Economies of scale vs societal interest in small autonomous systems

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Energy Systems Integration 102
National Renewable Energy Laboratory
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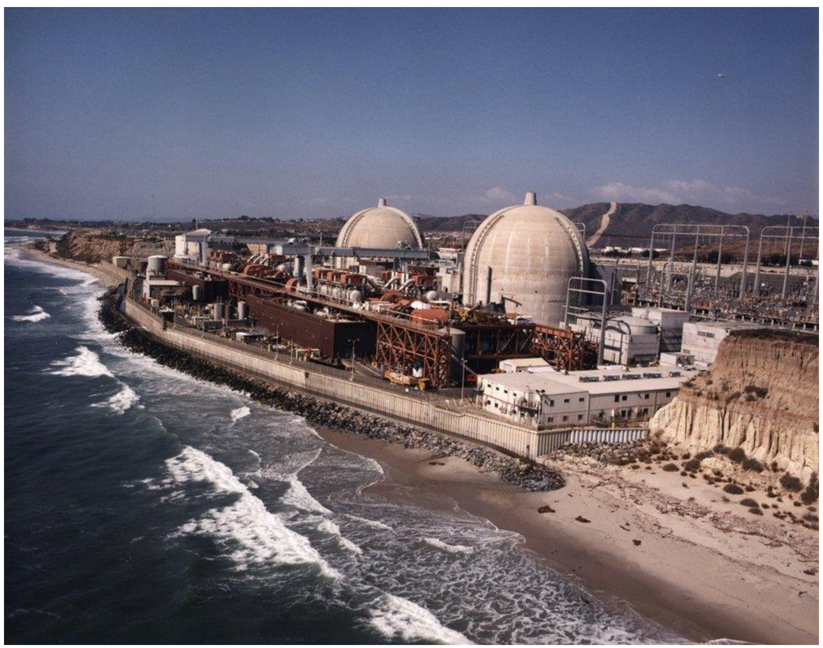


San Onofre Nuclear Power Plant,
Southern California

A neighborhood in Sacramento, CA, 2014

Overview

1. **Assignment**
2. **Vision diversity**
3. **Flex-fuel polygeneration power plants**
4. **Design objectives**
    - **Flexibility**
    - **Reliability**
    - **Resilience**
    - **Adaptability**
    - **Economics:**
        - **Economies of scale**
        - **Other influences**
        - **What do investors think about technologies?**
5. **Paths forward**
6. **Concluding comment**

Assignment

- Form groups of three-four, meet from 10:00-10:45.
- Your group is charged with answering the following questions:

  1. What technologies *should* provide the highest percentage of ________________ electrical energy production in 2035?
  2. What is the main weakness of each option?

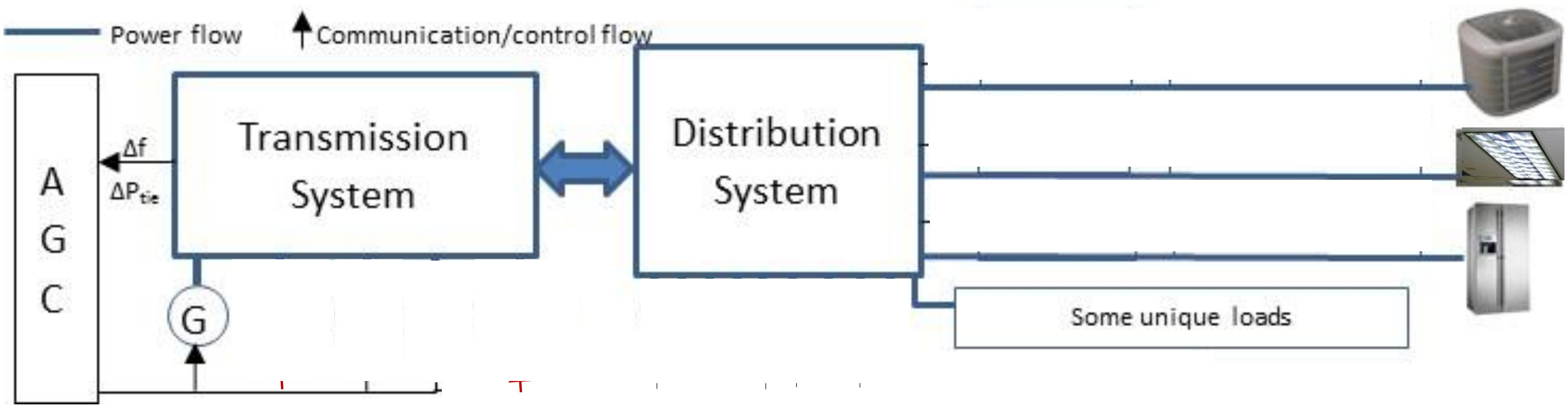
Insert name of continent, country, interconnection, region, state, city, or community.

- The continent, country, interconnection, etc., chosen for this exercise should be the same one chosen for the course project.
- To facilitate your group's discussion, fill the chart on the next page, giving each technology, for each attribute, one of the following grades:
  - A: the technology performs "very well" in this attribute
  - C: the technology performs "fair" in this attribute
  - F: the technology performs "very poor" in this attribute
- You may add technologies & attributes as you deem appropriate
- Each group will provide a 10 min report from 10:45-12:00.

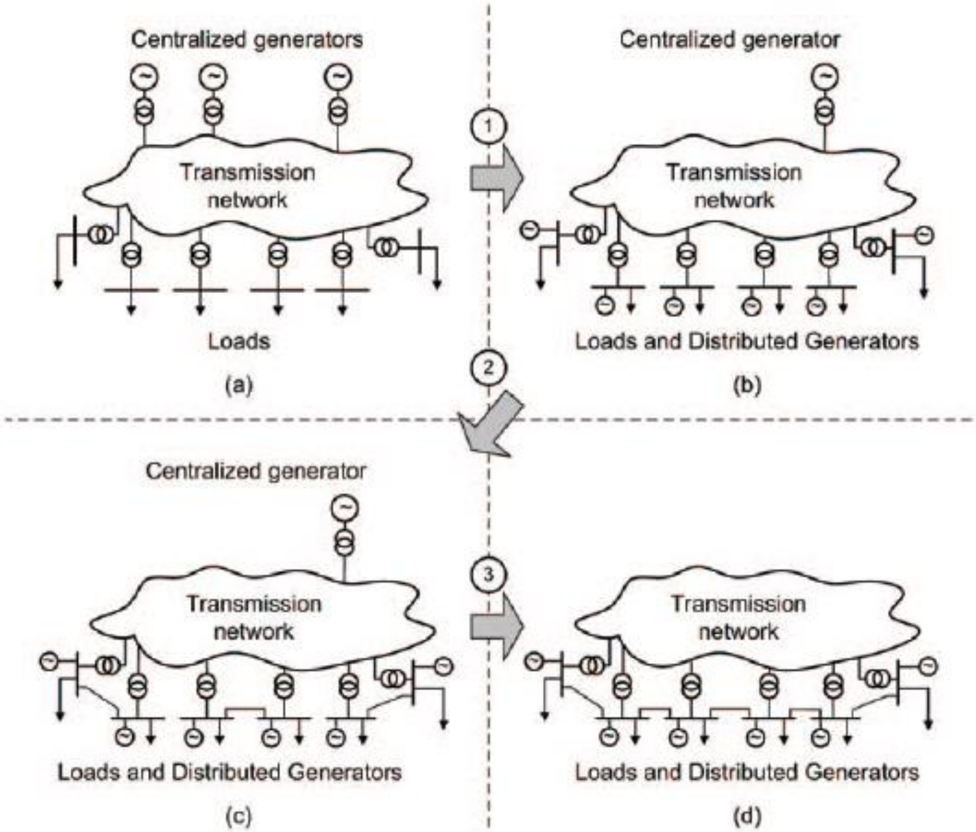
Additional technologies

	Attribute	Rftp Solar	utlity wind	Ntrl Gas CC	Ntrl Gas CT	CHP				
	Technology levelized cost									
Fuel	Fuel production – land use									
	Fuel production – water use									
	Fuel production – GHG emissions									
	Fuel transport – land use									
	Fuel transport – public resistance									
Power Plant	Power plant – land use									
	Power plant – water use									
	Power plant – CO_2 emissions									
	Power plant – other, e.g., wildlife effects									
Electric Transm	Electric transmission – land use									
	Electric transmission – public resistance									
	Requires operational flexibility									
	Provides operational flexibility									
	Reliability, i.e., service availability									
	Price resilience to med-term shocks									
	Cost of adapting to long-term change, e.g., climate, policy, technology									
	Future risks of heavy deployment									
Additional Attributes										

Vision Diversity



Vision Diversity

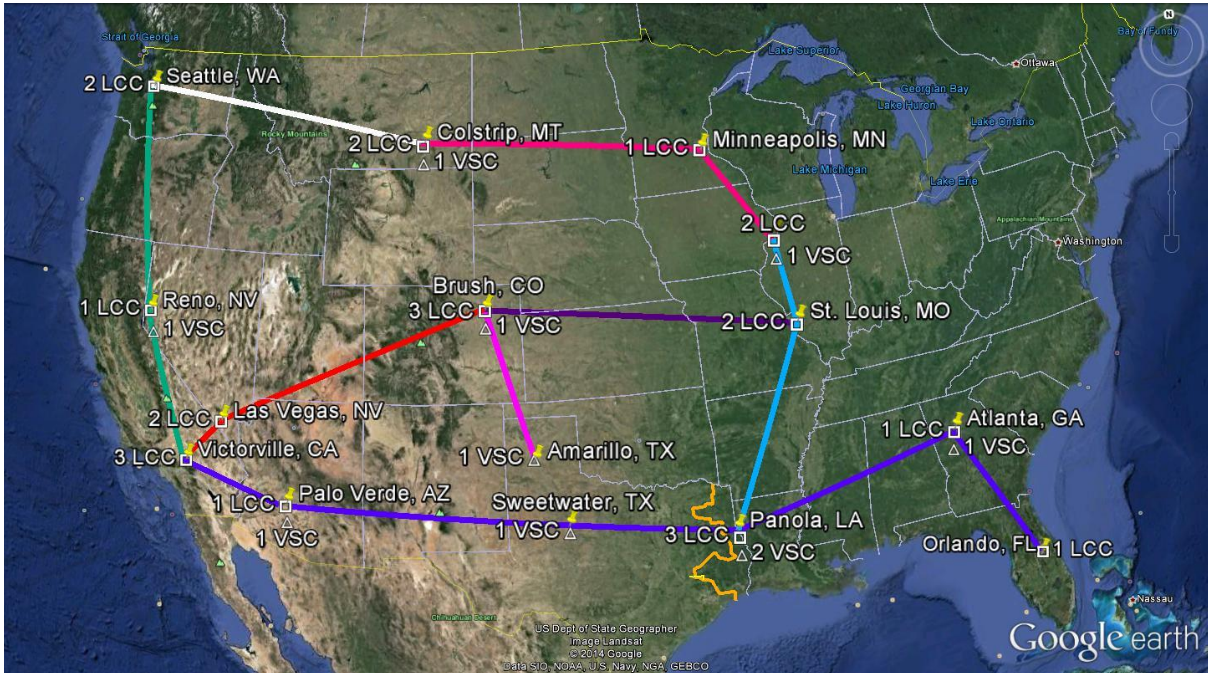


M. Reza, "Stability analysis of transmission systems with high penetration of distributed generation," Ph.D. dissertation, Delft University of Technology, Delft, the Netherlands, 2006.

"…as DG becomes ubiquitous the need for a classical power transmission system disappears; there is no need for long-distance bulk-power transfer if power sources are distributed within close proximity."

- S. Bush, "Distributed generation and transmission," in "Smart Grid: Communication-Enabled Intelligence for the Electric Power Grid," First Edition. 2014 John Wiley & Sons, Ltd.

Vision Diversity



Benefit	Total	
Load Diversity	$ 21.0 Billion	46%
Frequency Response	$ 9.8 Billion	22%
Wind Diversity	$ 2.2 Billion	5%
Other Energy Based Benefits	$ 12.2 Billion	27%
Grand Total	**$45.3 Billion**	

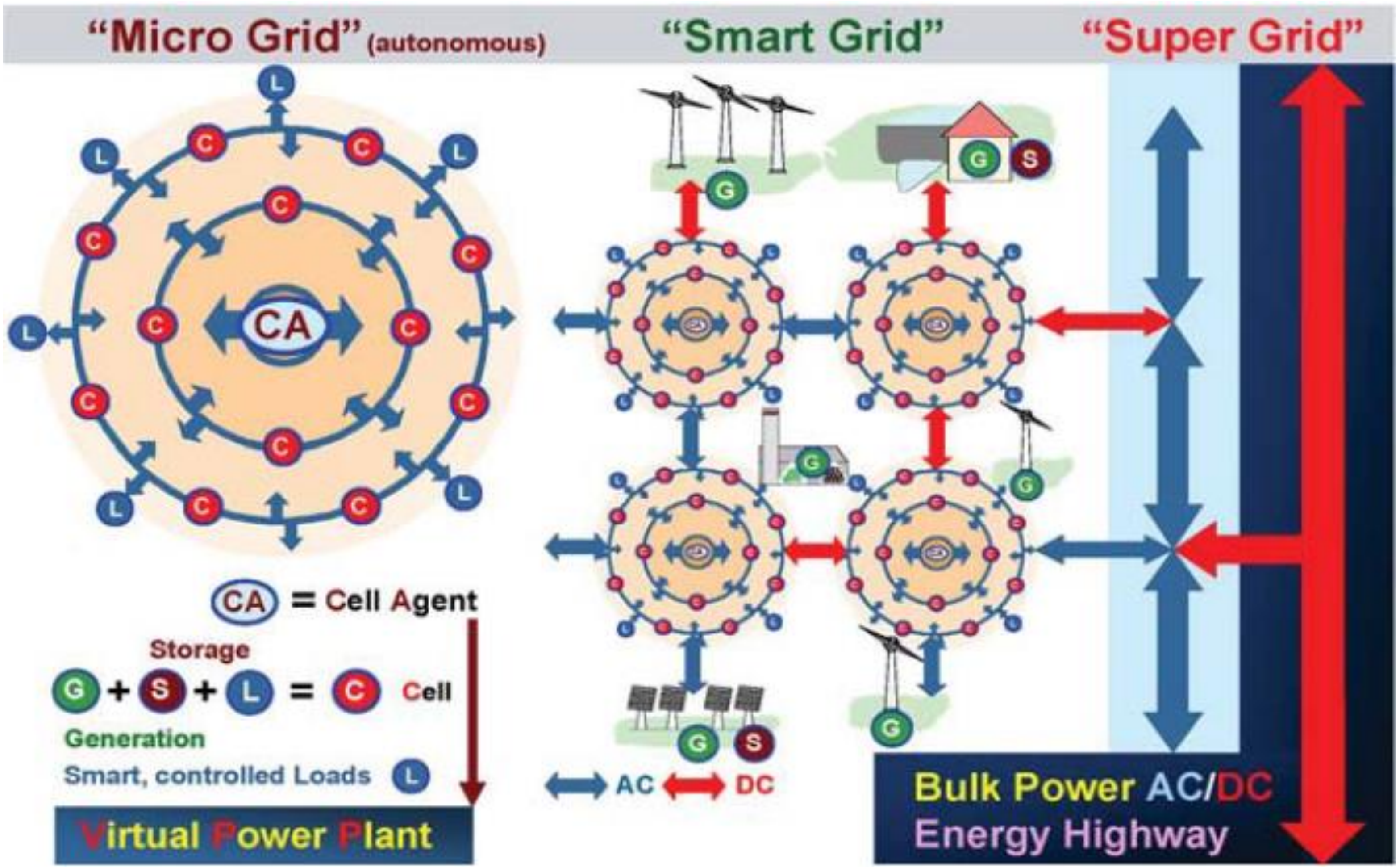
Courtesy of Dale Osborn, Mid-Continent Independent System Operator (MISO), 2015.

Vision Diversity

"Distributed Generation (DG) is generally considered as an alternative to bulk power transport. The basic idea is that the presence of electricity generation inside the distribution systems leads to a reduction of the local electricity needs, which consequently leads to a reduced need for power transmission capacity and thus a deferral of investments in transmission lines. However, due to the different operational characteristics of the plethora of types of distributed generation, this hypothesis may prove invalid. Controllable distributed generation, defined as local generation of which the power output can be regulated by the system operator (e.g. stand-alone gas-fired combustion units) will certainly have a positive impact on this direction."

