Catalyzing mass production of solar photovoltaic cells using university driven green purchasing

Mass production
of solar
photovoltaic cells

425

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Abstract

Purpose – The purpose of this paper is to explore the use of the purchase power of the higher education system to catalyze the economy of scale necessary to ensure market competitiveness for solar photovoltaic electricity.

Design/methodology/approach – The approach used here was to first determine the demand necessary to construct “Solar City factories”, factories that possess equipment and processes sized, dedicated and optimized to produce only solar photovoltaic systems. Inexpensive solar cells from these factories could produce solar electricity at rates comparable to conventional fossil-fuel derived electricity. Then it was determined if sufficient demand could be guaranteed by green purchasing from the international university system.

Findings – A focused effort from the university community to purchase on-sight produced electricity would make it possible to construct truly large-scale dedicated solar photovoltaic factories rather than follow the piecemeal production increases currently observed in the industry.

Practical implications – Direct economic competitiveness of an energy source having markedly lower environmental, social and health externalities would have a positive-spiral (virtuous cycle) effect encouraging the transition of the global energy infrastructure away from polluting fossil fuels to green solar energy.

Originality/value – Despite significant commercial progress in the conversion efficiency of sunlight into electricity with solar photovoltaic cells, their widespread adoption is still limited by high costs relative to conventional fossil fuel-based sources of electricity. The concept outlined and critically reviewed in this paper represents a novel and economical method of transitioning the electric supply system to renewable solar energy.

Keywords Solar power, Higher education, Renewable energy

Paper type Conceptual paper

Introduction

The environmental challenges facing contemporary society are substantial with the most serious threat coming from anthropogenic interference with the global climate system. The consensus among the 2004 Intergovernmental Panel on Climate Change (IPCC) and the 1993 World Energy Council’s Global Energy Scenarios to 2050 is that if current trends continue, our earth will reach a point of no return (Hoffert *et al.*, 2002). Global climate destabilization is primarily driven through the combustion of fossil fuels for energy and the resultant greenhouse gas (GHG) emissions (The IPCC, 1995; The IPCC, 2001). Solar photovoltaic (PV) cells, which convert sunlight directly into electricity, offer a technically sustainable solution to our enormous future energy demands without additional GHG emissions and climate forcing during their use

(Pearce, 2002). Solar PV cells are not currently ubiquitous because the electricity they produce is high compared to fossil-fuel derived electricity. With no additional technical improvements the cost of solar electricity could be competitive with conventional electricity if solar cells were produced on a scale 100X current manufacturing facilities (Keshner and Arya, 2004). Thus, there is an acute need to increase demand for solar PV cells.

Because universities possess access to the most up-to-date knowledge of both environmental problems and technical solutions, they have the responsibility to lead society toward environmentally sustainable policies and practices (Uhl and Anderson 2001). Both the majority of evidence for climate change and breakthroughs in solar PV technology have been researched and developed by universities. However, like the remainder of society, the higher education system continues to rely on fossil fuels for the majority of its operational needs. The use of consumer pressure in greening the fossil-fuel based energy system has long been advocated by environmentalists. Although there exists overwhelming consumer support for renewable energy, the traditional image of the consumer as the primary agent of environmental change has been demonstrated to be inadequate for creating a renewable-energy based economy. Following Green *et al.* (2000) successful efforts to green the economy require an understanding of corporations and public organizations as consumers. This paper explores the use of the purchase power of the higher education system to catalyze the economy of scale necessary to ensure market competitiveness for solar PV electricity.

The purchasing power of universities has already been used as a tool for the diffusion of environmentally beneficial innovations through "green purchasing" practices. Green purchasing refers to purchasing that places preference on products which have reduced environmental impact in their life cycle (development, manufacturing, use, recycling, and disposal), or which are designated as eco-friendly by firms that are active proponents of environmental preservation. In the context of energy, green purchasing is centered on renewable power that does not contain direct purchases of nuclear power. Green energy is cleaner because it results in lower air emissions, less nuclear and mining waste, and is produced from renewable resources.

As models for leveraging large-scale photovoltaic production, three systems of green purchasing will be reviewed here:

- (1) energy service contracting;
- (2) commodities such as recycled paper and recycling services; and
- (3) large scale wind power.

