Low Cost ZNE! Implementation of a Zero Net Energy Community at UC Davis' West Village

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ABSTRACT

West Village, a multi-use development underway at the University of California, Davis, is a ground-breaking sustainable community that will incorporate energy efficiency measures and on-site renewable generation to achieve community-level zero net energy (ZNE) goals[1][2]. What makes the West Village project unique is that, for its single-family homes, UC Davis is seeking to achieve these goals at no higher cost to homeowners or the project developer. This paper examines the feasibility of meeting the West Village's energy and economic goals, arguing that both are within reach. California's Big Bold Energy Efficiency Strategy will require that all new residential construction be ZNE by 2020[3]. This study provides a detailed look at how a real project with over 300 homes might achieve this goal at no (or very little) additional cost.

Introduction

West Village, a planned ZNE community at UC Davis, is currently in the design phase for 343 single-family homes that will house faculty and staff. UC Davis hired a consultant team[4] to develop for the single-family home portion of West Village a ZNE roadmap that would enable the West Village community to serve its annual energy consumption with renewable resources at no higher cost to homeowners and the project developer.

This paper summarizes the roadmap and rationale for key decisions for achieving a ZNE community at the West Village. To the extent feasible and cost-effective, the roadmap sought to incorporate community-scale resources, create integrated technology applications, locate generation onsite, and design solutions that are replicable. The roadmap also aimed to describe potential ZNE pathways under multiple sources of uncertainty, providing a framework for accommodating change. A business model analysis identified successful ZNE business models under a range of technological, regulatory, and economic scenarios.

Approach

Our approach focuses on three core elements: (1) energy efficiency design and evaluation; (2) solar PV design and costing; and (3) financial modeling and regulatory

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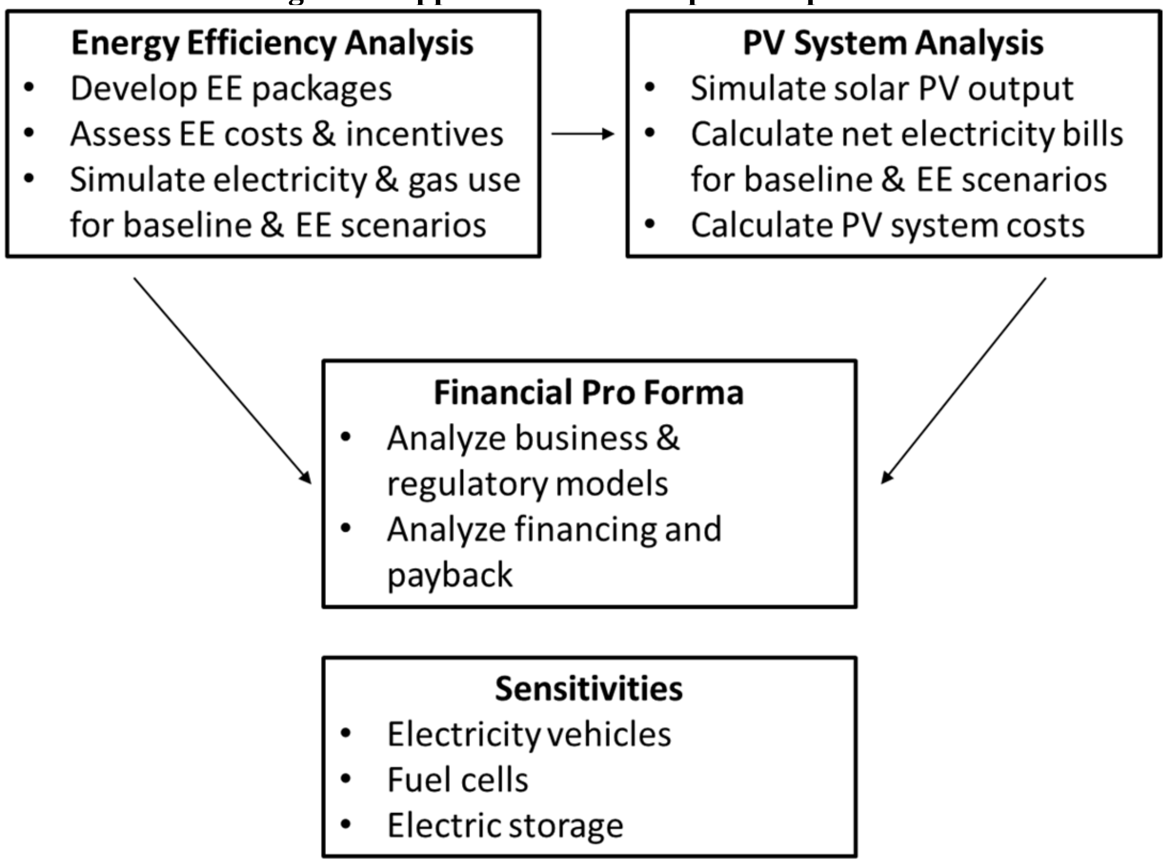
[1] Zero Energy Communities: UC Davis' West Village Community, Dakin et al, 2010 ACEEE Summer Study on Energy Efficiency in Buildings
[2] West Village: A Process & Business Model for Achieving Zero-Net Energy at the Community-Scale, Finkelor et al, 2010 ACEEE Summer Study on Energy Efficiency in Buildings
[3] California Energy Efficiency Strategic Plan, 2008
[4] The consultant team included Energy and Environmental Economics, Inc. (E3), Clean Power Research (CPR), and Davis Energy Group (DEG).