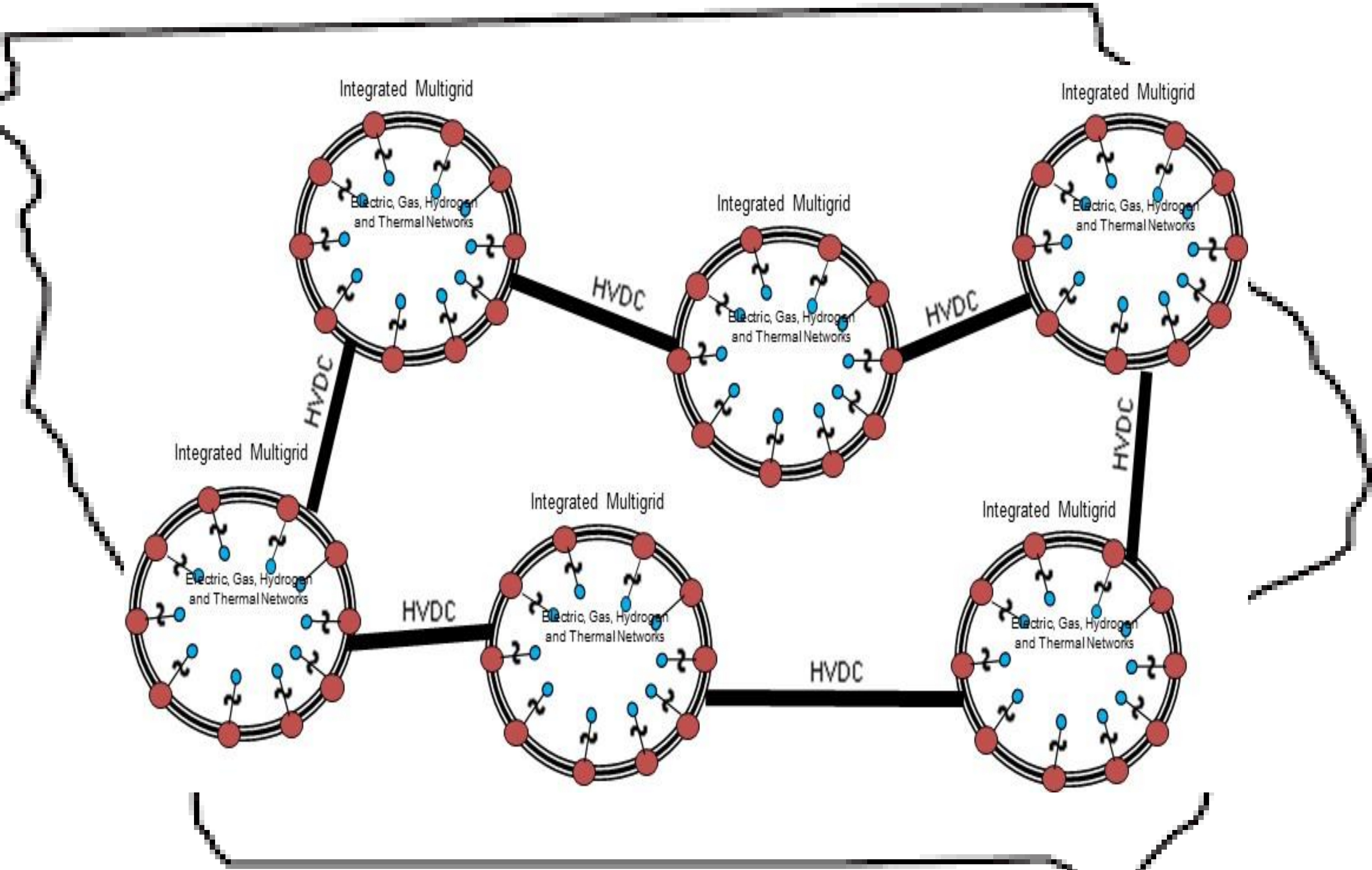
G. Papaefthymiou, M. Houwing, M.P.C. Weijnen and L. van der Sluis, "Distributed generation vs. bulk transmission," First International Conference on Infrastructure Systems and Services: Building Networks for a Brighter Future, 2008.

Vision Diversity

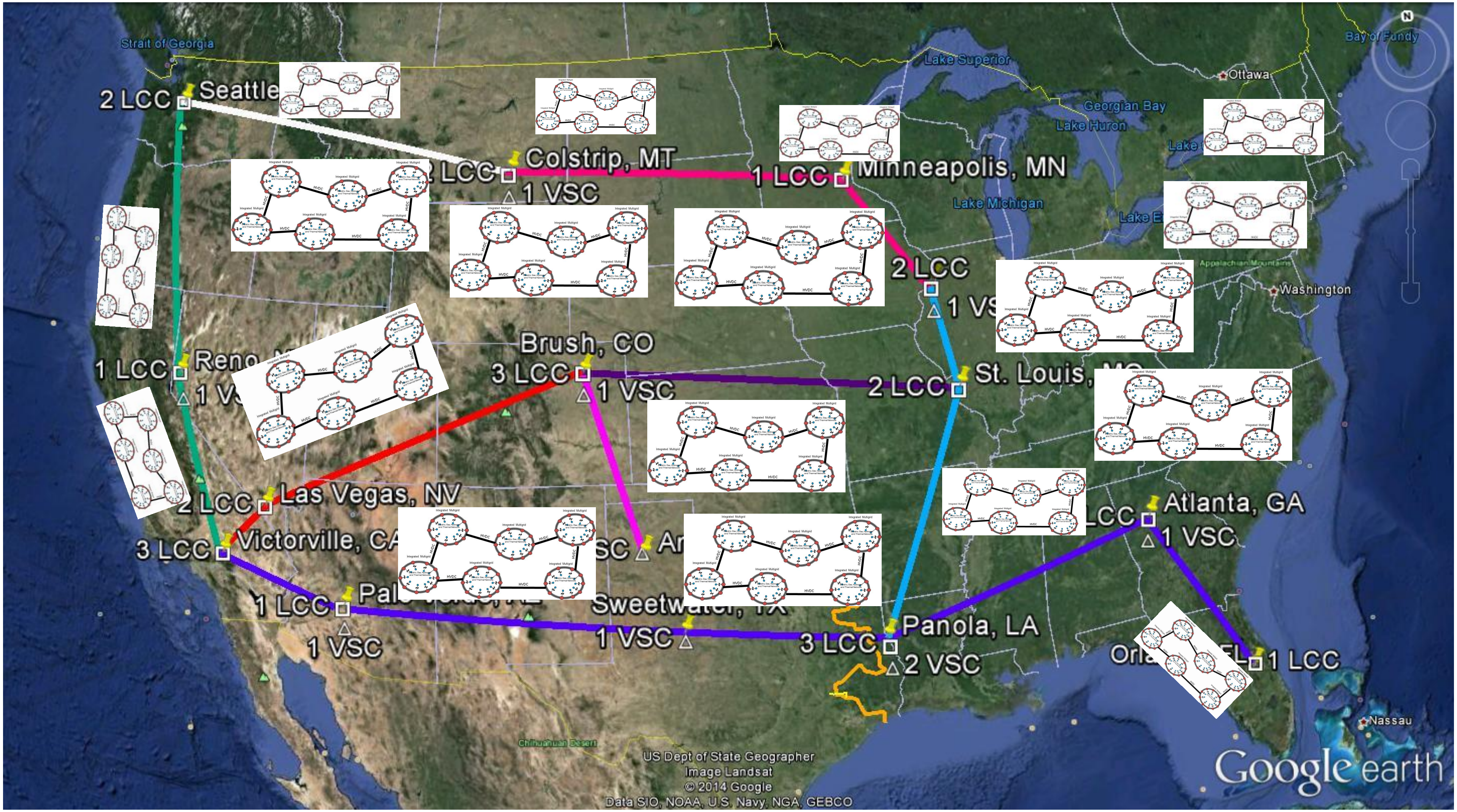


T. Hammons, V. Lescale, K. Uecker, M. Haeusler, D. Retzmann, K. Staschus, S. Lepy, "State of the Art in Ultrahigh-Voltage Transmission," Proceedings of the IEEE, Vol. 100, No. 2, February 2012.

Vision Diversity

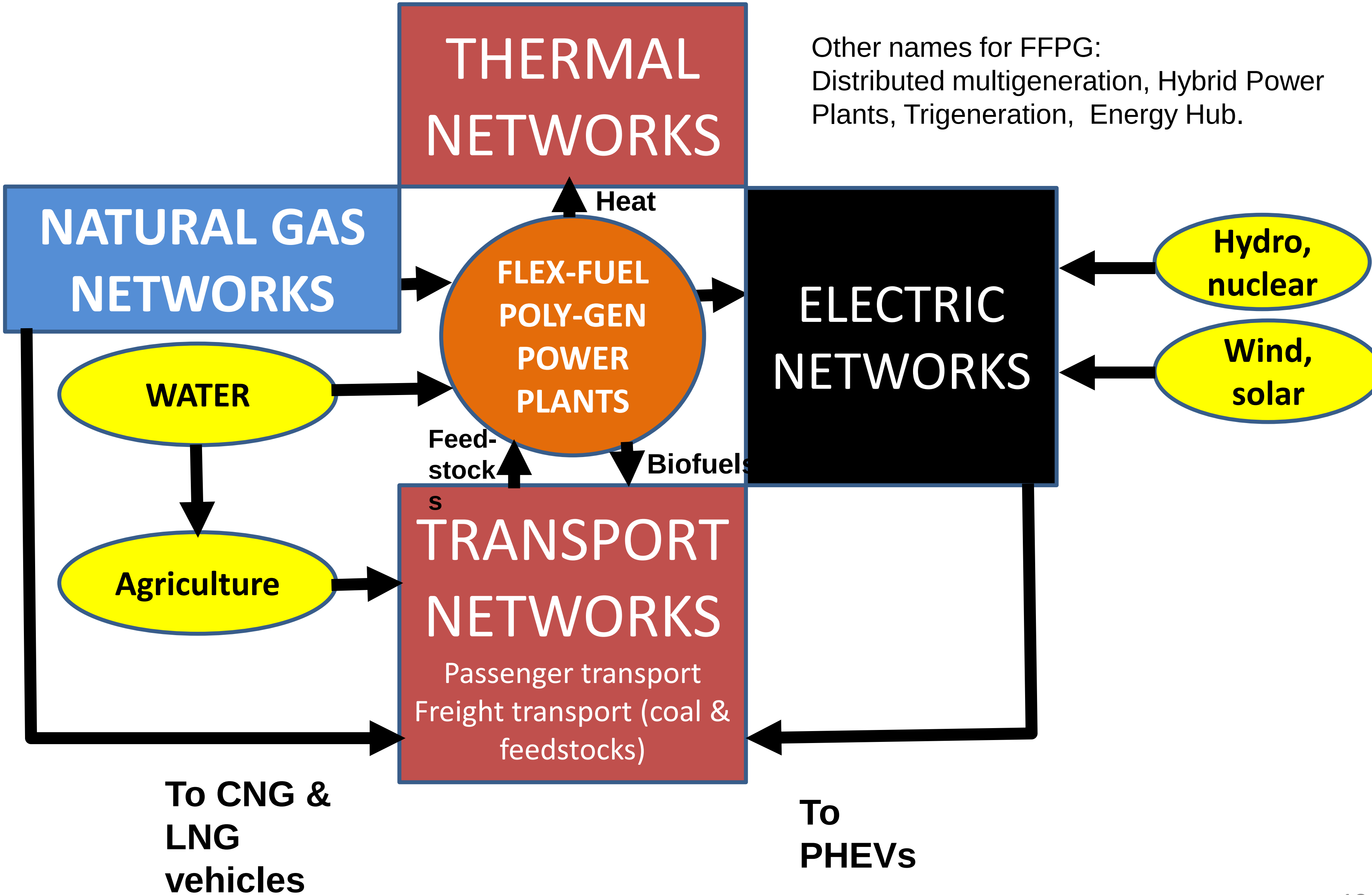


Vision Diversity

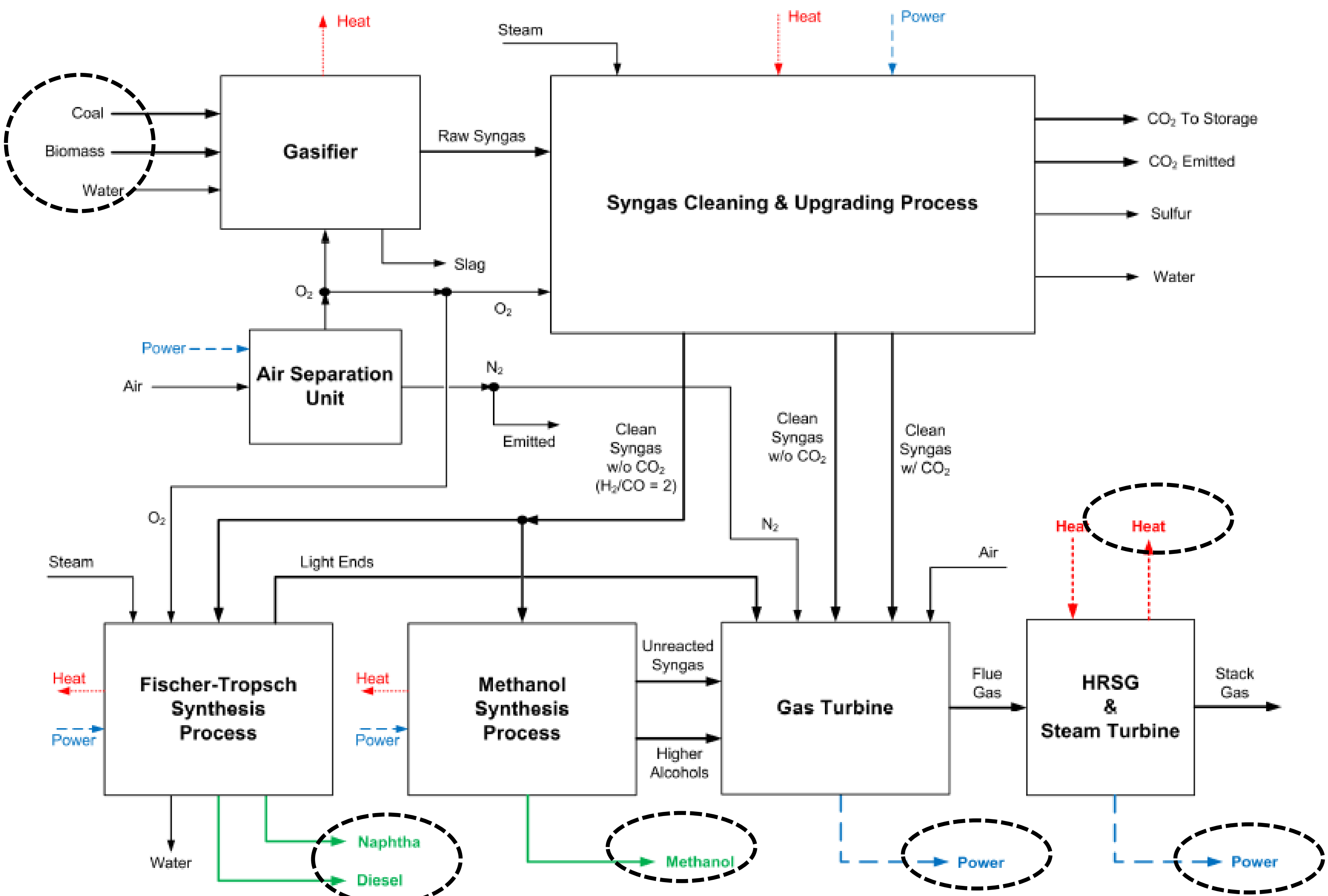


Vision Diversity: MultiGrids

Other names for FFPG:
Distributed multigeneration, Hybrid Power Plants, Trigeneration, Energy Hub.

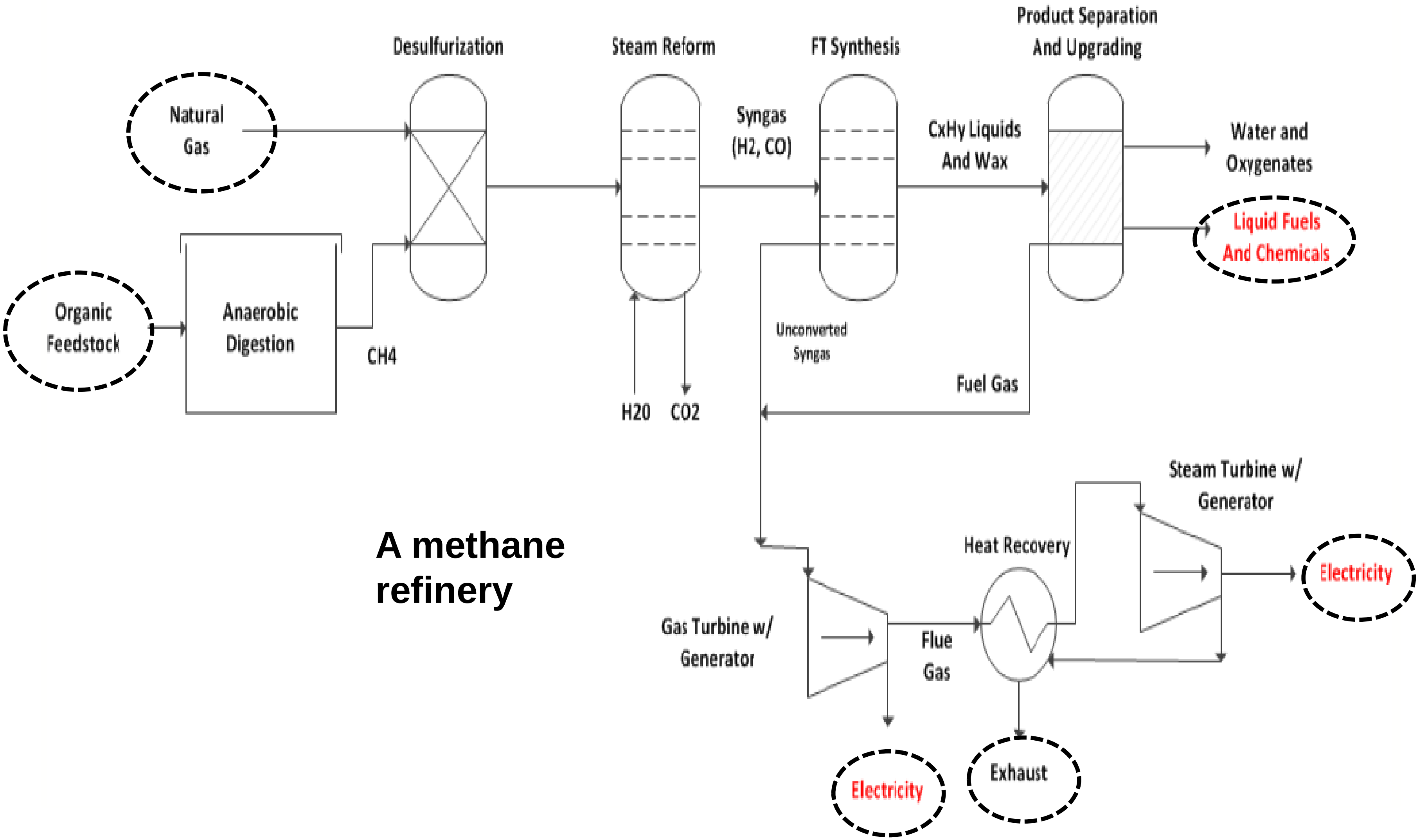


Combustion-based FFPG: Flex Fuel (Coal/Biomass) Poly-Generation (power/heat/biofuels/methanol)



Y. Chen, "Optimal Design and Operation of Energy Polygeneration Systems," Ph.D. Dissertation, Massachusetts Institute of Technology, 2013.

