Large-scale Photovoltaic Generation Deployment

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Exceptional service in the national interest

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

1. Sandia and Energy-Related R&D
2. Photovoltaics (PV) deployment and trends
3. Challenges to future large-scale deployment
   - Grid access
   - Operational integration

Q&A (time permitting)

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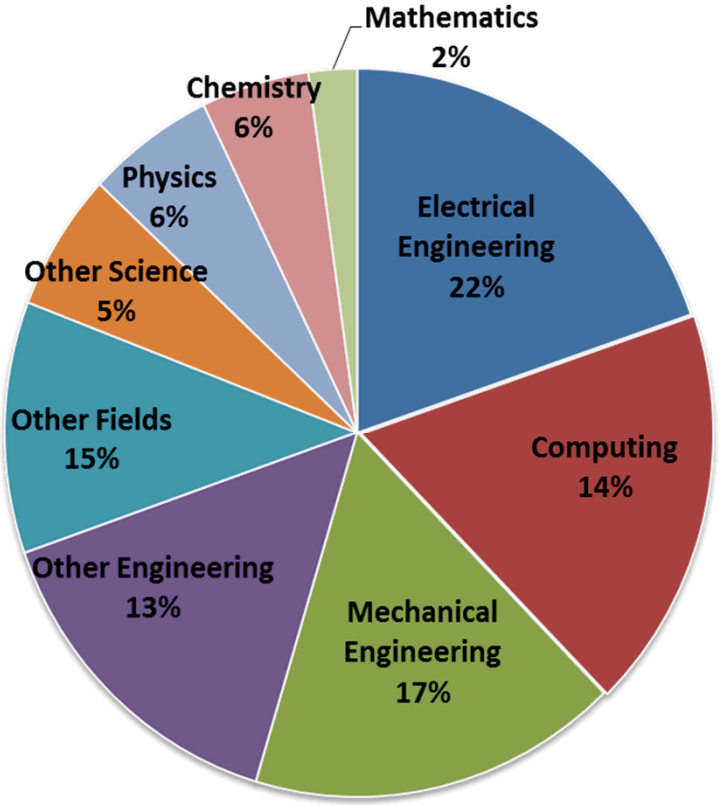
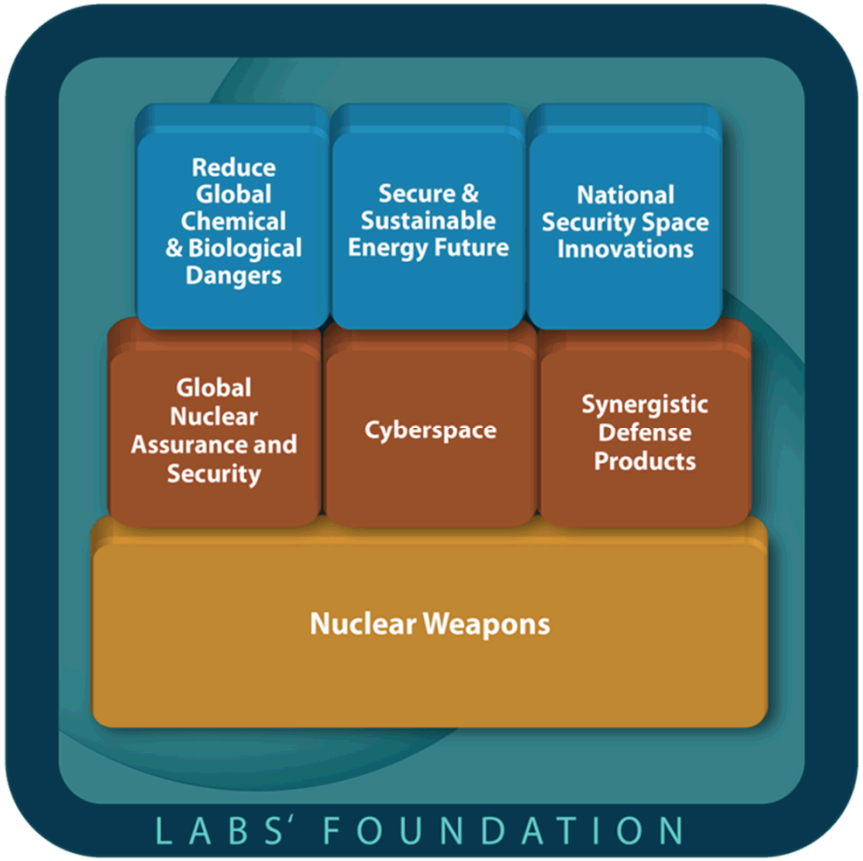
- Total Sandia workforce: 12,609
- Regular employees: 10,330
- Advanced degrees: 5,790 (56%)
- Total Expenditures: $2.7B

Data as of July 20, 2015



Sandia Mission



History of Sandia Energy Programs

1970
- Energy crisis of the 1970s spawned the beginning of significant energy work
- Strategic Petroleum Reserve
- Vertical-axis Wind Turbine

1980
- Combustion Research Facility (CRF) opens to researchers
- Solar Tower opens
- NRC cask certification studies & core melt studies
- Distributed Energy Technology Laboratory (DETL)

1990
- DOE's Tech Transfer Initiative established by Congress in 1991
- MELCOR code released

2000
- Energy Policy Act of 2005
- Advent Solar
- Power grid reliability study
- SunCatcher™ & Stirling Energy Systems
- Sunshine to Petrol Pilot Test
- Large-scale pool fire tests of liquefied natural gas (LNG) on water

2010
- CRF & Cummins partnership
- Joint BioEnergy Institute
- Water Power Program
- Solar Energy Grid Integration Systems (SEGIS)
- Climate study uncertainties to economies
- Combustion Research Computation and Visualization (CRCV) opens

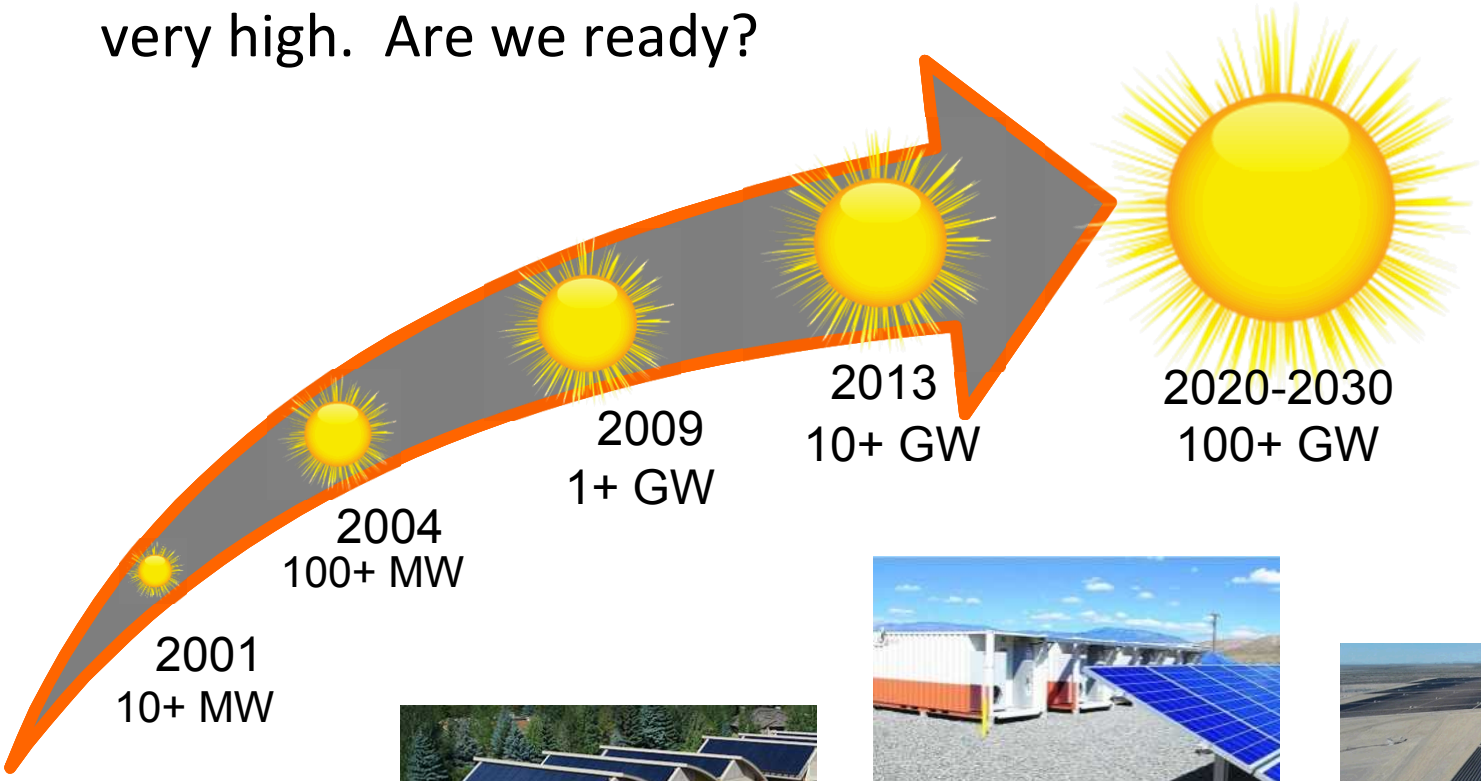
2011
- MEPV
- Mesa del Sol microgrid demo
- Sandia Cooler
- CREW published
- Fukushima Recovery

2012
- Criegee combustion intermediates
- PV Regional Test Centers (RTCs)
- Biofuels: ionic liquid pretreatment
- Electricity Storage Handbook

2013
- Solar Glare Analysis Tool (SGHAT)
- New diesel low-temp combustion model
- PVLib Toolset

Racing toward massive PV deployment…

- Installed PV capacity is growing fast, and future potential is very high. Are we ready?



Solar and the future of world electricity

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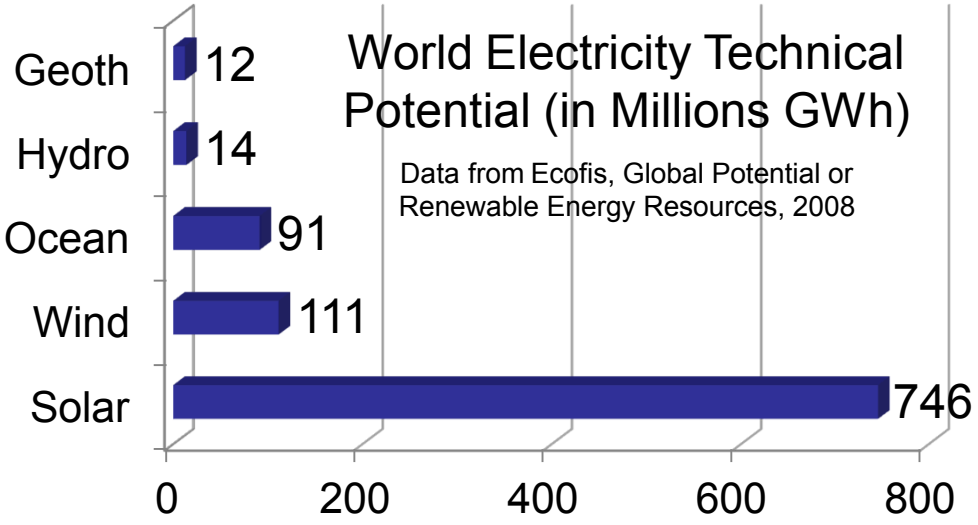
- Over one year, global electricity consumption is 20 Million GWh.
  - Over 20% of this total consumed by the US.
- Due to practical considerations (conversion efficiency, geography, land use), solar is the best carbon-free non-nuclear long-term option



More energy from sunlight strikes the Earth in one hour than all the energy consumed on the planet in one year.