assessment. The relationship between each of these components is shown in Figure 1, below, and the analysis for each core element is described in the next three sections of the paper.

Figure 1: Approach to Roadmap Development



Energy Efficiency Analysis

Energy efficiency costs and savings were assessed against a comparable baseline ("Standard") home. For the purposes of analysis, two Standard homes were established: (1) a home compliant with 2008 Title 24, and (2) a home compliant with the local Davis city ordinance, which since 2008 has required new homes to be 15% more energy efficient than Title 24. Energy use profiles for the single-family housing units were based on a 3-bedroom, 3-bathroom, two-story floor plan provided by the developer, with a total conditioned floor area of 1,756 square feet (sq ft) and a window area equal to 25% of the conditioned floor area. In addition, we assumed that 60 percent of the homes have separate studio units, which we assume will be rented to lower income occupants, such as graduate students. Energy use was scaled to adjust for home size variations (between ~1,400 sq ft to ~2,500 sq ft) and orientation to create an overall usage profile for the West Village single-family home community.

Fuel Type: All-Electric or Electric and Natural Gas?

Early in the design phase, the consultant team, in close collaboration with UC Davis and the developer, made a decision to use both electricity and natural gas in the West Village's single family homes. Currently, there is no formal definition of ZNE that requires all renewable generation be at the home or within the community. Our analysis found that using retail natural gas with biogas offsets would result in lower costs, higher levels of energy efficiency, and more marketable homes. Table 1 lists the pros and cons of a combined electricity and natural gas scenario. Biogas procurement is described in the Biogas Analysis section below.

Table 1: Pros and Cons of the Combined Electricity and Natural Gas Scenario

Pros of an electricity and natural gas scenario	Cons of an electricity and natural gas scenario
• Significantly lower lifecycle cost of ownership than all-electric scenario • Less difficult to demonstrate 'multiple renewables' in the community • Overall source efficiency is higher • Natural gas stoves make homes more attractive from a marketing standpoint	• Cannot eliminate gas lines (however, free service extensions reduce the cost) • Cannot eliminate combustion appliances in the home • May be more difficult to market a home as "ZNE" since an "energy offset" is required to offset the natural gas use

Energy Efficiency Package Development

We developed energy efficiency measure (EEM) packages for both the Standard homes and West Village homes. To account for the mix of energy efficiency levels in the current housing stock, we designed EEM packages for Standard homes that meet Title 24 or Title 24 + 15% specifications. For the West Village homes, we worked closely with the developer and architect to develop three EEM packages: (1) a basic performance package; (2) an advanced package (Advanced A) that provides energy savings beyond the basic package; and (3) a second advanced package (Advanced B) that provides savings beyond Advanced A. Measures for each EEM package are shown in Table 2, below.

