Final Economic Analysis Report

University of Colorado
Solar Decathlon 2007

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Executive Summary

Since its inception, the Solar Decathlon has aimed to provide a real-world basis for workers, consumers and policy makers to transform the residential home industry from a 20^{th} century relic marred by colossal energy waste and pollution into a modern leader in the race to protect natural resources. Contest organizers hope to manifest an economic juggernaut retooled for the production of efficient, solar-powered homes on a massive scale and ask the next generation of decision makers to lead the way. Thus, with its 2007 competition entry the University of Colorado offers a prototype that is the result of an innovative industrial system geared to mass produce zero-energy homes that meet the strict demands of a competitive market and offer the same or a better level of comfort as any production home. Code named the REAL (Renewable, Efficient, Adaptive and Livable) System, it presents a methodology for the mass production and distribution of a mechanical core designed to be the heart of any solar powered home. It also outlines a procedure for mass customization and design flexibility that enables consumers not only specify appliances and finishes, but to determine entire floor plans and wall constructions appropriate for any geographic location, building site and living situation.

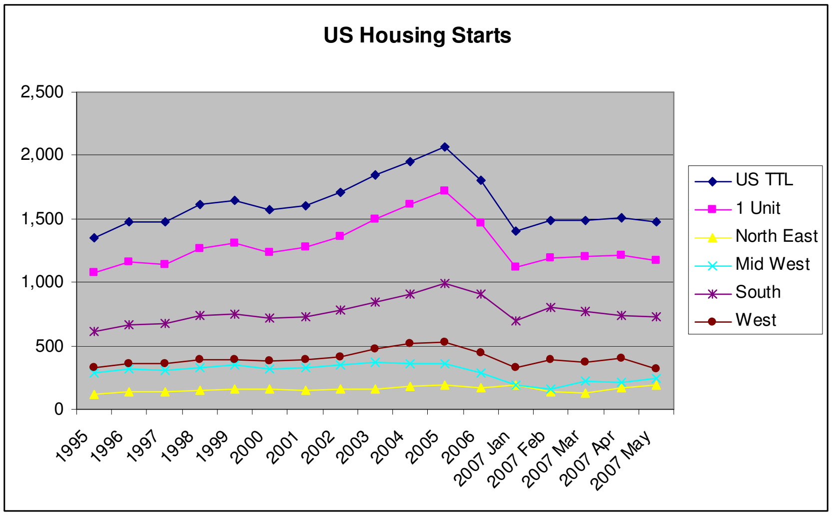
From Concept to Market: Creating a Product with Broad Appeal

Underlying our development effort is the guiding philosophy that to have a significant impact on global energy challenges and environmental problems, renewable energy and energy efficient building technologies must have very broad consumer appeal. As such, we approached the challenge of defining the REAL House System from the outside-in. Instead of organizing around an "idealized" zero-energy house design, we sought to first understand the general housing market and key trends within that market. Then, we strived to define and estimate the size of a consumer segment within the housing market that would be most likely to buy a zero-energy home. After confirming that a sizeable group of potential customers existed, we developed a series of key market differentiators that would propel the market viability of the REAL Houses among consumers and industry – even during a sluggish home. These drivers essentially became our team's design goals and acted to shape the REAL House System and the marketable prototype presented on the National Mall.

Market Research

The General Housing Market

The U.S. housing market has been in decline since 2005. In June 2007, seasonally adjusted annual housing starts in the West dropped to 352,000, down from a high of 583,000 in August 2005. Nationwide, the sale of existing homes is also sluggish dropping 1.2% to 6.67 million units in May 2007. The future housing forecast index, seasonally adjusted building permits for June 2007, dropped 7.5% indicating the national housing market will continue to struggle in the near future.[1]



Definition and Quantification of a Consumer Segment

Although the net-zero energy houses produced by the REAL House System significantly exceeds consumer expectations of what constitutes a green house, it is useful to consider the sentiments of consumers in the broader green building market space and adopt them as the target consumer segment. Typical consumers of the houses will therefore be females or married couples, (entering) middle-age, college-educated, and fall into a middle-income bracket.

Market research further indicates that there are explanations for consumer behavior in the energy efficient and environmentally-friendly housing market. Monetary incentives such as tax credits and an understanding of energy cost savings accrued over the life of the home help drive sales. Increasingly, LEED certification or similar state and local certification programs improve consumer understanding related to the benefits of owning such a home. Finally, increasing numbers of home buyers cite their desire to make a difference on environmental protection through sustainable buying habits.

2005 data on the Colorado market indicate[2] that 28% of all new homes in Denver Metro area were certified in the state "Built Green" program (which is being re-branded as "Built Better"). Statewide, 12% of new homes received this certification. As state programs become integrated with new national LEED for homes standards, it is likely that recognition amongst consumers of green housing options will increase. In 2005, nearly 40% of new home buyers in Colorado claimed that an environmentally positive certification for homes was a factor in their purchase decision.