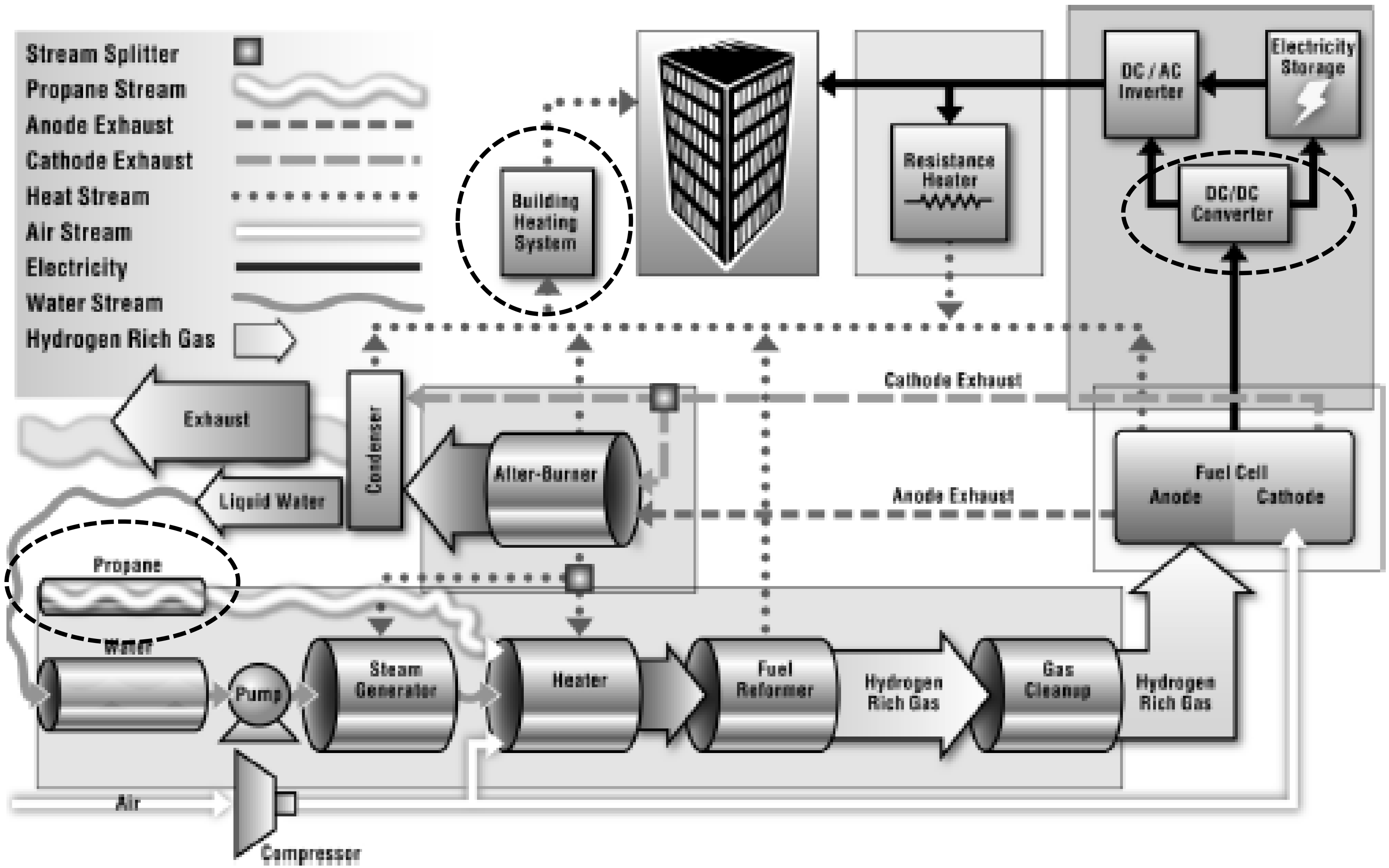
Combustion-based FFPG: Flex Fuel (Gas/Biomass) Poly-Generation (power/heat/biofuels)



A methane refinery

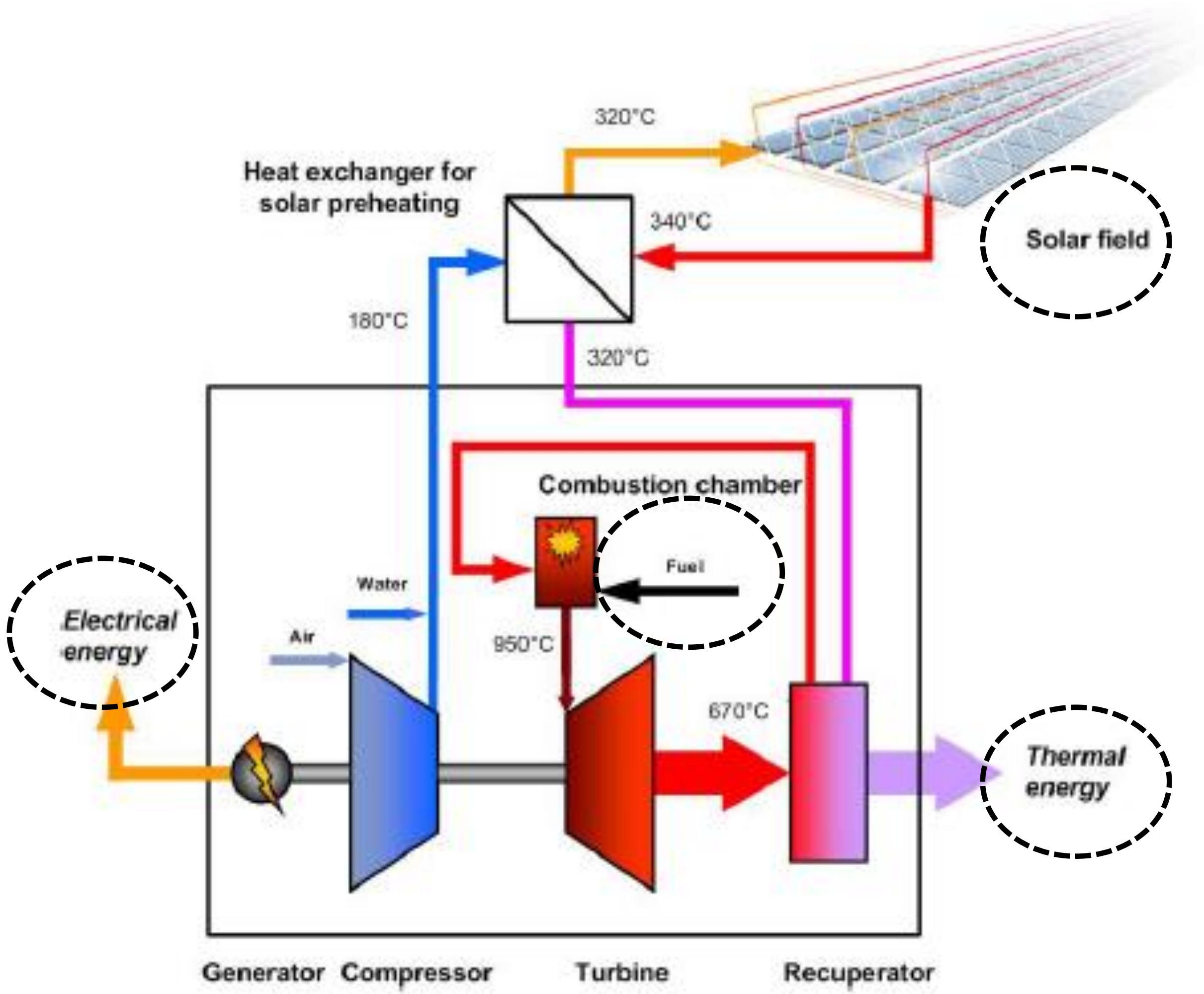
Wright M. M., Seifkar N., Green W. H., Roman-Leshkov Y. "Natural Gas and Cellulosic Biomass: a Clean Fuel Combination? Determining the Natural Gas Blending Wall in Biofuel Production" Environmental Science & Technology (published online - 2015)

Fuel-cell based FFPG: Flex Fuel (Gas to H_2) Poly-Generation (power/heat)



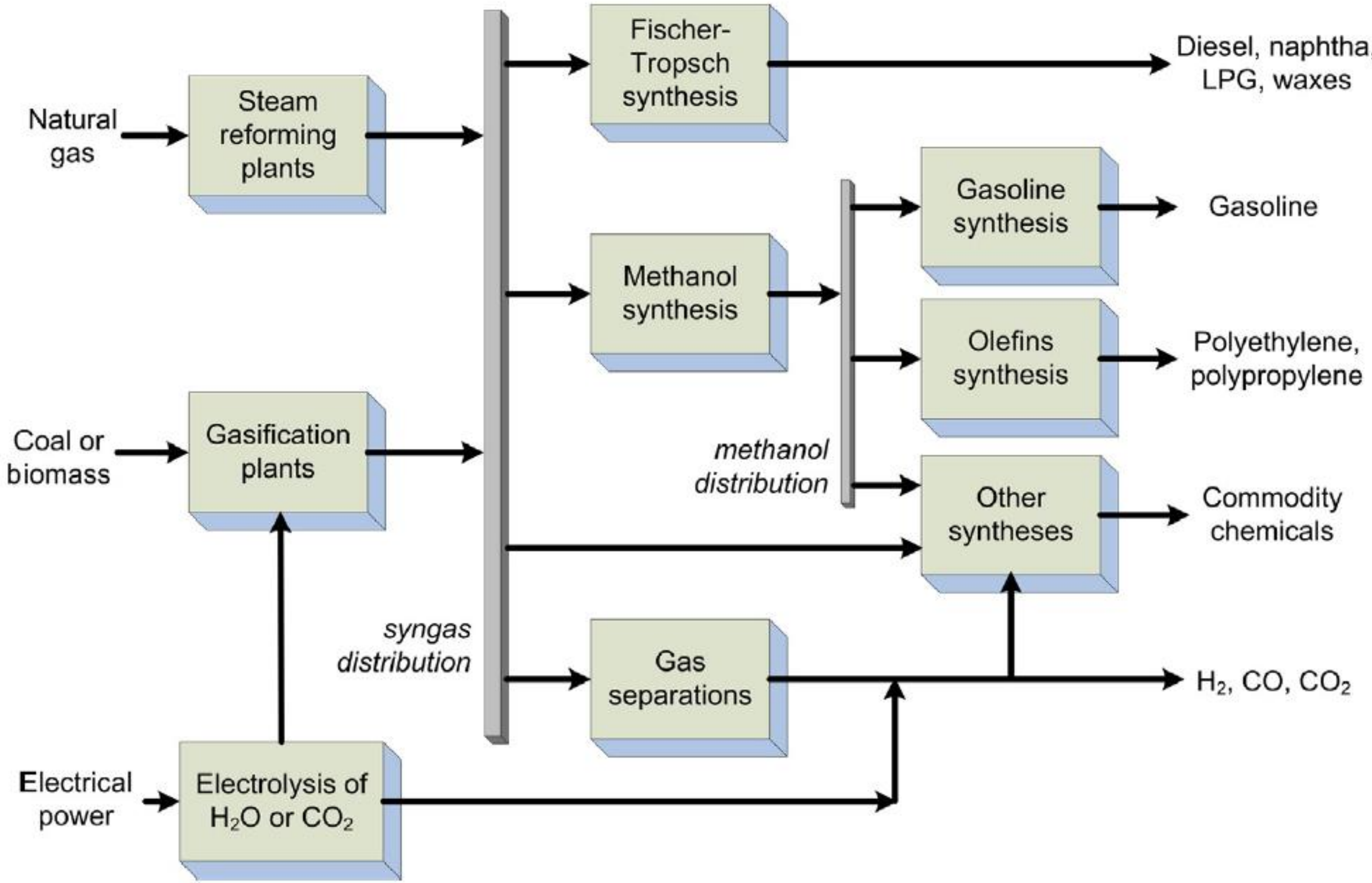
W. Colella, "Network design optimization of fuel cell systems and distributed energy devices," Sandia Report SAND2010-5071, July 2010.

Solar-based FFPG: Flex Fuel (Solar) Poly-Generation (power/heat)



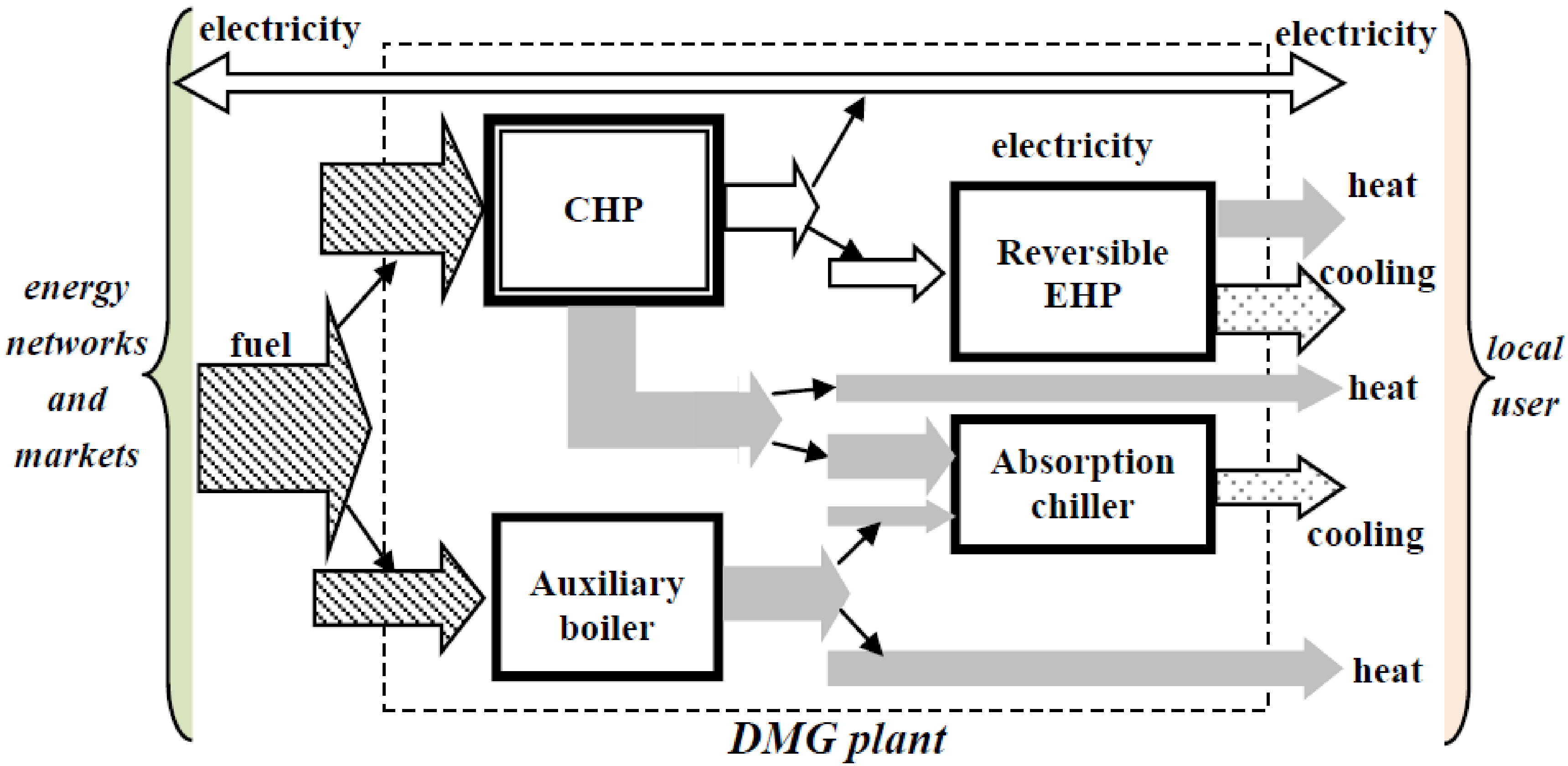
O. Iglauer and C. Zahler, "A new solar combined heat and power system for sustainable automobile manufacturing," Energy Procedia 48 (2014) 1181-1187.

Syngas-based FFPG: Flex Fuel (Natural Gas/Coal/Biomass/Power) Poly-Generation (Biofuels, Gasoline, H_2, Chemicals)



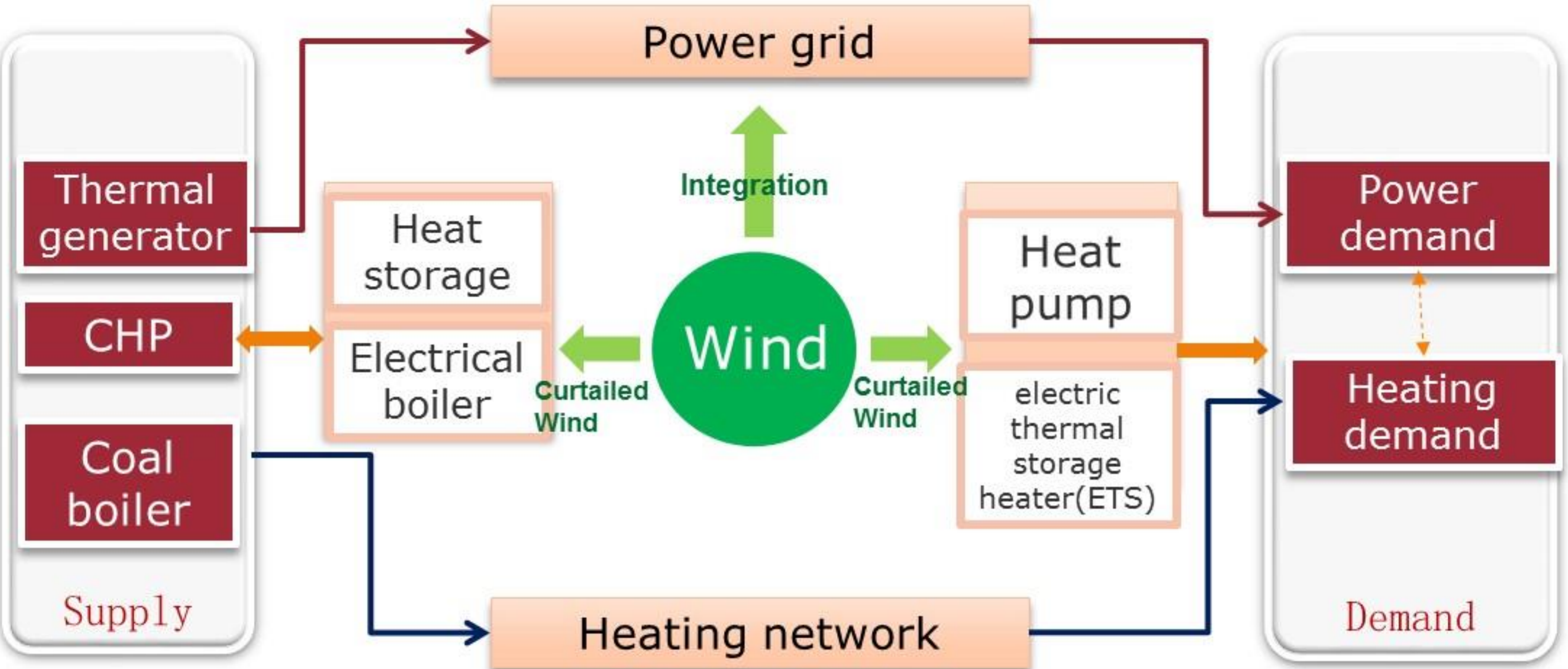
M. Ruth, O. Zinaman, M. Antkowiak, R. Boardman, R. Cherry, and M. Bazilian, “Nuclear-renewable hybrid energy systems: opportunities, interconnections, and needs,” Energy Conversion and Management 78 (2014) pp. 684-694..

