Transmission Design at the National Level: Benefits, Risks and Possible Paths Forward

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PSERC Future Grid Initiative Webinar
January 24, 2012

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Preliminaries

This white paper should not be perceived as either supporting or opposing development of a national transmission overlay. Rather, it frames the discussion and provides objective information to use in further considerations.

The objective of this paper is to identify benefits to building a national transmission overlay, to lay out essential elements to facilitate continued dialogue on this topic, and to frame possible paths by which it could be realized.

Acknowledgments:

- **US Department of Energy (DOE)**
- **Power System Engineering Research Center (PSERC)**
- **Jim Bushnell, Venkat Krishnan, Santiago Cano**
- **Seven industry reviewers (listed in white paper)**

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Outline

- Introduction
- Essential background
- Potential benefits
- Engineering considerations
- Issues and concerns
- Possible paths forward
- Conclusions

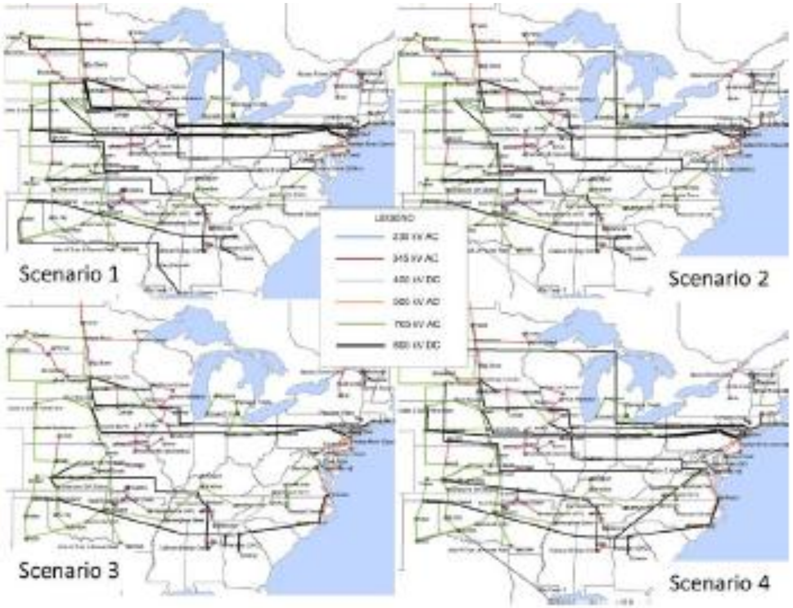
Introduction

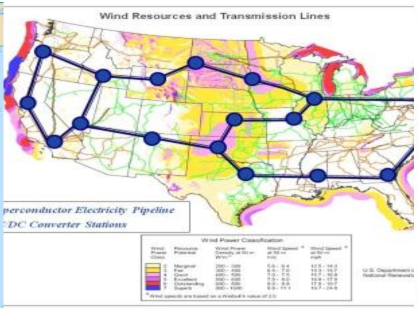
- **2002, ‘06, ‘09 DOE Congestion Studies**
- **2005 Energy Power Act: DOE responsible for designating “national interest corridors” (NICs). FERC obtains siting authority on NICs if state fails to approve a transmission application.**
- **ARRA-funded interconnection planning EI, WECC, ERCOT**
- **July 2011: FERC Order 1000**

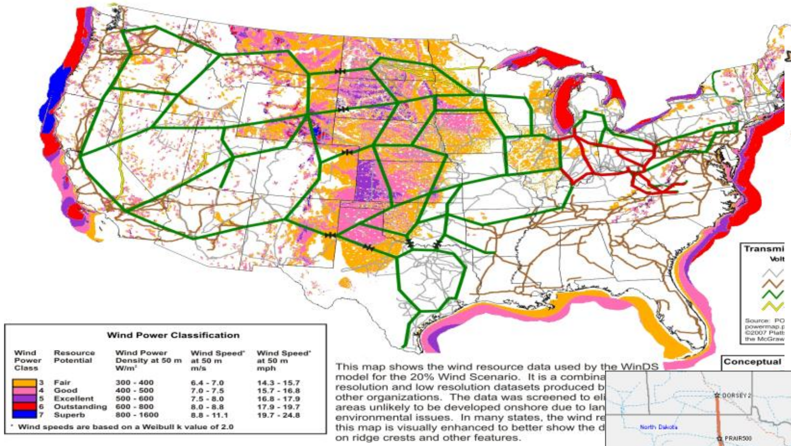
➔Interregional Transmission Planning Requirements:

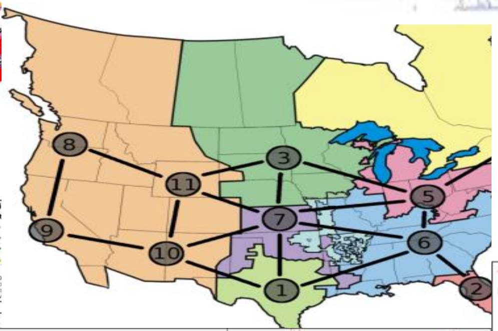
  – **Each pair of neighboring RTOs must share information, coordinate and jointly evaluate interregional transmission, develop interregional tariffs**