According to a recent study in Colorado by the Home Builders Association of Denver[3], 41% of new home buyers are aware of green home certification standards, and 40% of these buyers are influenced by such standards. Therefore, 16.4% of new home buyers in a typical western state like Colorado can be categorized as possible buyers. Applying 16.4% to an estimated 25 million households in the American West, allows us to identify a market size of 4.1 million potential buyers. Applying this same calculus to 352,000 new home starts in 2007, results in a potential client base of 57,700 for 2007. Many factors will play into what percentage of that client base can be captured and how large the client base will be from year to year. Price will be the largest factor, but there are other important drivers that can be identified by analysis of key trends within the housing market. We chose three trends to study and from them derived specific design responses that met the market need associated with those trends with the goal of buoying our product throughout a sluggish housing market.

Key Trends within the General Housing Market

The REAL House System has been developed in response to three trends within the general housing market that will enable it to produce houses that will remain competitive throughout the housing market decline. These three trends and their responses are shown in the table below.

Market Trend/Need	**Design Response**
1. Demand for environmentally friendly housing.	Energy efficiency and renewable energy infrastructure.
2. Rising costs of labor, materials and land.	Mass production of modular mechanical core.
3. Demand for uniquely suited homes	Mass customization.

Trend 1: Environmentally Friendly Housing

In 2005, just 0.3% of all residential construction qualified as a "green built", which has a loose definition, but is generally used to describe homes that beat the local building code requirements for energy and water efficiency and include natural building materials in their construction. The green built market at this time was sized at $1.8 billion nationwide and projected to grow to at least $6.5 Billion by 2010.[4] Expectations for strong growth in this market abound as 70% of architects, engineers, contractors and building owners believe sales of environmentally friendly buildings will increase significantly in coming years.[5] Furthermore, LEED new construction projects are expected to grow four times by the end of this decade and increase by 25% per annum, thereafter. [6]

Fueled by rising energy prices along with state and federal incentives, energy efficiency improvements and renewable energy systems (such as photovoltaics) are gaining speed in most U.S. States. According to the Database of State Incentives for Renewable Energy, 48 states offer a form of solar or renewable energy incentive such as investment credits, rebates, sales or property tax waivers. In June 2007, Robb Crocker of BUILDER Online News Service reveals that "In the suburb of Rocklin, outside of Sacramento, Calif., solar-powered home sales are doubling the sales of standard... Families who purchase the solar-powered homes are reportedly saving up to $120 a month."

Trend 2: Rising Costs of Materials, Labor and Land and Modular Housing

In March 2007, the Association of Contractors estimated that by the end of the year, materials costs could be rising 6-8% and wages rising at a pace of 5%[7]. Production home-builders do better than smaller builders with the top 400 making an average margin of 23.3% in 2006[8], but this was a 4 point reduction from the previous year. Modular and prefabricated construction has been touted for decades as the future of production housing. By prefabricating only the core of the house, our production concept allows for tremendous construction efficiency and cost savings while overcoming challenges to market acceptance of prefabrication by insisting on high quality construction and materials, and allowing for architectural flexibility described in the next section.

Although market share of modular homes is still small, consumers have increasingly been drawn to modular housing because of its lower cost and increased speed of construction relative to stick framed homes. Modular homes including panelized and prefabricated factory built structures comprised 4.3% of new single family houses in the U.S. in 2005, but only 1.2% in the American West[9]. This market share is significantly higher in the eastern U.S. (where most modular builders are located), and stood at 11% of all new homes in 2005. Overall, the modular housing market grew 4% in 2005 and a total of 48% over the 1992-2002 time period.[10] This is compared to an overall growth in housing starts of 5.7% from 2004 to 2005 and 42.1% from 1992-2002.[11]

Trend 3: Demand for Uniquely Suited Homes and Mass Customization

Dr. Frank Piller, chair professor of management at the Technology & Innovation Management Group of RWTH Aachen University, Germany and faculty member of the MIT Smart Customization Group, defines Mass Customization as "a customer co-design process of products and services which meet the needs of each individual customer with regard to *certain product features*."[12] Recently, Mass Customization has seen the most visible success in the automotive industry with BMW employing advanced tooling techniques to offer a wide range of features.[13] Dell Computer, Nike, and eWatchfactories.com, are examples of companies in other industries that have made fortunes, or are banking their future fortunes on Mass Customization. For the REAL System, the customizable features would begin with appliances and interior design components. However, the idea of mass customization is extended with the modularity of the mechanical core itself that works in conjunction with virtually any floor plan and wall construction – prefabricated or not.

Key Market Differentiators Driving Market Appeal

A series of focus groups were held among team members and members of the Boulder, CO community who matched the target demographic or who will enter the customer segment in within ten years. In addition to the obvious differentiator of price, the following key market differentiators were identified and translated into design goals for the houses produced by the REAL System.

Responsiveness: A REAL House will blend into the natural environ of its site and react to a wide range of weather, offering comfort under any condition.

Integrated: A REAL House fits well into mixed-use communities designed to reduce sprawl where working, living and outdoor spaces exist in the same neighborhood.

Evolving: A REAL House has the capacity to adapt to meet the needs of present and future occupants and offer flexible use spaces.

Conscientious: A REAL House embodies the conscientious intentions of the occupants and neighbors, who want to reduce their impact on the environment.