FFPG: Flex Fuel (Natural Gas/Coal/Biomass/Power) Poly-Generation (Power, Heat, Cooling)



Pierluigi Mancarella, “Business cases for distributed multi-energy systems,” Presentation slides, Short Course on Energy Systems Integration, NREL, Golden CO, August 3, 2015.

FFPG: Flex Fuel (Natural Gas/Coal/Biomass/Power) Poly-Generation (Power, Heat)

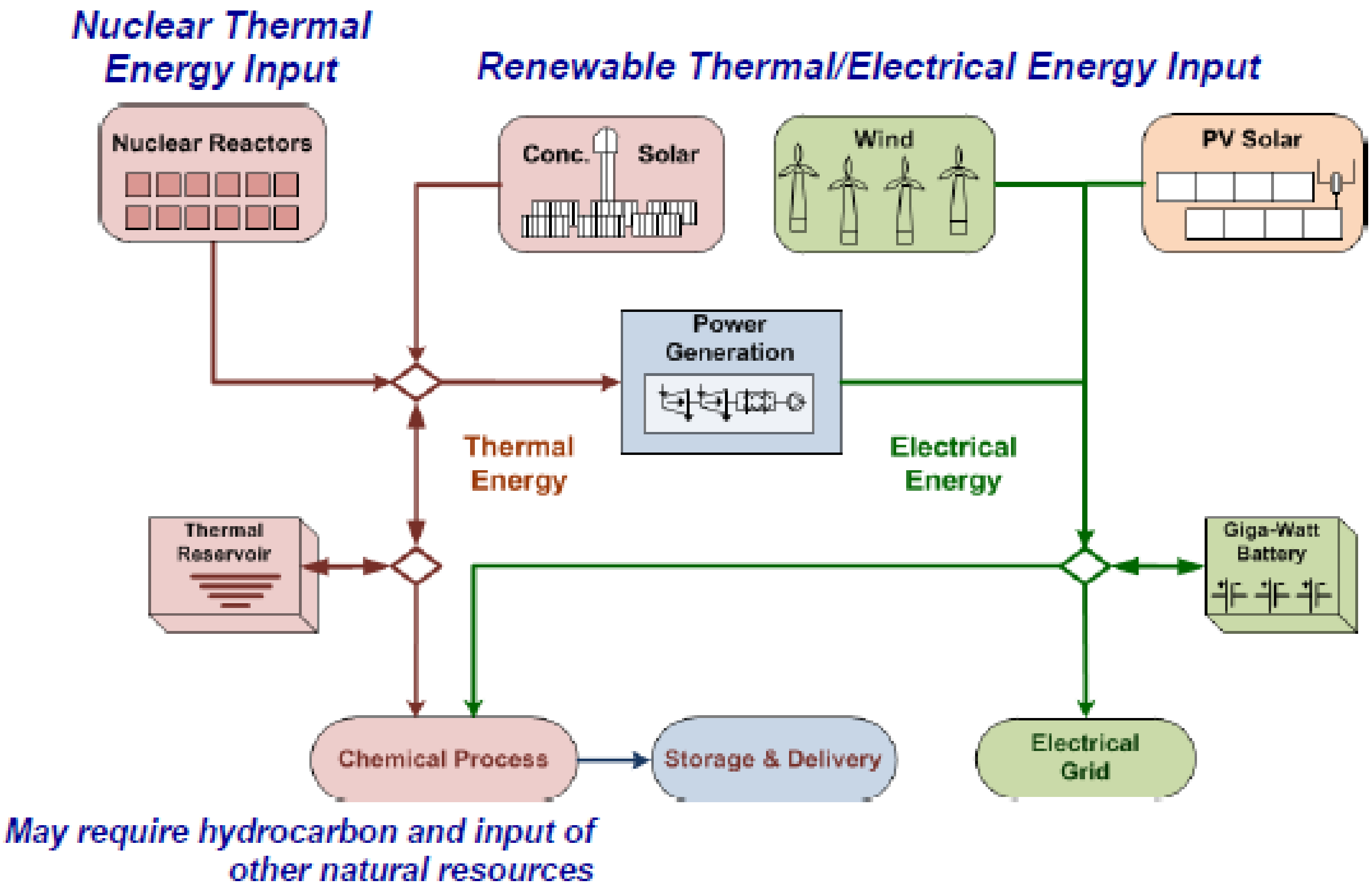


1. Supply side:
Increasing the flexibility of CHP by interacting with heat storage, electrical boiler and wind power

2. Demand side:
Synergize the wind power and space heating demand, using thermal inertia to mitigate the fluctuation from wind power

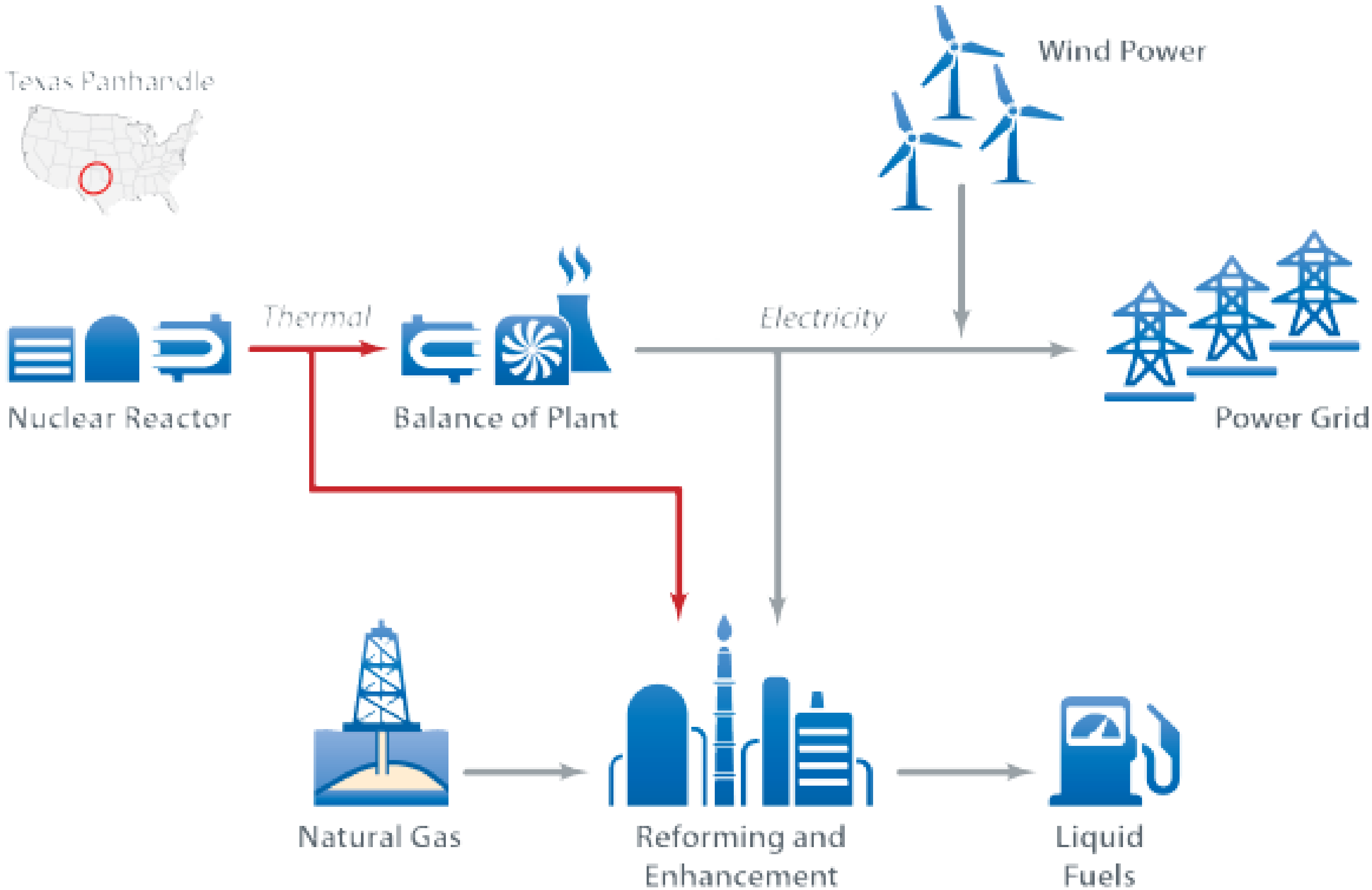
C. Kang, “The coordination of combined heat and power to increase wind energy penetration in China,” presentation slides at the Panel Session on Energy Systems Integration, IEEE PES General Meeting, Denver, July 28, 2015.

FFPG: Flex Fuel (Nuclear thermal/Power) Poly-Generation (Power, Chemical)



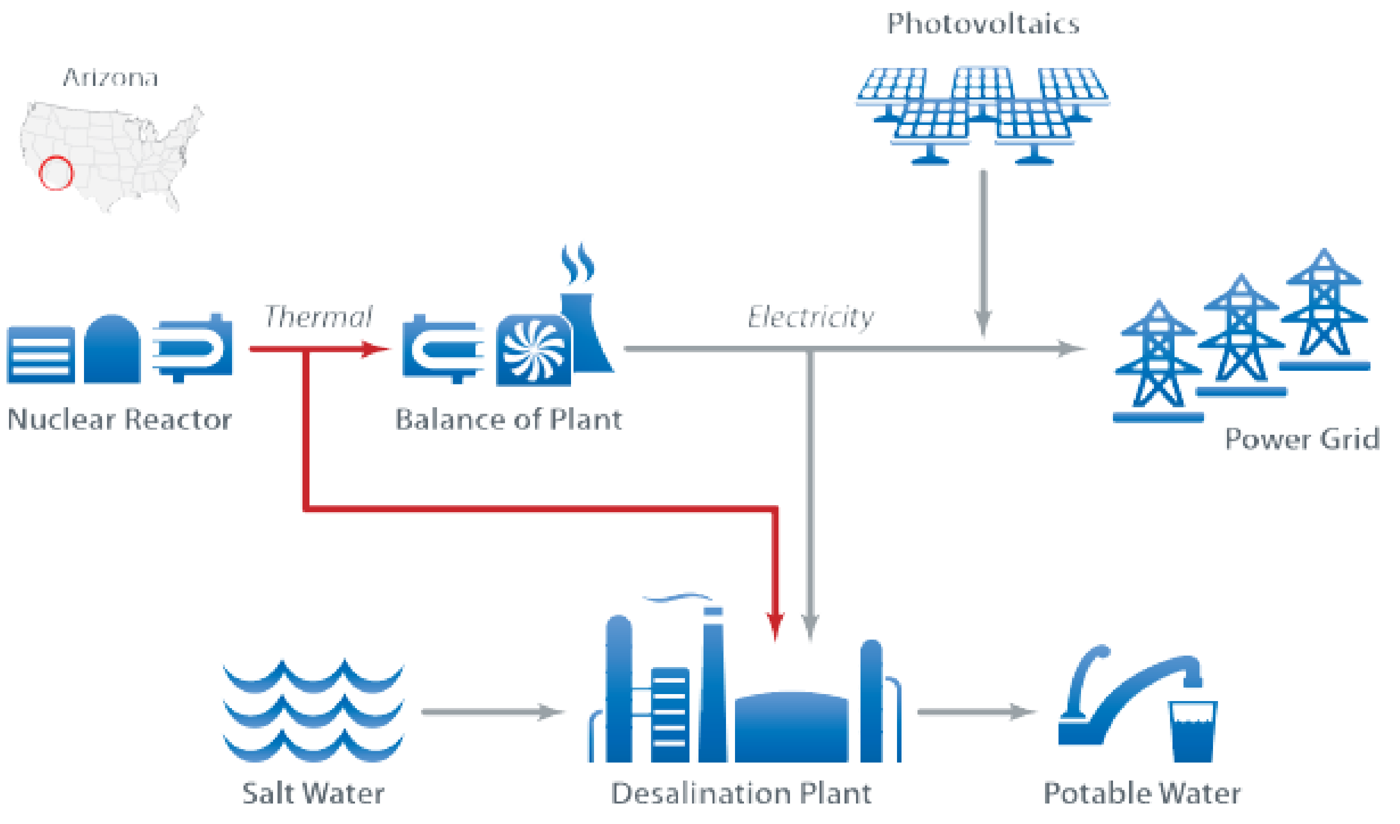
M. Ruth, "Industrial scale energy systems integration," presentation slides at the Panel Session on Energy Systems Integration, IEEE PES General Meeting, Denver, July 28, 2015.

FFPG: Flex Fuel (Nuclear thermal, Power, Gas) Poly-Generation (Power, Liquid fuels)



M. Ruth, "Industrial scale energy systems integration," presentation slides at the Panel Session on Energy Systems Integration, IEEE PES General Meeting, Denver, July 28, 2015.

FFPG: Flex Fuel (Nuclear thermal/Power) Poly-Generation (Power, Water)



M. Ruth, "Industrial scale energy systems integration," presentation slides at the Panel Session on Energy Systems Integration, IEEE PES General Meeting, Denver, July 28, 2015.

Design objectives: EES-S/FRRA

- **E: Environmental sustainability;**
- **E: Economic sustainability;**
- **S: Social sustainability;**
- **FRRA:**
  - **Flexibility: operational speed of response;**
  - **Reliability: service availability (SAIDI, SAIFI);**
  - **Resilience: economic service availability – ability to minimize & recover from price-consequences of extreme events;**
  - **Adaptability: A long-term version of resilience – ability to economically adapt infrastructure to adverse and permanent changes in technology/fuel availability or cost.**

Enforcing Flexibility in Expansion Planning

When wind / solar are preferred investments,

- Wind and/or solar will be overbuilt
- Fast ramping units will be underbuilt

unless reserve constraints are modeled:

REGULATING RESERVES

CpbltyRegUpRsrvs>k_1[1min netload 3*standard deviation]

CpbltyRegDownRsrvs>k_2[1min netload 3*standard deviation]

10-MIN LOAD FOLLOWING

CpbltyLF,UpRsrvs>k_3[10min netload 3*standard deviation]

CpbltyLF,DownRsrvs>k_4[10min netload 3*standard deviation]

10-MIN CONTINGENCY RESERVES

Cpblty10MRsrvs>k_5[10min contingency reserve requirement]

30-MIN SUPPLEMENTARY RESERVES

Cpblty30MRsrvs>k_6[30min contingency reserve requirement]

*V. Krishnan, *T. Das, *E. Ibanez, *C. Lopez, and J. McCalley, "Modeling Operational Effects of Variable Generation within National Long-term Infrastructure Planning Software," Vol. 28, Issue 2, *IEEE Trans on Power Systems*, 2013, pp. 1308-1317.

Enforcing Flexibility in Expansion Planning

TECHNOLOGY	WITHOUT OPERATIONAL CONSTRAINTS (GW)	WITH OPERATIONAL CONSTRAINTS (GW)
NUCLEAR	491.1	491.3
NG COMBINED CYCLE	246.6	253.3
NG COMBUSTION TURBINE	13.2	106.4
SOLAR PV	7.5	7.5
SOLAR THERMAL	3.0	3.5
WIND	375	368.4
GEOTHERMAL	173.6	175.5
OTEC	5.0	5.0
TIDAL	3.0	3.0

*V. Krishnan, *T. Das, *E. Ibanez, *C. Lopez, and J. McCalley, "Modeling Operational Effects of Variable Generation within National Long-term Infrastructure Planning Software," Vol. 28, Issue 2, *IEEE Trans on Power Systems*, 2013, pp. 1308-1317.

Reliability

Reliability of a power system refers to the probability of its satisfactory operation over the long run. It denotes the ability to supply adequate electric service on a nearly continuous basis, with few interruptions over an extended time period.
- IEEE Paper on Terms & Definitions, 2004

Reliability is about avoiding interruptions.

"90% of customer outage minutes due to distribution system, in small local events" [1.]

➔Transmission is not a significant cause of interruptions.

