FLORIDA SOLAR ENERGY CENTER®

Creating Energy Independence

~~Grid-Scale~~ Energy Storage with Increased PV And EVs

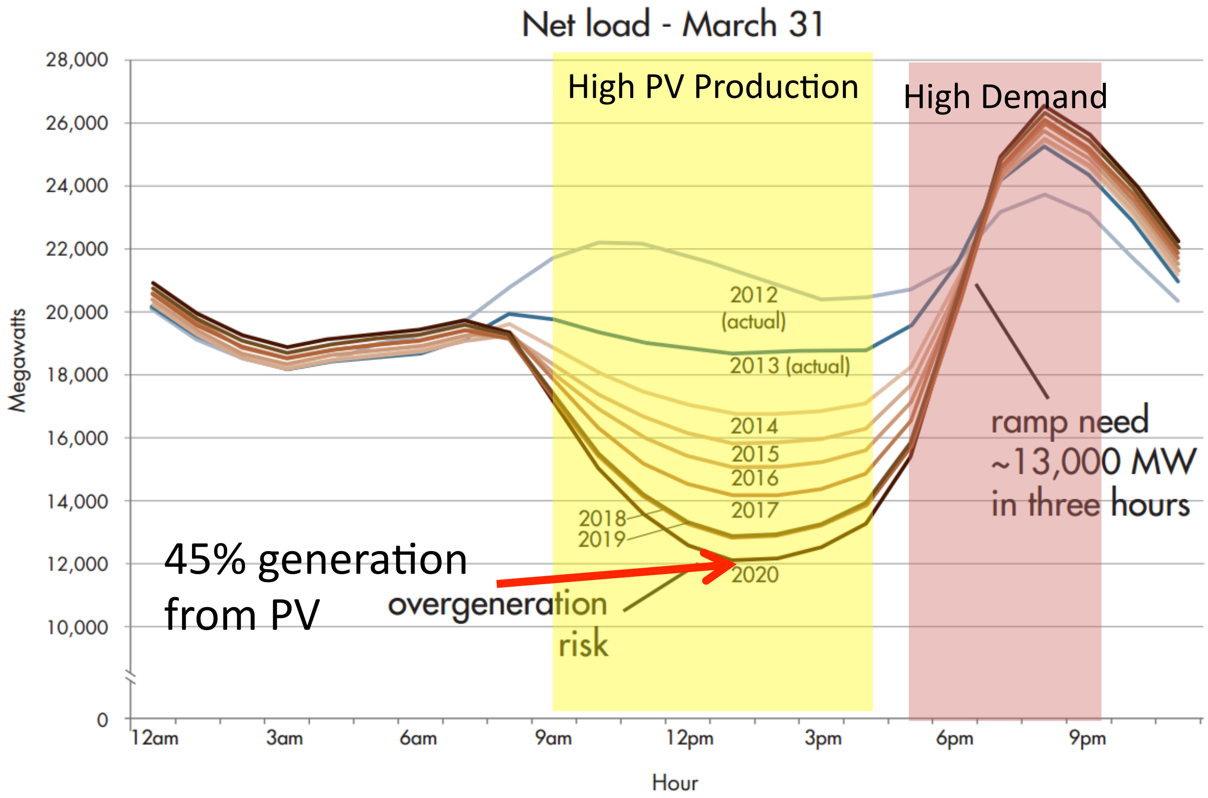
Paul Brooker

FSEC Advisory Board Meeting

October 21, 2016

Effects of PV on the Grid

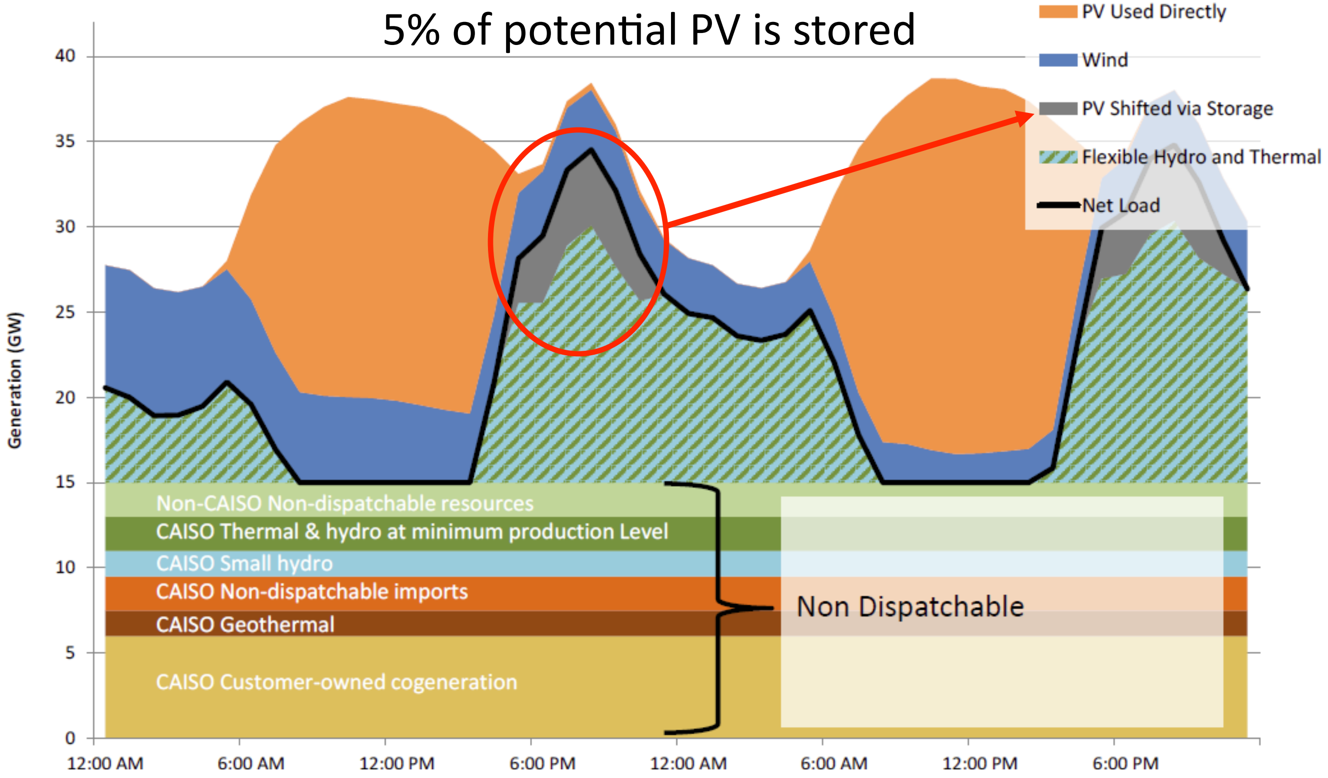
- Mismatched supply and demand lead to “the duck curve”



45% generation from PV

Modeled PV and Baseload Conflict

- Impacts on utilities will occur before 45% PV
  - NREL predicts 20% PV is sufficient to require energy storage



5% of potential PV is stored

P. Denholm and R. Margolis. “Energy Storage Requirements for Achieving 50% Penetration of Solar Photovoltaic Energy in California. National Renewable Energy Laboratory, NREL/PR-6A20-66970

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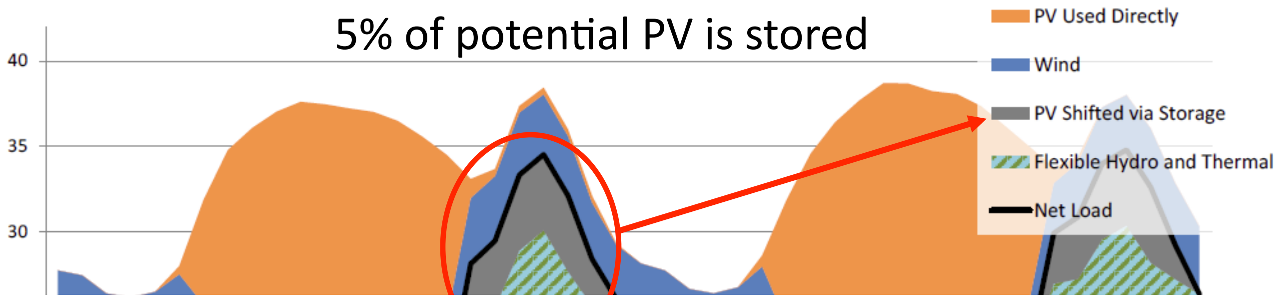
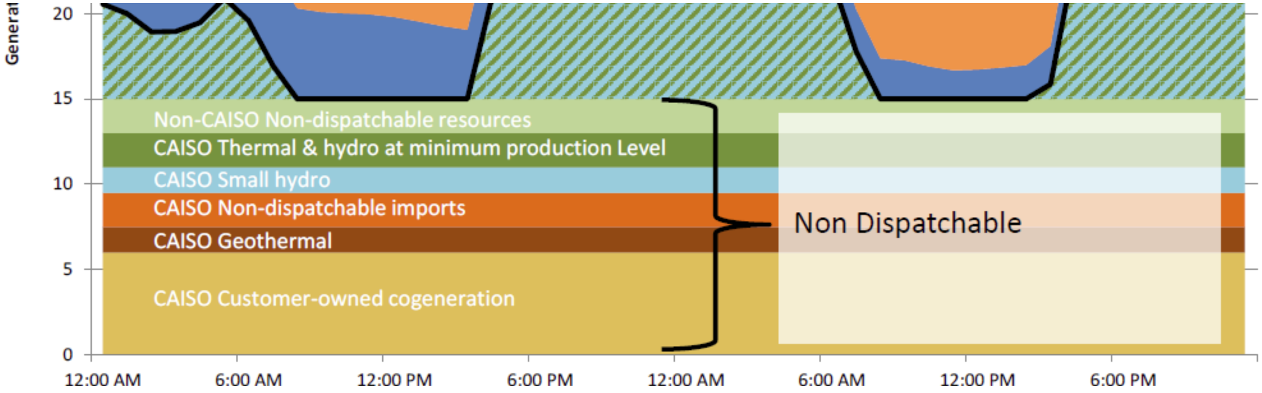


5% of potential PV is stored

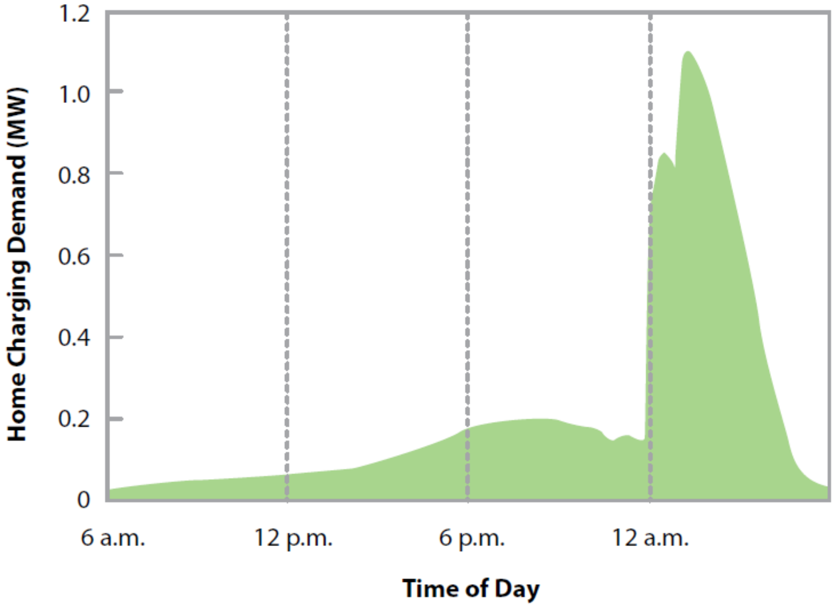
But we don't have to wait for PV for storage to become relevant



