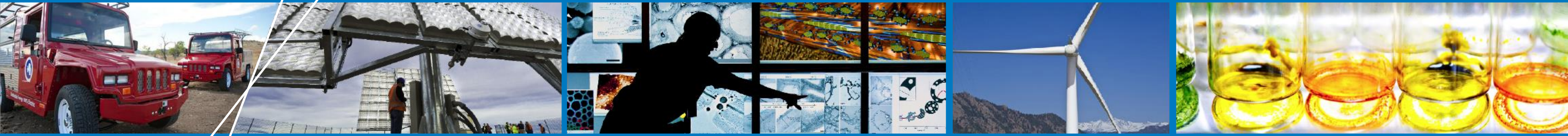
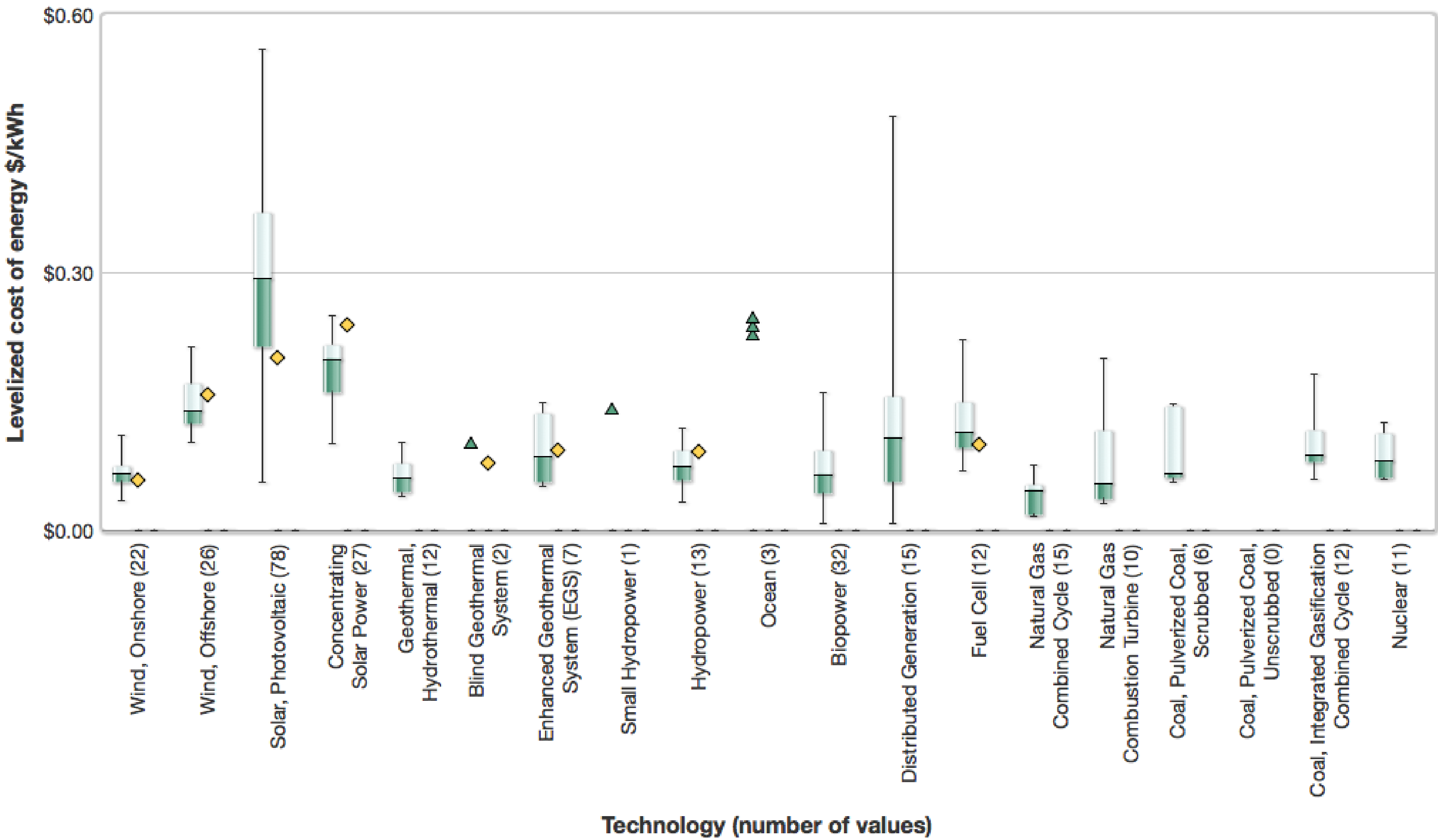
The Status of Clean Energy in the United States