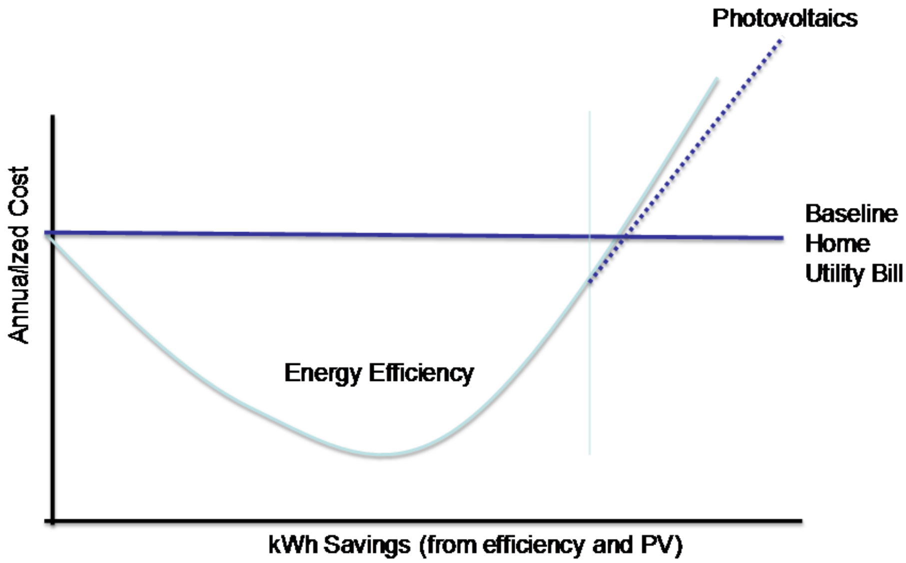
Table 2. EEM Package Details for the Main House

Measure Category	Basic Performance	Advanced A	Advanced B
Envelope			
Window Area - % of Conditioned Floor Area	26%	22%	22%
Exterior Wall Construction	2x6 16"oc	2x6 24"oc Advanced Framing	2x6 24"oc Advanced Framing
Exterior Wall Insulation	R-21		R-21 Batt w/ 1" R-4 sheathing
Foundation Type & Insulation	Slab on Grade - Uninsulated		
Floor Over Garage/Open	R-19 Batt		
Roofing Material & Color	CRRC Certified with 0.28 Reflectance, 0.91 Emittance		
Ceiling Insulation	R-49 Blown Cellulose		
Radiant Barrier	Yes		
Interior Thermal Mass	None		5/8" Drywall
House Infiltration - Blower Door Test (HERS)	SLA 1.8		
Thermal Bypass Inspection - QII (HERS)	Yes		
Windows & Patio Doors	Dual Non-Metal 0.32 / 0.23		
HVAC Equipment			
Heating Type & Efficiency	Gas Furnace / AFUE 92%	Combined Hydronic	Combined Hydronic
AC Type & Efficiency	AC / SEER 15, EER 12.5		
Duct Location & Insulation	Conditioned Space, R-6		
Mechanical Ventilation	ENERGY STAR exhaust meeting ASHRAE 62.2		
Ventilation Cooling	None		Whole House Fan
Water Heating Equipment			
Water Heater Type & Efficiency	Gas Tankless, EF 0.82	Condensing Tankless, EF 0.96	Condensing Tankless, EF 0.96
HW Distribution	PEX Piping, Engineered Design, Ktchn Pipe Insulated		
Solar Water Heater Type & Solar Fraction	None		
Appliances, Lighting & MELs			
Appliances	ENERGY STAR Dishwasher	ENERGY STAR Dishwasher, Fridge & Clothes Washer	ENERGY STAR Dishwasher, Fridge & Clothes Washer
Dryer Fuel	Gas		

Oven / Range Fuel Fluorescent Lighting Package MEL Controls	Gas 100% w/ Controls & Ceiling Fans None		

To develop the EEM packages, we included measures in order of cost-effectiveness until net measure cost exceeded the cost of renewable energy. The cost of renewable energy thus defines the level of the EEM packages. This interaction between EEM costs and renewable energy costs is illustrated in Figure 2.

Figure 2. Interaction between Energy Efficiency and Renewable Energy Costs



Levelized incremental costs of renewable generation used to compare to the EEMs were developed using the incremental costs provided in Table 3, below.

Table 3: Levelized cost of renewable energy scenarios used for EEM analysis

LCOE Scenario	PV ($/kWh)	Biogas ($/Therm)	EEM Package
Low LCOE	$0.14	$2.00	Advanced A
High LCOE	$0.30	$2.40	Advanced B

Based on energy use profiles and EEM packages, we conducted a detailed simulation of energy consumption by end use — heating, cooling, domestic hot water, lighting, appliances, and miscellaneous electric loads — in the homes and studios using the National Renewable Energy Laboratory's (NREL's) BEopt modeling software. We used EnergyPro to evaluate EEM performance relative to Title-24 code and calculate EEM incentives. Total energy use by EEM package for medium-sized homes, including 60% of estimated studio energy use (assuming that 60% of homes have an attached studio), is shown in Table 4.