Spacious: A REAL House offers a feeling of vastness but makes very efficient use of space, is comfortable, yet may be smaller than the normal American home.

Pricing

The REAL House System must produce houses that compete well against the homes of production builders. However, the avoided cost of energy must be considered. Higher capital costs are inevitable because of the expense of solar power systems, but will be offset by the avoided cost of energy. As such, we have limited the base cost of a mechanical module to $100,000 or less. A cost estimate for an entire REAL House is available in the section titled *Marketable Prototype Cost Estimate*.

Summary of Market Opportunity

In summary, the University of Colorado has created an industrial system geared to produce zero-energy houses that have a strong likelihood of garnering consumer acceptance in western U.S. housing markets. REAL Houses will satisfy growing consumer demand for environmentally friendly, energy efficient housing. Their net zero energy usage will excite consumers drawn to these benefits, and offer them prestige as early adopters and innovators amongst likeminded friends and family.

Our system is also poised for success due to our modular and mass customizable approach to construction. While, the entire house is not modular, the mechanical core is designed for pre-fabrication, making it marketable to builders of striving to meet virtually any design condition. The cost savings that can be realized by mass production of the mechanical spine will be significant. These savings help offset the costs associated with the advanced renewable energy systems and energy efficiency measures included in the prototypical design described in the next section. Modular builders will likely wish to use the concepts imbedded in the marketable prototype to offer consumers of modular homes a broader range of benefits.

2007 University of Colorado Marketable Prototype

A Pragmatic Approach for Market Acceptance

This competition challenges each team to design, build, and operate a small, solar-powered home on the National Mall in Washington, D.C. The Solar Decathlon seeks to provide real-world training for the next generation of engineers and architects, to promote the development of innovative solutions for sustainable building design, to transfer these solutions to a diverse building industry, and to educate the public about the energy solutions available in today's market.

Some of the constraints of the Solar Decathlon competition, however, pose a challenge for meeting these underlying objectives. Specifically, the competition rules and practical logistics call for homes that are small, lightweight, easy to transport, all-electric, off-grid, and completely covered with solar energy systems. Few of these competition artifacts exist in the market we seek to penetrate. While competition rules limit the floor area to about 700 ft^2 (70 m^2), most Americans require more living space - the average new home in the US has a floor area of 2349 sf[14].

While the competition is constrained by design, build, and transport requirements, the University of Colorado has chosen an approach that will increase the relevance of the competition to students, homeowners, the building industry, and the public.

Our marketable prototype seeks to provide real-world solutions for the real energy challenges we face – while honoring the constraints of the Solar Decathlon competition. Although the competition limits each team's home size to about 700 ft^2, the Colorado team is taking the approach of building a 2100 ft^2 full-size home and delivering a smaller competition module to Washington, D.C.

The competition module will represent the full house in the Solar Decathlon events. The module conforms to the constraints of the competition and includes only the kitchen, part of the living room, guest bedroom, bathroom, and an integrated hallway and mechanical room.

The full-size house includes three bedrooms, three bathrooms, a larger living room and a small family/office area. All building systems, including mechanical, electrical, and solar energy systems, are designed and sized for the house, rather than the module. All heating, cooling, and indoor air quality control systems will be sized for the full house, yet will allow modularity for the competition module. The PV system used for the competition will provide the full house with an appropriately-sized array to make it a net zero energy home.

Contest Criteria: Addressing Livability, Buildability and Flexibility

Criterion 1: Livability

Our team has sought to create a home that meets the highest levels of efficiency and economy by designing living space that maximizes the comfort and safety of occupants. The following attributes address our team's approach to livability.

Size:	At 2100 sf, the house meets the size expectations most American families.
Space:	Efficient design and opportunity for flexible uses of space.
Layout:	Presents a clear distinction between private and public spaces.
Envelope Thermal Performance:	Structural Insulated Panels and insulated windows facilitate comfort and energy efficiency.
Natural Ventilation:	Operable windows, vents enable cooling with cross drafts.
Indoor Air Quality:	Use of non-VOC and natural materials protect indoor air quality.
Design Opportunity:	Modular and prefab combined mechanical core with flexibility of floor plan.
Daylighting and Views:	Promote health and a connection to the outdoors.
Energy Cost Savings:	Facilitate the accumulation of wealth over time.
Carbon Reduction:	Energy savings result in lower green-house gas emissions.
Courtyard:	Allows for natural ventilation, light, privacy and a connection to nature.
Global Security:	Reduction in pollution and energy use support international stability.
Hedge against Energy Price Volatility:	Facilitates a consistent monthly energy cost.
Flexibility of Wall Constructions:	Allows for use of vernacular and local materials.
Heating and Cooling:	Heat exchangers provide heating and cooling for individual rooms.
Lighting:	Electric lighting is integrated with daylighting to provide an aesthetic environment promoting efficiency and dynamism.

Criterion 2: Buildability

Effective and efficient construction is a hallmark of the marketable prototype. The design of a modular engineering spine will create multiple benefits for builders, and subsequently, for home owners. The following explanations summarize our approach to buildability.