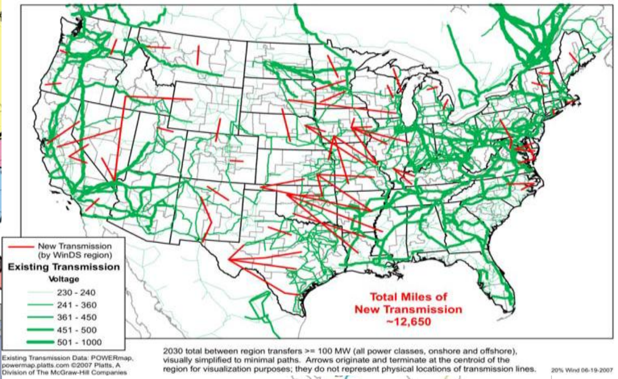
Introduction

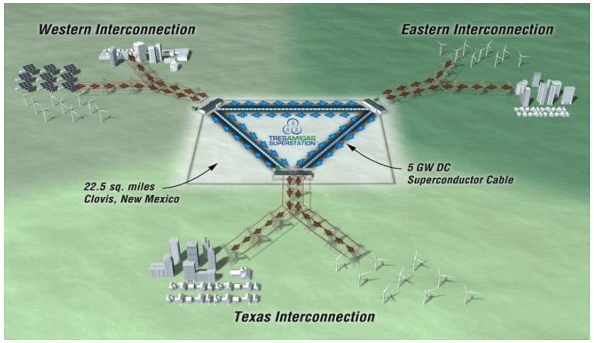


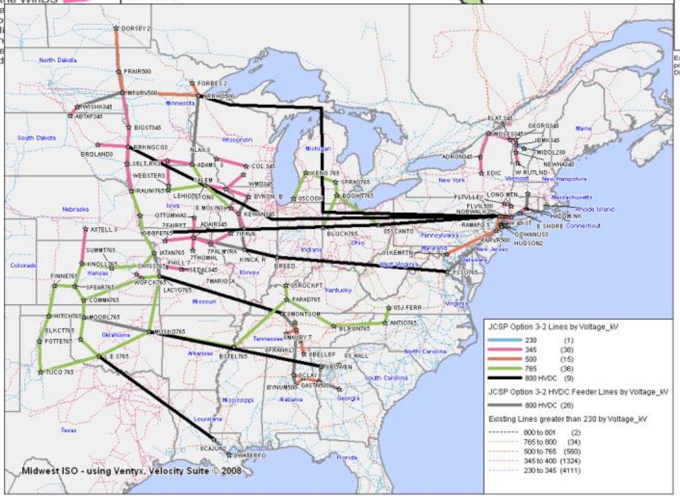


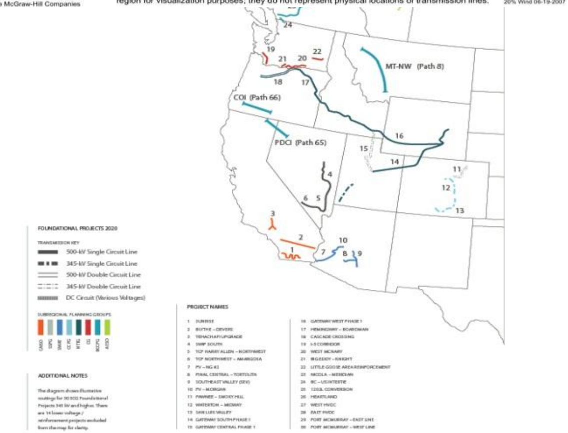












Introduction

National transmission overlay: high capacity, multi-regional grid, potentially spanning all 3 interconnections, designed as single integrated system to provide national economic & environmental benefits.

Why hasn't this been done before?

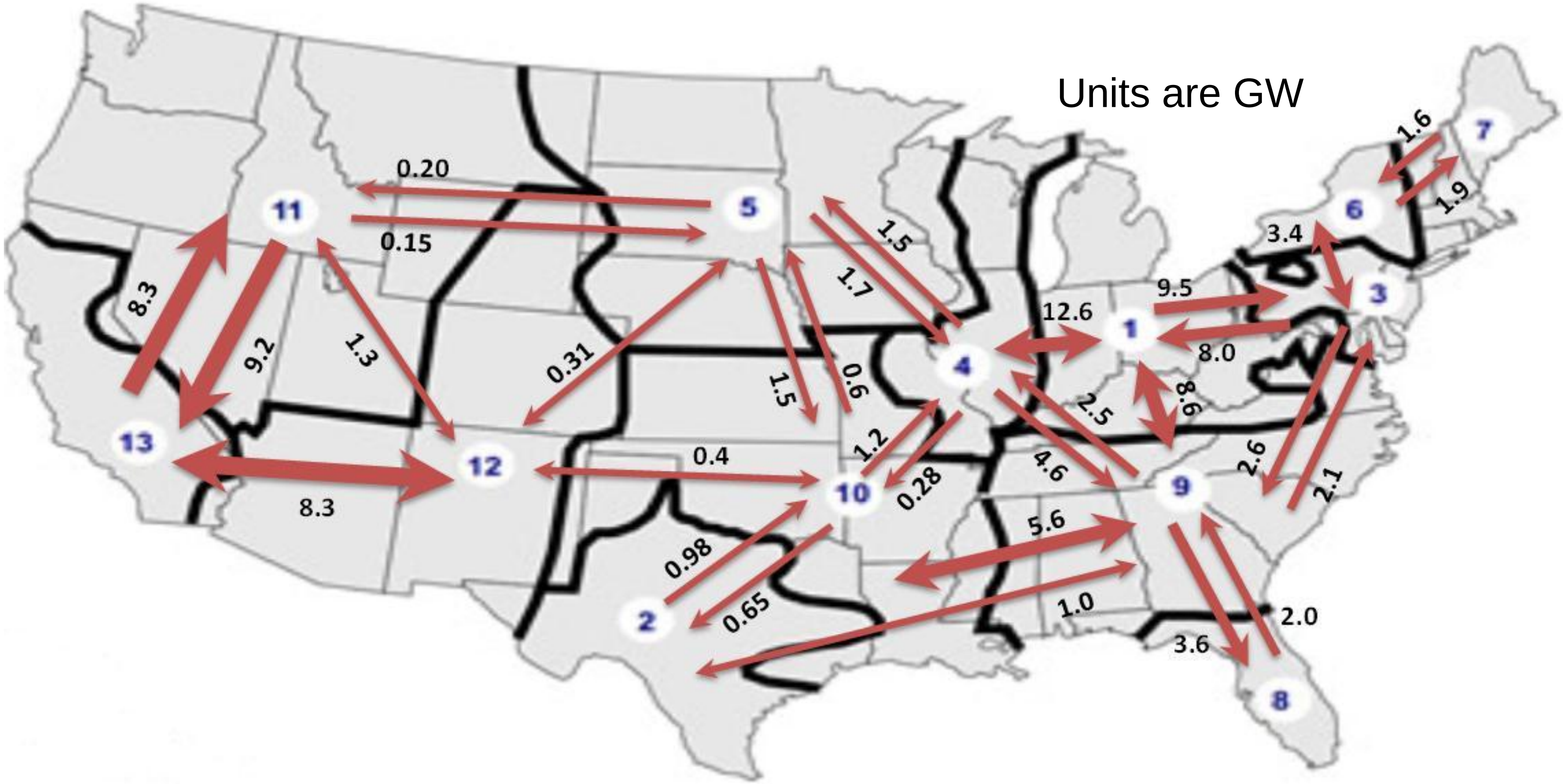
1. **Renewables, which drive it, were thought to be a potentially significant player in future energy portfolio only recently.**
2. **Building transmission of any distance is difficult due to the**
   - **need to show transmission is the most economical alternative,**
   - **complexity of cost allocation,**
   - **need to obtain right-of-way,**
   - **technical challenges,**
   - **need to satisfy public opinion.**
3. **Multiregional trans requires involvement of many organizations, is procedurally complex, and is politically sensitive.**

Introduction

Interest in a national transmission overlay is motivated by the potential for high renewable growth, driven by environmental issues, and the need to maintain inexpensive energy and a resilient energy infrastructure.