Table 4. Electricity and Natural Gas Use by EEM Package

	Electricity (kWh)	Natural Gas (Therms)	Source Energy Savings Over Title-24 Compliant Home	Source Energy Savings Over Title-24 + 15% Home
Title 24	9,573	795	0%	N/A
Title 24 + 15%	9,173	633	N/A	0%
Basic Performance Package	7,343	538	28%	18%
Advanced A	6,988	476	34%	24%
Advanced B	6,676	452	37%	28%

Package Incremental Costs and Energy Efficiency Incentives

We calculated incremental costs, measured against the Title 24 and Title 24 + 15% base cases, for the proposed EEM packages both before and after taking into account utility efficiency incentives (Table 5).[5] The net EEM package costs demonstrate that large amounts of energy efficiency can be accomplished at relatively modest additional cost.

Table 5. EEM Package Costs Compared to the Title-24 and Title-24 + 15% Base Cases

Package	Incremental Cost versus Title-24 Compliant Home		Incremental Cost versus Title-24 + 15% Home		Net Cost After Incentives (Title-24)	Net Cost After Incentives (Title 24 + 15%)
	Main House	Studio	Main House	Studio	Average Home with 60% Studio	Average Home with 60% Studio
Basic Performance	$ 5,395	$ 1,338	$ 4,320	$ 1,123	$2,667	$1,831
Advanced A	$ 5,052	$ 4,207	$ 3,977	$ 3,992	$3,390	$2,554
Advance	$	$	$	$	$8,719	$7,883

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[5] Two additional incentives are available through the California Advanced Home Partnership (CAHP): the New Solar Homes Partnership (NSHP) Tier II incentive of $1,000 per home and CAHP zero peak homes $/kW incentive. These incentives are only included in the project economics for applicable business model scenarios (i.e., community-scale installations are not eligible).

d B	10,080	5,082	9,004	4,866		

Note: These costs include a 15% soft costs adder reflecting developer carrying costs such as overhead, financing, and insurance.

Additional Energy Efficiency Measures Evaluated

Several technologies were considered and eliminated from evaluation early on. They were eliminated either because they were deemed too difficult to implement or would not work at West Village due to space constraints or other concerns. These measures include (a) structurally insulated panels (SIPs), (b) ground-coupled heat pumps, and (c) combined heat and power (CHP), utilizing the university central plant.

In addition to the above technologies, there were a number of measures that were evaluated and identified as not cost-effective under the evaluation methodology employed for this study. For these measures, the incremental cost was not justified by the energy savings when compared to the cost of renewable energy described in Table 3. These measures are listed in Table 6, below.

Table 6: Non-economic Energy Efficiency Measures

Exterior Foam Sheathing	Heat Pump Water Heating
Slab Edge Insulation	Condensing Storage Water Heater
Evaporative Condenser	Solar Water Heating
High Efficiency Central Heat Pump	Advanced Lighting Design (LED lighting and architectural soffits for indirect lighting)
Mini-split Heat Pump	Miscellaneous Electric Loads (MEL) Controls
NightBreeze central fan night ventilation system	

Biogas Analysis

We recommended that natural gas be supplied to the West Village via PG&E's retail distribution network, with an additional purchase of a biogas offset. Biogas is an economically viable option at West Village because quantities could be procured for the entire development at prices that ranged from $1.30 to $1.65 per therm at the time of the analysis (though our analysis conservatively assumed prices of $2.00-$2.40 per therm). Since biogas offsets would be purchased for the entire community, minimum procurement obligations and transaction costs that might limit the availability of biogas for single residences or smaller communities were not deemed an impediment.

The use of biogas offsets eliminates the need to achieve ZNE obligations with excess solar PV that is compensated at a very low market value (~$0.04/kWh) under California's current Net Energy Metering (NEM) policy. Additionally, West Village home owners will periodically pay community dues and upkeep fees, through which incremental biogas offset costs can be collected. Finally, in the future purchased biogas can be replaced with a dedicated biogas project at or near the West Village community if and when it becomes economic.