Mechanical, Electrical and Plumbing:	Centralized in a modular, pre-fabricated, structural core. No plumbing or ducts are installed outside of the core, eliminating losses and reducing time and the cost of construction.
Design Flexibility:	The mechanical spine may be stacked one on top of the other, may have elements attached to it and may support weight load on top or attached laterally. This provides flexibility in building and designing the envelop of the house.
Factory Benefits:	By prefabricating a modular engineering spine, these core functions of the house may be built under controlled conditions. This portion of the house can be pre-configured, pre-wired and pre-plumbed, all of which reduces the need for contractors on-site—a tremendous advantage for efficiency and cost control during construction. Also build under controlled conditions = no delay in schedule.
Off the Shelf Components:	Low risk and easy maintenance of systems.
Structural Insulated Panels:	Fast construction with exceptional insulation and low infiltration.
Shipping Container:	To promote the reuse of materials, our team is employing used shipping containers to house the mechanical spine. This novel idea was spurred from consideration of the obvious waste created when contents of a shipment were separated from the container with no further use for the container itself. This element of building design will help meet the goals of potential customers who are dedicated to reusing and recycling materials. Because ISO standards ensure a common size for all shipping containers, the building design benefits from this accepted regularity. Of course, shipping containers don't

	have to be used to house the mechanical core if their market appeal is not enduring.
Building Integrated Photovoltaics	Most current PV systems are installed over the roof, with additional cost for the PV support system and framing. Our design showcases a prototypical BIPV system in which the PV system is the weather proof membrane of the roof. This allows full-size PV modules from a variety of manufacturers to be coated and mounted without additional shingles underneath. Integration eliminates redundant construction elements and improves overall cost effectiveness.

Criterion 3: Flexibility

The marketable prototype is designed to accommodate the wants and needs of a wide range of potential buyers. Once again, the modular, mechanical core and flexible envelope approach helps to achieve flexibility for architects, builders and buyers. The following explanations summarize our approach to flexibility.

- Our team's concept is based on a pre-fabricated, modular, mechanical spine that contains the core engineering functions of the house, with the remainder of the house open for a virtually unlimited range of design and construction options. In a sense, the CU submission at its core is based in the concept of a need for flexibility in order to be viable in an existing housing market.

- Additional mechanical spines could be added on to the house during or after construction if it were demanded by the larger house envelop.

- Because the larger envelope is inherently flexible, the size and cost of the house can be adjustable to meet the needs of a potential buyer.

- A system comprised of structurally integrated panels (SIPS) for walls, floors, and roof structure provides architectural flexibility while retaining modularity.

Sustainable Competitive Advantage

Due to the nature of competitive markets, a business will struggle to survive and remain viable if it does not possess a sustainable competitive advantage. A business has such an advantage if it possesses technical expertise, intellectual property, brand equity, or other characteristics that allow it to keep competitors at arms length.

Cost competitiveness can be achieved through economies of scale created with mass production of our mechanical core. This will help differentiate REAL Houses among competitors. Furthermore, the ease of transportation of the mechanical core on rail, ship or truck, allows for efficiencies in construction that will be difficult to match by other companies that offer green or modular housing. Finally, a net zero energy house is a significant step over most houses that offer elements of efficiency, but fail to reach the standard of energy independence. This further differentiates the REAL Houses and will help sustain a niche in the marketplace.

Conclusion

It is exciting to think that the work of students across the country can help drive housing markets toward greater sustainability. In the course of this Market Appeal study, we have examined the role of important players in the housing industry, focused on customer characteristics, identified potential market size, and considered the market opportunity. We contend that the REAL House System and REAL Houses stand an excellent chance of competing in current markets because of its unique ultra-efficient and environmentally friendly characteristics which are aligned with current trends in consumer tastes. In addition, we are pleased that the market size estimate indicates we have over 7.5 million possible customers who live in the western U.S. REAL Houses will appeal to buyers, builders, communities, policymakers and financiers. Ultimately, our efforts to create a house that is at once livable, buildable and flexible will help us to sell to early adopters of innovative technologies in this immerging market, an essential aspect to the market viability of the REAL House System concept.

BIPV Economic Analysis

Executive Summary

With the exception of nuclear and geothermal power, the sun is the sole source of energy for all living things on the planet. Photosynthesis is the mechanism by which the sun's energy is put into the food we eat, the gasoline we put in our cars and the coal we put in our power plants. The sun also drives the wind that turns our wind turbines and creates the rain that fills our dams. During clear days the earth's surface receives approximately 1000 W per square meter of energy from the sun, enough power to light forty 25 W compact fluorescent lamps at once. However, our technology, the laws of thermodynamics and the simple reality of night and overcast skies prevents us from capturing all but a small percentage of this power and not necessarily when we need it. This coupled with price competition from entrenched energy sources, causes us to strive to optimize the efficacy of our solar power production systems. Out of this effort has come a promising category of systems described as Building Integrated Photovoltaic (BIPV). Now, BIPV system are more expensive than standard PV systems, but with advances in technology described in this report, we expect BIPV to not only become the price leader, but also fall in installed price to $1/W or below by 2015.