US Generation Stats (2012)

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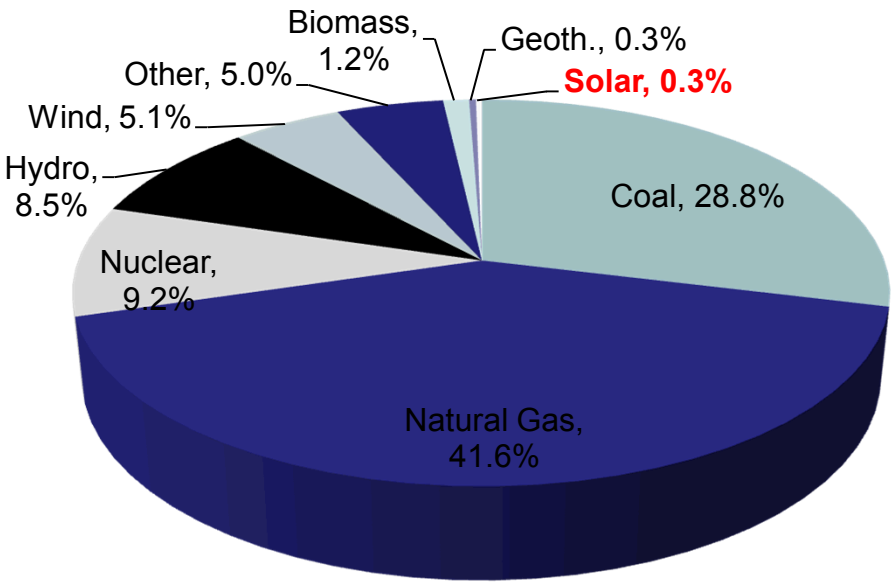
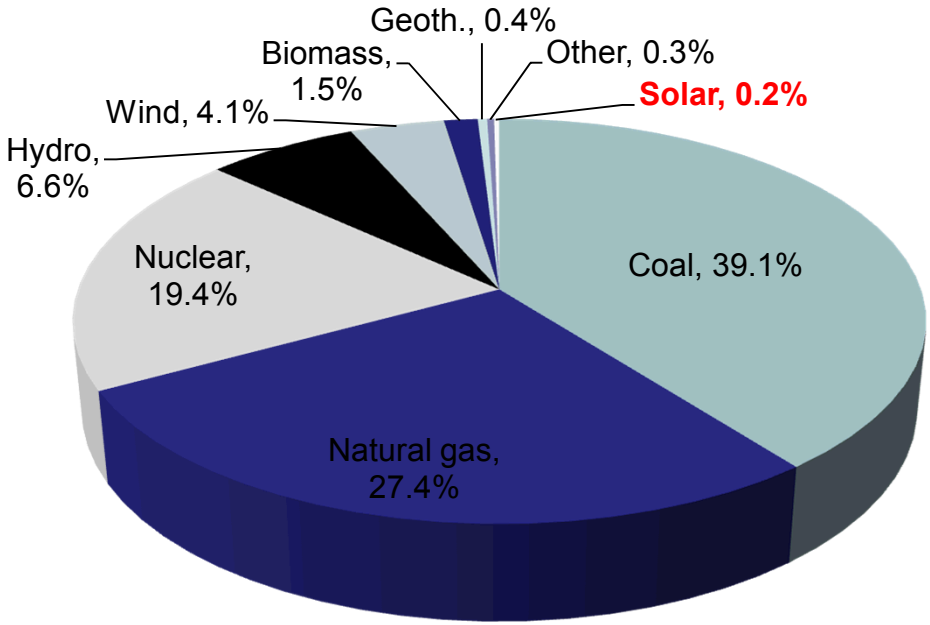
By Capacity (Nameplate)

Total = 1,167 MW



By Annual Energy Produced

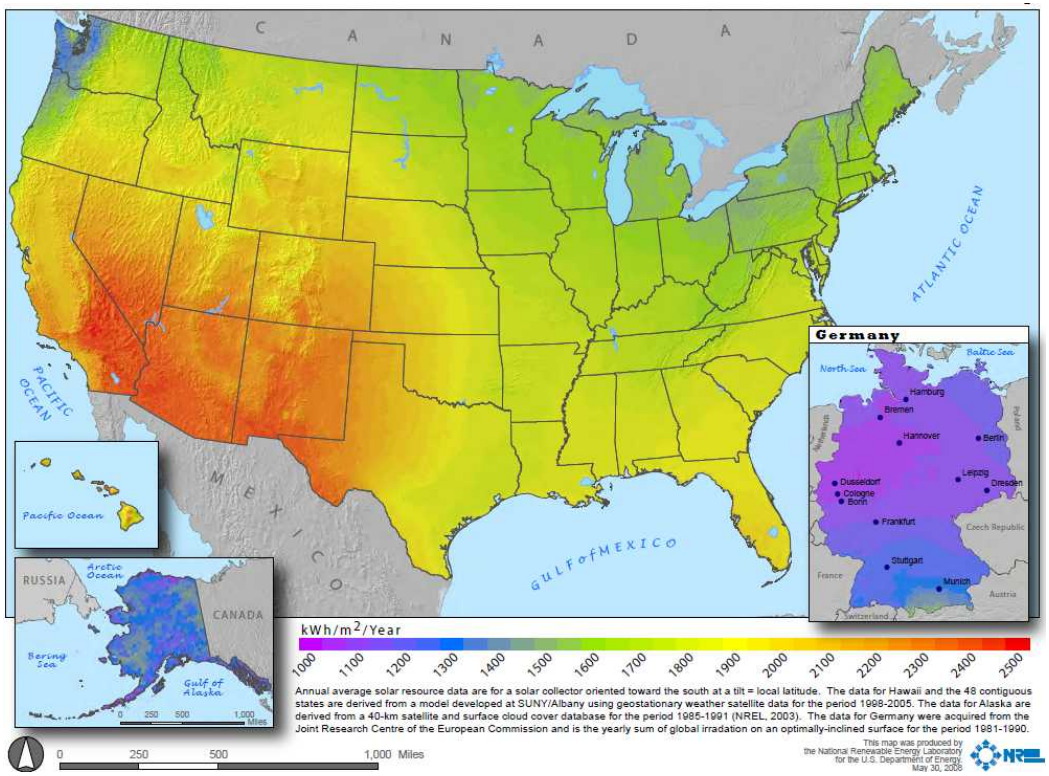
Total = 4,058 Million MW-h

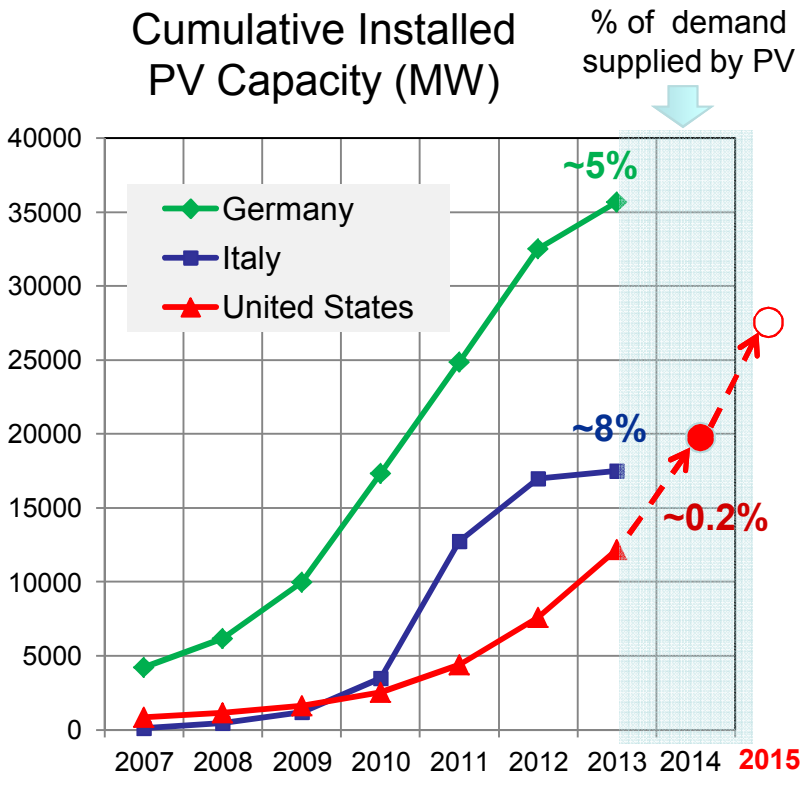


Source: IEA, 2014

US solar (PV) deployment

- US installed PV capacity by Dec 2014: 19 GW
  - Ranks 5th after Germany, China, Italy and Japan
- Growth rate and technical potential are very high!