Tribal Energy Program Review
May 6, 2015

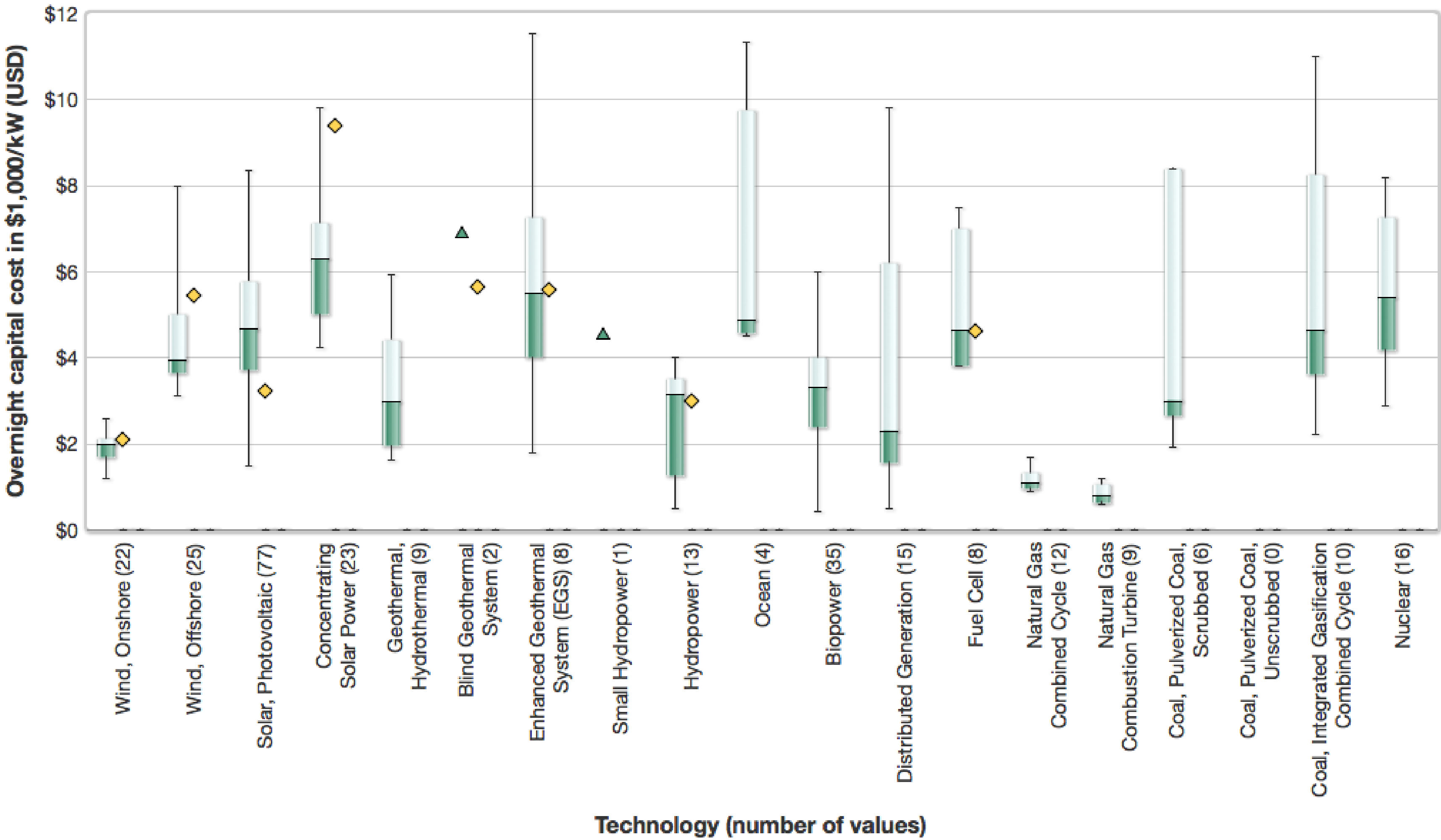
Travis Lowder, NREL

Lazard's Levelized Cost of Energy (LCOE) Estimates



Source: Lazard 2013

Lazard's Capital Cost Estimates



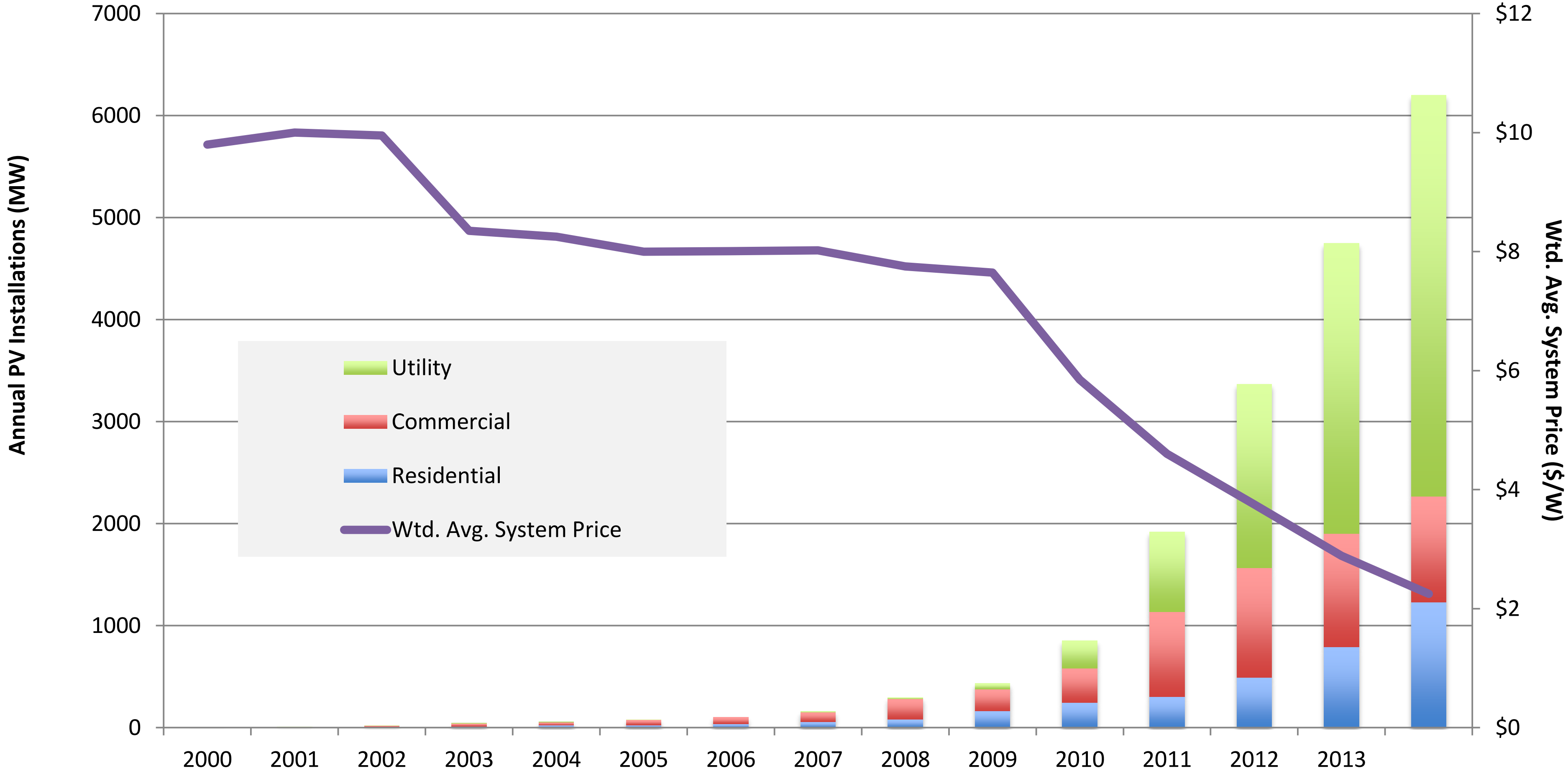
Source: Lazard 2013

EIA Estimates (2012 data)

Plant type	Capacity factor (%)	Levelized capital cost	Fixed O&M	Variable O&M (including fuel)	Transmission investment	Total system LCOE	Subsidy[1]	Total LCOE including Subsidy
Dispatchable Technologies								
Conventional Coal	85	60.0	4.2	30.3	1.2	95.6		
Integrated Coal-Gasification Combined Cycle (IGCC)	85	76.1	6.9	31.7	1.2	115.9		
IGCC with CCS	85	97.8	9.8	38.6	1.2	147.4		
Natural Gas-fired								
Conventional Combined Cycle	87	14.3	1.7	49.1	1.2	66.3		
Advanced Combined Cycle	87	15.7	2.0	45.5	1.2	64.4		
Advanced CC with CCS	87	30.3	4.2	55.6	1.2	91.3		
Conventional Combustion Turbine	30	40.2	2.8	82.0	3.4	128.4		
Advanced Combustion Turbine	30	27.3	2.7	70.3	3.4	103.8		
Advanced Nuclear	90	71.4	11.8	11.8	1.1	96.1	-10.0	86.1
Geothermal	92	34.2	12.2	0.0	1.4	47.9	-3.4	44.5
Biomass	83	47.4	14.5	39.5	1.2	102.6		
Non-Dispatchable Technologies								
Wind	35	64.1	13.0	0.0	3.2	80.3		
Wind-Offshore	37	175.4	22.8	0.0	5.8	204.1		
Solar PV[2]	25	114.5	11.4	0.0	4.1	130.0	-11.5	118.6
Solar Thermal	20	195.0	42.1	0.0	6.0	243.1	-19.5	223.6
Hydro[3]	53	72.0	4.1	6.4	2.0	84.5		

