ANALYSIS OF BERKEN ENERGY THERMOELECTRIC TECHNOLOGY

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The development of a new and sustainable energy supply is one of the most important issues being addressed by the U. S. Department of Energy (DOE). A number of options are under consideration that involves an energy mix, so that complete reliance on fossil fuels is lessened. The DOE has invested a large amount of financial resources, $2.9 billion in 2012, into the development of wind, photovoltaic energy (PV), geothermal and biomass development through the various funding arms of the agency. This funding has been distributed between the National Renewable Energy Laboratory (NREL), academic institutions, and private industry.

Both wind and PV industries have enjoyed tremendous growth over the last decade. PV production has been growing at the rate of above 40%/year with world wide sales of about 100 billion dollars in 2011. The worldwide PV production was 28.4 GW in 2011. The total sales were 23.0 GW as production outpaced demands because of the lagging world economy. The total world sales history is shown in the figure at the end of this analysis. The installation costs vary from about $2.50/W in Germany to over $6.00/W in California. The cost of the basic module has dropped to about $1.00/W in the last year. China produced 44% of the world product in 2011. However, Germany was the largest consumer at 69% of the world market. The growth data are shown in fig. 1.

> *The Department of Energy investment in wind, photovoltaic, geothermal, and biomass energy solutions has not increased the base power production. "That potential application of stable and low cost base power is one of the attractive features of the Berken technology."*

One of the many limitations wind and PV is the current lack of a viable storage technology. Both energy sources have become markedly less expensive, but are intermittent for energy production. For example, I have a PV system on my Lakewood home that is rated at 5500 peak watts. In the field, the system produces a max output of 4800 watts. In peak season (June and July), the peak daily output of the system is about 40 KW/h per day. Thus, the peak duty cycle of the system is about 25%. In the two years since installation, the system has produced about 18,000 KW hours of energy. However, the 24/7 output is about 2% of the peak output. Therefore, a base power source could be priced at a considerable multiple of $1.00/peak W and still be cost competitive with PV. And yet, PV has become competitive with conventional power sources. Current standalone prices of 10 to 20 cents/KWH are being quoted today.

Large amounts of research funds have been directed into R&D that are linked to electric storage technology, but the success of the research products have been disappointing. Consequently, the choices of cost-effective Base Power (BP) sources have attracted a great deal of interest. At the current time, natural gas is a leading source because of the abundance of U. S. sources and the lower carbon content relative to coal. A novel base power source that is nonpolluting (or not carbon producing) and cost competitive with fossil fuels would be a tremendous asset to the energy mix. That potential application of stable and low cost base power is one of the attractive features of the Berken technology. Because of the continuous operation of these devices, the product could be cost competitive at a considerable multiple of the current PV market price or other sources when compared on a cost/watt basis. The market potential for a cost competitive base power source is astronomical.

Geothermal development has been under investigation for a number of years as an alternative power source. It has the potential to be a base power source as it is independent of the sun and/or weather. Geothermal can provide power on a 24/7 basis and is therefore a candidate as a base power source. A primary obstacle has been cost and geographical limitation. Los Alamos National Laboratory (LANL) recently reactivated a hot rock geothermal project in the 1980s, but this relied on very deep drilling and the existence of very hot steam producing rock near the surface of the earth. The technology was quite expensive and limited in applicability to selected regions of the earth's crust. A technology that could function for electricity production at more modest elevated temperatures (and therefore more shallow drilling) would be a significant improvement in providing a geothermal electrical source. Various studies have shown that temperatures in the 100 C range are available over a much wider region of the earth's surface. These temperatures are more abundant at much shallower depths and therefore geothermal plants could be developed more inexpensively than the deep-hot-rock technology. This prospect is the really exciting aspect of the solid-state thermoelectric converter being developed at Berken Energy. These devices have the promise as being low-cost, moderate efficiency devices that could be produced on a production line. As such, they could be the driving components of geothermal electrical generating plants that could provide the much-needed base power electrical sources at a competitive installed cost of $4.00/ peak watt. Because of the continuous operation of thermoelectric power, the basic device cost could be $40 to $100/w and be cost competitive with PV.

Access to geothermal temperatures in the 100C range presents opportunity for novel power producing solutions.

"This prospect is the really exciting aspect of the solid state thermoelectric converter being developed at Berken Energy."

Thermoelectric Device Development

There has been a great deal of interest in thermoelectric conversion of heat to electricity over the past decade. When a conducting material is subjected to a thermal gradient, a net concentration of electrons diffuse to the cold side of the material. As the electrons diffuse along the gradient, a voltage develops between the hot and cold junctions of the material. The voltage can drive current in an external circuit and deliver thermoelectric power to a load. The Department of Defense (DARPA) funded a large R&D project to develop efficient TE devices for military application. Great improvements were made in both device fabrication and device theory. Current super lattice, thin film devices were invented that had remarkable figures of merit (termed the ZT factor) under the DARPA program. However, these devices were grown by metal-organic chemical vapor deposition

(MOCVD) and are quite expensive. The cost is not of great concern to the military but would not allow for commercial applications of this TE technology.