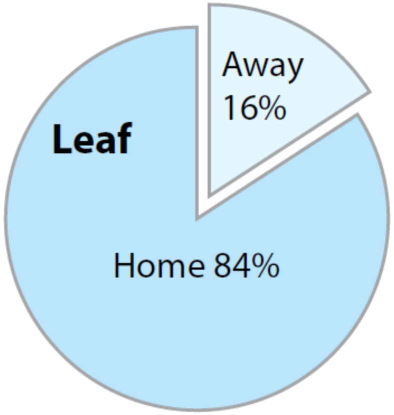
P. Denholm and R. Margolis. “Energy Storage Requirements for Achieving 50% Penetration of Solar Photovoltaic Energy in California. National Renewable Energy Laboratory, NREL/PR-6A20-66970

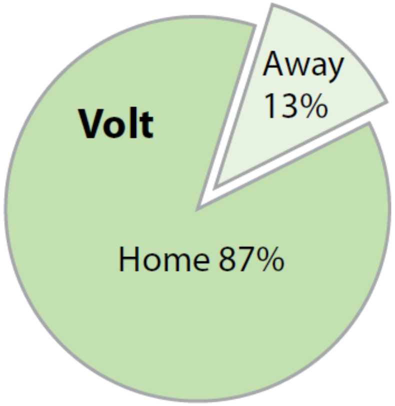
Impact of EVs on the Grid: Residential

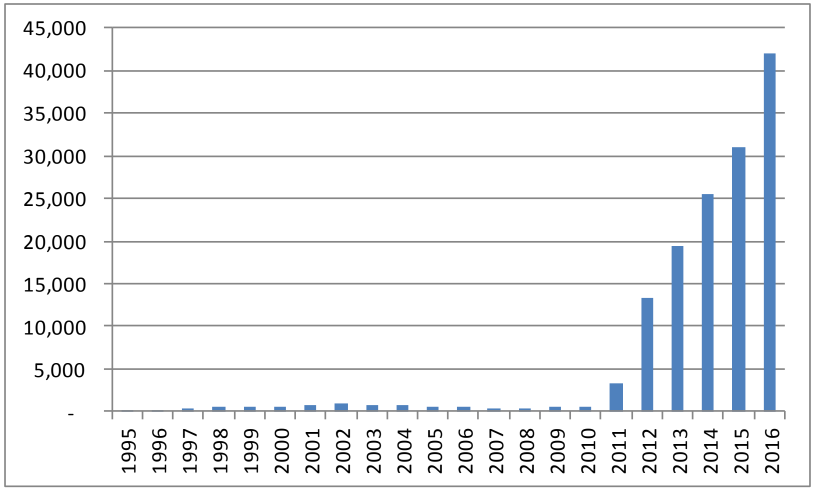
- Grid capacity can accommodate Evs for several decades
  - May have local transformer loads exceeded in residential neighborhoods
- Residential TOU rates causes a shift in charge start time
  - Introduces new peaks after midnight



Electric Charger Usage







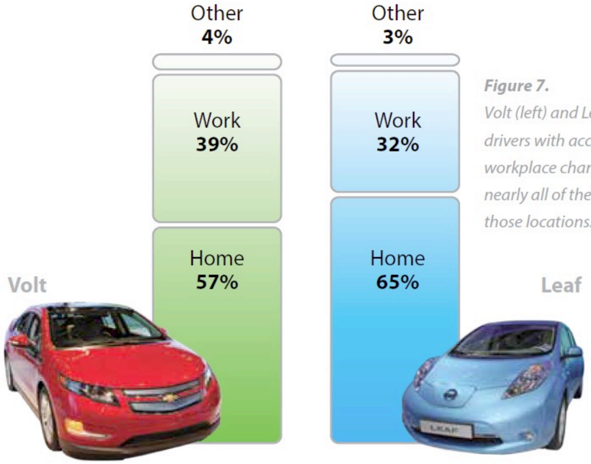
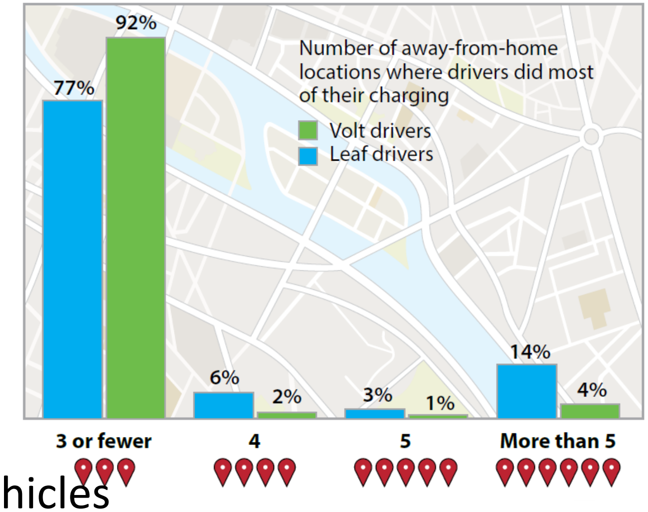


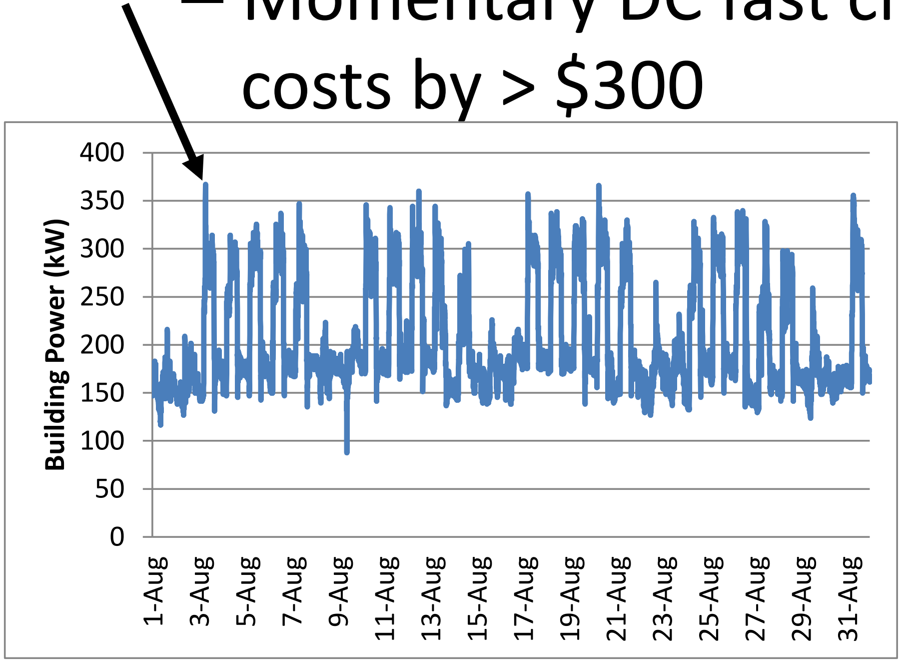
Figure 7.
Volt (left) and Leaf (right) drivers with access to home and workplace charging performed nearly all of their charging at those locations.



Plugged in: How Americans Charge their Electric Vehicles

Impact of EVs on the Grid: Commercial

- Building demand charges could be increased
  - High number of AC L2 chargers could increase building power levels
  - Momentary DC fast charge peak could increase costs by > $300



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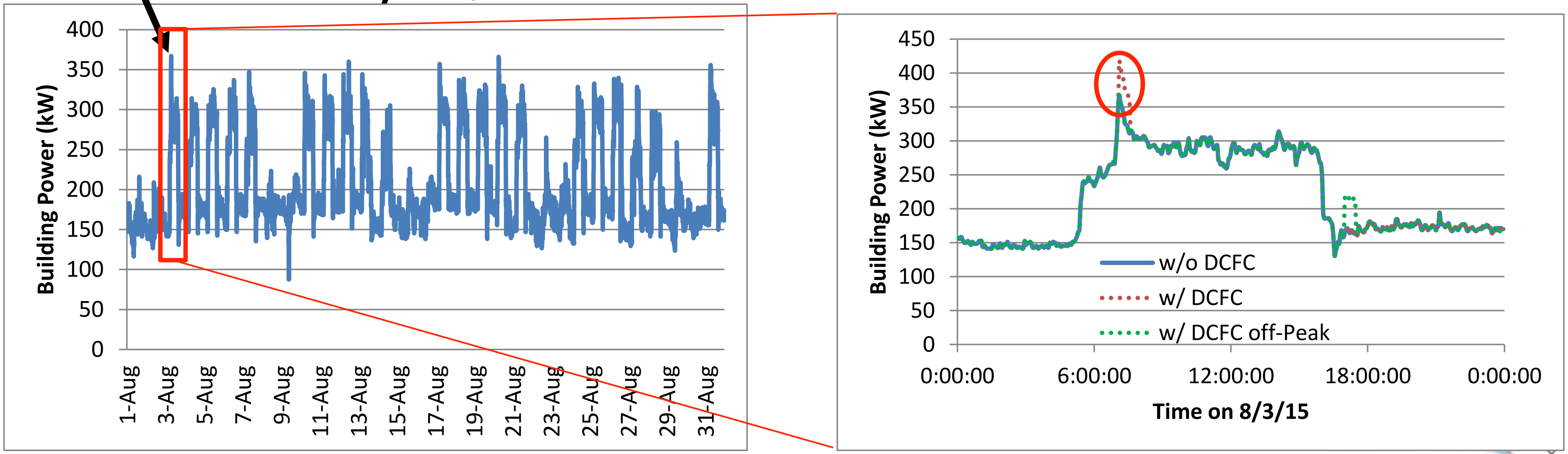
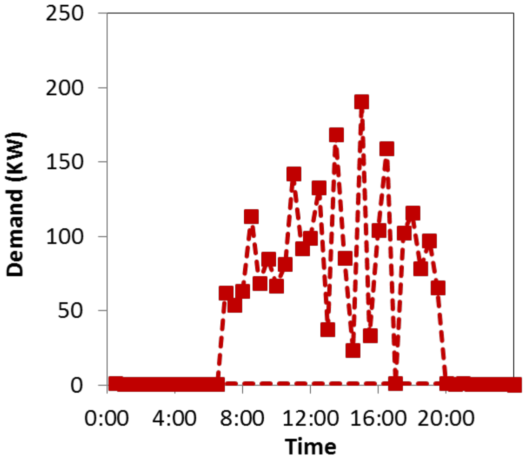


Effect of DC Fast Charging on EBs

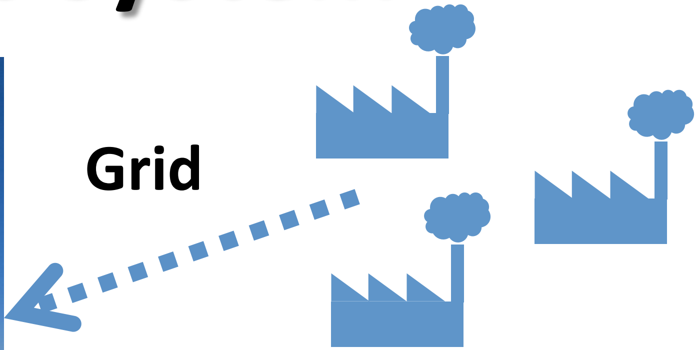
- Tallahassee electric bus route uses in-route fast charging
- Without demand charges = $0.06/kWh
- With demand charges = $0.28/kWh