Six simple variables determine the value of a BIPV system:

1. Energy Production
2. Energy Storage
3. System Lifetime
4. Site Compatibility
5. Consumer Acceptance
6. Energy Cost

As in any complex system, each variable influences the others and the work required to determine an optimal system design is non-trivial. However, with the help of computer modeling, knowledge of markets, consumer appeal and expected near-term in advances in applicable technology, the University of Colorado has designed a BIPV system that will compete well with electricity and heat produced by any other means. The following is a description of the system organized by the variables listed above. The system we have built for competition on the National Mall approaches the design described here, but is not totally consistent because of certain technologies that have not yet come to market. Differences between the system built and the system designed are noted.

1. **Energy Production**

   To make the best use of area and materials, Colorado's BIPV system produces both electricity and heat at the same time using the same area. The system is layered with the PV array floating directly above a heat absorption manifold.

a. Photovoltaic Material

The monocrystalline PV material selected for use on the National Mall from SunPower Corporation produces the most power per area of any similar product on the market. However, the selection of PV material is a function of area available, material efficiency and cost. Advances in PV material design are expected and as such, our BIPV system is prepared to handle any PV material without redesign.

By 2015, it is likely that thin-film technology will advance to such a degree and increase in production to such a volume, that we will see manufacturing costs of approximately $0.30 per Watt. In fact, First Solar Corporation has stated that they are already producing thin-film PV at $1.40 per watt.[15] In the chart below, Bolko von Roedern, senior scientist with the National Center for Photovoltaics and NREL, shows a linear correlation between price per Watt of PV. As can be seen in the chart, simpler manufacturing techniques and fewer materials, make thin-film PV less expensive than crystalline PV. In a report to be released in August, market research group NanoMarkets predicts that by 2015, thin-film shipments will reach 500 MW per year.[16] Applying Bolko's correlation, we see expect that the manufacturing cost of thin-film will be $0.30/W by 2015.

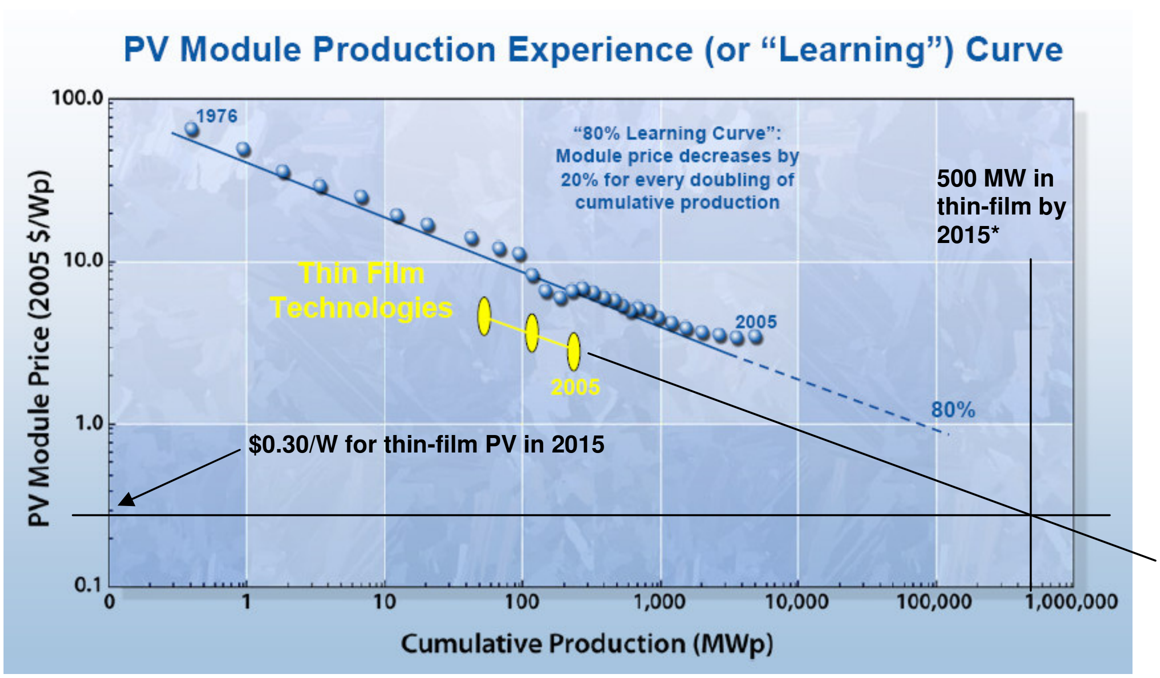


Figure 1: *PV research activities in the US* by Bolko von Roedern, National Center for Photovoltaics, National Renewable Energy Laboratory
* NanoMarkets report on thin-film, August 2007

b. Balance of System

Today, the components that make up the inverters, maximum power point trackers and other devices that condition photovoltaic power cost approximately 14% of the total cost of a solar power system[17]. And, and often unnoted maintenance expense is the replacement of large capacitors in the inverters that is required every five to ten years which can be 10% or more of the installed price of the PV.

