PNM 2017-2036 Integrated Resource Plan

JULY 27, 2016

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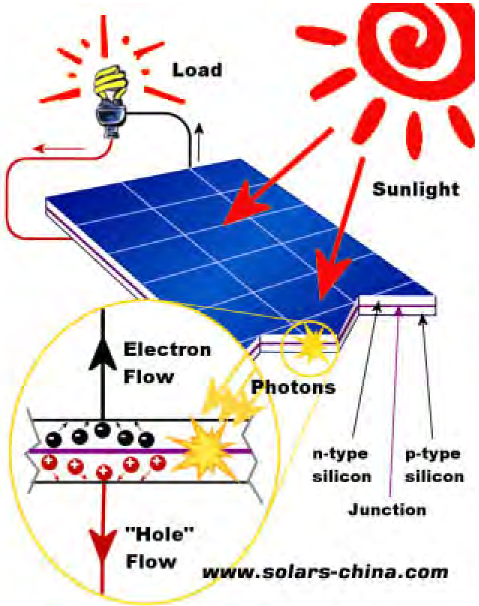
SOLAR PHOTOVOLTAIC (PV) – BY FAR THE MOST COMMON

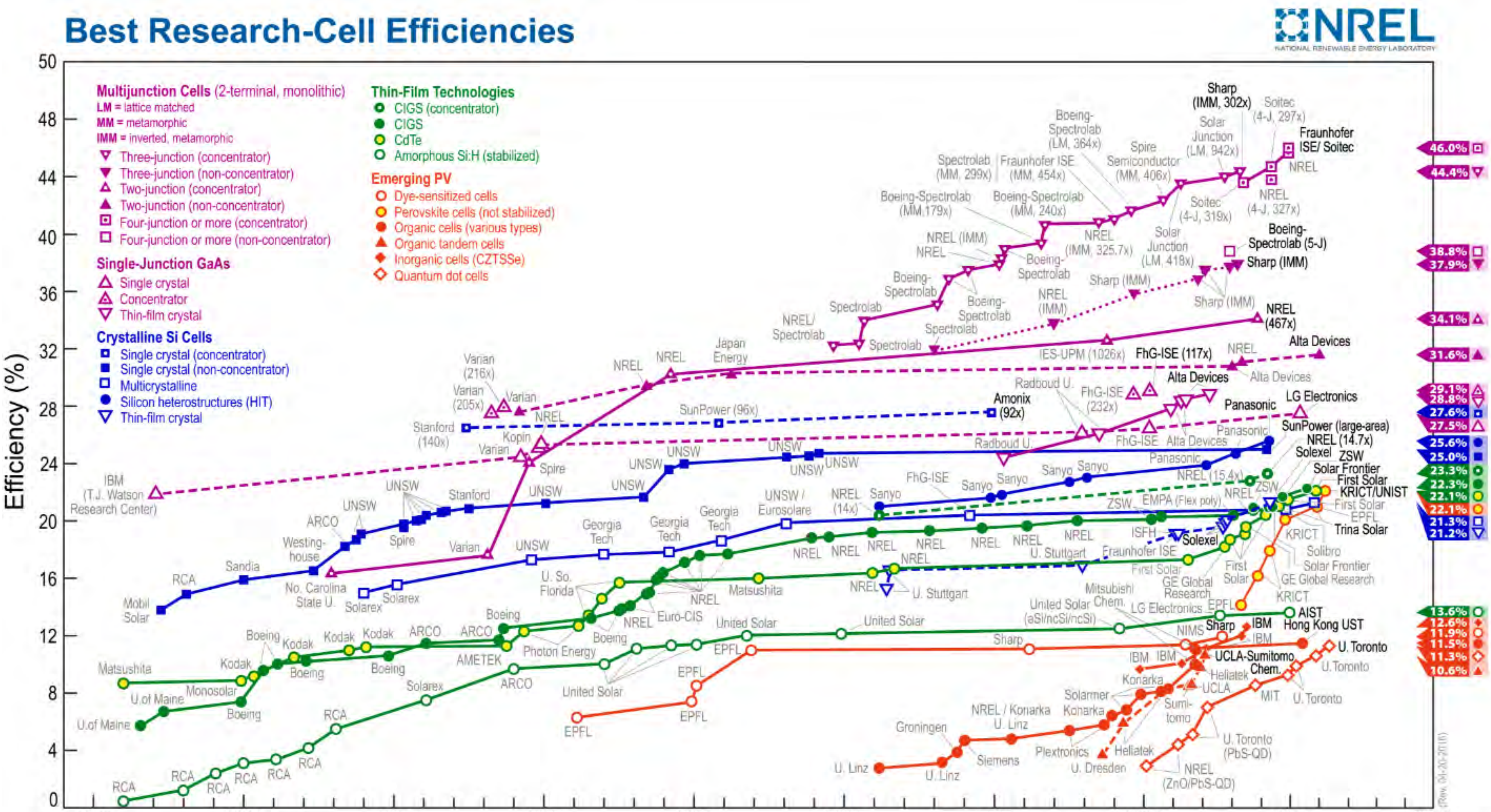


- Fastest growing renewable technology
- Sizes range anywhere from panels on a home (kWs) to large utility scale (MWs)
- Key points – non-dispatchable, variability issues, alignment with peak usage, inverter technologies, operation of the grid with significant distributed resources