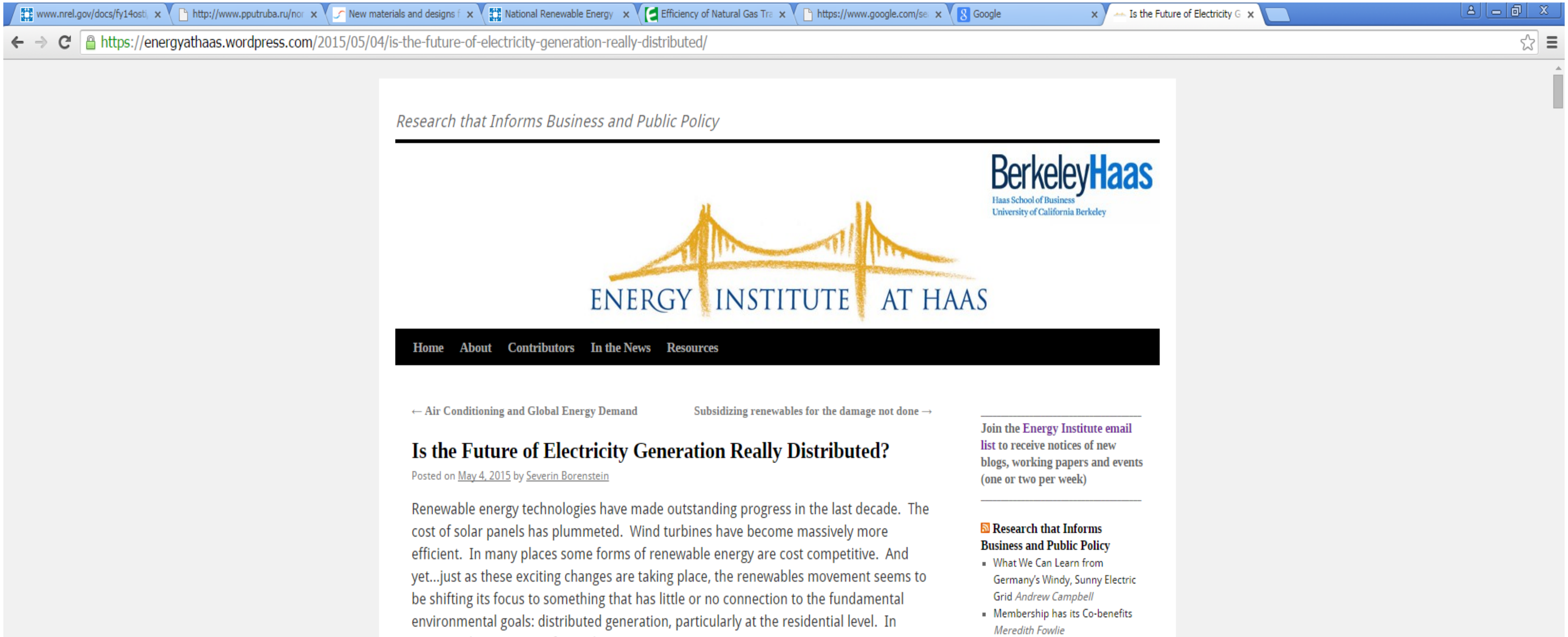
It is commonly thought that DG helps reliability, but…

- **Does DG become a common-mode failure?**
  - **The problem with Sandy was loss of D, not loss of G or T.**
  - **What if NE had 20% rooftop solar during Sandy?**
- **What does DG do to maintenance requirements?**

➔One centrally maintained 1000 MW plant or a thousand individually maintained 1 MW plants?

1. Alison Silverstein, Transmission 101, National Association of Regulatory Utility Commissioners, April 20, 2011, p. 30, www.naruc.org/grants/Documents/Silverstein%20NCEP%20T-101%200420111.pdf

Another View: Severin Borenstein



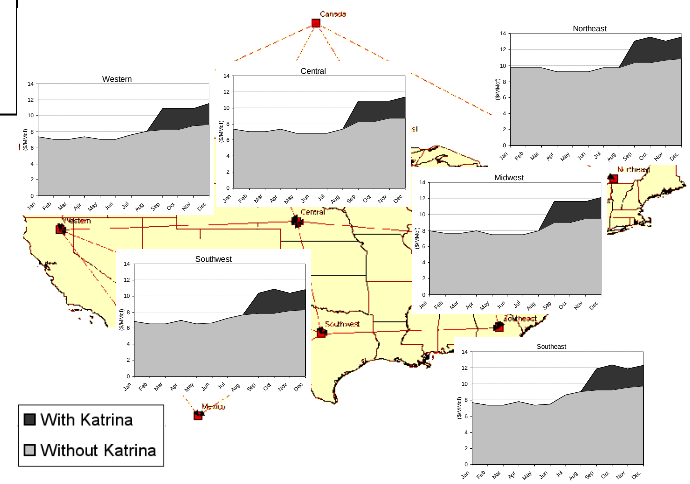
"That's not to say that distributed generation couldn't be the best way for some people at some locations to adopt renewables, but simply that DG should not be the goal in itself. We desperately need to reduce greenhouse gases from the electricity sector, not just in the U.S., but around the world, including some very poor countries where affordability is a real barrier and electricity access is life-changing. If DG is the least costly way to get that done, I'm in, but the choice should be driven by real cost-benefit analysis, not slogans about energy freedom."

https://energyathaas.wordpress.com/2015/05/04/is-the-future-of-electricity-generation-really-distributed/

Resilience

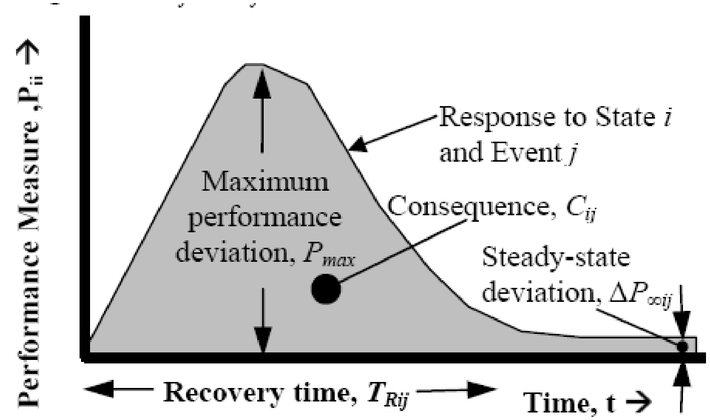
<u>Resilience</u>: Ability to minimize & recover from price-consequences of extreme events [1]

EXAMPLE: KATRINA/RITA [2]



<u>Other examples</u>:

- **6 mnth loss of rail access to Powder River Basin coal;**
- **1 yr interruption of 90% of Middle East oil;**
- **6 mnth interruption of Canadian gas supply;**
- **1 yr loss of US hydro due to extreme drought;**
- **Sustained flooding in Midwest destroying crops, reducing biofuels, interrupting E-W rail system.**



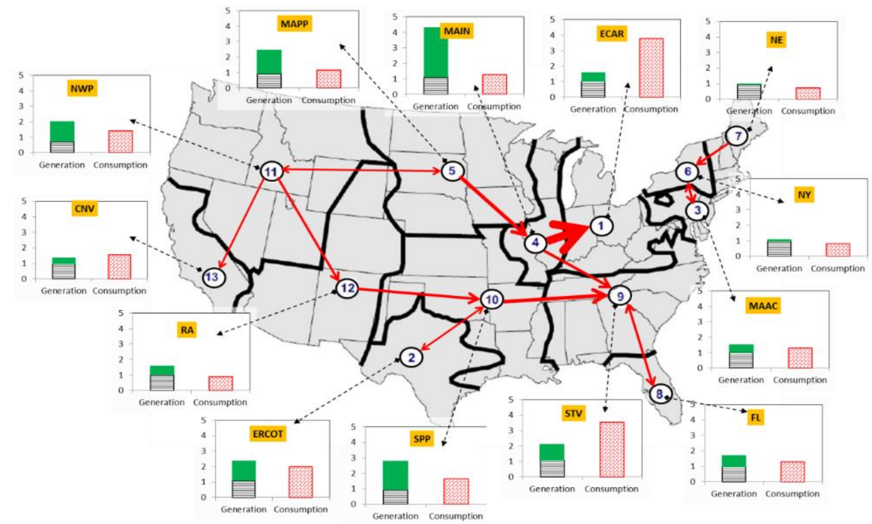
Resilience metric for an event & state

[1] E. Ibanez, V. Krishnan, S. Lavrenz, D. Mejia, K. Gkritza, J. McCalley, & A. Somani, "Resilience and robustness in long-term planning of the national energy and transportation system," to appear in *International Journal of Critical Infrastructures*, 2014.

[2] E. Gil and J. McCalley, "A US Energy System Model for Disruption Analysis: Evaluating the Effects of 2005 Hurricanes," *IEEE Transactions on Power Systems*, Volume: 26 , Issue: 3, 2011, pp. 1040 – 1049.

Resilience

<u>Experiment</u>: For a 40 year investment strategy, simulate total failure of each of 14 generation technologies at year 25.
Did this with national transmission expansion and without.
<u>Resilience metric:</u> Averaged the 1 year operational cost increase across 14 events with respect to the no-event case.

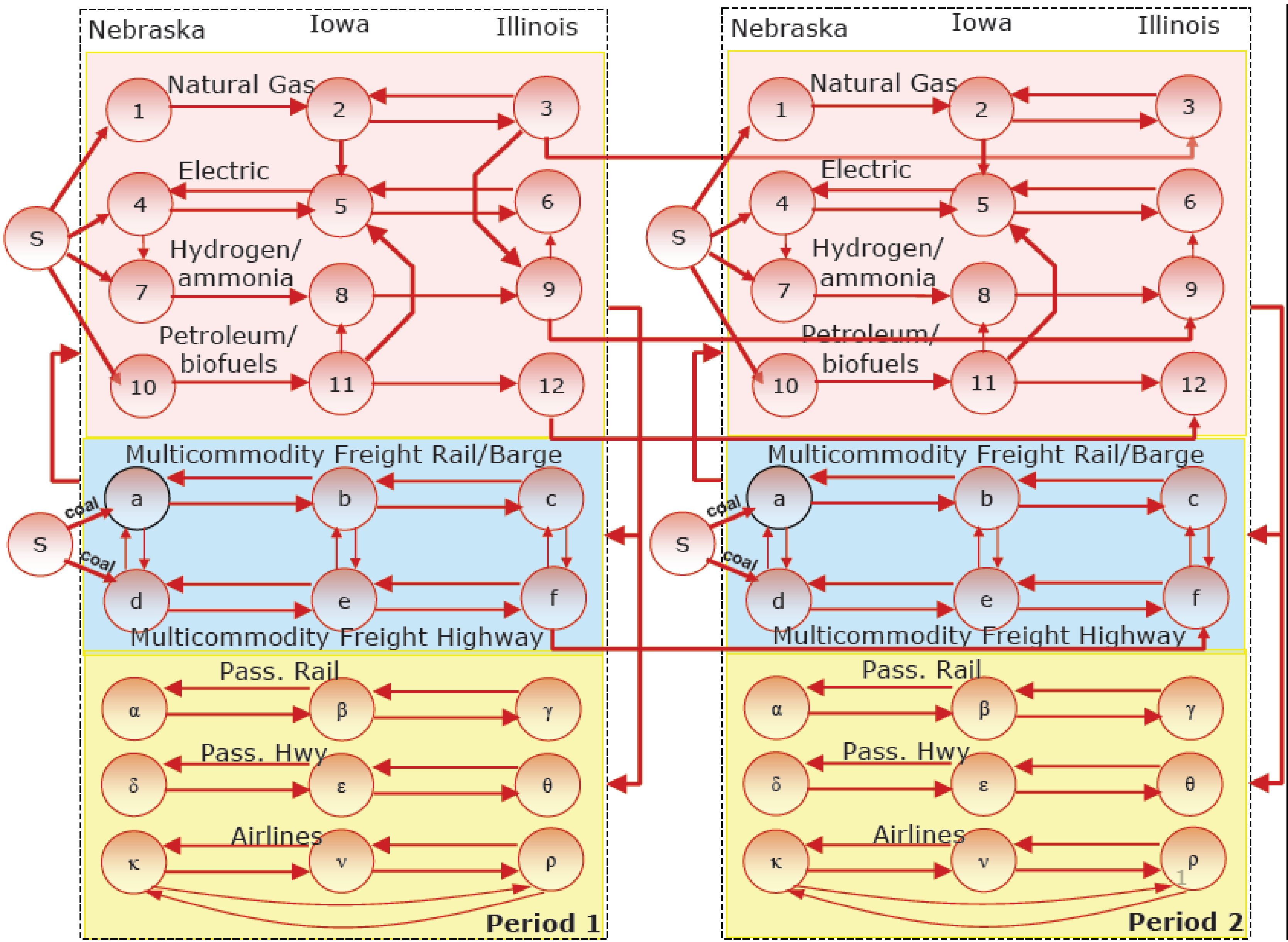


Societal consequence
=$5B without trans expansion
=$450M with trans expansion

WHY? **RESILIENCE (AND ADAPTABILITY) IMPROVES WITH**

- **INTERCONNECTEDNESS**
- **DIVERSIFICATION**

The Integrated Energy System



The Flex Fuel Poly-Generation (FFPG) Power Plant

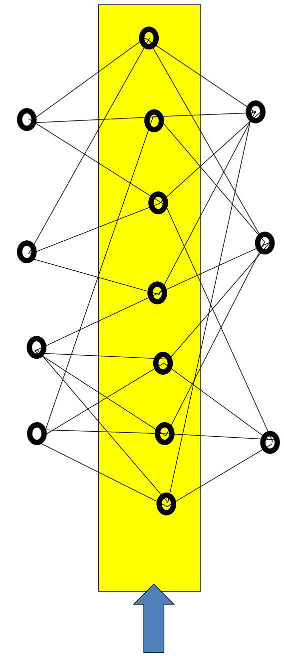
Coal
Natural gas
Biomass
Wind
Solar
Geothermal
Hydrogen

→

Flex Fuel Poly-generation Plant

→

Power
Heat
Syngas
Liquid Fuels



Multi-input, multi-output energy converters

FFPG power plants are multiple input, multiple output energy converters; in the multi-grid network, they are nodes with multiple connections, increasing the density of the multigrid network; thus enhancing resilience.

Adaptability

<u>Adaptability</u>: Ability to economically adapt infrastructure to adverse & permanent changes in technology/fuel availability or cost.

➔A "long-term" version of resilience.

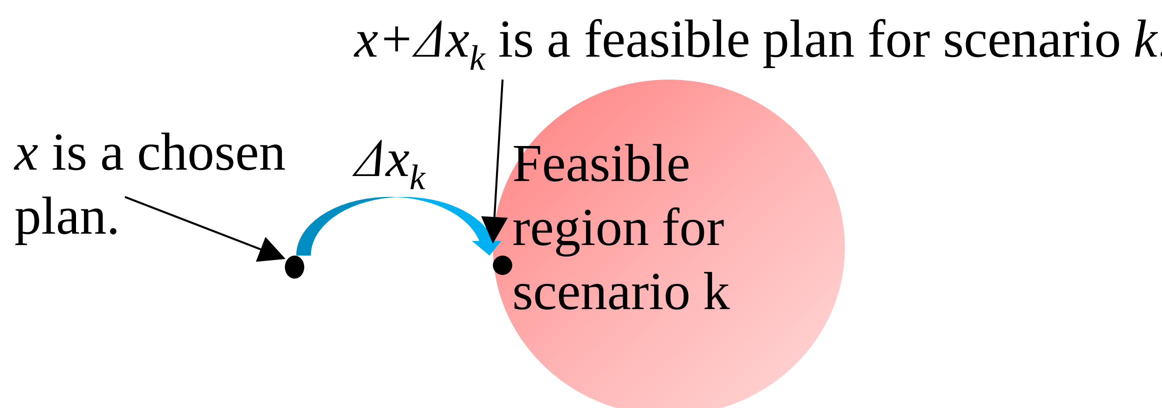
<u>Examples</u>:

- **Permanent loss of U.S. nuclear supply, like Fukushima**
- **Permanent loss of shale gas supply;**
- **Government-imposed elimination of all GHG-emitting electric resources**

Adaptation is the additional *<u>investment</u>* necessary for plan x to acceptably perform under scenario k:

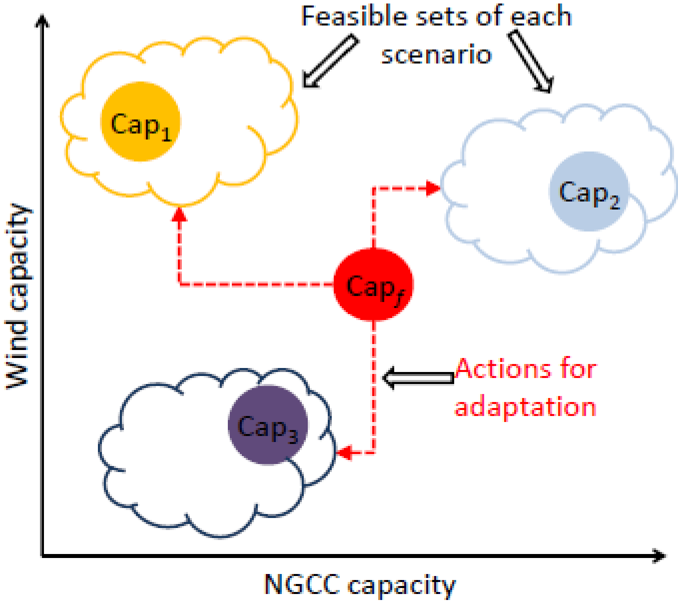
- **the adaptation cost of additional investment is AC(Δx_k)**
- **Δx_k=0 if plan x is designed under scenario k**

The <u>adaptation cost</u> of *x* to scenario *k* is the minimum cost to move *x* to a feasible design in scenario *k*.
It measures the additional cost of our plan *x* if scenario *k* happens.