1. **Location heavily influences economic viability of a given renewable project; this is not the case for non-renewables.**
2. **Renewable energy can be moved only by electric transmission; this is not the case for non-renewables.**
3. **Transmission costs comprise a relatively small percent of long-term power system investment and operation cost.**

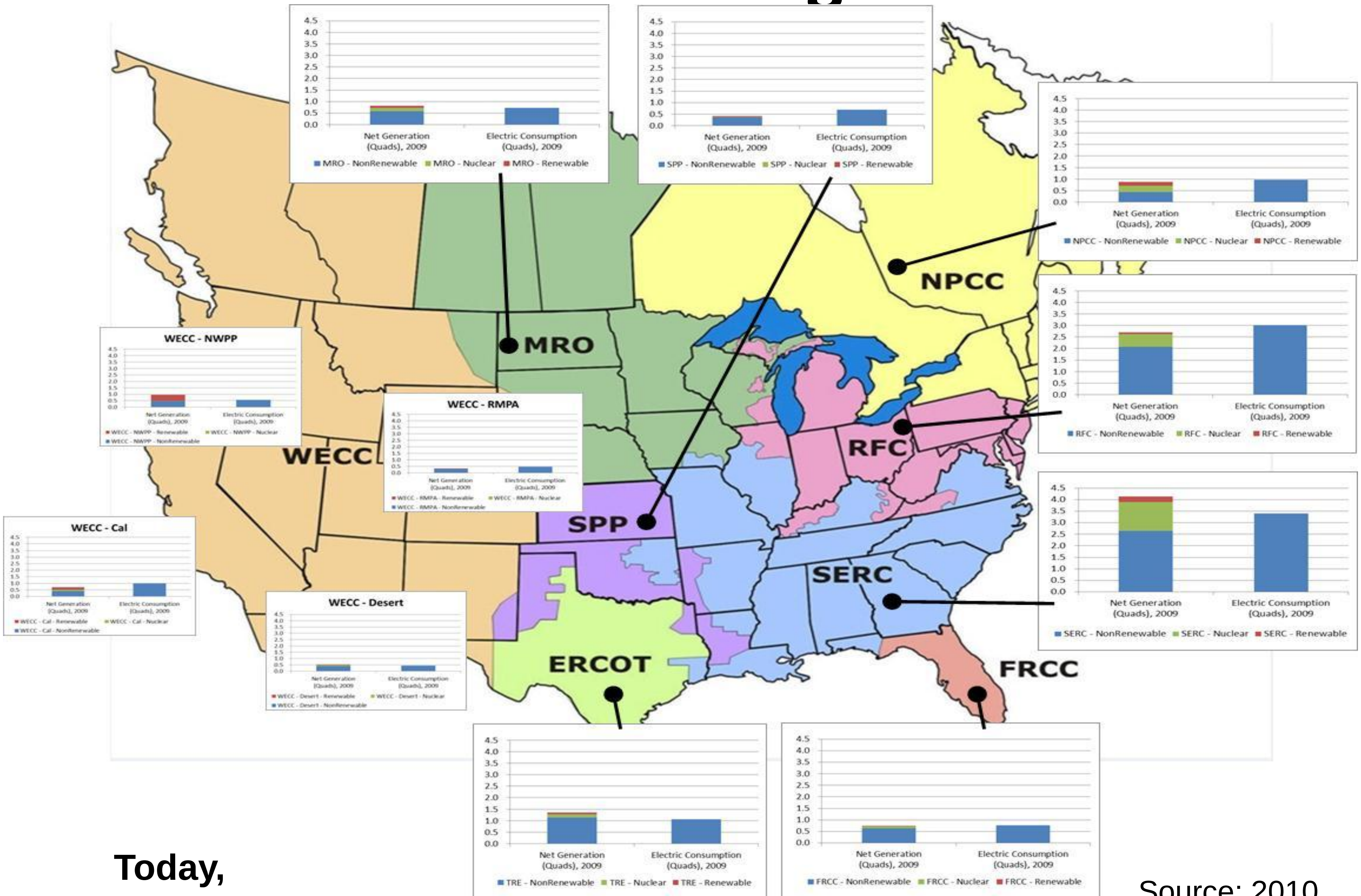
Essential background



Interregional transmission does exist today.

(Values, based on several public sources, were not verified with the various operating organizations)

Essential background



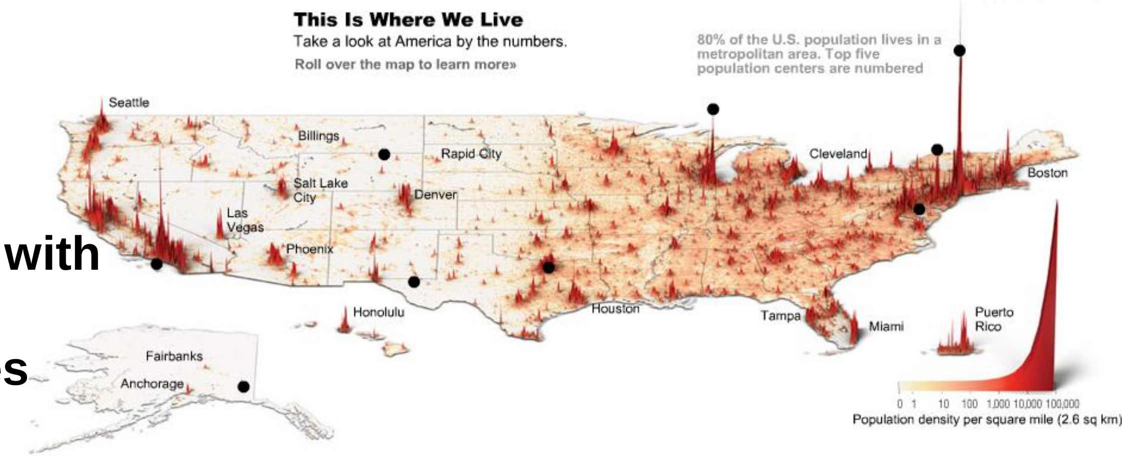
Today, energy generated ≈energy consumed in each region