DC to AC

(Or could be string micro-inverters)

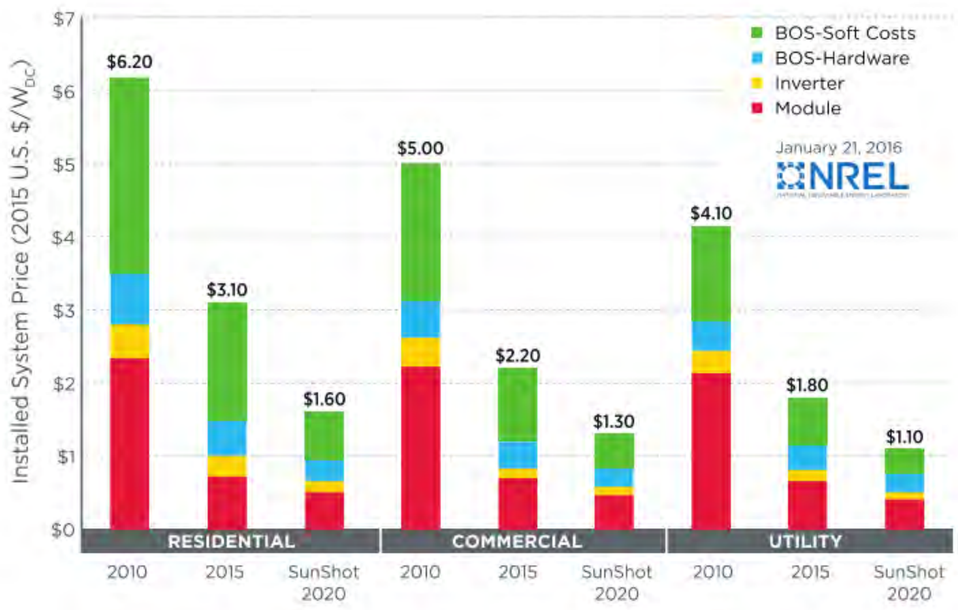
SOLAR PV TECHNOLOGY TREND – EFFICIENCIES



Source: http://www.nrel.gov/ncpv/images/efficiency_chart.jpg , 2016

EFFICIENCY IMPROVEMENT – HOW DOES IT AFFECT COSTS?

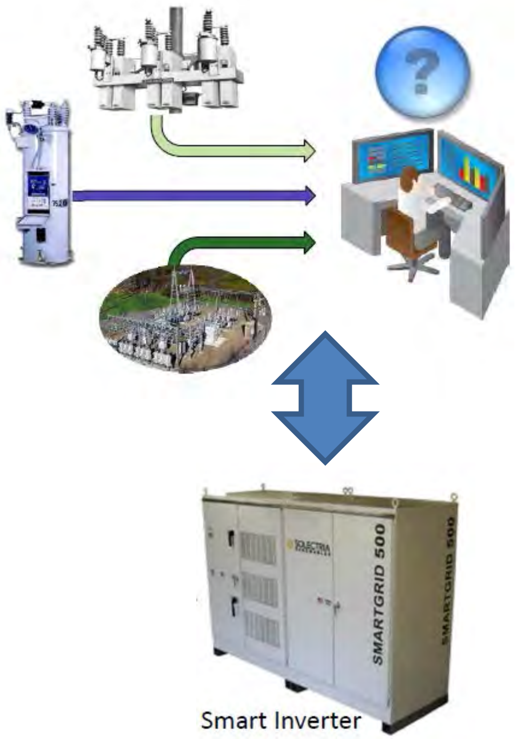
- As an example – efficiency difference between Silicon or Thin film vs. multi-junction ~ 20%
    - 20% improvement in efficiency does not mean 20% cost reduction
- Why? - Too many variables - examples
    - Balance of system costs (wire, inverter, installation, etc.) remain the same for the same output
    - Cost of materials may be higher
    - Cost of land may be lower (although may not apply to roof space)
- Bottom line – Improved efficiency equates to more Watts/footprint which may but not directly equate to equivalent cost savings.



Source: On the Path to Sunshot - The role of Advancements in Solar Photovoltaic Efficiency, Reliability, and Costs, NREL, May 2016