What is adaptation? (Single-period)

β determines the dependency on adaptation:
Small β➔high adaptation costs
High β➔low adaptation costs



Minimize:

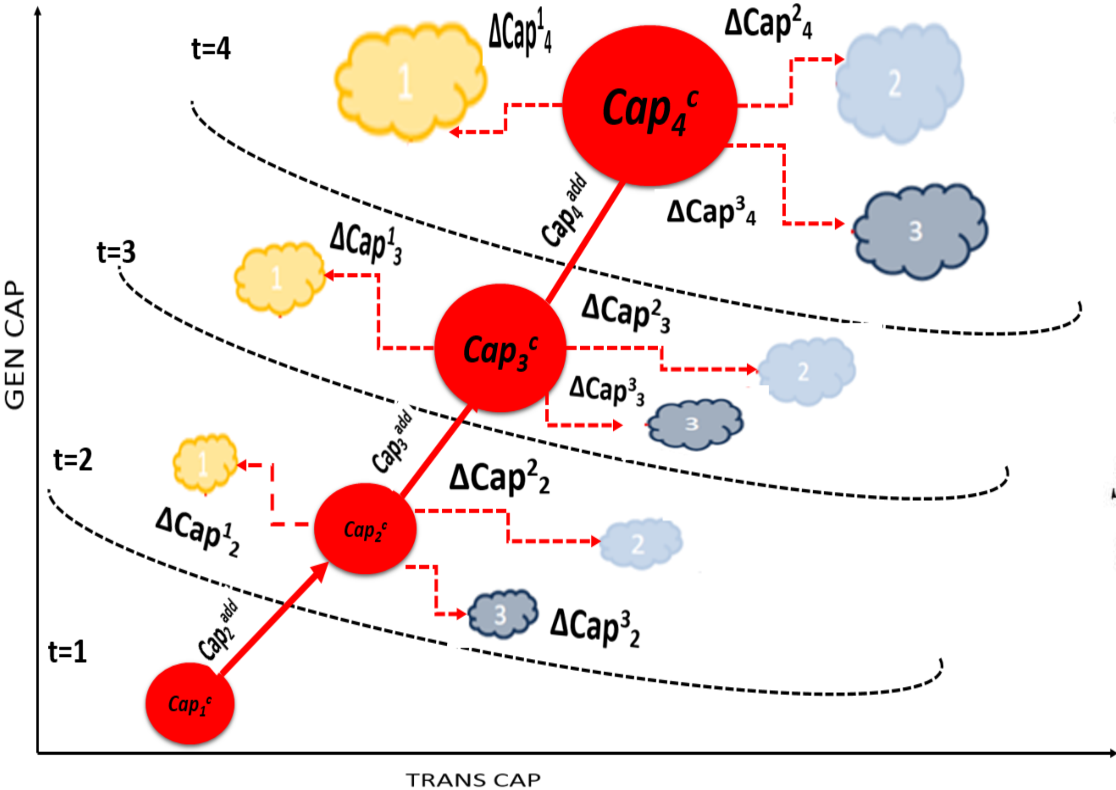
CoreCosts($\underline{x}$)+β[Σ_k AdaptationCost($\Delta\underline{x}_k$)]

Subject to:

Constraints for scenario k=1,…N: $\underline{g}_k(\underline{x}+\Delta\underline{x}_k)\leq\underline{b}_k$

$\underline{\mathbf{x}}$: Core investments, to be used by all scenarios k
$\Delta\underline{\mathbf{x}}_k$: Additional investments needed to adapt to scenario k

What is adaptation? (Multi-period)



$$\mathit{Minimize} \sum_{t} \text{Core Investment cost}$$
$$+\sum_{s} P^{s} \sum_{t} \text{Operating cost}$$
$$+\beta \sum_{s} P^{s} \sum_{t} \text{Investment adaptation cost}$$

subject to

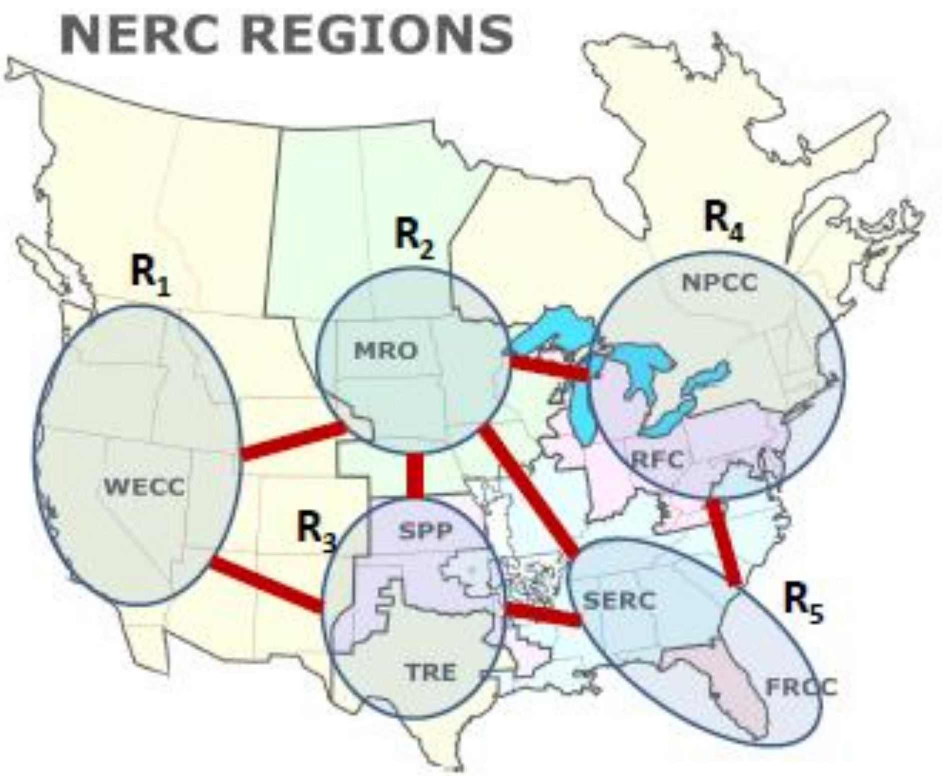
Operational constraints for each scenario s.

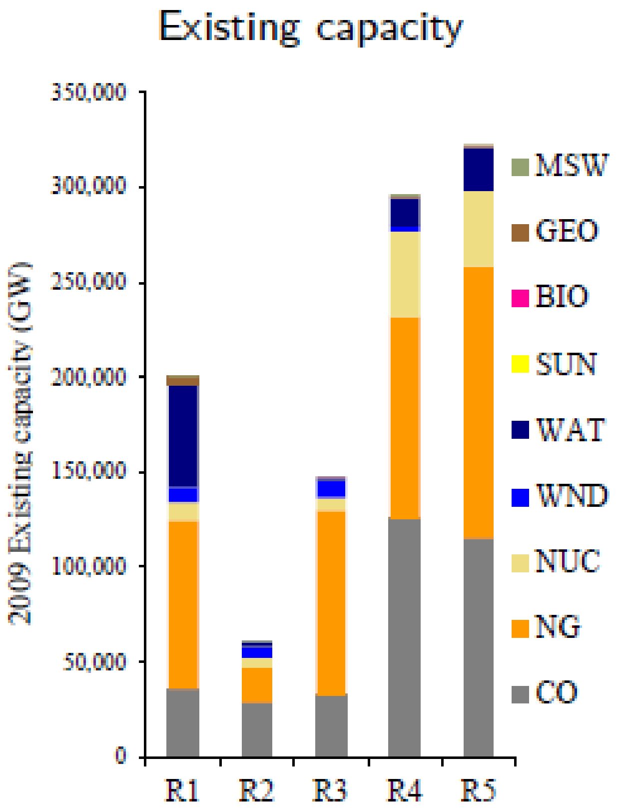
“Futures” through time must be designed in terms of the uncertainties. Then we minimize core plus adaptation costs to identify the core investment.

[1] D. Mejia-Giraldo and James McCalley, “Adjustable decisions for reducing the price of robustness of capacity expansion planning," *IEEE Transactions on Power Systems*, Vol. 29, Issue 4, 2014, pp. 1573-1582.

[2] D. Mejia-Giraldo and J. McCalley, “Maximizing future flexibility in electric generation portfolios," *IEEE Transactions on Power Systems*, Vol. 29, Issue 1, 2014, pp. 279-288.

Illustration





Identify flexible generation expansion plan over 40-year planning horizon.

Futures

Cluster	Gas price GP	Gas production limits GPL	Demand D	RPS	CO_2^{cap}	Wind investment cost WC
Benchmark	L	No	L	No	No	H
1	L	No	L	No	No	L
2	L	No	L	Yes	No	H
3	L	No	L	Yes	Yes	L
4	L	No	H	No	Yes	H
5	L	Yes	L	Yes	Yes	H
6	H	No	L	Yes	Yes	L
7	H	No	H	No	Yes	L
8	H	Yes	L	No	No	L
9	H	Yes	L	Yes	Yes	H
10	H	Yes	H	Yes	No	H

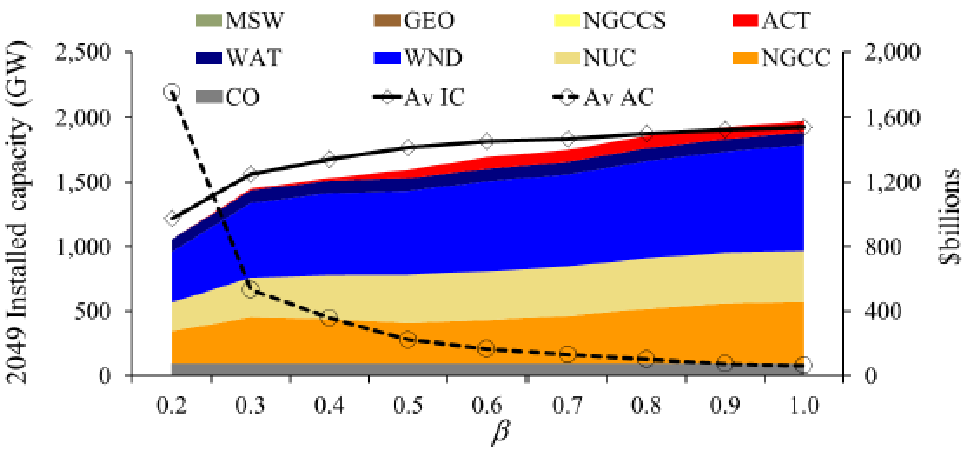
GEP Solution

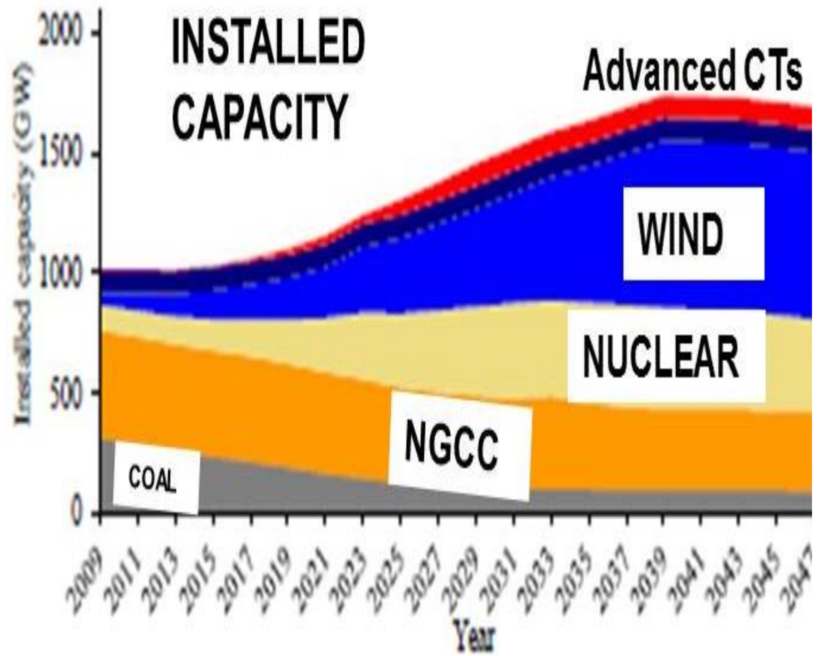
$$Minimize \sum_{t} \text{Core Investment cost} + \sum_{s} P^{s} \sum_{t} \text{Operating cost} + \beta \sum_{s} P^{s} \sum_{t} \text{Investment adaptation cost}$$

subject to

Operational constraints for each scenario s.

For β=0.6





Adaptability means, in this particular design:

- **Increase combustion turbines, wind, nuclear**
- **Maintain NGCC**
- **Retire Coal**

Adaptability

Electric system expansion plans can be:

- **Highly robust**: Performs well under all of the different scenarios (but not very economic ☹);
- **Highly economic**: Very good for a single “most likely” future (but not very robust ☹);
- **Adaptable**: Something in between, economic, while using adaptability to achieve robustness ☺.

Economies of Scale

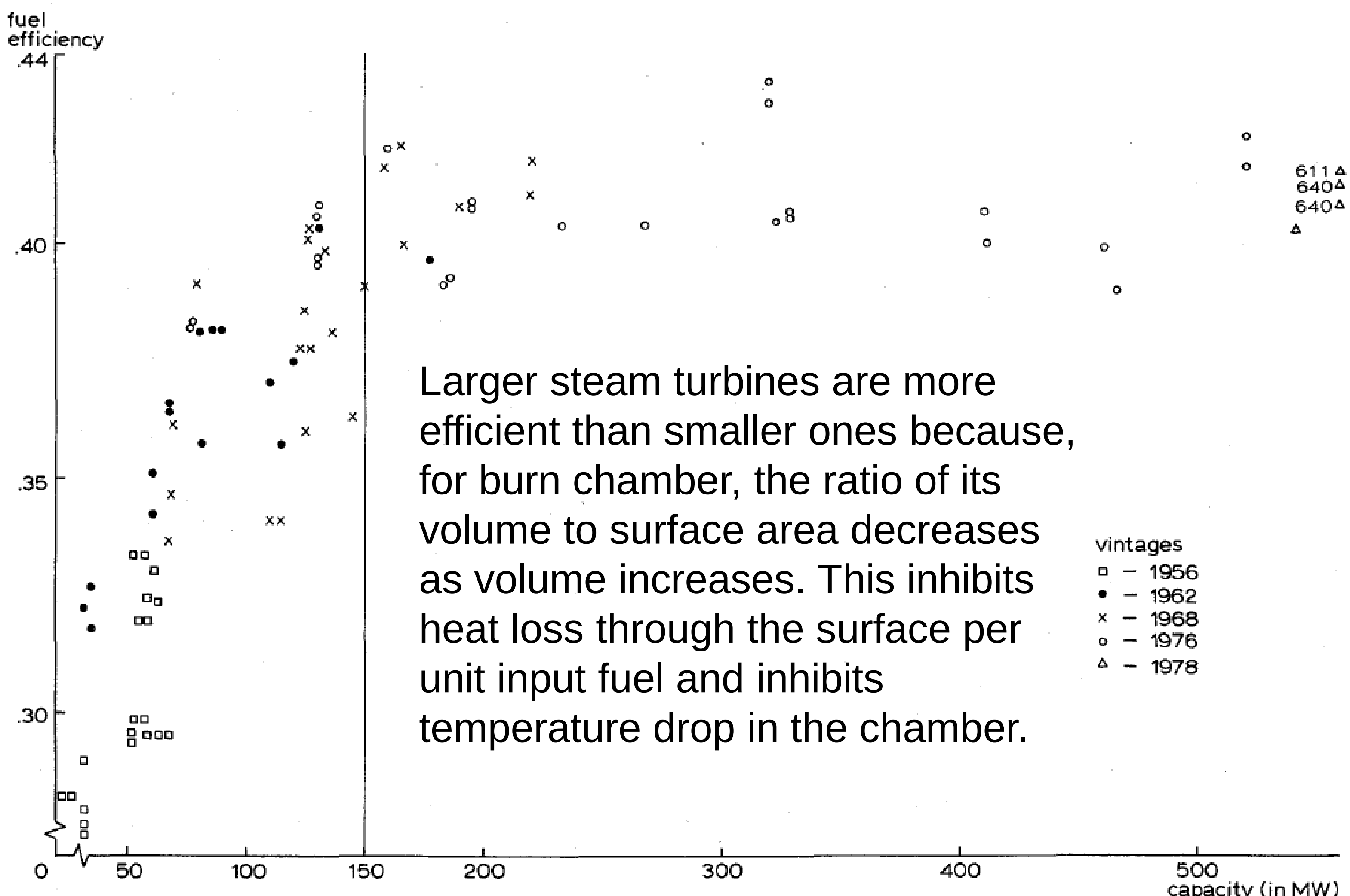
1903 Samuel Insull understanding economies of scale (generators when scaled up produce power at a lower average $/kWhr) installs 5 MW generator in Chicago and manages load to increase his load factor (avg load/max load) to increase profits.

1907 Insull realizes that profitability from managing economies of scale and load factor grows with corporate size, and so forms Commonwealth Edison, Chicago, by buying all of his competitors.

Economies of scale are economic efficiencies that result from carrying out a process (such as power generation) on an increasingly larger scale. They arise when an increase in output reduces average costs. For power plants, they can occur from

- Decreasing average fixed O&M cost with size (labor cost per MW for maintenance is lower for a 100 MW wind plant than for a 10 MW wind plant).
- Decreasing average investment cost with size (installation cost per MW is lower for a 100 MW wind plant than for a 10 MW wind plant).
- Decreasing average fuel cost with size (see next slide)

Economies of Scale



Larger steam turbines are more efficient than smaller ones because, for burn chamber, the ratio of its volume to surface area decreases as volume increases. This inhibits heat loss through the surface per unit input fuel and inhibits temperature drop in the chamber.

Figure 2 – The relationship between capacity and fuel efficiency for different vintage groups.

G. Van Helden and J. Muysken, "Economies of scale and technological change in electricity generation in the Netherlands," De Economist 129, NR. 4, 1981.

Economies of Scale

Make investment & retirement decisions to MINIMIZE…

PRESENT WORTH

Investment costs
+ Fixed O&M Costs
+ Var O&M Costs
+ Environmental Costs

SUBJECT TO:

Operational & environmental constraints on energy, fuels, transportation, water

Uncertainty characterization

Year 1 | **Year 2** | **. . .** | **Year N**

MAKE THESE A FUNCTION OF SIZE, WHERE SIZE IS A DECISION VARIABLE

A Scaling Model

$$C_{js} = c_j \times \left(CAP_{js}\right)^{\alpha_j}$$

Investment cost coefficient of technology j of capacity s, \$/MW.

Reference investment cost coefficient of technology j, \$/MW, i.e., it is investment cost coefficient for α_j=0.

Capacity of technology j at size s.