Source: 2010 NERC Supply & Demand Database

Potential Benefits to National Transmission Overlay

- Cost reduction
- Sustainability
- Resilience
- Planning flexibility

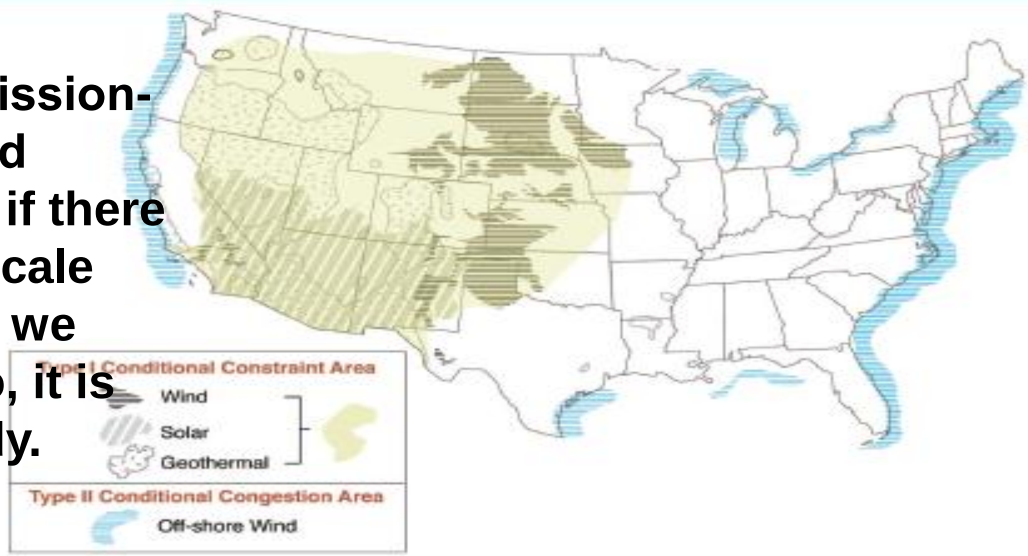
Study approach



Five options:

1. **Build least-cost renewables with transmission.**
2. **Build higher-cost renewables with less transmission.**
3. **Build other types of generation (nuclear, clean-coal, natural gas)**
4. **Build small-scale, distributed gen**
5. **Some combination of above.**

We assume the most "transmission-friendly" future of option 1 and conduct studies to determine if there is economic benefit to large-scale transmission build-out. If not, we need not discuss further, if so, it is worthwhile continuing to study.



Study approach

A simulation study was conducted and is described.

The results are not intended to be conclusive but rather to illustrate potential.

Firm conclusions regarding influence on costs, both nationally and regionally, will depend on additional studies using more refined models, data, and transmission designs.

Study approach

Energy system modeling for cost minimization model

NETPLAN was used for the analysis.

- A long-term energy planning software developed at ISU.
- Co-optimizes gen, transm investments at national level
- Accounts for investment, production costs, capacity factors by technology and by geographical region

- Generalized flow transportation model
- Commodity: energy
- Paths (arcs)
  - Electric transmission
  - Conversion (generation)

- Decision variables
  - Flows across the system, in the arcs
  - Capacity investment in arcs

Minimize: NetPresentValue {Investments+ProdCosts}

Subject to: Meet energy demand in month (inelastic demand)

Study approach

Energy system modeling for cost minimization model

- Initialized with 2010 gen, load, interregional transmission capacity
- 13 regions (1 node/region)
- Assumed transmission cost is $1B/GW/1000miles; also performed sensitivity at $1.5B/GW/1000miles, with length between adjacent regions assumed to be between geo-centers
- 2%/year load growth
- Assumed $30/ton for CO_2
- Inflation and (real) discount rate assumed 2% and 7%, respectively
- Did not impose regional capacity reserve constraints
- Transmission losses represented as linear function of loading & distance, based on data for an 800 kV HVDC line
- Generation retirements occurred at assumed end-of-life, e.g., 60 years for nuclear, 40 for coal, 30 for NGCC, 25 for wind, etc.
- Monthly time steps over 40 years (480 periods)

Study approach

Generation Technology	*Capacity Factor*	*Investment Cost (M$/GW)*	*Lifespan (years)*	*Operational Cost (M$/GWh)*	*CO_2 (Short ton/GWh)*
Nuclear	0.95	3156	60	0.002349	8.51
Coal	0.85	1788	40	0.002404	919.35
IGCC	0.85	2673	40	0.002159	865.1
IPCC	0.85	3311	30	0.011884	-
NGCC	0.61	827	30	0.002591	407.07
Oil	0.85	1655	30	0.003048	808.1
CT	0.2	551	30	0.003654	555.69
PV Solar	0.1-0.25	4603	30	0	-
PV Thermal	0.15-0.32	3617	30	0.001	-
Wind	0.1-0.5	1150	25	0.000268	-
Offshore	0-0.4	2662	25	0	-
Geothermal	0.9	3149-7747	50	0	123.57
OTEC	0.3	6163	50	0	-
Tidal	0.3	18286	50	0	-
Hydro	0.5	4594	100	0.002835	-

GENERATION TECHNOLOGY DATA

LOCATIONAL EFFECTS ON RENEWABLES

Region, j	*Base Demand (GW)*	*Inland Wind CF*	*Offshore Wind CF*	*Solar PV CF*	*Solar Thermal CF*	*Geothermal investment cost ($/GW)*
1- ECAR	75.90865	0.3	0	0.15	0.22	5426.167401
2- ERCOT	39.61863	0.4	0.2	0.2	0.25	4514.472362
3- MAAC	25.73917	0.3	0.4	0.15	0.22	7747.659574
4- MAIN	25.32782	0.5	0	0.15	0.22	5601.56682
5- MAPP	23.00705	0.5	0	0.15	0.22	5352.181425
6- NY	16.4444	0.3	0	0.15	0.22	7558.14433
7- NE	14.04696	0.3	0.4	0.15	0.22	5281.016949
8- FL	25.81881	0.3	0.4	0.22	0.27	6203.554377
9- STV	70.62432	0.1	0.4	0.2	0.25	5547.272727
10- SPP	32.72866	0.4	0	0.2	0.25	4238.181818
11- NWP	28.25084	0.4	0.4	0.1	0.15	3149.20354
12- RA	18.12711	0.2	0	0.25	0.32	3714.545455
13- CNV	30.61133	0.3	0.3	0.22	0.27	4020

