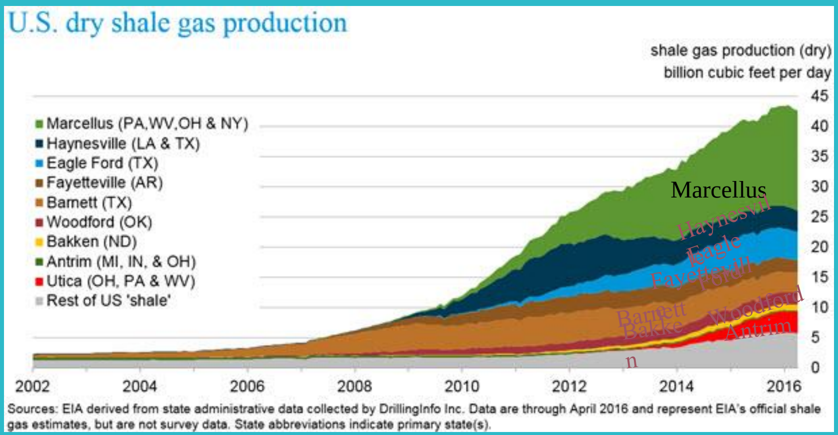
"Energy Systems"
A Critical National Infrastructure
Slide Deck #2

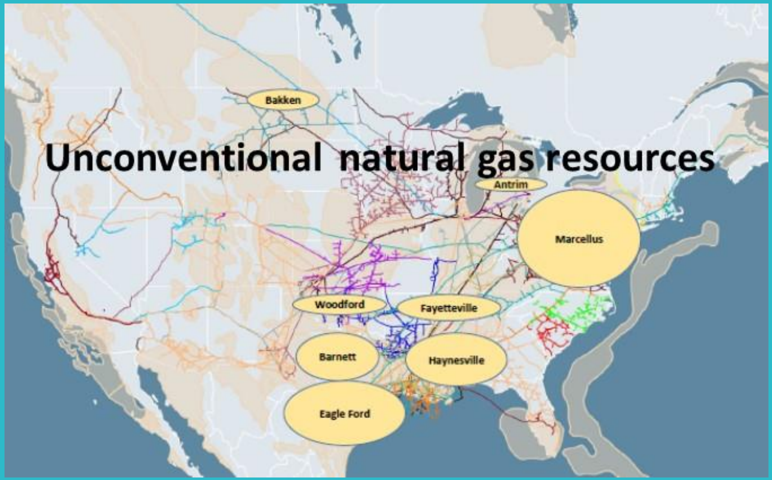
James D. McCalley
Professor of Electrical and Computer Engineering
Iowa State University Ames, IA