Photovoltaic (PV) Analysis

The main source of electricity in the West Village homes is solar PV systems. Our analysis examined two possible configurations for these systems: rooftop and community scale. For both systems, we developed capital costs, an hourly generation profile, and average capacity factors. Cost estimates were intended to be conservative, based on median values from the California Solar Initiative (CSI) database. Estimated costs were $7,418/kW (AC) for a rooftop system and $5,318/kW (AC) for a community system.

A variety of solar energy incentives are available to both rooftop and community-scale PV systems. Incentive amounts through the New Solar Homes Partnership (NHSP) were $2.35/W at the time of this analysis and only available for new residential rooftop systems. CSI incentives were available for larger systems up to 5 MW; however, the maximum incentive capacity is 1 MW.

Both rooftop and community-scale systems were assumed to be financed with a power purchase agreement (PPA). This method of financing ensures PV capital costs are not included in the developer's scope, and yields federal investment tax credit (ITC) and 5-year Modified Accelerated Cost Recovery System (MACRS) tax depreciation benefits. Estimated 25-year real levelized costs after incentives were $0.1884/kWh for the rooftop PV system and $0.1626/kWh for the community-scale PV system. The levelized cost for community PV excludes utility trench and security costs for the PV site, but does include an annual land cost. An overview of PV analysis results is shown in Table 7.

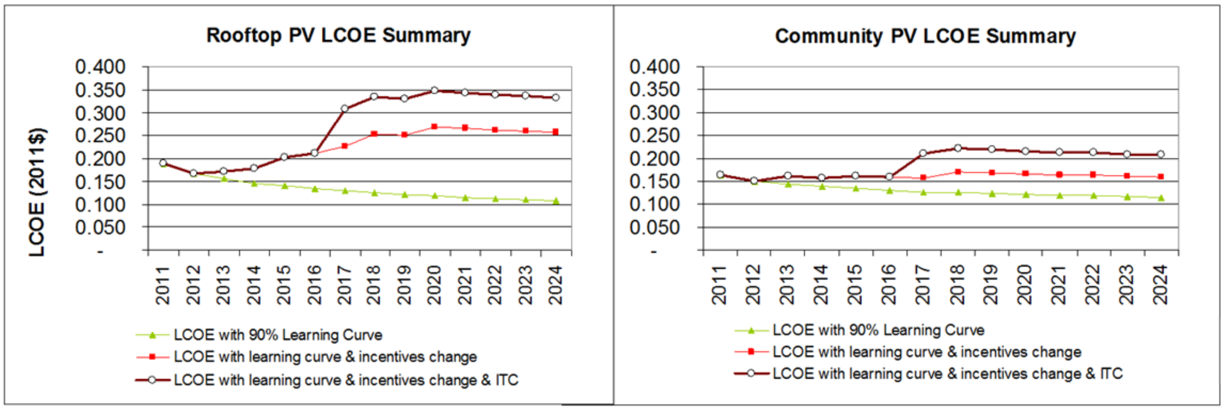
Table 7. Overview of PV Modeling Results

	Rooftop	Community
Inverter	Xantrex 6 kW (Model XW6048-120/240)	Xantrex 6 kW (Model XW6048-120/240)
PV Array	Sunpower 100 W (Model PL-ASE-100)	Sunpower 100 W (Model PL-ASE-100)
Orientation	West, 4:12 roof pitch (18^o)	South, 38^o
NZE Ratings (per household)	7.8 kW DC, 6.392 kW CEC-AC	6.7 kW DC, 5.491 kW CEC-AC
5-year Energy Production	51,427 kWh per household	51,597 kWh per household
Capacity Factor	18.4%	21.5%
Cost ($/kW, CEC-AC)	$7,418	$5,138
LCOE (2011$/kWh)	$0.1884	$0.1626

Changes in Incentives and System Costs over Time

Both the NSHP and CSI incentives are expected to decline over time, and the federal ITC is expected to fall from 30% to 10% starting in 2017. At the same time, reductions in PV system costs may offset some of the declines in incentives. We evaluate two potential cost trajectories using a learning curve with progress ratios[6] of 90% and a 75%. Based on a learning curve with a 90% progress ratio, for instance, Figure 3 shows the balance between PV cost reductions and incentive declines over time for both the rooftop PV and community-scale PV systems. The top line on each graph shows the final levelized cost trajectory after taking into consideration cost reductions, changes in incentive levels, and the ITC step down. In the rooftop scenario, learning curve cost reductions largely offset NSHP incentive, but not ITC declines. In the community scenario, learning curve cost reductions are greater than CSI incentive declines, and eventually also nearly offset the ITC step down.