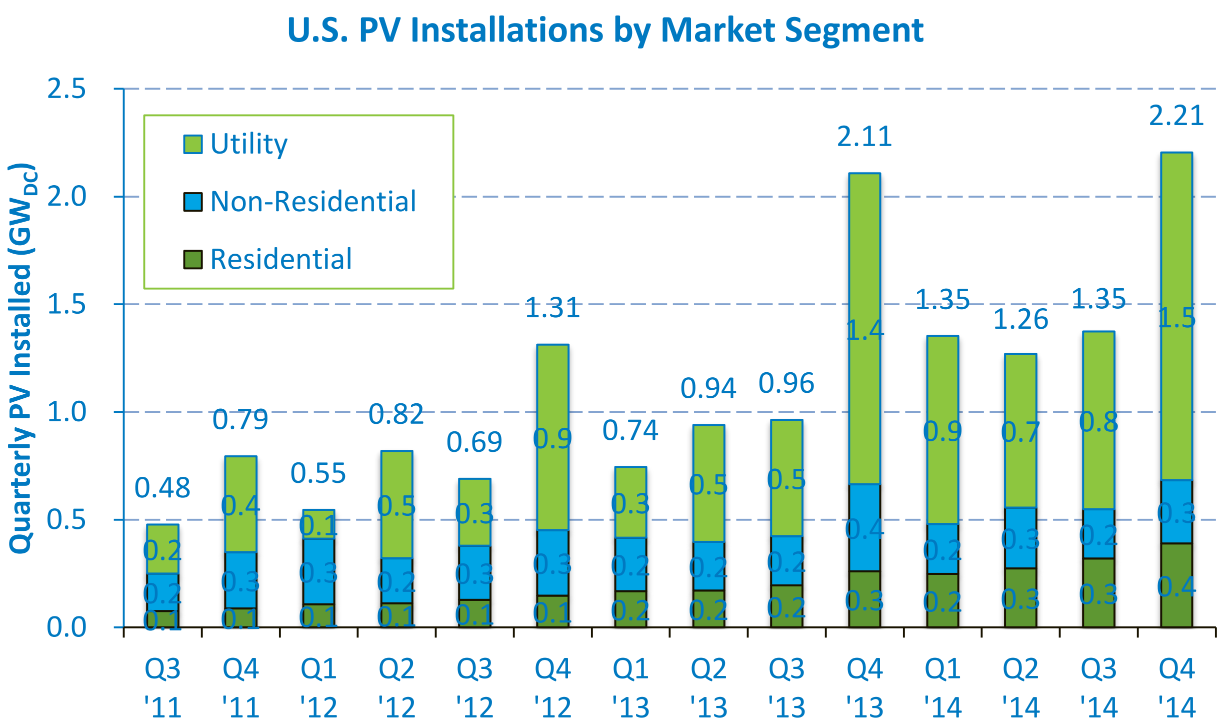
Solar PV

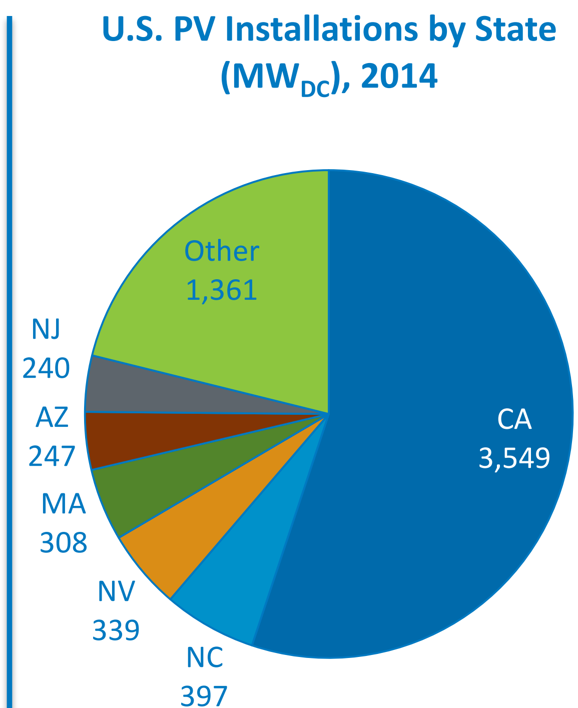
Solar PV Installed Capacity and Weighted Average System Cost



