Comments on EPIC Second Investment Plan

My name is Jim Shnell, and I am the President/CEO of the Ocean Geothermal Energy Foundation, which is a California non-profit public benefit corporation formed for charitable, scientific and educational purposes in accordance with Section 501(c)(3) of the Internal Revenue Code, established to research, develop and demonstrate the innovations needed to make ocean geothermal energy the baseload foundation for California's energy industry. I would like to emphasize and explain why ocean geothermal energy is a critical research initiative that should be included in the Second Investment Plan, and how it should be integrated into the Plan. I will begin with a brief description of the concept of ocean geothermal energy, then comment on the ways in which the concept should be integrated into the Plan, and finish with a more detailed description of the ocean geothermal system to be developed.

Brief Description. In recent years, increases in wind and solar generation have provided much of the new electric generating capacity in California. These sources are, however, intermittent, and they have some undesirable effects on the environment. Geothermal energy is the only form of clean, renewable energy that can provide enough baseload electricity to replace coal, petroleum, natural gas and nuclear power as the primary source of electricity. The geothermal resources on land, however, are not adequate to achieve that objective. A solution to the need for baseload renewable power can be achieved through several inter-related innovations, which adapt and use existing technologies to access geothermal resources in the deep sea floor. Access to vast amounts of geothermal energy can be gained through the ocean floors, under which abundant geothermal resources can be found in a supercritical state. The Gorda Rise and the Juan de Fuca Rise, which parallel the coast of Northern California, Oregon and Washington for a distance of about 500 miles, could provide access to enough energy to generate 80 gigawatts of electricity or more. (Compare the much smaller geothermal resource area at the Salton Sea, which lies on top of the northern terminus of the East Pacific Rift Zone, and note that "A range of studies estimate the [Salton Sea] field's generation capacity between 1,700 and 2,900 MW" according to Geothermal Energy Weekly, February 5, 2014.) Because of the very high temperature and efficiency, such ocean geothermal energy will cost about seven cents per kilowatt hour. (See the cost analysis in the Detailed Description below.) Supercritical geothermal resources will enable the generation of electricity on an efficient, economical and highly reliable basis through the first innovation, the use of remote-controlled turbine generators on the ocean floor that will supply both the grid's demand for electricity and, by operating during off-peak hours, the power needed to replace existing transportation fuels. These advancements in geothermal technology, to develop a very high-temperature and therefore very efficient form of geothermal generation, will make geothermal energy more affordable. Such generation, being both bountiful and inexpensive, will form the foundation for a further innovation, the restructuring of the transportation and electrical energy industries so that the provision of inventories of transportation energy (in accordance with current industry practice) serves as a buffer for the load following demands for electricity. In addition, the ocean geothermal system can be operated in coordination with other energy sources or on a stand-alone basis to transform the energy generation and delivery industries.

Moreover, Californians will benefit indirectly from the adoption of the system globally and the further reduction in greenhouse gases. Geothermal resources are accessible in the ocean floor all around the world. Abundant resources are easily available near Iceland and the West Coast of the United States, but such resources in fact wrap all around the world. California can, as it has done in the past and plans to do in the future, lead the world in the development of these technological advancements, providing a global response to global warming and an even greater benefit to California residents.

Comments. One of the Strategic Objectives that would apply to a new concept like ocean geothermal energy is S10, to advance the early development of breakthrough energy concepts. Although an increasing number of experts and organizations have recently begun to advocate ocean geothermal development, it is clear that such development would represent a new breakthrough in energy technology, on a scale that will ultimately restructure the entire energy industry. It should be noted that much of the effort is currently carried on by "individual innovators, small research teams and small companies," as noted in the Plan, and seed-stage funding at the concept level would be important to the success of this effort.

