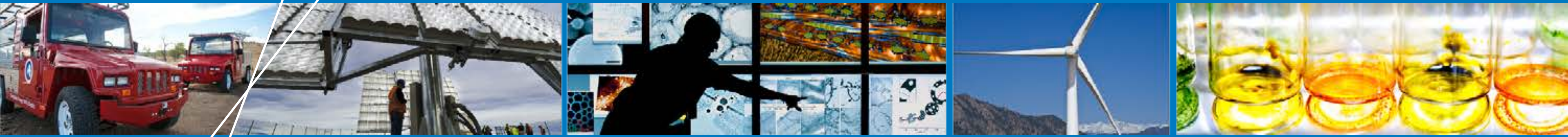
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Analysis of Community Energy



2013 DOE Annual Merit Review & Peer Evaluation Meeting

Darlene Steward, National Renewable Energy Laboratory

May 14, 2013

Project ID# AN043

Project Context

Overview

Analysis of Community Energy

ANL	Argonne National Laboratory
FCT	Fuel Cell Technology Office (DOE)
FPITT	Fuel Pathway Integration Tech Team
GREET	Greenhouse Gases, Regulated Emissions & Energy Use in Transportation Model
HDSAM	Hydrogen Delivery Scenario Analysis Model
HTAC	Hydrogen and Fuel Cell Technical Advisory Committee
NREL	National Renewable Energy Laboratory

HTAC
FPITT

HTAC, FCT Office, & External Reviews

Analysis Framework

NREL

- building load profiles
- solar resource data
- H2A design parameters

ANL

- GREET & HDSAM design parameters

Models & Tools

FCPower Model

Studies & Analysis

Integration of high penetration of distributed PV and vehicle refueling

Outputs & Deliverables

Report to HTAC
NREL Publication

Improved understanding of how distributed (home) vehicle refueling can enable high penetration of distributed PV by leveling output to the grid

National Labs
ANL – GREET & HDSAM
NREL – H2A

Project Overview

Timeline

- Project start date: September 2011
- Project end date: April 2013*
- Percent complete: 100% FY12 work*

*April publication of report. Overall project continuation and direction determined annually by DOE

Budget

- Total project funding
  - DOE share: 100%
- Funding received in FY12: $30K
- Funding for FY13: $95K

Barriers

- Stove-piped/Siloed Analytical Capability [4.5.B]
- Insufficient Suite of Models and Tools [4.5.D]
- Unplanned Studies and Analyses [4.5.E]

Partners

- Hydrogen and Fuel Cell Technical Advisory Committee – Hydrogen Energy Storage Subcommittee
- Fuel Pathway Integration Tech Team

1. HTAC member affiliations; Arete Venture Management, Ballard (Ida Tech, LLC), Brookhaven National Laboratory, General Motors Powertrain, Pacific International Center for High Technology Research & the Hawaii Renewable Energy Development Venture, University of Michigan.

Relevance and Objective

The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) evaluates the benefits of hydrogen for enabling deployment of renewable electricity technologies.

- This study evaluates the potential benefits of integrating renewable (photovoltaic) electricity generation with transportation fueling.
- An analysis of hydrogen for community-scale electricity storage was completed previously.

