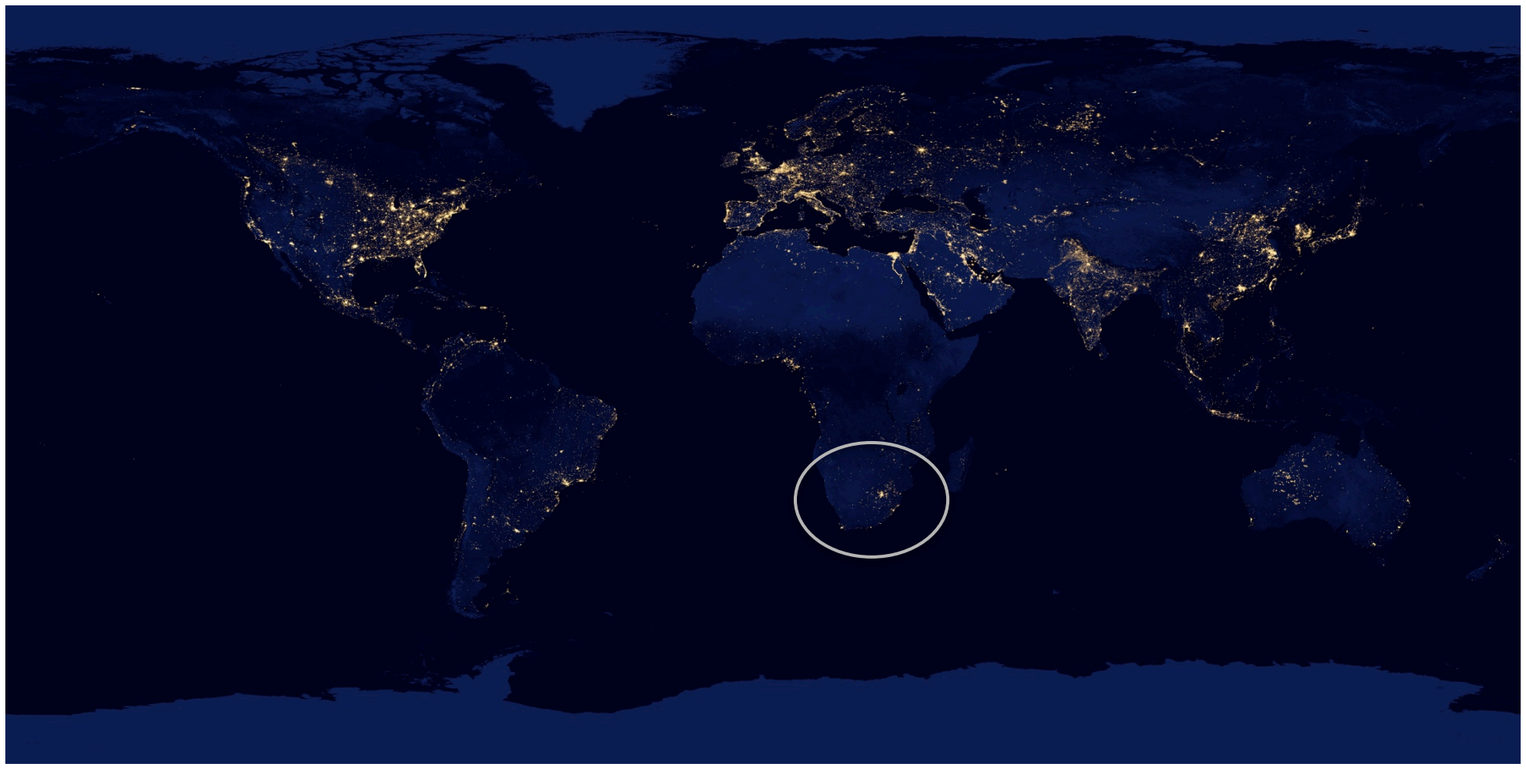
NREL | 40
NATIONAL RENEWABLE ENERGY LABORATORY
1977 – 2017

Modernizing the Electric Grid

Annabelle Pratt, Ph.D.
Principal Engineer
Power Systems Engineering Center

July 28, 2017

ASA Conference



https://earthobservatory.nasa.gov

B.Eng. & M. Eng., Electronic and Electrical Engineering

University of Stellenbosch, South Africa

www.sun.ac.za

Ph.D., Electrical Engineering

Oregon State University

- ***Join ASA***

Advanced Energy, Fort Collins, CO

- ***Rocky Mountain chapter board***
- ***Attend first ASA annual meeting***

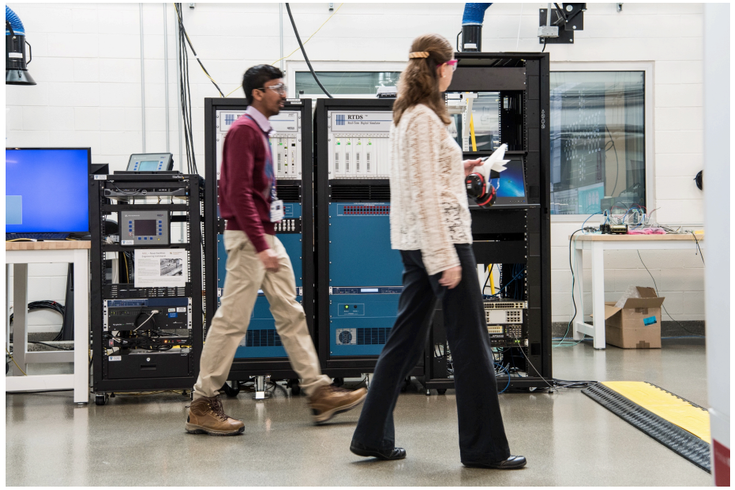
Intel Labs, Hillsboro, OR

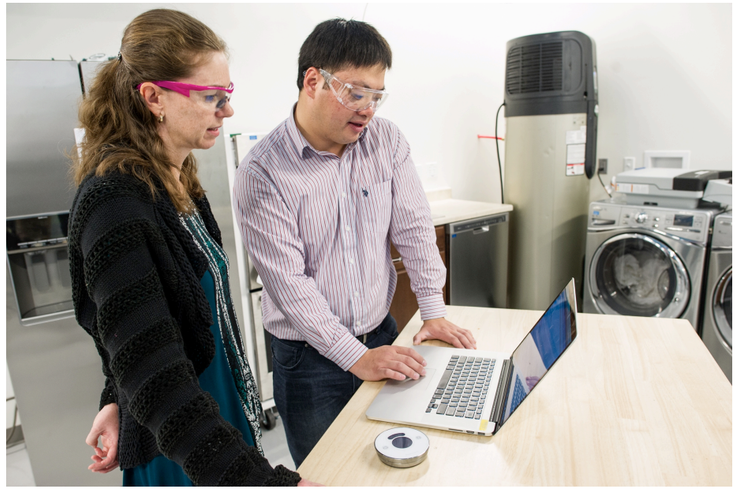
- ***Oregon area chapter***

Principal Engineer

NREL, Golden, CO

- ***RM chapter board***



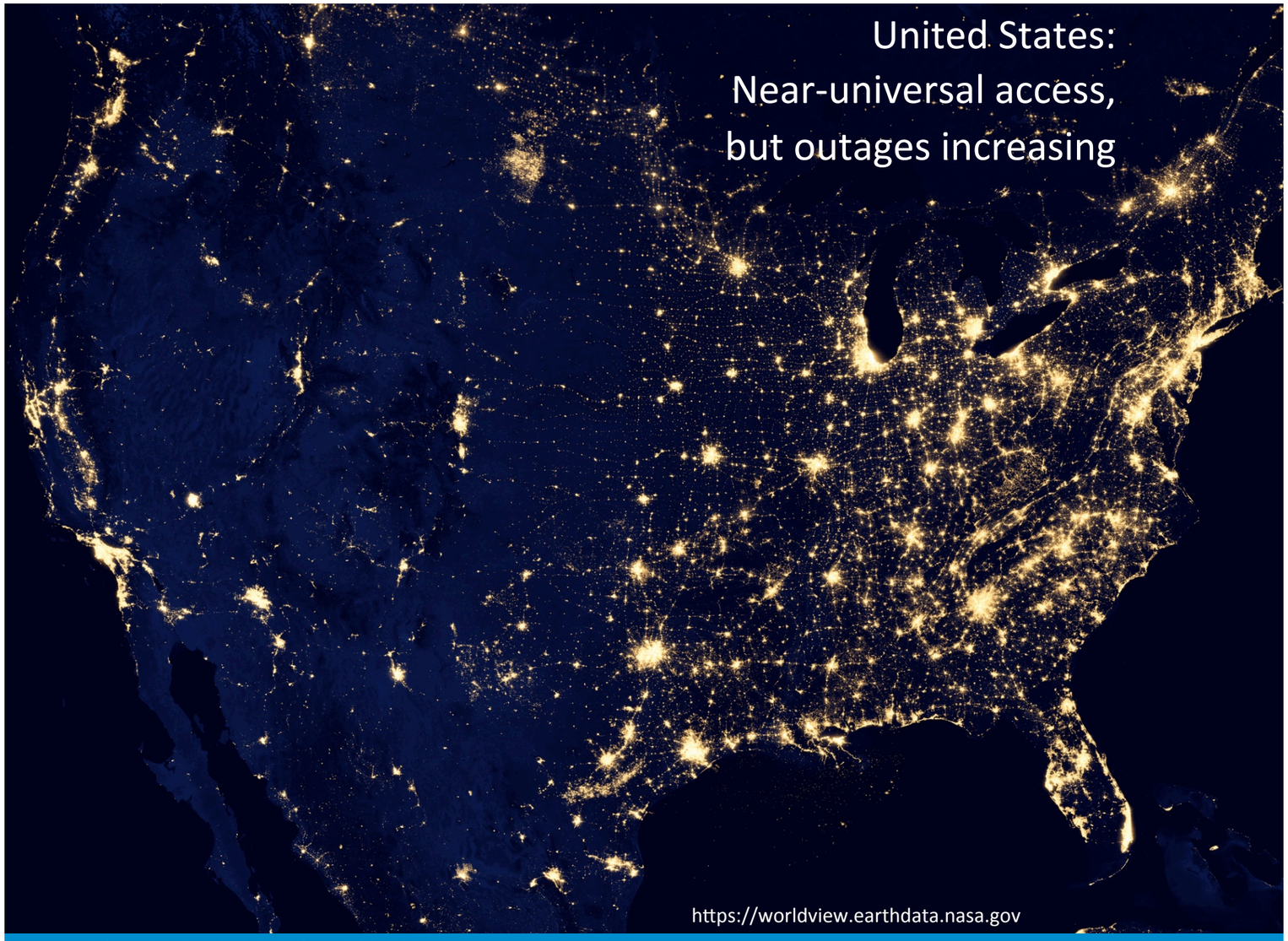


National Renewable Energy Laboratory

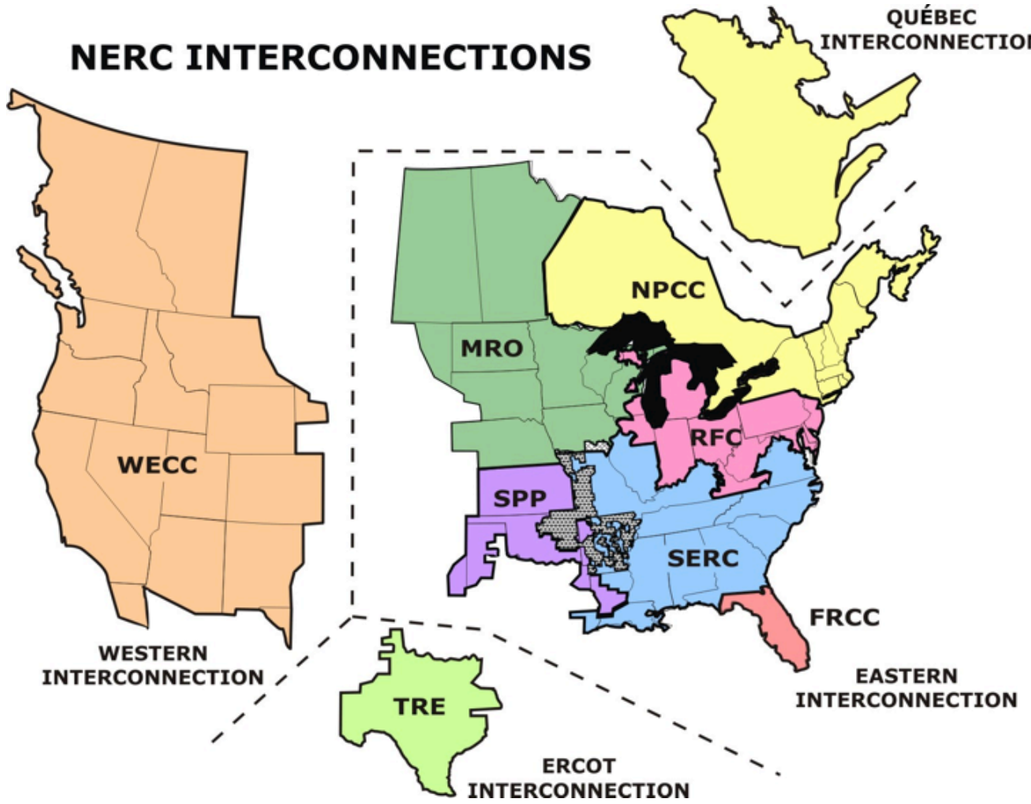
- One of 12 DOE laboratories
- Only one ***dedicated*** to Renewable Energy and Energy Efficiency R&D
- 1977: SERI (40 years!)
- 1991: National lab status

Main Campus in Golden, CO

National Wind Technology Center (NWTC) in Boulder, CO

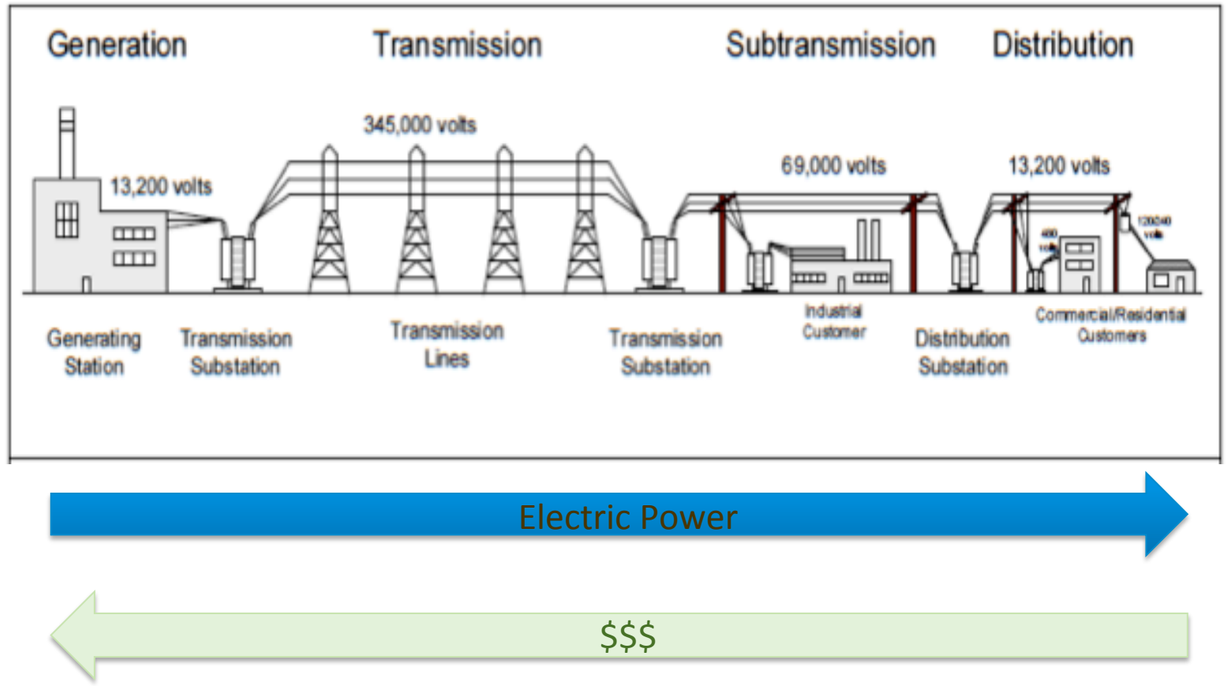

United States:
Near-universal access,
but outages increasing
https://worldview.earthdata.nasa.gov

The world's largest machine



Source: North American Reliability Corporation (www.nerc.com)