At the same time, the development of ocean geothermal technology should also be considered in connection with Strategic Objective S4 (to "improve power plant performance, reduce cost and accelerate market acceptance of emerging utility-scale renewable energy generation systems") and particularly Strategic Objective S4.3 (to "develop advanced technologies to improve the cost-effectiveness of geothermal energy production"). The most productive geothermal facilities on land use resources at a temperature of only 250°C, but thin ocean floors make it possible to reach temperatures of over 500°C and use supercritical technology, which has never before been used for geothermal generation. Strategic Objective S4.3 focuses on applied research and development, and much of the technology needed on the ocean floor will be adopted and adapted from existing technologies, including ocean well drilling (from the oil and gas industry), supercritical generation (which has been used in coal-fired generation since the 1920's) and operation by remote control (which is already used in the geothermal industry on land). Cost-effective recovery of valuable co-products will also be a major factor in ocean geothermal, because the ocean floor is a rich source of metals and minerals, which will be leached out of the ocean floor in high concentrations because of the supercritical nature of the brine. Another area of concern to be addressed under Strategic Objective S4.3 is emissions and water use, which is also an area in which ocean geothermal (with, literally, an ocean of water readily available) would have an advantage (although care to avoid abusing the oceans would be an important requirement).

Strategic Objective S5 sets forth concerns regarding which ocean geothermal energy would be very effective. Geothermal generation on land has a very small footprint; on the ocean floor, geothermal generation would have negligible effects if carried out properly (*e.g.*, avoid interfering with black smokers and the related fauna and flora on the ocean floor). Obviously, ocean geothermal generation would not use any of the water resources on land, and would not need cooling towers. More importantly, ocean geothermal energy would not be affected at all by climate change. While little is known about many areas of the ocean floor, the rift zones have been studied extensively, and much is already known about them; further study should, however, be a goal to be fulfilled in connection with Strategic Objective S5.2 ("developing environmental tools and information for future renewable energy conservation plans").

Another part of the Plan in which ocean geothermal energy should be considered is Strategic Objective S6 ("advance the use of smart inverters"). Since electricity generated on the ocean floor will be transmitted to shore by high voltage direct current lines, the use of inverters will be a major factor, and such use must be considered in connection with developing smart inverters.

Detailed Description of Ocean Geothermal Energy. Geothermal energy has advantages over other forms of energy used to generate electricity. Coal creates pollution and greenhouse gases and is not a renewable resource. Other fossil fuels may create less global warming, but they are more expensive and in shorter supply than coal. Nuclear energy creates hazards such as the potential for spills of radioactive contamination and the diversion of the fuel or waste for terrorist or other weaponry purposes, and there is no generally accepted method for disposal of nuclear waste, much of which is still held in "temporary" storage. Wind and solar energy are relatively clean and renewable (although they both have environmental effects) but they are not suitable for baseload generation of electricity. Hydropower is clean and renewable and capable of baseload generation, but there are few remaining opportunities for significant additions to hydrothermal generation. Geothermal energy is currently almost cost competitive with coal-fired plants, and is clean and renewable and well suited for baseload generation of electricity.

The current state of the art in geothermal production of electricity uses the heat in geothermal reservoirs of hot water or steam found under the land. However, the accessible geothermal resource base in the United States that is useable in existing geothermal technology is not sufficient to solve the current major issues in the electric generating industry such as climate change, pollution, and the costs and risks inherent in the reliance on fossil fuels or in the disposal of nuclear wastes. Satisfying the increasing demand for electricity while enabling the retirement of less desirable modes of generating electricity, such as the burning of coal, will require much more geothermal energy than is available using existing geothermal technology. Fortunately, the amount of geothermal heat available is far greater than the geothermal resource base that is accessible using current methods. Professor Jefferson Tester (then of the Massachusetts Institute of Technology, now at Cornell University) has estimated that 100 million quads of usable geothermal energy could be harvested per year, thousands of times the total global primary energy consumption of 472 quads in 2006. *See also* Tester *et al*., "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century" (the "MIT Study"). The innovation proposed here uses a large part of these vast geothermal resources, efficiently and effectively.