Source: GTM/SEIA 2015

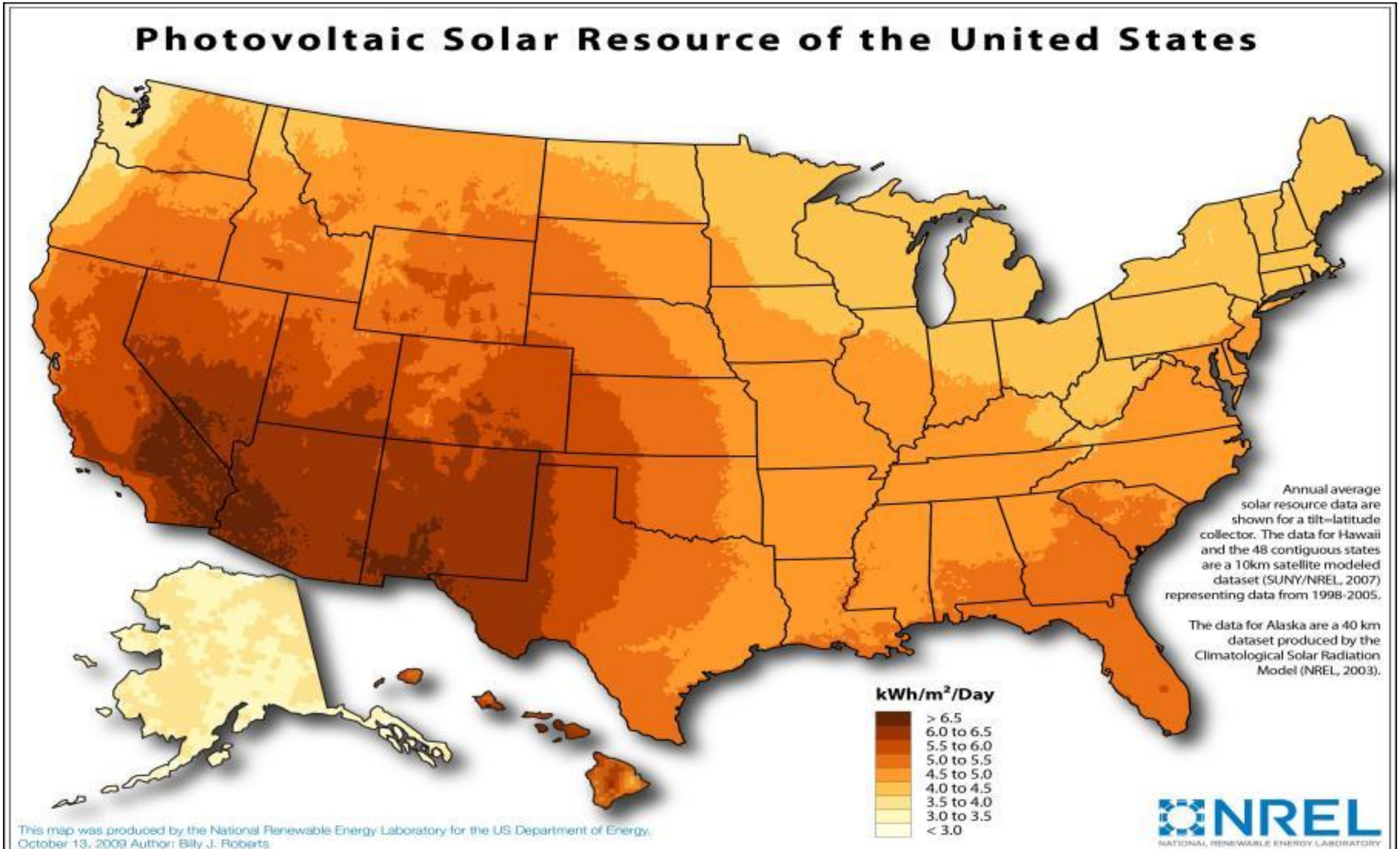
U.S. Installation Breakdown



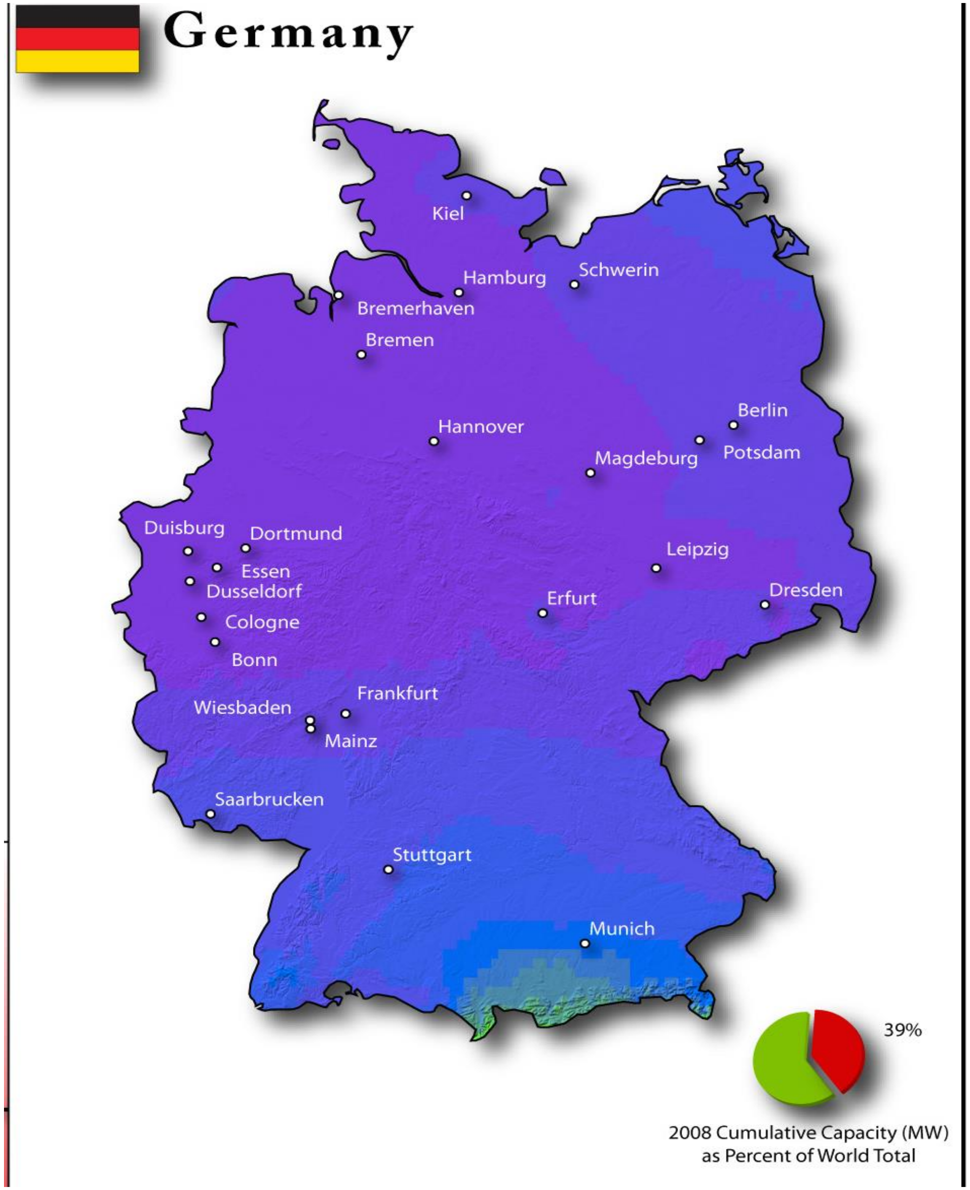


- U.S. Installed 6.2 GW of PV in 2014 (4.8 GW in ‘13)
- Cumulative PV 18.3 GW (20 GW including CSP)