In a decade this equipment will likely be replaced by "on-board electronics" integrated directly into the PV cells or solar panels. Work funded by the Solar America Initiative is about to get underway at the University of Colorado and partner organizations to miniaturize inverter and maximum power point (MPP) trackers. The inverter components will use new, light-weight and inexpensive materials for capacitors and microchips will be designed to do the MPP directly on the PV cell or panel. The cost of these components will experience an economy of scale discount that we are accustomed to in the electronics industry bring making the price pennies per Watt. System lifetime is also expected to increase to match the standard warranty life of solar panels, 25 years. Another interesting benefit is that this technology will also obviate the requirement that a solar panel array be in a single plane. Instead, maximum power point trackers placed on the backs of small sections of PV will enable arrays to be multi-planar, following the shape of a variety of common roofs.[18]

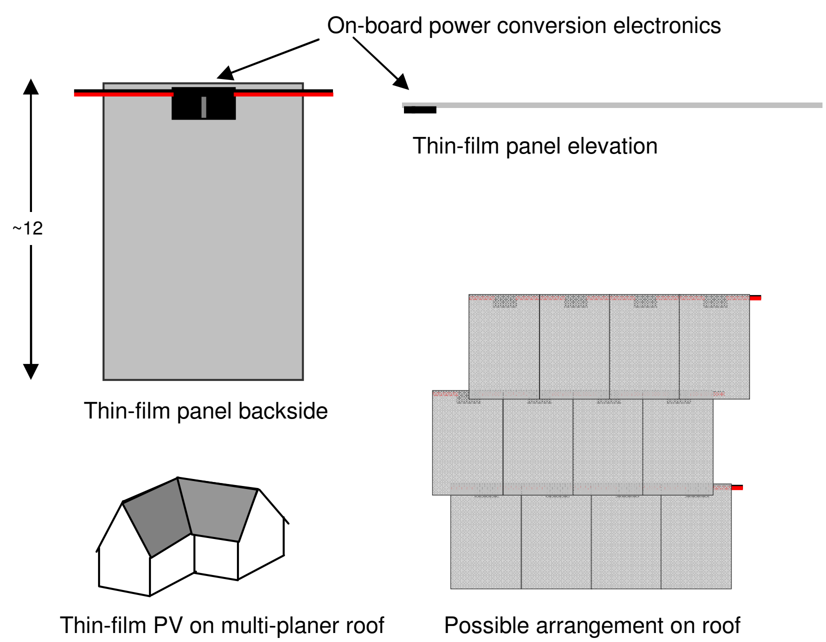


Figure 2: Future thin-film PV panels with on-board power conversion electronics.

c. Solar Thermal Absorption

Heat is absorbed through a simple manifold made of aluminum flanges connected to copper pipes that, depending on the potential for freezing, use water or a non-toxic solution of propylene glycol to carry the heat into the house. Unlike PV, this technology is already inexpensive and effective. However, research at the National Renewable Energy Laboratory suggests that system cost and reliability can be improved through the use of plastics instead of metals and by leveraging thermosyphons to eliminate some if not all pumps.

d. PV Efficiency Boost

PV material produces more power as it cools, so as the heat absorption manifold takes heat from the PV material, the efficiency of the system will increase. This efficiency boost has been considered in the energy model used for the Levelized Cost of Energy calculation stated later in this report.

2. Energy Storage

a. Electricity Storage

No remote storage system is recommended for use with Colorado's BIPV system. Instead, it will be customary for the BIPV system to be connected directly to the utility grid so any power not used on site immediately will be used somewhere else. It is important that the connection be metered using "net-metering" so any power sent onto the grid is subtracted from power taken from the grid at another time.

It is also important that time-of-use (TOU) electricity rates be considered as a value proposition for home owners within the next decade. TOU rates price electricity based on times of peak-demand. Hence, energy purchased from the grid in the afternoon is much more expensive than energy purchased in the morning or at night, primarily because of the popularity of air conditioners.

TOU pricing is only available to commercial customers at this time, but in ten years, we predict that it will be common for residential consumers. And, since many PV systems produce the close to peak power around the time of peak-demand, the avoided cost of electricity otherwise drawn from the grid will be high.

b. Heat Storage

The most straightforward method to store heat is in water. As such, the system will be combined with appropriately sized thermal storage tanks. In many climates, the heat absorption manifold will produce enough heat to avoid buying any natural gas, the most common source of heat. In fact, in some climates the system will produce more heat than required during some times of year. Fortunately, the liquid circulation in the manifold can be reversed during those time and heat rejected through the panels into the black body of the night sky.

3. **System Lifetime**

   The longer the lifetime of the system, the better the value. Consistent with manufacturer warranties and observed functional lifetimes, we expect the PV and heat absorption manifold, piping and wiring to last 30 years. Unfortunately, capacitors contained in the inverters used for the system on the National Mall will only last five to ten years. However, as mentioned previously, inverters are expected to be developed within the next ten years will likely have lifetimes similar to that of the rest of the system.