One way to provide more geothermal power currently is to drill deeper into the Earth's crust for heat, because geothermal temperatures increase with depth. Increased depth of drilling, however, increases the difficulty of drilling and the cost per meter of drilling. The difficulty and cost have prevented the use of deeper wells to provide more energy. The land areas where geothermal heat rises close enough to the surface to be economically accessible are limited, and few of those resources reach a temperature of 250°C. One response to this limitation is the current focus on enhanced geothermal systems ("EGS"). EGS is expected to access a greater volume of resources, but will do so by drilling wells to depths of 5,000 meters or more, which would raise the cost of the energy substantially. Unfortunately, the resources that EGS is expected to reach are still limited to a temperature of 250°C. An instructive exception to the temperature limitation of 250°C is Iceland, which has very productive geothermal resources because it is located on the mid-ocean rift zone of the Atlantic Ocean. As a result, Iceland has comparatively easy access to large, high-quality geothermal resources. A consortium of national governments and energy companies is seeking to use these exceptional resources by drilling to a depth of approximately 5,000 meters in order to tap supercritical geothermal resources. It is estimated that beneath three of the developed geothermal fields in Iceland, temperatures should exceed 550°C to 650°C, and the occurrence of frequent seismic activity below 5 km, indicates that the rocks are brittle and therefore likely to be permeable. The engineers working on this Iceland Deep Drilling Project have calculated that supercritical geothermal fluids could provide up to ten times as much power, per unit of volume, as the geothermal fluids used in the current technology. "A conventional well that produces dry steam only, at a wellhead pressure of 25 bar_a and a downhole pressure of 30 bar_a can yield approximately 5 MW of electric power if the volumetric rate of inflow to the well is 0.67 m^3s^{-1}. An IDDP well tapping a supercritical reservoir with temperatures of 430 – 550 °C and pressures of 230 - 260 bar may be expected to yield 50 MW of electric power given the same volumetric inflow rate, 0.67 m^3s^{-1}. An IDDP well may thus afford a tenfold improvement in power output over a typical conventional well." A more recent study by Tester *et al.* indicated that a liter of supercritical water at a temperature of 400°C and a pressure of 250 bars "has more than five times the power producing potential than a hydrothermal liquid water geofluid at 225°C." A few years ago, the Iceland Deep Drilling Project, in seeking to drill a deeper geothermal well, drilled into magma at a depth of approximately 2,000 meters, and a temperature of 900°C.

The geothermal resources accessible in Iceland are very unusual, however, because it is situated in a mid-oceanic rift zone. Very few areas on land lie on a rift zone (although areas that are so located, such as the area around the Salton Sea in California, often present significant geothermal resources). In other areas on land, it is necessary to drill much deeper to access such temperatures. The difficulty and cost of drilling through a large amount of rock can be avoided by drilling offshore. According to the USGS, the Earth's crust in continental landmasses averages approximately 30,000 meters in thickness, and can be as thick as 100,000 meters, but the thickness of the Earth's crust under the oceans averages about 5,000 meters and is less in some areas. The most promising area on the ocean floor is the oceanic rift zone, which wraps around the world "like the seams on a baseball," as described in a recent National Geographic production ("Drain the Ocean").

The first innovation provides for the development of geothermal energy from the ocean floor, a vast, high-temperature resource never before accessed for the generation of electricity. The innovation is a self-contained, submersible, remote-controlled electric generating station that will sit on the ocean floor at depths of 2,000 meters or more, where it can access geothermal resources at supercritical temperatures and pressures and use a super-critical turbine (which is more efficient than turbines currently used for geothermal energy) coupled to a generator for converting geothermal energy to electricity. These improvements will enable geothermal energy to compete with fossil-fueled power plants on a cost basis. This approach will also access much more extensive geothermal resources than the conventional geothermal resources currently used.