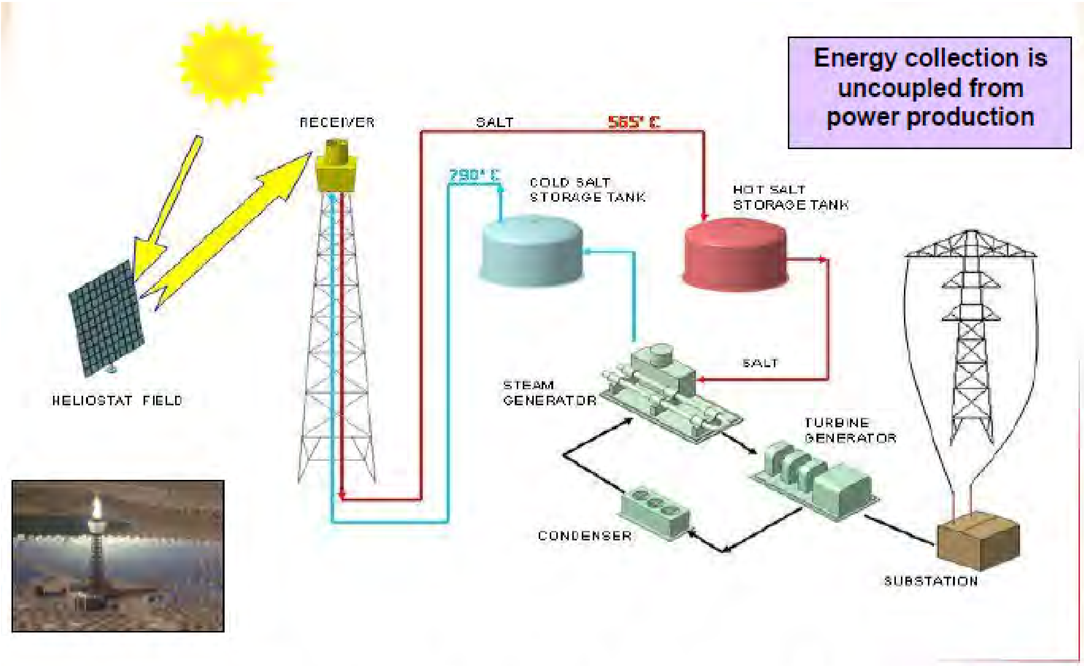
SMART INVERTERS

- Smart inverter is a solar inverter with additional functions
  - Communications
  - Low/High Voltage ride through (seconds or less)
  - Help support voltage (reactive support) and limit some intermittency
- Starting to see inverters that are UL listed
- Today many utilities are doing trial installations – technology advancing but not mature
- Questions
  - What is the optimization objective?
  - Can this be a utility resource?
  - How much can a utility count on the resource?
- Challenges
  - Communication standards and methods
  - Standardization of protocols
  - Control room integration
- Many inverters being used in utility scale have smart inverter functionality.
- Current EPRI research working on control center software and control strategies of multiple inverters.



SOLAR THERMAL

- Solar energy collected by the solar troughs heats the thermal oil or molten salt solutions.
- The heated solution, circulating in a closed loop, heats high volumes of water to generate steam at high temperatures (up to 400°C).
- Steam turbine generates electricity.
- Many do burn some fossil fuels on start-up to get oil/salt solutions to temperature



Challenge: Transition of Molten-Salt Technology to Troughs

Sandia National Laboratories

TYPES OF SOLAR THERMAL

Parabolic Trough

- Most mature technology
- High water requirement (cooling)
- Efficiency – 13.5%
- Challenges: Cost reduction, freeze protection of molten salt

Power tower

- Highest land requirement
- High water requirement (cooling)
- Currently lowest cost
- Efficiency – 8 to 25%
- Challenges: cost reductions, scale up, bird mortality in solar flux

TYPES OF SOLAR THERMAL

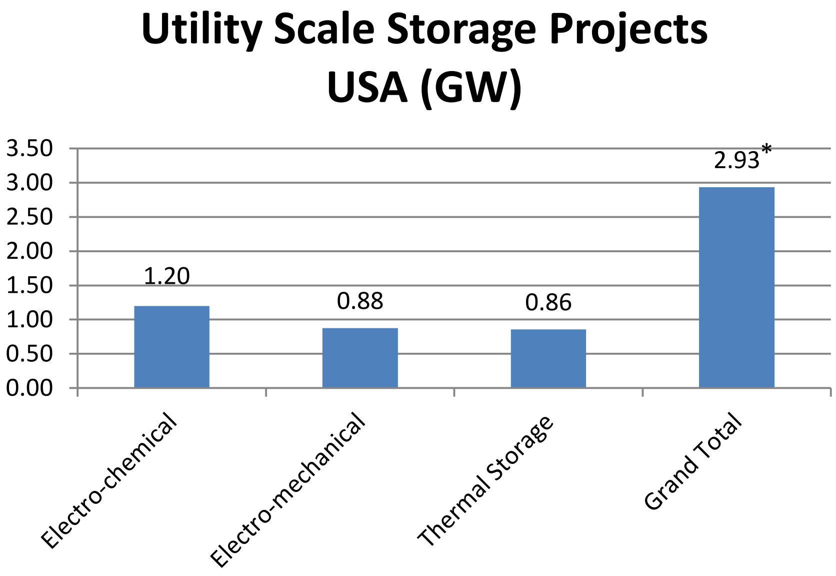
Dish Engine

- Uses a Sterling engine that basically takes advantage of temperature differences to move the engine
- Highest Efficiency
- Early technology deployments
- Limited Deployment
- Efficiency – 16 to 30%
- Challenges: Maintenance Costs, variability

Linear Fresnel Reflector

- High water requirement
- Least mature technology
- Efficiency – approximately 15%
- Challenges: sufficient cost reduction to offset lower efficiencies, thermal energy storage