Model Hourly PV, Fueling & Grid Interactions

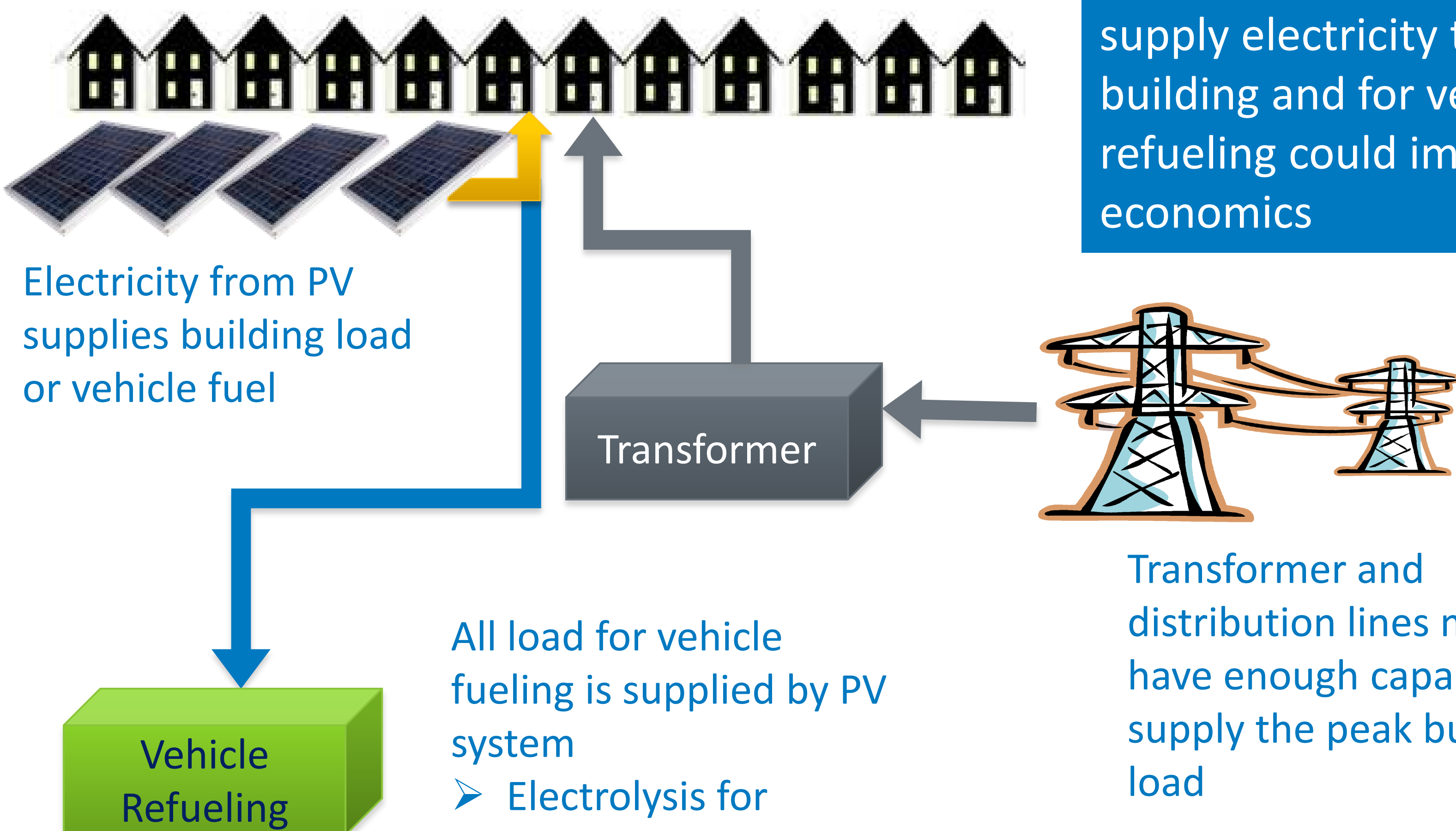
Approach

1. Create simulated hydrogen- and battery/electric-based PV refueling systems in FCPower Model:
   - PV systems
   - Electrolyzer, compressor, storage, dispenser (for H_2 system)
   - Storage and charger (for battery/electric system)
2. Establish hourly building load profile from empirical load data
3. Apply empirical solar resource data to PV systems to determine PV output
4. Establish vehicle-refueling profiles (using modified H2A parameters)
5. Model system hourly energy flows: PV output, electricity to building (from PV and grid), electricity to storage (from PV), stored electricity to vehicles
6. Calculate system electricity and fuel costs

PV & Vehicle-Refueling System Schematic

Approach

Electricity load for a community of about 100 houses



Electricity from PV supplies building load or vehicle fuel

Using the PV output to supply electricity to a building and for vehicle refueling could improve economics

All load for vehicle fueling is supplied by PV system

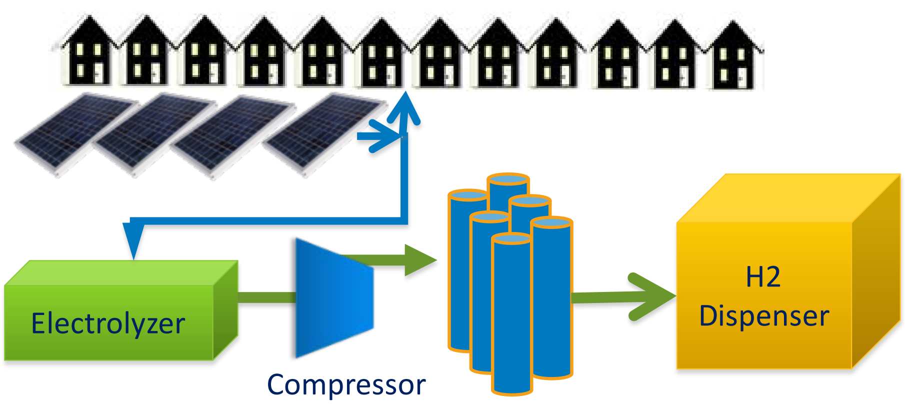
- Electrolysis for hydrogen production
- Battery for electric vehicle charging

Transformer and distribution lines must have enough capacity to supply the peak building load

When PV output is less than building load, the grid supplies the difference

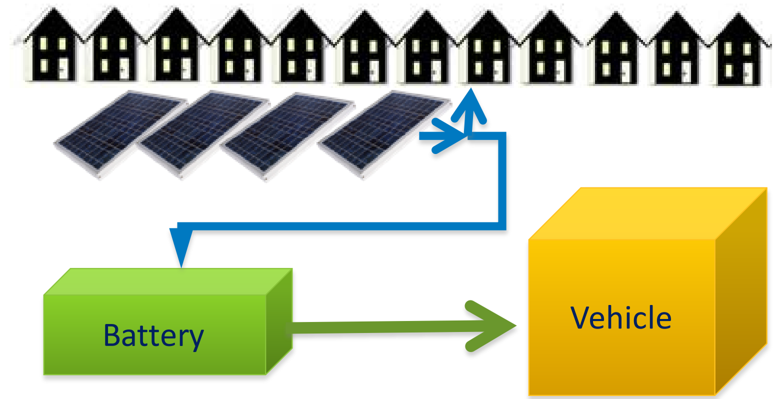
Hydrogen & Battery Refueling Systems Compared

Hydrogen



Electrolyzer	Sized to maximum difference between PV output and building load
Compressor	Sized to peak hourly hydrogen flow rate
Hydrogen storage	Assumed daily full cycling of storage system (no multi-day storage)
Hydrogen dispenser	One assumed in all cases (350-bar dispensing)

Battery/Electric



Zinc-air battery	Sized to maximum kWh in storage + 50% assuming full discharge of the battery daily (no multi-day storage)
Level I charging	Assume home vehicle charging (comparable to 350-bar hydrogen system)