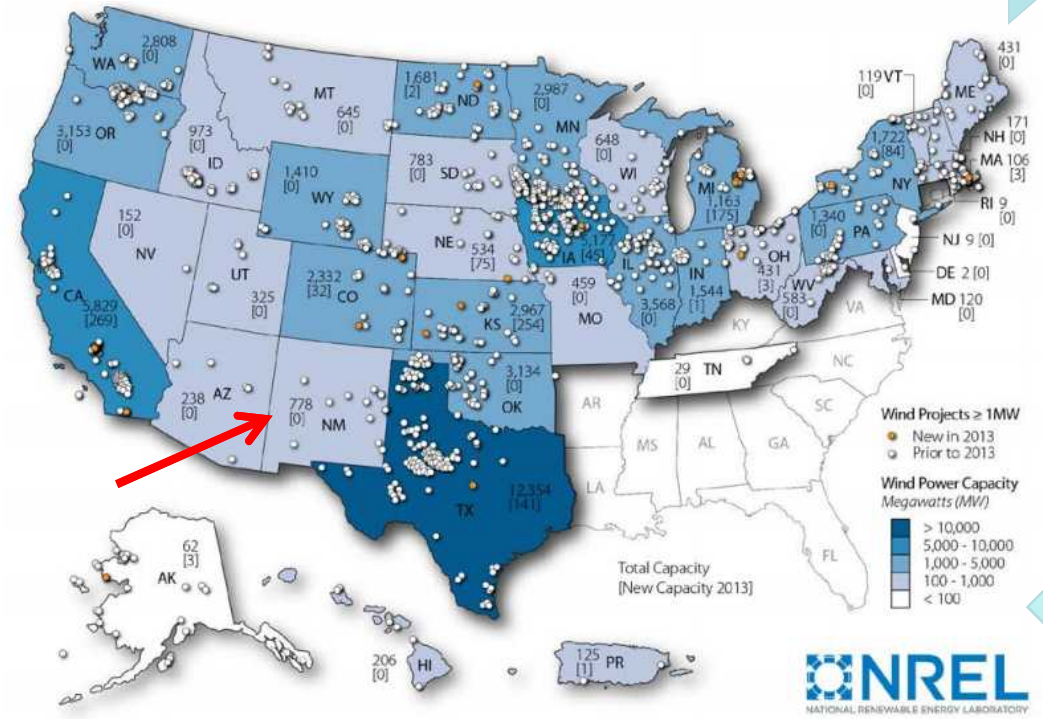




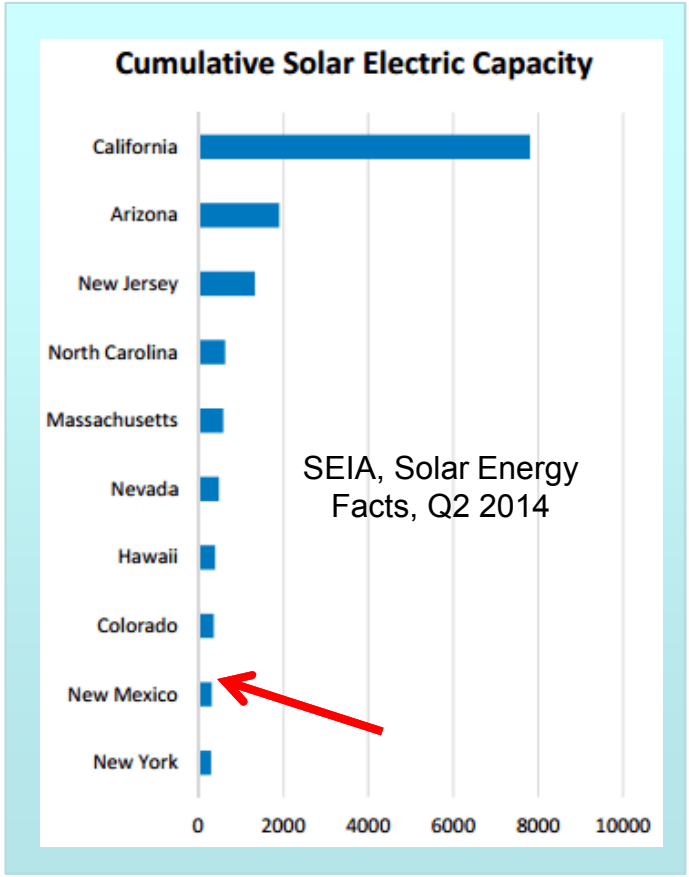
PV and Wind in New Mexico

NM ranks high in both wind & solar potential

- Installed (Q2, 2014): 312 MW (9th)
- Enough for 71,000 homes



Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2013.



- Wind in NM: 778 MW (17th)
- Enough for 345,000 homes

How much does PV cost?

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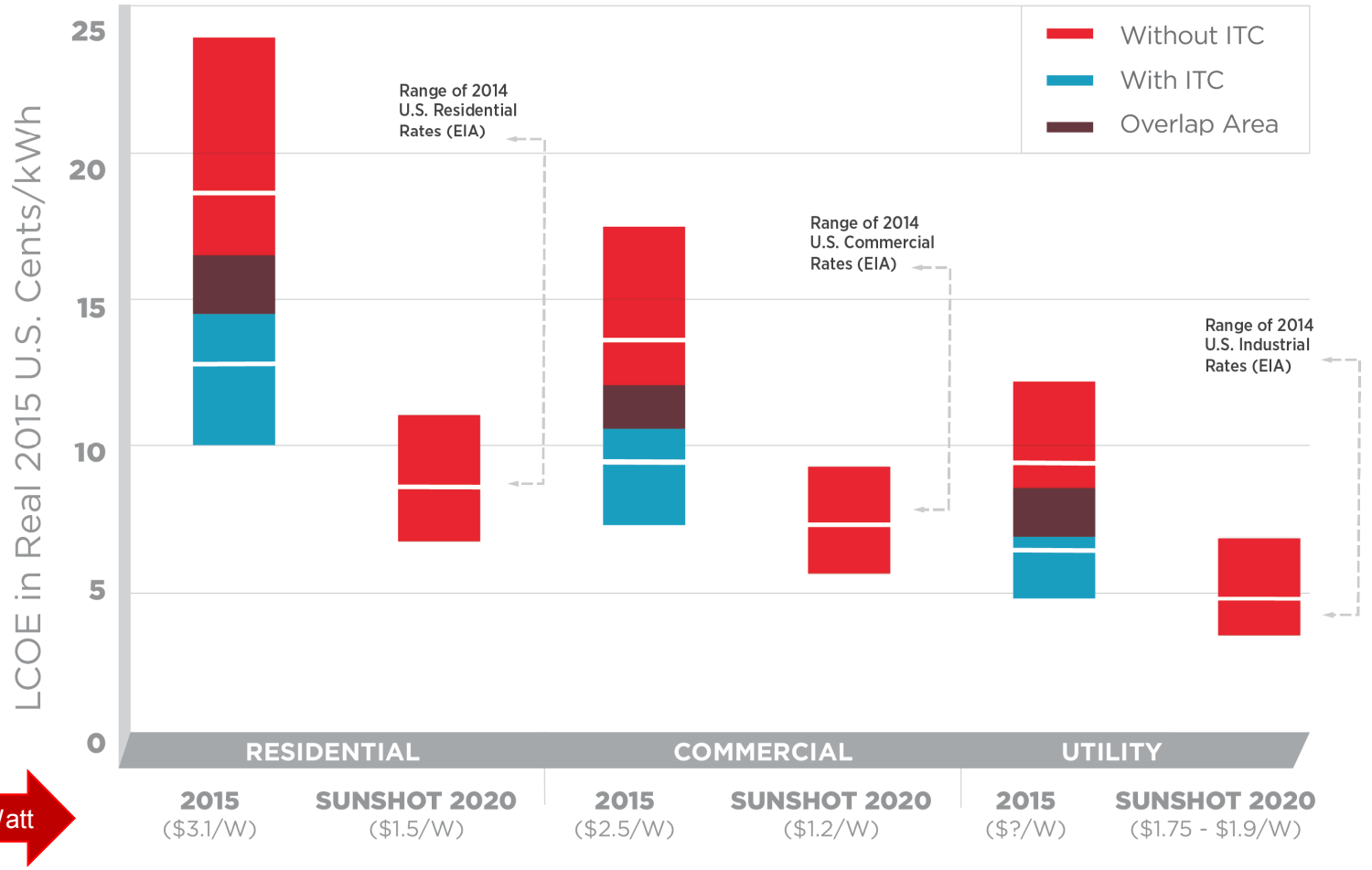
Calculated LCOE for Photovoltaics Systems In the United States

30% Federal ITC in 2015 (when included) and no Federal ITC in SunShot Scenarios. 1120 to 2380 kWh/kW systems.



How much does PV cost?