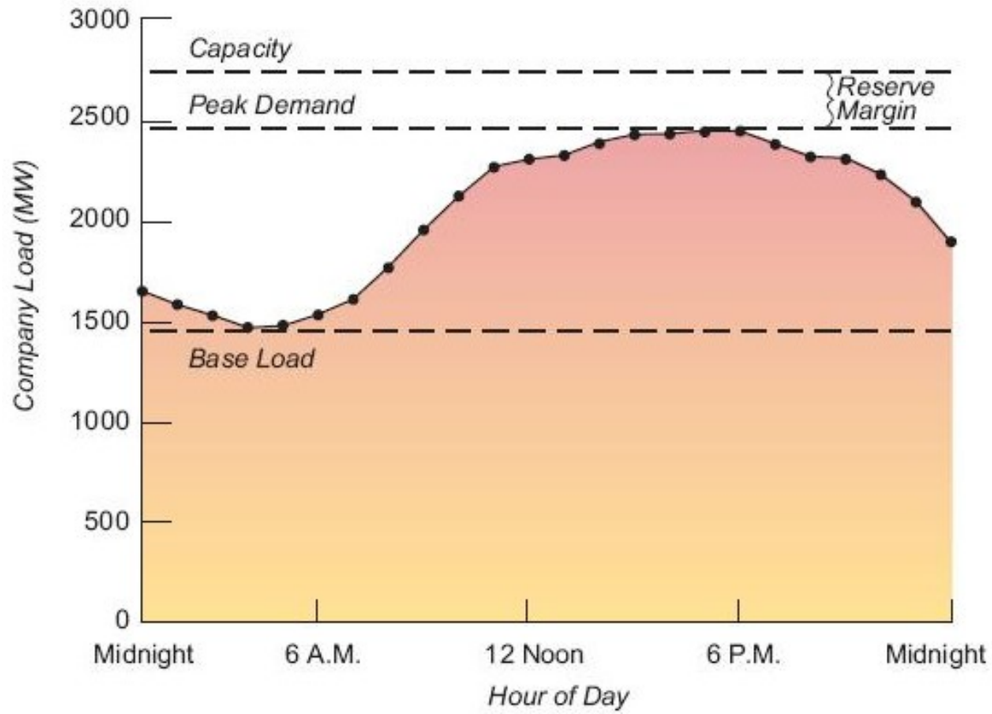
Traditional Electric Power System



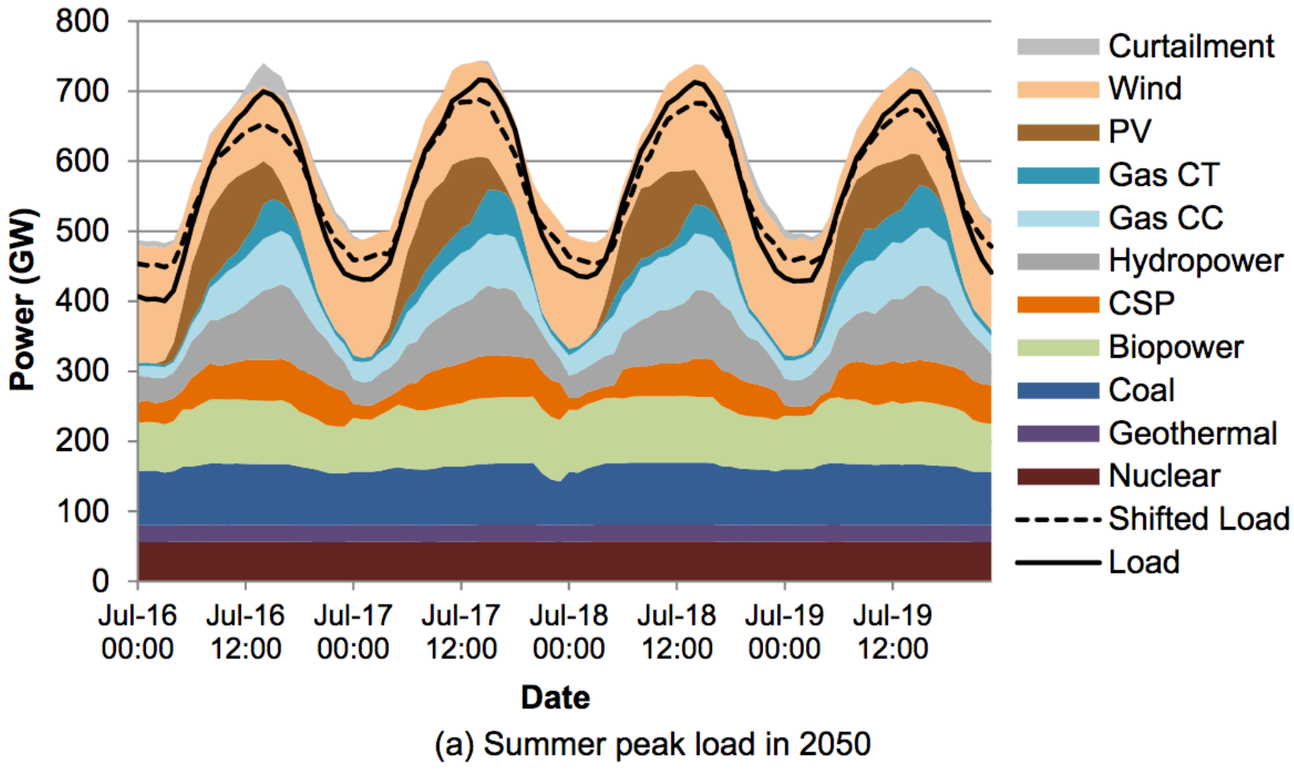
Regulated monopolies: FERC and state public utility commissions (PUCs)

Instantaneous generation & load matching

- Only ~ 2% long term storage

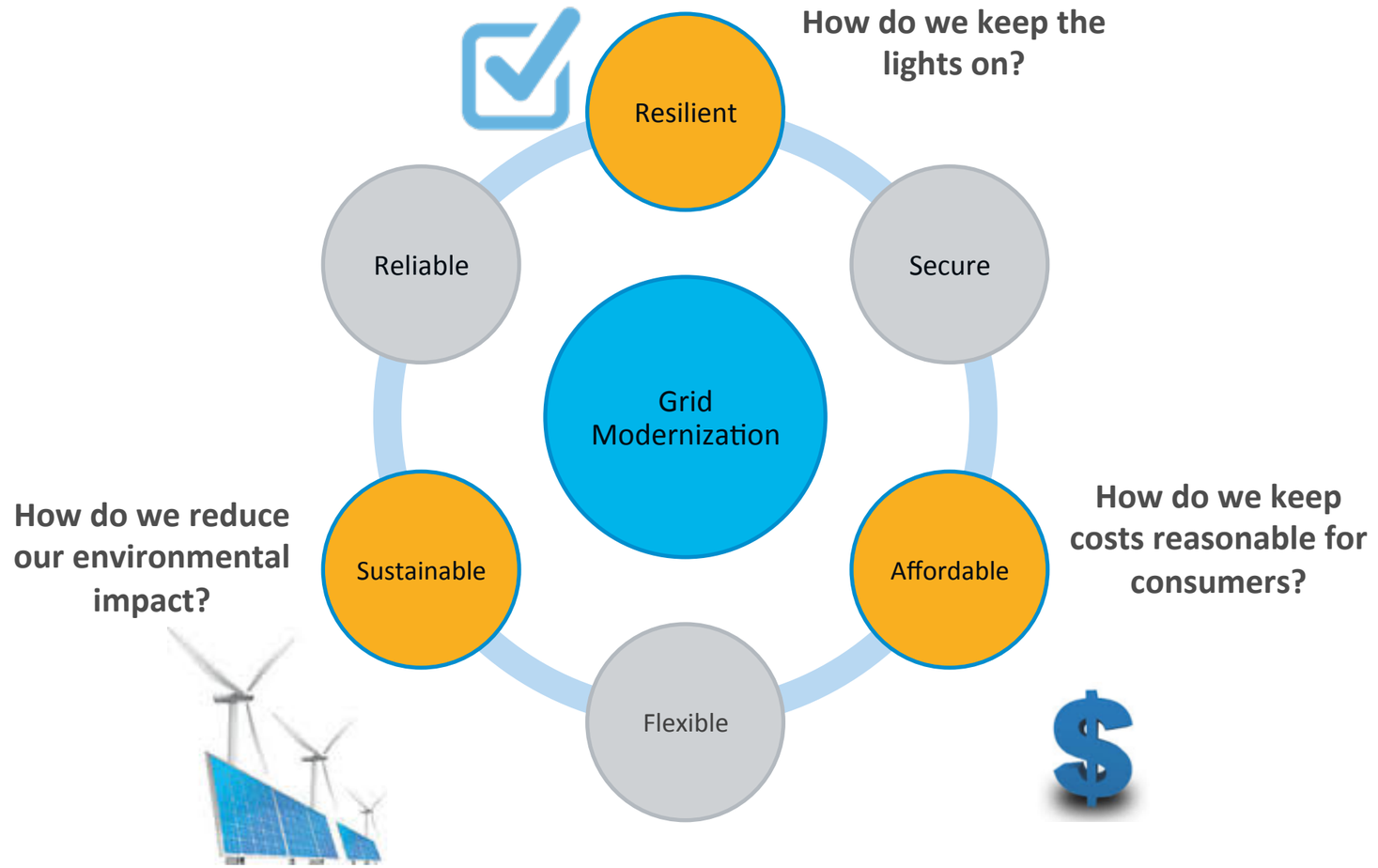


Generation scheduling to match load



(a) Summer peak load in 2050

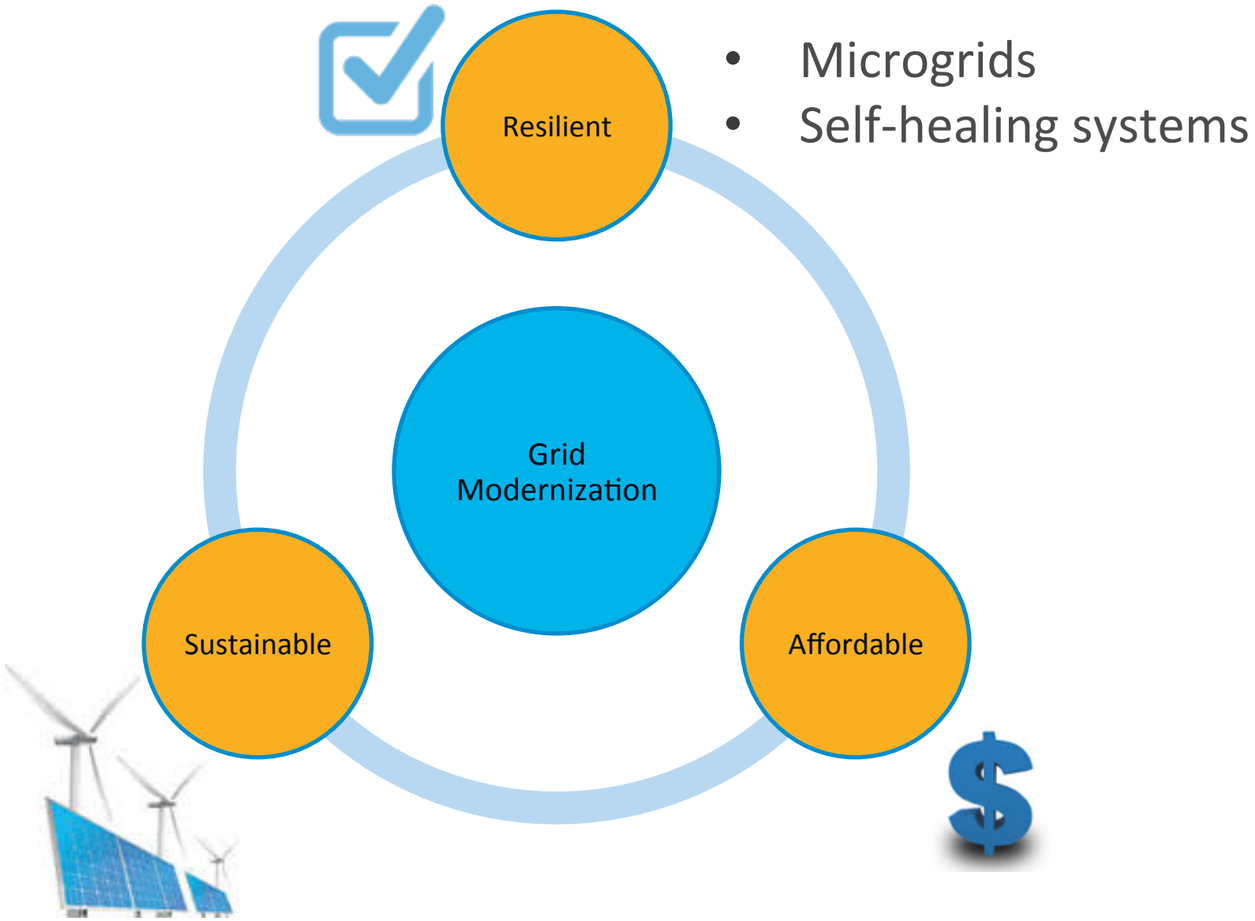
Source: Renewable Energy Futures Study, NREL (2012)



Source: DOE Grid Modernization Initiative, Multi-Year Project Plan, Nov 2015

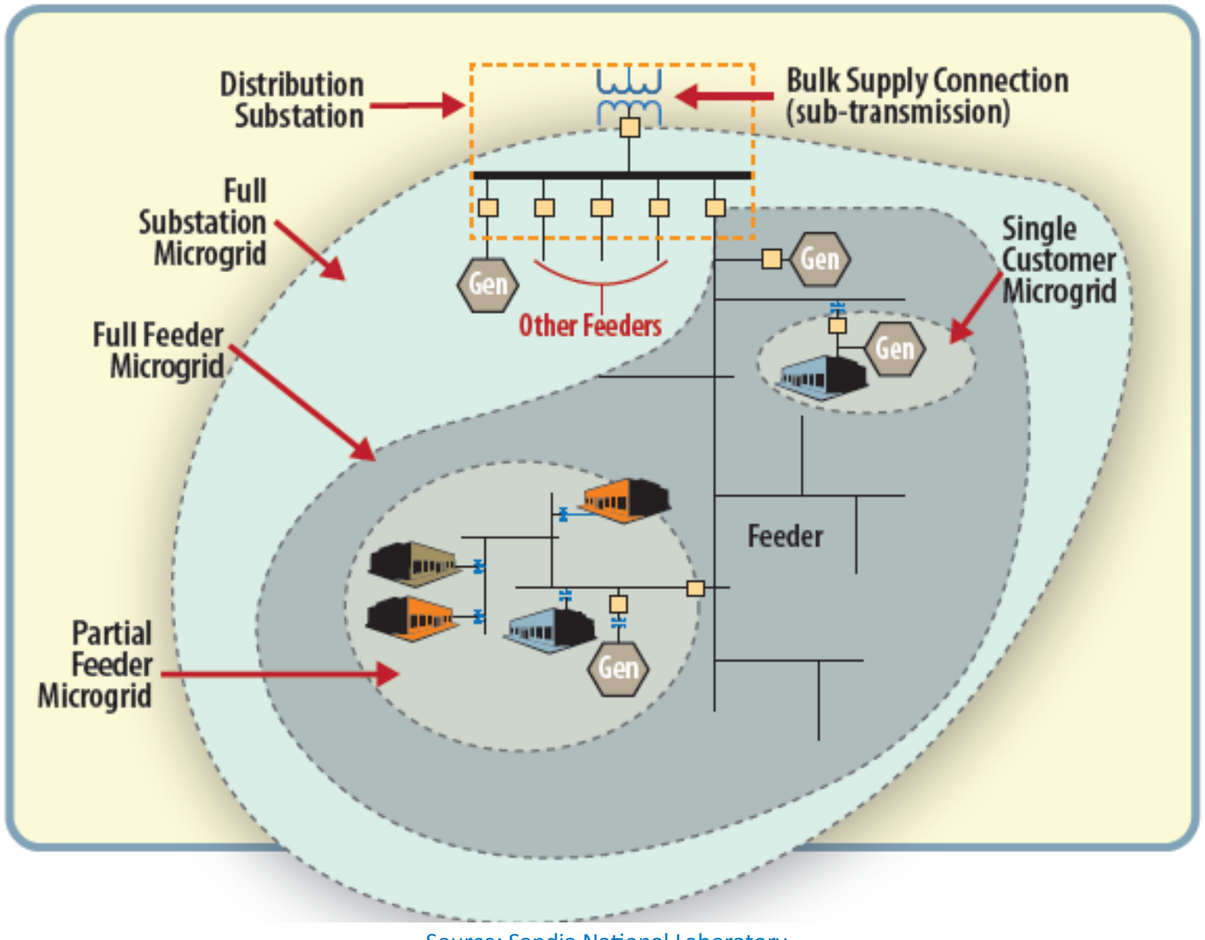
- Resilience: the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions

Source: phys.org



Source: DOE Grid Modernization Initiative, Multi-Year Project Plan, Nov 2015

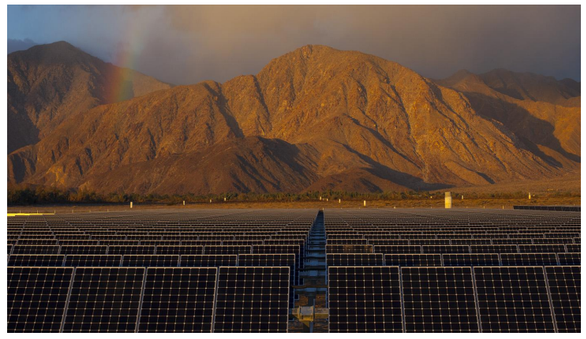
Microgrids



Source: Sandia National Laboratory

Fort Carson, CO. Source: NREL

NJ Transit. Source: njtransitresilienceprogram.com; nextcity.org

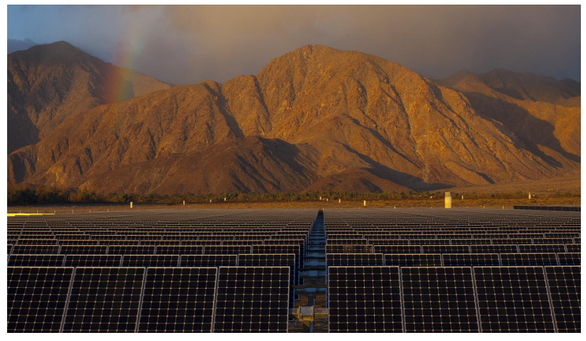


Borrego Springs, CA. Source: SDG&E

Potsdam, NY. Source: microgridknowledge.com

How to recover costs justly?