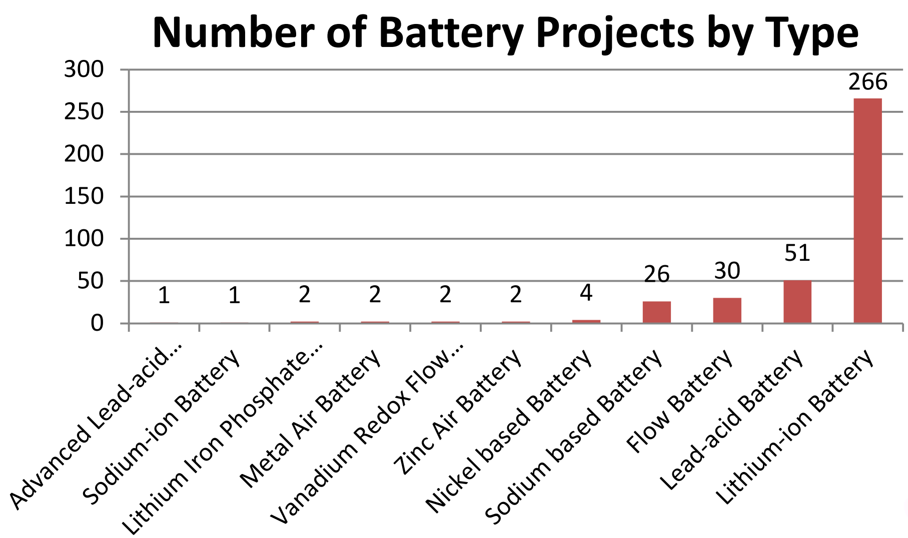
ENERGY STORAGE



* Pumped Hydro adds another 28.91 GW

- Most common battery type being installed is Lithium ion, typically between 4 and 6 hour storage
- Applications depend on region:
    - PJM – Frequency response
    - California – Energy dispatch/renewables

- Published system costs are not always complete:
    - Many quotes still not public
    - Prices quoted as battery pack only
    - KW vs. KWh – most references don't provide both
    - Important to know both energy and power ratings



STORAGE TECHNOLOGIES

Technology	Readiness	Applications	Cost
Lithium Ion	Mature	Power and energy for minutes to 6 hours	$400 to $600 kWh (battery pack only)
Lead Acid	Mature	Power and energy for minutes to 6 hours	$300 to $400/kWh (battery pack only)
Sodium based	NaS mature, but sodium nickel and metal halide still maturing	Energy primarily – peak shaving 2 to 6 hours	$800 to $1000/kWh (battery pack only)
Flow batteries	Few commercial deployments. Vanadium redox furthest along.	Power and energy applications for 4 to 12 hours, however mostly for energy.	$500 to $850/kWh (battery pack only) – however still unproven
Aqueous batteries	Only a handful of implementations	4 to 20 hour for energy applications	No data available – proprietary
Liquid Metal	Demonstration	2 to 12 hour for energy applications	No data available – unproven
Zinc Air	Demonstration	4 hour discharge energy applications although can be used for power	No data available
Ultra Capacitor	Demonstration	1 minute or less - power application	No data available
Fly wheel	Commercially viable	30 minute or less – frequency regulation	DC based price approximately $1000/kW

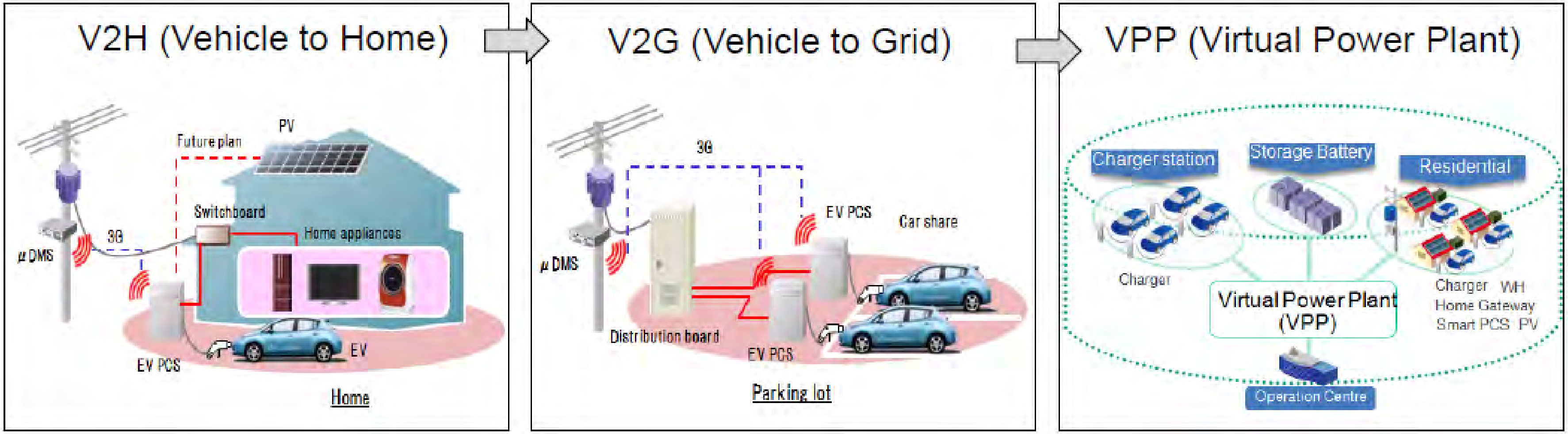
Balance of system costs rule of thumb is double cost of battery pack