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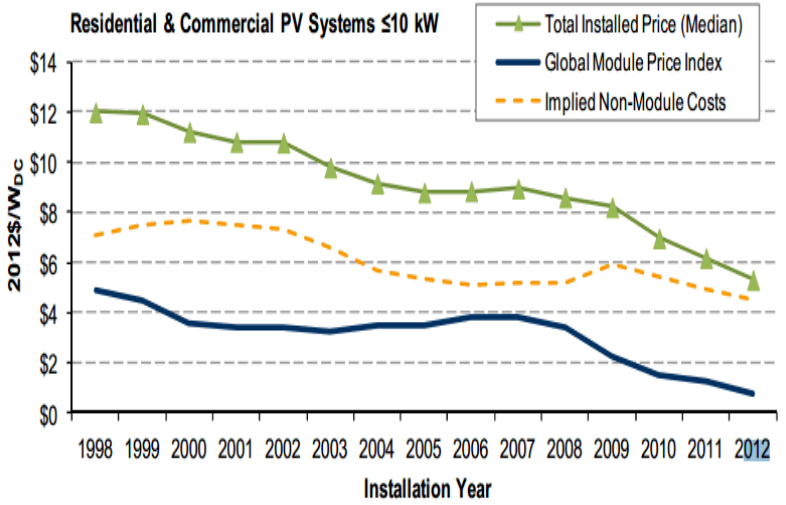
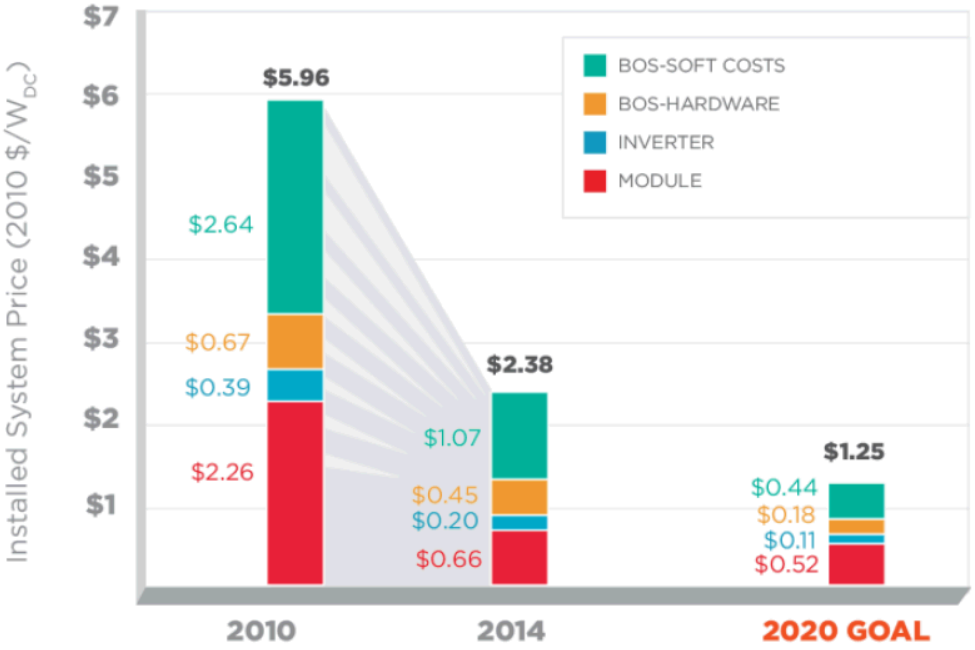
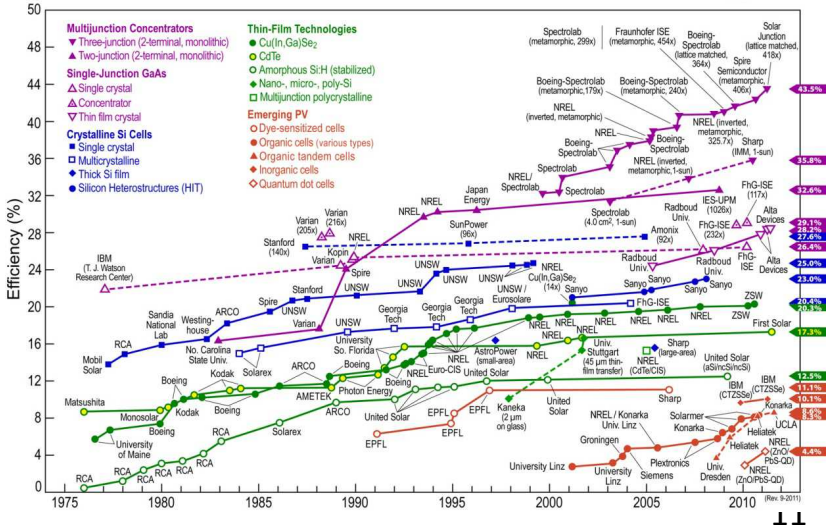
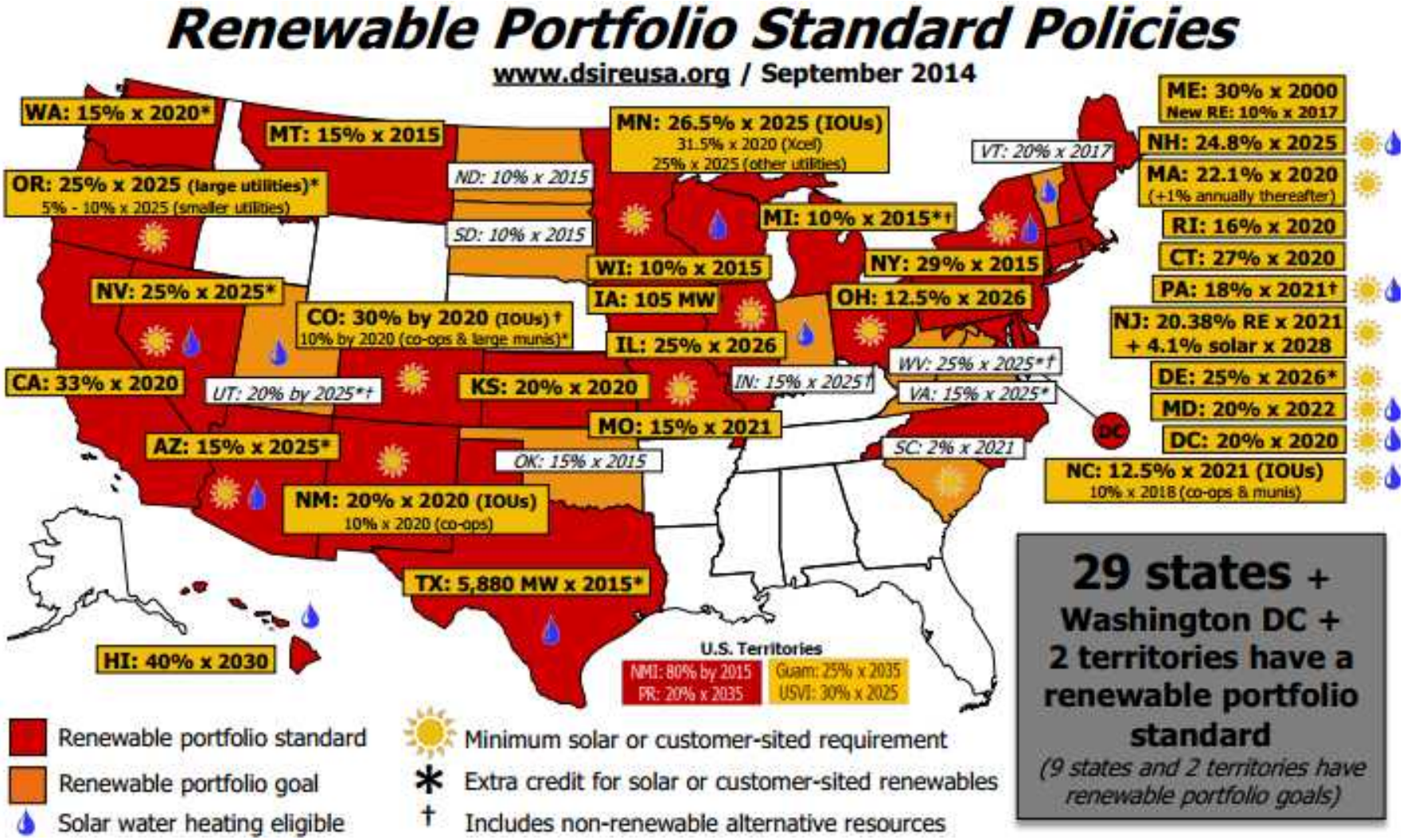
- Historical perspective since 1980
  - Module price: $35/watt to $0.65/watt
  - Module efficiency: 6% to 18%
  - Lifetime: 5 years to 30 years
  - Costs still falling!







Federal/State tax incentives and RPS



Source: http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf

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So much potential… what's the hold-up?

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- Resource potential
- Geography & land use
- Market demand
- Policy goals & incentives
- Competiveness Vs. alternatives
  - Capital cost
  - Financing
  - Grid integration
  - …

Grid access for large-scale deployment

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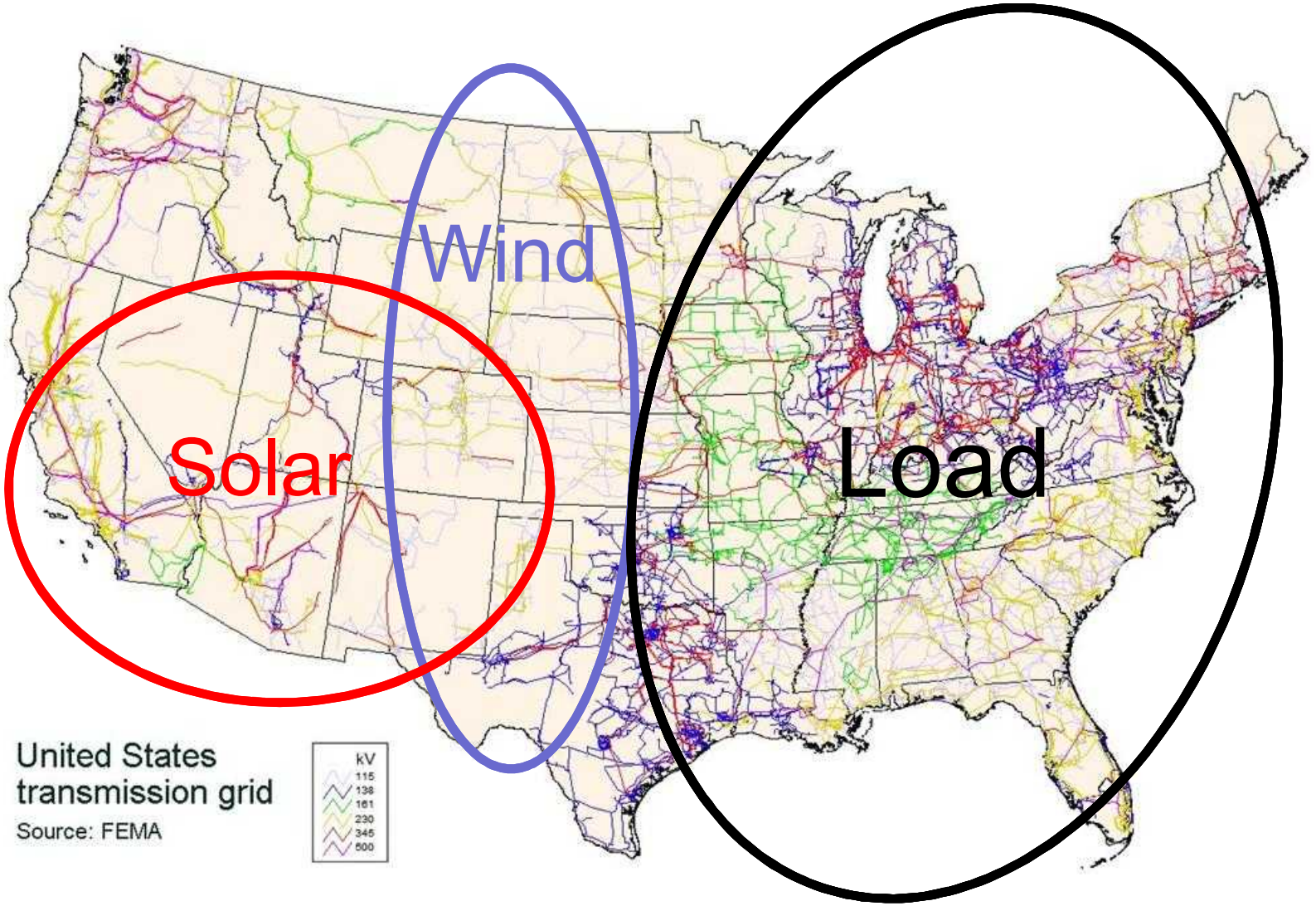
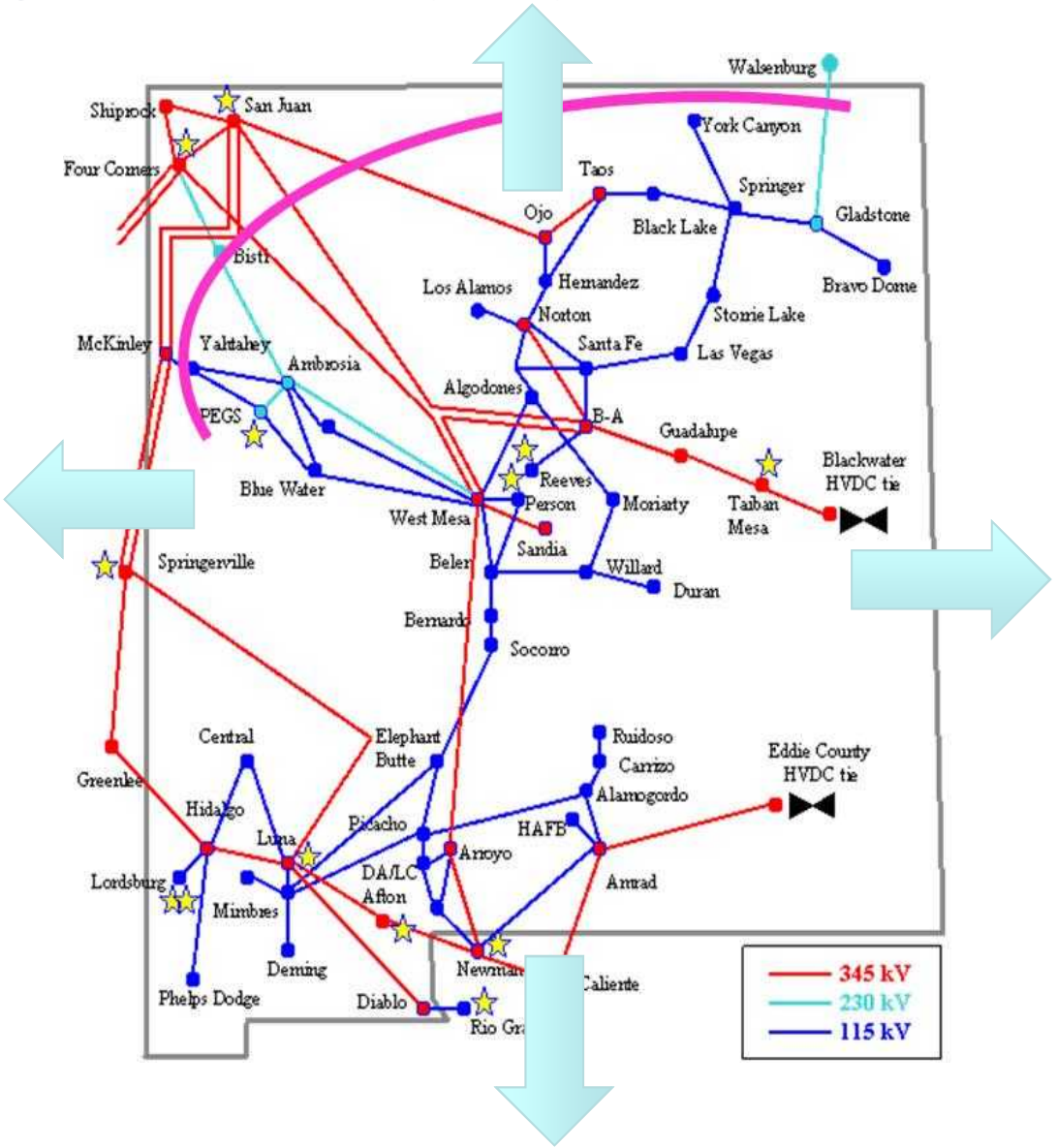