Study approach

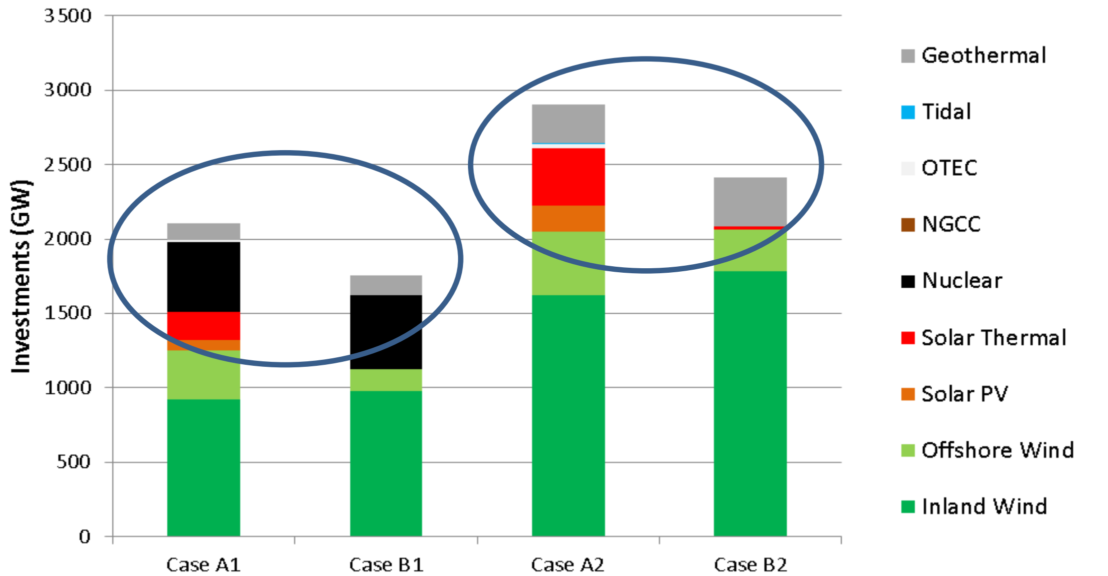
FIVE ASSESSMENTS:

- case A maintained transmission capacity at 2010 levels,
- case B allowed transmission expansion.
- geothermal constrained differently because cost data is uncertain.

- Cases A1, B1, renewable+nuke, geothermal light: These cases allow 520 GW of nuclear, with the rest inland wind, offshore wind, solar PV, solar thermal, and geothermal. Geothermal built only in west.
- Cases A2, B2, all renewable geothermal light: These cases allow only inland wind, offshore wind, solar PV, solar thermal, and geothermal to be built. Geothermal built only in the West.
- Cases A3, B3, all renewable, no geothermal: These cases allow only inland wind, offshore wind, solar PV, and solar thermal to be built.
- Cases A4, B4, all renewable, geothermal heavy: These cases allow only inland and offshore wind, solar PV and thermal, and geothermal to be built. Geothermal may be built anywhere.
- Case B1-1.5T: Same as B1, but transm costs at $1.5B/GW/1000miles

Results: gen/trans investments

Generation investment over 40 years

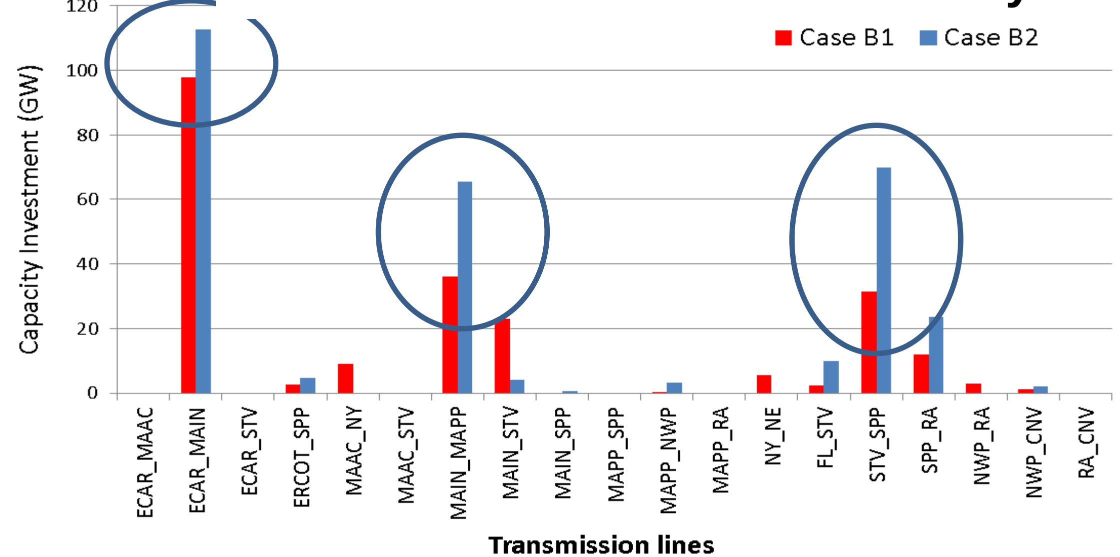


Cases A1, B1 (renewable & nuclear, geothermal-light)

Cases A2, B2 (all-renewable, geothermal-light)