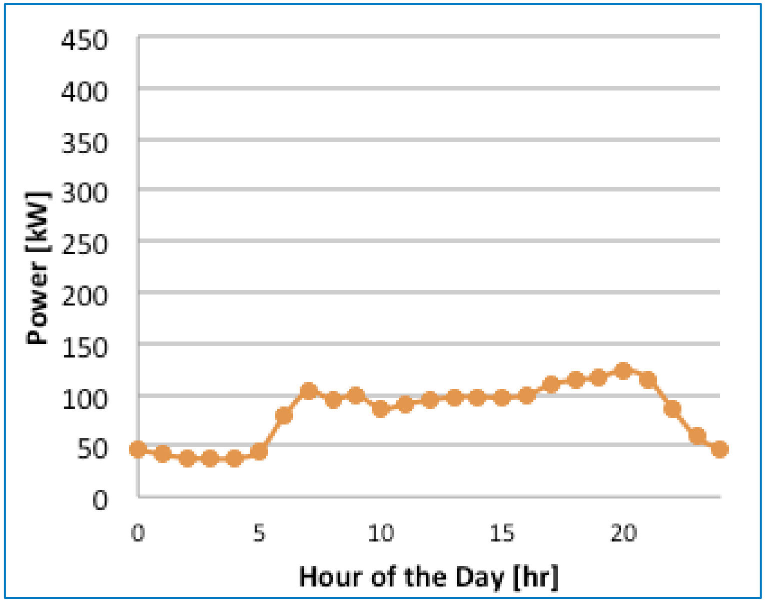
Building Load, PV Systems, Refueling Cases

Approach

Hourly Building Load

Based on Boulder hotel (similar to housing)

Demand maximum (kW)	125.3
Demand minimum (kW)	28.4
Demand average (kW)	65.4
Demand Stdev (kW)	22.8
Demand total (kWh/year)	572,518



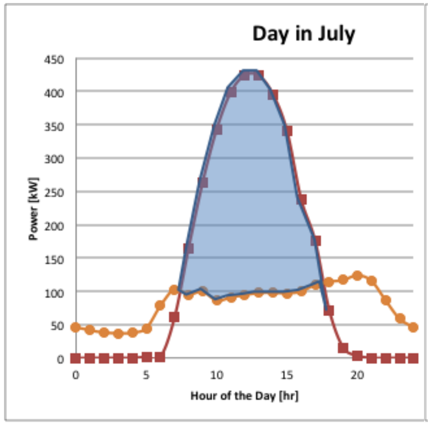
Building electricity demand, day in July

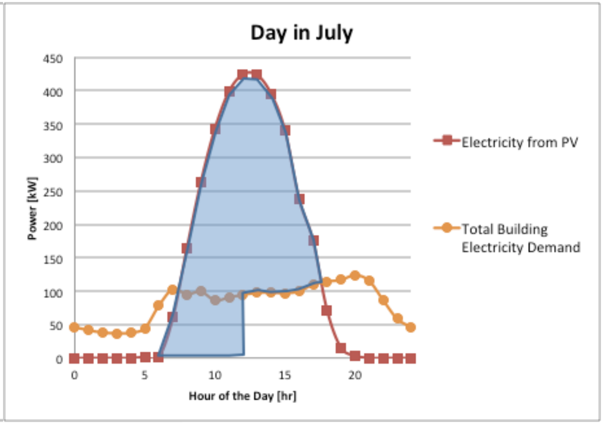
Three PV Systems

Based on Boulder solar data, current PV tech

PV System Size (m^2)	Peak Rated Output (kW)	Output (kWh/y)	% Bldg Load
1,200	183	286,704	50
4,000	611	955,681	170
7,000	1,069	1,672,442	290

Two PV/Vehicle Refueling Cases





Case 1 – PV output in excess of building load to vehicle refueling

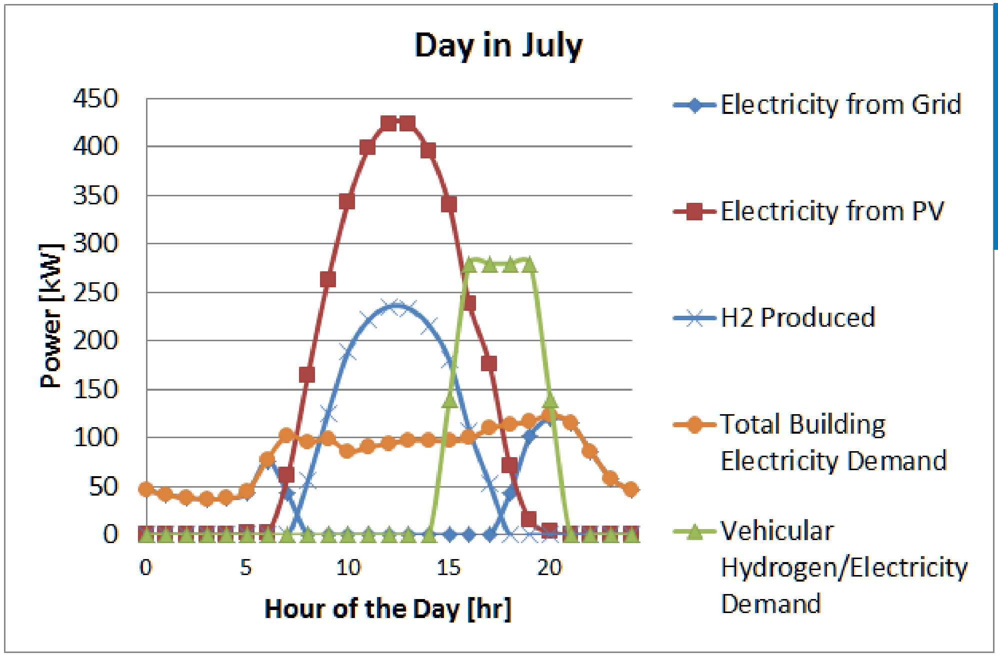
Case 2 – PV output before noon and output in excess of building load to vehicle refueling

Accomplishments and Progress

- Hourly modeling of all system energy flows using measured solar data and NREL Commercial Building Benchmark Models
- Realistic analysis of grid impacts for three levels of distributed PV electricity generation "behind the meter"
- Comparison of hydrogen fuel cell vehicles to competing technology.