Grid access for large-scale deployment

- How to tap NM's large wind and solar potential (1000's of MW)?
  - Displace existing conventional generation

  Or

  - Build substantial new transmission to large regional load centers



How about an EHV grid overlay?

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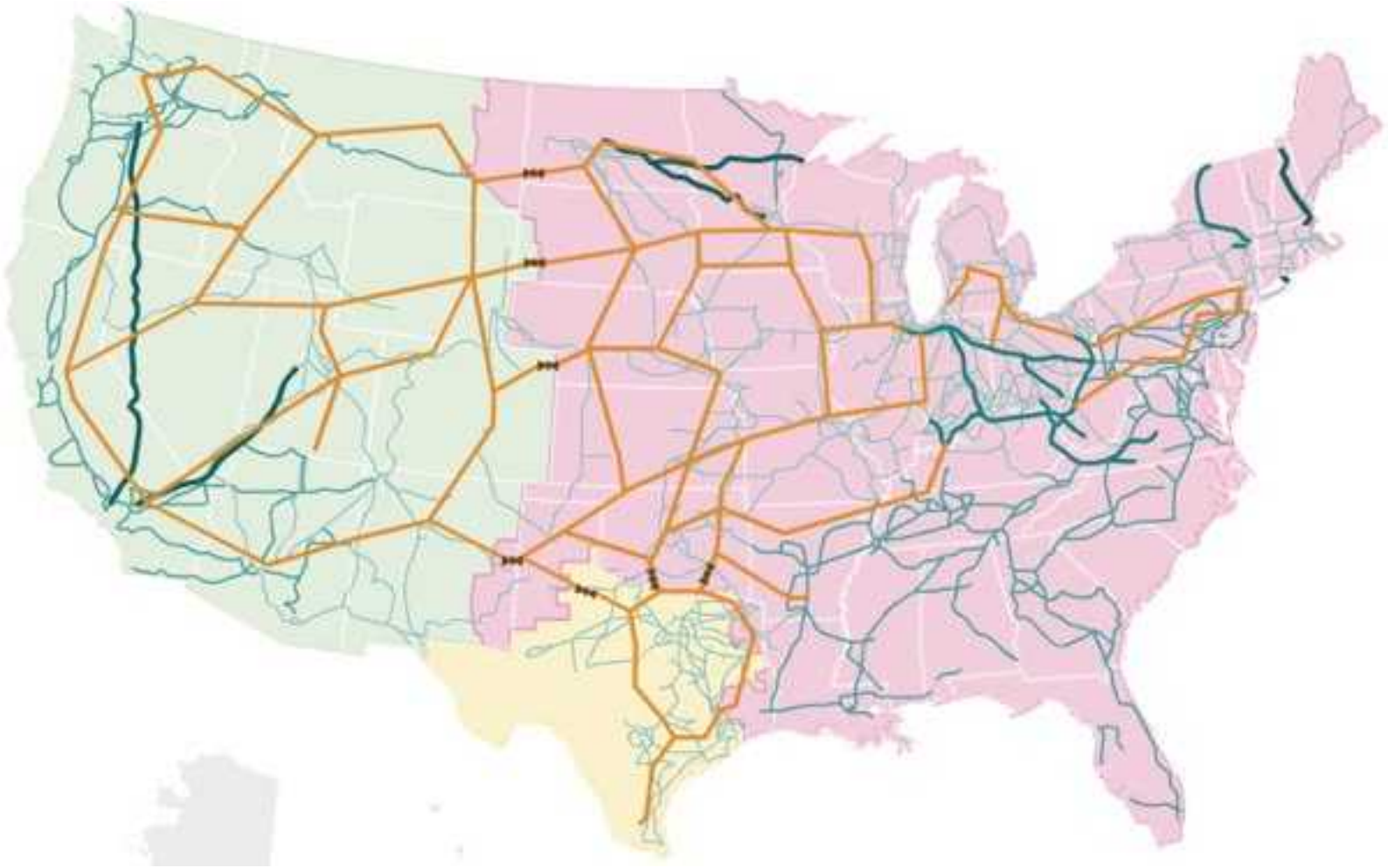
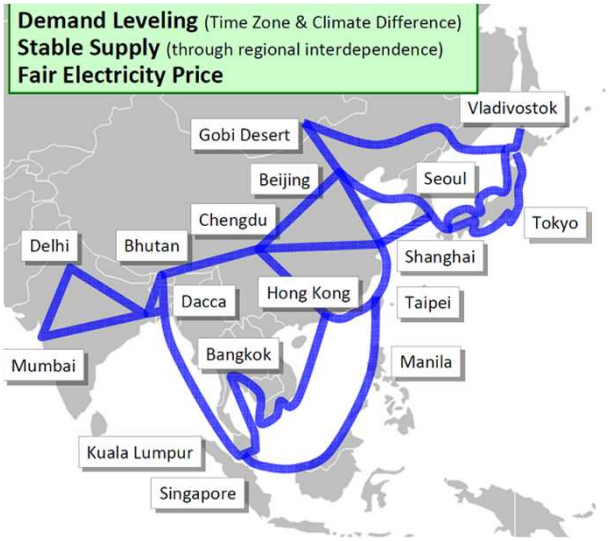
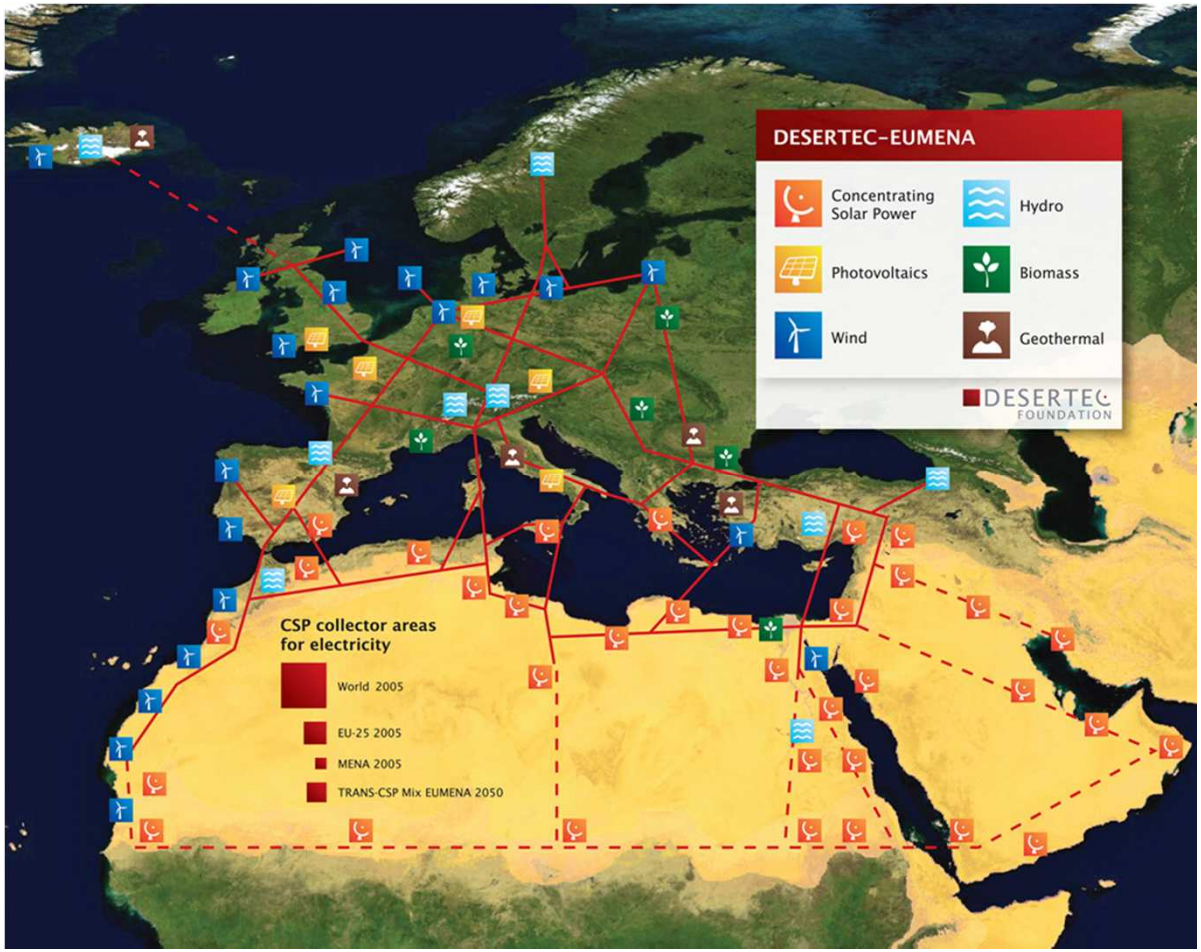


- Studies show positive ROI, but scope and upfront cost are prohibitive
- Federal Highway 2.0?