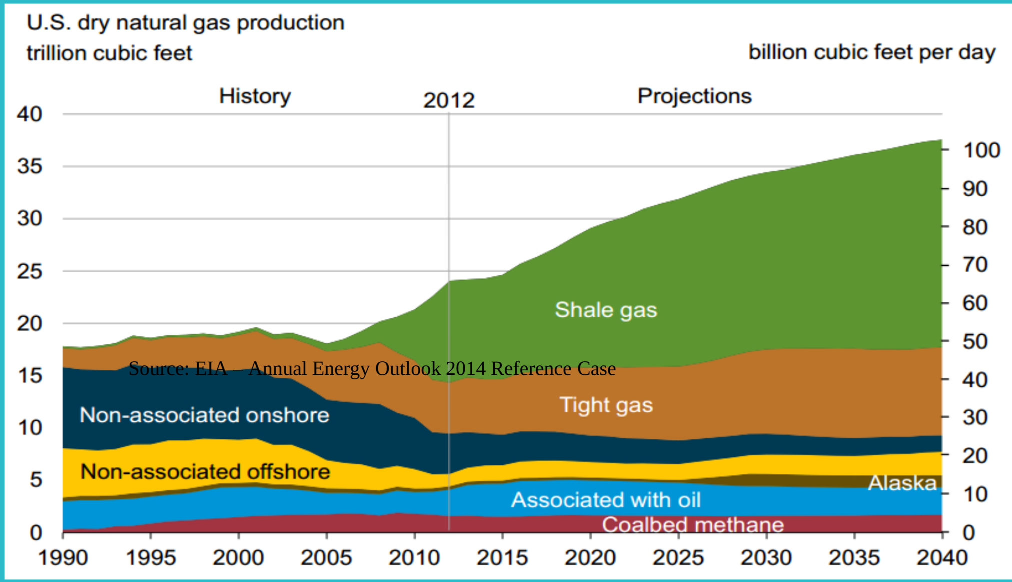
The Future of Energy

- Shale gas growth
- Big picture!
- Renewables
- Distributed generation
- Costs

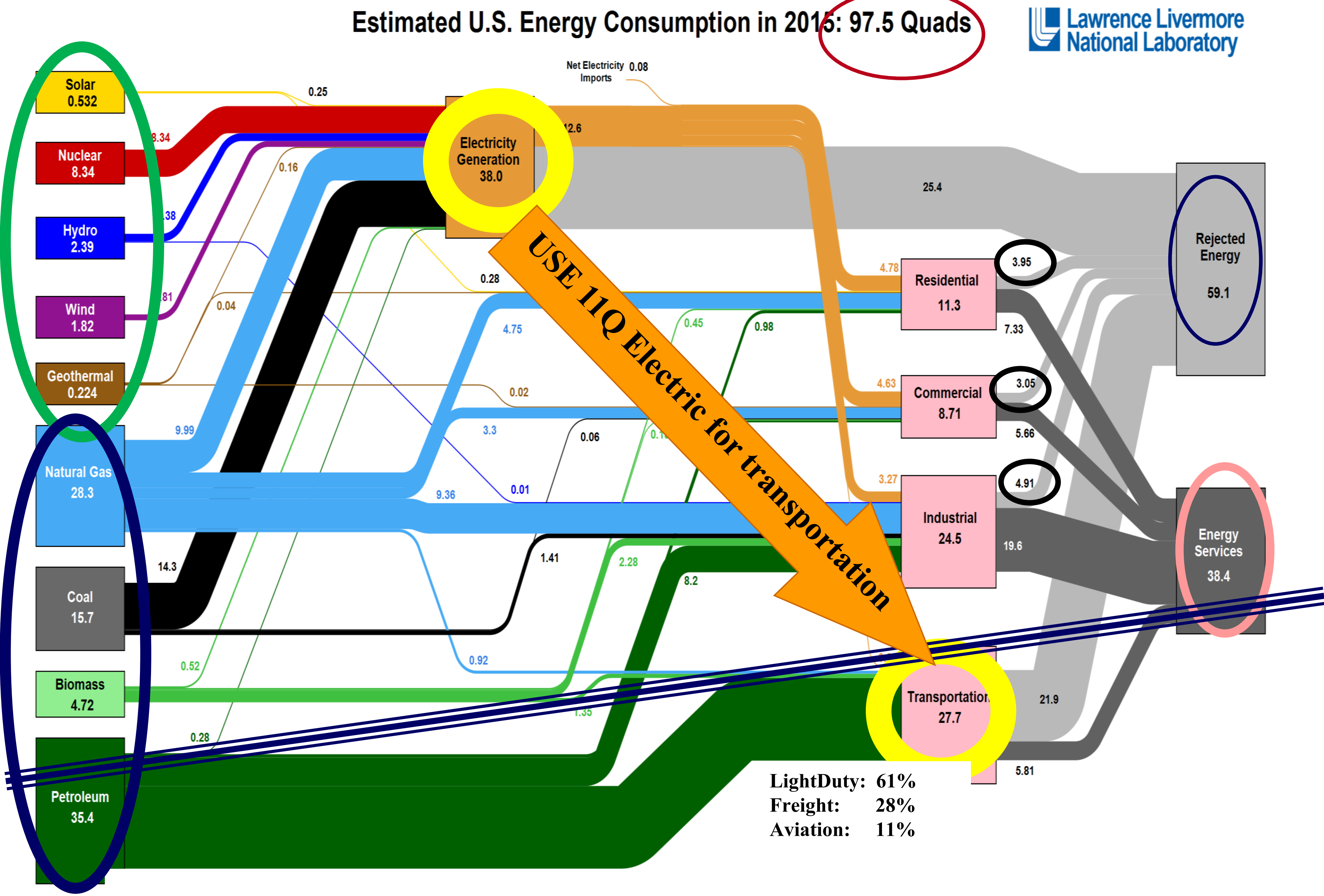
Shale gas growth







3

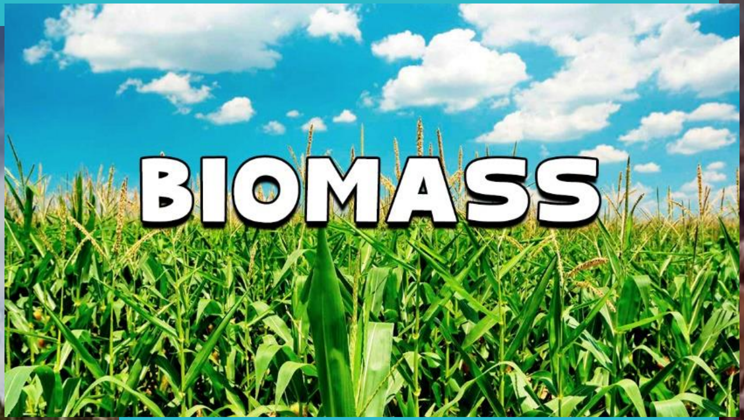


US Energy View: 2015

https://flowcharts.llnl.gov/index.html

Renewable Energy

Geothermal



Where are US wind turbines today?