The coast of California has excellent geothermal resources that lie close to the shore. Features have been recently discovered that demonstrate these resources clearly. The Juan de Fuca tectonic plate is a (comparatively) small tectonic plate that forms the ocean floor along the coast of Northern California and the Pacific Northwest. A number of "black smokers" have been discovered on the plate approximately 100 miles from shore. (A "black smoker" is a submarine geothermal vent that spews hot water, generally at a temperature of approximately 400°C, into the ocean. Black smokers are found at an average depth of approximately 2,100 meters below sea level.) The Juan de Fuca plate also has a "spreading zone," where the sea floor splits and magma rises to form new crust, along the Gorda Rise and the Juan de Fuca Rise, which parallel the coast of Northern California, Oregon and Washington. South of the Gorda Rise, at least six seamounts of volcanic origin, the Gumdrop, Pioneer, Guide, Davidson, Rodriguez and San Juan seamounts (the latter two located off the coast of Santa Barbara and approximately 200 miles from Los Angeles, respectively) lie along the coast of California, approximately 150 miles off shore. A more graphic and fully documented indication of the available resource under the ocean floor, the Geothermal Map of North America (see http://www.smu.edu/geothermal/2004NAMap/2004Namap.htm) shows the surface heat flows in many of the most favorable areas of the Western United States, such as the Geysers and the Salton Sea, in shades of orange and medium red. Most of the area of the ocean floor off the coast of the Western United States, however, is shown in shades ranging from red to bright pink, indicating that huge areas adjacent to the coast are significantly more productive of heat than the most productive areas on land.

The objective is to discover and develop areas under the rift zone having temperatures of 500°C or more and to drill into reservoirs of geothermal fluid at such temperatures, or to create such reservoirs using ocean water and EGS technologies. This proposal contemplates the drilling of vertical injection wells, whether EGS wells or wells drilled into existing reservoirs, in areas near oceanic rift zones where the crust is approximately 2,000 meters thick and the magma beneath the crust is at a temperature of 700°C. Each injection well would then be surrounded by four production wells, each slant drilled to points approximately 500 meters laterally distant from the injection well and 1,500 meters below the ocean floor, so that (assuming that the crust conducts heat uniformly) the resource temperature should be 525°C. The four production wells should produce 50 MW (thermal) each, supporting a generating station with a capacity of 100 MW (assuming a supercritical power plant efficiency of 50%).

The technology of offshore drilling to the depths contemplated by this proposal has already been developed in drilling for the oil and gas industry. The largest oil field in the Gulf of Mexico is approximately 150 miles from shore. Recently, oil companies have drilled wells that reach as much as 8,000 meters beneath the ocean floor, and have drilled wells in water as deep as 2,800 meters. Drilling for geothermal resources will, however, be conducted in rock formations that do not contain any oil or natural gas deposits, but that present an unusual challenge. The rock to be drilled is igneous, rather than sedimentary, and it is harder. Geothermal wells in Iceland, however, are drilled in basalt and Gudmunder recently estimated that drilling geothermal wells 2,000 meters deep in Iceland costs about $5,000,000 per well.

A significant advantage to drilling offshore is the much higher temperatures at which the geothermal resources can be accessed. Most of the geothermal reservoirs under development in the West provide heat at a temperature of 250°C or less. Based on submarine geothermal discoveries, offshore geothermal resources can exceed 500°C. The higher temperature provides a disproportionately large advantage in efficiency. Another major advantage is that the reservoirs are more sustainable, because the heat flow through the ocean floor is much higher, as reflected in the Geothermal Map described above. Also, there is a virtually unlimited supply of water with which to create or enlarge geothermal reservoirs, if enhanced geothermal systems are necessary, or to help to recharge existing reservoirs.

Direct current is significantly more effective than alternating current for the underwater transmission of electricity, so the generating stations in the rift zones will be built to generate direct current, which will be transmitted to the continental coastlines by high-voltage direct current ("HVDC") transmission lines, similar to the transmission line from Norway under the North Sea to the Netherlands. In the United States, the Pacific DC Intertie transmits up to 2 gigawatts of direct current from the Oregon-Washington border to Los Angeles, a distance of approximately 850 miles. Such lines can transmit power efficiently over distances of 2,000 kilometers or more. The transmission lines may be brought to shore in the midst of load centers and avoiding the need to create new or additional transmission lines over land from remote generating locations.