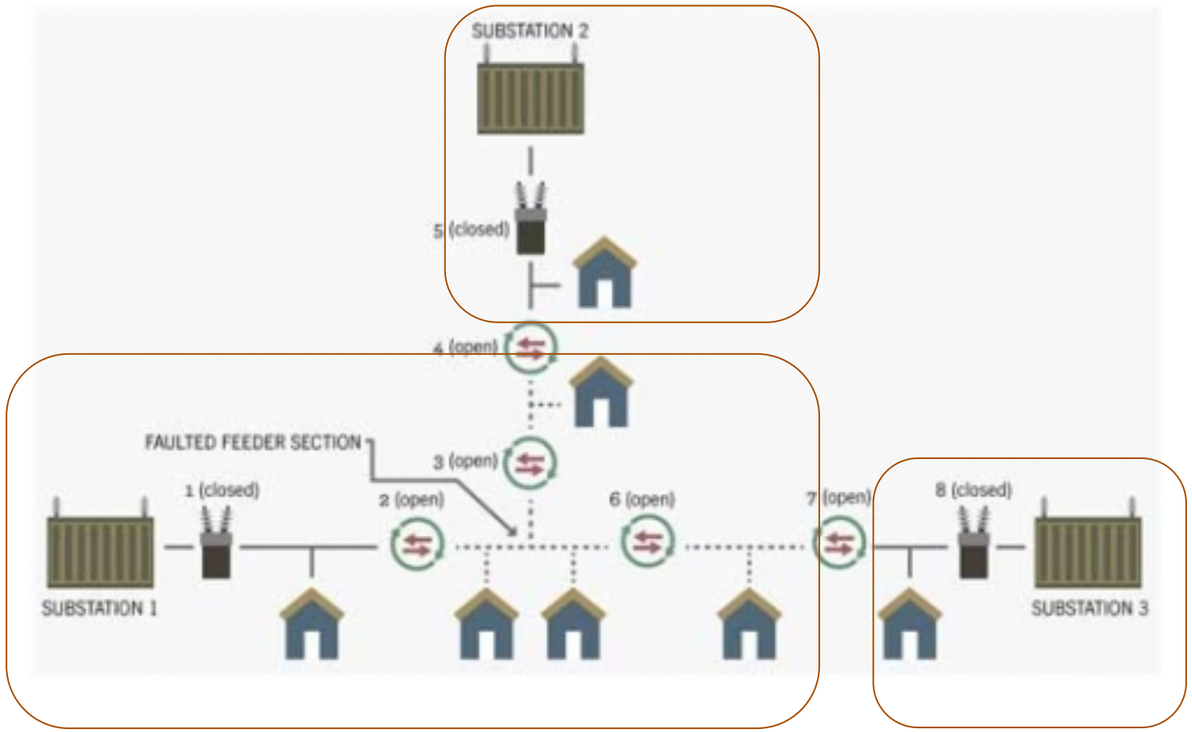
Charity is no substitute for justice withheld.
- St. Augustine



Borrego Springs, CA. Source: SDG&E

Potsdam, NY. Source: microgridknowledge.com

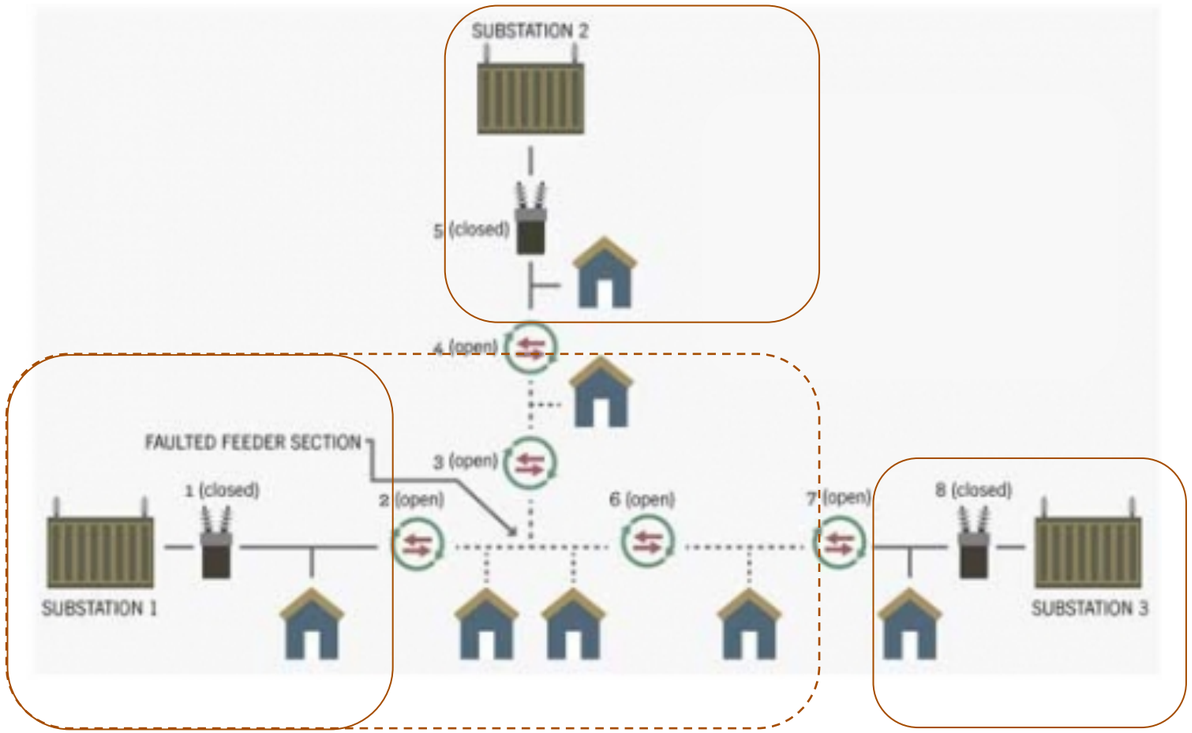
Self-healing systems



Source: https://www.greentechmedia.com/articles/read/flisr-when-an-hour-outage-becomes-two-minutes

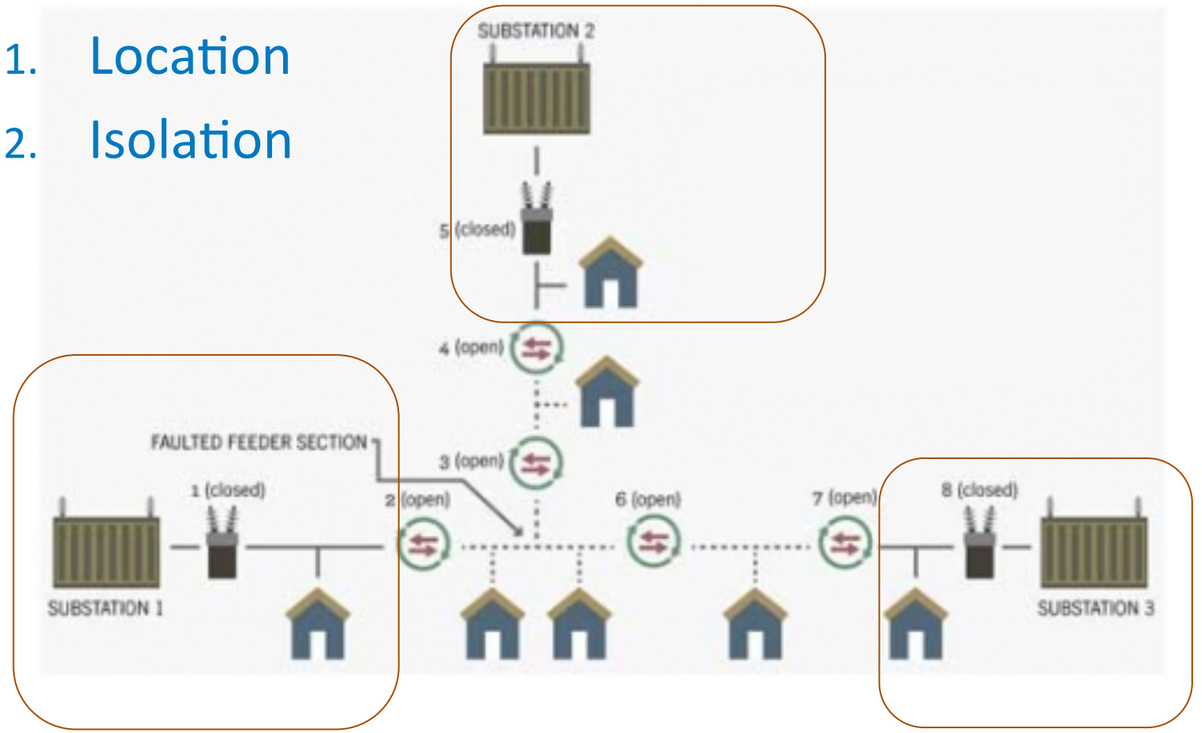
Self-healing systems

- Local protection (cycles)



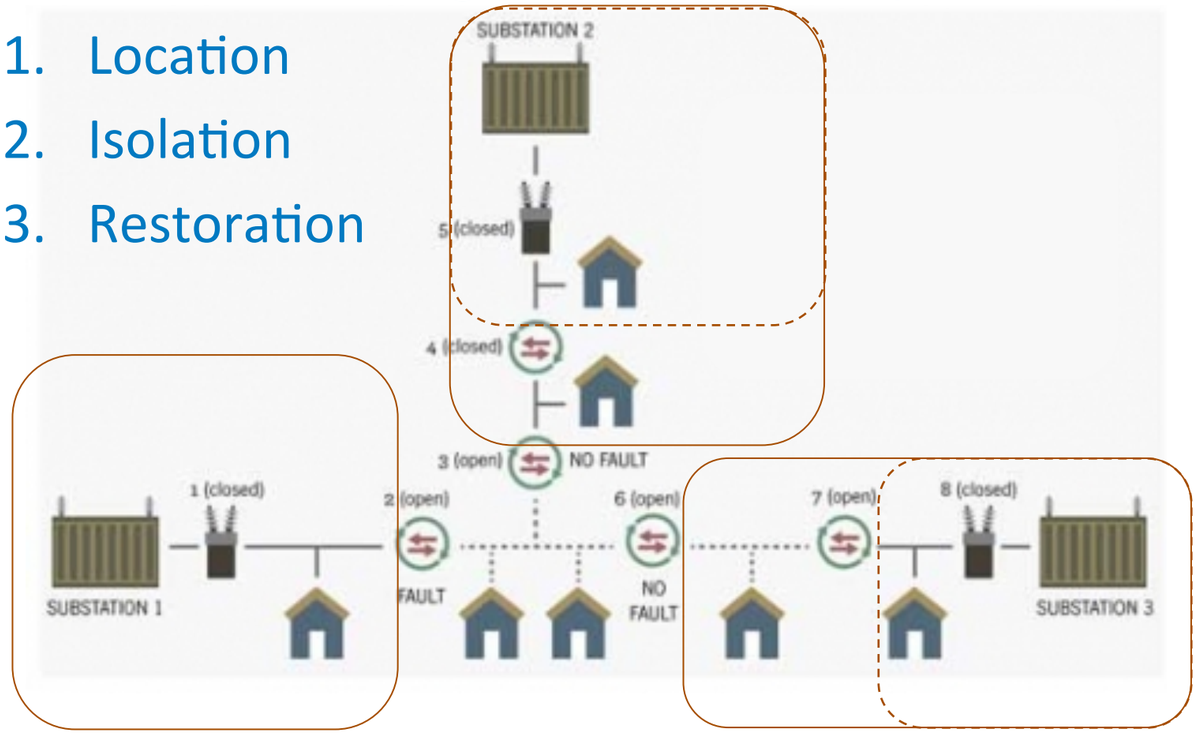
Self-healing systems

- Distribution Management Systems (minutes)
  1. Location
  2. Isolation

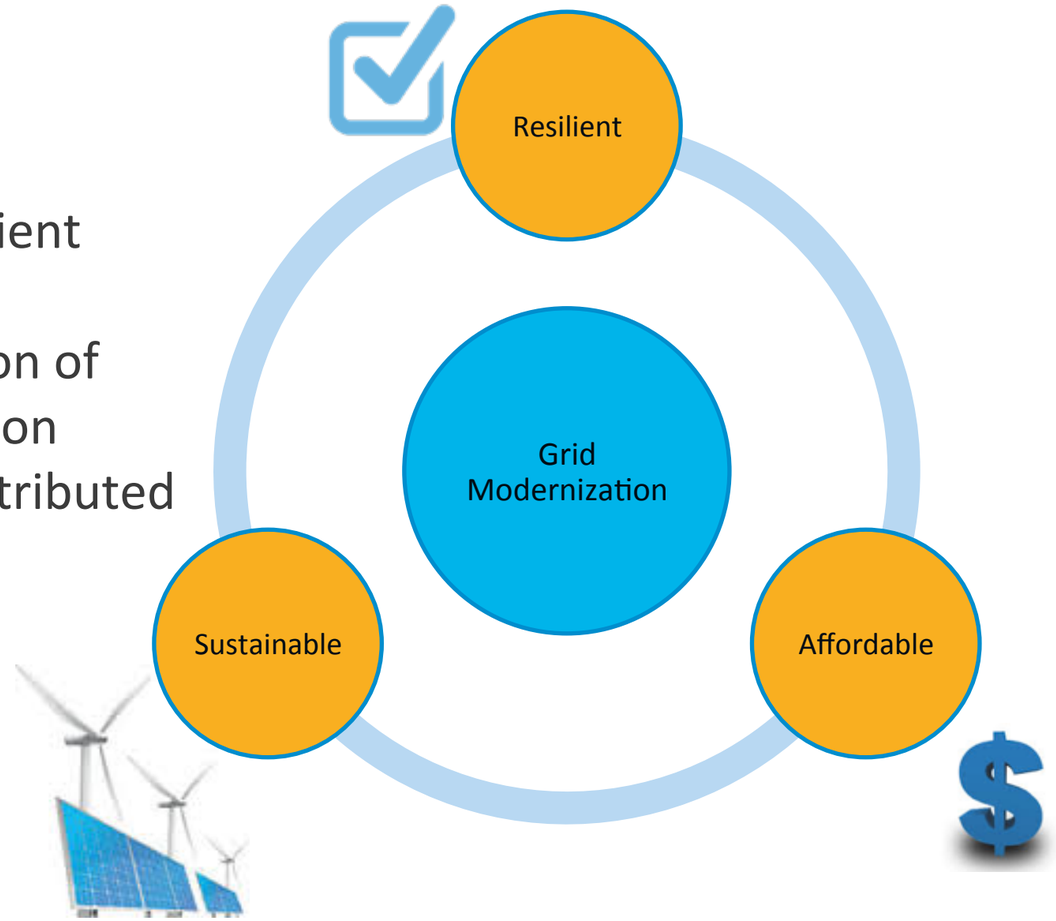


Self-healing systems

- Distribution Management Systems (minutes)
  1. Location
  2. Isolation
  3. Restoration