Source: US DOE, **2015 Wind technologies market report,**
https://energy.gov/sites/prod/files/2016/08/f33/2015-Wind-Technologies-Market-Report-08162016.pdf

- 15 of top 20 are in the interior of the nation.
- Top 3 coastal states are West.
- East coast is light on wind but heavy on load.
- Implication?

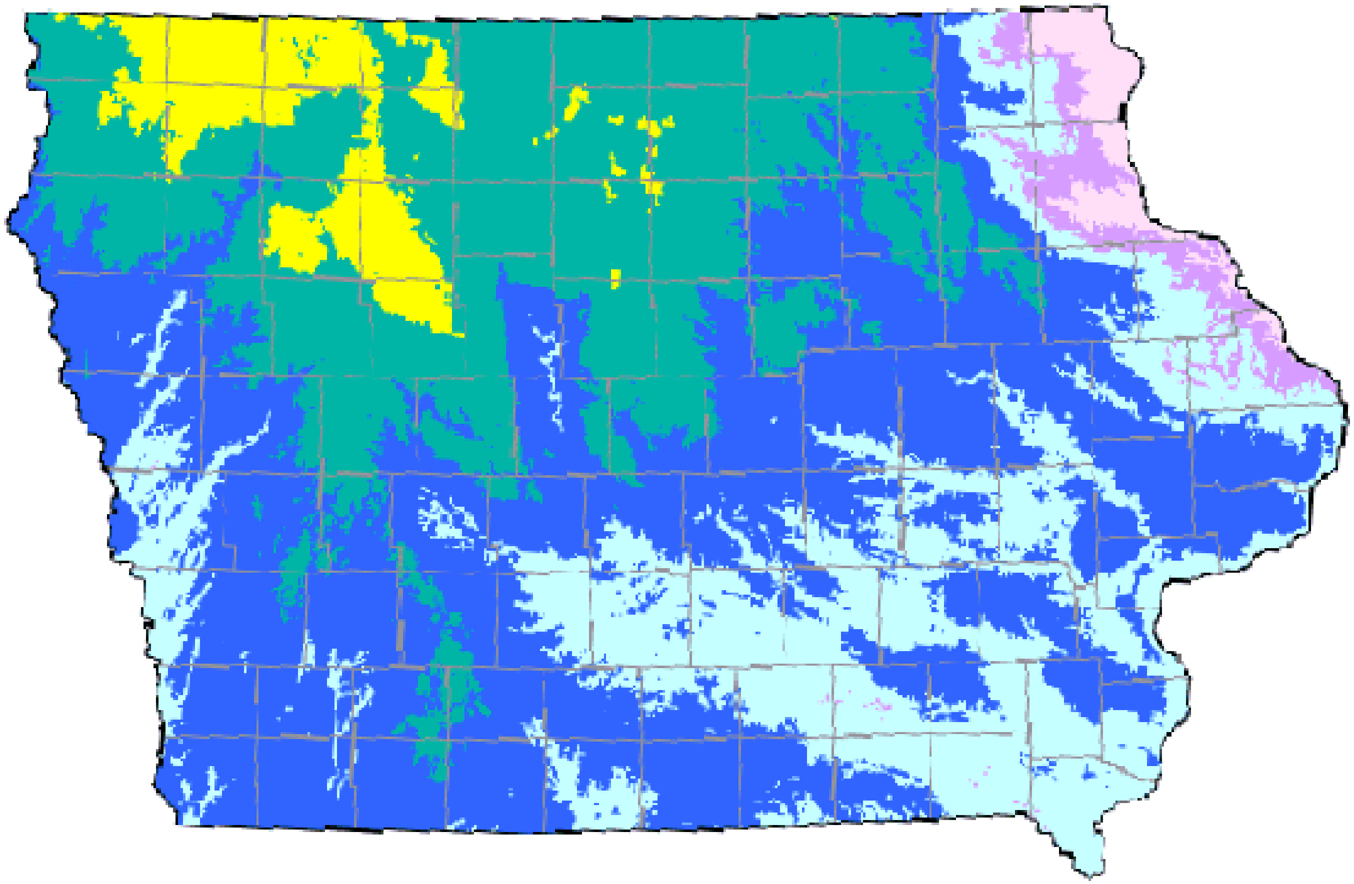
➔3 options for East coast use of wind:
Build high cost inland wind,
go offshore, or
use transmission to move it from Midwest