Next, the technical aspects of solar photovoltaics will be briefly discussed in the context of utilizing the purchasing power of universities to create a large-scale mass manufacturing plant or "Solar City". Finally, the social viability of large-scale university purchases of solar photovoltaics will be explored and conclusions on this method of innovation diffusion will be drawn.

Energy service contracting

Energy service companies (ESCOs) guarantee that the energy and cost savings produced by the comprehensive capital energy project will cover all the costs associated with implementing the energy conservation measures (ECMs) covered by the project (Donahue, 2003). What was once a relatively small industry is expanding

rapidly at a 24 percent annualized rate to over \$2B in projects in 2000 (Osborn *et al.*, 2002). This growth, in a large part, is fueled because many schools and universities are finding ESCO contracts to be financially responsible means to bring their facilities up to date while contributing to their environmental missions. Most educational institutions have degrading infrastructures with extremely inefficient energy use (Pearce and Uhl, 2003). Although this situation is ripe for economic gain, some universities have failed to capitalize on the enviro-economic opportunities primarily because of the following factors:

- the low priority of operations for decision makers;
- deferred maintenance backlogs;
- lack of initial capital (funding) and/or labor; and
- sub-optimal behavior of building occupants (Pearce and Miller, 2006).

An energy service contract represents a method to economically implement ECMs to overcome these challenges at the university level. Examples of ECM include: high efficiency lighting, high efficiency heating and air conditioning, efficient motors and variable speed drives, insulation and weather proofing, motion sensors, and centralized energy management systems. An ESCO's services typically include:

- developing, designing, and financing energy and water efficiency projects;
- installing and maintaining the energy efficient equipment involved;
- measuring, monitoring, and verifying the project's energy savings; and
- assuming the risk that the project will save the amount of energy guaranteed.

These services are bundled into the project's cost and are repaid through the economic savings generated.

Many universities have undertaken ESCO contracts. The University of Buffalo completed a comprehensive \$17 million project involving a plethora of ECMs that produced more than \$3 million in annual savings as well as a 15 percent reduction in SO₂, NO_x, and CO₂ emissions from campus energy use (Simpson, 2003). The Penn State energy service project prevented the use of 5,387,000 gallons of water and 5,905 tons of CO₂ and saving over \$856,000 per year (Pearce and Miller, 2006). Other universities that have successfully utilized ESCOs to decrease their operating costs while moving towards sustainability include: Duquesne University (Donahue, 2003), Baylor University, Florida International University, Eastern Illinois University, Syracuse University, California State University, and many others (Eilbott, 2001).

This method of using a service contract over a long life cycle could be used by individual universities to purchase renewable energy from solar PV power suppliers or solar cells to install on university buildings.

Green purchasing of commodities

Universities routinely use their size to purchase bulk commodities like electricity or computer paper for a discount. This trend is now evolving to include some universities using that same purchasing power to increase environmental stewardship. For example, two University of Wisconsin (UW) programs used the Universities magnitude for both purchasing and disposing of products in order to foster environmental stewardship.

First, UW was under a long-time contract for recyclables in which they were being paid the same rate as the average commercial or municipal waste streams. However, the waste from the University was far higher fraction of aluminum cans over glass than the municipality. This was proven in a garbage audit by students. Aluminum has a much higher recycling value than glass so UW ended up saving the university ~\$21,000/year (Eagan and Keniry, 1998, p. 65). In the second case, UW was paying tipping fees of \$48,000/year to a recycling contractor to dispose of recyclable paper goods and the University received no revenue regardless of the market value of the material. A graduate student developed a new approach to request and review bids for the University's supply of paper for recycling. Using this new method on paper, newsprint, and cardboard, the University saves \$120,000/year (Eagan and Keniry, 1998, p. 64). Similarly, a university could use its size to purchase solar PV panels in bulk and have the modules installed using a standardized technique and equipment to significantly reduce costs.