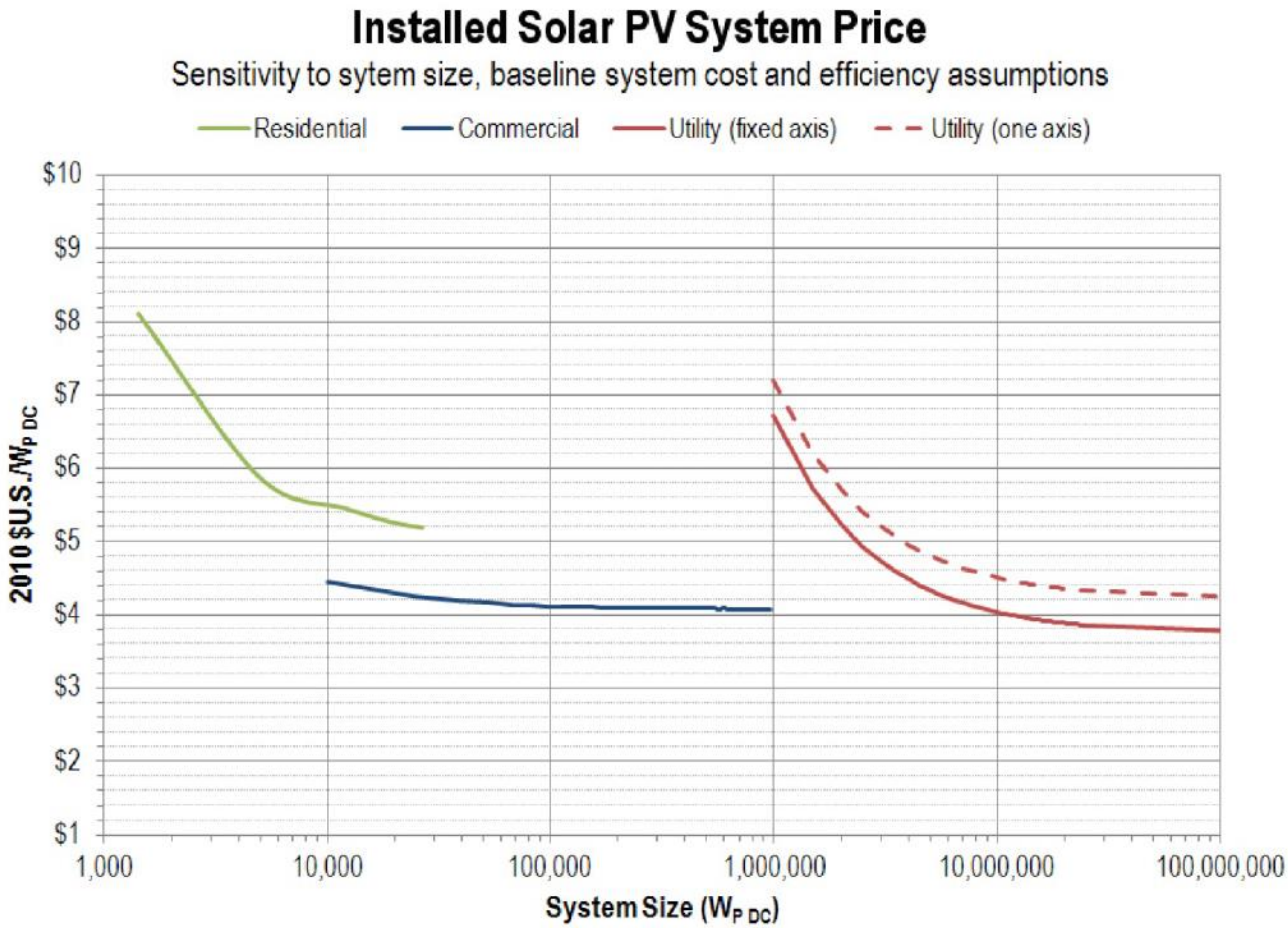
Scaling parameter for technology j.

α_j=0 gives constant investment regardless of size.

α_j<0 gives economies of scale.

$$\log C_{js} = \log c_j + \alpha_j \log CAP_{js}$$

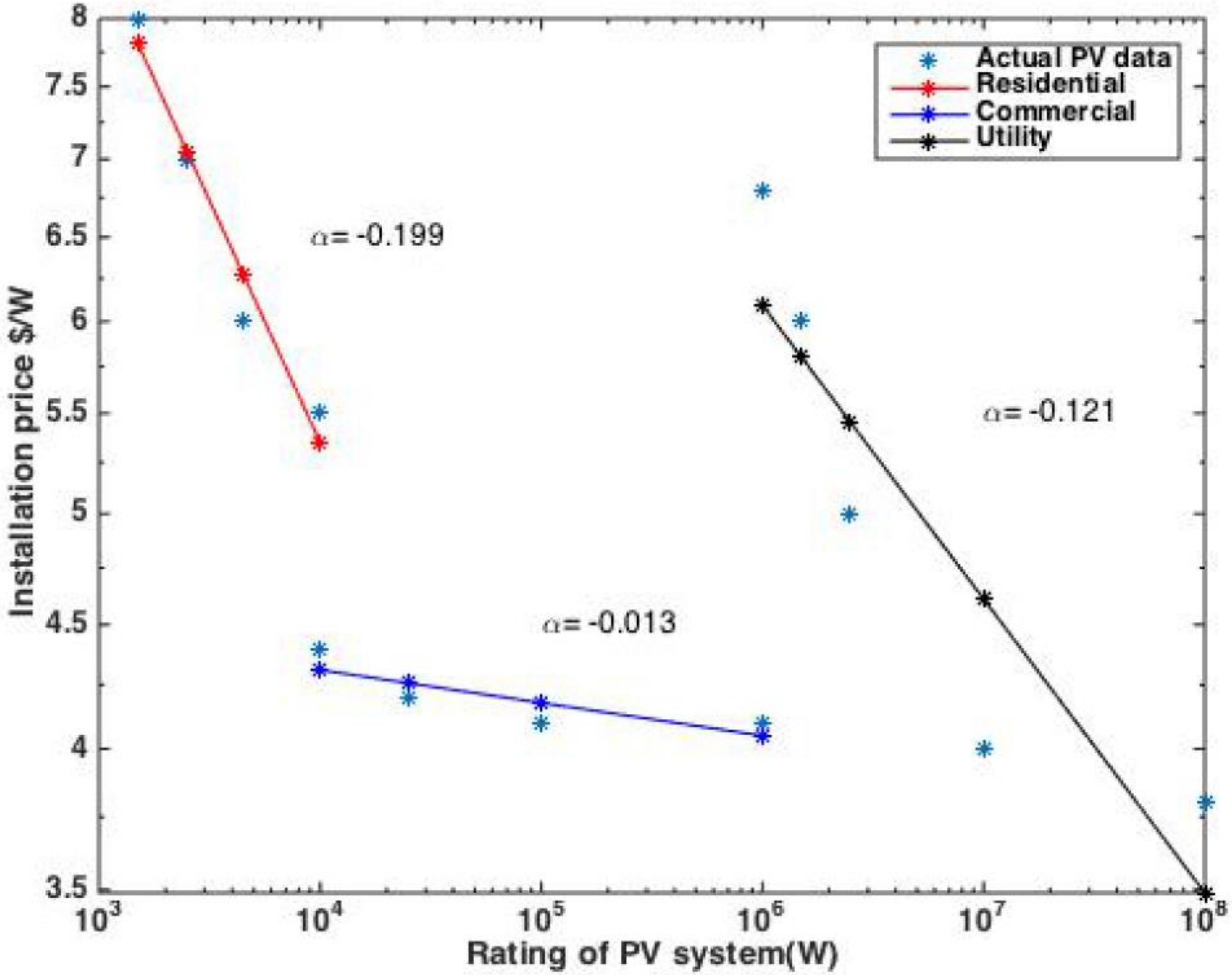
A Scaling Model



A. Goodrich, T. James, and M. Woodhouse, "Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities," NREL/TP=6A20-53347, Feb., 2012, available at http://www.nrel.gov/docs/fy12osti/53347.pdf.

A Scaling Model

$$\log C_{js} = \log c_j + \alpha_j \log CAP_{js}$$



A Generation Expansion Problem

$$\min \underbrace{\sum}_{\substack{\text{node}\\ n}} \underbrace{\sum}_{\substack{\text{tech}\\ j}} \underbrace{\sum}_{\substack{\text{size}\\ s}} \underbrace{\sum}_{\substack{\text{time}\\ t}} u_{njst} \underbrace{C_{js} CAP_{js}}$$

C_{js}, CAP_{js} are discrete points of various size taken from functions on previous slide. The product gives the cost in $ of choosing technology j at size s.

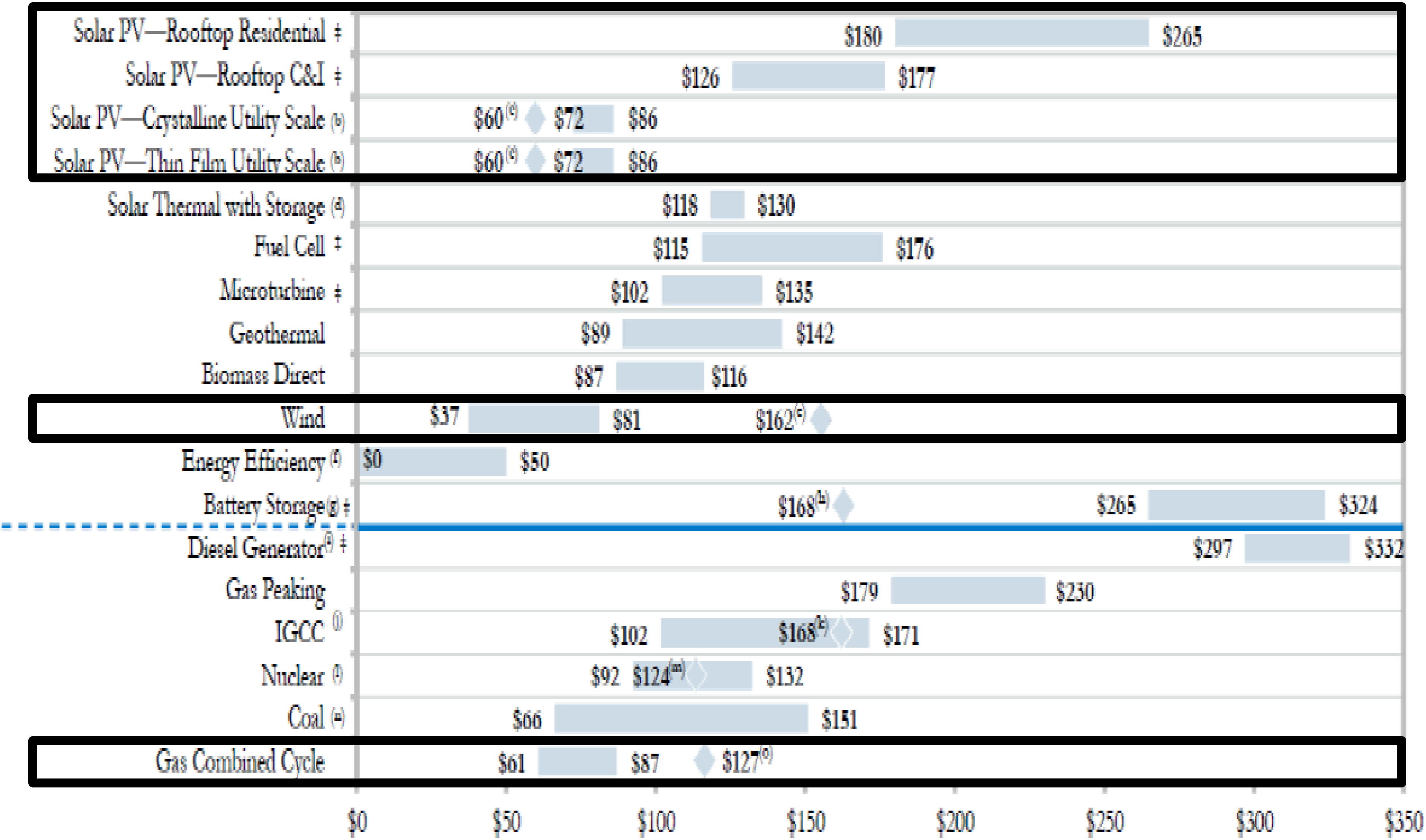
Subject to
- u_{njst} is integer
- DC power flow network constraints
- Flow limits

- This problem will not only compete different technologies (as is usual in GEP) but also different technologies at different sizes, e.g., very small solar against very large NGCC plants.
- We need to extend the problem to co-optimize G, T, D in order to see the effect of different generation sizes on the network.

Other influences

1. **Economies of number:** DG may increase innovation because of the need for producers and operators to specialize, the necessity to find solutions tailored to local contexts and the opportunity of mutual learning, and cost reductions gained via the ability to enhance manufacturing processes based on high volume production (economies of number).
2. **Influence on technology maturation:** The cost of any technology can be driven down by investing in that technology through (a) research and (b) usage subsidies, but such cost reductions in some technologies may be more readily achieved than others.
3. **Consumer preferences:** Is there preference for being “small”? Is there preference for autonomy? How to account for this in our designs.
4. **Market-based?** Can we “do” de-carbonization in the market? Is it a public good? Can cap and trade work?

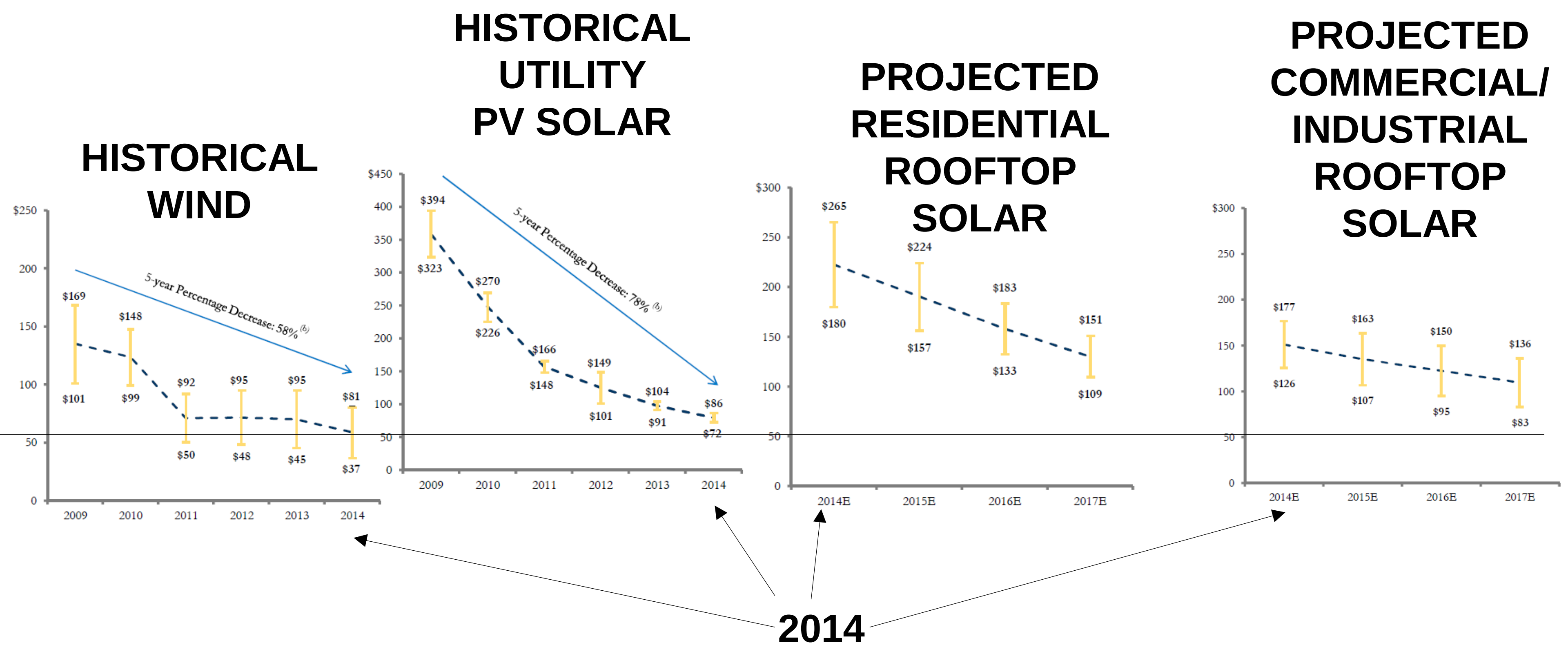
What do investors think about technologies



Lazard's levelized cost of energy analysis- Version 8.0, September 2014, available
http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf

What do investors think about technologies

- Historical utility PV has tracking; rooftop has tracking at hi end, fixed tilt at low end
- Each yr range of LOCEs reflect CFs for wind; CF/tracking (hi) fixed tilt (lo) for solar
- Lower range comparison indicates best we can do:
  - Midwestern wind: $37 in 2014
  - PV solar in southwest w/tracking: $72 in 2014
  - Residential rooftop solar in southwest w/tracking: $109 in 2017
  - Commercial/industrial rooftop solar in southwest w/tracking: $83 in 2017