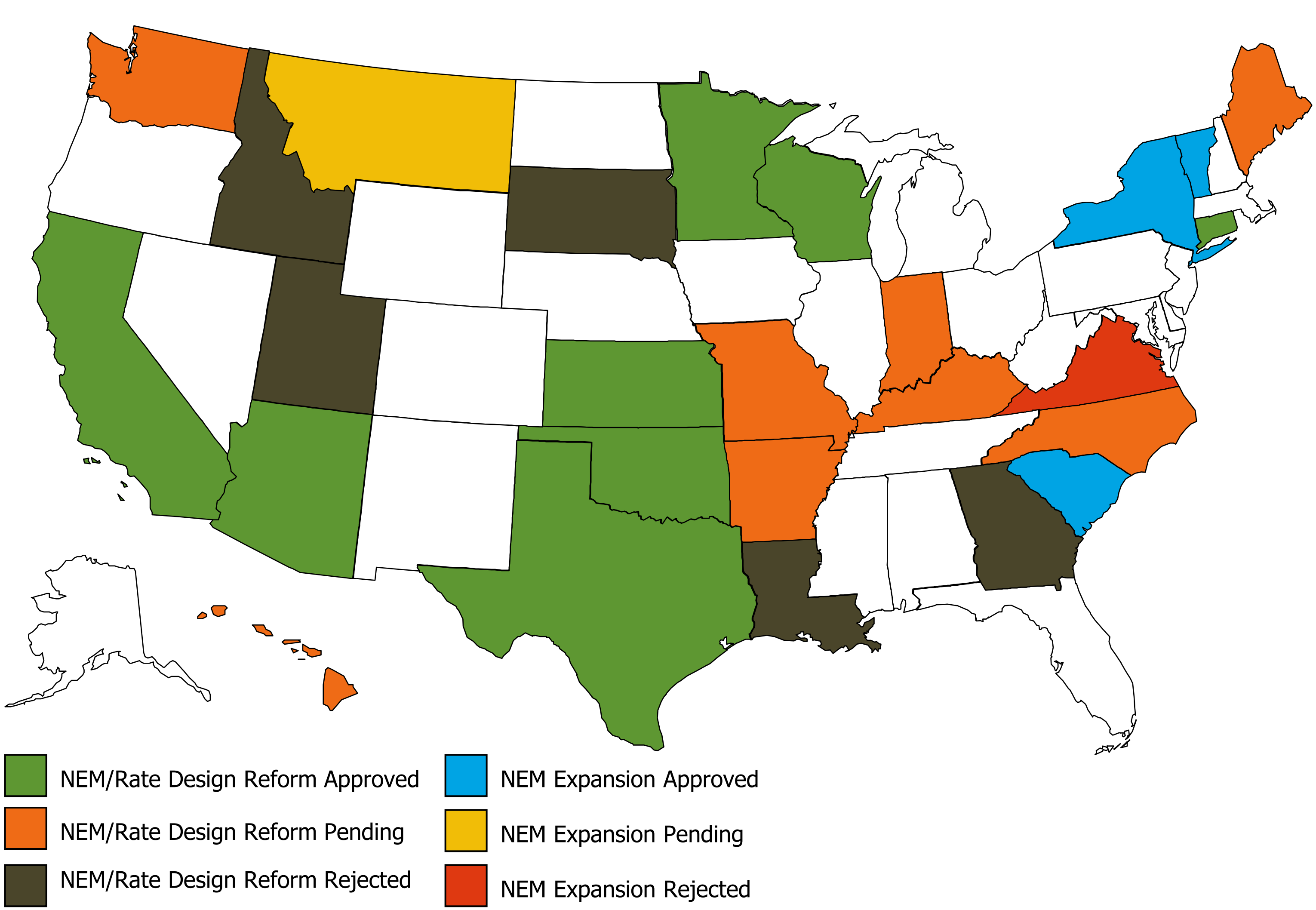
U.S. Solar PV Resource



World Leader in Installed PV

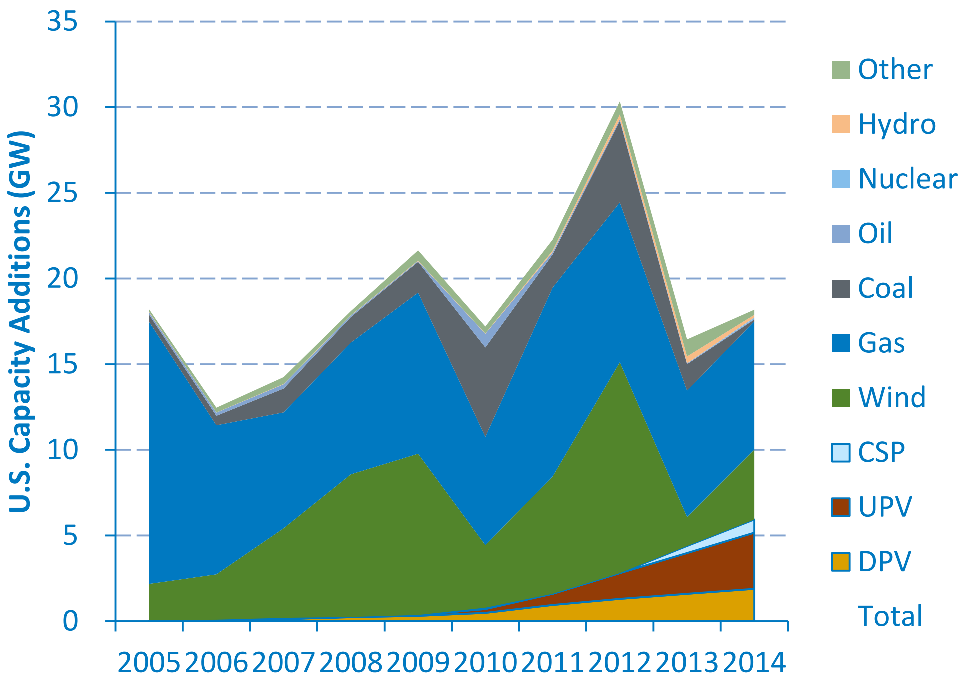


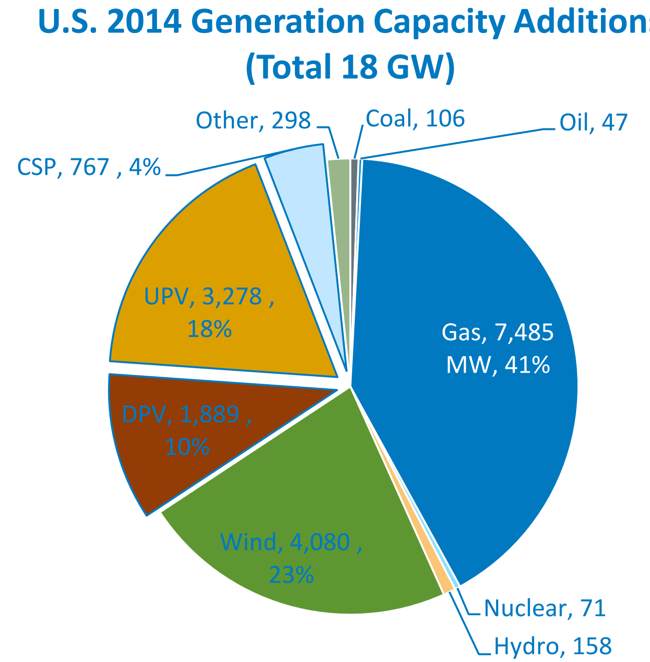
Recent Legislative Action for Net-Metering / Rate Design Effecting PV



Source: SEIA/GTM "U.S. Solar Market Insight: 2014 Year-in-Review."

U.S. Generation Capacity Additions by Source

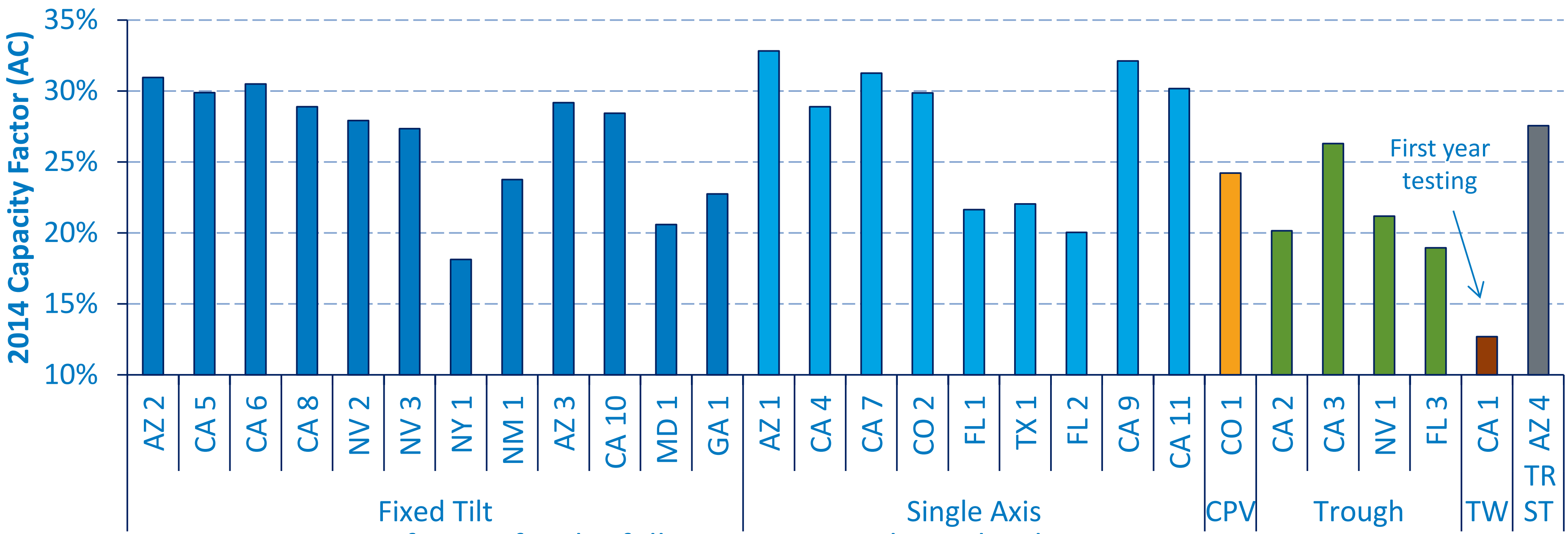




- U.S. has installed ~19 GW of new capacity per year in past decade
  - Natural gas and wind have been largest contributors but solar is becoming a significant portion of new generation
  - Would take 50-60 years to change entire U.S. fleet
- In 2014, solar was responsible for approximately 1/3 of all new generation capacity in the U.S.
  - Wind and solar combined for 55% of new generation

Sources: 2004-2010 (except solar): EIA.U.S installed capacity, Form 860. 2011-2013: FERC: "Office of Energy Projects Energy Infrastructure Update for December 2012/2013/2014." Solar, GTM/SEIA, U.S. Solar Market Insight Q4 2014.
Note: PV converted to AC using .8333 derate factor.

Capacity Factor of Solar Projects



- Average capacity factors for the following projects by technology:
  - Single Axis PV: 30%
  - Fixed Tilt PV: 29%
  - CSP Trough: 22%
  - CSP Tower: 13% (Ivanpah)
  - CSP Trough + Storage: 28% (Solana)
  - CPV: 24% (Alamosa)
- PV systems in southwestern states have significantly higher capacity factors
  - PV systems on East Coast: 21%; others 30%