Wind power purchases in Pennsylvania

In order to make the operation of the university system more consistent with the environmental values promoted by the academic community itself, many higher education institutions are purchasing a fraction of their electricity from renewable energy resources. Kyoto compliance is often a university goal and can be achieved without any ECMs with the purchase of off-campus GHG emissions reductions in the form of offset or green energy purchases. Purchasing offsets is essentially providing funding to projects that reduce GHG emissions. The reduction in GHG emissions from these projects is then subtracted from the offset purchaser's total emissions to calculate net emissions. (Dautremont-Smith, 2003). An example of this approach has been started in Pennsylvania. A large multi-university initiative is underway in Pennsylvania in partnership with Community Energy Inc. to purchase wind-generated electricity. By 2003, 33 Pennsylvania Colleges and Universities committed to wind-generated power from Mid-Atlantic wind farms, the most of any state in the country. The majority of the thirty-three schools are members of the Pennsylvania Consortium for Interdisciplinary Environmental Policy (PCIEP, 2003). To begin this initiative, in 2001, the University of Pennsylvania, Pennsylvania State University, and Carnegie Mellon University made the three largest retail wind energy purchases in the USA, each for 5 percent of their electric usage. These purchases represented significant amounts of energy. For example, under the Pennsylvania State University agreement, the university will purchase 13.2 million kW-h of certificates annually, representing the annual output of more than three, 1.5-MW wind turbines. The State System of Higher Education and many independent Pennsylvania colleges and universities have also joined the initiative and made it possible by reducing market risk to develop several wind power projects in southwestern Pennsylvania. This same method of combining purchase power across several universities could be utilized to reduce market risk for solar PV manufacturers as a whole.

Photovoltaic energy production

Solar PV energy conversion is a sustainable and environmentally friendly method of producing energy (Pearce, 2002). The energy used to produce PV is recovered in 1-5 years (Pearce and Lau, 2002). PV electrical production also discharges no

greenhouse gases, such as carbon dioxide, so it will help offset emissions that contribute to global climate destabilization. International cooperation and technology investment over the past 25 years has resulted in fantastic gains in solar PV cell performance. Solar cells made from a variety of materials have demonstrated efficiencies > 10 percent and are currently manufactured globally. As the technological proficiency of the solar cell industry matured the total shipments of solar cells increased rapidly. The world PV installations in 2004 rose to 0.93 GW ($\text{GW} = 10^9 \text{ W}$), representing growth of 62 percent over 2003 installations and the consolidated world production of PV increased to 1.15 GW (Solarbuzz, 2005). This growth rate, while impressive, must be kept in context of the global energy market. In 2000, the peak electrical generation capacity in the USA was 825 GW while the cumulative total global installed solar PV was less than a single GW. In the last few years the market has surged although it is still a tiny fraction of the overall global energy supply.

Mass production
of solar
photovoltaic cells

429

Just as the price of commercially available computers plummeted from millions of dollars to only several hundred when in mass production, as the production volume of solar PV cells increased the price per module fell rapidly from the mid-1970s to the present. The 1980s and 1990s displayed an unremitting price reduction of 7.5 percent/year during which the average worldwide production of modules increased by 18 percent/year (Shah *et al.*, 1999). The economic figure of merit for a solar PV module is the price per peak Watt (\$/Wp). Watt peak (Wp) is the power output in Watts of a solar PV module when it is illuminated under standard testing conditions: under a very high and direct irradiation of $1,000 \text{ W/m}^2$, one type of solar spectrum (AM 1.5) and under a module temperature of 25°C . Although, currently (for a short time) the prices are increasing because of limited supplies of purified crystalline feedstock (Gartner, 2005), the price per Watt peak has fallen from over \$20.00/Wp to 3.71/Wp as of January, 2006. Unfortunately, the cost of solar electricity from fully installed systems at even \$3/Wp is \$0.09/kW-hr, which is still not competitive with the average cost of electricity in the USA of $\sim \$0.08/\text{kW-hr}$ or the production costs of less than $\sim \$0.03/\text{kW-hr}$ (Energy Information Administration, 2005). The Long-term goal of the US Photovoltaic Industry is to bring PV modules to less than 50 cents per Watt (US Photovoltaic Industry Roadmap, 2003). Although, it should be noted that solar PV electricity could compete on a level-playing field with the bulk generation of fossil-fuel generated electricity, if the price of installed solar systems can be brought down to $\sim \$1/\text{Wp}$. At this price, the payback time from savings for a consumer's electric bill is about five years in locations with high utility costs in the U.S. (e.g. $\$0.12/\text{kW-hr}$) and is much shorter in Japan and Germany with rates $\sim \$0.20$ per kW-hr. By reducing payback times the demand for solar PV panels on residential and commercial rooftops would be expanded from the current niche market to a significant global energy source.