	Electric Bus	Diesel Bus
Efficiency (kWh/mile)	2.5	9.7
Cost per Mile ($)	0.7	0.9



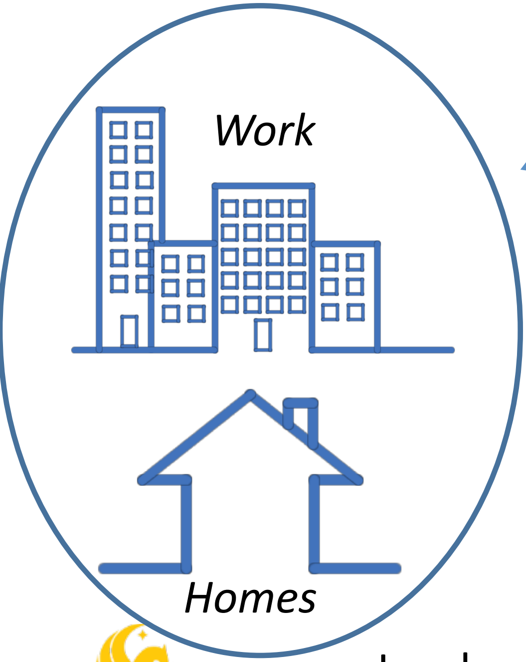
Current Electric System

Incorporating renewable energy is challenging



Grid

Reserves kept operating for grid stability



Loads

Must be stable at 60Hz

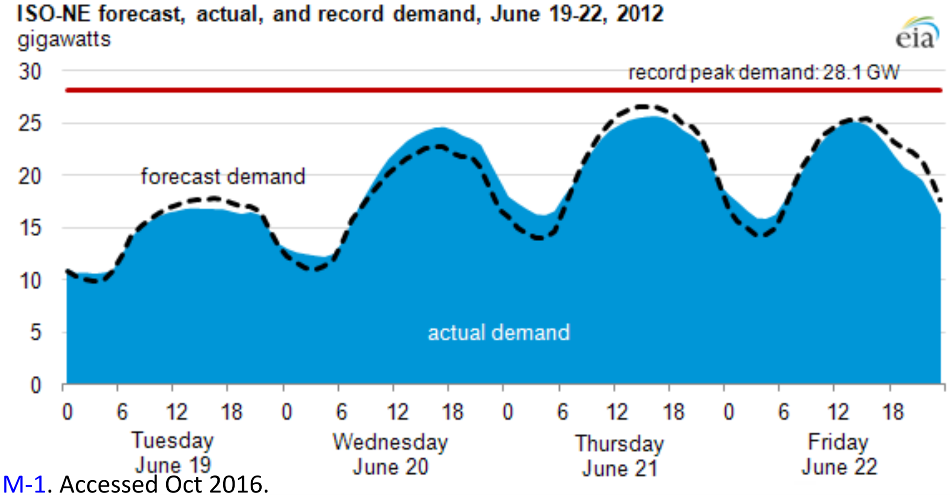
Load and generation must be matched

Types of power plants:
- Base load
- Load following
- Peaker

Types of grid services:
- Frequency/voltage regulation
    - 0-10s response = low energy
    - 10s-1min response = med energy
    - 1-10min response = high energy
- Spinning reserves
    - Daily load following

Electricity Demand Forecasting

- Daily and seasonal variation requires day-ahead forecasting
  - Establish contracts to purchase/sell electricity for the next day
- Actual vs. forecast differences are met through reserves

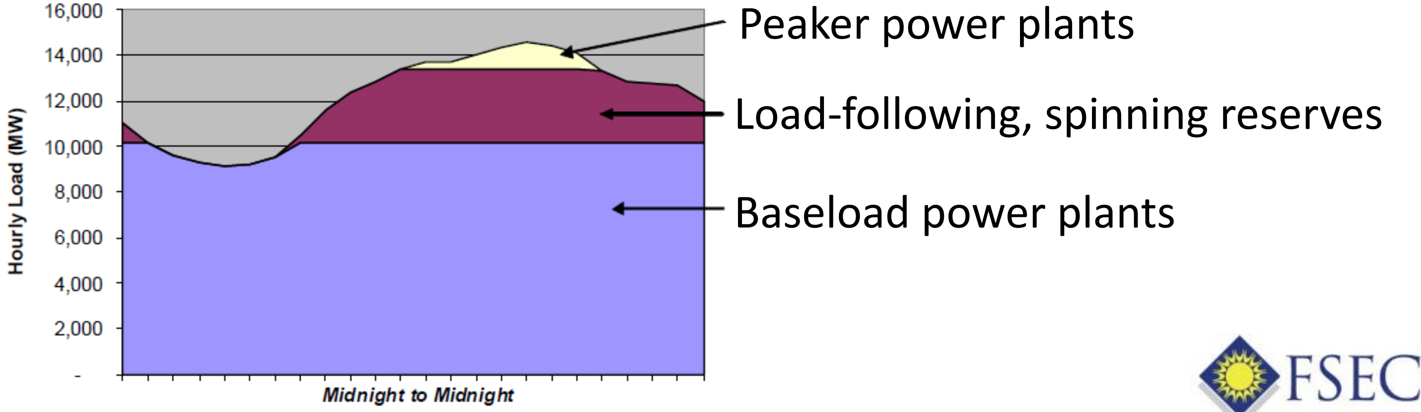


ISO-NE forecast, actual, and record demand, June 19-22, 2012

Chart from http://www.eia.gov/todayinenergy/detail.php?id=7070#tabs_PJM-1. Accessed Oct 2016.

Dispatchable vs. Base Generation

- “Dispatchable” = vary power plant output
  - – Natural gas power plants
- “Baseload” = constant power output (minor variation acceptable)
  - – Nuclear, coal geothermal



Peaker power plants

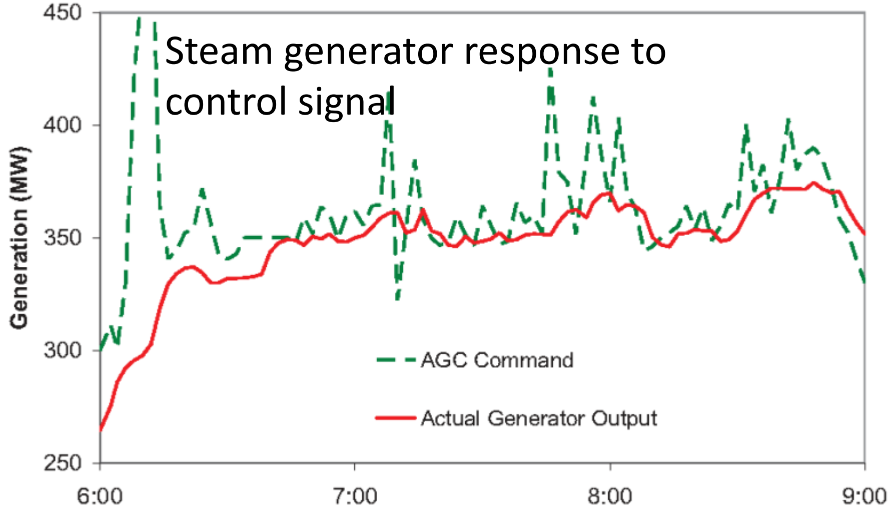
Load-following, spinning reserves

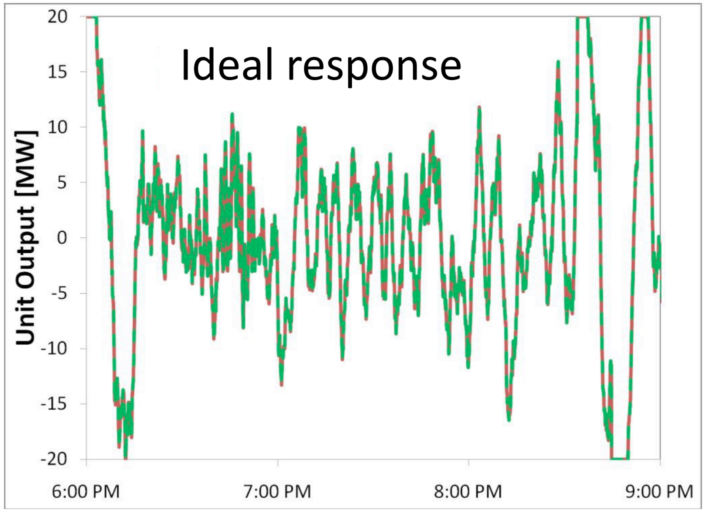
Baseload power plants

S. Kaplan. “Power Plants: Characteristics and Costs”, CRS Report for Congress Order Code RL34746, November 13, 2008

Power Plant Response Times

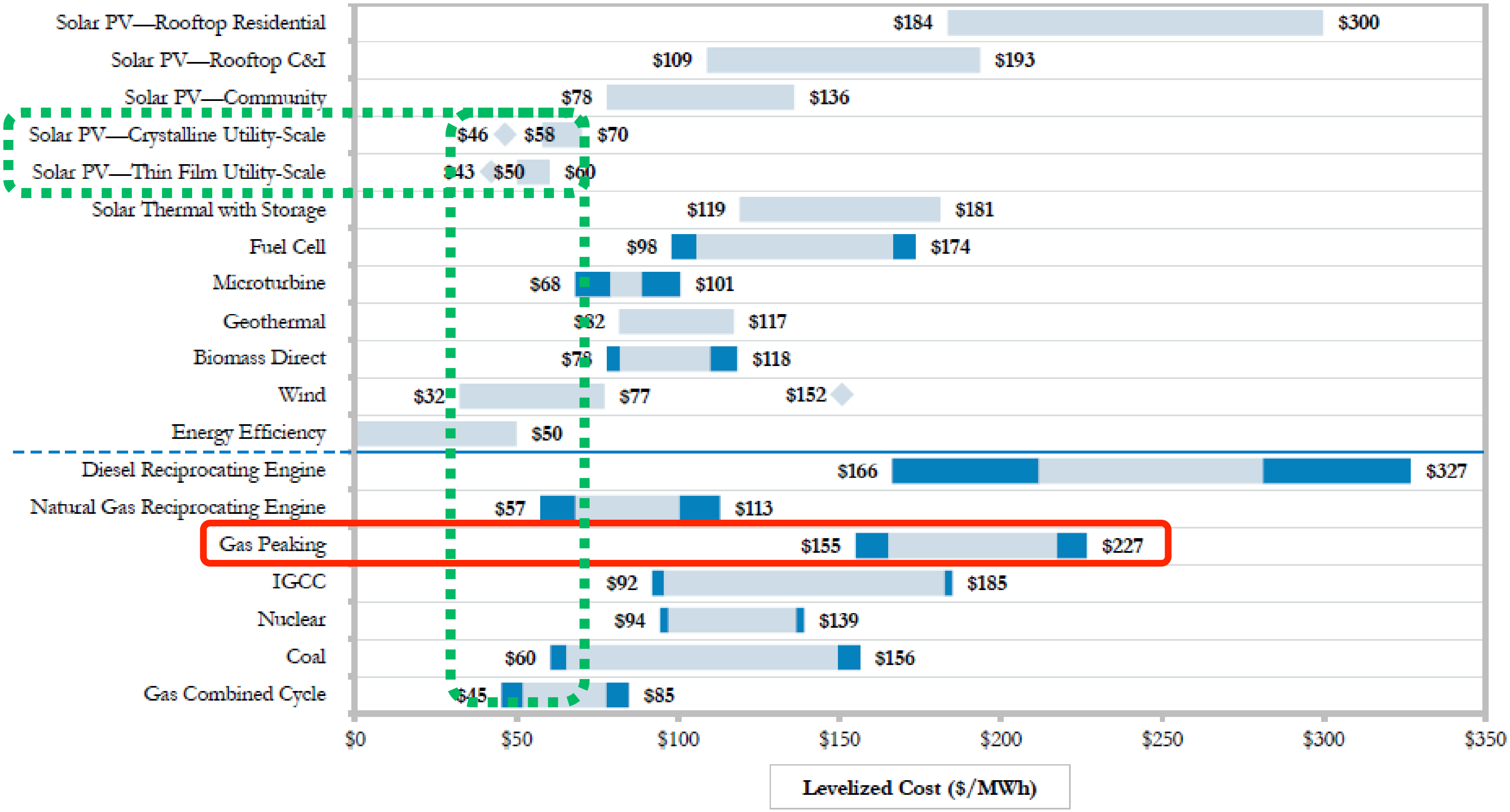
- More rapid response has greater value to grid
  - Steam generators are slow
  - Batteries are nearly instantaneous