The major automobile manufacturers have also had R&D programs over the same time period. The major interest there is waste heat utilization where the heat in automobiles contributes to the electrical generation of electricity and battery charging. The net goal here is a more efficient automobile. It is not clear if that R&D has produced anything yet that can be incorporated into a consumer product. However by producing and applying an economical TE device, waste heat capture could also become more viable.

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Outside of the United States, energy recycling is more common. Denmark is probably the most active energy recycler, obtaining about 55% of its energy from cogeneration and waste heat recovery. In 2008 Tom Casten, chairman of Recycled Energy Development, said that "*We think we could make about 19 to 20 percent of U.S. electricity with heat that is currently thrown away by industry.*" Micro-cogeneration is a component of a distributed energy resource (DER). Such installations are usually less than 5 kW in a house or small business. The waste heat from burning fuel used for heating space or water is captured, and some of the energy is converted to electricity. This electricity can be used within the home or business or, sold back to the electric power grid. This recent development of small scale combined heat and power (CHP) systems has provided the opportunity for in-house power backup of residential-scale photovoltaic (PV) arrays. Utilizing Berken's TE material could take this to the next step. On a larger scale, an installation is often between 5 kW and 500 kW in a building or medium sized business. Such base loads arise where building occupation or process activities are extended or continuous in operation. This typically includes for hospitals, prisons, manufacturing processes, swimming pools, airports, hotels, apartment blocks, etc. These installations are described mini-cogeneration sources and become part of the distributed energy resource.

The Berken Thermoelectric Device

Berken has produced several novel methods of device fabrication and demonstrated very promising performance on a laboratory scale device. These materials are described as "thick films" and the growth technique enjoys great flexibility of size, shape, and alloy composition. One example is that the TE device theory of Gao Min1 and coworkers provides geometrical sizes that maximize the TE effect. These considerations are easily incorporated into the Berken fabrication technique so that optimum size devices can be fabricated without addition wire sawing or polishing. The latter feature is, for example, one of the cost drivers for wafer processing in the dominant silicon PV technology, but that cost is completely avoided in the Berken TE material. The Berken growth technique also allows for the lateral dimensions of the final device to be a space filling device geometry using the full the cross-sectional area of the module. This feature allows the final module to be most efficient in collecting heat from the exchanger. This issue again in important in the silicon PV technology as the wafers are cylindrical as grown and there are subsequent "dead areas" on the final wired module. The interconnection methods lead to higher cross-sectional coverage in modules leading to increased performance. The performance of these devices is also variable with the elemental composition, and the latter is easily changed in the Berken process. The optimum composition can be easily determined for application to the production environment.

Much of our current technology has developed along what is known as a learning curve. The learning curve for PV is shown in Fig. 2. As the manufacturing volume increases, the cost of production decreases accordingly. Current experience with PV is that as the yearly production doubles, the cost decreases by 20%. The same could be expected for any new technology such as the Berken TE device. The laboratory device that I observed performed as expected and appears to be amenable to scale up for mass production. There is considerable history of the pressing technology, primarily that of Eastman Kodak in the hot pressing of infrared (IR) window materials. These materials (the Itran 1 Gao Min et al product line) were scaled to large areas and used in the large nose cone windows of missiles as an example. This production technology appears to be applicable to the Berken device. As such, I think that this is a very promising material for base power production and should be scaled up to the production level as soon as possible.

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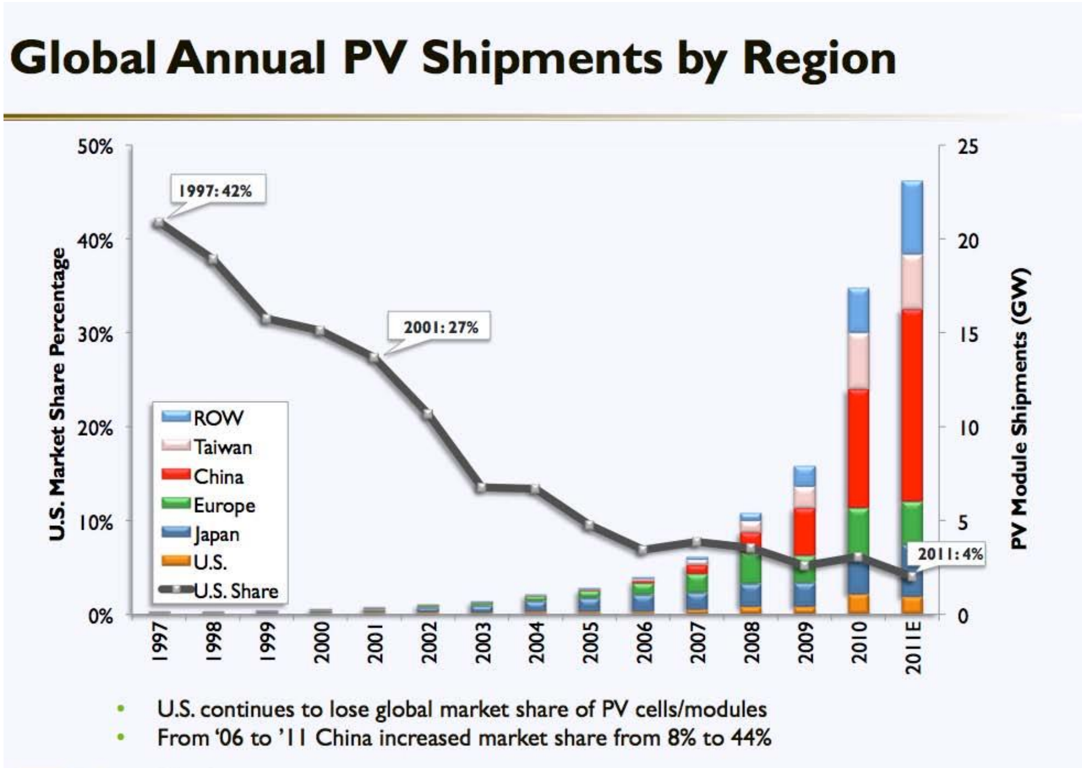