4. **Site Compatibility**

   Rather than be added to an existing roof, Colorado's BIPV system is intended to be designed as the south-facing roof. As such, in most scenarios ample roof area will be achieved by simply orienting the house properly on the site and specifying a large-planed flat roof. However, in cases where this is not possible, Colorado's BIPV system will eventually make use of the previously mentioned new inverter and maximum power point tracker technology being developed by the University of Colorado and other partners though the Solar America Initiative that will make it easier for the BIPV system to become multi-planer, following different angles of a roof.

5. **Consumer Acceptance**

   Consumer acceptance is determined by cost, aesthetics and trend. The BIPV system is uniquely qualified to be mass produced at a low cost and compete well with competitive energy technologies. From an aesthetic perspective, we are employing the value-proposition of "mass customizability". Mass customizability is the ability for a product to be mass produced in a factory, but still follow customer specifications. Advances in tooling technologies will enable customers to purchase Colorado's BIPV system in shapes that match their roofs. Although a wide range of PV cell colors are not available now and will probably not be available in the future because of the nature of the PV phenomenon, colors of the BIPV frames can be easily specified.

Levelized Costs of Energy Analysis (BIPV and EEM)

Introduction

The following is an analysis of the value of the BIPV system and Energy Efficiency Measures combined over the lifetime of the system. Inflation and the nominal interest rates have been considered. Two scenarios were analyzed:

> Scenario 1: The BIPV and EEM systems for the Marketable Prototype demonstrated by Colorado on the National Mall.
>
> Scenario 2: The future BIPV system that we hope will be available in 2015 that was described in the previous section of this report.

Assumptions and Notes

1. $1/W cost of installed PV and BOS in 2015 follows rationale described in BIPV Economic Analysis for the cost of thin films and balance of system.
2. EEM cost estimates are derived from a comparison between the Building America Benchmark list of estimated costs, and similar items listed in the Marketable Prototype Cost Estimate
3. Incremental EEM costs over the Building America Benchmark for 2015 were assumed to be similar as today. However, it is important to know that this is a "worst case scenario. One would hope that building codes will be improved to such a degree that the Energy Efficiency Measures proposed in the 2007 analysis will be commonplace in 2015 and hence, have no added cost.
4. PV sizes are adjusted for location based on solar resource and energy requirements derived from model.
5. PV production and building loads were taken from energy models of the marketable prototype developed for each location.
6. Operation and Maintenance costs were assumed to be very low even with the replacement of inverters in years 5 to 10. $100 a month was used as a conservative cost estimate.
7. Least Cost of Energy results were calculated using the LCoE tool provided by Solar Decathlon contest organizers.

Special Note on the Value of Solar Thermal Power

The BIPV system developed produced heat that is used directly to heat the house and domestic hot water. In most instances, the heat produced by thermal portion of the BIPV will displace natural gas.

The value of the thermal portion of the BIPV system can be calculated in a similar manner as the Least Cost of Energy for the PV and EEM or simply integrated into that calculation. The thermal portion installed cost is approximately $3000 and the useful heat it produces is predicted from the energy model developed for this project. (However, this heating estimate was not available upon the writing this section.) As such, the LCoE estimates below would be lower in reality because of the displacement of natural gas by the BIPV system.

Scenario 1: LCoE with Crystalline PV System used in Marketable Prototype

	Boulder	**Phoenix**	**D.C.**
Total rated DC power output at STC conditions (kW)	6391	7513	8815
Total PV and BOS cost	$57,518	$67,615	$79,335
Total incremental cost above (or below) benchmark	$21,509	$25,614	$30,033
Operation, etc EEM (per year)	$100	$100	$100
Gross annual load (benchmark) (kWh/year)	30,240	28,899	29,555
Gross annual load (prototype) (kWh/year)	8,051	10,425	9,405
PV system energy production in 2007 (kWh/year)	8,000	10,515	13,675
$LCoE_{PV}$ (per kWh)	**$0.52**	**$0.47**	**$0.42**
$LCoE_{EEM}$ (per kWh)	**$0.05**	**$0.07**	**$0.07**
$LCoE_{UTIL}$ (per kWh)	**$0.08**	**$0.08**	**$0.08**
$LCoE_{WH}$ (per kWh)	**$0.16**	**$0.20**	**$0.22**

Scenario 2: LCoE with Future Thin-Film and BOS Available in 2015

	Boulder	**Phoenix**	**D.C.**
Total rated DC power output at STC conditions (kW)	6391	7513	8815
Total PV and BOS cost	$6,391	$7,513	$8,815
Total incremental cost above (or below) benchmark	$21,509	$25,614	$30,033
Operation, etc EEM (per year)	$100	$100	$100
Gross annual load (benchmark) (kWh/year)	30,240	28,899	29,555
Gross annual load (prototype) (kWh/year)	8,051	10,425	9,405
PV system energy production in 2007 (kWh/year)	8,000	10,515	13,675
$LCoE_{PV}$ (per kWh)	**$0.17**	**$0.15**	**$0.14**
$LCoE_{EEM}$ (per kWh)	**$0.05**	**$0.07**	**$0.07**
$LCoE_{UTIL}$ (per kWh)	**$0.09**	**$0.08**	**$0.07**
$LCoE_{WH}$ (per kWh)	**$0.08**	**$0.09**	**$0.10**

Conclusion

The Levelized Cost of Energy (LCoE) for the whole house with no PV and no EEM added is $0.08/kWh, the national average. As can be seen in the Levelized Cost of Energy tables, Scenario 1 performs poorly relative to the national standard ranging from $0.16/kWh in Boulder to $0.22/kWh in Washington, D.C. However, it should be noted that in some states suffering from very high energy prices, these results are nearly competitive. Add the value of reducing environmental impact and government incentives, and the cost of the system become palatable to many consumers.