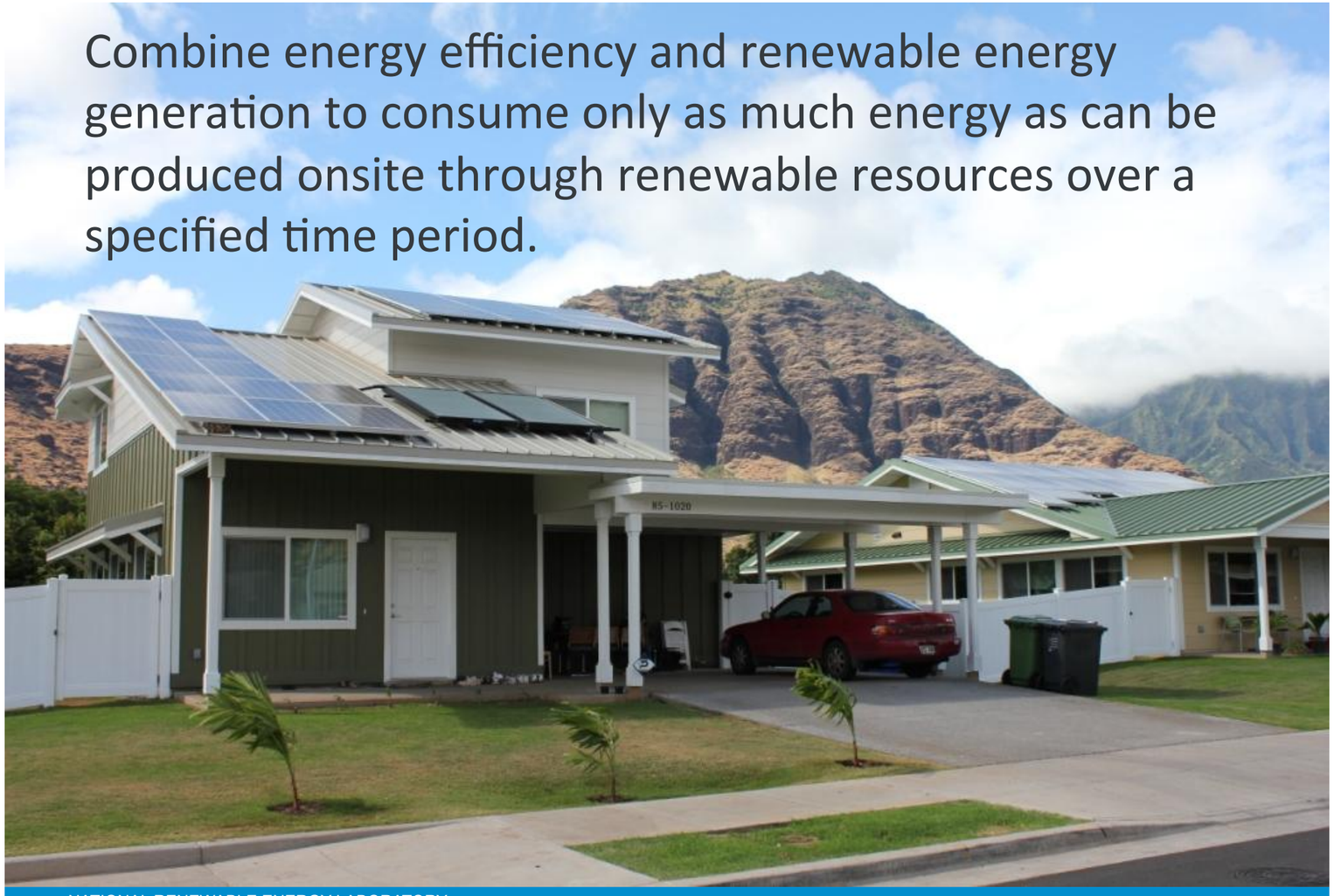


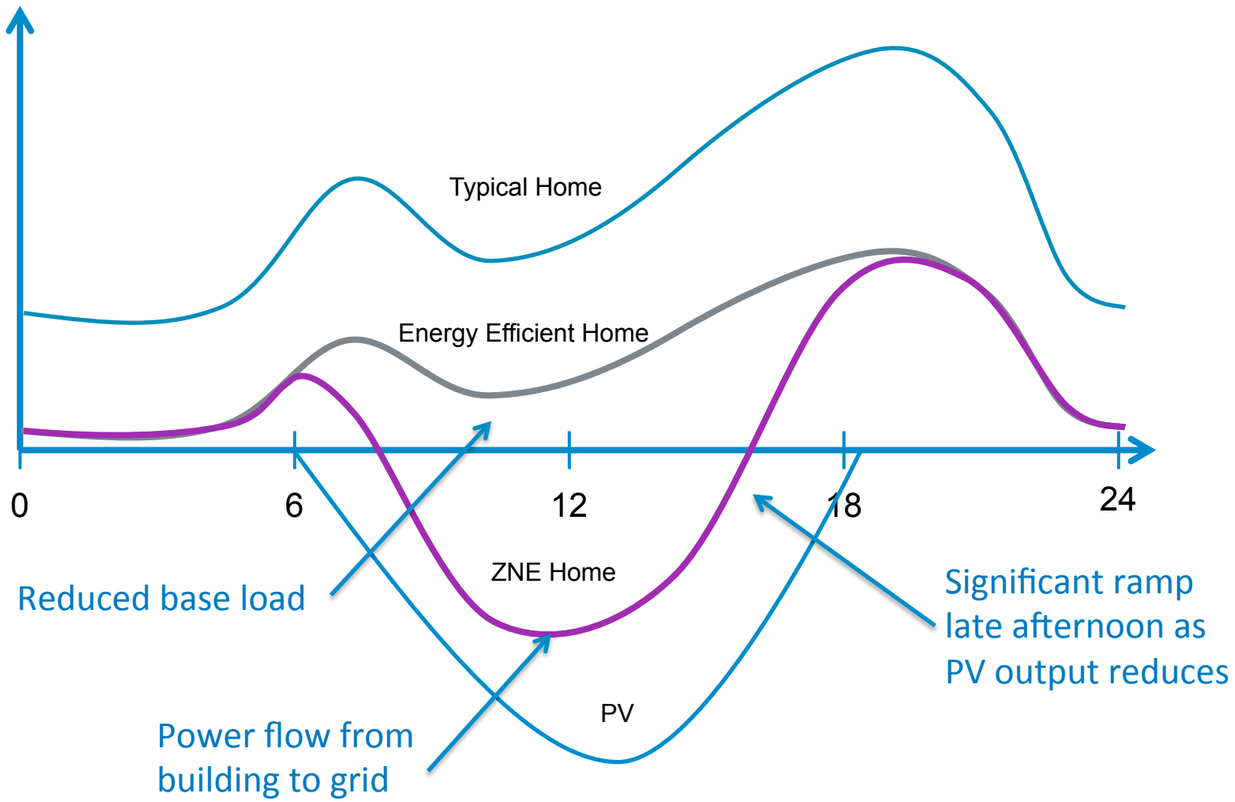
- Energy efficient buildings
- Electrification of transportation
- Variable distributed generation



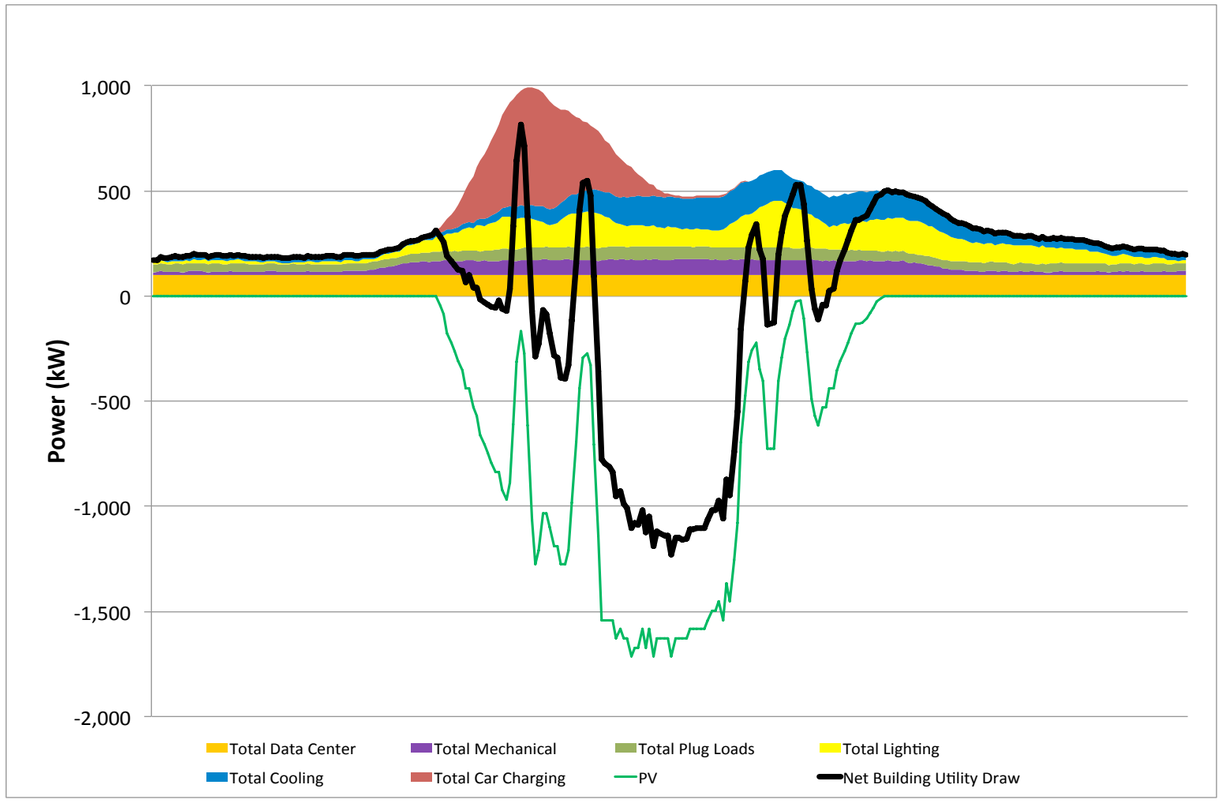
Zero Net Energy Buildings

Combine energy efficiency and renewable energy generation to consume only as much energy as can be produced onsite through renewable resources over a specified time period.



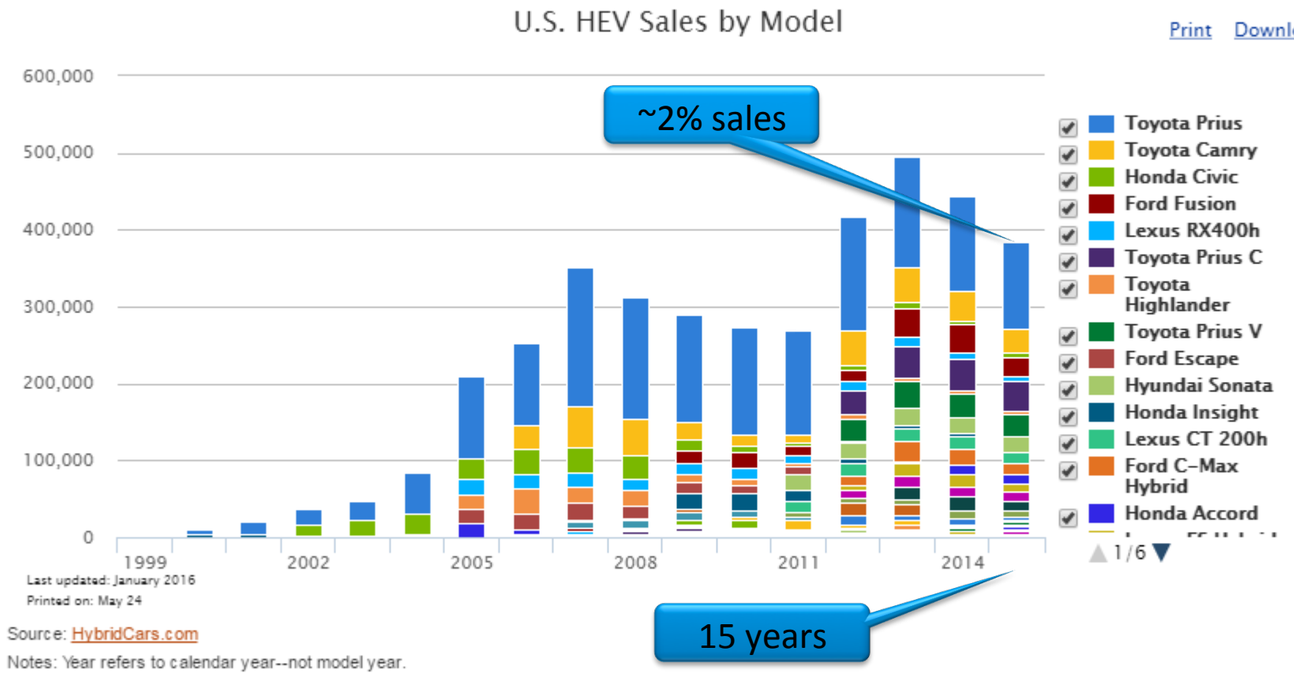

Typical Home
Energy Efficient Home
0
6
12
18
24
ZNE Home
Reduced base load
Power flow from
building to grid
PV
Significant ramp
late afternoon as
PV output reduces

NREL RSF building power profile



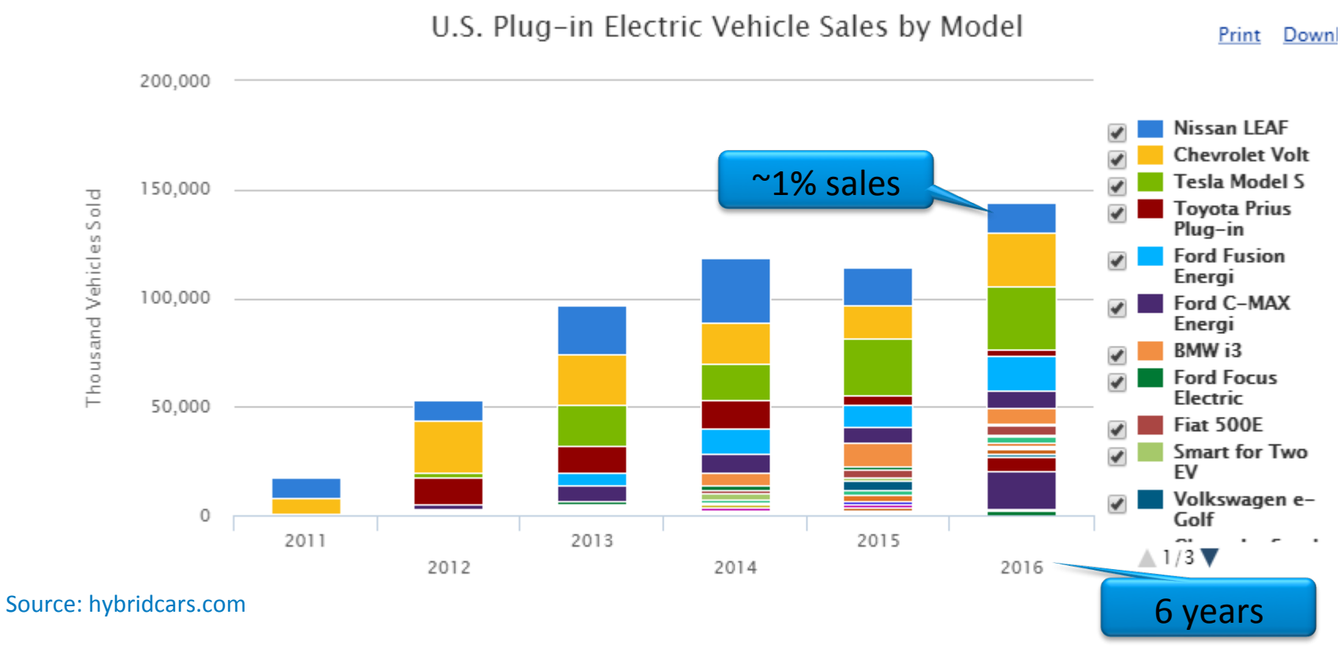
Challenges: Protection coordination & Voltage regulation

Hybrid Electric Vehicle Sales



https://www.afdc.energy.gov/data/10301

Plug-in Electric Vehicle Sales

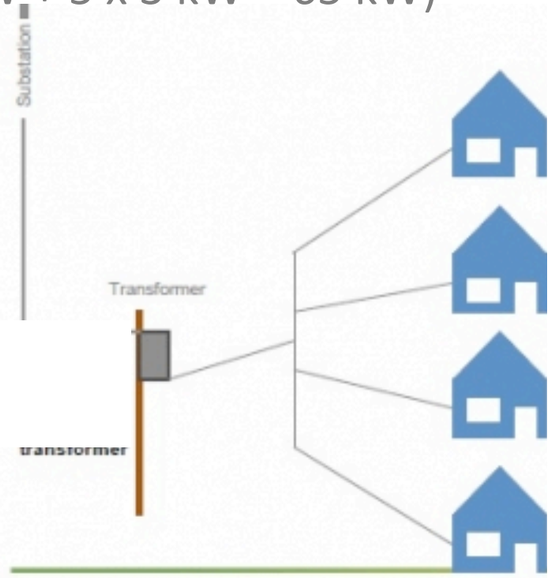


Source: hybridcars.com

https://www.afdc.energy.gov/data/widgets/10567

Transformer impact

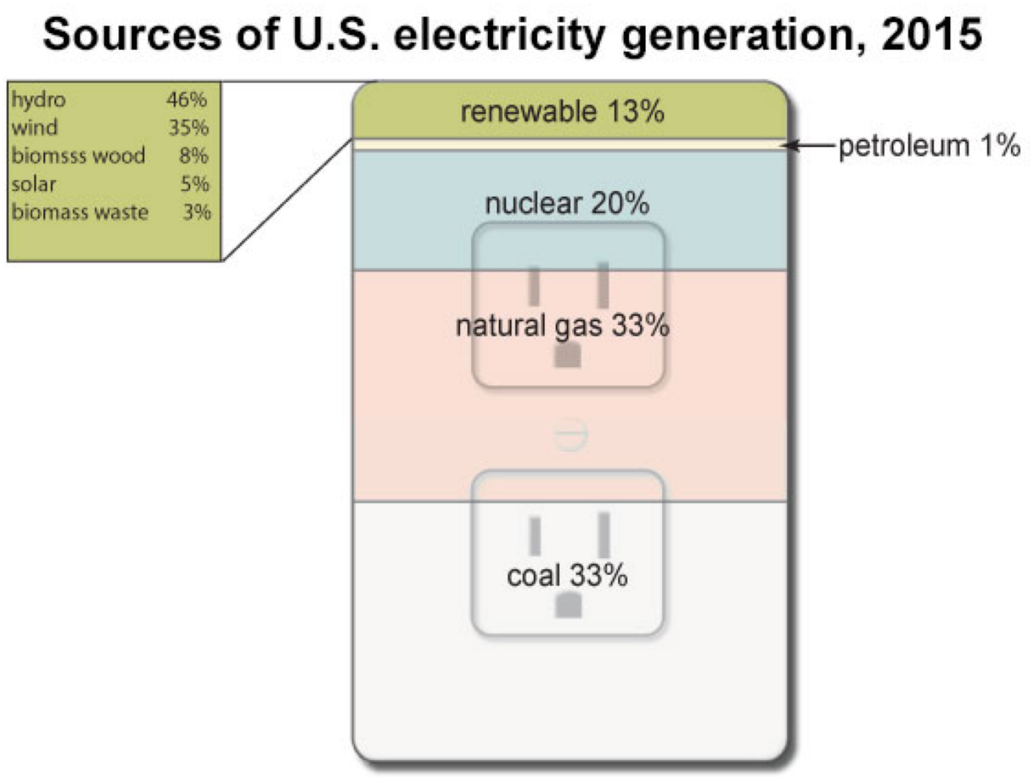
House peak load ~ 10 kW
~ 5 homes / transformer
Transformer ~ 50 kW
EV charge rates: ~ 3 kW
Possible transformer overload:
(50kW + 5 x 3 kW = 65 kW)



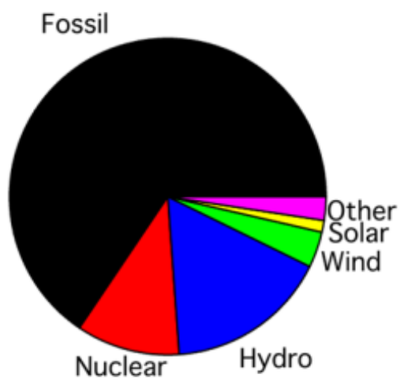
Source: greentechmedia.com

→ Smart charging, consumer flexibility

Increased Renewable Generation

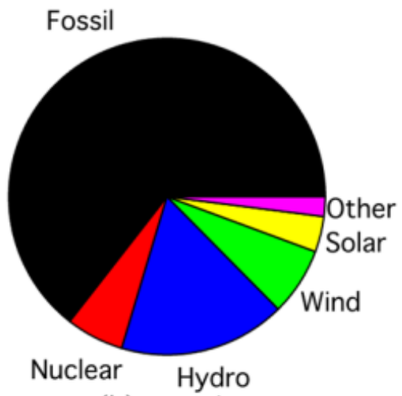


PV: 1% and 20% at the same time



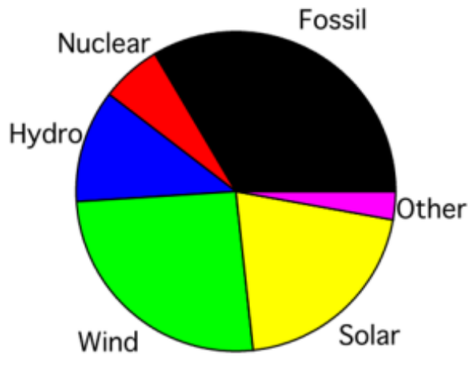
(a) electricity

~1% of world electricity in 2015 (MWh)



(b) capacity

~3% of world electricity generating capacity (MW)