STORAGE – BEHIND THE METER

- Approximately 14.8 MW[1] installed in U.S. from 2013 to 2015 (29.9 MWh[1])
- General cost information – estimated $950 to $2000/kWh (2 hour discharge)[1]
  - Example: Tesla - $3000 (does not include inverter and installation ($3000)), Size - 3.3 kW, 6.4 kWh (the 10 kWh battery was discontinued and 7 kWh rating reduced in March of 2016), 9.5 A DC, life of battery projected at 10 years.
- Challenges
  - Continued development of standards
    - How to talk to devices
    - In what protocol
    - What applications will it perform
  - Continued development of smart inverters
  - Continued advances in utility control systems
  - Ways to provide incentives to customers to act
  - Continued reductions in cost of storage
- Maturity – Emerging. Some developments in California, Hawaii Vermont. Mostly for supplementing renewables (PV) as opposed to "off grid" functions.

[1] *Source: U.S. energy Storage Monitor Q3 2015 Full Report, gtmresearch, December 2015*

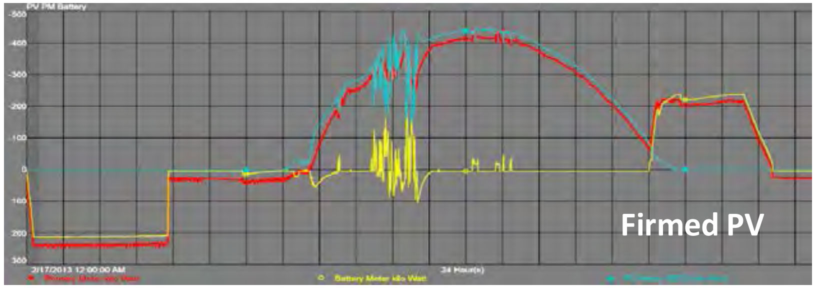
ELECTRIC VEHICLE AS STORAGE

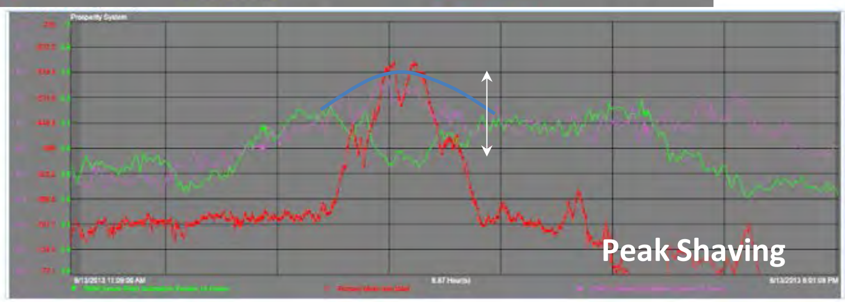


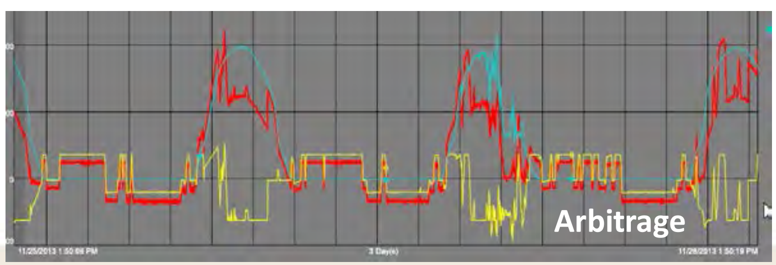
Source: IRED 2014 Conference – Fumitoshi Emura, Hitachi

- Project currently underway in Hawaii with Maui Electric, NEDO, and other partners
- Research ongoing
- Currently we have approximately 671 Electric or hybrid electric vehicles in NM.
- Challenges
  - Communication protocols
  - Architecture
  - Policies, programs, and value proposition for the vehicle owner

STACKED BENEFITS – WHICH SHOULD WE CHOOSE?







- Where it is connected matters.

- How might we prioritize these at the distribution level?
    - Frequency Response?
    - Voltage support
    - Peak Shaving (reliability)
    - Firming renewables
    - Supply capacity (could be same as renewable firming)

- Capabilities of lower priority
    - Arbitrage (no market)
    - Spinning Reserve (rule change needed)
    - Reactive power support (untested)
    - Distribution Upgrade Deferral
    - Transmission Upgrade Deferral (more value at distribution level?)