Modeling of realistic energy output and consumption on an hourly basis highlights time-dependent impacts of distributed generation

Example Daily System Energy Flows

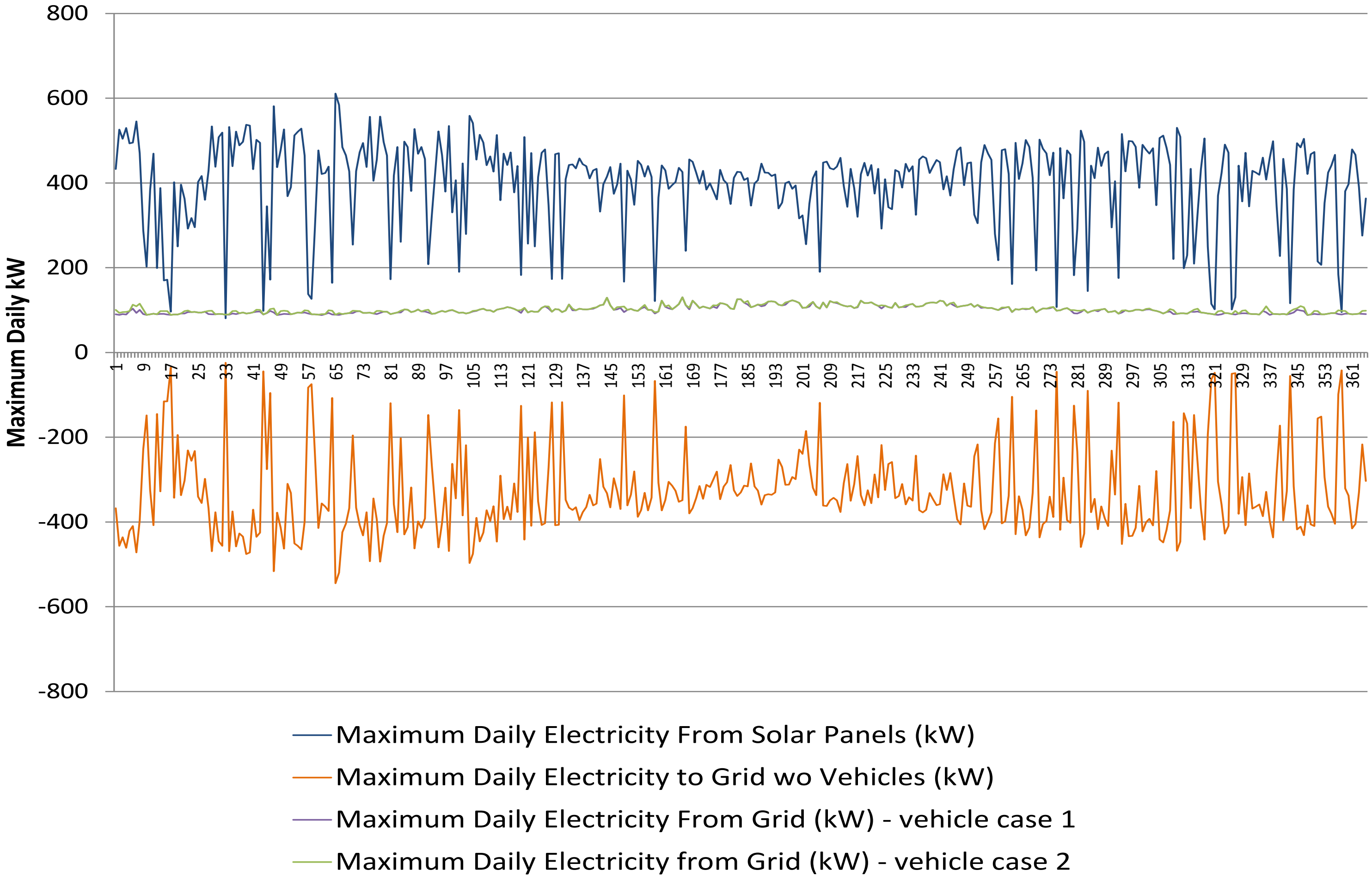


Both building and vehicle peak demand are offset from the PV system peak output

4,000 m2 PV System - Hydrogen (or electricity to battery) produced when PV system output exceeds the building load (Case 1)

Equipment	Size	Yearly Output	Capacity Factor	% Bldg Load
PV system	4,000 m^2	955,681 kWh	18	167 (total) 47 (direct supply)
Electrolyzer (H2 system)	560 kW input	14,564 kg	40	—
Hydrogen Storage (H2 system)	85 kg	~ 1 cycle per day	—	—
Vehicle Electricity (battery system)	—	500,755 kWh	—	—
Battery Storage (battery system)	2,954 kWh	~ 1 cycle per day	—	—
Grid	—	303,744 kWh	—	53