Similar ideas from other regions…





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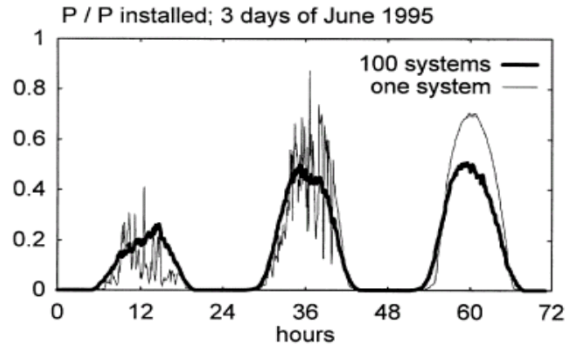
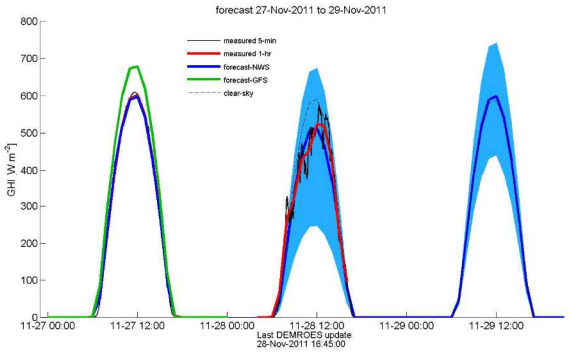
Operational Integration

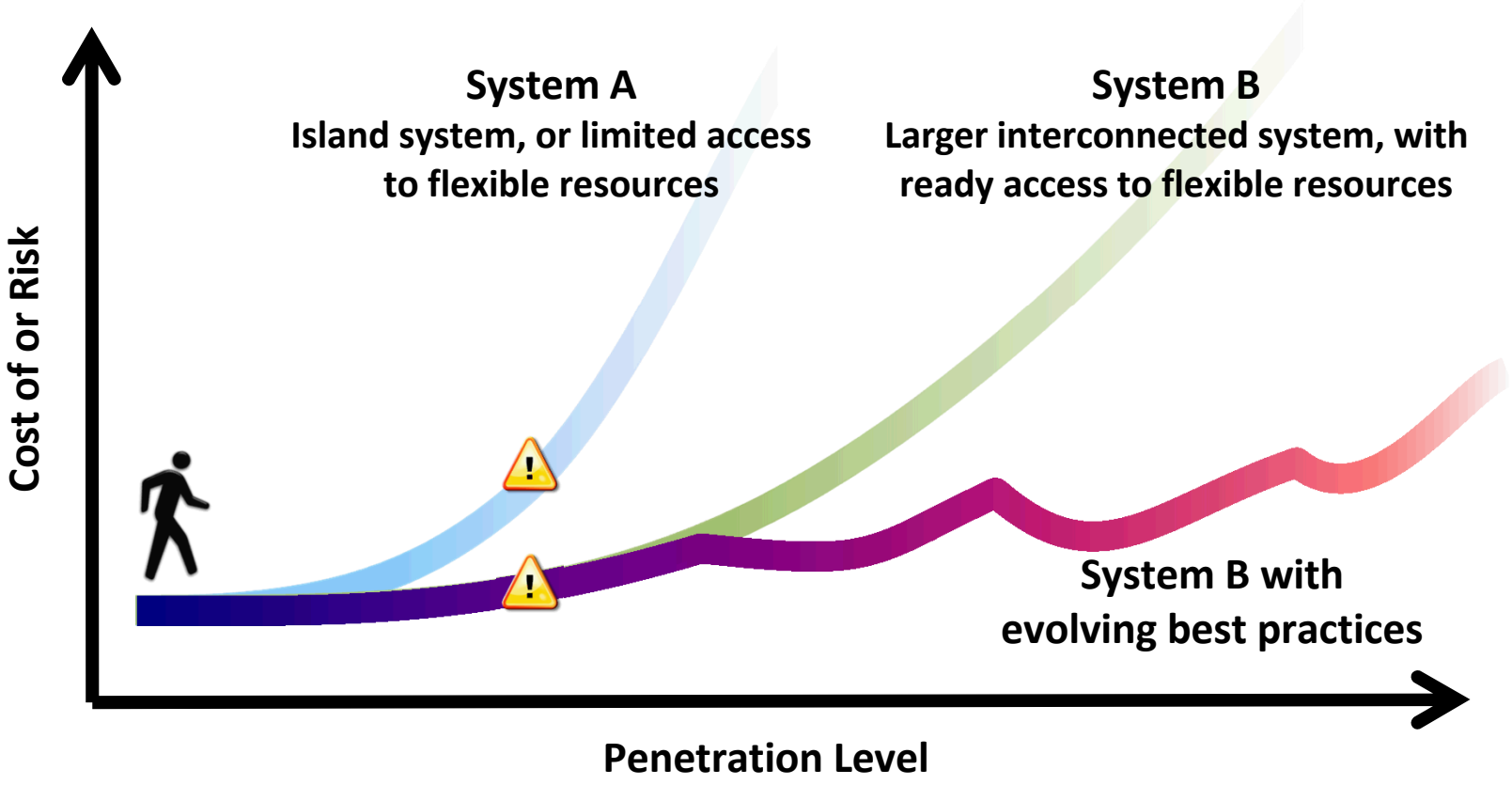
- Wind and solar generation are different…
  - Variable – weather-driven, can't be dispatched
  - Uncertain – can't forecast output precisely
  - Distributed – millions of embedded PV systems!
  - Inverter-based – No inertia (skating at high speed)
- Utility industry catching up… slowly
  - Working with a legacy system, practices, standards, regulatory framework…
  - Reliability, safety, cost-effectiveness
- Are there "limits" to the amount of load that can be served from Wind/Solar?





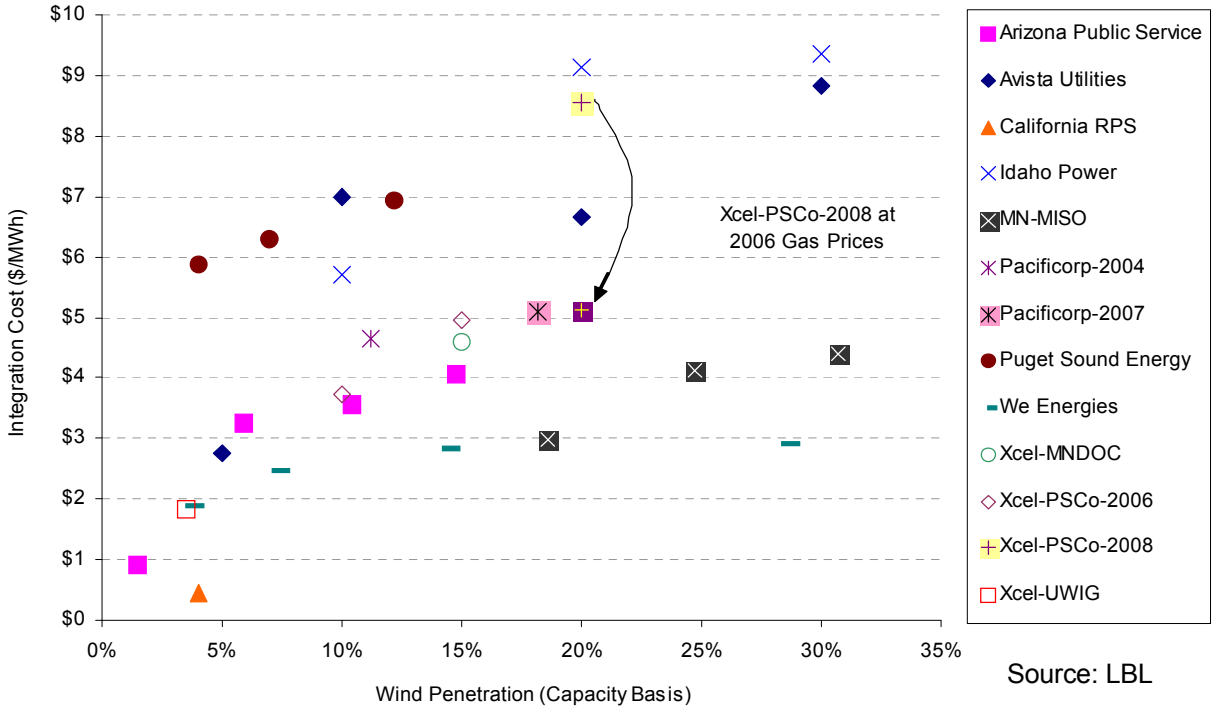
Are there limits?

- There are no absolute technical limits to wind/solar deployment
  - Adding flexibility and innovation can help
  - Forecasting, demand response, large-scale storage, demand response, smart grid…