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Source: EIA Form 923

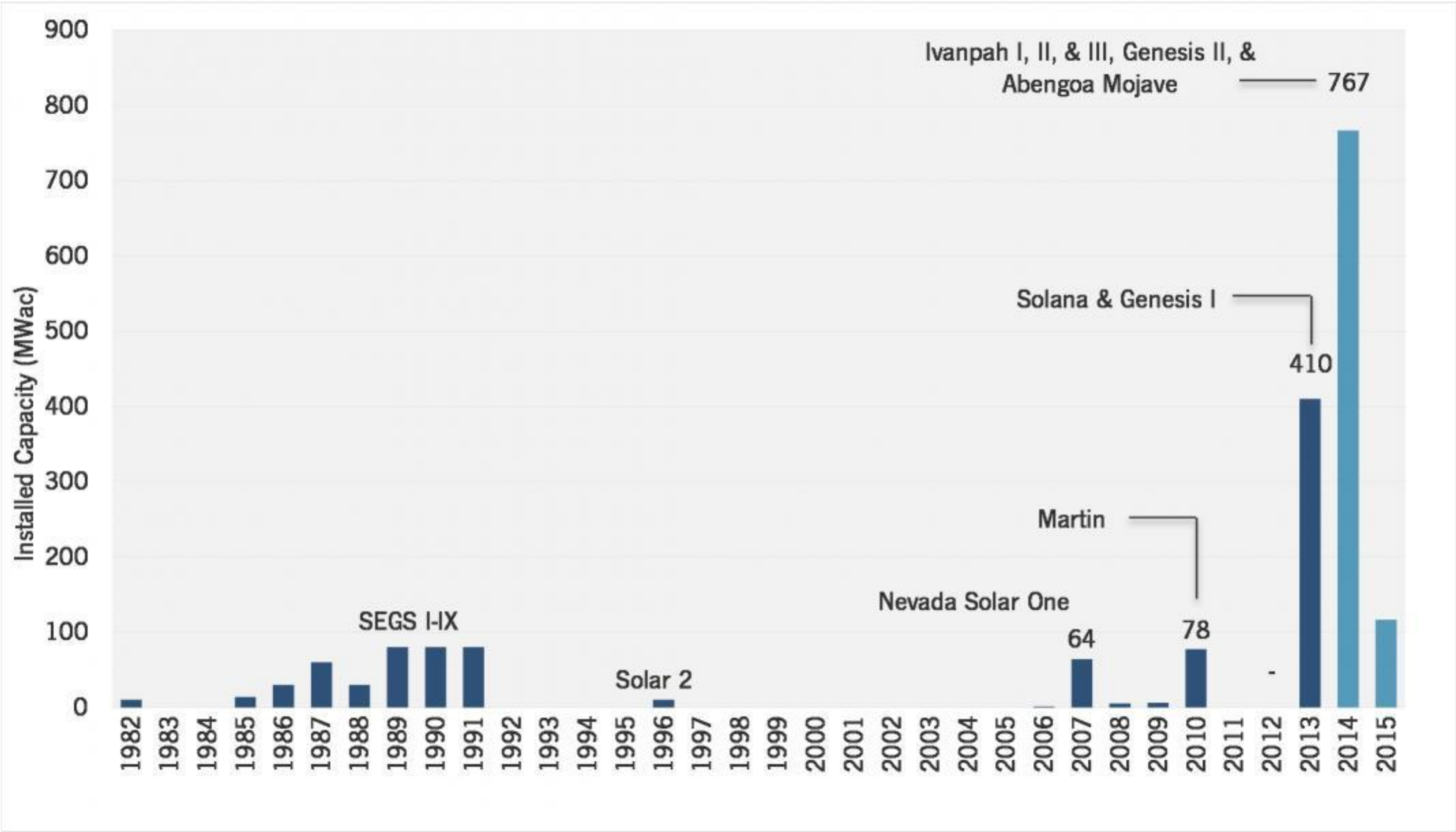
Solar CSP

Technologies

Tower

Parabolic Trough

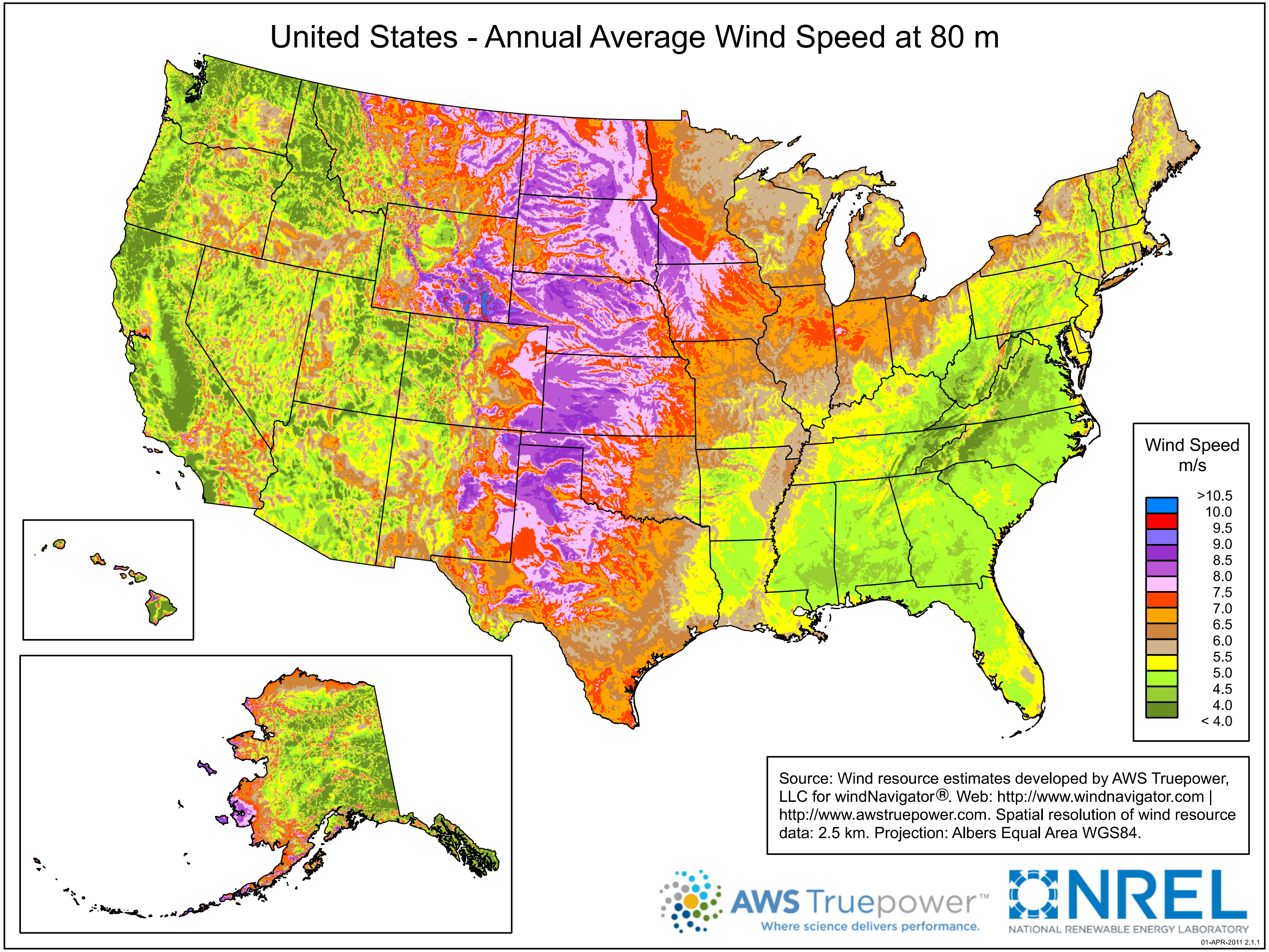
CSP Installations



Source: GTM/SEIA 2015

Wind

U.S. Wind Resource



Wind Market Update

- **5.1GW of annual installations in 2014**
- **65.9 GW of cumulative installations at beginning of 2015**

Top Five States with Wind Power Capacity Additions during the Fourth Quarter 2014

State	Capacity, MW
Texas	1,122
Oklahoma	648
Iowa	511
Washington	267
Colorado	261

Best Uses for Technology (size, installed cost)

On-Site Power ($6-$12/W)

- **Remote (<10 kW)**
  - Water pumping, electrification
    - Water pump = 1 kW, House = 5 kW, Farm = 10 kW

Grid Connected ($3.50 -$7/W)

- **Small (1 kW – 50 kW)**
  - Residence, business, farm/ranch
- **Mid-Size (100 kW – 1 megawatt [MW])**
  - Facility, community, industrial
    - Convenience store = 50 kW, school = 250 kW

Energy for Sale ($2-$3.50/W)