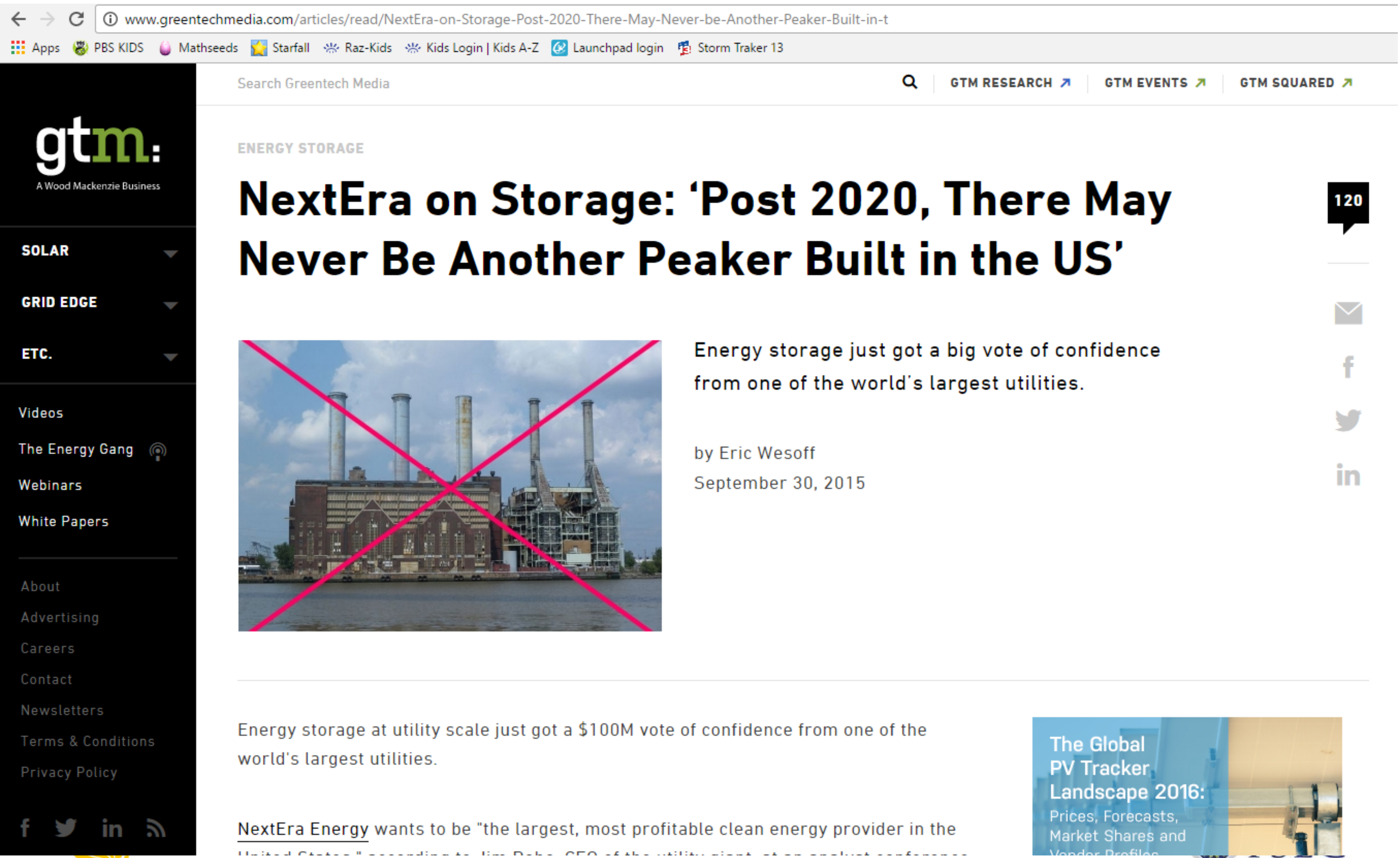




C. Glazer, “Markets, regulation and Energy Storage: A Match Made in Heaven?”, EIA 2013 Energy Conference June 17, 2013

LCOE for Generation Technologies





ENERGY STORAGE

NextEra on Storage: 'Post 2020, There May Never Be Another Peaker Built in the US'

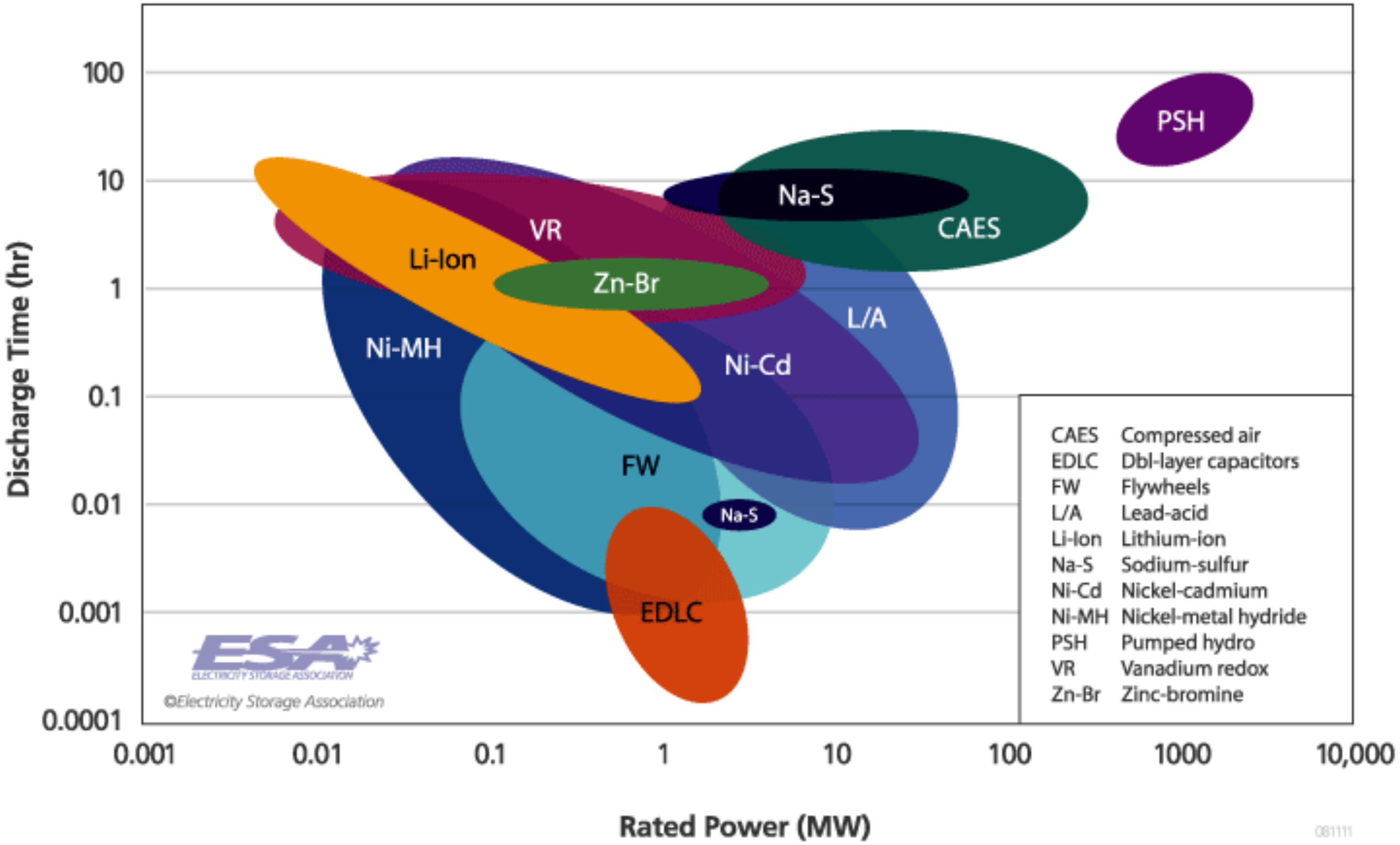
Energy storage just got a big vote of confidence from one of the world's largest utilities.

by Eric Wesoff
September 30, 2015

Energy storage at utility scale just got a $100M vote of confidence from one of the world's largest utilities.

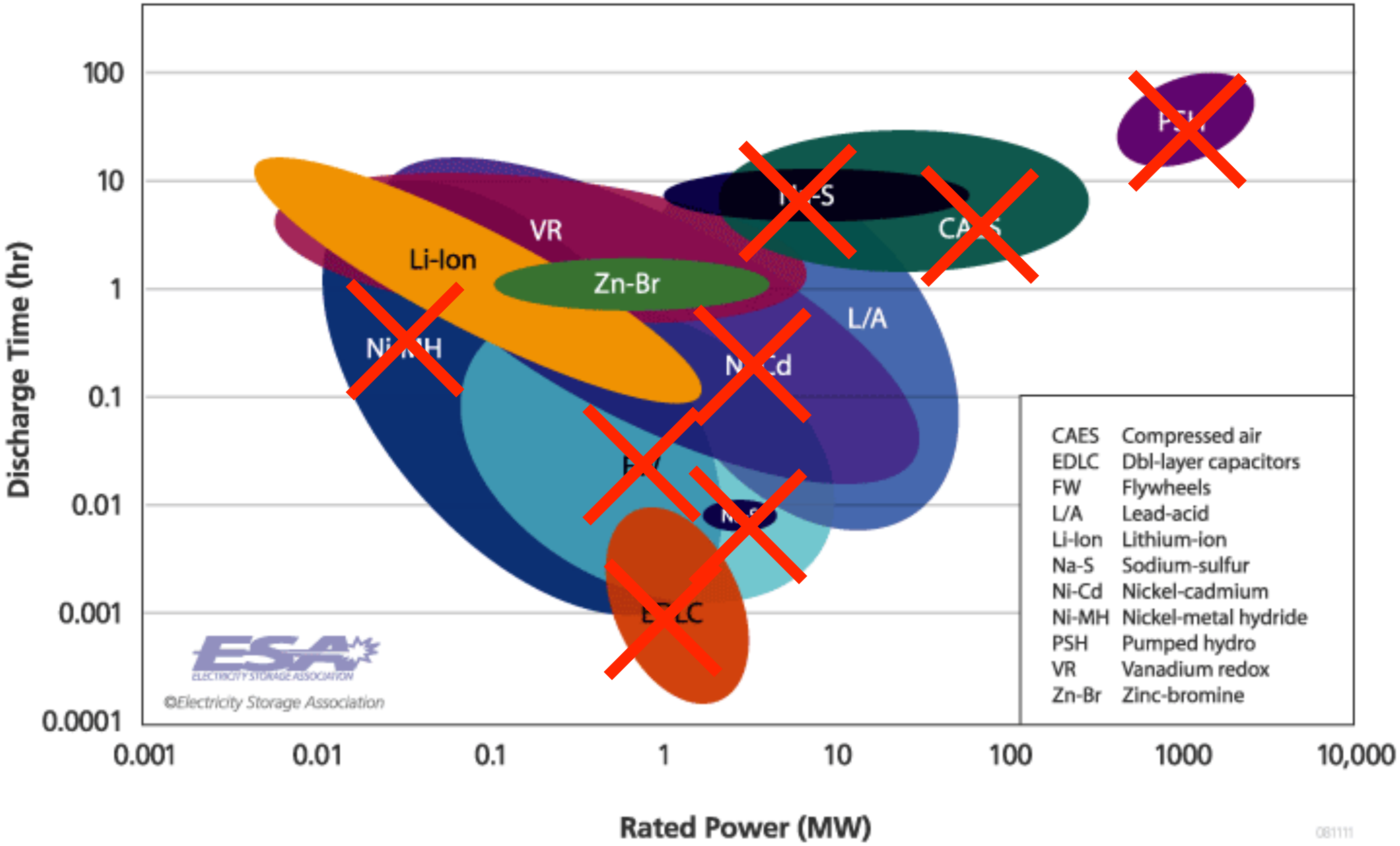
NextEra Energy wants to be "the largest, most profitable clean energy provider in the

Energy Storage Solutions



http://www.electricitystorage.org/images/uploads/static_content/technology/technology_resources/ratings_large.gif