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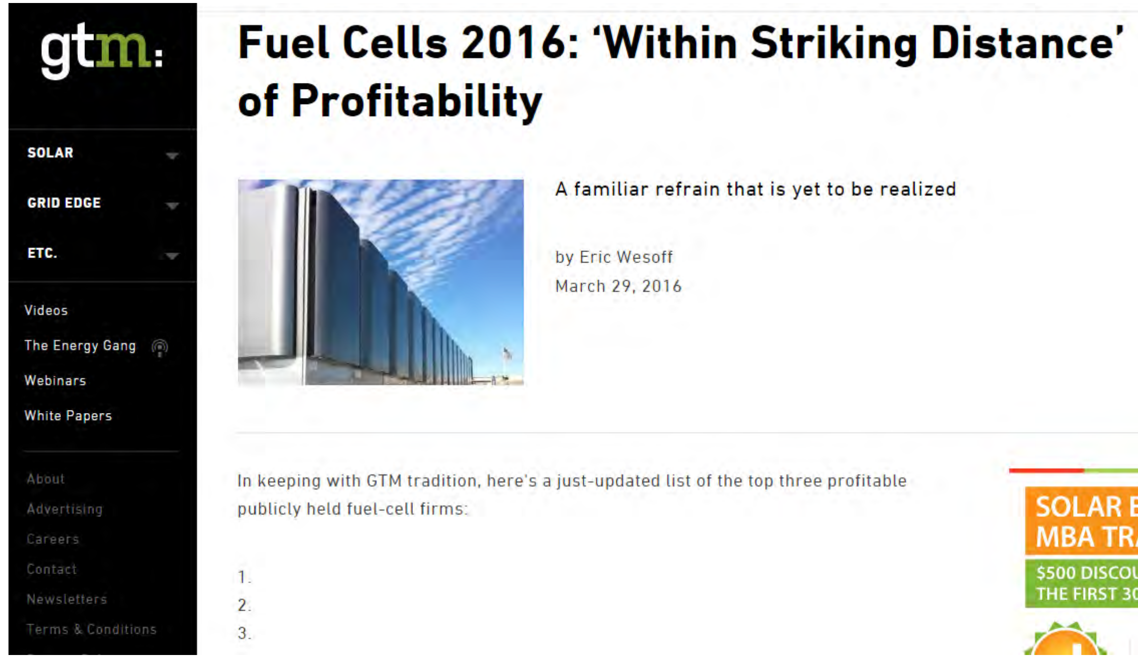
FUEL CELLS

- Still a handful of fuel cell companies, but the market leader today is still Bloom Energy (others – Fuel Cell Energy, Plug Power)
- Ability to apply for SGIP program incentives in California recently challenged, still available in Connecticut
- Base load resource
- Challenges
  - o CO2 emissions (natural gas fueled)
  - o Costs – approx. $7000 to $8000/kW
- Maturity – technology well known, but costs very high



Source: http://www.greentechmedia.com/articles/read/Fuel-Cells-2016-Within-Striking-Distance-of-Profitability

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SMR (SMALL MODULAR REACTOR)

- Still in development, although work has slowed. Not even to demonstration phase.
  - B&W mPower joint venture with TVA was scaled back in 2014
  - Westinghouse scaled back efforts on SMR
  - TVA filed an application in May
  - Idaho National Labs project with NuScale permit has been filed expected in service 2023
- Nuclear produces no CO_2
- Challenges
  - NRC Licensing and Design Certification (probably 6 to 8 yrs.)
  - Funding and Financing (1st of a kind hard)
  - No real cost data.

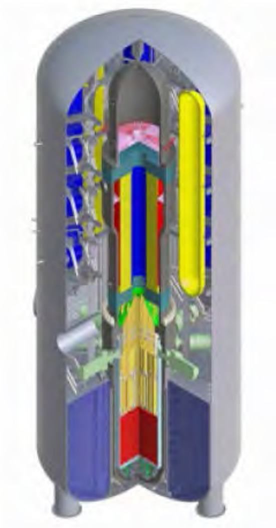


Figure 4-1. Westinghouse SMR
Source: Westinghouse Nuclear

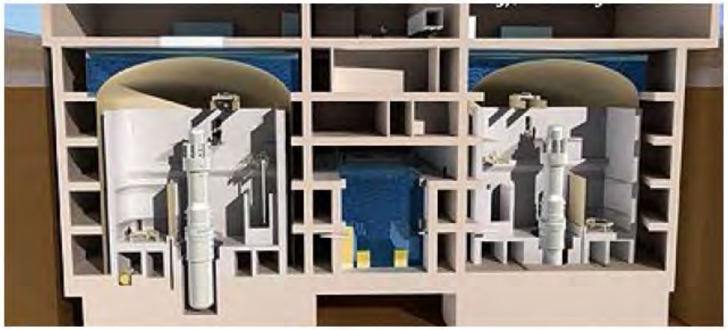
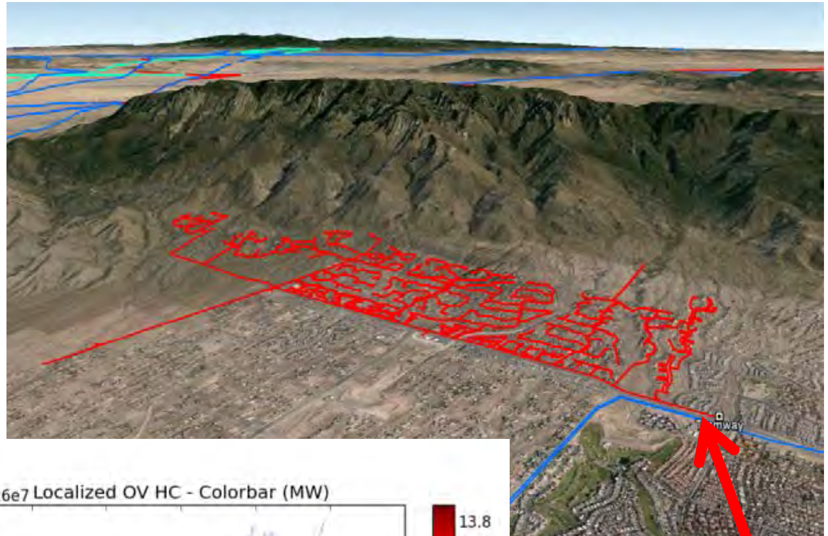