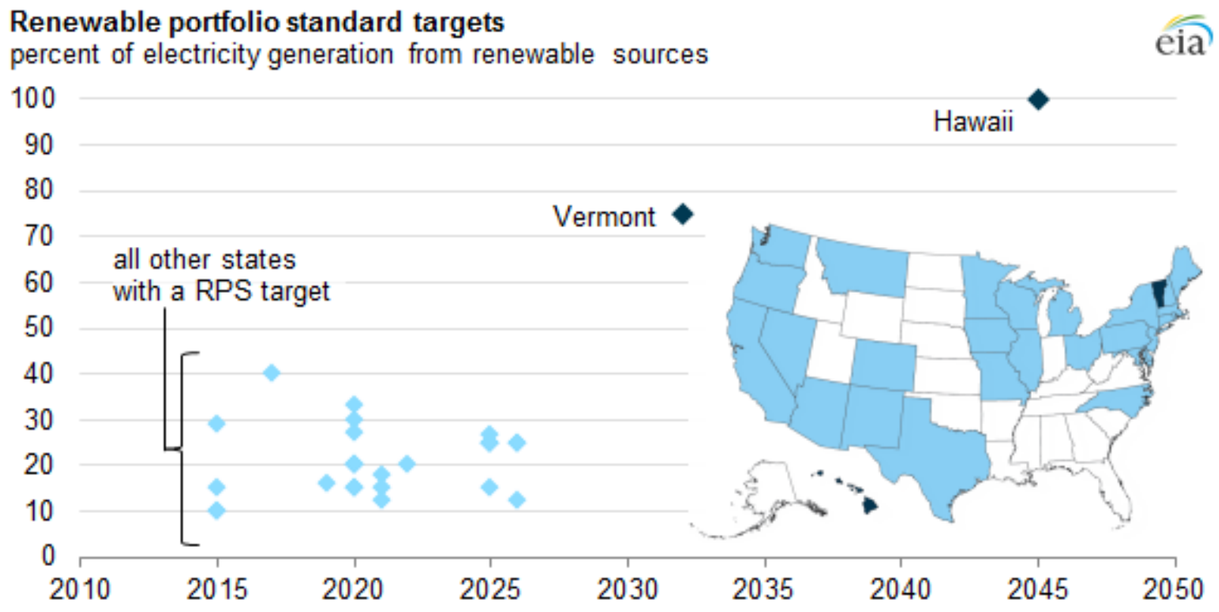


(c) capacity expansions

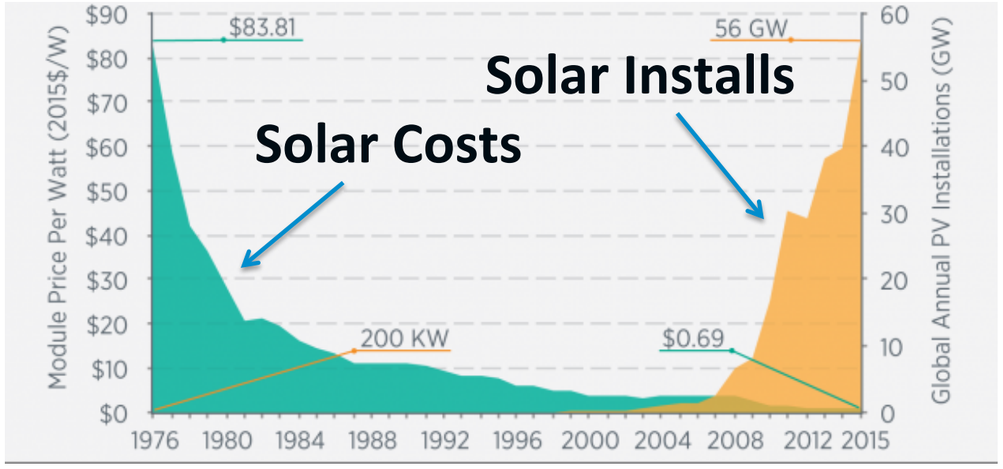
~20% of expanded capacity in 2015 (MW)

Source: Kurtz et. al. Nature Photonics 2017

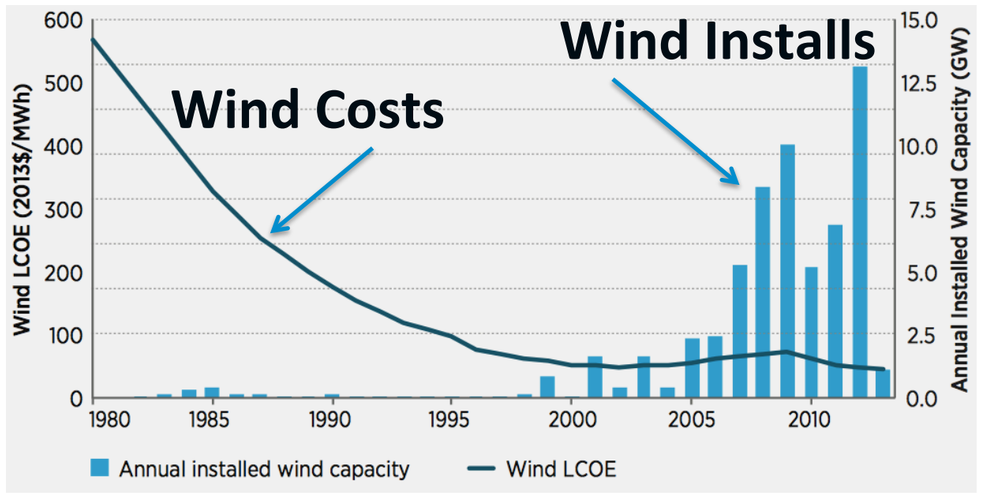
Renewable Portfolio Standards



Source: Energy Information Agency (2015)

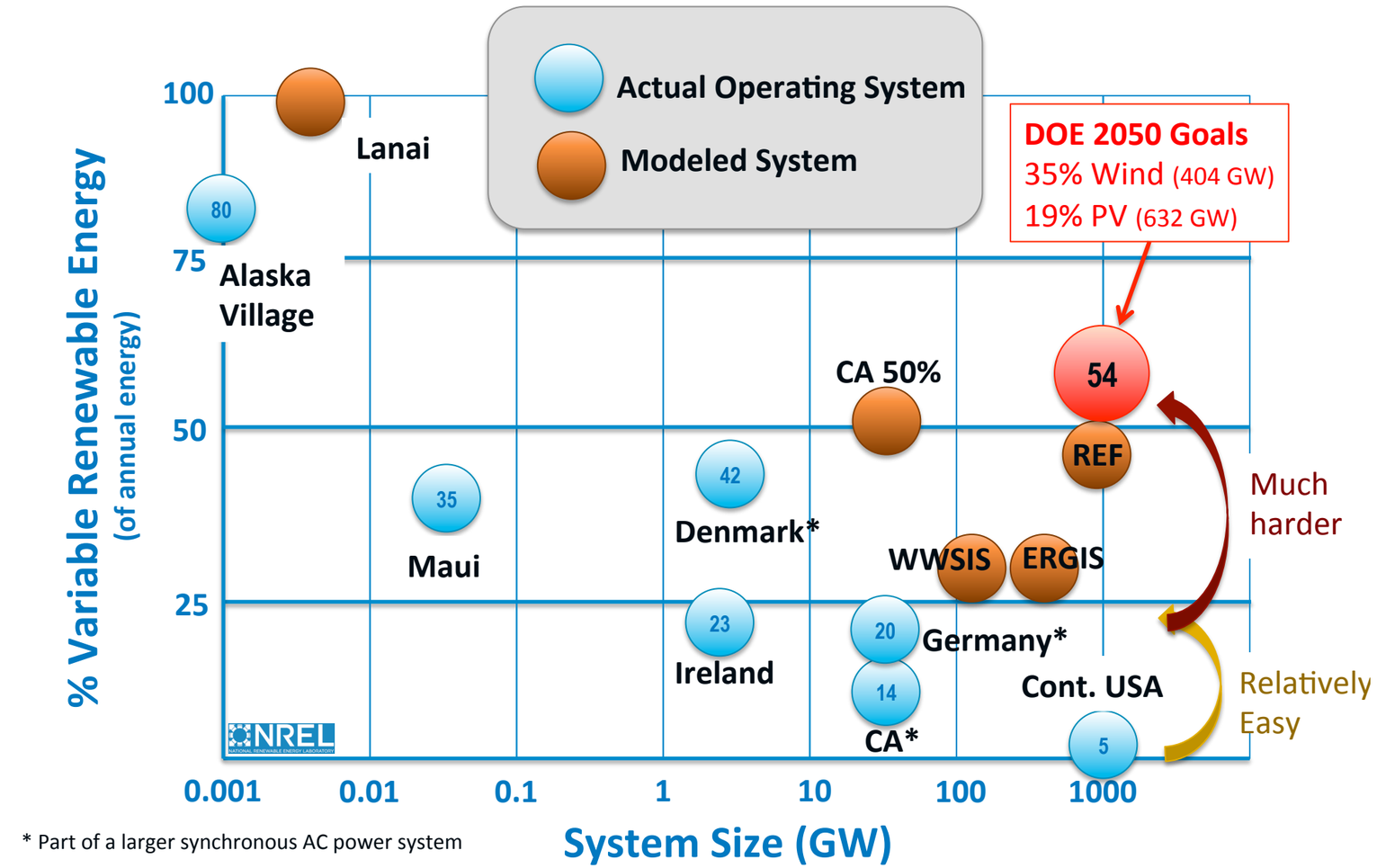


Source**: DOE On the Path to SunShot**
http://energy.gov/eere/sunshot/path-sunshot



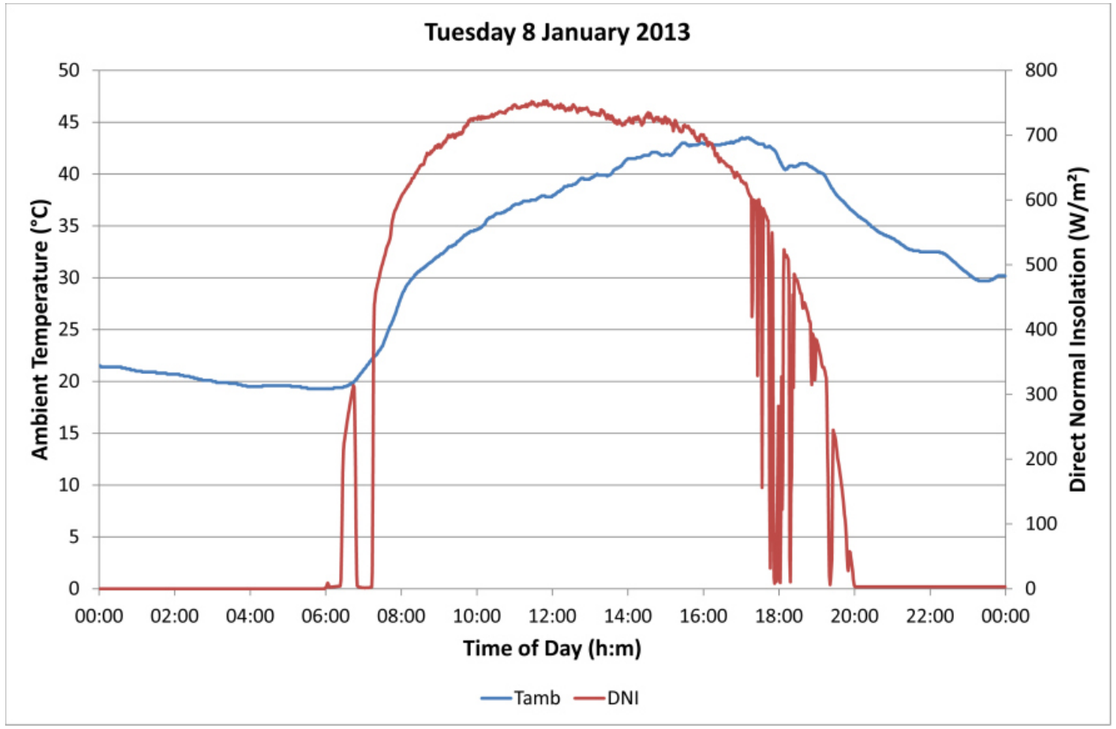
Source: **DOE Wind Vision Study**
http://energy.gov/eere/wind/downloads/wind-vision-new-era-wind-power-united-states

Enabling Higher Penetrations of Renewables



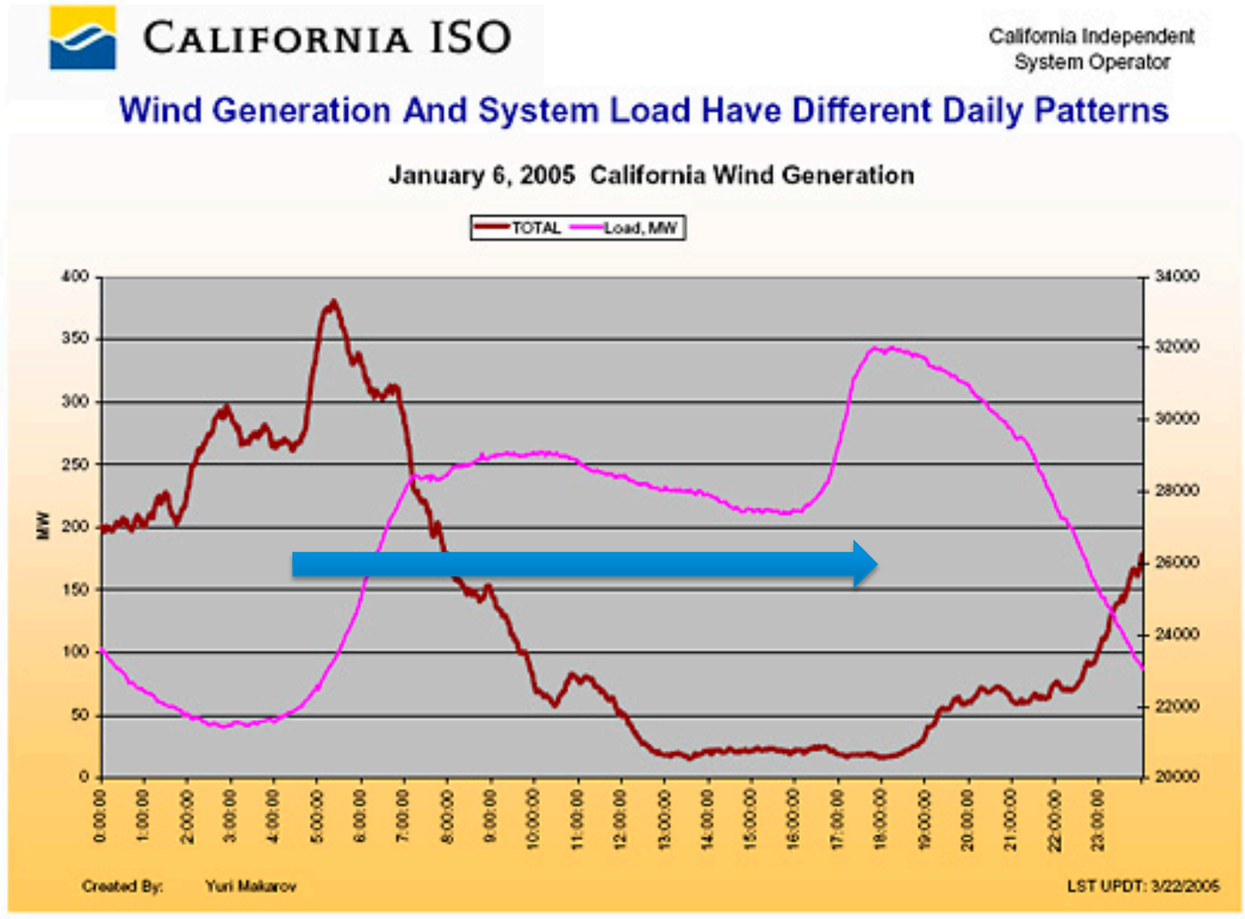
* Part of a larger synchronous AC power system

Increased Variability and Uncertainty



- Developing better forecasting

Generation no longer follows load



Balance with Energy Storage: Peak shaving

- Prices dropping, but still expensive
- May compete with natural gas “peaker” plants by 2030

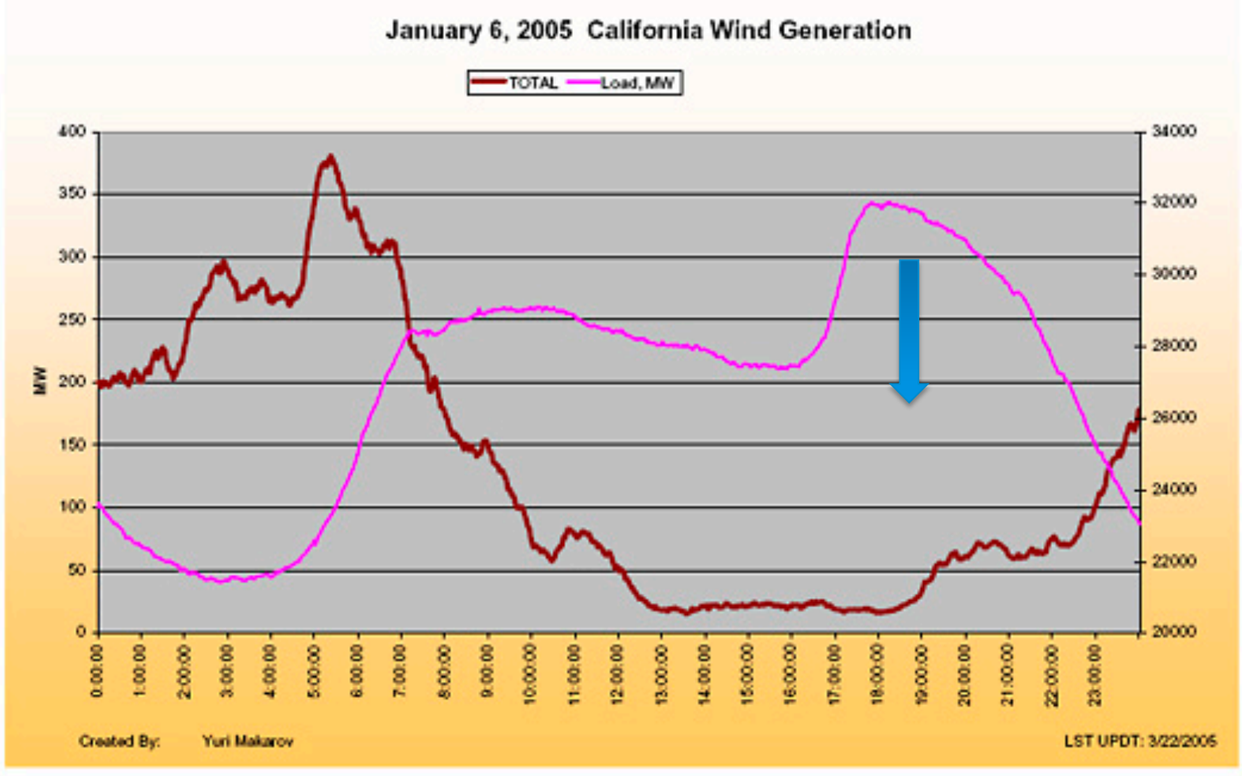
World’s largest lithium-ion battery energy storage facility: 30 MW/120 MWh
~ 20,000 customers for 4 hours