Daily Maximum System Energy Flows

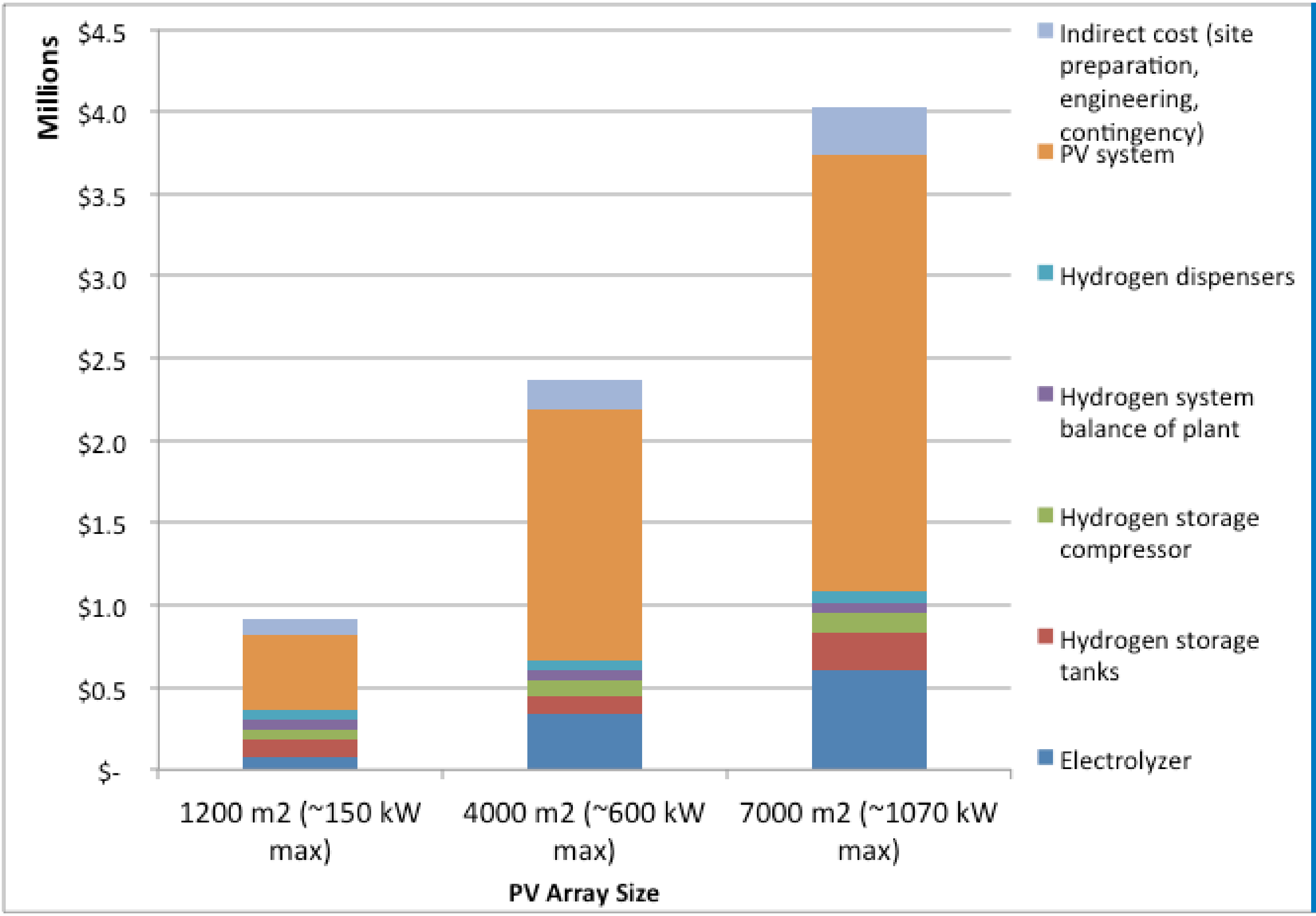


4,000 m2 PV System

Vehicle refueling completely eliminates reverse flow of electricity to the grid

Full System Costs Including PV Panels

Accomplishments



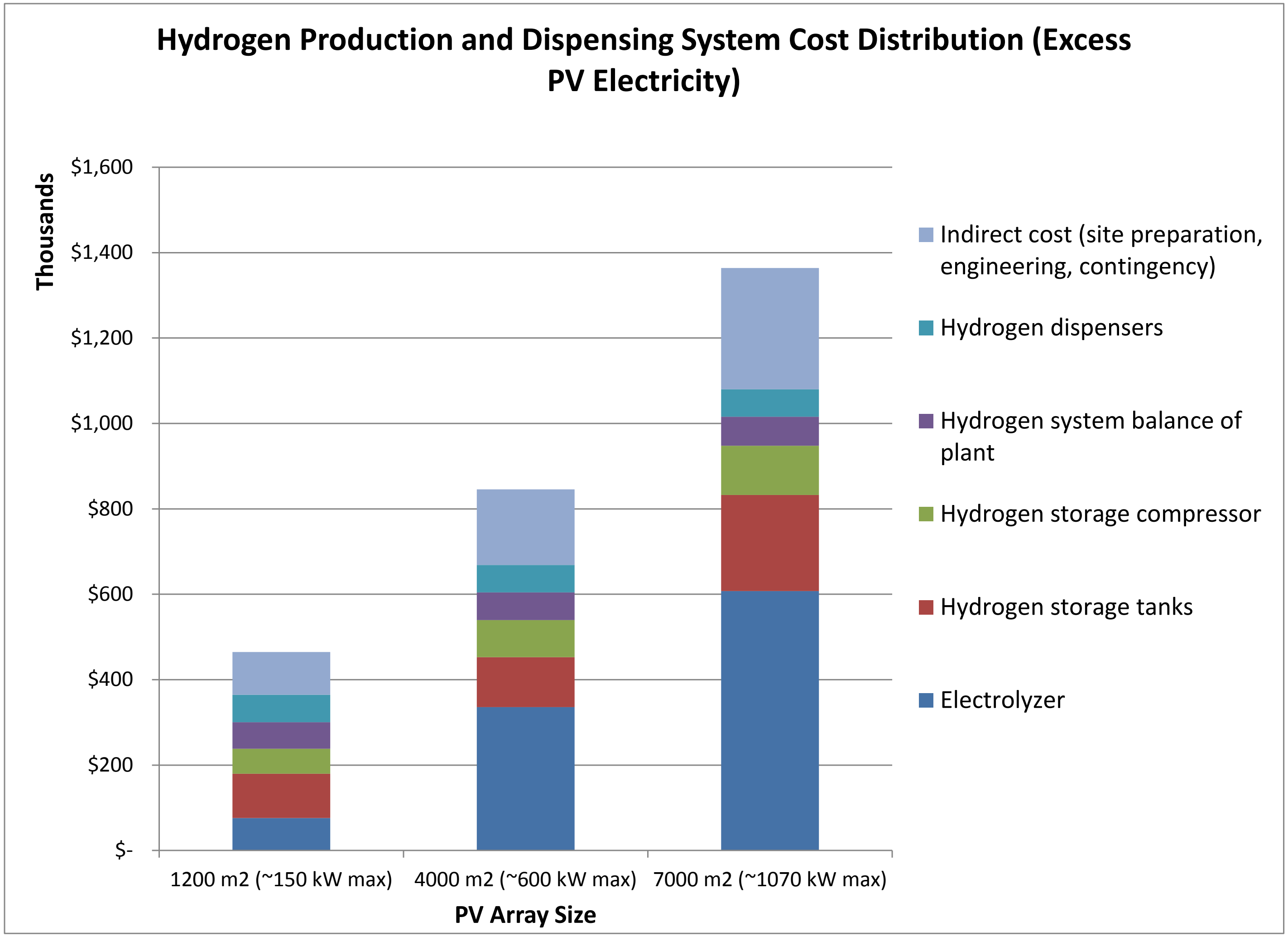
PV system is the largest cost item @ $2.50/Watt

Other System Cost Assumptions (installed):

- Dispensers: $64,000
