Marine Renewable Energy

- *Electric power production:* The primary application of marine energy technologies is electrical power production. Most planned installations would consist of arrays of multiple, small generating devices, optimally positioned to take advantage of a particular resource (e.g. waves, tidal flows, etc.). The multiple devices would feed their power into a centralized hub located on the sea floor, which, in turn, would be connected to a substation on the beach, and from there to the power grid.

- *Desalination:* One virtue of locating a clean, renewable energy producing device in seawater is that it is optimally positioned to use that energy for desalination. In areas where fresh drinking water is at a premium, marine renewables can make an important contribution to solving that problem.

- *Air conditioning:* Air conditioning is a possible byproduct of some marine energy technologies. For example, spent cold seawater from a thermal conversion plant can chill fresh water in a heat exchanger or flow directly into a cooling system on shore. Simple systems of this type have air conditioned buildings at the Natural Energy Laboratory in Hawaii for several years.

Benefits of Marine Renewable Energy

- *Predictability:* Unlike some renewable energy sources, notably wind, marine renewable energy production can be forecast to a high degree of certainty well in advance. Using satellite observations, wave power can be forecast up to three days in advance. Tides can be forecast years in advance. Ocean thermal is capable of providing a constant, base-load supply of power. This predictability makes it easier to integrate marine renewables into a diverse generation portfolio.

- *No fuel costs:* Marine renewables benefit from a free and inexhaustible source of “fuel”, freeing operators and consumers from concerns about future fuel availability and price volatility.

- *Pollution prevention*: Like other renewable energy technologies, marine renewables are attractive because they emit no pollutants or greenhouse gases in the process of producing energy. Devices are also designed to prevent any pollution to the ocean waters.

- *Jobs and security:* Marine renewable energy technologies can be produced domestically, thereby providing jobs for Americans and helping to reduce security concerns associated with depending on foreign countries for oil and natural gas. The large size of the resource, both in the United States and overseas, creates significant market opportunities for marine renewable energy technology companies.

- *Aesthetically unobjectionable*: Often opposition to energy development projects, whether onshore or off, is motivated by complaints that they obstruct or detract from otherwise beautiful land- or sea-scapes. In contrast to most other technologies, many marine renewable energy technologies are submerged out of sight. Other marine renewables have such a low profile and/or are located so far from shore that they generate no significant opposition on aesthetic grounds.

Cost

Cost estimates are difficult for wave and tidal, which, in contrast to offshore wind, lack operational history. For wave, costs have been estimated as between 9 and 16 cents/kWh, far more favorable than the 40 cents/kWh that offshore wind cost "out of the box." For in-stream tidal, the Electric Power Research Institute has predicted costs from 4 to 12 cents/kWh, depending on the rate of water flow. Because of tidal power's similarities to wind, it may benefit from the advancements already made in wind turbine development and may potentially share economies of scale with that industry.

Issues

- *Environmental Impact:* The greatest concern with marine renewables is the impact of power generation technologies on the marine environment and ecosystems. Significant research remains to be done in this area to ensure that these devices do not have significant negative environmental impacts. Turbine technologies, to harness tides and ocean currents, have raised particular questions. There are open questions about the impact of tidal turbines on local fisheries and marine mammals. This is an area requiring in-depth study. It is important that studies look not just at the impact of individual turbines, but also the impacts of large arrays of multiple turbines in a give location, as such arrays are what would be necessary to generate power on a utility scale.

  For marine renewable technologies that engage in desalination, steps must be taken to ensure that the concentrated brine produced as a byproduct of these operations does not have a negative impact on local marine ecosystems.

  Finally, there are open questions relating to potential environmental impacts of extracting too much energy from tidal flows or ocean currents. In the case of tidal flows, care must be taken not to reduce the flow by too much to avoid harm to marine ecosystems. In the case of the Gulf Stream, the same ecological concerns apply, and in addition, since the thermal energy carried by the Gulf Stream plays an important role in regulating the climate in Europe, it is important to understand whether extracting energy from this system might have negative impacts on weather systems that depend on its steady flow. While this possibility may be remote, it is a question that warrants further study.

- *Marine navigation*: Since many marine renewable energy conversion devices float on the water, or rest on the bottom of navigable waterways, they raise concerns about possible interference with marine navigation. It is important that devices be well-marked, easily visible by day and night, and appear on all current nautical charts. Efforts should be made to make devices visible to radar as well.

- *Survivability*: Marine renewable energy devices spend their entire lifecycle immersed in corrosive seawater and exposed to severe weather and sea conditions. Steps must be taken to ensure the survivability, and reliability, of these devices in these harsh conditions to ensure the uninterrupted supply of power.

Marine Renewable Energy Programs at DOE

The United States became involved in marine renewable energy research in 1974 with the establishment of the Natural Energy Laboratory of Hawaii Authority. The Laboratory became one of the world's leading test facilities for Ocean Thermal Energy Conversion technology, but work there was discontinued in 2000. Existing OTEC systems have an overall efficiency of only 1% to 3%, but there is reason to believe that subsequent technology advances and changes in the overall electric power environment may make a fresh look at OTEC technologies worthwhile.

In the Energy Policy Act of 2005, Section 931(a)(2)(E) included a broad authorization for research, development, demonstration, and commercial application programs for "(i) ocean energy, including wave energy". However, that authorization contains no further instructions on how to structure such a program and the authorization expires after FY 2009. Despite this authorization, DOE has not made a budget request to support marine energy programs since EPACT '05 was passed, nor have funds been appropriated. This is despite the fact that FERC has begun to issue permits to companies and investors interested in developing in-stream tidal sites, and several private companies – in Europe, Australia, and the United States – have begun to test prototype marine renewable energy technologies of various design.