Source: SDG&E

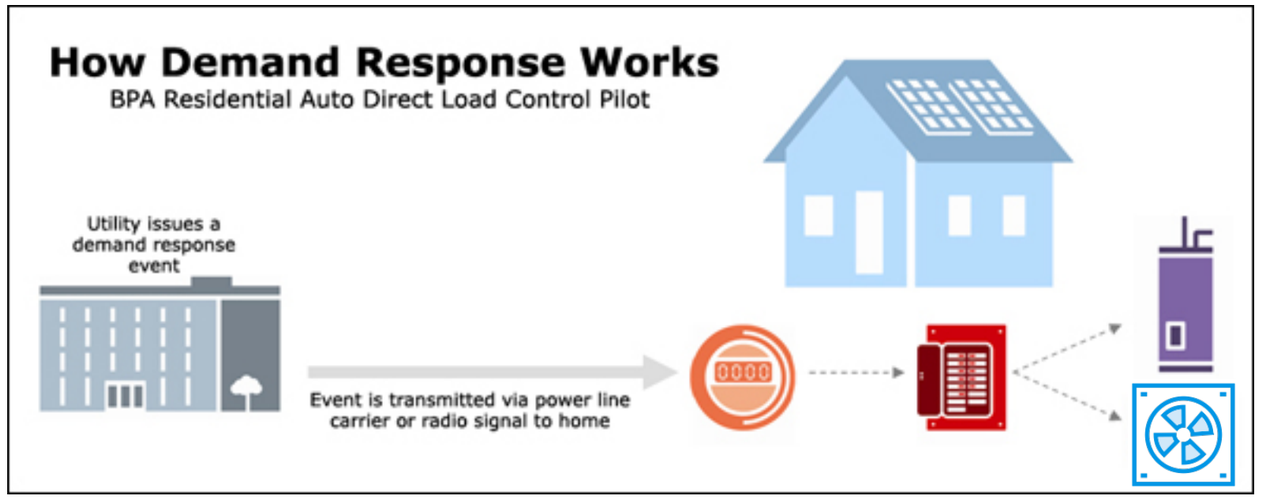
CALIFORNIA ISO

California Independent System Operator

Wind Generation And System Load Have Different Daily Patterns

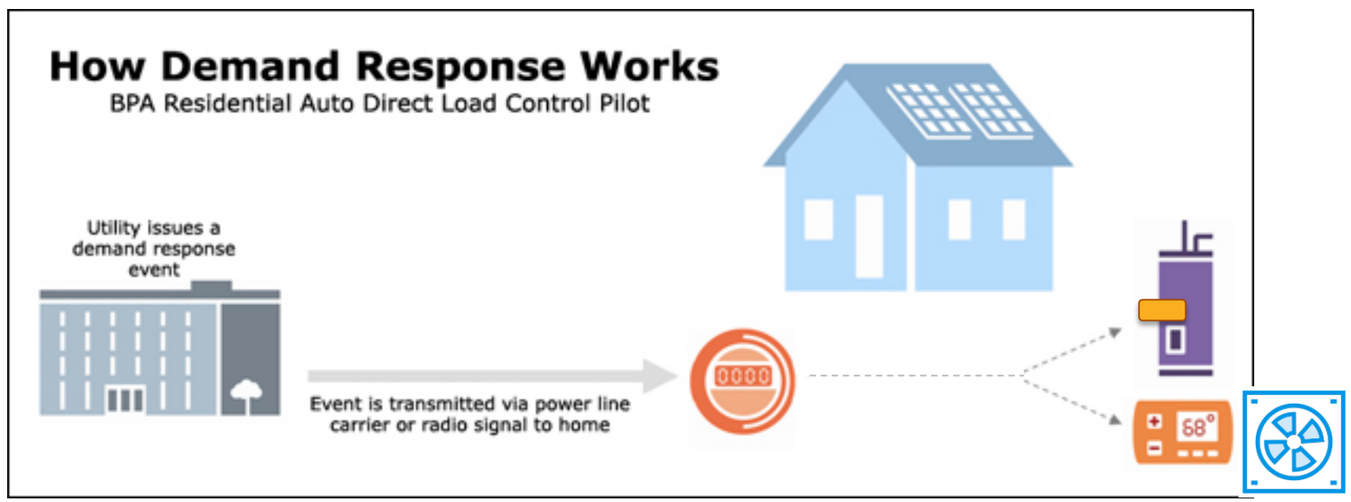


Balance with Demand Response



Source: bpa.gov (Bonneville Power Administration)