Now consider, the thin-film BIPV system anticipated for 2015 and described in the previous section. Even with the same cost of EEM, the LCoE of the system is predicted to be $0.10/kWh or less for the three cities considered – just a cent over the price energy predicted by the Energy Information Administration for that year. Time will tell if the $0.10/kWh will come to fruition, but Colorado is bullish about the economic success of the BIPV system proposed by the year 2015

Marketable Prototype Cost Estimate

Home Cost Estimate

The current cost estimate for the 2,100 sf prototype is shown in the following tables. The total costs include a land price of $100,000, economies of scale discounts for mass production (10%-25% depending on component), and cost modifiers based on ICBO (International Conference of Building Officials) standards for the locations listed.

Estimated Cost of Materials and Construction	
$231,105	Colorado
$238,599	Arizona
$247,298	District of Colombia

Estimated Land and Fees	
$96,059	Colorado
$94,118	Arizona
$102,851	District of Colombia

Estimated Development Budget	
$392,985	Colorado
$400,672	Arizona
$420,581	District of Colombia

Background

The construction cost estimate presented was performed with the purposes of calculating construction costs for a marketable prototype model of the house. This prototype consists of the same layout that the competition module has, plus a new wing added to the north of the house. The complete house adds up to a total square footage of 2,100.

On the whole, the addition to the competition module is made up of another shipping container and additional assemblies of structural insulated panels (SIP's) that conform the floor, walls and roof of the new annex, just as the competition module was designed and built. Similarly, a panel of windows makes the fascia of the south part of this new structure.

With regard to construction operation and assemblies, the marketable prototype possesses the same characteristic as that of the competition module. Unlike the competition module, however, certain components and materials such as mechanical parts, lighting and plumbing fixtures, appliances, casework and countertops and control systems, will be different in order to meet market prices and practices for mass customization. In this light, certain components of the competition module are specially customized for the special occasion and others are experimental systems which costs are prohibited for an average family to afford.

Assumptions and Methodology

The cost estimate was prepared using MasterFormat 2004 standards and divisions, a software package called Timberland Estimating, and a cost database called Residential Cost Data 2007 published by RS Means. Predefined construction assemblies were used wherever possible. However, when no assemblies provided by these sources matched the prototype, assemblies were customized to the actual specifications of the house using individual components and materials.

Materials with average prices were selected as long as they complied with the energy efficiency design requirements for the house. Because of the house's unique shape, some customized items were necessary that carry a slightly higher in price than those obtained for average homes. Also it should be noted that many components were chosen to satisfy ADA requirements and environmental protection. Thus, our home would be characterizes in the Custom-Luxury variety.

Special Considerations

Foundation

The foundation system and its cost will depend on the type of soil the house is going to rest on, so a typical square-foot estimate for a 1-1/2 story homes was used. However, by considering that our home uses light systems and components, as is evidenced by the jack-foundation system; the foundation cost was reduced by 50%. The rational was based on the fact that the reference's assumptions offered a clearly over-designed foundation system.

Glazing

Windows for the competition module are more expensive than the normal house because they are customized, have special glazing and fiber-glass framing. Thus, a 25% discount was applied. However because the windows are still double paned and insulated, the glazing for the prototype is still more expensive than most glazing on the market.

Lighting

The competition module uses dimmable lighting and controls that have extremely high costs when compared to average lighting. Indeed, our actual lighting cost is based on high-end commercial construction and not on residential construction. To reduce the costs for the marketable prototype, an analysis was done that determined that overall lighting costs could be reduced by a 75%.

Solar Power System

The highest efficiency and most expensive solar power system was selected for the competition house along with additional power electronics that were required for use with the battery banks. As such, the cost of the solar panel system for the marketable prototype was reduced to a market average.

Cost Adjustment for Location

The following cost adjustments from the International Conference of Building Officials were applied to the national average prices provided by R.S. Means.

Boulder, CO	99%
Washington, D.C.	106%
Phoenix, AZ	97%

Mass Customization and Production (Mechanical Spine)

For the marketable prototype, the mechanical spine is formed by two shipping containers that contain all appliances, HVAC systems, bathrooms, plumbing, major electrical elements, countertops, and other important finishes. These cores can be mass produced under controlled environments where manufacturing practices such as lean construction can be used, and where productivity ratios can be considerably increased. Large risks that result in delays and extra costs such as bad weather and human error are also nearly reduced to nearly zero. Site costs are also reduced as labor is not required on site as long as under normal circumstances. As a result, the mechanical equipment costs and some overhead construction costs of the marketable prototype are reduced significantly.

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