Fig. 1. Annual PV production from 1997 to 2011 showing the impressive growth

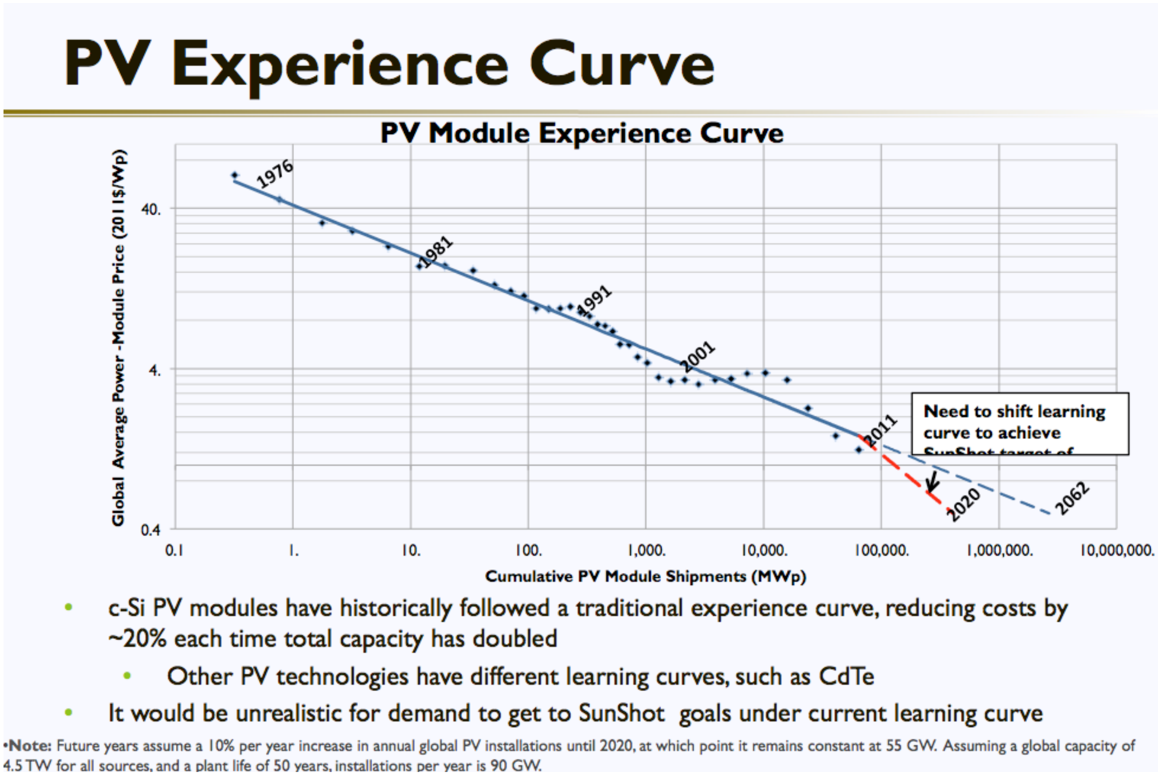

Fig. 2. PV Learning curve

SUMMARY

1. Thermoelectric devices have great potential for energy generation using heat sources such as shallow geothermal wells
2. These devices can operate 24/7 and are therefore potential candidates as base power sources that can complement the existing energy mix
3. Because of the continuous deliver of power, compared to intermittent sources such as solar and wind, TE devices can be somewhat more expensive to produce and still be cost competitive with PV and wind.
4. There are other important applications of TE devices such as waste heat recovery and cogeneration of electricity in conventional power plants.
5. The key to success will be the ability to scale up the laboratory technology to the production level and produce devices that are cost competitive with current base power sources.
6. The learning curve that is well known for all technologies, should be applicable to the TE technology, producing lower cost/watt as manufacturing capacity increases.
7. A practical and inexpensive TE technology has an enormous range of markets and applications in our current energy economy.