Figure 4-2. Conceptual drawing of an underground containment housing two B&W mPower reactor modules
Source: B&W Nuclear Energy

GRID MANAGEMENT – AMI



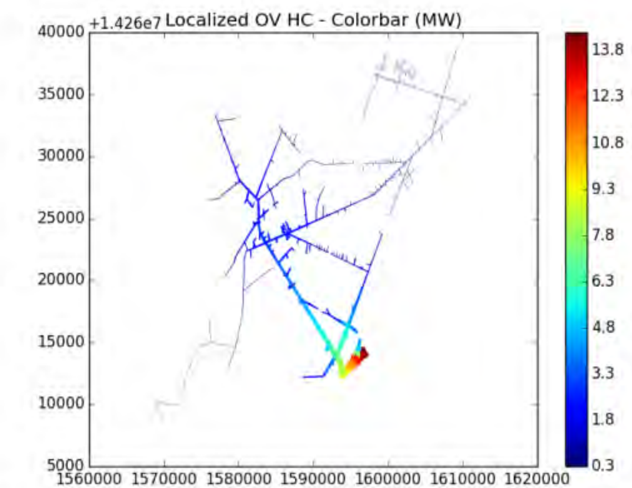


Figure 5-1
Sample Results from Streamlined Method Implementation in CYME/Python

We know and/or manage the characteristics (Voltage, Current, Power) typically only at this point.

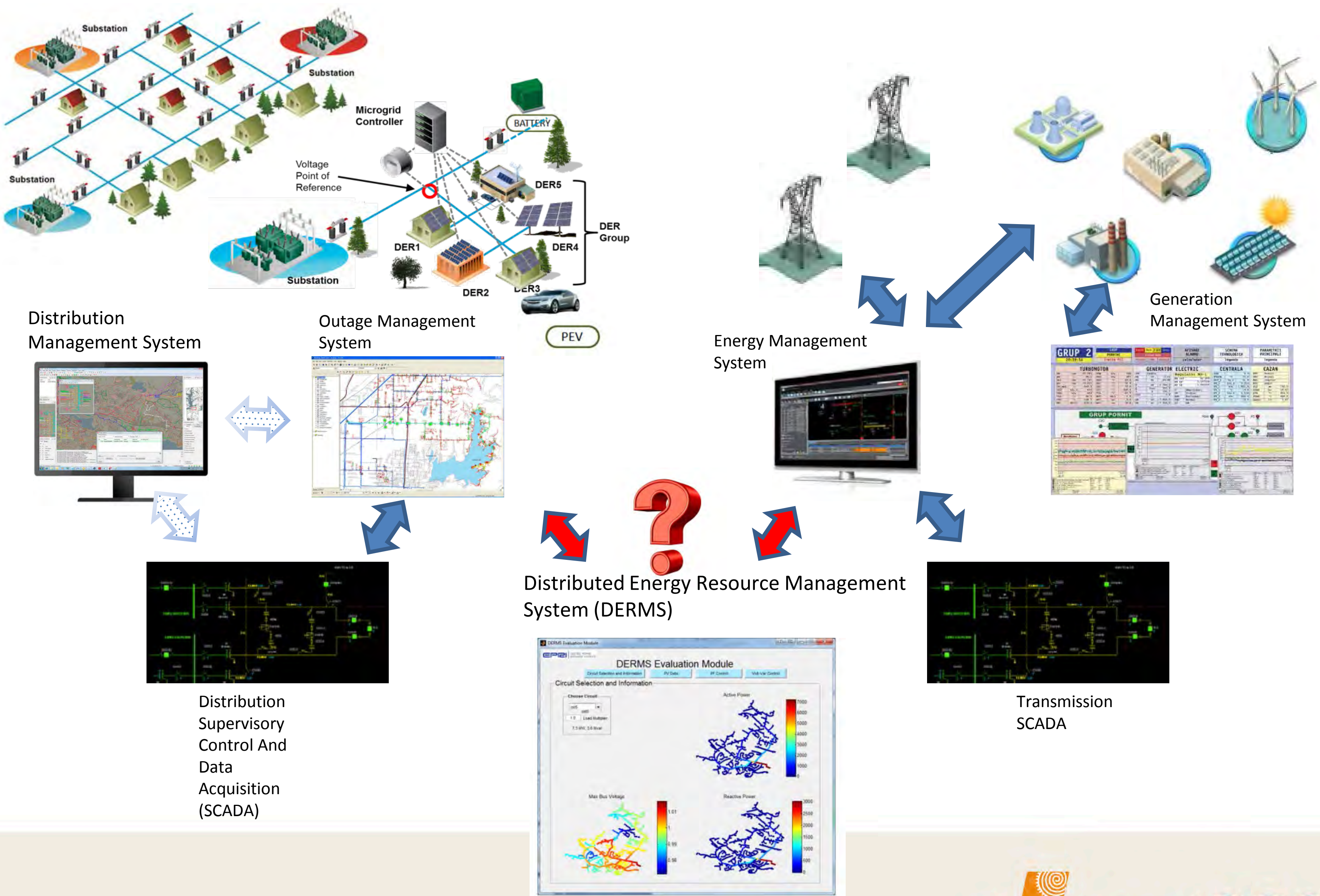
Indicative problem – not this actual feeder