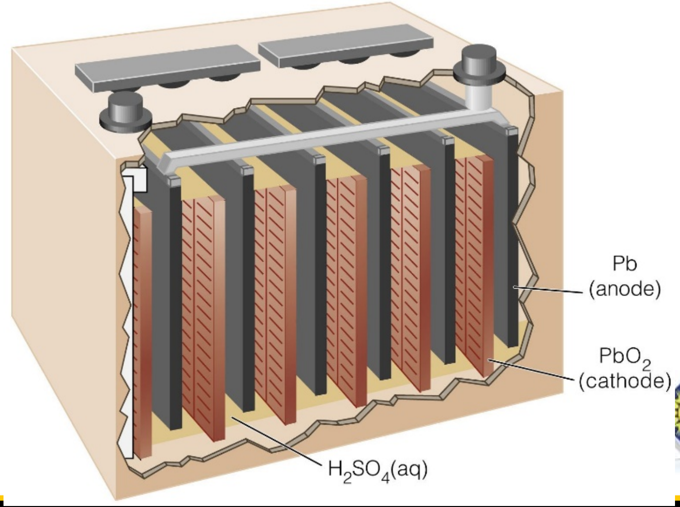
Energy Storage Solutions



http://www.electricitystorage.org/images/uploads/static_content/technology/technology_resources/ratings_large.gif

Energy Storage Solutions

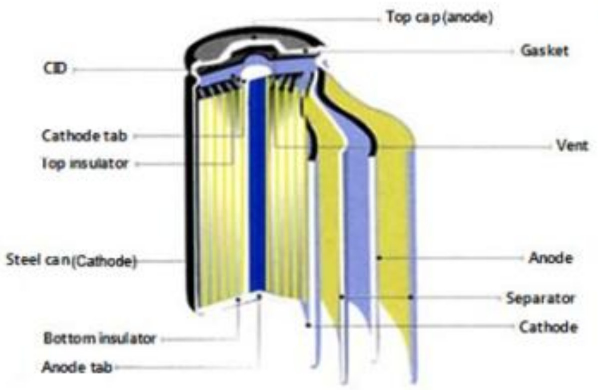
- Lead acid
  - – Oldest, most well-known
  - – Highly developed recycling chain
  - – Lowest cost/kWh
  - – Relatively low energy storage capacity
  - – < 3 year lifetime

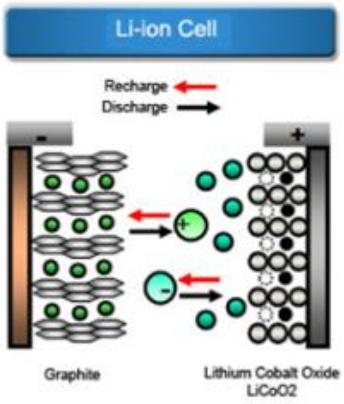


http://www.pospic.com/?image=http://www.wedocable.com/photo/lead-acid-battery-cell-diagram-48902.jpeg&title=Lead%20Acid%20Battery%20Cell%20Diagram&tag=Dry%20Cell%20Battery%20Diagram%20Simple

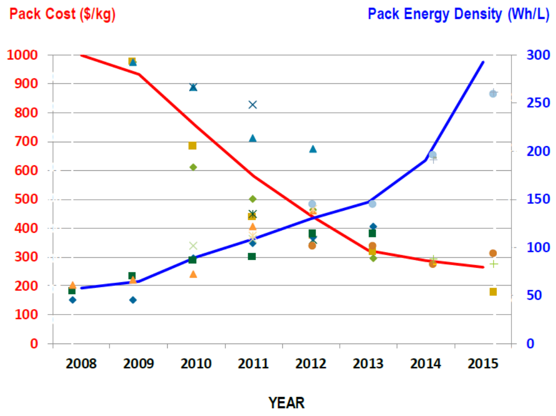
Energy Storage Solutions

- Lithium ion
  - Widely accepted in the technology field
  - Employed by EVs more than any other battery
  - Cost/kWh has decreased by 70% in last 8 years
  - < 5 year lifetime





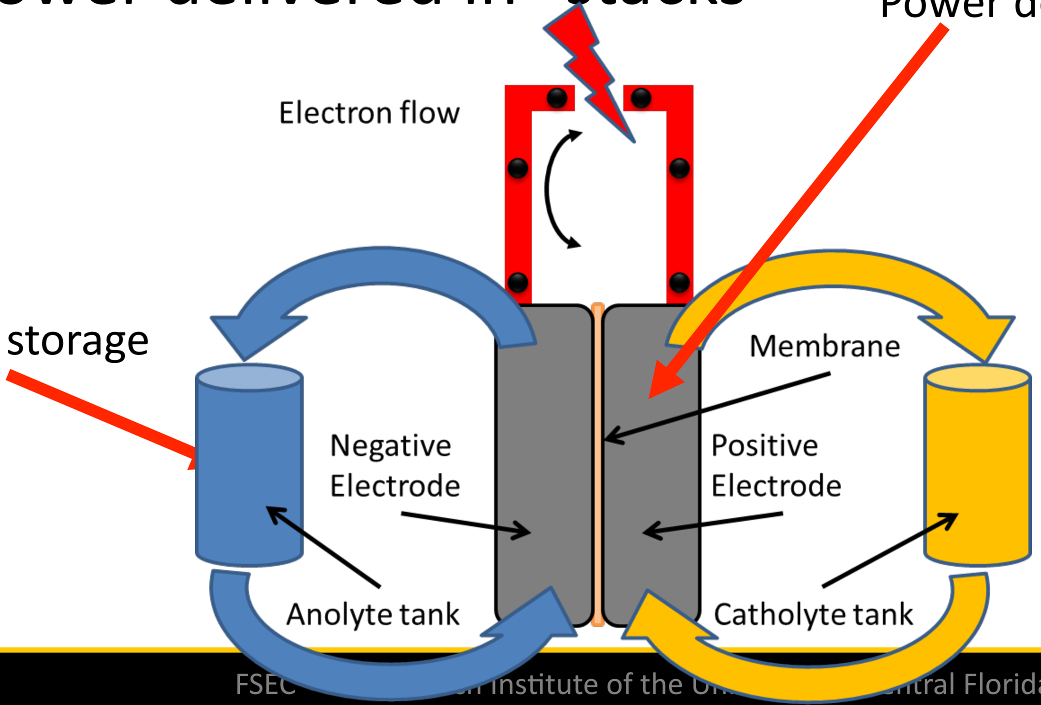
http://www.aglmediagroup.com/evolving-lithium-batteries-for-the-internet-of-everything/



C. Cooper. “Vehicle Technologies Office Overview”. Annual Merit Review and Peer Evaluation Meeting, June 6 2016.

Energy Storage Solutions

- Flow battery
  - NASA technology from the ‘70s
  - Energy stored in tanks
  - Power delivered in “stacks”



Power delivery

Energy storage

Energy Storage Solutions

- All Vanadium
  - Anode: V^{2+}/V^{3+}df
  - Cathode: VO^{2+}/VO_2^+
- High tolerance to deep discharge
- No dendrite formation
- High capital cost ($>500/ kWh)
- Commercially available (Gildemeister CellCube)
- > 15 year lifetime

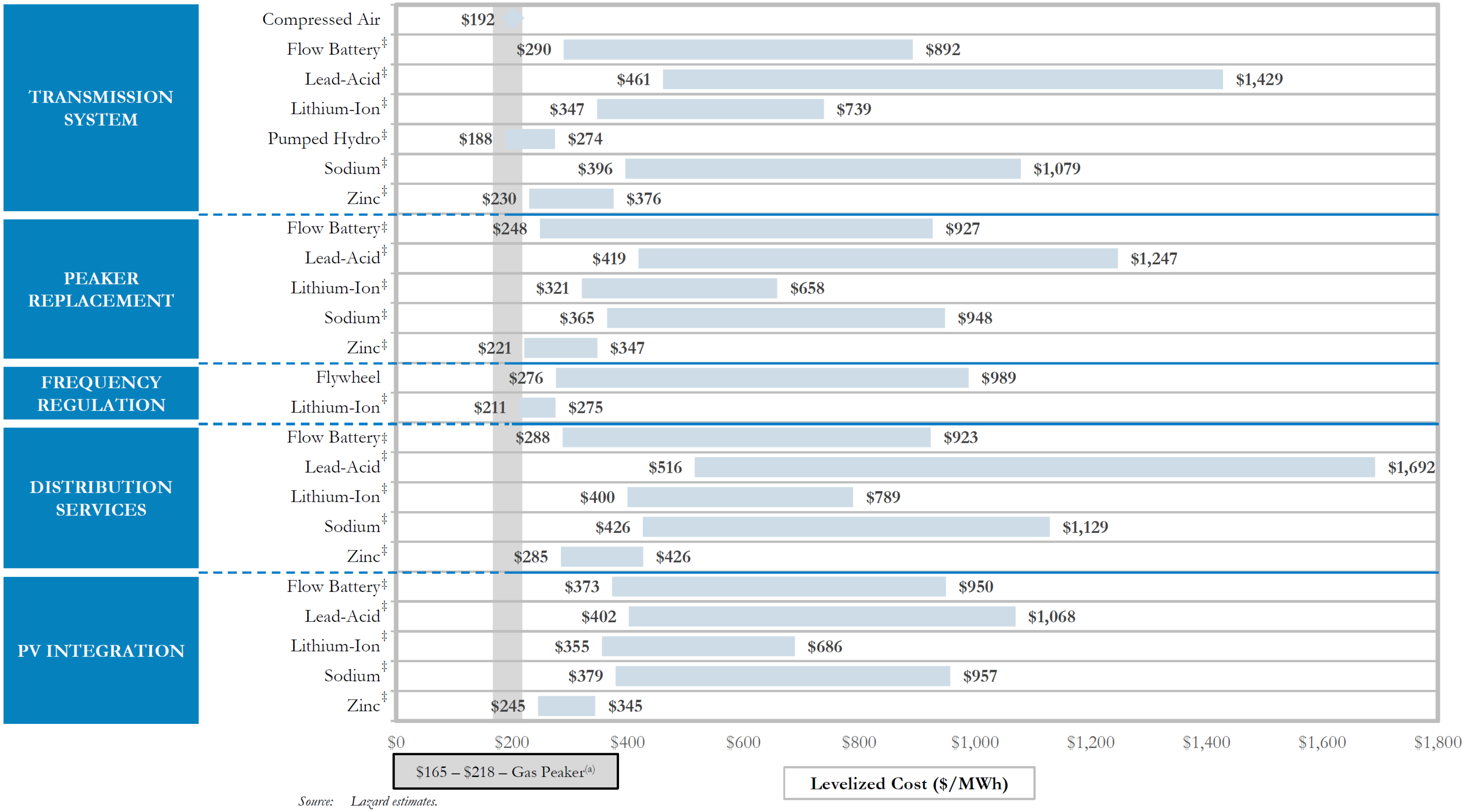
- Zn-Br
  - Anode: Zn/Zn^{2+}
  - Cathode: Br^-/Br_2
- Possible dendrite formation
- Oil phase required for bromine stability
- High capital cost
- Commercially available (ZBB, RedFlow)
- > 10 year lifetime

Energy Storage Use Cases

		Storage Tech	Energy req'd (MWh)	Lifetime (yrs)	100% DOD cyc/ day
Grid operators	Transmission	LA, Li, Flow	800	20	1
	Peaker	LA, Li, Flow	100	20	1
	Frequency	Li	5	20	4.8
	Distribution	LA, Li, Flow	16	20	1
	PV Integration	LA, Li, Flow	4	20	1.25
	Microgrid	LA, Li, Flow	2	20	2
Buildings	Island Grid	LA, Li, Flow	6	20	1
	Commercial/Industrial	LA, Li, Flow	4	10	1
	Commercial appliance	LA, Li, Flow	0.2	10	1
	Residential	LA, Li, Flow	0.01	10	1