- Compressor: $2,600 - $11,000/kW (depending on size)
- H2 storage: ~$1,400/kg
- Electrolyzer: ~$600/kWin ($750/kW incl indirect costs)

Hydrogen System Costs

Hydrogen system – Case 1. The electrolyzer system is the largest cost for the two larger systems



The electrolyzer must be sized to the maximum difference between PV and building load

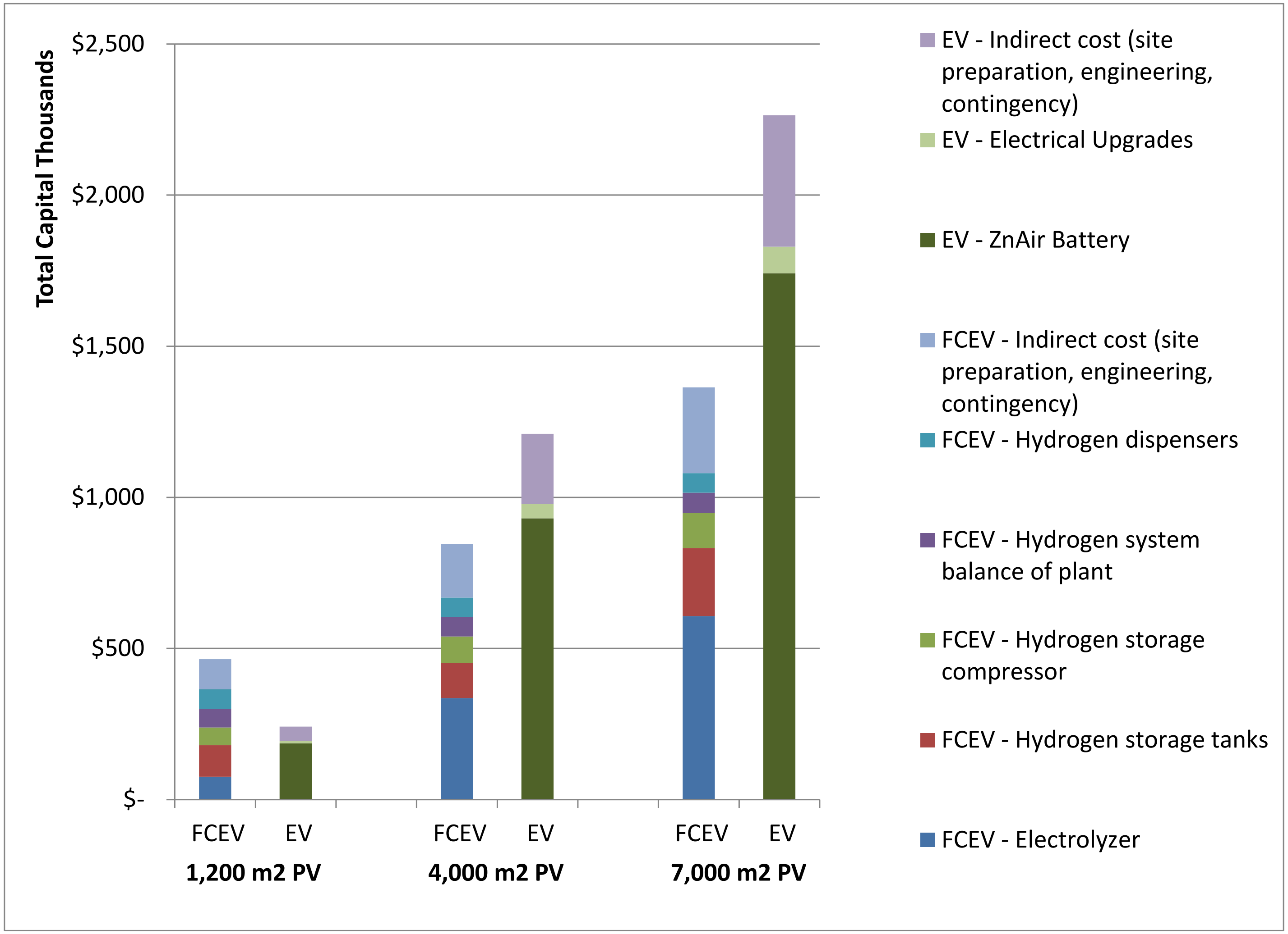
Cost Assumptions (installed):