- **Utility (>1MW)**
  - Wind farm

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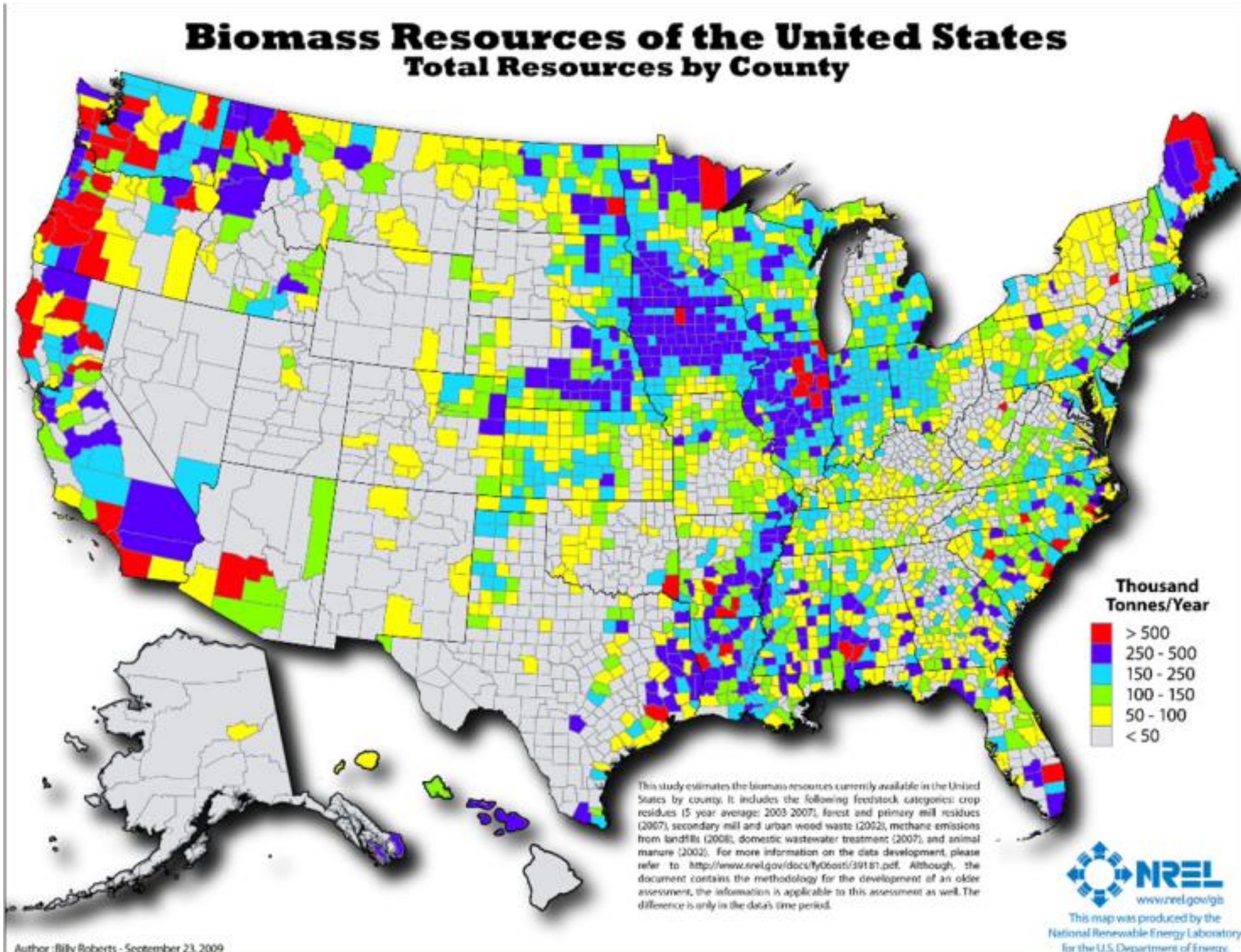
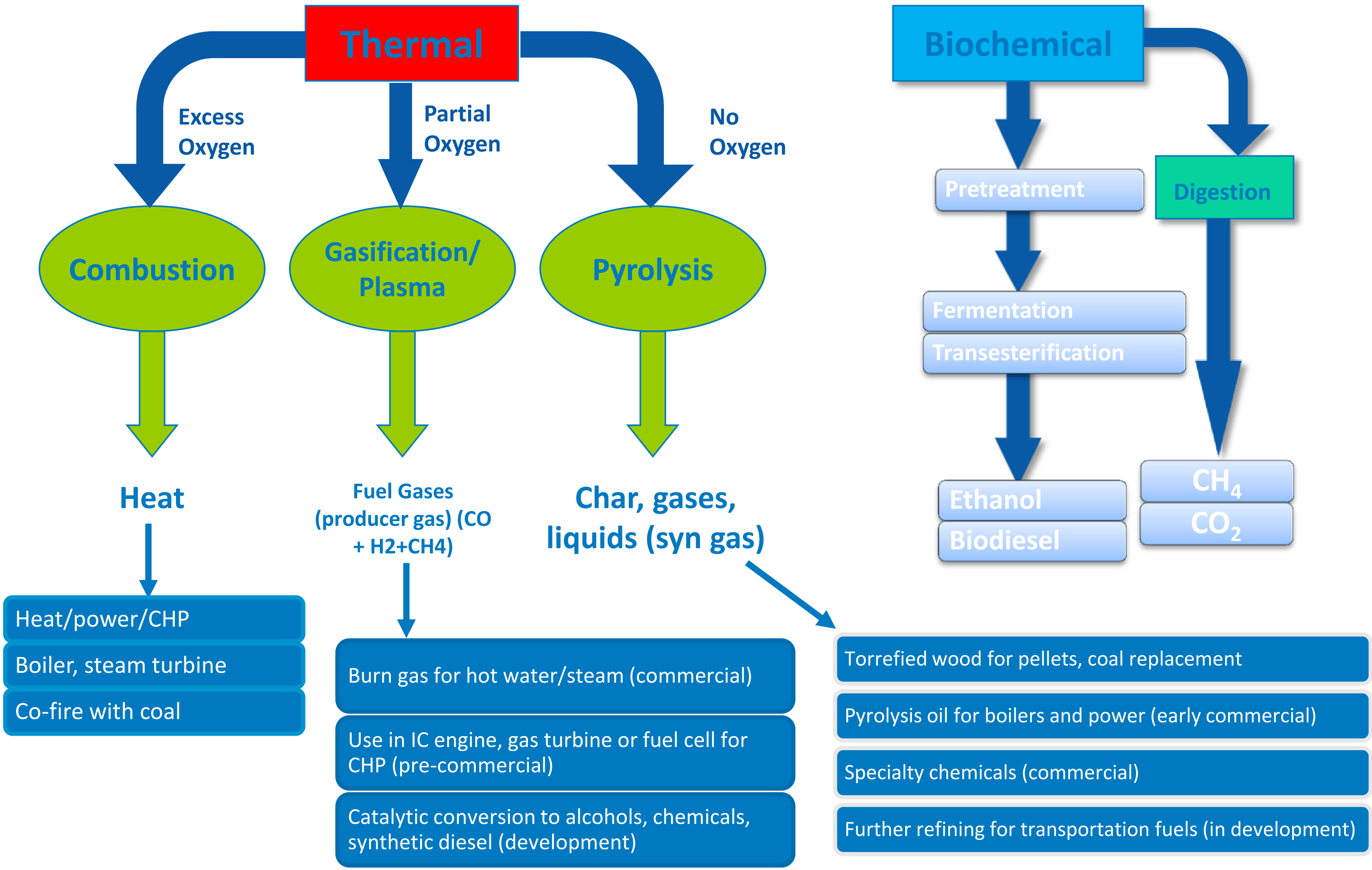
Biomass

Biomass Resources



Bioenergy Pathways



Biomass Costs - Electric

- **Installed costs $1,900 - $5,500/kilowatt (kW)**
- **Larger systems (>5 megawatt [MW]) have better economics**
- **LCOE = $0.08 - $0.20/kilowatt-hour (kWh)**
- **A typical biopower scale for a tribal or community application would probably be about 10-MW, and cost ~$40 M**
- **LCOE could be $0.10 - 0.12/kWh**
    - this strongly depends on feedstock cost

Biomass Costs - Thermal

- **Heating plants: average $350,000 per MMBtu/hr (*), with smaller plants having a higher cost intensity than larger ones**
- **Operation and maintenance costs include:**
  - Fuel
  - Labor (2-5 hours per week, including fuel ordering and a daily walk-through)
  - Repair and replacement of mechanical parts
  - Ash disposal