- Wires that feed neighborhoods can be many circuit miles long (example: Far North East heights of ABQ - 75 miles long serving 1,888 customers)
- Distributed generation/storage can cause very localized conditions
- Resource additions can only be calculated, not measured
- Individual loads must be estimated
- Proposed AMI system uses open and interoperable standards
    - More flexible future upgrades
    - More flexible in working with distributed resources
- AMI = Advanced Metering Infrastructure

DEMAND RESPONSE (DR) – TECHNOLOGY PERSPECTIVE

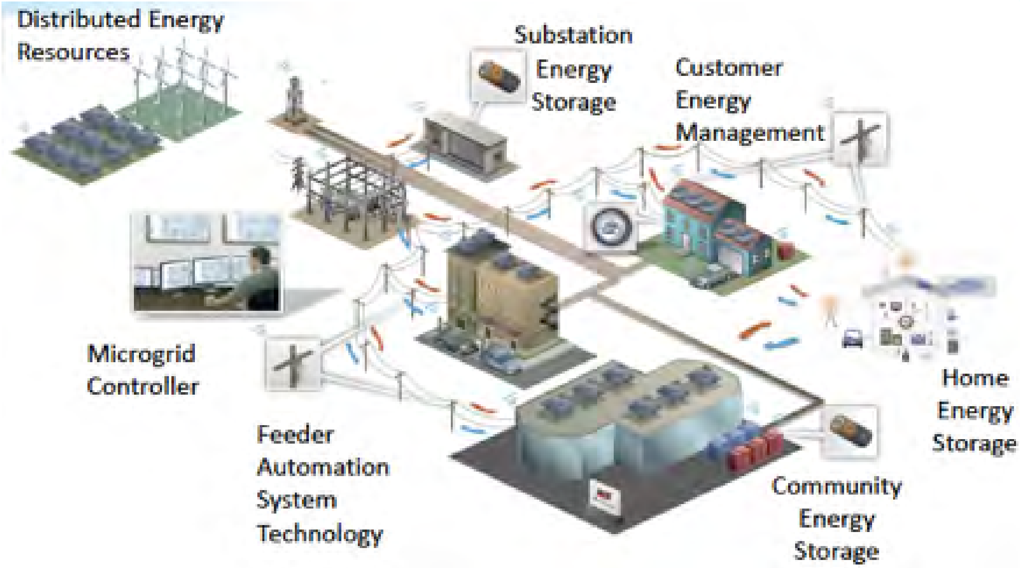
- Trends
  - One-way moving to two-way communications
  - Load shifting vs. only load reduction (flexibility)
  - Auto DR
  - Expanding DR to other timeframes
  - Integrating DR with Renewables - demonstrations
- Devices
  - Thermostats
  - Water Heaters
  - Pool pumps
  - Air Conditioners/Heat Pumps
  - Appliances
  - Commercial equipment
- Challenges
  - Communication methods
  - Communication protocols
  - Integration with utility
  - Consumer adoption/potential

CONTROL CENTER SOFTWARE



MICROGRID

- What is it?
  - A set of controllable loads combined with distributed generation (renewable, gas, etc.)
  - Clearly defined electrical boundaries
  - Acts as a single controllable resource and can disconnect from the grid
- Utility are piloting
  - SDG&E –reliability (Borrego Springs)
  - Duke – R&D
  - New England States – reliability for severe weather events
  - Department of Defense
  - Single Building or Campus
- Challenges
  - Cost
  - Regulatory
  - Policy
  - Controls and Coordination
  - Coordination and Planning



TECHNOLOGY COST

Technology	Maturity	Cost
Energy Storage	Demonstration to Mature depending on technology type	$2,100 - $7,500/kW (Most common Lithium Ion $4,500/kW)
PV Utility Scale	Mature	$1,700/kW
PV Customer install	Mature	$3.10/W Residential ($3,100/kW) $2.20/W Commercial ($2,200/kW)
Solar Thermal	Demonstration	$7,000 - $10,000/kW
Fuel Cells	Mature	$7,000 to $8,000/kW

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Register your email on sign-in sheets for alerts of upcoming meetings and notices that we have posted new information to the website.

Meetings Schedule:

Thursday, August 11, 2016, 10 am – 3 pm

Thursday, Sept. 1, 2016, 10 am – 3 pm

Thank you

Talk to us.