- Dispensers: $64,000
- Compressor: $2,600 - $11,000/kW (depending on size)
- H2 storage: ~$1,400/kg
- Electrolyzer: ~$600/kWin ($750/kW incl indirect costs)

Comparison of FCEV and EV Costs

Accomplishments

Case 1. The battery capital costs are higher than the hydrogen system capital cost for the 4,000 m2 and 7,000 m2 systems.



The battery system produces ~3 percent more energy than the hydrogen system because of it's higher efficiency

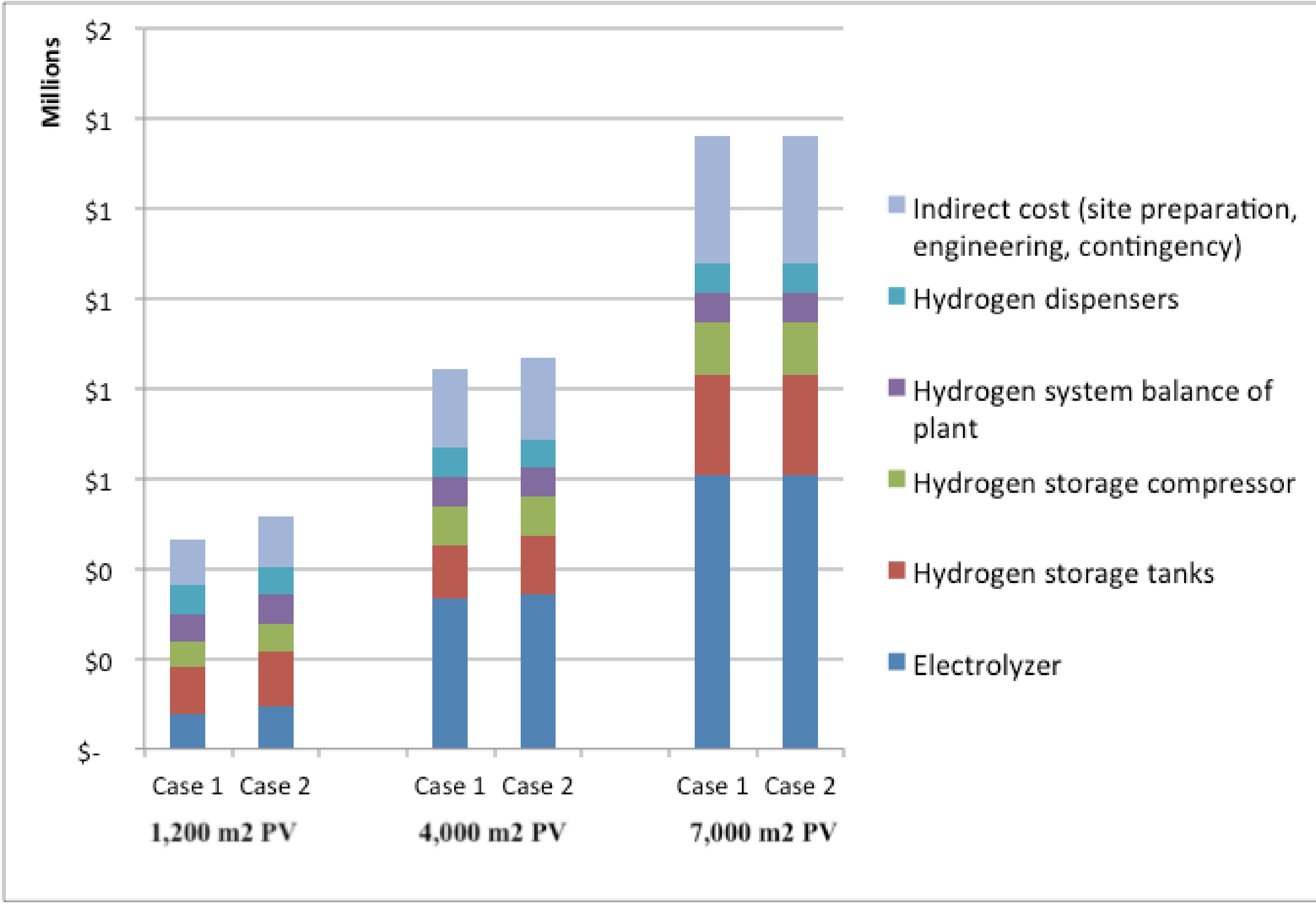
Cost Assumptions (installed):