The Solar City factory and economically competitive solar electricity

Striving for the ambitious target of $\$1/\text{Wp}$ for installed PV at first seems beyond the capabilities of the current solar PV technology, but can be reached by a massive scale-up of solar cell manufacturing facilities. Keshner and Arya (2004) propose a factory capable of making 2.1-3.6 GW/year named a "Solar City factory", which would integrate several current separate industries to convert raw materials into the components of solar PV systems on site. In essence a collection or system of sub-factories housed with the Solar City, would possess equipment and processes

sized, dedicated and optimized to produce only solar PV systems. The Solar City factory would obtain enormous cost decreases by utilizing five key principles (Keshner and Arya, 2004):

- (1) Utilize durable long-lasting substrate, packaging, and mounting materials. The non-active materials making up the panels must survive for the full life-cycle of a solar PV array (normally warranted for 25-30 years) on the outside of buildings, exposed to full sun, temperature and humidity cycles and in all relevant climates.
- (2) Transportation and handling of all materials would be minimized. In the Solar City, clean tunnels between equipment could be fully automated and used rather than standard clean rooms to eliminate handling within the factory to reduce cleaning, breakage and costs while improving the yields of the solar panels.
- (3) The materials necessary for the construction of the panels will be dedicated and optimized for solar panel production (e.g. substrate glass specifically manufactured without iron for solar cells can increase the sunlight entering the cell by about 15 percent).
- (4) Schedule and utilize rotating planned downtime for cleaning and maintenance of production equipment by using multiple lines of identical equipment. By minimizing unplanned downtime and having access to planned equipment maintenance the cost of the equipment, and the cost of maintenance and operations would all be less than standard solar production facilities.
- (5) Maximize utilization rates for high purity input materials and minimize use of rare materials. These steps will both reduce costs directly and improve availability of rare materials for some types of solar cells (e.g. tellurium, selenium and indium).

With piecemeal increases in production only part of the above benefits would be realized along with only a fraction of the cost decreases.

Economy of scale can be used to compete with fossil fuel power plants as an electricity source on a scale much smaller than a multi-GW Solar City factory. Several authors have argued that even a 100 MW peak (million peak Watts or MWp) thin film amorphous silicon PV plant would drop costs far enough to compete directly with conventional electricity in some grid-tied markets (Schramm and Kern, 2000; DeMeo, 1999; and Payne *et al.*, 2000). Payne *et al.* (2001) show that installed amorphous silicon solar cells could fall under \$3/Wp (AC) with a market 80X larger than the production facility of 100 MWp plant once financing, capital equipment costs, direct and indirect manufacturing costs, installation, power conditioning, operation and maintenance costs, and tax benefits are all taken into account. The enormous market generated from the first amorphous silicon 100 MWp/yr plant could then cause a positive spiral effect and largely increase the market for solar panels. A 100 MWp per year amorphous silicon fabrication plant is well within reach of our current technology and even medium sized solar cell manufactures; unfortunately industry appears to be reluctant to take even such a small a risk. This underscores the necessity of identifying a secure market for solar PV, so either a 100 MWp thin film plant or a more formidable multi-GWp Solar City factory will be constructed.

Current solar photovoltaic applications at universities

Universities may be able to provide such a large market based on their early adoption of solar photovoltaics in some applications. Solar photovoltaics have long been integrated into educational outreach at universities. The longest-running research project at the EcoVillage in Ithaca has been the development of solar PV systems for educational purposes. Students designed, produced construction documents, welded together the components, produced instruction manuals, and have given public lectures on the development of mobile solar PV systems on standard utility trailers. The solar trailers have proven very useful as interactive demonstrations both off (e.g. power music for student hot spots) and on campus in environmental science, chemistry and physics classes (Allen-Gil *et al.*, 2005).