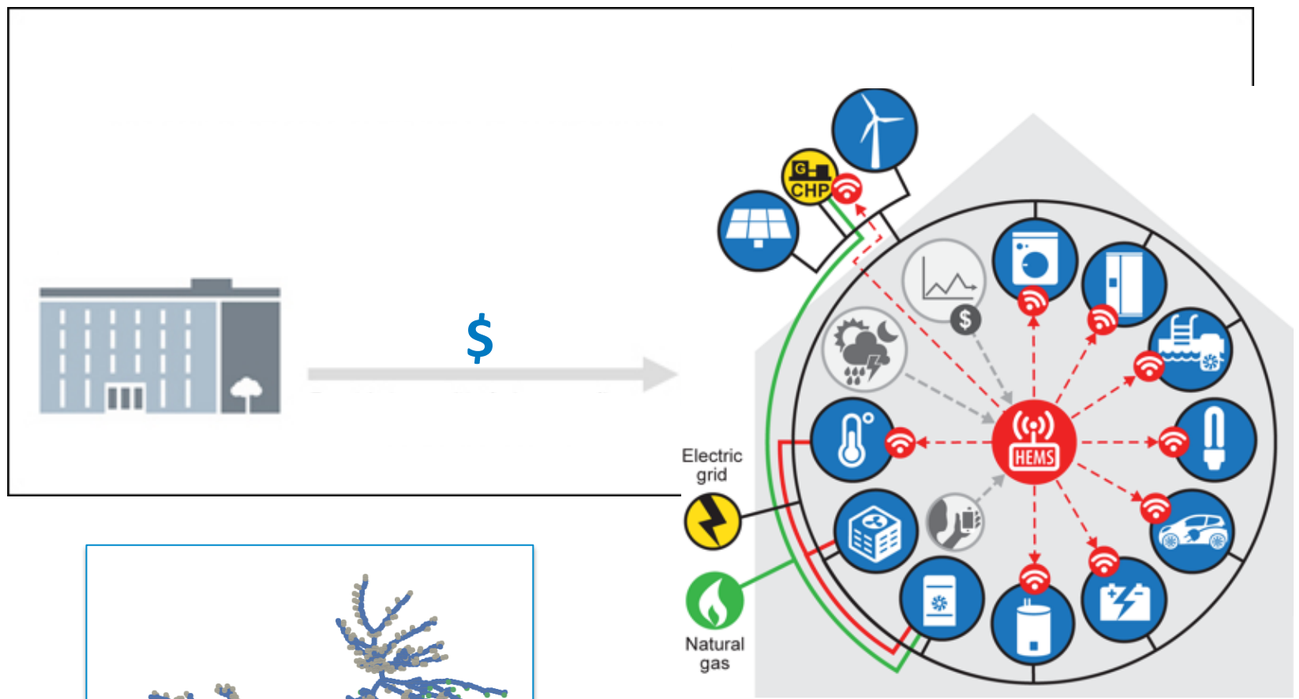
Balance with Demand Response

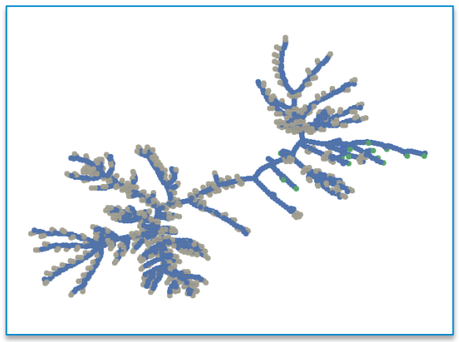


Consumer flexibility →

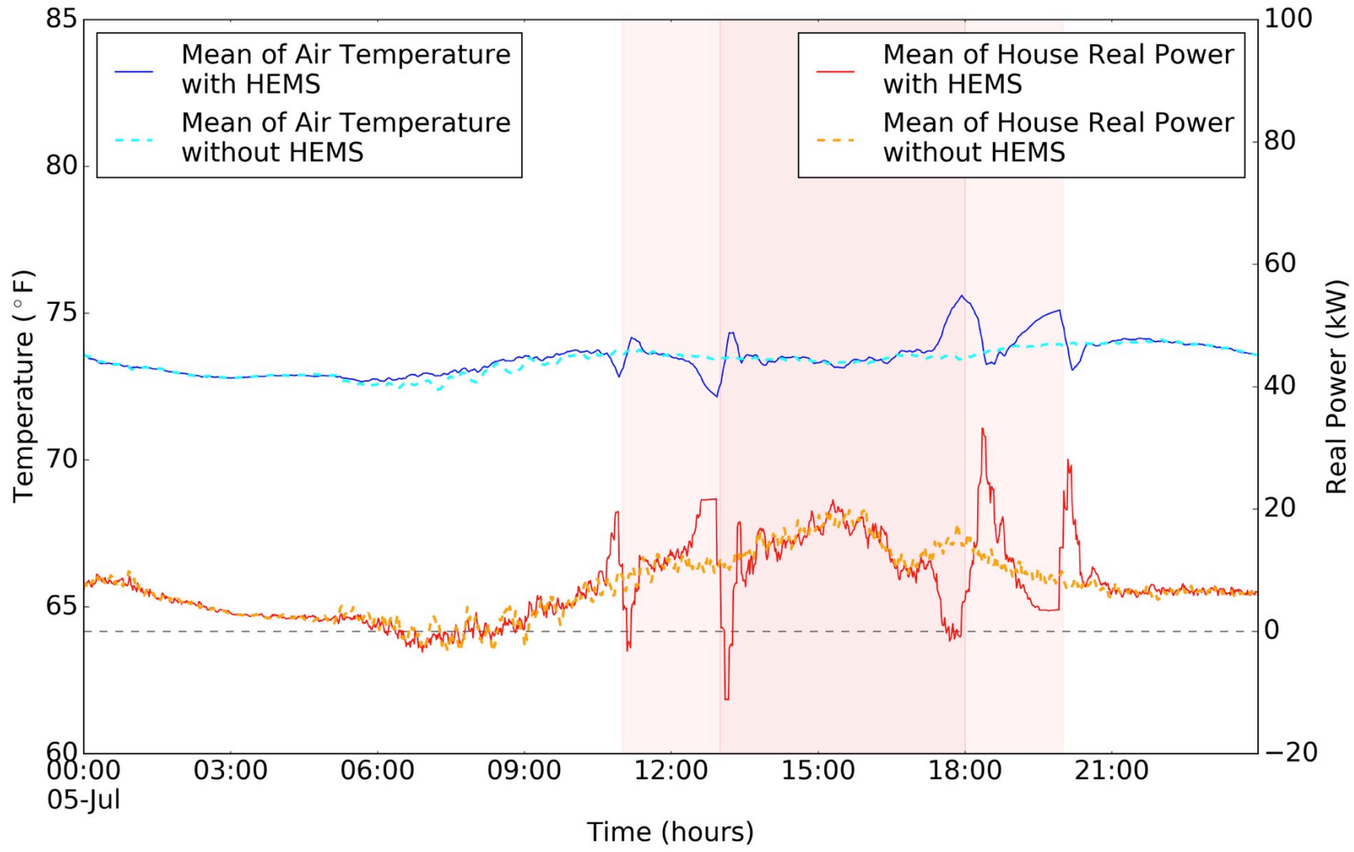
- More renewables
- Lower cost

Balance with Price-Responsive Demand

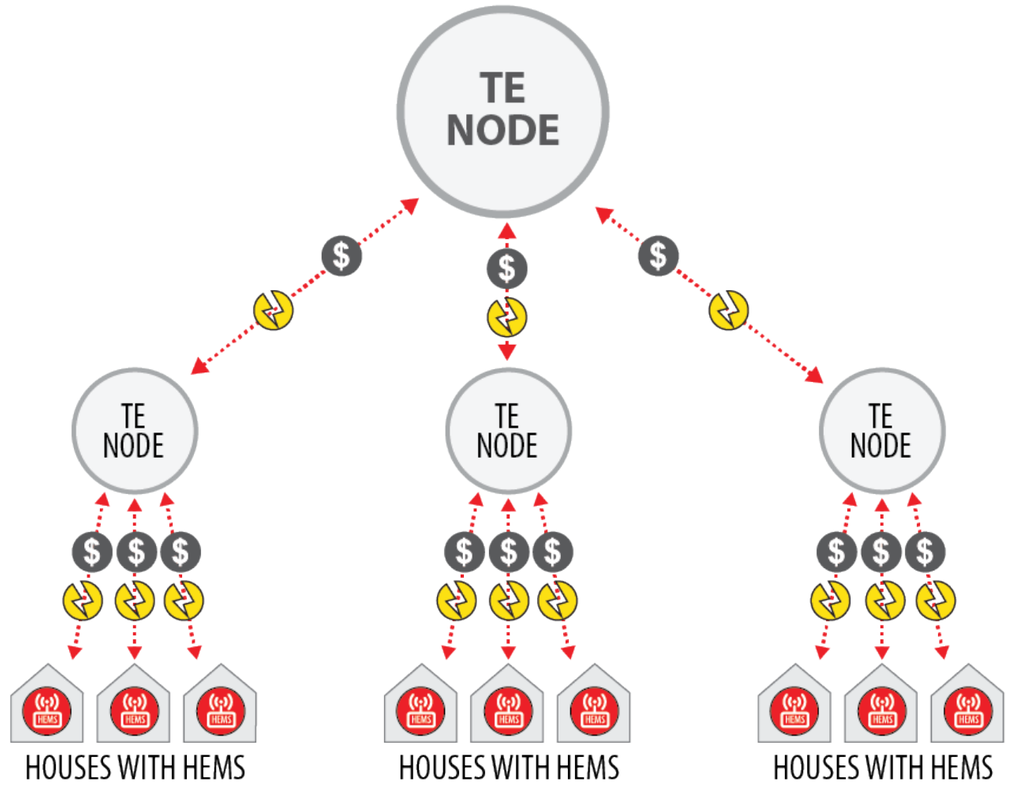


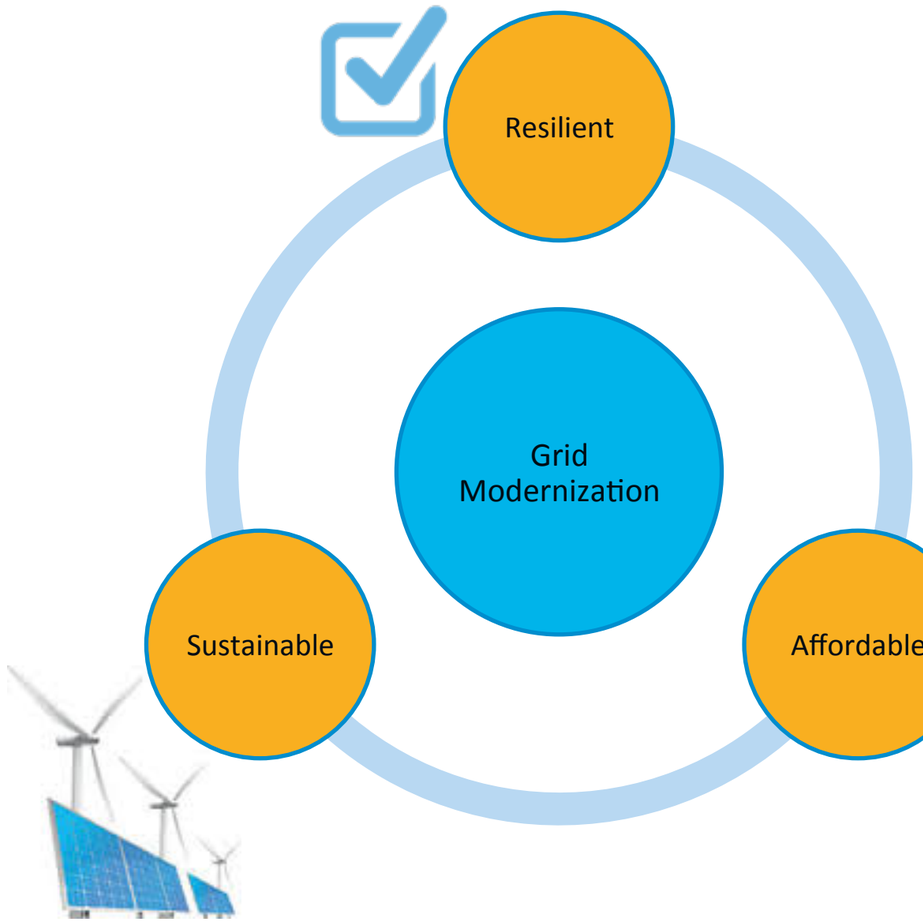


Price-Responsive Demand: Time-of-Use price



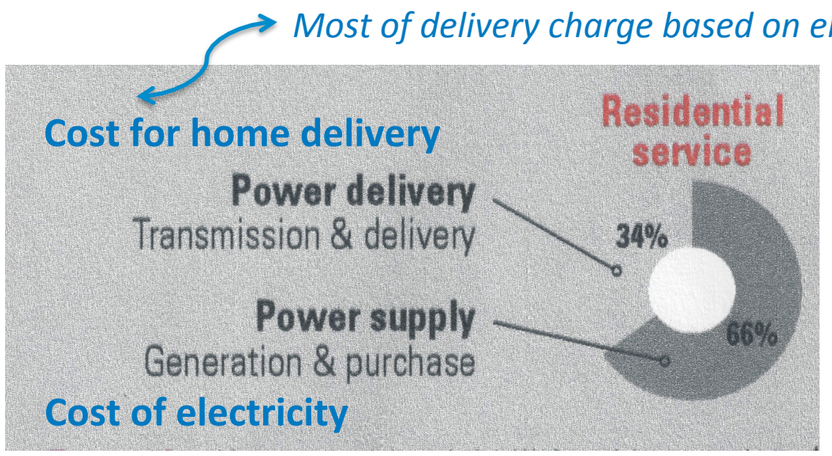
Transactive Energy





- New business models

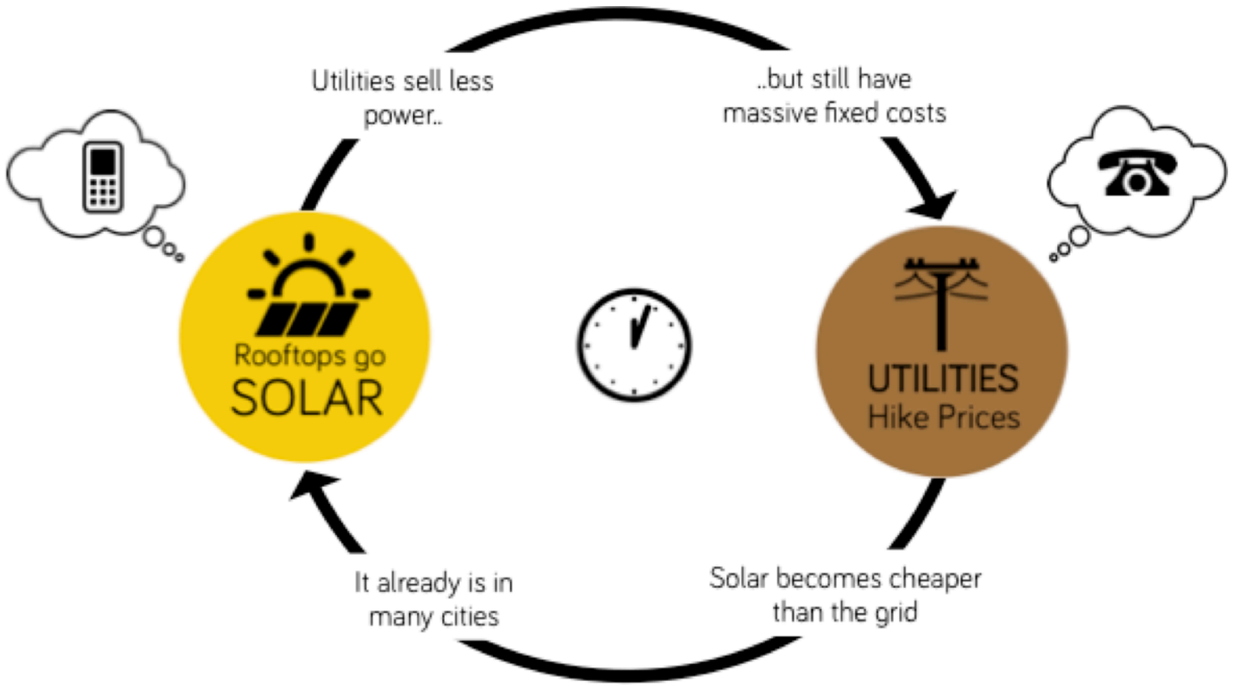
Electricity Bills



Source: Xcel Energy

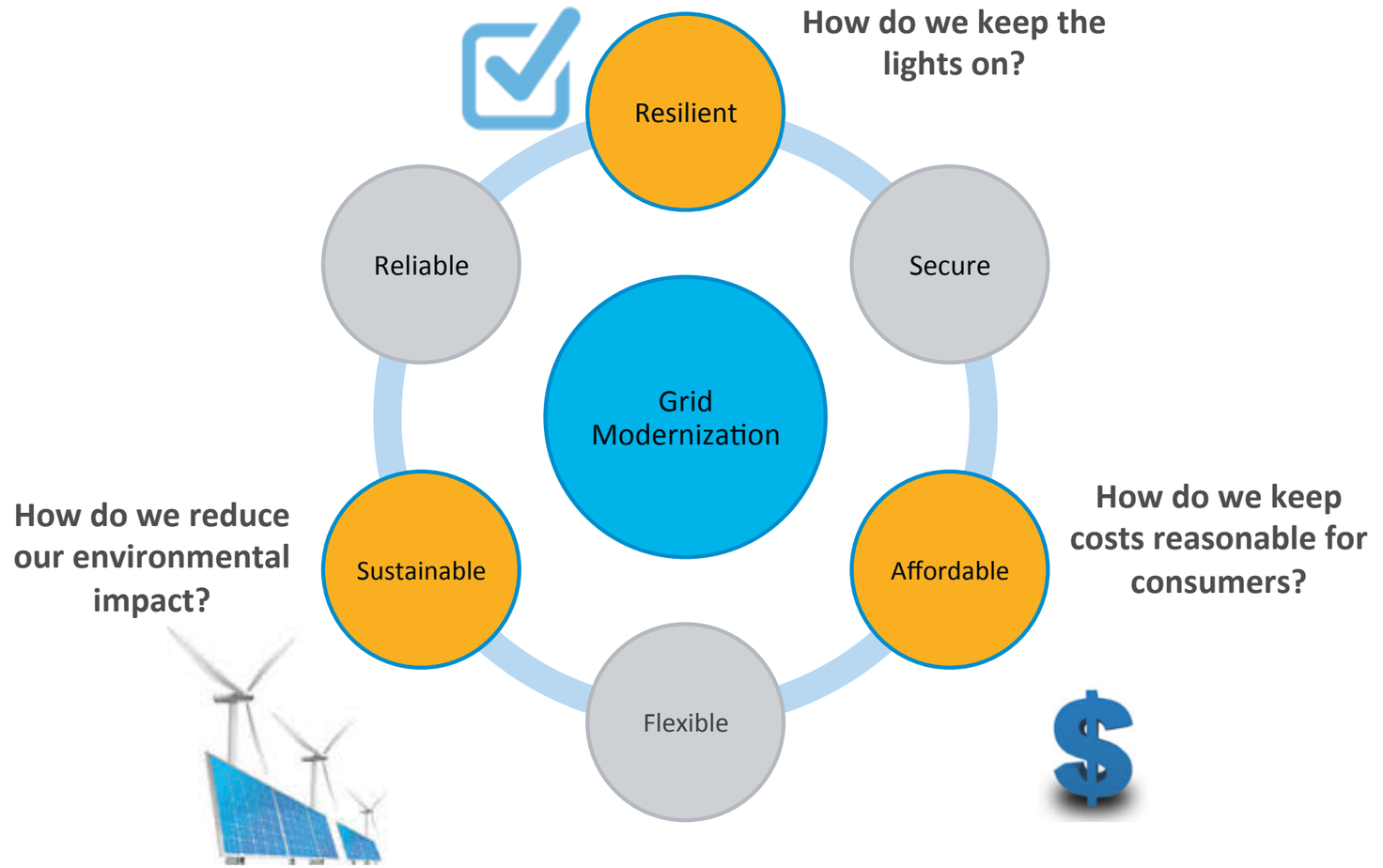
- The more electricity you use, the more you pay

The “Utility Death Spiral”



Source: The Energy Collective

Need to reform rate structures & utility business models

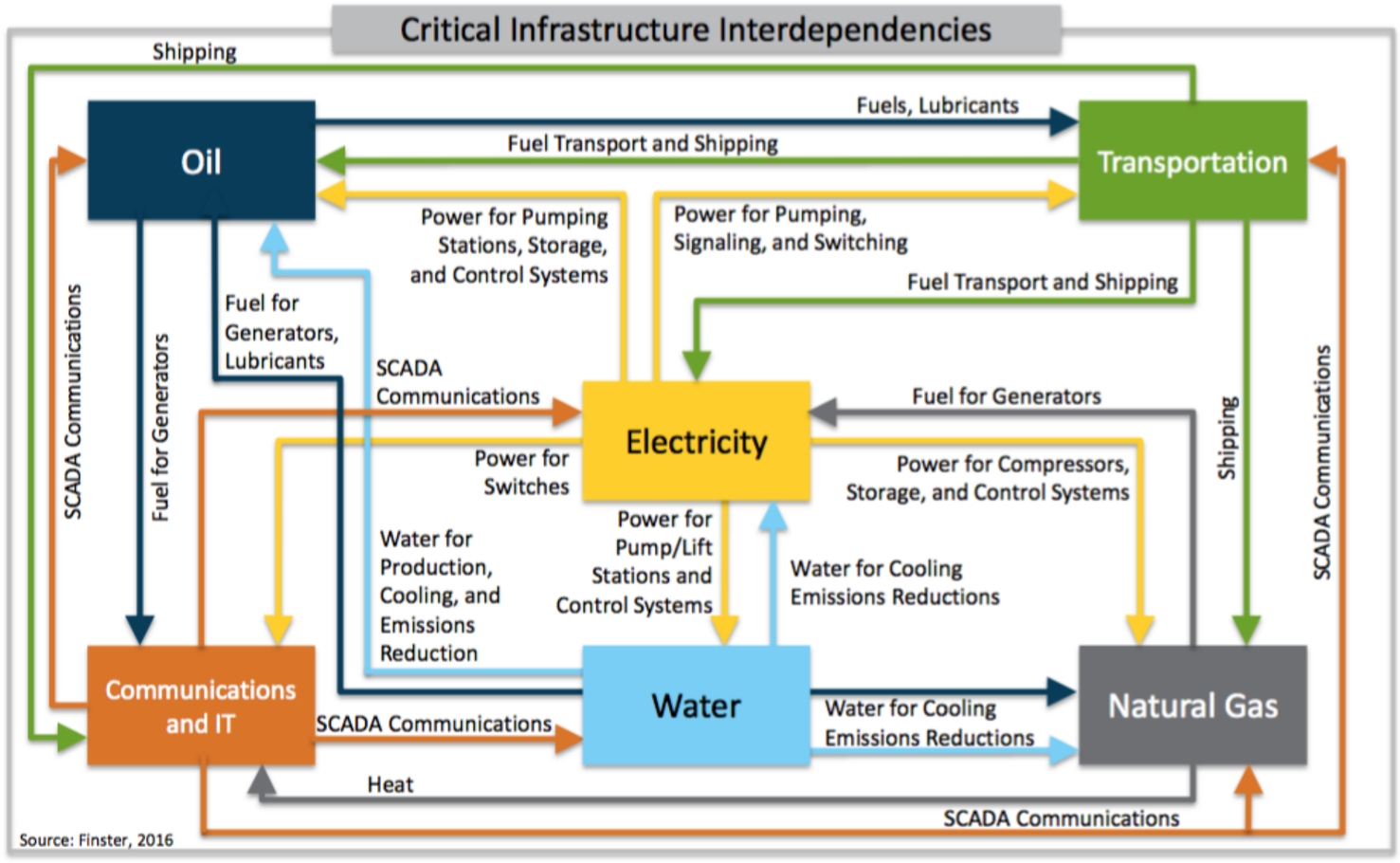


Source: DOE Grid Modernization Initiative, Multi-Year Project Plan, Nov 2015

Takeaways

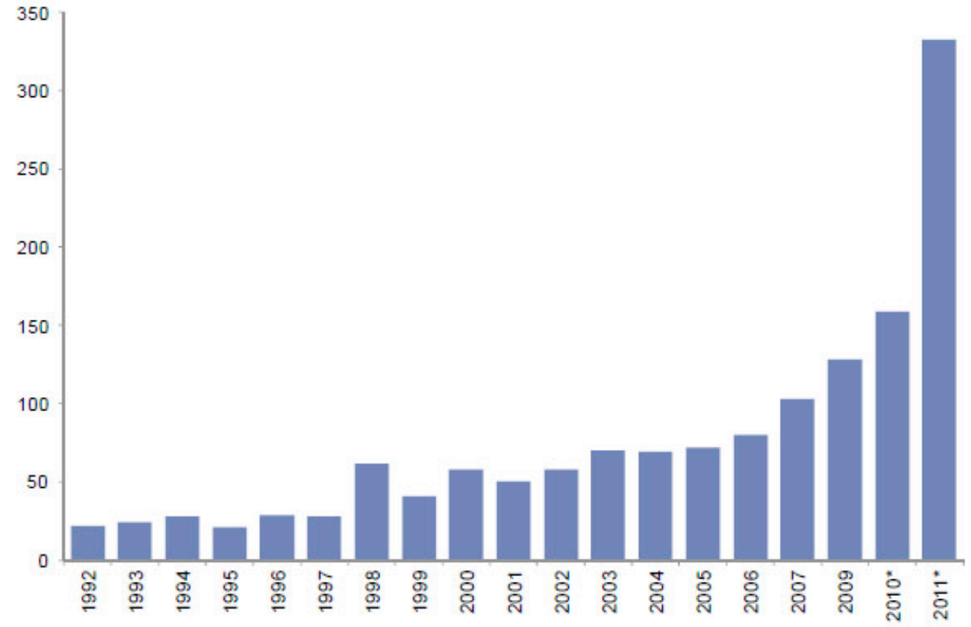
- Every time you plug a device into an outlet, you are connecting to a marvelously complex machine – technically, financially and socially
- We need to invest in modernizing the grid so that we can continue to have access to affordable, reliable and sustainable power
- Technologies are developing so that you can take an active part in a modernized grid


Thank You!!
Annabelle Pratt, Ph.D.
Principal Engineer
Power Systems Engineering Center
annabelle.pratt@nrel.gov


Critical Infrastructure Interdependencies
Shipping
Oil
Fuels, Lubricants
Fuel Transport and Shipping
Transportation
Power for Pumping Stations, Storage, and Control Systems
Power for Pumping, Signaling, and Switching
Fuel Transport and Shipping
SCADA Communications
Fuel for Generators, Lubricants
SCADA Communications
Electricity
Fuel for Generators
Power for Switches
Power for Compressors, Storage, and Control Systems
Shipping
SCADA Communications
Water for Production, Cooling, and Emissions Reduction
Power for Pump/Lift Stations and Control Systems
Water for Cooling Emissions Reductions
Communications and IT
SCADA Communications
Water
Water for Cooling Emissions Reductions
Natural Gas
Heat
SCADA Communications
Source: Finster, 2016

Power outages have risen sharply over the last decade

Major power disturbances in North America



*Note: * NERC equivalent data estimated based on the trends seen in the Eaton Blackout tracker for number of outages affecting over 50,000 people.*

Source: NERC, Eaton Blackout Tracker, Goldman Sachs Research estimates.

Note:* Data for Germany for 2012 ** Data for Spain for 2009
***Date for the USA for 2008
Source: CEER 2011, Bundesnetzagentur 2013, DUH 2013

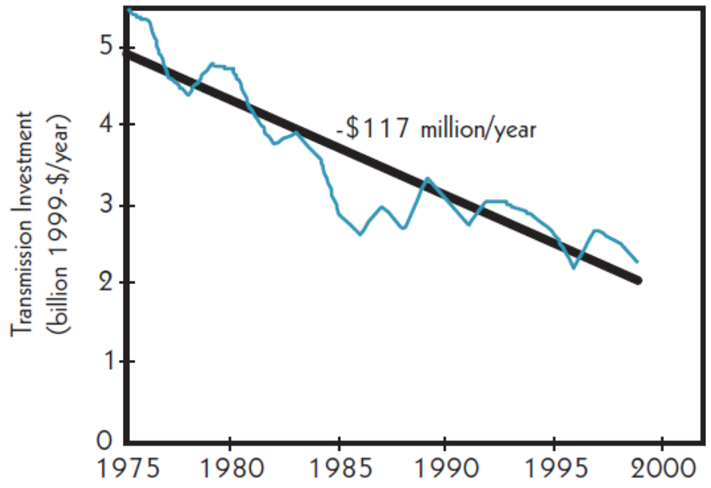
Average outage duration:
United States:
120 min and growing
Rest of industrialized world:
10 min and shrinking

Economic impact:
2003 East Coast blackout = $6B loss

Aging infrastructure:
>70% of transmission lines & transformers > 25 years old

U.S. Transmission Investments

Annual investment in transmission facilities has been declining since 1975.