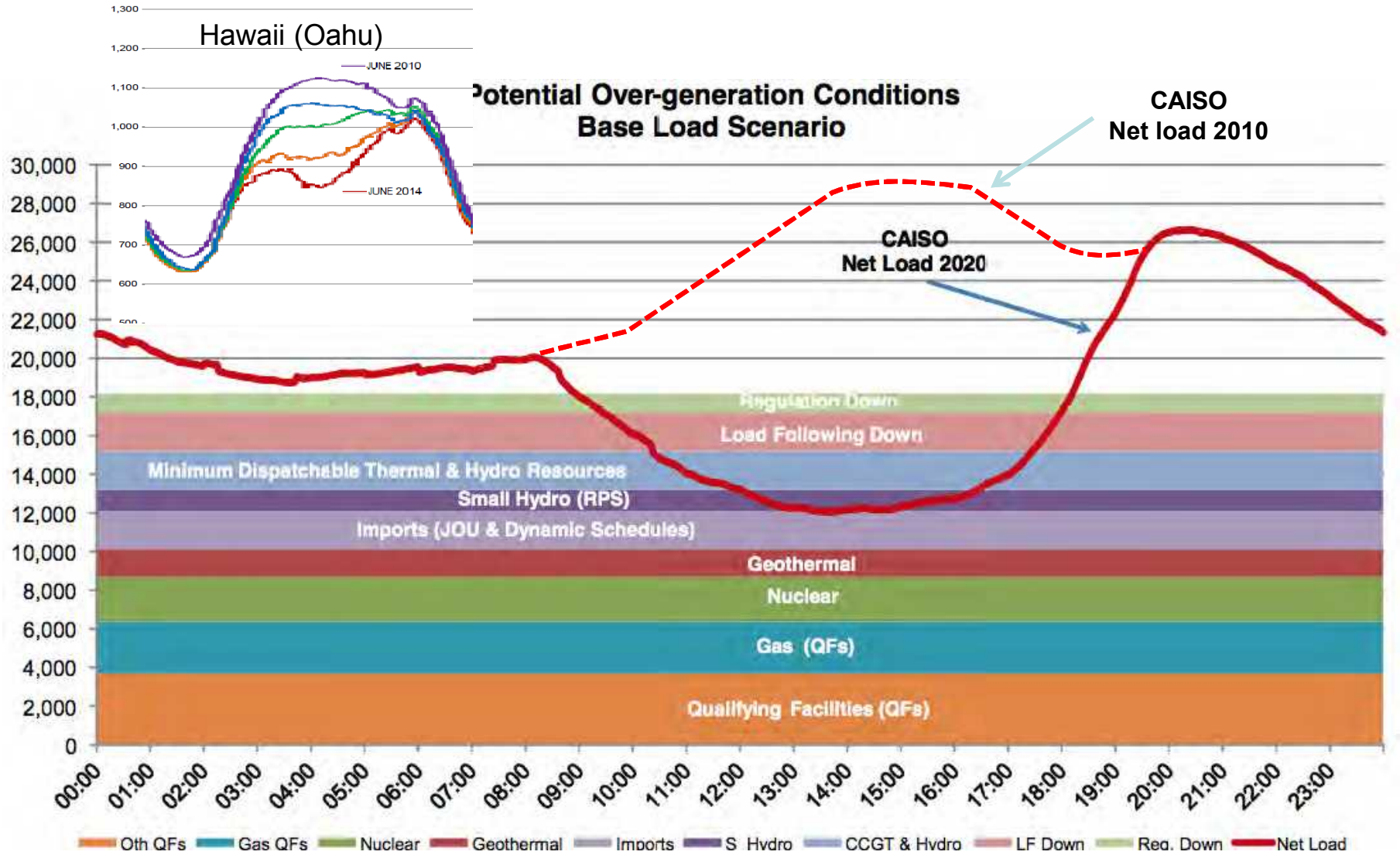
Studies: Integration Cost are Modest

- Increasing wind/solar levels correlates with higher operational cost
- Increase cost will be modest (<10% of retail electricity cost) at much higher deployment—without the need for technical breakthroughs!
  - There are other societal benefits to renewables…