Several other universities have already begun experimenting with solar photovoltaics in both modest installations for safety phones, irrigation pumps, parking lights and rooftop installations wherever financially possible. For example, there was an integrated solar PV/wind powered street light installed on the University of Glamorgan campus in Wales, used to provide lighting near to student accommodation buildings (Price, 2005). The University of Texas (Houston) installed a 20 kW photovoltaic system to provide daytime lighting to a parking garage. This initiative received media attention since it was the largest installation in the gulf coast area at the time (Bandy, 1998) and Georgetown University annually saves \$45,000 on photovoltaic panels installed on its roof (Eagan and Keniry, 1998, p. 28). A representative sampling of other university arrays include: a 5 kW modular PV roof on the Royal Tyler Theater at the University of Vermont, a 12 kW PV roof on the Jarecki Center at Aquinas College in Grand Rapids Michigan, a 14.1 kW PV Screens and roof on Instituto de Energia Solar at the Universidad Politecnica de Madrid, a 18.8 kW PV screens and roof system at the Technical University of Munich in Germany, and a 54.3 kW PV screens and roof at the Jubilee Campus at the University of Nottingham in Great Britain. Many other systems can be found at the International Energy Agency (n.d.).

Reducing market risk with university green purchasing

A capital investment of ~\$600 million is necessary to construct such a Solar City factory (Keshner and Arya, 2004). Although both semiconductor and flat panel display industry invest over a billion dollars on their factories and a single nuclear power plant construction costs can be more than a billion dollars, this level of exposure is a substantial investment for the solar industry, which has historically had a relatively high market risk because of volatile energy prices and widely swinging government support. A method of providing reduced risk must be employed to accelerate the construction of such a Solar City factory or a 100 MWp thin film plant. Following the examples presented for ESCOs, bulk commodities, and wind power in Pennsylvania, the university system could provide the market that could reduce the PV fabrication investment risk.

Both the US higher education system alone and the world university system could have a significant catalytic effect on the super-mass production of solar PV cells. This is due to a combination to their numbers, buying power, and ecological responsibility. In order to obtain a semi-quantitative analysis for the impact of the higher education on a solar PV production consider that in the 2002-2003 academic years there were 4,168 postsecondary institutions of higher learning in the USA made up of 1,712 public schools and 2,456 private schools (IPEDS, 2003). To guarantee the entire first year of

production from the thin film plant the US universities would only need to commit to purchase a 24 kW PV system each. To put this number in perspective, Clarion University of Pennsylvania is currently covering a small fraction of its new Science and Technology Center with a 30 kW of building-integrated amorphous silicon thin-film photovoltaic panels. Even at modern efficiencies this will only cover ~7,000 feet of roof area an almost insignificant fraction to both the roof area of the campus and the cost (<1 percent) of construction of the building. The project will also fund an information kiosk and solar energy exhibit for the grand entryway of the building. The solar panels and kiosk will educate thousands of college students (many themselves future teachers) and community members. Thus, this project will not only reduce air and water pollution by offsetting coal-fired electricity, but will be a highly-visible proof of the viability of solar PV electricity in western Pennsylvania, an area with solar fluxes comparable to Alaska. Although, all US universities are not in the financial position to invest the necessary amount for a 24 kW system (typical systems range in price from \$5/Wp to 8/Wp installed), only 1,000 American universities would need to commit to 100 kW.

Universities catalyzing the first, Solar City factory

The university system providing the entire first year market for the Solar City factory is more challenging. Each US university would need to provide between 500 and 864 kW (or 16-29 30 kW systems). The global university system, however, makes the scale somewhat tractable. The world list of universities and other institutions of higher education includes information on 16,000 institutions in over 180 countries (International Association of Universities, 2004). If all the world's higher education institutions provided a solar PV market commitments of only 131-225 kW (or 4.4-7.5 30 kW systems) per institution would be necessary. At the photovoltaic industry planned growth rate the GW/year production of solar PVs would reach the level of the Solar City somewhere between 2008 and 2011. At the more robust growth of 62 percent observed in 2004, the demand of the production of a Solar City factory could be reached in as little as two years. This would be the total global demand and all current and planned production facilities excluding the Solar City could meet that demand. A focused effort from the university community would make it possible to construct truly large-scale dedicated solar PV factories rather than follow the piecemeal production increases currently observed in the industry.