- Dispensers: $64,000
- Compressor: $2,600 - $11,000/kW (depending on size)
- H2 storage: ~$1,400/kg
- Electrolyzer: ~$600/kWin ($750/kW incl indirect costs)
- Battery: $315/kWh

Comparison of Case 1 and Case 2

Accomplishments

Hydrogen system – Case 2 storage systems are slightly larger



Cost Assumptions (installed):

- Dispensers: $64,000
- Compressor: $2,600 - $11,000/kW (depending on size)
- H2 storage: ~$1,400/kg
- Electrolyzer: ~$600/kWin ($750/kW incl indirect costs)

Overview of Results

Accomplishments

Hydrogen								
PV System Size (% of total building load)	Case 1 - Excess Electricity (kg H2/year)	Number of vehicles	$/kg	¢/mile	Case 2 - Morning Output + Excess Electricity (kg H2/year)	Number of vehicles	$/kg	¢/mile*
1200 m² (~50)	1,804	8	34	63	3,541	17	24	41
4000 m² (~170)	14,564	71	13	22	16,985	83	12	21
7000 m² (~300)	29,274	143	12	20	31,898	156	11	19
Full Electric Vehicle (EV)								
PV System Size	Case 1 - Excess Electricity (kWh/year)	Number of vehicles	$/kWh	¢/mile	Case 2 - Morning Output + Excess Electricity (kWh/year)	Number of vehicles	$/kWh	¢/mile*
1200 m²	61,726	15	$1.04	35	121,936	30	0.45	15
4000 m²	500,755	123	$0.41	14	585,475	145	0.40	13
7000 m²	1,008,212	249	$0.39	13	1,100,877	272	0.39	13

*¢/mile value is for fuel only and does not include vehicle cost or maintenance.

In this case, battery electric vehicles are less expensive on a per mile basis because EVs use less energy per mile; 33.7 kWh/100 miles (EV) v. 56.4 kWh/100 miles (FCEV)

Conclusions

Accomplishments

- The additional equipment for the hydrogen system hurts the economics for smaller systems.
- The flexibility of the hydrogen system configuration improves the economics for larger systems.
- For both hydrogen and electric vehicles, diverting more electricity from the PV system improves the economics, but the effect is more pronounced for the hydrogen system
- Best case hydrogen cost is for the 7,000 m^2 PV system Case 2
  - About 90% of the PV output goes to hydrogen production or battery storage for EV charging
  - 28% of the building load is supplied by the PV system
  - The electrolysis system produces about 32,000 kg/year (~90 kg/day) or supply for 160 vehicles
  - **Hydrogen cost is about $11/kg or 19 cents/mile**

Collaborations

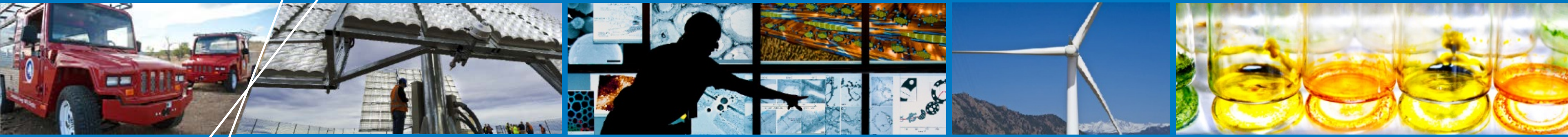
- Hydrogen and Fuel Cell Technical Advisory Committee
- Xcel Energy
- Fuel Pathway Integration Tech Team
- NREL Electricity, Resources & Building Systems Integration Center

Proposed Future Work

Explore more realistic scenarios for dealing with seasonal variation in PV output

Explore methodologies for optimizing hydrogen system configuration

Explore the impact of incentives and net metering for economics



Technical Back-Up Slides

Critical Assumptions and Issues: Hydrogen Refueling

Hydrogen compression, storage and dispensing costs adapted from the H2A forecourt models

System	Design Calculations	Values
Electrolyzer	Electrolyzer sized to maximum difference between PV output and building load	~100 – 1,000 kWinput, ~600/kWinput installed, ~$750/kWinput including all indirect costs
Primary compressor – one compressor assumed for both low pressure storage and cascade storage	Compressor design calculations taken from H2A forecourt model/HDSAM	~ 2.4 kW compressor power/(kg/h) H2 flowrate ~$6,000 /kW (for comparison, at 1,500 kg/day the cost is ~1,800/kW, $3,900/kg/h)
Dispenser	Source: H2A forecourt models	~$64,000 installed
Cascade storage – one cascade system assumed	Total volume 65 kg H2 (in 3-tank system)	~$1,400 per kg installed
Low pressure storage	Volume varies by application	~$1,350 per kg installed

Battery and electric vehicle information

System	Design Calculations	Values
Zinc air battery	Design based on maximum kWh in "storage" at any time during the year	$315/kWh installed
Electrical upgrades and charging stations	5% of installed battery cost	
All electric vehicle based on the Nissan LEAF®	100 mile all electric range	12,000 miles per year 33.7 kWh/100 miles

Critical Assumptions and IssuesBuilding Load Statistics

Building Load Statistics

Demand maximum (kW)	125.3
Demand minimum (kW)	28.4
Demand average (kW)	65.4
Demand st dev (kW)	22.8
Demand total (kWh/year)	572,518