Installed Capacity (MW)				Percentage of In-State Generation	
Annual (2015)		Cumulative (end of 2015)		Actual (2015)*	
Texas	3,615	Texas	17,711	Iowa	31.3%
Oklahoma	1,402	Iowa	6,209	South Dakota	25.5%
Kansas	799	California	5,662	Kansas	23.9%
Iowa	524	Oklahoma	5,184	Oklahoma	18.4%
Colorado	399	Illinois	3,842	North Dakota	17.7%
Illinois	274	Kansas	3,764	Minnesota	17.0%
New Mexico	268	Minnesota	3,235	Idaho	16.2%
North Dakota	258	Oregon	3,153	Vermont	15.4%
Minnesota	200	Washington	3,075	Colorado	14.2%
California	194	Colorado	2,965	Oregon	11.3%
South Dakota	175	North Dakota	2,143	Maine	10.5%
Maine	173	Indiana	1,895	Texas	10.0%
Indiana	150	New York	1,749	Nebraska	8.0%
Nebraska	80	Michigan	1,531	Wyoming	7.7%
Arizona	30	Wyoming	1,410	Montana	6.6%
Maryland	30	Pennsylvania	1,340	Washington	6.5%
New Hampshire	14	New Mexico	1,080	New Mexico	6.3%
Ohio	8	South Dakota	977	California	6.2%
Connecticut	5	Idaho	973	Hawaii	6.1%
New York	1	Nebraska	890	Illinois	5.5%
Rest of U.S.	0	*Rest of U.S.*	5,203	*Rest of U.S.*	1.0%
TOTAL	8,598	TOTAL	73,992	TOTAL	4.7%

→**35% for 2016**

Estimated Average Annual Wind Speeds

Typical average wind speeds on well exposed sites at 50 m above ground

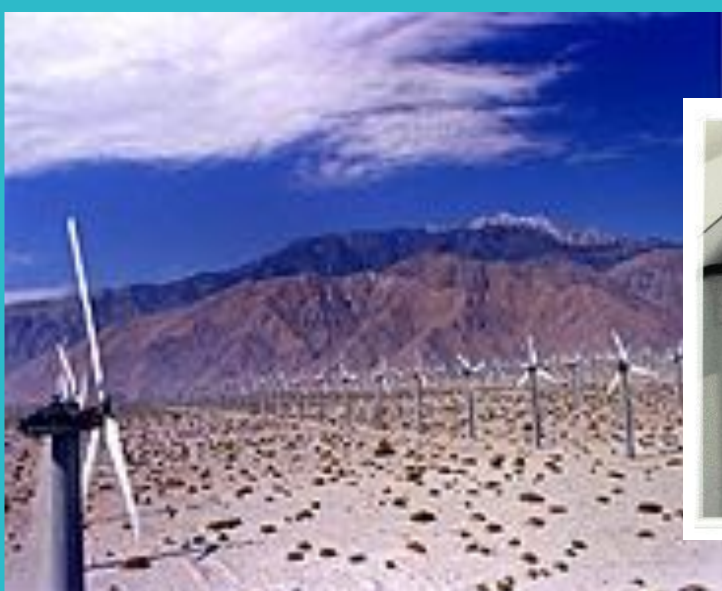


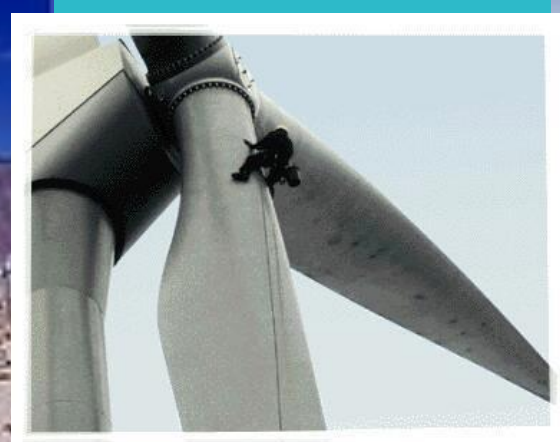
MPH		m/s
>19.0		>8.5
17.9-19.0		8.0-8.5
16.8-17.9		7.5-8.0
15.7-16.8		7.0-7.5
14.5-15.7		6.5-7.0
13.4-14.5		6.0-6.5
12.3-13.4		5.5-6.0
<12.3		<5.5

Iowa Energy Center

This map was generated from data collected by the Iowa Wind Energy Institute under Iowa Energy Center Grant No. 93-04-02. The map was created using a model developed by Brower & Company, Andover, MA.

Iowa Energy Center, 2521 Elwood Drive, Suite 124, Ames, IA 50010-8263 Phone: (515) 294-8819 Fax: (515) 294-9912






Wind

The future: US wind potential by state

Annual wind energy potential (10^{12} w-hrs)

R= Annual wind energy potential / 2006 state annual retail sales

States with high production and R-ratio have high export potential (Montana, Dakotas, Wyoming, Nebraska, Kansas)

Analysis assumes (a) only sites having capacity factor > 20% included; (a) loss of 20% and 10% of potential power for onshore and offshore, respectively, caused by interturbine interference, (c) offshore siting distance within 50 nm (92.6 km) of nearest shoreline.

Source: Xi Lua, M. McElroya, and J. Kiviluomac, "Global potential for wind-generated electricity," Proc. of the National Academy of Sciences, 2009, www.pnas.orgcgidoi10.1073pnas.0904101106.