Figure 3. Levelized Cost of Energy for Rooftop and Community PV Systems with Declining Incentives and 90% Progress Ratio



Business and Regulatory Models for PV

There are two primary regulatory models applicable to the West Village: (1) small rooftop systems with NEM, or (2) community-scale PV connected to the UC Davis-owned distribution system (or 'loops') with a single commercial PG&E meter.[7] These are structured into business model scenarios using combinations of rooftop and/or community-scale PV when viable.

The choice of business model is highly sensitive to home construction rates and PV cost reductions. For each EEM package, business and regulatory model, and learning curve scenario, we examined three construction rates. The construction rate scenarios assumed that 30, 60, and 100 homes are built per year, depending on market demand. If the rate were 60 per year, for instance, construction would be complete in 2018. At 30 per year, about 50% of homes would be completed by the end of 2017.

[6] Progress ratio is the factor by which the costs decline for every doubling of installed capacity. For example, if the installed capacity of rooftop PV systems doubles and the progress ratio is 90%, then the new systems will cost 90% of what they initially cost.

[7] A third regulatory option, PG&E's bill credit transfer (RES-BCT) program was evaluated and eliminated early on because it credits only the generation portion of the rate, hence is less economic than the other two regulatory options.

Results: Lifecycle Benefits (Costs) for the West Village

Table 8 and 9 show additional lifecycle costs of West Village homes with slower and faster PV cost declines, respectively. Results are measured as the net present value (NPV) of the total cost difference (in 2011$) between West Village homes and Standard homes. The West Village homes may be more/less economic than Standard homes; a positive NPV here indicates that the West Village home is more economic.

Across scenarios, three trends emerge: (1) a faster construction schedule is more economic because of PV incentive declines; (2) PV cost declines are key to project economics — under a 90% progress ratio scenario, only one scenario is cost-effective; and (3) two loops are less economic than either rooftop or rooftop + delayed loop.

Table 8. NPV of Incremental Costs, Slow PV Cost Decline (90% Progress Ratio)

Home Construction Rate	EEM Package	Two Loops 2013 PPA	Two Loops, 2013 & 2015 (60) or 2018 (30) PPA	Rooftop PPA	Rooftop + Delayed 2017 Loop PPA
30	Basic	(2.5)	(2.6)	(2.5)	(1.0)
30	Adv A	(1.7)	(1.8)	(1.7)	(0.3)
30	Adv B	(2.6)	(2.7)	(2.5)	(1.1)
60	Basic	(2.0)	(1.8)	(1.3)	(1.0)
60	Adv A	(1.2)	(1.1)	(0.5)	(0.2)
60	Adv B	(2.2)	(2.0)	(1.4)	(1.0)
100	Basic	(1.7)	n/a	(0.2)	(0.8)
100	Adv A	(1.0)	n/a	0.6	(0.2)
100	Adv B	(2.0)	n/a	(0.4)	(1.3)

Table 9. NPV of Incremental Costs, Fast PV Cost Decline (75% Progress Ratio)

Home Construction Rate	EEM Package	Two Loops 2013 PPA	Two Loops, COD 2013 & 2015 (60) or 2018 (30) PPA	Rooftop PPA	Rooftop + Delayed 2017 Loop PPA
30	Basic	(1.8)	(1.3)	0.2	0.6
30	Adv A	(1.1)	(0.7)	0.9	1.3
30	Adv B	(2.0)	(1.6)	0	0.3
60	Basic	(1.3)	(0.2)	1.0	0.9
60	Adv A	(0.6)	(0.2)	1.8	1.5
60	Adv B	(1.6)	(1.2)	0.8	0.9
100	Basic	(1.1)	n/a	1.8	1.0
100	Adv A	(0.4)	n/a	2.5	1.7
100	Adv B	(1.4)	n/a	1.4	0.6

Additional Considerations

Variation in Energy Use and Behavioral Change

Our analysis of lifecycle costs is based on an assumption of constant resident energy use over time. If home energy use increases over time it raises two issues: (1) how to maintain ZNE at the West Village, and (2) whether the West Village remains economic relative to the Standard home. The most economic strategy for maintaining ZNE is through purchasing renewable energy credits (RECs) to offset small increases in energy use, versus initially oversizing the PV system and receiving net surplus compensation at ~$0.04/kWh. Using RECs, the renewable content can always match consumption. Depending on future technology costs, future shortfalls in onsite energy supply may also be addressed with additional onsite generation.