A: w/o transmission expansion
B: w/ transmission expansion

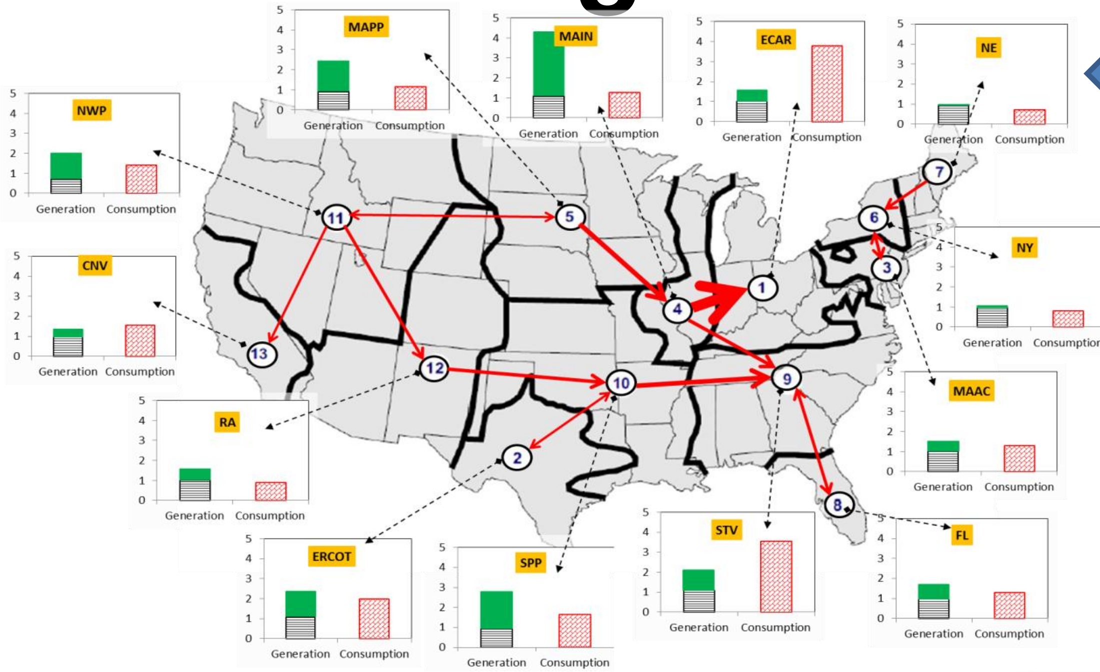
Transmission investment over 40 years



Transmission reduces required capacity investment.

Increasing renewable levels increases need for transmission.

Results: gen/trans investments



Case B1 (renewable & nuclear, geothermal-light)

➔Flow is west to east.

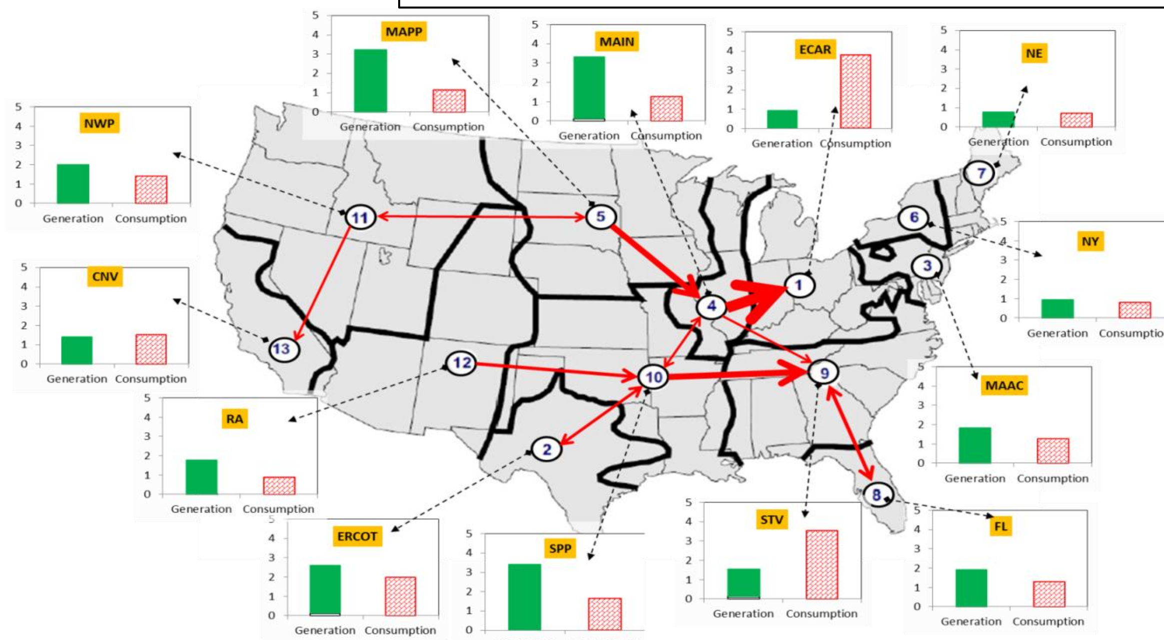
➔Highest trans cap investment is MAIN (4) to ECAR (1) because:

- CF (0.5 in MAIN, 0.3 in ECAR)
- Load is very high in ECAR

➔High trans cap investment from SPP (10) to STV (9) because:

- CF (0.4 in SPP, 0.1 in STV)
- Load is very high in STV

Case B2 (all-renewable, geothermal-light)



Results (all cases): Costs difference with/without transmission expansion

Cases	Case description	Transmission	Cost (Billion$)	
			Present worth (2010 dollars)	Annualized over 40 years
A1	Mostly renewable, geothermal-light	Fixed	5013.12	376.03
B1		Expanded	4773.96	358.09
		Difference	**239.16**	**17.94**
A2	All-renewable, geothermal-light	Fixed	5517.83	413.89
B2		Expanded	5059.38	379.50
		Difference	**458.45**	**34.39**
A3	All-renewable, no geothermal	Fixed	5328.11	399.66
B3		Expanded	5053.70	377.57
		Difference	**274.41**	**20.58**
A4	All-renewable, geothermal-heavy	Fixed	5457.63	409.37
B4		Expanded	4965.48	372.47
		Difference	**492.15**	**36.92**
B1-1.5T	Same as B1, but w/increased transmission costs	Expanded	4807.06	360.53
		Difference	**206.12**	**15.46**

Benefits

1. Cost:
   - Cost reduction occurs because overlay opens up opportunities to use lower cost generation in one region to supply demand in another region.
   - Cost estimates do not account for upgrades to underlying system.

2. Sustainability: Overlay lowers cost per unit emission reduction over a given time frame, because transmission enables technologies with low GHG emission to be built in most cost-effective regions

Benefits

3. Resilience: "The ability to minimize and recover from the effects of an adverse (extreme) event."
   - 6 month loss of rail access to Powder River Basin coal,
   - Early retirement of 50% of U.S. nuclear fleet;
   - 6 month interruption of Canadian gas supply;
   - Earthquake in St. Louis with major loss of transmission, rail, oil, and gas pipelines, and extended interruption to Mississippi River barge traffic;
   - 1 year loss of U.S. hydro resources due to extreme drought;
   - 50% reduction in annual wind farm capacity factor due to climate change effects;
   - Simultaneous failure of all power transformers throughout the East Central region of the country due to a geomagnetic storm or an electromagnetic pulse.
   - Major hurricane on Gulf coast

The (simulated) operational cost increase in the year following one of these events is a useful resilience indicator.

Transmission provides interregional access and thus options when events reduce normal resource availability. This yields operational flexibility, which enhances resilience.

Benefits

4. Planning flexibility: “The ability to redirect investment plans following events and trends which cause permanent changes in expected futures.”

What if ocean-based electric generation resources (tidal, wave, OTEC, and off-shore wind) become the resource of choice? Or clean-coal (IGCC/CCS)? Or nuclear?