The future: US wind potential

Contiguous US annual wind energy potential , 10^{15} wh		Multiples of Total US Energy Consumption*
Onshore	62	2.12
Offshore, 0-20 meter	1.2	.041
Offshore, 20-50 m	2.1	.072
Offshore, 50-200 m	2.2	.075
Total	68	2.321

Total US Energy consumption across *all* sectors is 100 Quads:

$$100Q \times \frac{1E15BTU}{Q} \times \frac{kwh}{3413BTU} \times \frac{1000wh}{kwh} = 29.3E15wh$$

Source: Xi Lua, M. McElroya, and J. Kiviluomac, "Global potential for wind-generated electricity," Proc. of the National Academy of Sciences, 2009, www.pnas.orgcgidoi10.1073pnas.0904101106.

What about biomass & heat?

Biomass to anaerobic digester to biogas provides low-GHG flexibility in gas system

CHP provides high ramp capability

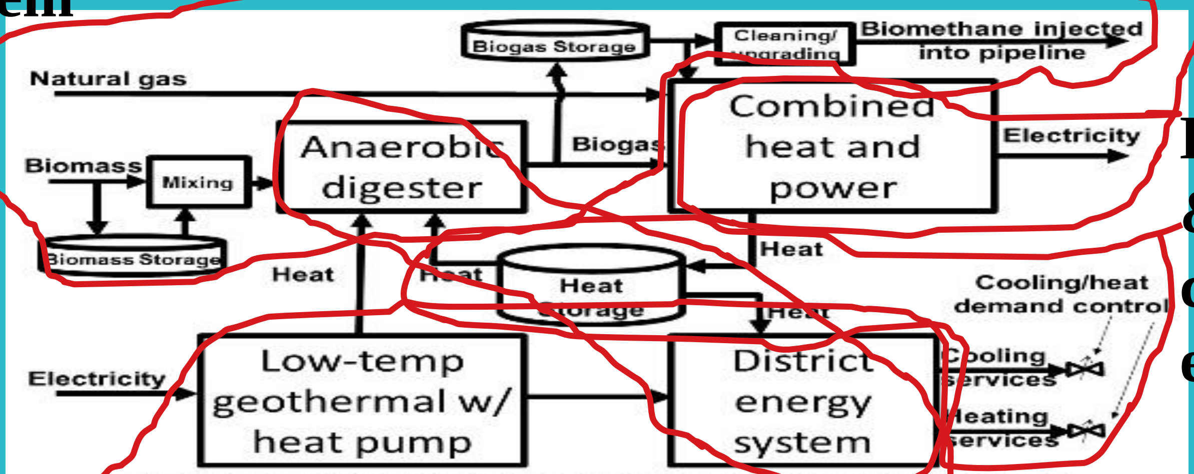


Fig. 2: HES Design Appropriate for the Midwest US

Heat storage & heating & cooling demand control enables electric-side flexibility

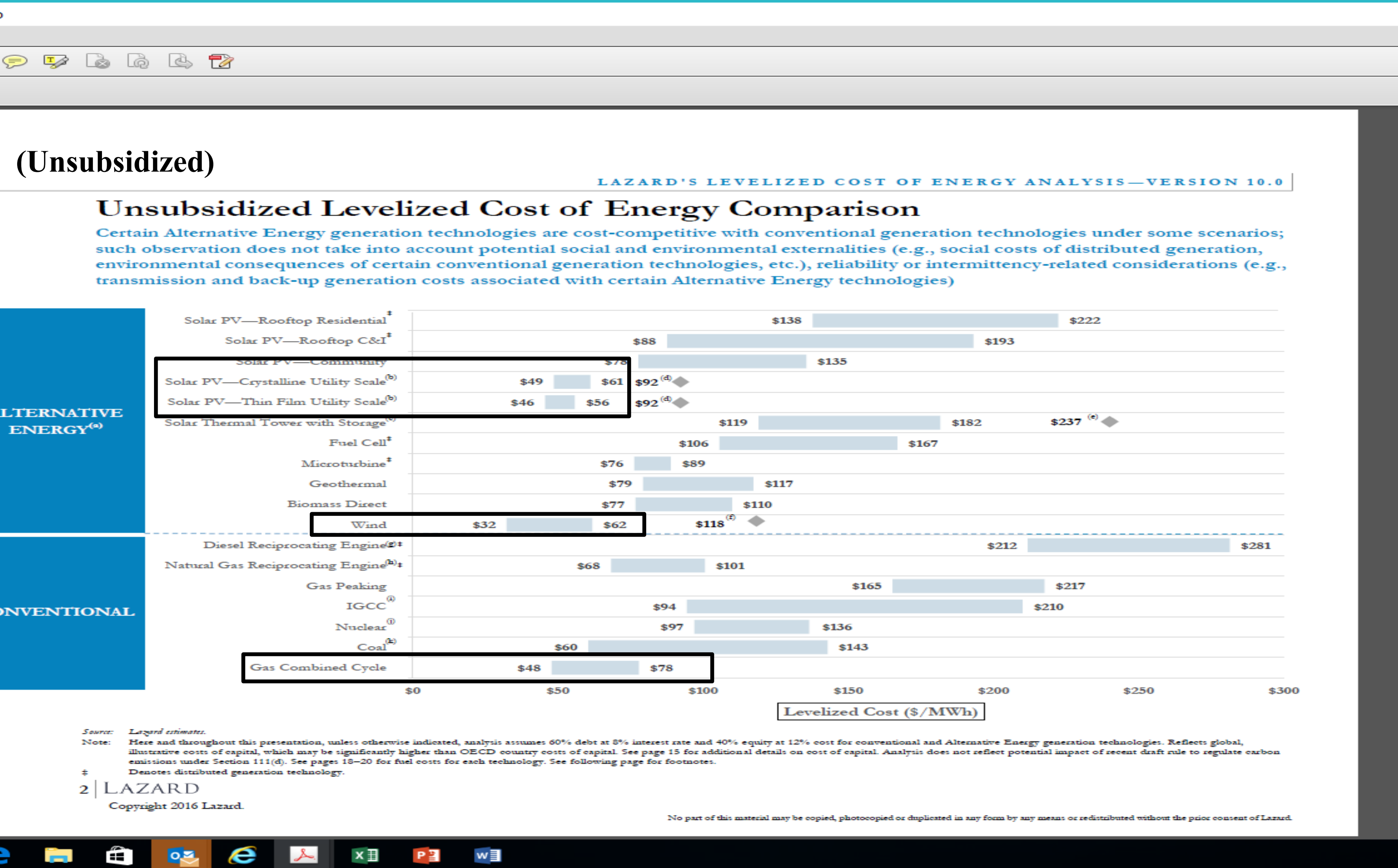
Use of low-temp geothermal w/heat pump or district heating system from CHP is more efficient than gas furnaces