The proposed geothermal approach uses a heat exchanger and separates the supercritical turbine from the minerals in the resource, which would otherwise build up in the turbine. The build-up of minerals can be cleaned from the heat exchanger using current geothermal techniques, more easily than it can be cleaned from the turbine. The turbine then operates like a standard supercritical turbine without the complications of scaling. Standardized turbines, rather than turbines that have been designed for the conditions of a specific well, are less expensive to build and maintain, and a turbine can be replaced with another turbine when maintenance is required. By operating on the ocean floor, the system will not only reduce biological, land use and air-quality impacts; by using virtually unlimited amounts of cold ocean water for cooling (and to make up reservoirs, if necessary) it will also eliminate water-related impacts.

One of the technical issues is the efficiency of the project, both in extracting geothermal energy from reservoirs and in converting it to electricity. For example, highly-efficient turbines driven by supercritical fluids were developed for coal-fired, and more recently for nuclear-powered, generating plants. Conventional geothermal resources on land rarely achieve supercritical temperatures. With the discovery of the accessibility of supercritical geothermal resources in the ocean floor, the feasibility of adapting the supercritical steam generators, and the state-of-the-art designs for supercritical CO_2 turbines, for use with geothermal fluids from the ocean floor must be assessed as a critical issue regarding the possibility of using these highly efficient turbines for the first time with geothermal resources. Similarly, while offshore drilling has been practiced in the energy industry for more than a century, the adaptation of such drilling for use in accessing supercritical geothermal resources will be an advance for the energy industry, because supercritical resources are substantially more efficient than hot water or even live steam in bringing the energy in geothermal resources to the generating station. Success in these technical areas is critical to the efficiency, and to the issues of power and availability, of the proposed system.

This innovation uses a self-contained, submersible, remote-controlled geothermal-powered electric generating station that uses a supercritical CO_2 turbine coupled to a generator to convert geothermal energy to electricity. The station can be built on a barge, which can be towed by a tug to the ocean surface above the geothermal wells, then submerged and lowered by winches on the tug to the site on the ocean floor prepared for the station. There, by remote control, with the assistance (to the extent needed) of a remotely operable submersible vehicle operated from the tug, the station is coupled to the wellheads for the geothermal production wells and to the wellhead for the injection well. The station uses the production from more than one well, each of which is started in close proximity to the others but accesses different geothermal reservoirs, or different areas of the same reservoir, by directional drilling. The station is also connected to a remote control cable that enables control of the station from a facility on land, and to an undersea transmission cable that delivers the electricity to the electrical grid on land. The station is detachable from the wellheads and the cables by remote control, so that the station can be retrieved by a tug, raised to the surface and towed to shore every one to two years for maintenance and overhaul. These regular overhauls, combined with the very cold water and the low levels of oxygen in the water at such depths, prevent corrosion from being a problem for the station. If the stations are built on a standardized design, an identical station can immediately replace a station that is retrieved. A submersible remotely operable vehicle, operated from a ship on the ocean surface, can handle minor repairs and adjustments that may be necessary between overhauls, to the extent that they can't be handled with the remote controls built into the station.

Another potential economic advantage is the recovery of metals and minerals. As a further innovation, the heat exchanger for the station can be designed to remove and collect metals and minerals from the geothermal fluids selectively, and the metals and minerals will provide an additional source of revenue from the proposed system, which would make the ocean geothermal system even more competitive economically. This removal capability may be particularly important under the circumstances of the proposed system. For one thing, the ocean floor is particularly rich in many important metals and minerals. For another thing, supercritical water has special properties and will therefore dissolve metals and minerals from the rock more readily than will hot water.

Another major innovation inherent in this project, discussed above, is the restructuring of the transportation and electrical energy industries. Whether by charging the batteries of electric cars or by providing hydrogen through electrolysis (which can be performed advantageously on the ocean floor), baseload geothermal generation, with an availability factor of over 90%, will provide inventories of transportation energy (as petroleum does in current industry practice) to serve as a buffer for the load-following demands for electricity, better than relying on cycling the limited amount of hydroelectric power available (which exacerbate hydropower's effects on the environment).