Lazard's Levelized Cost of Storage Analysis – Version 1.0. November 2015

LCOS for Grid-Scale



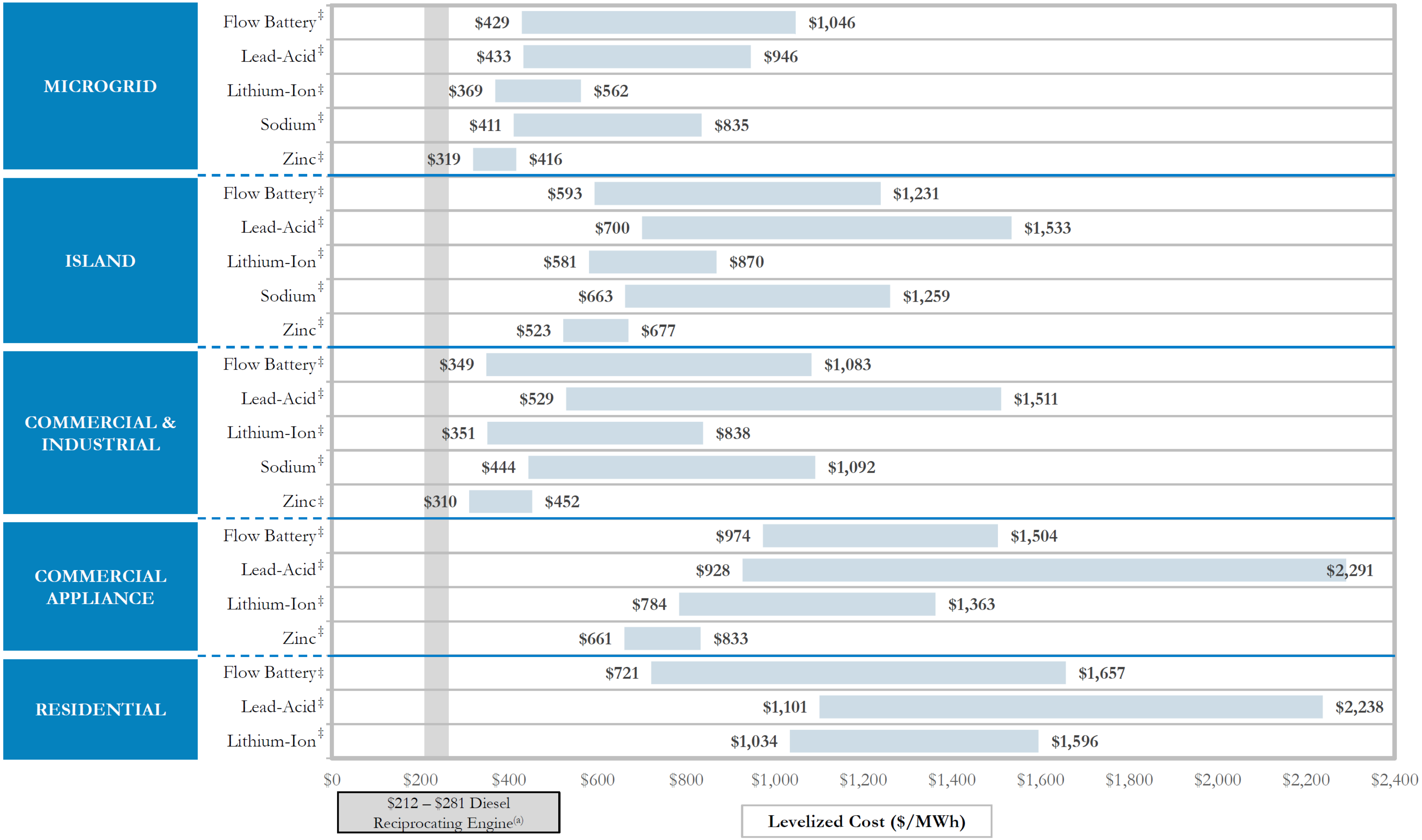
Source: *Lazard estimates.*

Note: Here and throughout this presentation, unless otherwise indicated, analysis assumes 20% debt at 8% interest rate and 80% equity at 12% cost for all technologies and use cases. Assumes seven year MACRS depreciation unless otherwise noted. Analysis does not reflect impact of evolving regulations/rules promulgated pursuant to the EPA's Clean Power Plan.

‡ Indicates battery technology.

(a) Indicates illustrative conventional alternative to energy storage. Not intended to reflect the sole conventional alternative (or source of value from replacing such alternatives). The lowest cost conventional alternative for a particular use case may not be the lowest cost conventional alternative for another use case.

LCOS for Building Operator



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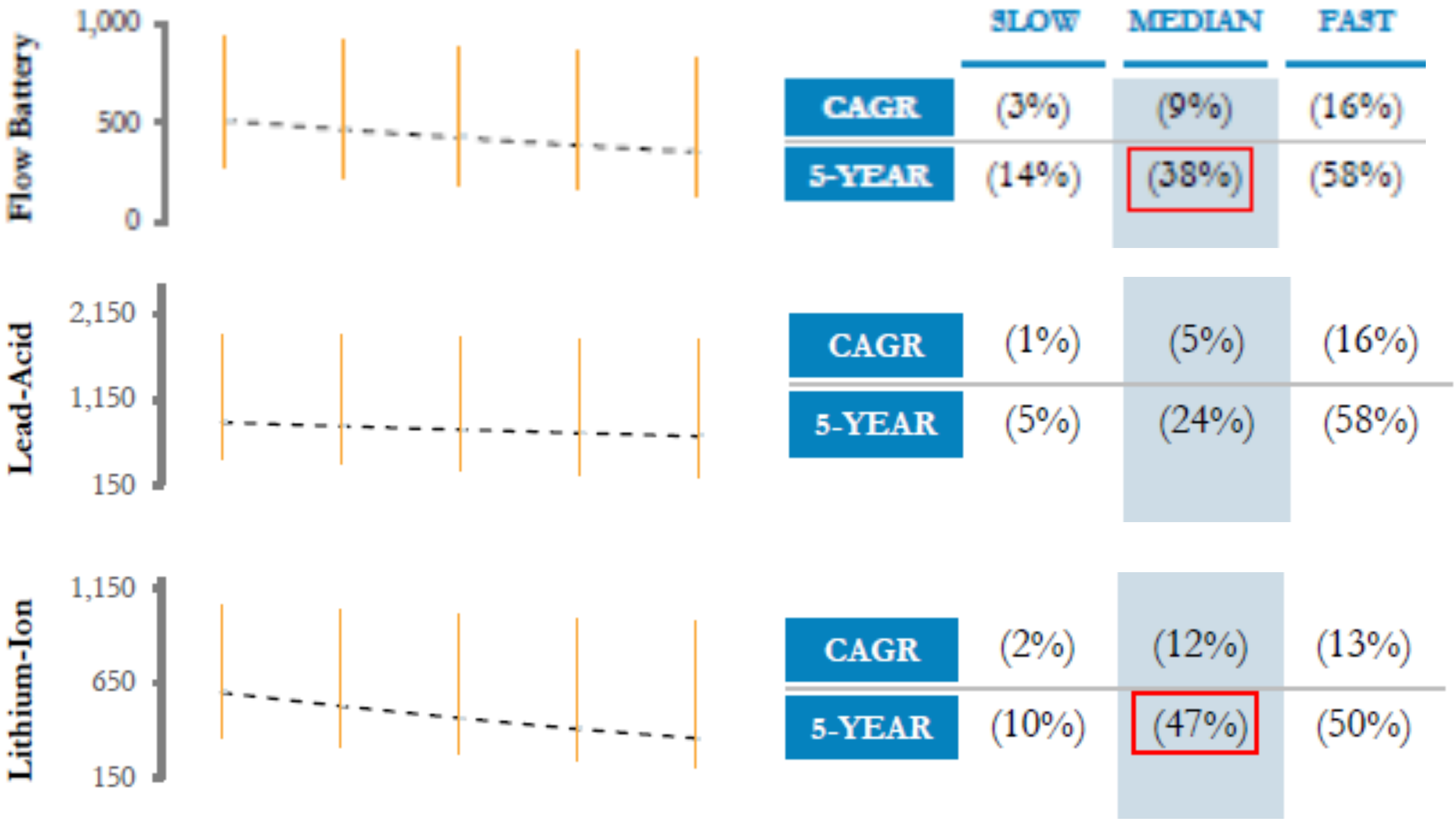
Cost Outlook

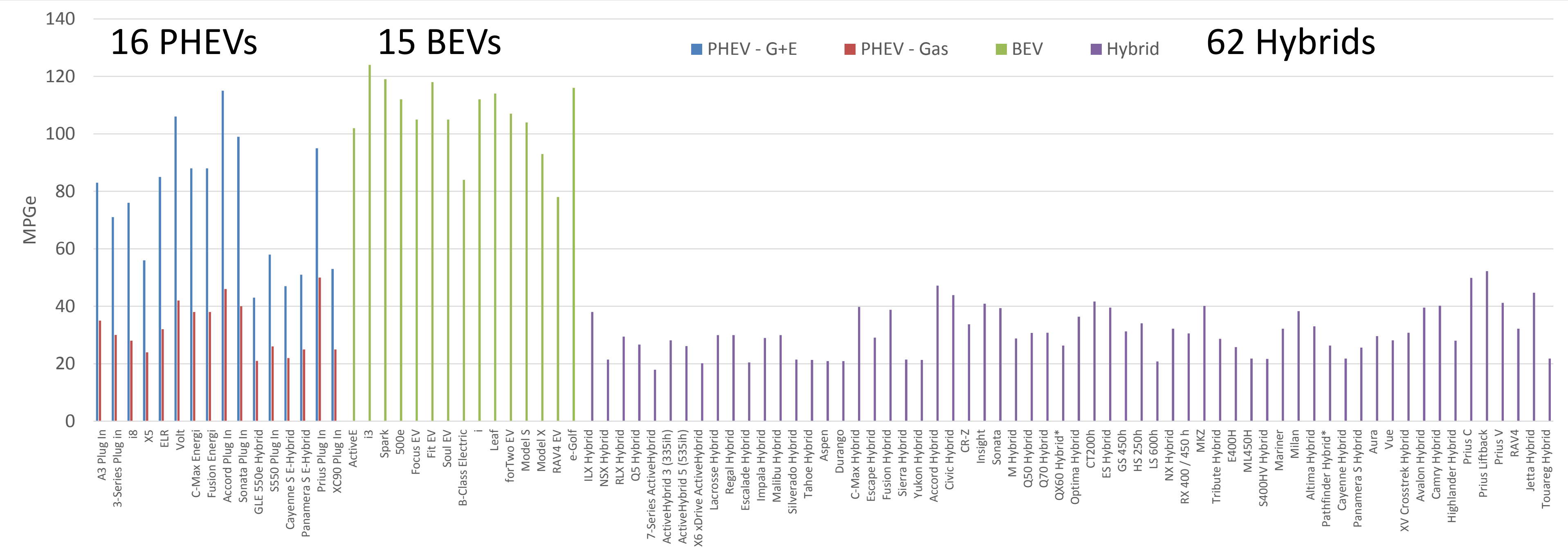


Flow Battery	SLOW	MEDIAN	FAST
CAGR	(3%)	(9%)	(16%)
5-YEAR	(14%)	(38%)	(58%)