Use of CHP waste-heat in low-temp apps increases plant efficiency

11

Cost comparison of different energy resources

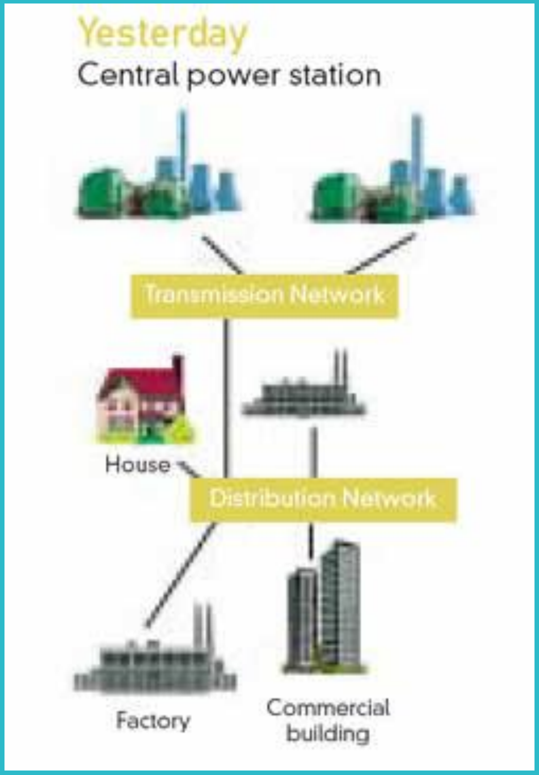
(Unsubsidized)