Interregional transmission may facilitate resource planning flexibility, particularly if changes require regional resource shifting.

Engineering considerations

1. Transmission technology choices:
   - EHVAC (500, 765 kV)
   - HVDC (±500, ±600, ±800 kV): thyristor/VSC, OH/UG, Bipole/Tripole
   - Superconducting (UG ±200 kV HVDC)
   - Integration of two or more of the above

   "It is likely that long-distance bulk transmission design at the national level would necessarily include an integration of both HVDC transmission, to take advantage of its lower cost per MW-mile, and EHVAC transmission, to obtain the flexibility AC provides in facilitating the numerous interconnections of new generation projects and load centers, and that systems will be designed so that the two are complementary assets."
2. Transmission cost estimates
3. ROW requirements
4. Reliability (outage frequency & consequence)
5. Short-circuit ratio for HVDC
6. Controllability
7. Transmission losses

Issues and concerns

1. **Localized decision-making, at state level, when regional, interregional, or national coordination is needed.**
   a. **Transmission between neighboring ISOs: Order 1000 requires procedures to evaluate expansion opportunities between ISOs.**
   b. **Influence on gen location through:**
      - **RTO interconnection procedures: cost allocation when new gen needs system reinforcement.**
      - **State-level policies which vary state-by-state**
   c. **Influence of local economic development: gens=jobs**
   d. **Installed reserve margin**

      The smaller the area that imposes the requirement, the more generation has to be built in that area, diminishing the ability of the area to take advantage of less expensive generation in another area.

Issues and concerns

2. **Changes in planning approach**
   - **Transmission planning by portfolio design**
   - **Longer decision horizons**
   - **Resource forecasting**
3. **Cost allocation:**
   - **General principle has been “beneficiaries pay” but it is hard to identify beneficiaries;**
   - **Other approach is “socialized,” but it may undermine regional cost advantages, and entities resist paying for transmission that provides them little benefit.**

Issues and concerns

4. **Market impacts of transmission investment**
   - **Markets settle at the offer of the (last) marginal seller**
   - **Exporting region: More production causes price rise; new and pre-existing production sold at higher prices.**
   - **Importing region: Cheaper power displaces more expensive power and prices fall; new and pre-existing production sold at lower prices.**
   - **Efficiency gain: on the displaced power.**
   - **Revenue transfer: from buyers to sellers in exporting region; from sellers to buyers in importing region.**

a. Differences across rows: impacts depend on which agents are considered.
b. Differences across columns: impacts on consumers, producers, TOs vary.
c. Compare agent benefits to total benefit: transfers can be much larger than eff. gains, creating strong forces that might oppose socially beneficial lines.

Perspective	Consumer Benefit (Mill.$)	Producer Benefit (Mill.$)	Trans. Owner Benefit (Mill.$)	Total Benefit (Mill.$)
PERFECT COMPETITION (COST-BASED OFFERS)				
WECC wide	1.6	1.0	-2.1	0.5
CAISO Ratepayer	-0.8	1.0	-0.8	-0.6
IMPERFECT COMPETITION (MARKET-BASED OFFERS)				
WECC wide	34.4	-25.8	-6.6	2.0
CAISO Ratepayer	11.1	-4.0	-0.9	6.2

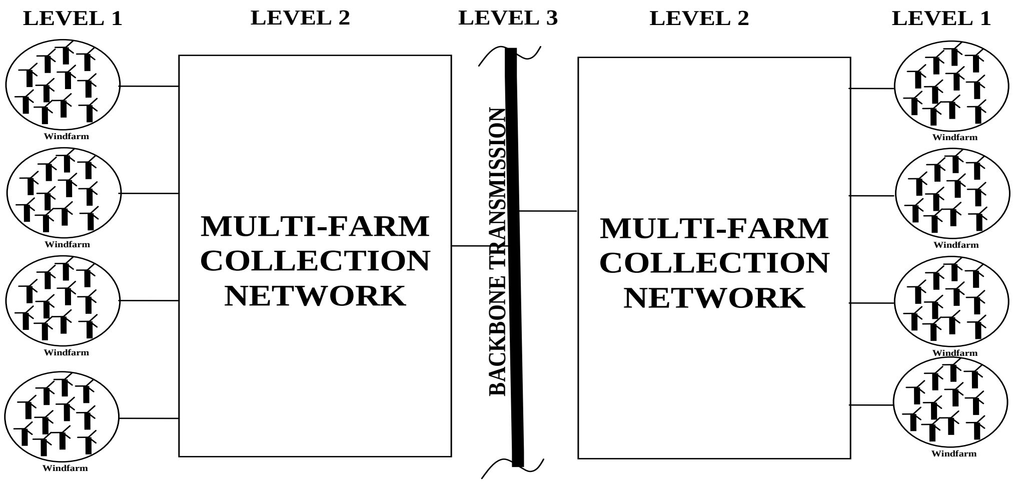
M. Awad, S. Broad, K. Casey, J. Chen, A. Geevarghese, J. Miller, A. Sheffrin, M. Zhang, E. Toolson, G. Drayton, A. Rahimi, and B. Hobbs, “The California ISO Transmission Economic Assessment Methodology,” Proc. of the 2006 IEEE PES General Meeting.

Issues and concerns

5. Uncertainty in policy
   - Do we need to create certainty via federal subsidies, RPS, cap-and-trade, and EPA requirements?
   - Or, given the cost of doing nothing, can we build transmission based purely on the “certainty” of existing state policies and CSAPR (cross-state air poll rule)?
6. Difficulty in obtaining ROW
   - “Pass-through” transmission difficult to sell locally
   - Underground more expensive but less pub resistance
7. Future scenarios less dependent on transmission
   - High DG: higher cost, does not provide backup to regional outages like transmission
   - High non-renewables: nuclear, clean coal, natural gas
8. Technology development: What if a whole new electric generation portfolio becomes dominant - will transmission facilitate or inhibit it?