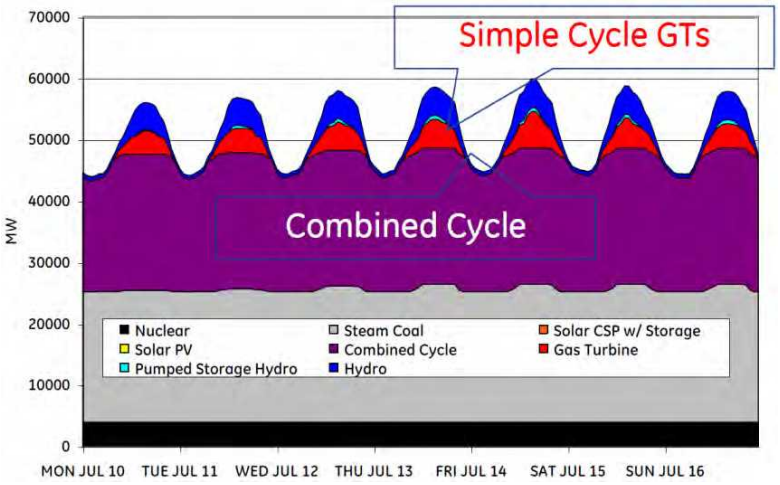


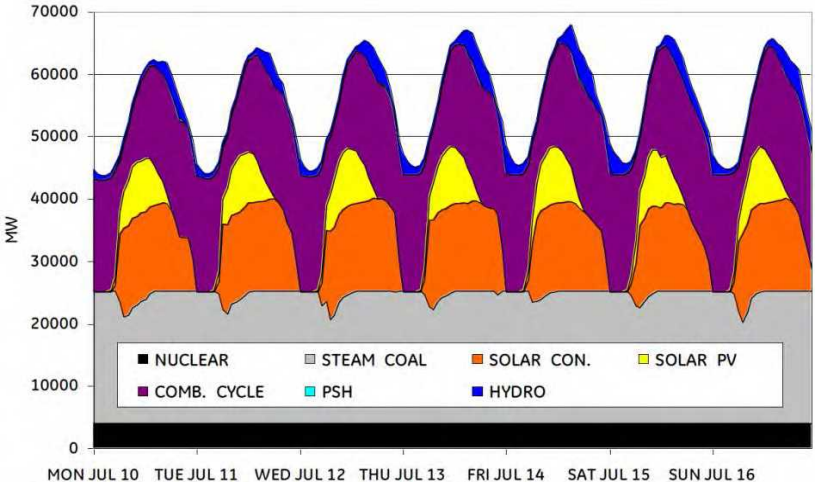
Source: LBL

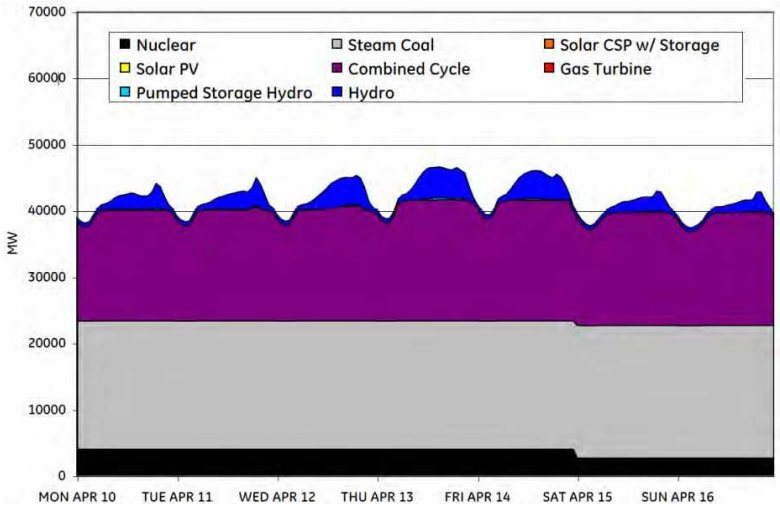
Serving load with lots of PV online

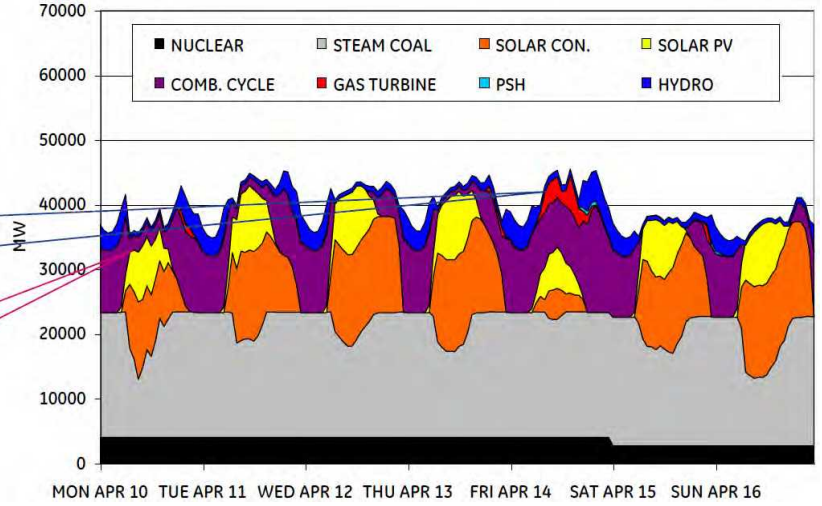


Serving load with lots of PV online





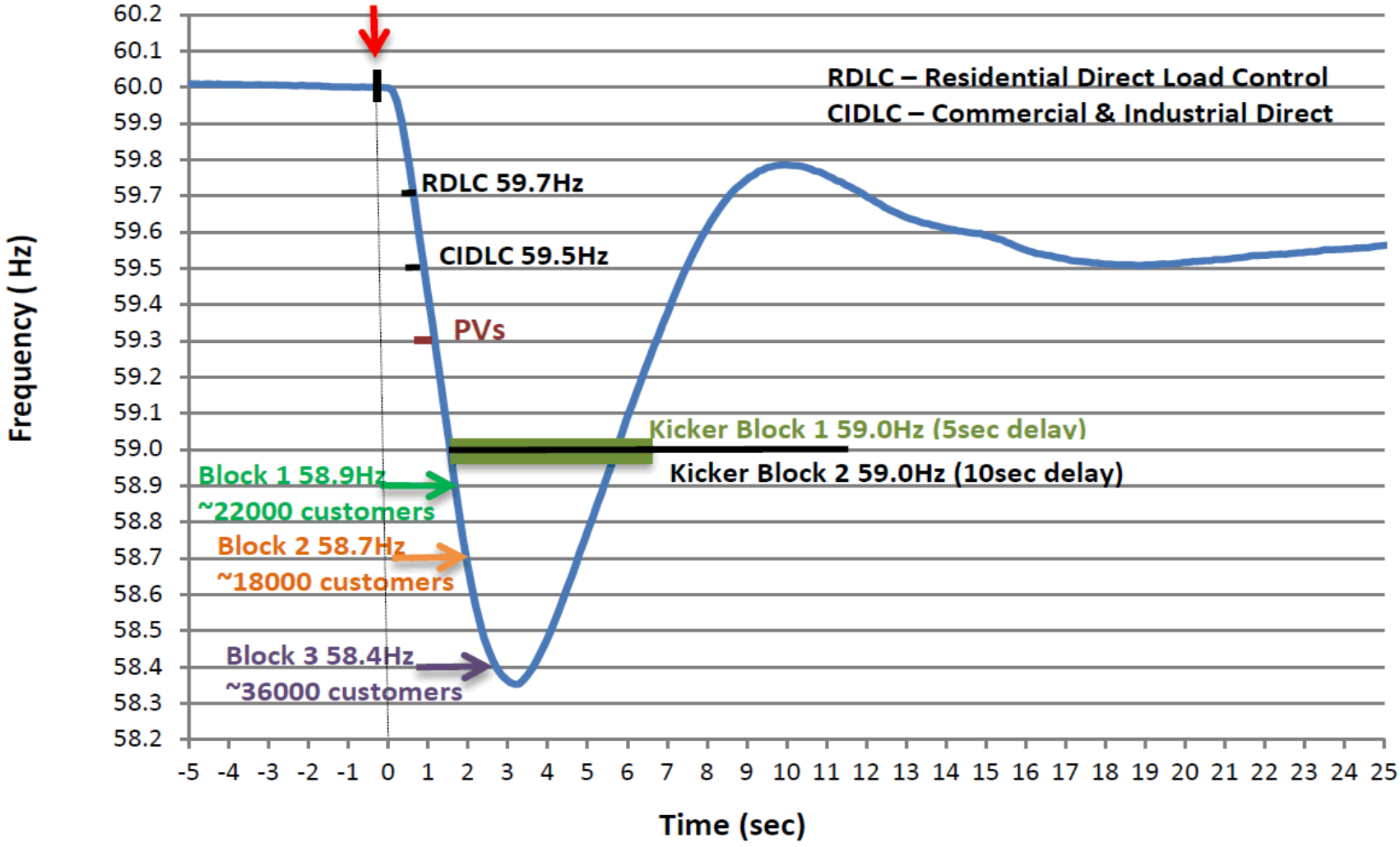




Frequency impacts

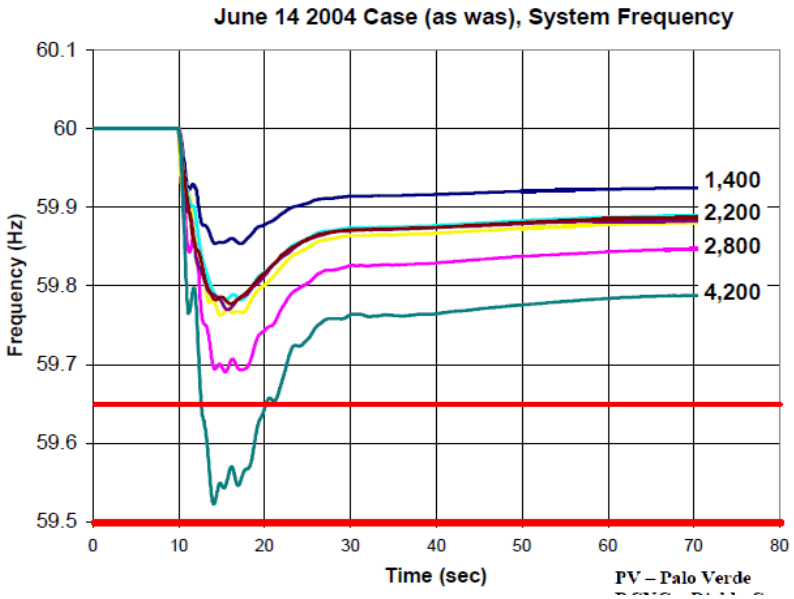
- System frequency changes when there are temporary generation-load imbalance events
  - Generation tripping events are common
- What keeps the system from going unstable after a generator trips?
  - Tolerance to frequency disturbances (keeps from cascading)
  - Inertia (arrests the rate of change)
  - Governor response (units have headroom to accelerate as needed)
  - AGC control (brings generation back to normal)
  - Load shedding (in case something goes horribly wrong)
- PV can make matters worse
  - Sub-par frequency tolerance (applies to distribution-connected PV)
  - No inertia (inverters). Also, PV displaces generators that have inertia
  - PV generators are typically operated at max power (no headroom to accelerate)

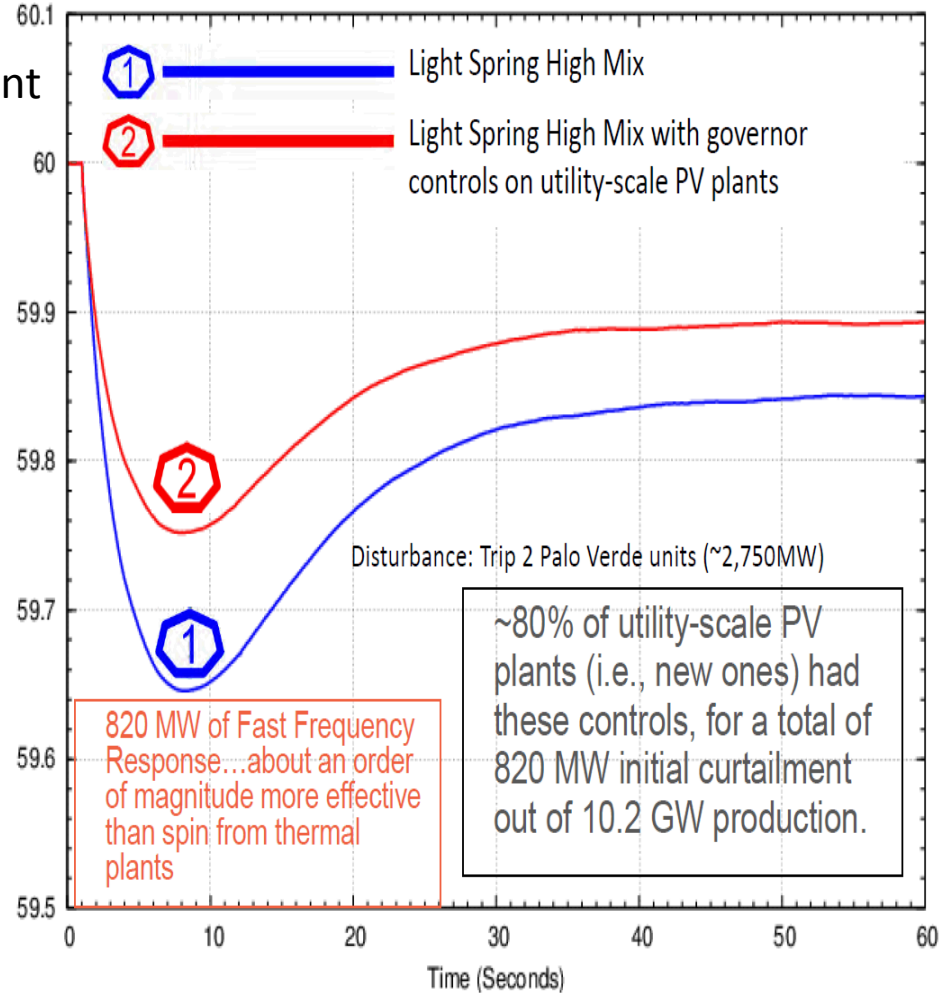
Frequency Impacts



Frequency Impacts

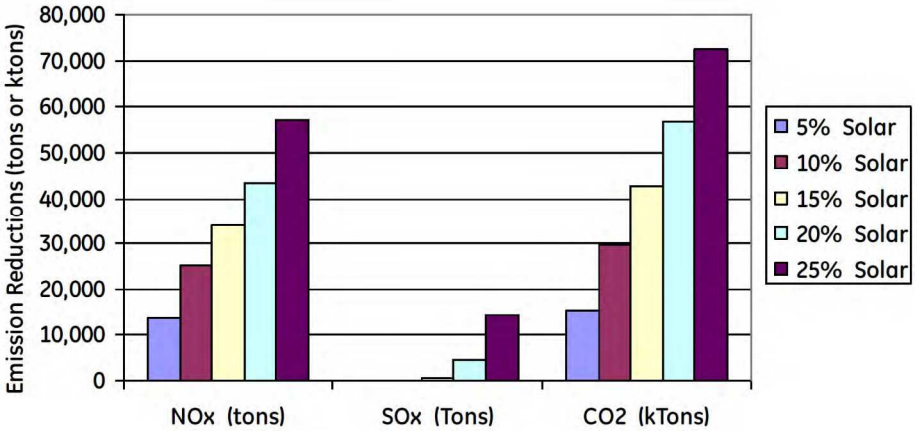
- Potential fixes:
  - Frequency ride-through requirement
  - Curtailment
  - Synthetic inertia
  - Energy storage

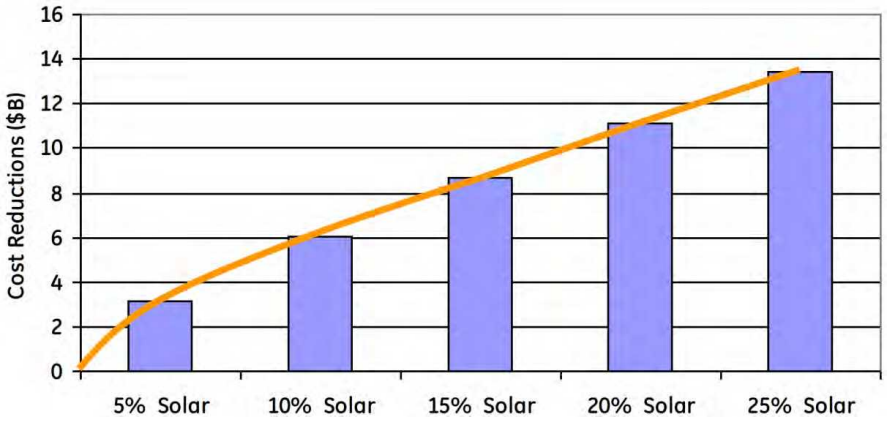




Does it make sense in the long run?

- Why are we doing this again?
  - Climate and Pollution
  - Lower cost (yes, that is right)





- OK. Need to find technical solutions!
  - Smarter grid management
  - Better technology (inverters)
  - Storage??

Thank You

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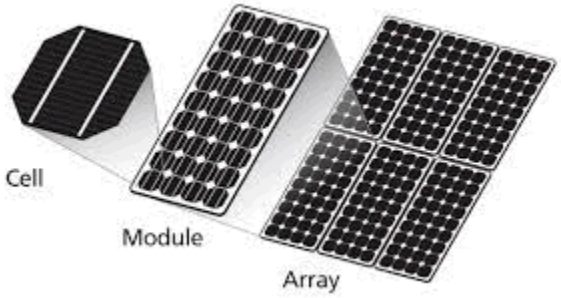
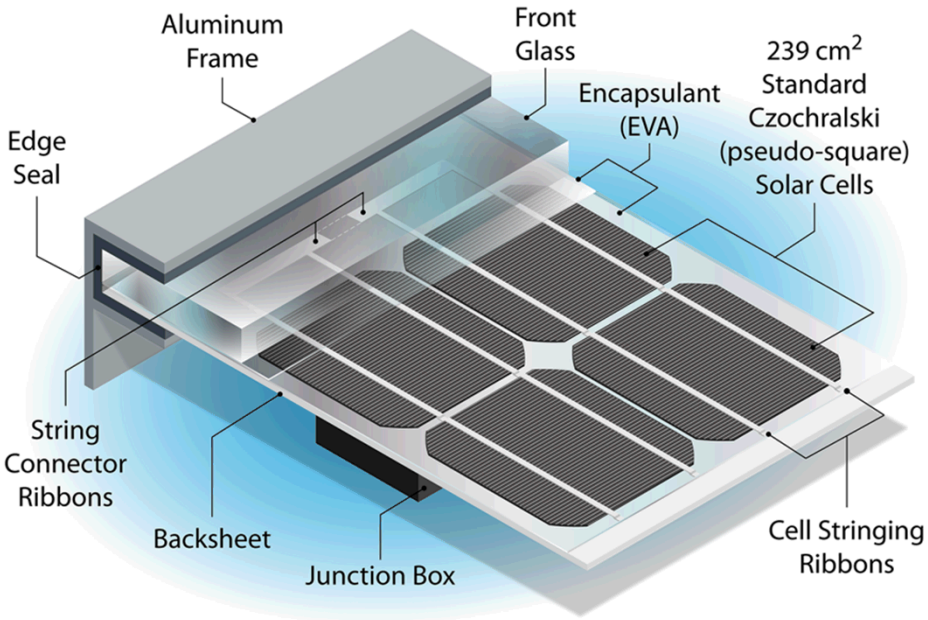
http://energy.sandia.gov/pv

PV cells, modules and systems





Major components of a PV plant

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