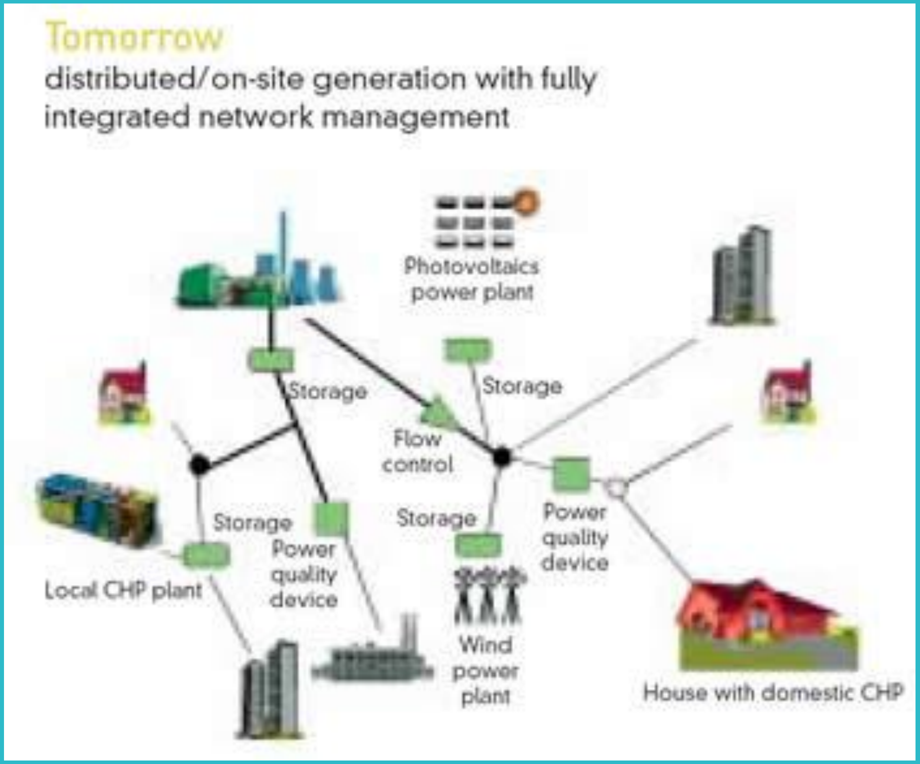


Lazard's levelized cost of energy analysis- Version 10.0, December 2016, available https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf

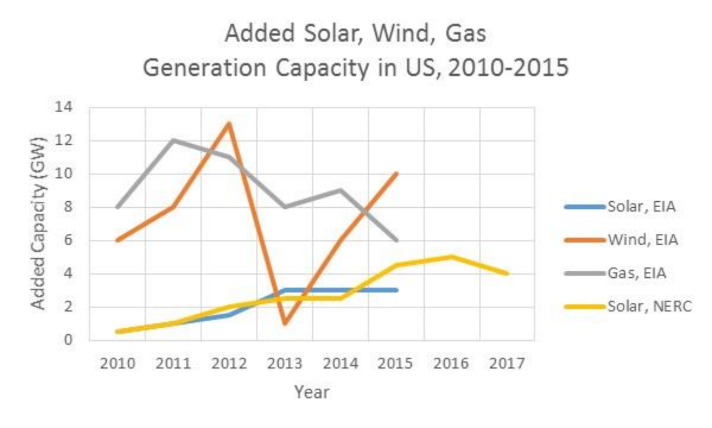
Distributed Generation

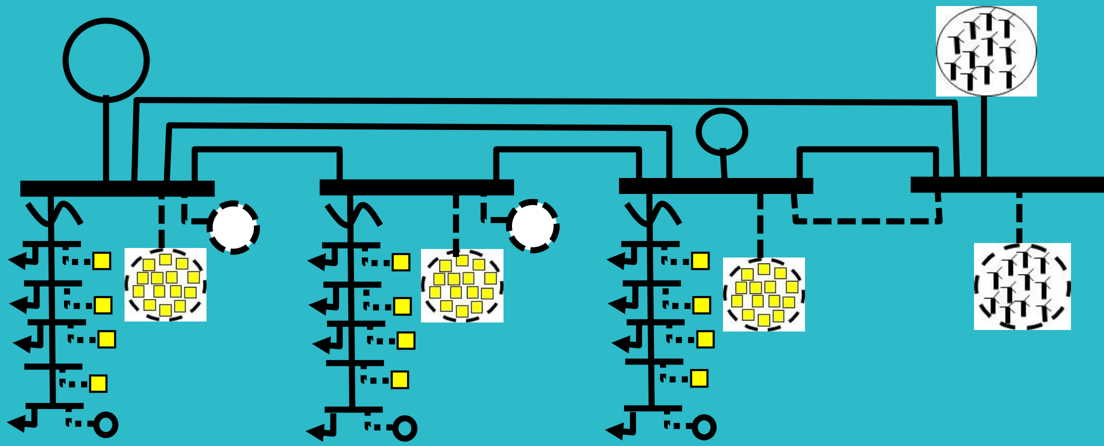
- **Distributed Generation: generation of energy close to the point of use.**
- **DG typically ranges from 1 kilowatt to 5 Megawatts in capacity, contrasting with Central Generation, which is associated with large 500 to 3000 MW generating plants usually located remote end-use location.**
- **DG resources include wind, solar, fuel cells, cogeneration, and microturbines (gas, propane, fuel-oil).**