(*) MMBtu is one million British thermal units

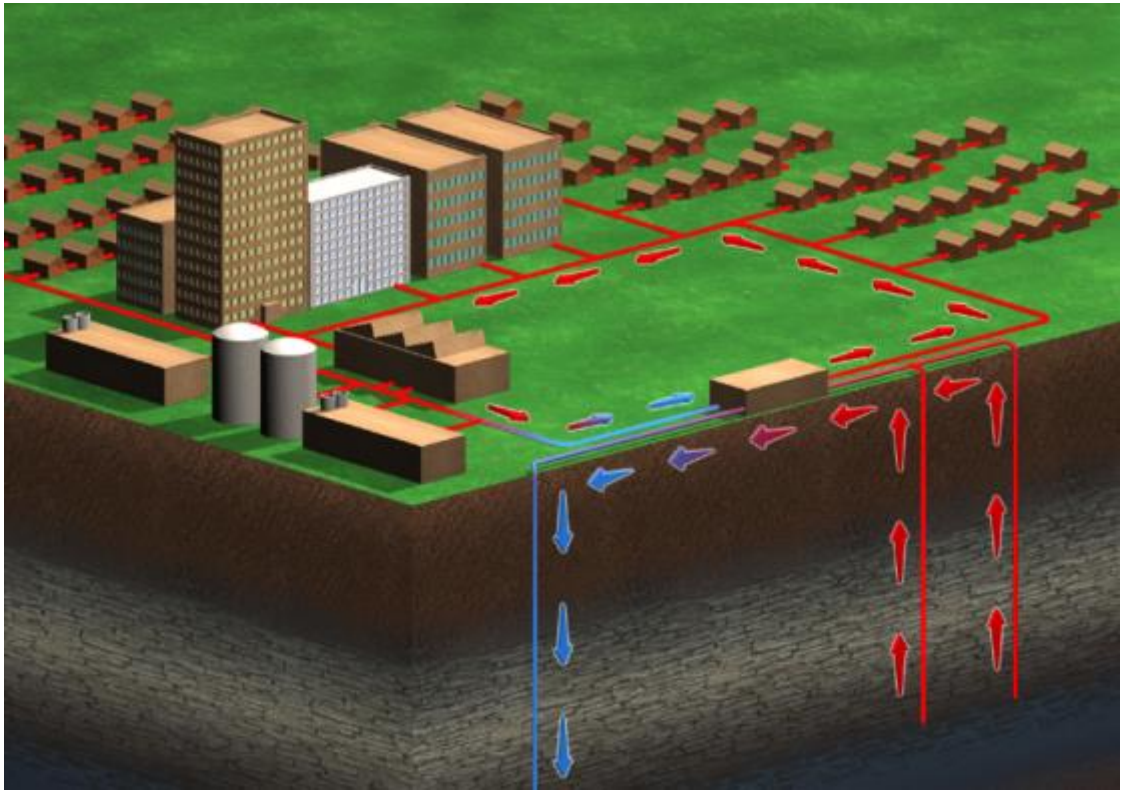
Biomass Performance Characteristics

- **Typical biomass boiler operating on fuel with a moisture content of 40% has a net efficiency of about 60-65%.**

- **Efficiency influenced by:**
  - Moisture content of the biomass
  - Combustion air distribution and amounts (excess air)
  - Operating temperature and pressure
  - Flue gas (exhaust) temperature

Geothermal (non-electric)

Community Scale



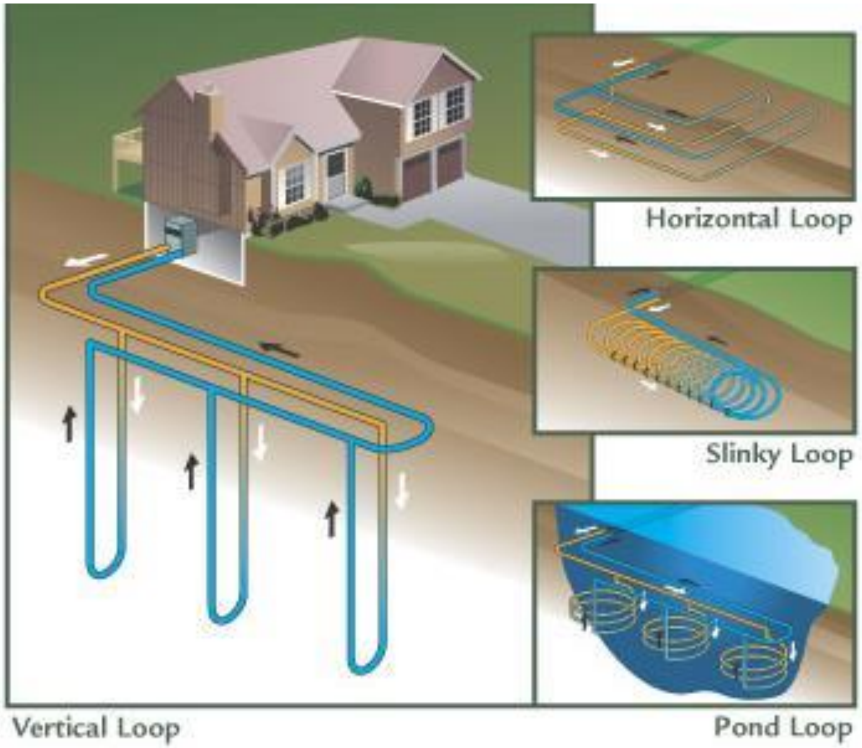
Direct Use

Uses low-temperature resources:

- **District Heating**
- **Process Heat**
- **Agriculture**
- **Aquaculture**

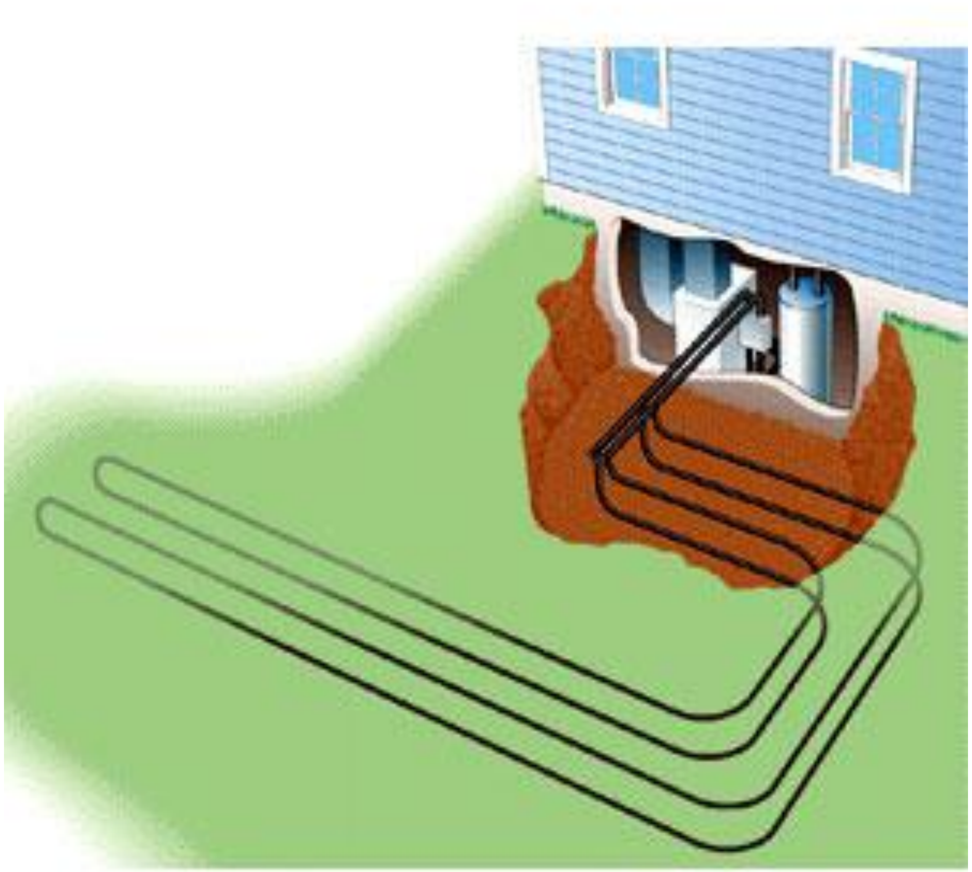
Residential Geothermal Heat Pumps

- Highly efficient method of providing ***<u>heating and cooling</u>***
- Work by using ground temperature as a renewable resource for pumping heat in winter and rejecting heat in summer
- Cost effective
- Economic and environmental benefits



Hot Water Facility-Scale Geothermal

- Can provide all or part of a facility's hot water
- An auxiliary heat exchanger uses waste heat from the geothermal compressor (superheated gases) to heat water
- Uses excess heat that would otherwise be expelled to the loop



Cost of Geothermal

- **Residential (single family)**
  - New Construction $15,000 to $20,000 for heating and cooling
  - Remodel $15,000 to $30,000 for heating and cooling
- **Community**
  - 107,000 ft_2 Middle School (600 students) GSHP built in 2011 $1.3 million
  - Community College: $860,000 GSHP
  - Geothermal Power Plant in Nevada: $4.4 million
- **Note that hybrid systems (coupled with a cooling tower or boiler) can make geothermal more cost effective**

Thank you!

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