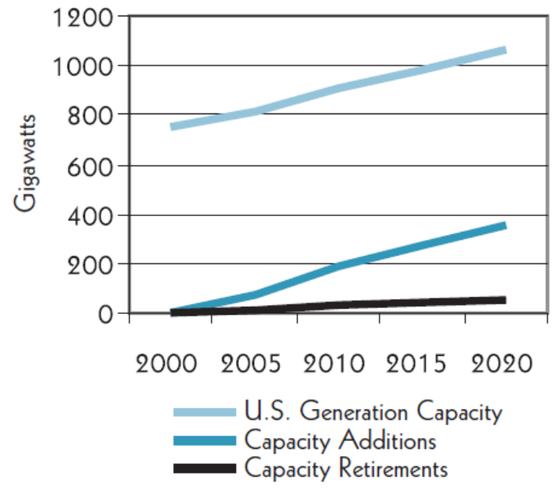


Source: "Grid 2030" – A National Vision for Electricity's Second 100 Years, U.S. Department of Energy. (July 2003)

Expanding Generation Needs

Forecast of Future Electric Generation

More than 350 GW of new capacity needed by 2020



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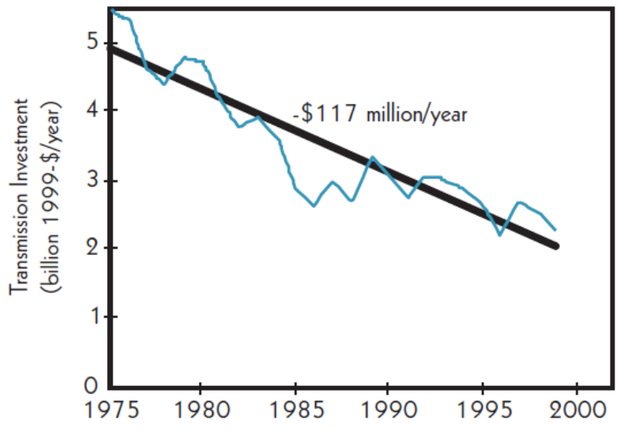
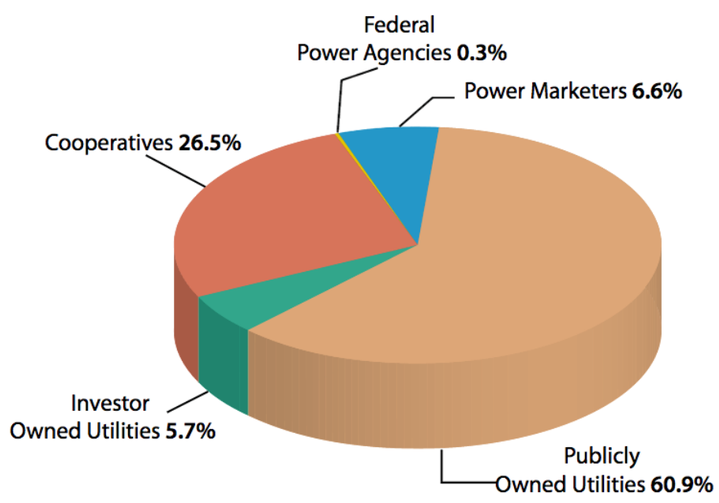
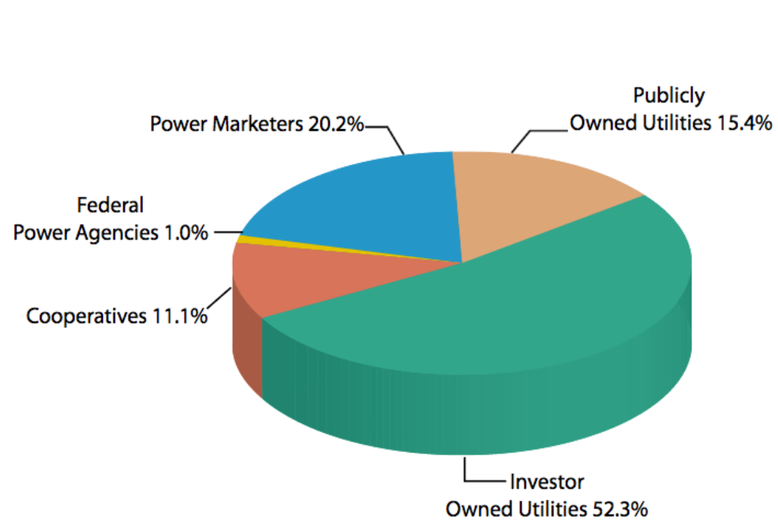


Source: "Grid 2030" – A National Vision for Electricity's Second 100 Years, U.S. Department of Energy. (July 2003)

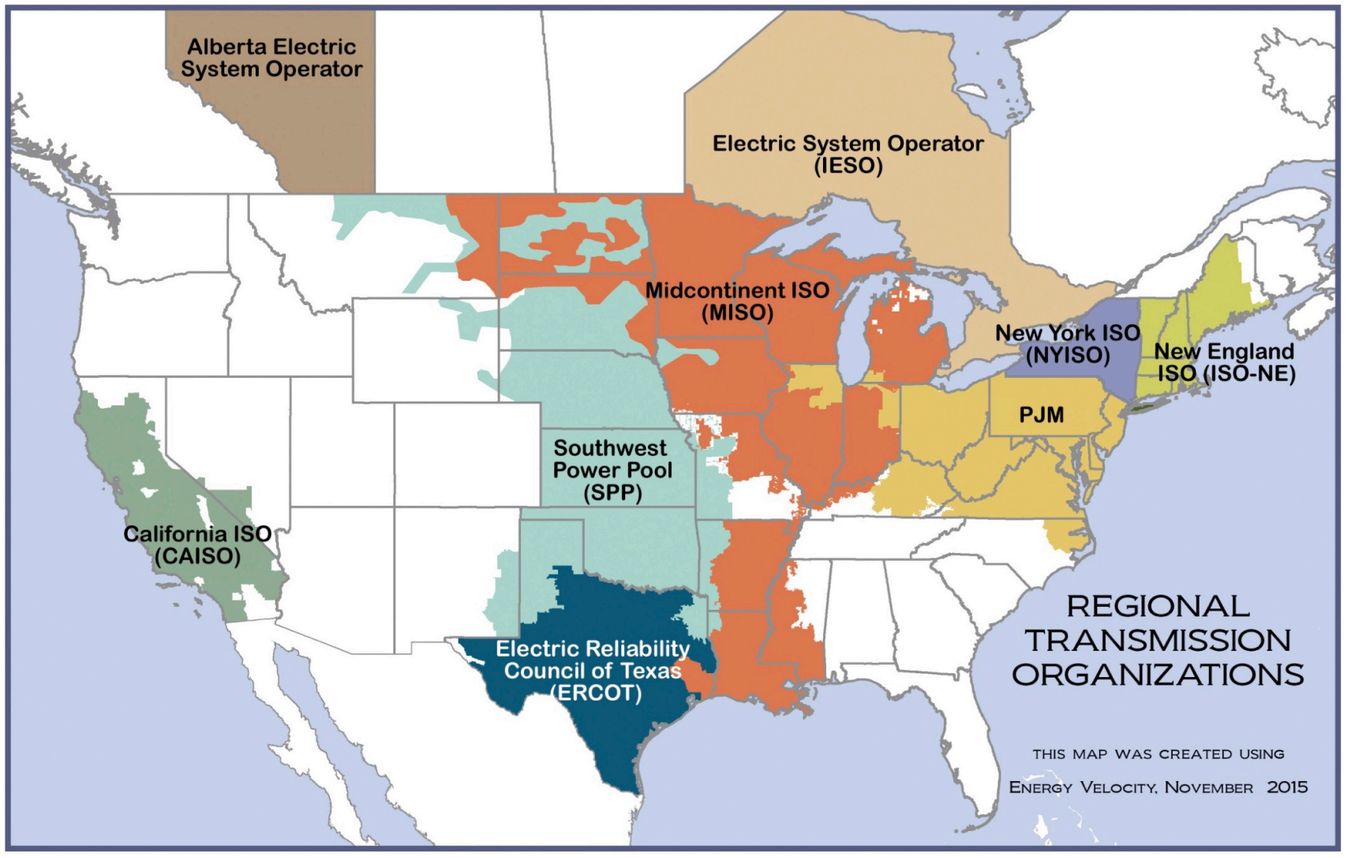
TYPE	NUMBER	%	% Load served
Publicly owned	2,013	60.9	16
Investor-owned	189	5.7	52
Cooperatives	877	26.5	11
Federal Agencies	9	0.3	1
Power Marketers	218	6.6	20





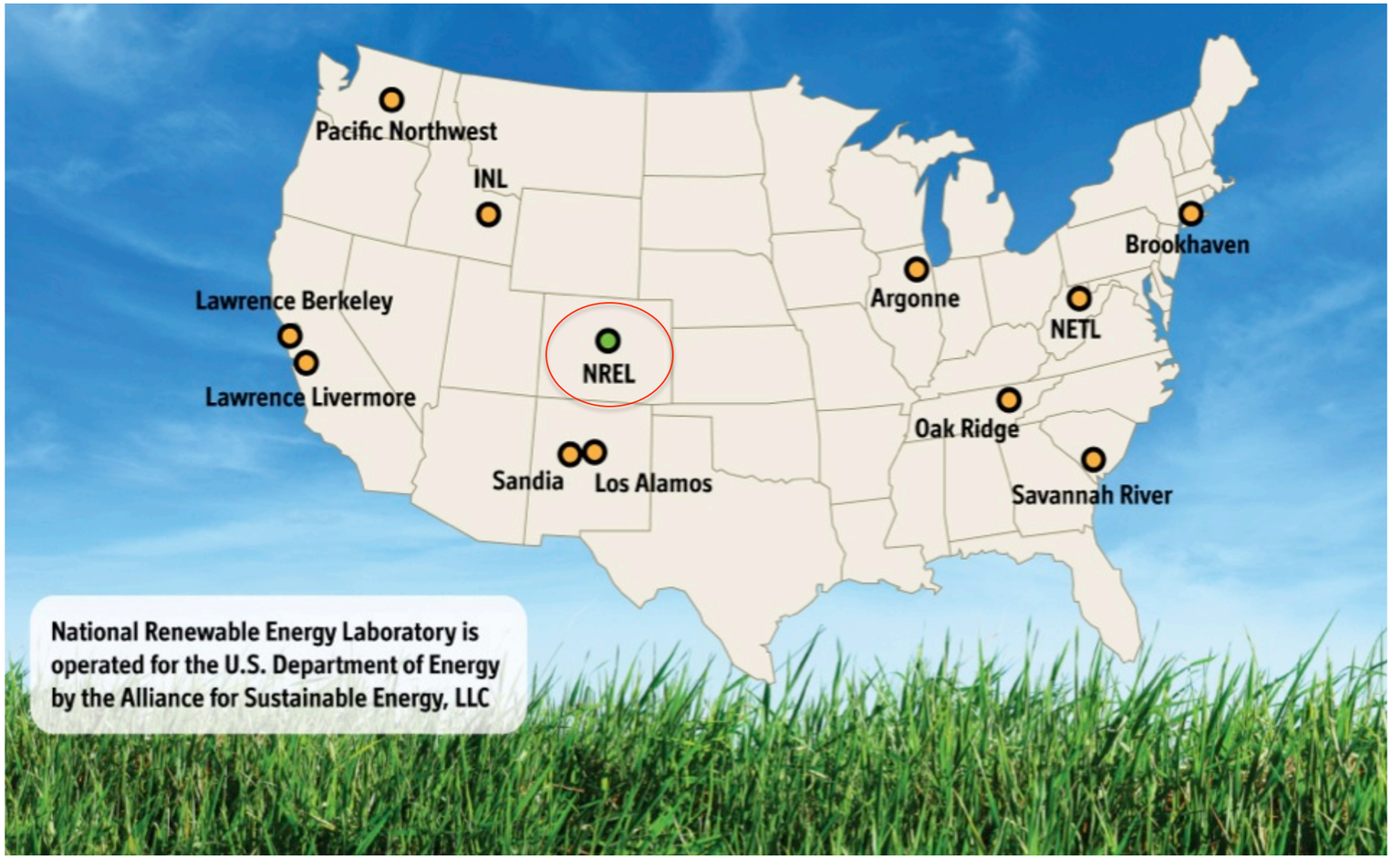
Source: http://www.publicpower.org

More than Wires

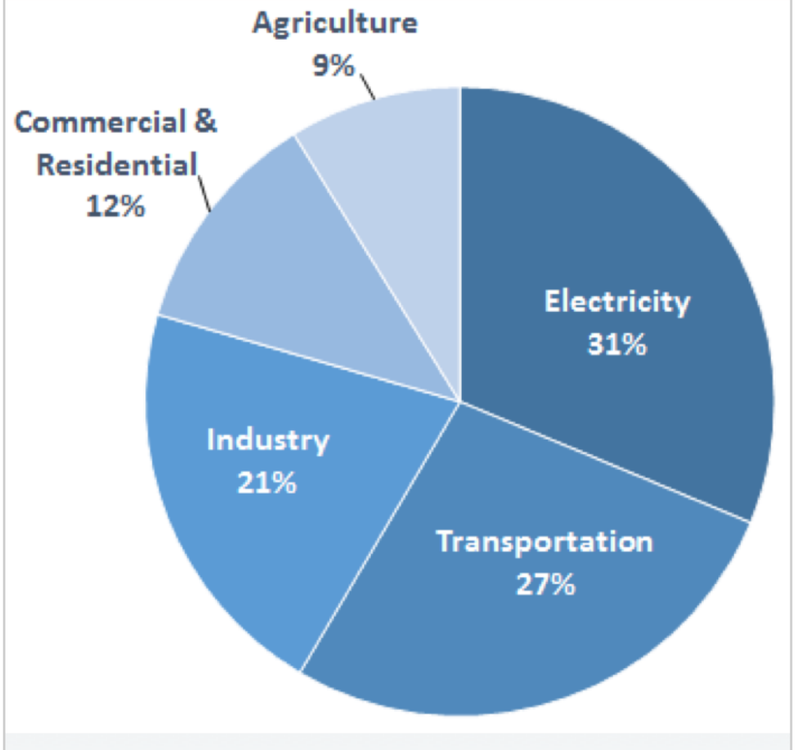


Source: Federal Energy Regulatory Commission (www.ferc.gov)

National Renewable Energy Laboratory

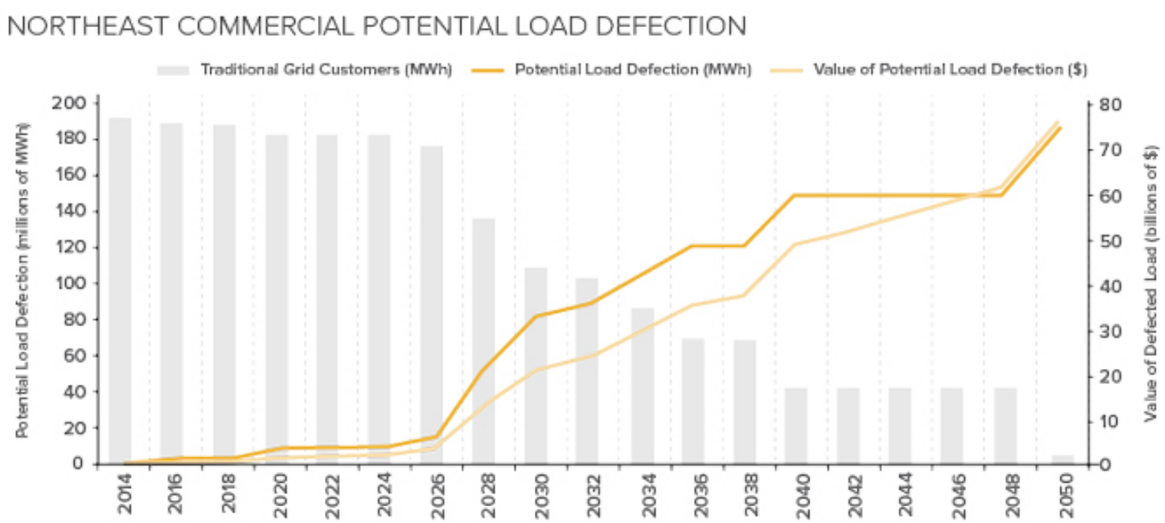


Total U.S. Greenhouse Gas Emissions by Economic Sector in 2013



Source: https://www3.epa.gov/climatechange/ghgemissions/sources.html

RMI study: PV + battery systems may be economic in 10–15 years for many customers in many parts of the country



Source: The Economics of Load Defection, Rocky Mountain Institute, rmi.org

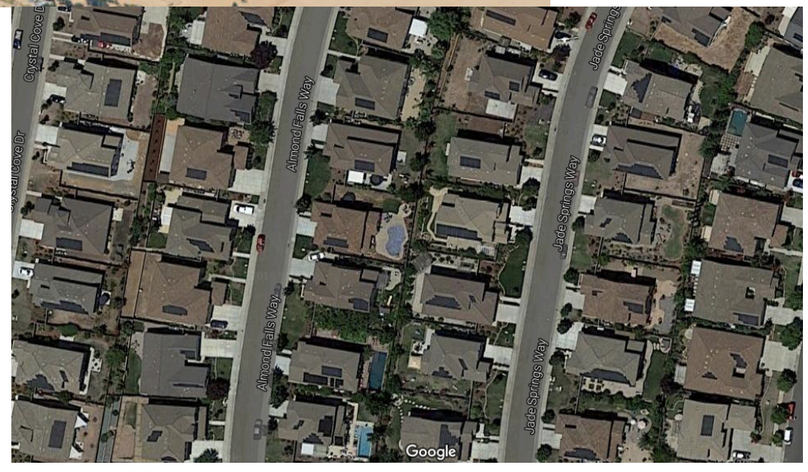
Need to reform rate structures & utility business models to make PV and batteries a part of the future grid, not a threat

Solar Star

QUICK FACTS	
Location:	Rosamond, California
Capacity:	579 MW
Owner:	MidAmerican Solar, a subsidiary of MidAmerican Renewables
Design/Construction:	SunPower
Power Purchaser:	Southern California Edison
Technology:	SunPower™ Oasis™ Power Plant
No. of Modules:	Approx. 1,720,000
Equivalent No. of Homes Powered:	Approx. 255,000
Acres:	Approx. 3,200

Source: Sunpower
https://us.sunpower.com/sites/sunpower/files/media-library/fact-sheets/fs-solar-star-projects-factsheet.pdf

Solar Subdivisions



Anatolia Subdivision – Rancho Cordova, CA - Source: Google Maps

Alta Wind Energy Center
Tehachapi Pass, CA[1]
600 Vestas Wind Turbines
1,547 MW
2,680.6 GWh/yr

Capricorn Ridge Wind Farm
Sterling and Coke County, TX[2]
407 GE & Siemens Turbines
663 MW

Shepard's Flats
Arlington OR[3]
338 GE Turbines
845 MW
2,000 GWh/yr

Sources:
[1]https://en.wikipedia.org/wiki/Alta_Wind_Energy_Center
[2] http://www.nexteraenergyresources.com/pdf_redesign/capricornridge.pdf
[3] https://en.wikipedia.org/wiki/Shepherds_Flat_Wind_Farm