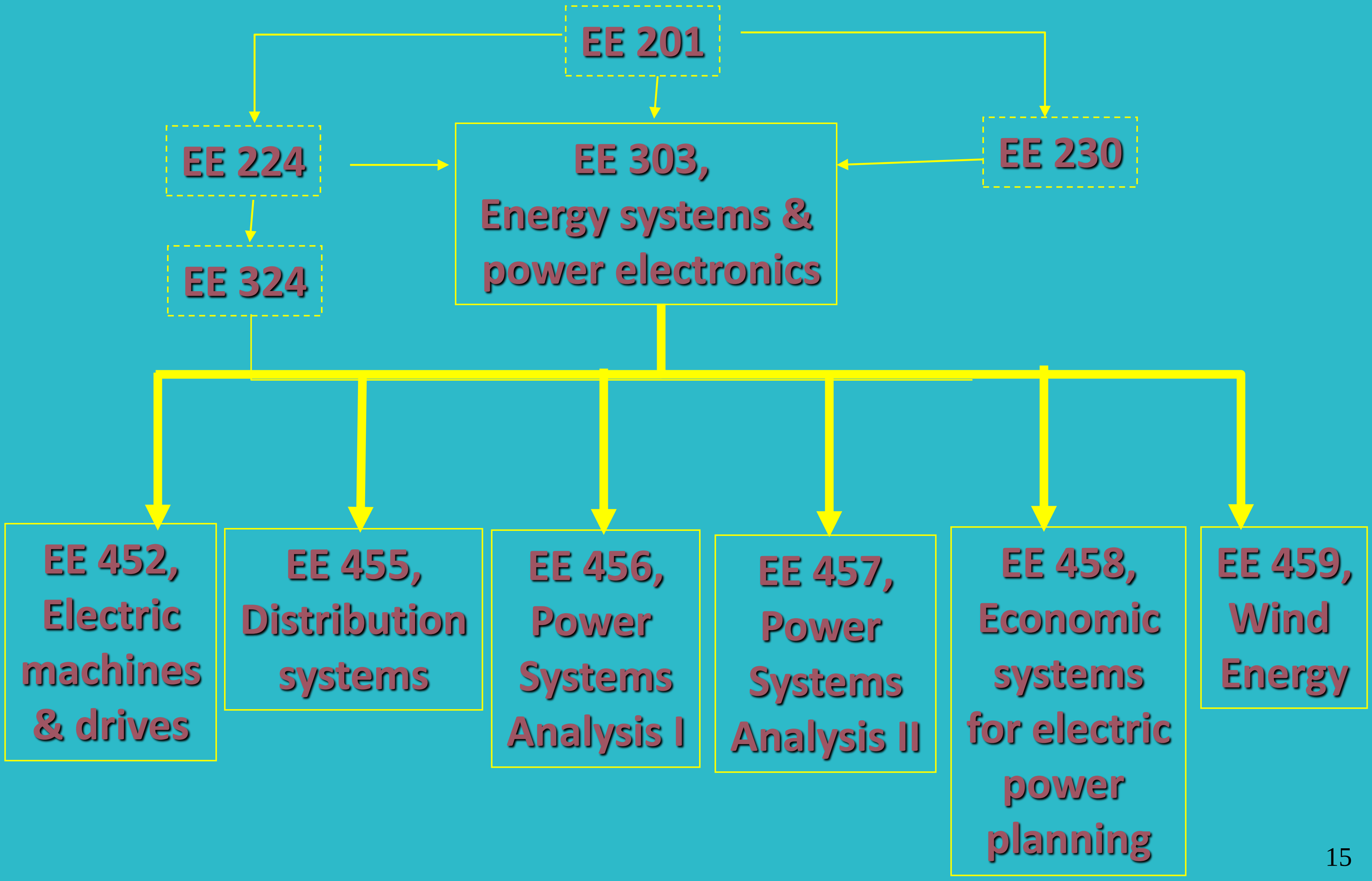
Other infrastructure – distributed resources





- DG benefits: less transmission, loss reduction.
- Investment cost: LCOE - $242 PV-rooftop; $64 PV-utility, $55 wind; $65 NGCC.
- Reliability: It is unclear whether reliability improves (w/, w/o microgrid), and if it does, whether improvement justifies the cost. Check SAIDI & SAIFI.
- O&M: Low for solar, hi for wind. Low for utility scale, high for DG.
- Green people: Can be satisfied with community solar.
- Analysis: Need co-optimization to answer these questions.

The Electric Power + Energy Systems Group has excellent series of courses to prepare you for an exciting career….



For whom might you work? (below - mainstream comp only)

- Investor-owned utilities: 239 (MEC, Alliant, Xcel, Exelon, …)
- Federally-owned: 10 (TVA, BPA, WAPA, SEPA, APA, SWPA…)
- Public-owned: 2009 (Ames, Cedar Falls, Dairyland, CIPCO…)
- Non-utility power producers: 1934 (Alcoa, DuPont,…)
- Power marketers: 400 (e.g., Cinergy, Mirant, Illinova, Shell Energy, PECO-Power Team, Williams Energy,…)
- Coordination organizations: 10 (ISO-NE, NYISO, PJM, MISO, SPP, ERCOT, CAISO, AESO, NBSO)
- Oversight organizations:
  - Regulatory: 50 state, 1 Fed (FERC)
  - Reliability: 1 National ((NERC), 8 regional entities
- Manufacturers: GE, ABB, Toshiba, Schweitzer, Westinghouse
- Consultants: Black&Veatch, Burns&McDonnell, HD Electric,…
- Vendors: Siemens, Areva, OSI,…
- Govt agencies: DOE, EPA, Labs,…
- Professional & advocacy organizations: IEEE, IWEA, …