The ocean floor geothermal generating station described above, capable of generating 100 MW, is projected to have, once the technology matures, a capital cost (including financing) of $1.365 billion and an operating cost of $7.16 million per year. Assuming a life span of thirty years and an average availability of ninety percent (90%), the levelized cost of electricity from the station is projected to be $0.067 per kilowatt-hour. These projections were calculated in large part on the basis of data provided in Shibaki for the Renewable Energy Policy Project ("REPP"), which in turn relies on World Bank Group data from 1999. The cost of the power plant was projected by calculating the mid-point of the cost of power plants as reported by REPP for large plants using high-quality resources ($925 per kilowatt), increasing that amount by fifty percent to provide for the added cost involved in modifying the power plant for operation on the ocean floor, and then adding an additional ten percent to reflect inflation in costs for a total of $153,000,000 for the 100 MW power plant. The capital cost of the steam field, however, was calculated on the basis of an estimate by Gudmundur. To support a capacity of 100 MW, it was projected that four production wells, with a production of 50 MW each (assuming a supercritical power plant efficiency of 50%), and one injection well are required. Gudmundur has estimated that the cost of drilling a conventional well to a depth of 2,000 meters in Iceland is currently approximately $5,000,000. It is commonly assumed that a well drilled offshore can cost up to ten times as much as an equivalent well drilled onshore. On that basis the offshore wells would cost up to $50,000,000 each, for a total well cost of $250,000,000. The cost of exploration was projected by comparing the mid-point of the cost of exploration as reported by REPP for large plants using high-quality resources ($250 per kilowatt) to the mid-point of the cost of the steam field reported by REPP for such plants ($375 per kilowatt) and multiplying the ratio thus established (*i.e.*, two-thirds) times the $250,000,000 projected above to estimate exploration costs of $167,000,000. Thirty-year financing for all of the above costs at an after-tax seven percent cost of capital is projected to cost $795,000,000. Operating and maintenance costs were projected by calculating the mid-point of operating and maintenance costs as reported by REPP for large plants ($0.0055 per kilowatt-hour), increasing that amount by fifty percent to provide for the added costs involved in operating the power plant on the ocean floor, and then adding an additional ten percent to reflect inflation in costs for a total of $215,000,000, assuming that the power plant operates for thirty years at an availability of ninety percent. If the power plant operates for thirty years at an availability of ninety percent, 23,668,200,000 kilowatt-hours of electricity is produced and dividing that number into the total of $1,580,000,000 for the above capital and operating costs yields a levelized cost of $0.0666 per kilowatt-hour. This projected cost rises from $0.067 to $0.073 per kilowatt-hour if $0.0059 is added for "transmission investment" (which is the amount estimated by the EIA for transmission investment, in "Levelized Cost of New Generating Resources" in the Annual Energy Outlook 2011 at http://205.254.135.24/oiaf/aeo/electricity_generation.html, for off-shore wind energy). If such a cost seems unattainable, it should be noted that Iceland produces geothermal electricity at a cost of about four cents per kilowatt-hour, without using highly-efficient supercritical resources. The projected cost is competitive with the projected levelized cost for conventional combined cycle gas-fired plants and advanced combined cycle plants, and lower than the projected levelized cost for conventional coal-fired plants, advanced coal plants, conventional combustion turbine gas-fired plants, advanced combustion turbine plants, advanced nuclear plants, wind plants, solar photovoltaic plants, solar thermal plants or hydroelectric plants estimated by the U.S. Energy Information Agency for generating technologies to be brought on line in 2016 (see "Levelized Cost of New Generating Resources" cited above.) The electricity consumer will also reap the global-warming and other environmental benefits of geothermal generation, which has virtually no greenhouse gas or other omissions. Geothermal generation is also more reliable than other forms of generation, having an availability factor of 92%, as estimated by the Energy Information Agency in the study mentioned above. It should be noted that the capital and operating costs of the initial stations are likely to be higher than the foregoing projected costs, and that the projected costs are expected to be characteristic of the stations after the learning achieved from building and operating the initial stations.

It is anticipated that the innovations of this project will be adopted by power plant developers, utilities and other for-profit business entities and governmental agencies that are involved in generating electricity. These utilities, energy project developers and other entities involved in actually deploying the technology and techniques will be for-profit business entities or governmental agencies using the customary project financing models generally used for project development, because of the extremely capital-intensive nature of such projects.