Universities could purchase solar PV systems to offset a fraction of the electricity they needed for operations. A university could feed the electricity generated by their solar power arrays directly into their buildings. In the event of a sunny day with low usage within the university, energy could be fed back onto the grid. The average university would still use a net amount of electricity from the grid. This concept has been instituted in several US states and in countries outside of the US. With net metering electricity (measured in kW-h) delivered to an electrical provider from a university PV system are subtracted from the kW-h delivered from the electrical provider to the university for each billing cycle. If the kW-h calculation is net positive for the billing cycle, the electric provider will bill the net kW-h to the university under the applicable price plan. If the kW-h calculation is net negative for the billing cycle, the electric provider will credit the net kW-h from the university at an average market price (or more likely an avoided cost).

Social viability of large-scale university solar photovoltaic purchases

Globally, the vast majority of the public is in favor of solar PV electrical production because of its numerous positive attributes most notably those revolving around environmental stewardship and energy independence. For example, in the USA, the Program on International Policy Attitudes found that the American public wants the federal budget for renewable energy research like solar PV to increase by 1090 percent (Kull *et al.*, 2005). This is enhanced on university campuses because younger and more educated individuals are more likely to be concerned about the environment and support renewable energy (Van Liere and Dunlop, 1980; Nord *et al.*, 1988; Howell and Laska, 1992). It is largely because of such positive attitude towards PV, particularly from the students, that university communities would be likely to participate in the numbers necessary to guarantee the market for a 100MWp/yr thin film plant and assist in generating the market for a Solar City factory.

Universities are also favored as the first to systematically catalyze mass production of solar PV panels because they are able to look above simple economics in their purchasing decisions to ethical values. For example, Jameton and McGuire report that for over 15 years University of Nebraska Medical Center purchasing department has been authorized to pay up to 15 percent more for contracts which met a list of environmental criteria (2002). Interestingly, they report that as a result, over the years, many such items have come down in price as more manufacturers and distributors recognized their requirements (Jameton and McGuire, 2002). Students have also contributed to university green purchasing practices. Students from many universities have voted on referendums to support allocating student fees or even raise student charges to purchase renewable energy. For example, in 2003, over two thirds of Eastern University's undergraduate students chose to spend an additional \$22 to purchase 37 percent of the university's electricity from wind farms (Community Energy, 2003). Likewise, the Connecticut College student body agreed to raise their activity fee by \$25 in 2001 to pay for the additional cost of purchasing ~44 percent of their annual electricity from green power (EAD Environmental, 2003). These student initiatives tend to have enormous support. At University of North Carolina at Chapel Hill students passed a referendum in support of allocating student fees for renewable energy at \$4/semester by 74.5 percent. These methods that universities have used in the past to support green purchases could be utilized to catalyze mass large-scale production of solar PV cells.

Conclusions

Due to a combination of their numbers, buying power, and pledged ecological responsibility, the university system could have a significant catalytic effect on the price decrease of solar electricity via the super-mass production of solar PV cells. To guarantee the entire first year of production for a thin film photovoltaic plant, which could compete in US markets nearly two orders of magnitude larger than its size, the US universities would only need to commit to 24kW of solar panels purchases each. If all the world's higher education institutions provided a solar PV market commitments of only 131-225 kW per institution with the photovoltaic industry planned growth rate, the GW/year production of solar photovoltaics would reach the level of the Solar City and be capable of producing solar electricity less expensively than current fossil fuel derived electricity. This price would have a positive-spiral effect

Mass production
of solar
photovoltaic cells

encouraging many consumers to switch to solar electricity and transition the global energy infrastructure to renewable energy. Universities would be able to make such an investment by:

- following ESCO contract examples based on long life cycles;
- buying in bulk; and
- combining their purchase power to spur demand as many Pennsylvania institutions did to encourage wind energy.

Finally, this method could also be useful for other ecologically beneficial technologies that demand a large investment such as fuel cell vehicles, living machines, and the infrastructure for a hydrogen economy.

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