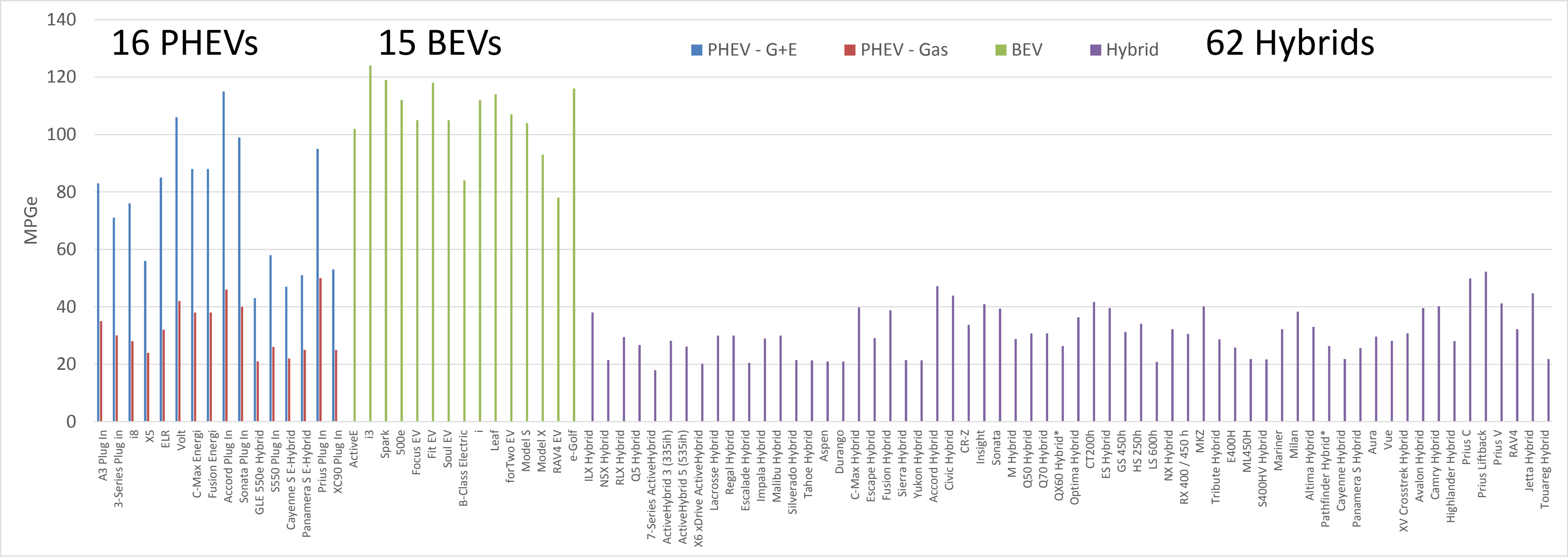
Lead-Acid	SLOW	MEDIAN	FAST
CAGR	(1%)	(5%)	(16%)
5-YEAR	(5%)	(24%)	(58%)

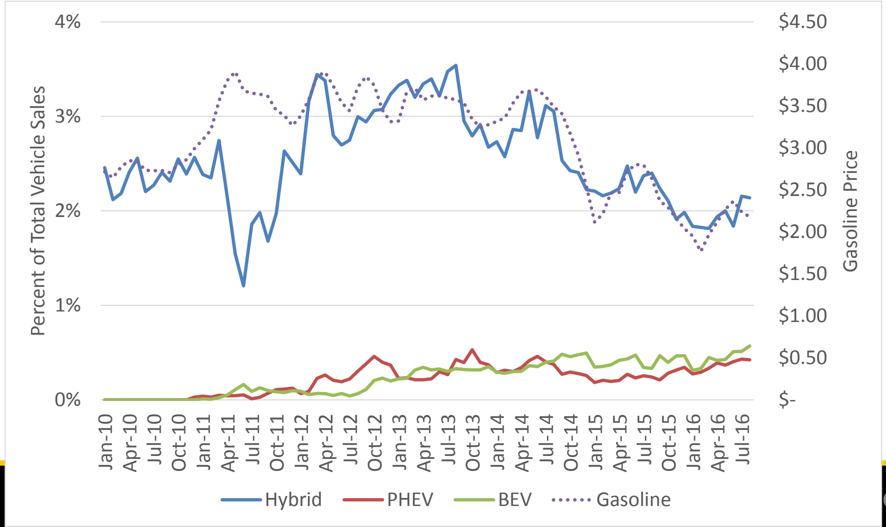
Lithium-Ion	SLOW	MEDIAN	FAST
CAGR	(2%)	(12%)	(13%)
5-YEAR	(10%)	(47%)	(50%)

Electric Vehicles



Electric Vehicles

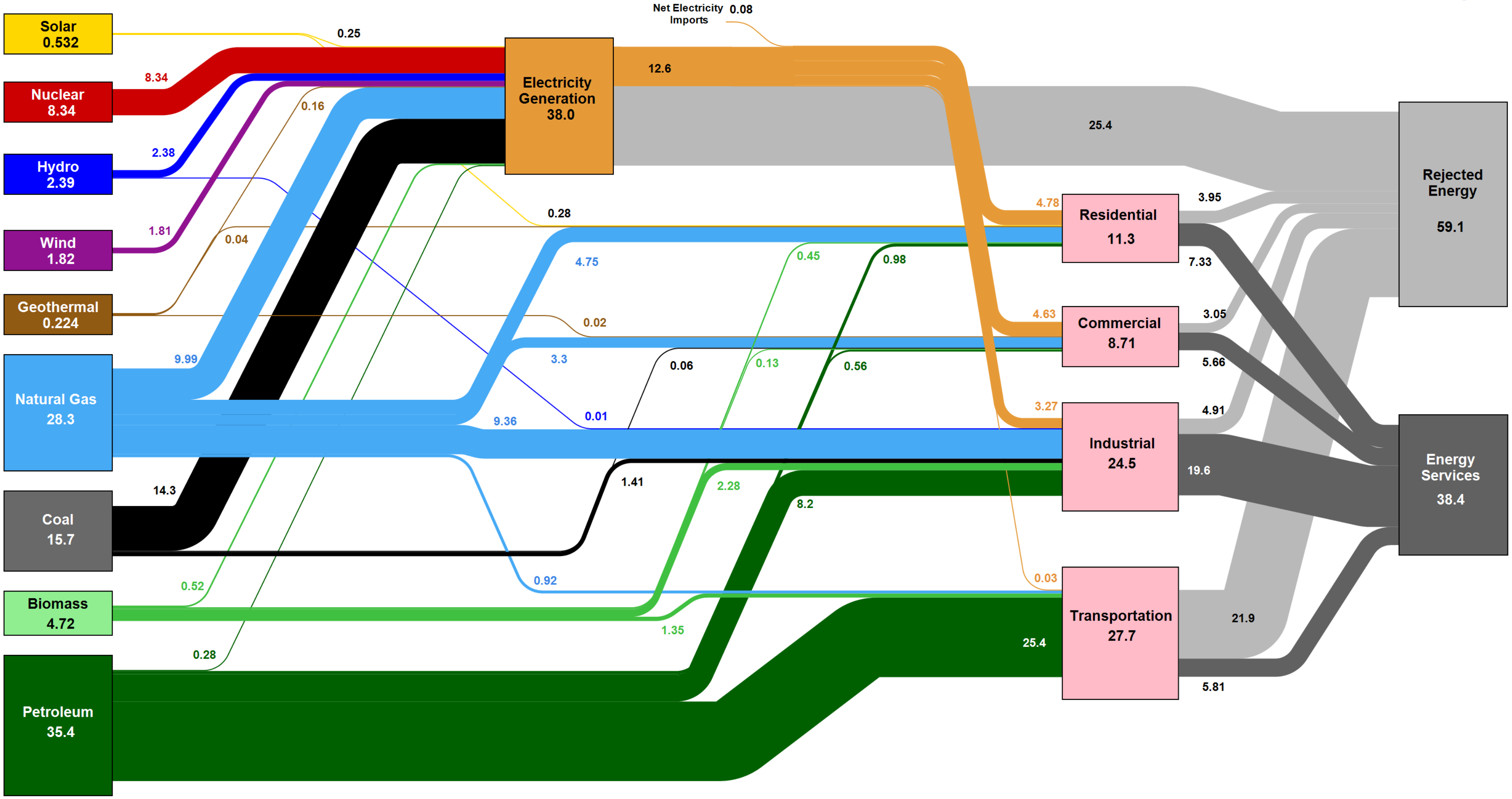




OR?

Estimated U.S. Energy Consumption in 2015: 97.5 Quads

Lawrence Livermore National Laboratory

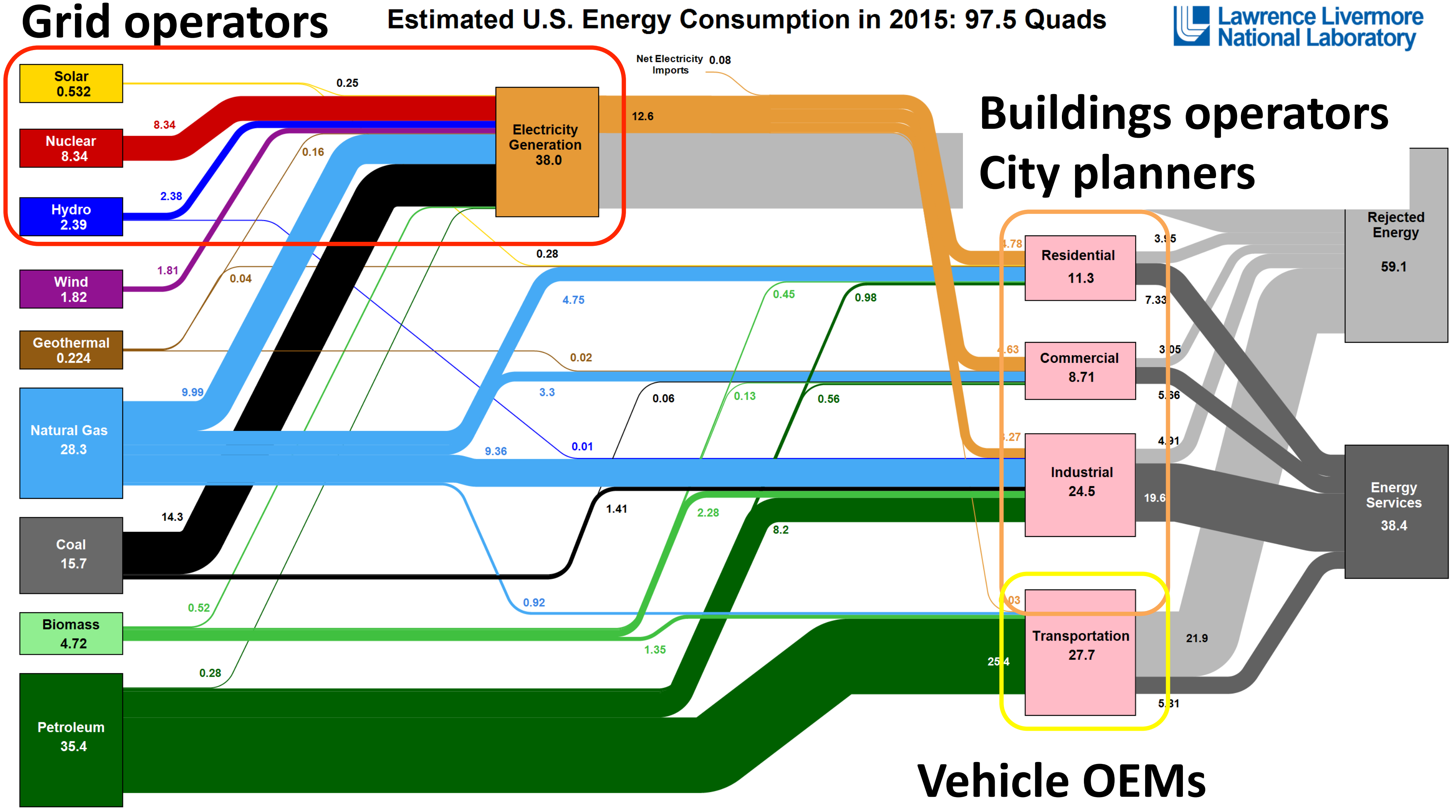


Source: LLNL March, 2016. Data is based on DOE/EIA MER (2015). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent Rounding. LLNL-MI-410527

Grid operators

Buildings operators
City planners

Vehicle OEMs
(Airplanes, freight, trains)