Lazard's levelized cost of energy analysis- Version 8.0, September 2014, available
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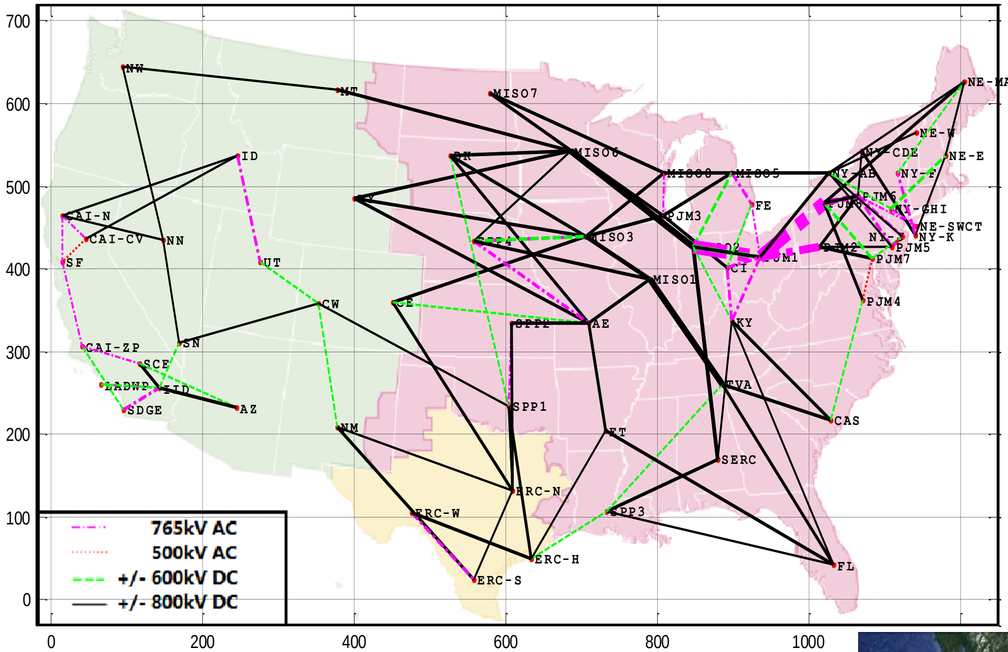
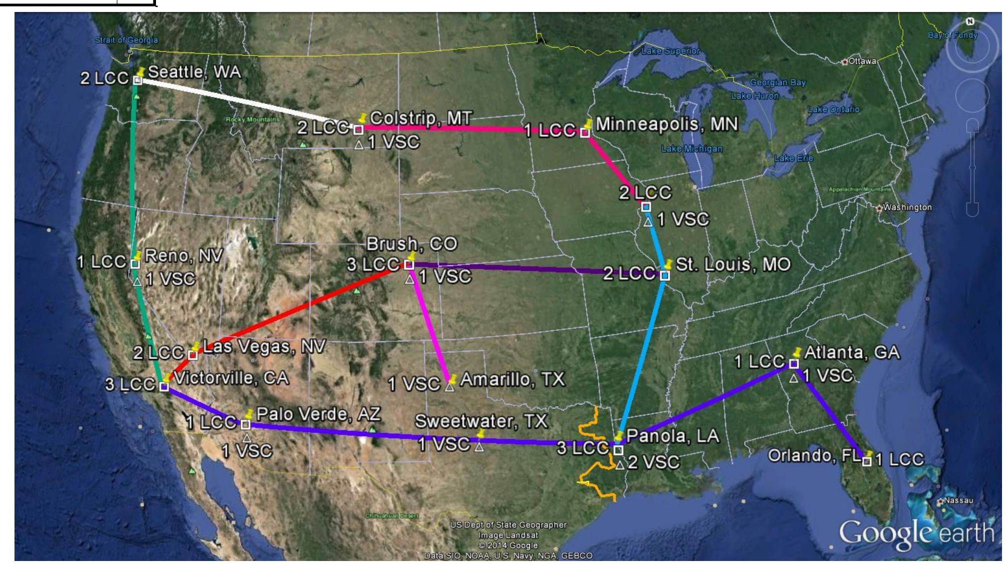
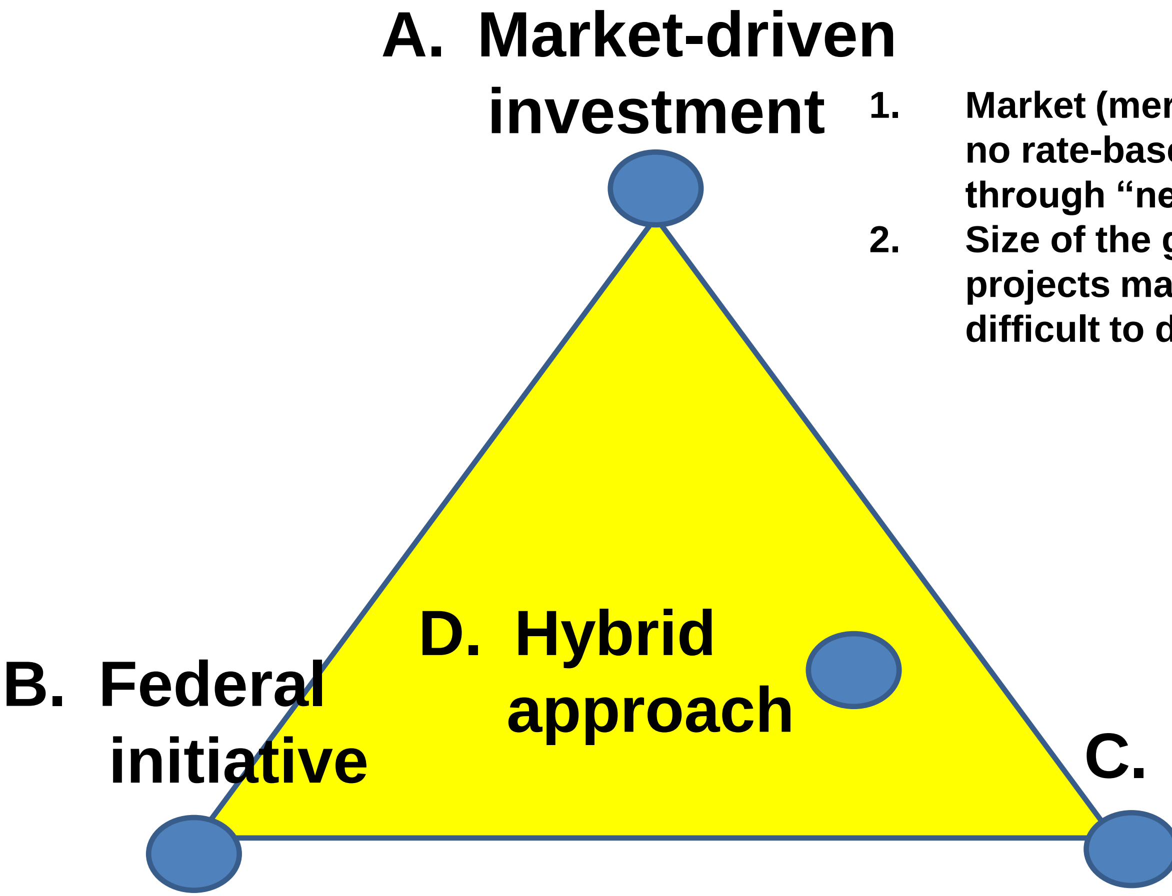
Solutions at/above the regional level?





Paths forward: frameworks



A. Market-driven investment

1. Market (merchant)-driven investment: no rate-base recovery, costs recovered through "negotiated rates."
2. Size of the groups to form for overlay projects may need to be very large and difficult to develop/manage.

B. Federal initiative

1. Similar to interstate highway system, where Feds paid 90% via gasoline tax, states 10%. States managed program for location, design, ROW acquisition, construction, O&M.
2. Differences: (a) Transmission "pass-through" feature is not shared with interstate highway system; (b) Economic development more at sending end.

C. Multiregional coordination

1. Establish permanent multiregional stakeholder group consisting of industry, state governments, advocacy groups to address:
2. States need to see benefit for taking multiregional view.
3. The above is evolving.

Paths forward: Frameworks
D. Hybrid approach

1. **Design it using multiregional collaborative stakeholder group of industry, states, advocacy, DOE, supported by Governors Associations. Impasses addressed by federally-appointed arbiters. Compensate losers.**
2. **Incentivize merchant transmission developers to build consistent with design ➔A "transmission market"?**
3. **Federalize what merchant developers will not or cannot build, but with careful Fed-State coordination and cooperation.**

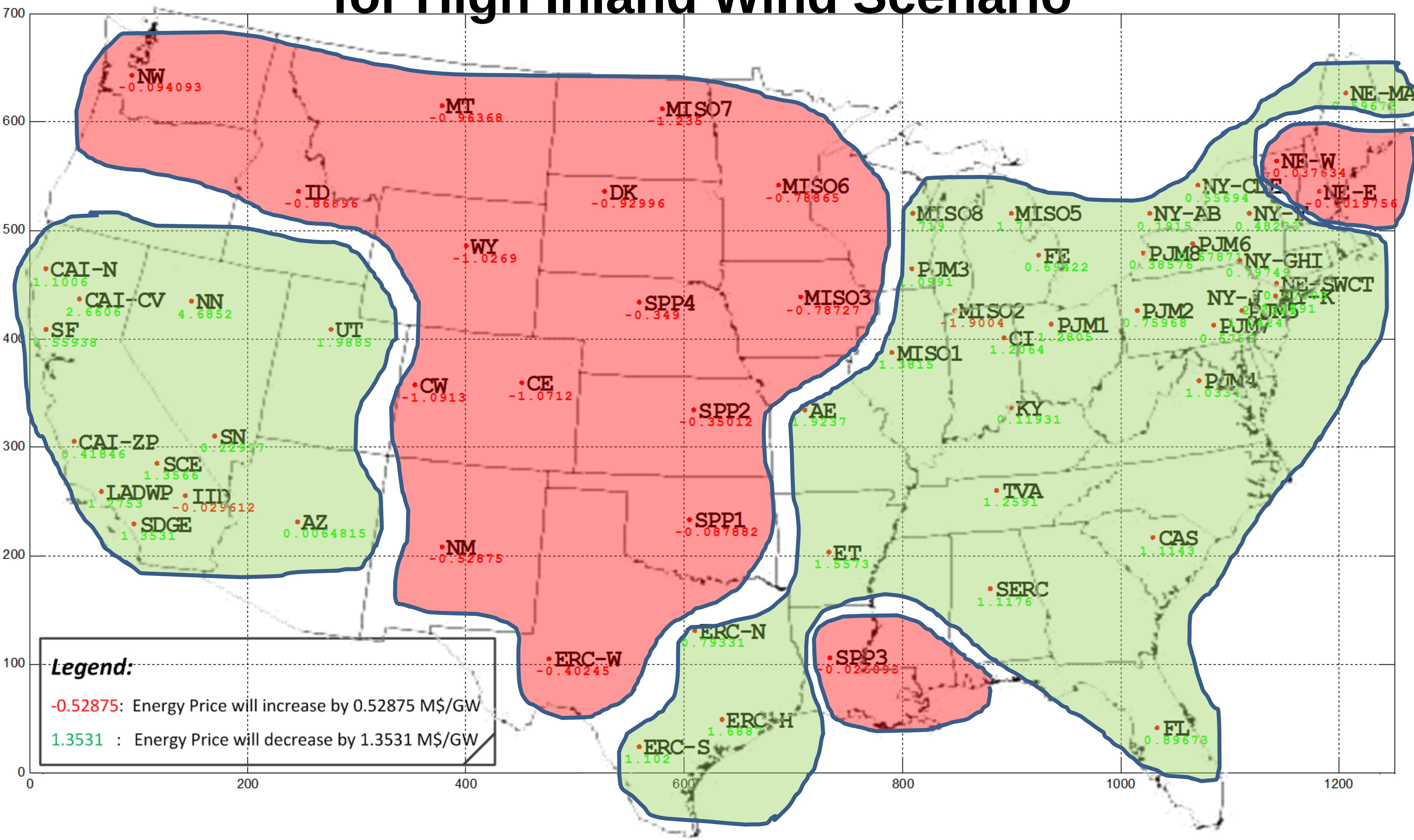
Resource Parochialism?

“One problem,” he said, is “resource nationalism,” in which individual states want to use local resources, whether they are coal or yet-to-be-built offshore wind, rather than importing from neighbors in a way that could be more economical.

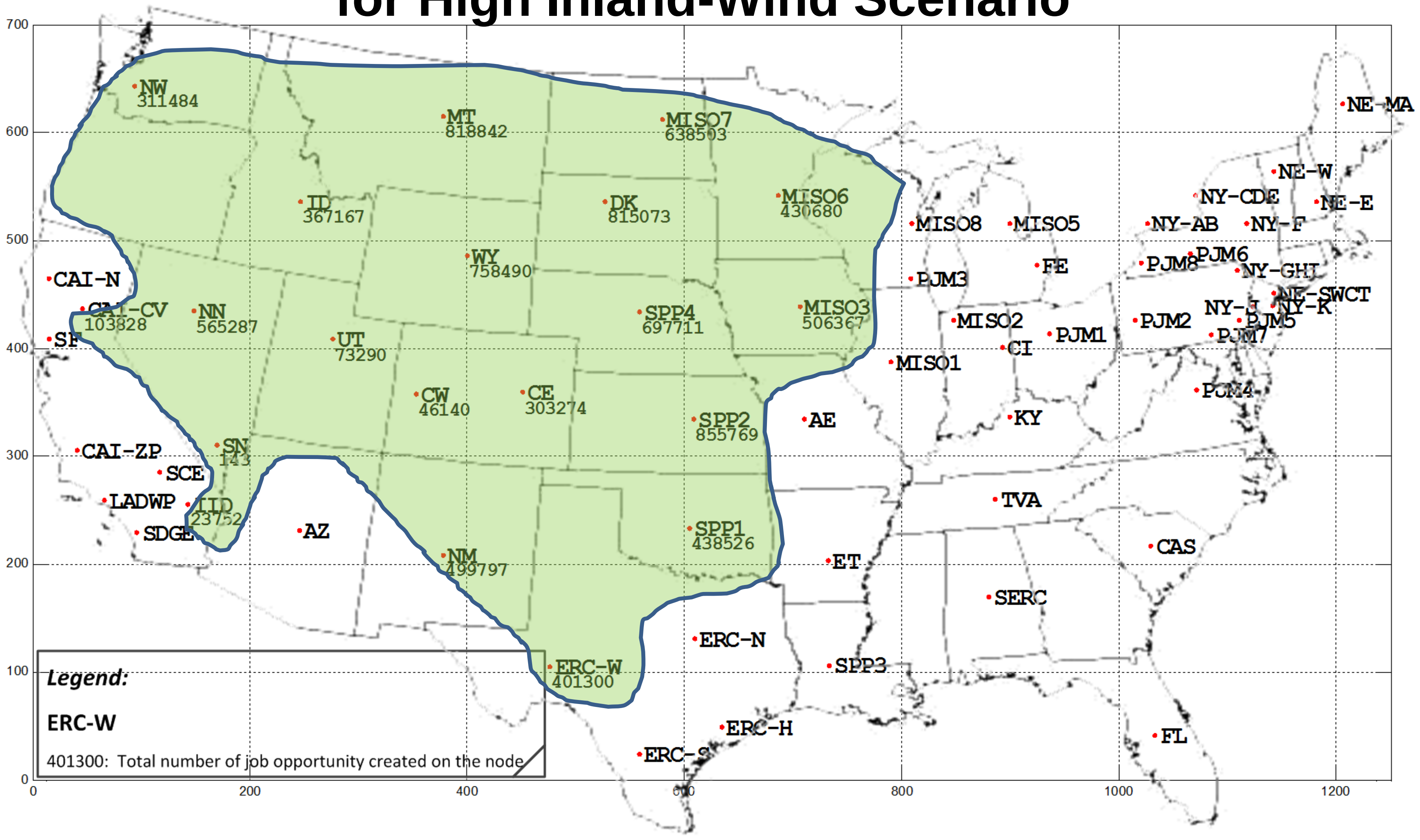
James Hoecker,
FERC Commissioner 1993-2001,
FERC Chair 1997-2001

in Matthew L. Wald, “Ideas to Bolster Power Grid Run Up Against the System’s Many Owners,” NY Times, July 12, 2013, www.nytimes.com/2013/07/13/us/ideas-to-bolster-power-grid-run-up-against-the-systems-many-owners.html?emc=eta1&_r=1&

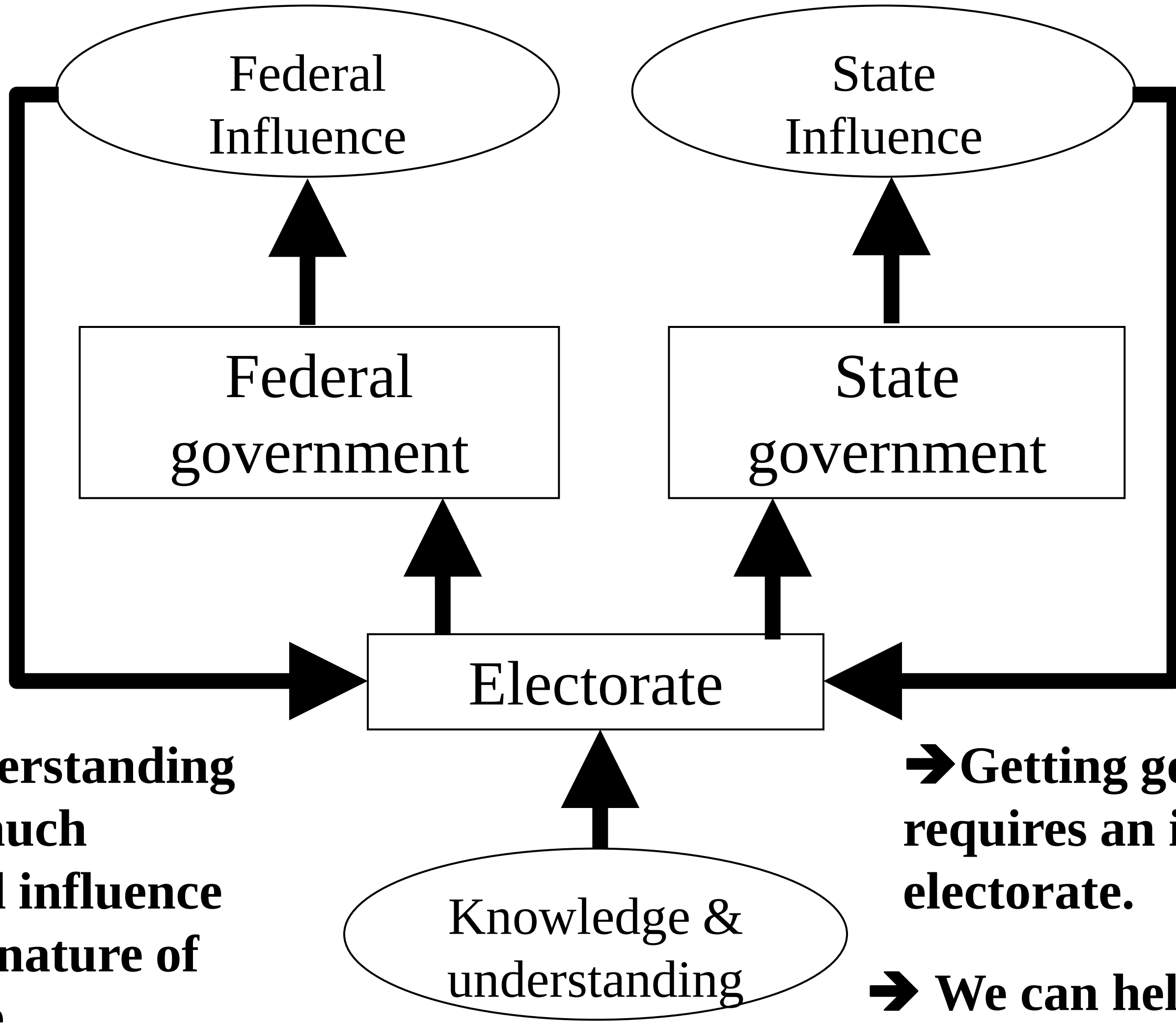
Impact of Transmission Expansion on Average LMPs for High Inland Wind Scenario



Impact of Generation Expansion on Job Creation for High Inland-Wind Scenario



Public Education and Policy



➔**Public understanding affects how much governmental influence occurs & the nature of that influence.**

➔**Getting good policy requires an informed electorate.**

➔ **We can help electorate (& policy-makers) see the impact on their lives of various infrastructure designs.**

Where infrastructure is very different