Maintaining zero net energy goals will likely require ongoing engagement with the West Village community. West Village residents will need regular feedback on their energy use, particularly as households purchase new appliances or add new family members. Feedback could be provided, for instance, through in-house displays that show real-time energy use. Community engagement could also be implemented through seminars and workshops that help residents manage their energy use, or fees that discourage excessive use.

Electric Vehicles

The adoption of plug-in electric vehicles (EVs) was included as a sensitivity in the analysis; no EVs were assumed in the base case results. EV assumptions included a $12,200 average incremental vehicle cost, plus learning curve cost reductions; $10,000 in federal and state incentives; and a range of vehicle ownership, driving, and charging scenarios. EVs were assumed to be submetered on PG&E's E-9 rate, with an additional charger cost of $1,500 and a meter cost of $450. EVs are cost-effective relative to gasoline-powered vehicles in the scenarios considered in this study. Adding EVs increases the NPV of benefits to West Village homeowners, but does not affect the choice of PV business model to be pursued.

Fuel Cells

Fuel cells provide a means of consuming biogas onsite rather than purchasing it as an offset, and would meet the secondary project goal of demonstrating multiple on-site renewable resources. However, the economics of fuel cell implementation at the West Village hinge on fuel cell capital costs. Based on current capital and operating costs and current incentive levels, we determined that fuel cells are currently not cost-effective.

Storage Applications

Potential storage applications at West Village include load following, firming of intermittent PV generation, backup generation during outages, and retail rate arbitrage. However, since West Village will be on the net metering tariff, the only possible economic storage opportunities are retail rate arbitrage and improved customer reliability. The other storage opportunities have potential savings to the utility, but not to West Village residents.

With current storage costs and electric rates, using storage for retail rate arbitrage is not economic. In the rooftop PV scenario, capital cost declines of over 60% are necessary to break even, in part because the TOU electric rates do not have demand charges. Commercial applications may have better economics. Improving the grid reliability with storage is even less economic. The benefits of avoiding outages were found to be on the order of 3% of the benefits from rate arbitrage, since outages are rare and the value of reduced outages to residential customers is not that large.

Conclusions

Roadmap for the West Village

The analysis approach led to a number of recommendations that together formed a 'roadmap' for the West Village:

- Pursue mid-level EEM package Advanced A.
- Because of regulatory obstacles to community-based solar, use rooftop solar strategy for electricity generation through 2014, then re-evaluate; explore a smaller, community-based system coupled with downsizing of rooftop PV to improve customer economics and optics.
- Use tradable RECs for demand/supply balancing of PV and biogas, given the challenge of forecasting future electricity and natural gas demand and solar PV degradation.
- Pursue natural gas homes with biogas offsets to reduce costs, improve system efficiency, and improve marketability of homes.
- Explore electric vehicle adoption; car share and/or in-home charging can improve economics and reduce overall carbon footprint of the community.
- Explore feedback mechanisms to manage energy consumption post-construction.

Achieving Zero Net Energy at No Higher Cost is (Very Nearly) Possible

We find that the goal of achieving ZNE at no higher cost to the developer is nearly within reach. The developer costs for constructing the ZNE homes are on the order of $2,500 per home relative to a comparable home in the City of Davis after incentives. These cost estimates are based on detailed architectural and engineering estimates, and include soft costs for incorporating energy efficiency. If these costs were passed on to the home buyer, or covered in a UC Davis financing arrangement, the developer could actually achieve no higher cost.

From the homeowner perspective, the lifecycle cost of buying and owning the home ranges from higher to lower than a conventional home. If PV cost reductions and home construction rates are slower, lifecycle costs of the West Village ZNE homes are higher than conventional homes. If construction rates are faster, or with more rapid PV cost declines (which we are currently witnessing), the ZNE homes cost less than conventional homes. In the scenario with the highest net benefits, we estimate that the lifecycle savings may be as large as $2.5 million, or more than $7,000 per home (see Table 9).