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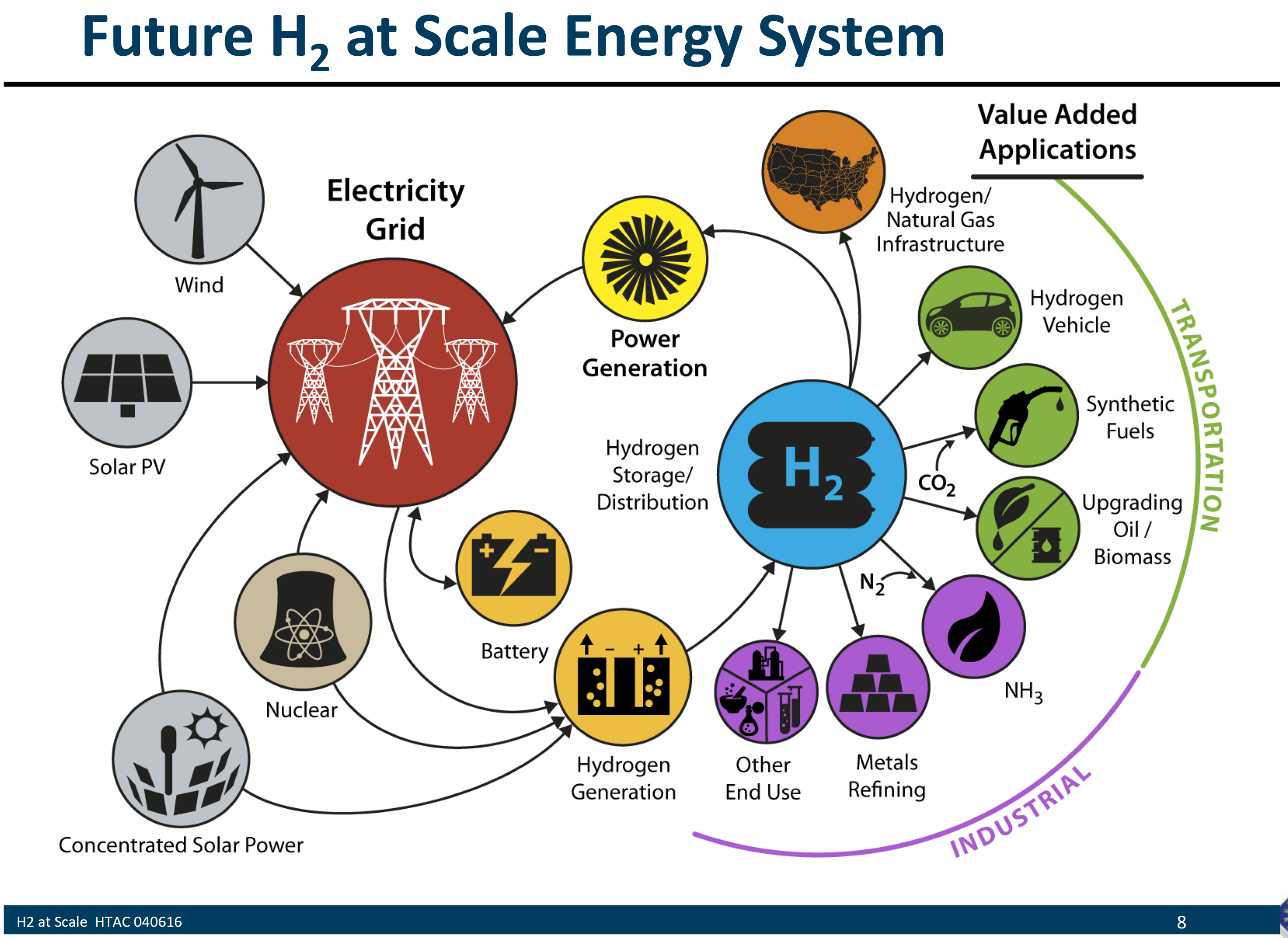
Potential Vision of Future Energy

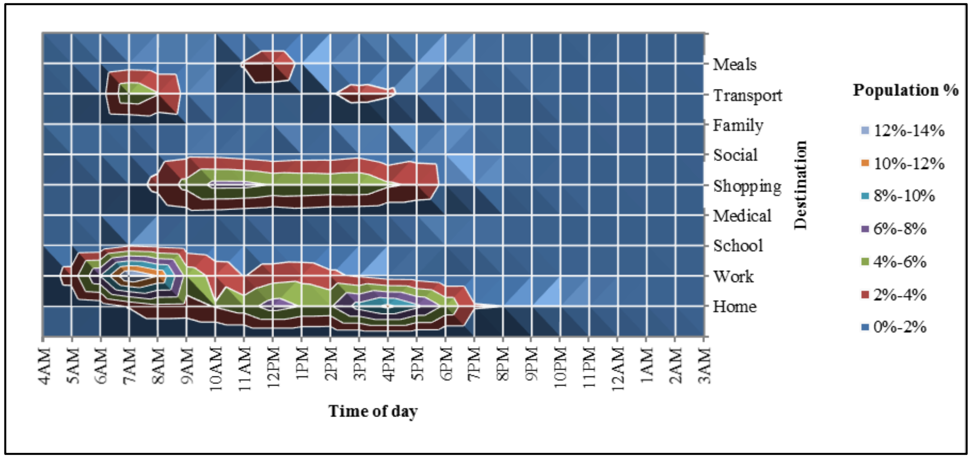


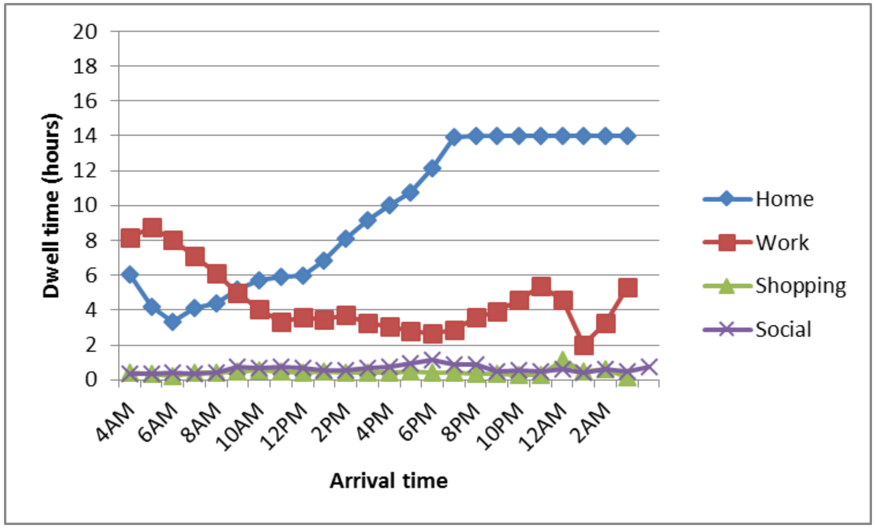
Future H_2 at Scale Energy System

H2 at Scale HTAC 040616 8

H2 at Scale: Deeply decarbonizing our Energy System. HTAC Presentation April 6, 2016

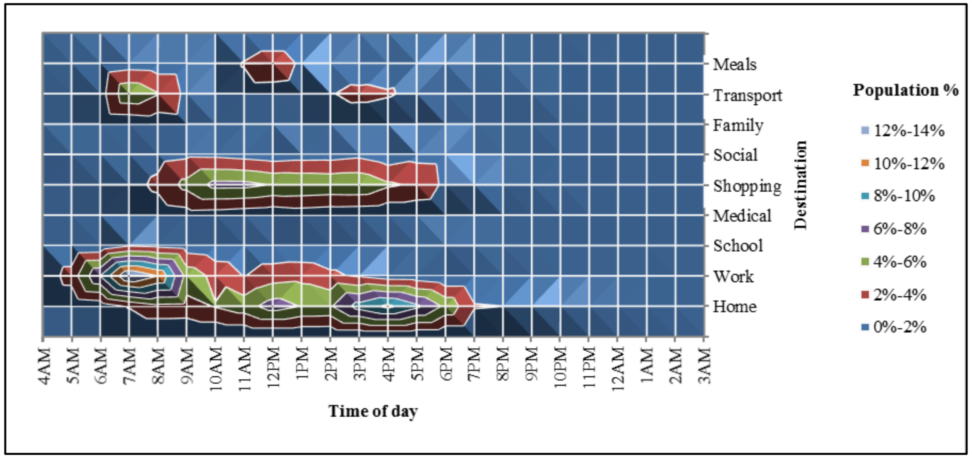
V2G Locations

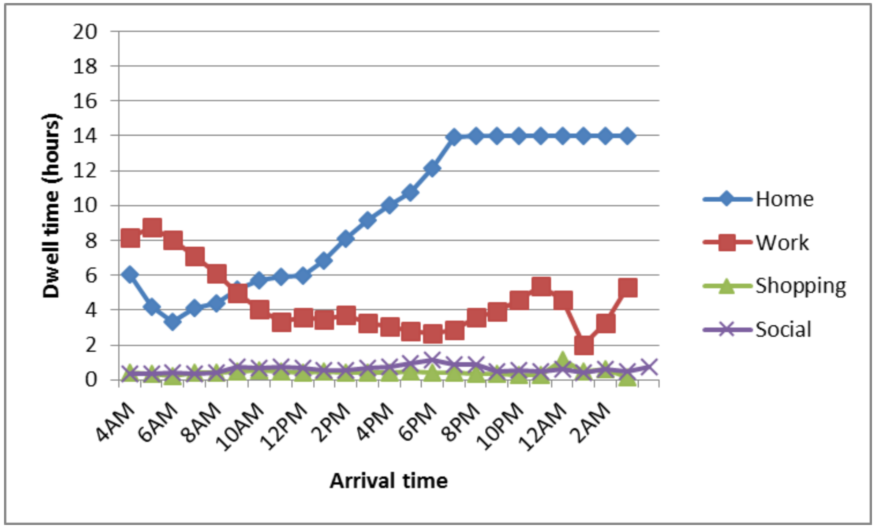


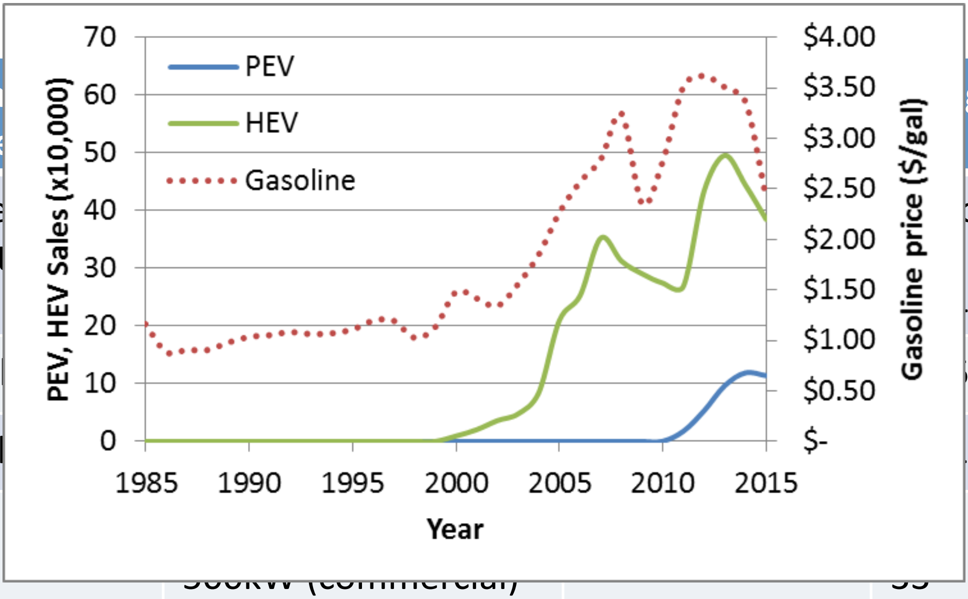


Ancillary Service	Minimum Power	Required Interval	Energy/vehicle	Ideal Locations for V2G
Frequency regulation	1 MW (primary) 2-3 MW (secondary) 10 MW (tertiary)	0 sec – 10 min 30 sec – 30 min 30 min – 6 hr	Up to 1 kWh 0.05 – 3 kWh 3 – 40 kWh	Home, Work, Shopping, Social Home, Work, Shopping, Social Home, Work
Peak Shaving	50-500 kW	2 – 10 hr	6 – 60 kWh	Home, Work
Load shifting	100 kW-2 MW	20 min – 1.5 hr	2 – 10 kWh	Home, Work
Back-up Power	5kW (residential) 500kW (commercial)	5 hr – 5 days	25 – 600 kWh 33 – 800 kWh	

V2G Locations







Ancilla Service			gy/vehicle	Ideal Locations for V2G
Freque regulat			o 1 kWh – 3 kWh 0 kWh	Home, Work, Shopping, Social Home, Work, Shopping, Social Home, Work
Peak Sl			0 kWh	Home, Work
Load sl			0 kWh	Home, Work
Back-u	300kW (commercial)		600 kWh 800 kWh	