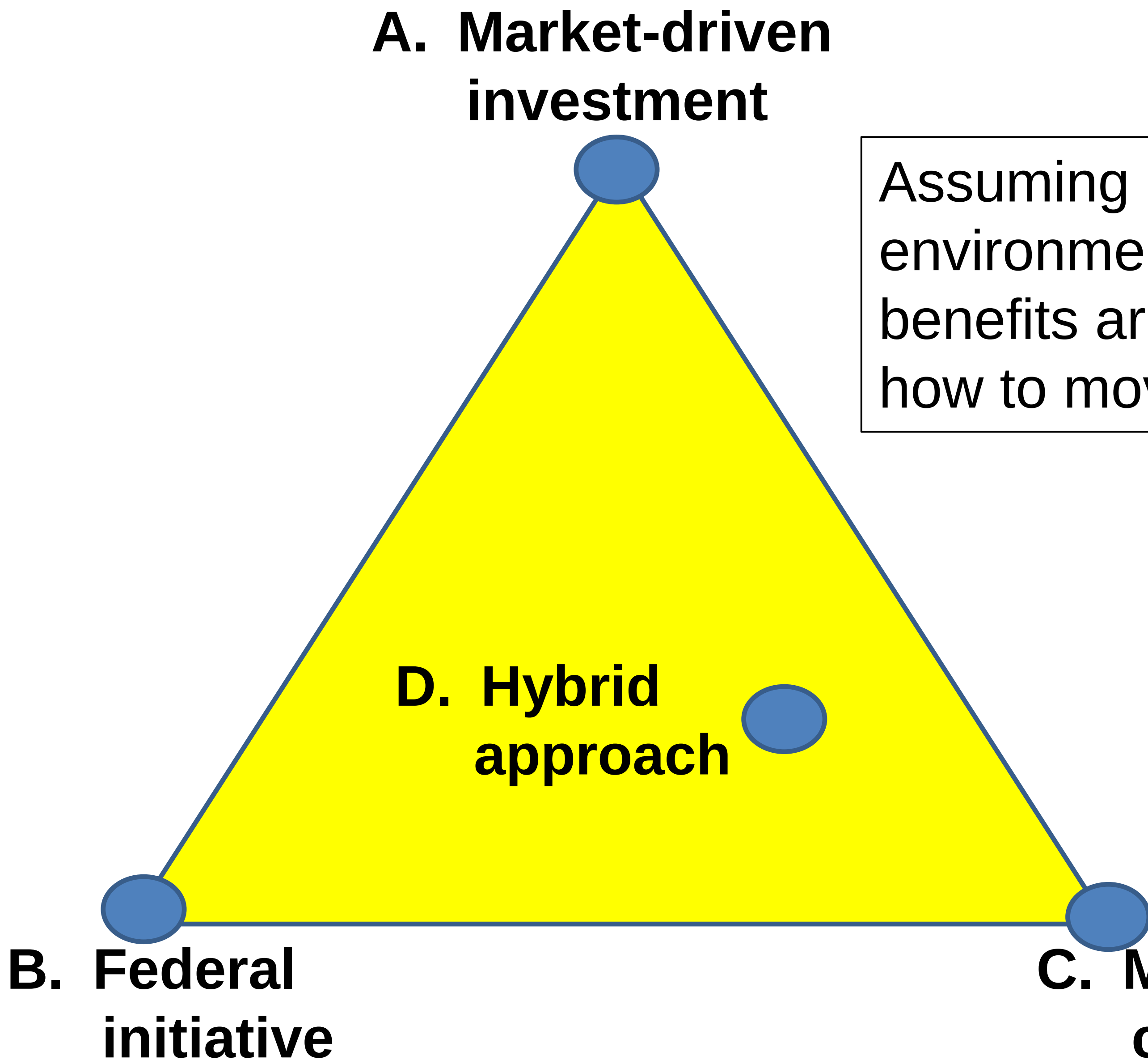
Issues and concerns

9. **Lack of long-term congestion hedging products**
   - **10-20 year power purchase agreements are attractive**
   - **Even if interregional transmission is available, will the local transmission present congestion exposure**
10. **Resource collection networks – will 300+ GW of wind impose a need for these?**



11. **Selective interregional transmission (instead of a “national transmission overlay”)**

Possible paths forward



Assuming economic, environmental, & social benefits are attractive how to move forward?

Possible paths forward: A. Market-driven investment

1. **Market (merchant)-driven investment: no rate-base recovery, costs recovered through "negotiated rates."**
2. **In the past:**
   - **Natural gas, petroleum, rail, telecom all do it**
   - **Merchant trans proposals tend towards interregional**
3. **Congestion rents insufficient so value must come from benefits transmission bestows on market participant groups.**
4. **Size of the groups to form for overlay projects may need to be very large and difficult to develop/manage.**

Possible paths forward: B. Federal initiative

- **Shares some similarities to the interstate highway system, which was a co-operative federal-state effort.**
  - **Feds paid 90% via gasoline tax, states 10%.**
  - **States managed program for location, design, ROW acquisition, construction, O&M.**
- **But there are differences:**
  - **Whereas interstate highway system offers a service (decreasing travel time) inherent to the highway itself, the service provided by electric transmission system (access to cheaper, more reliable, and/or cleaner energy) depends on the gen to which it provides access, an additional infrastructure. This makes it more difficult to assess and maintain the value of transmission, relative to the value of interstate highways.**
  - **It is not clear that the interstate highway system had a "pass-through" feature like an overlay may have.**

Possible paths forward:
B. Federal initiative

Three essentials for this path:

1. **Develop process for identifying investment projects, possibly through joint DOE/industry efforts extended from the DOE national interest corridor studies and the ARRA planning projects in the three interconnections.**
2. **Identify framework for collecting fees on a national basis, e.g., federal grid charge; must address issues of who benefits and who pays.**
   a. **Charge is flat, per kwhr, justified since env benefit is national, and since investment will tend to be in proportion to demand.**
   b. **Charge is adjusted based on positive or negative benefits, but "allowable" benefits must be well-defined and quantifiable.**
3. **Establish siting process which clarifies FERC's and state's authority to grant permits for transmission.**

Possible paths forward:
C. Multiregional coordination

1. **Establish permanent multiregional stakeholder group consisting of industry, state governments, advocacy groups to address:**
    - **Definitions, benefit calculations of reliability-based investments and gen-interconnection investments.**
    - **Cost-allocation mechanism to distribute costs of inter-regional projects,**
    - **Multiregional RPS that accommodates trade of renewable energy and renewable energy credits.**
    - **Previous experiences of interregional transmission**
    - **Multi-regional transmission designs**
2. **States need to see benefit for taking multiregional view.**
3. **The above may be evolving:**
    - **ARRA-funded interconnection-wide efforts in EI, WECC, and ERCOT**
    - **Governors associations, e.g., MGA and WGA**
    - **FERC Order 1000 which requires coordination between pairs of neighboring regions.**

Possible paths forward:
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.
2. Incentivize merchant transmission developers to build consistent with design.
3. Federalize what merchant developers will not or cannot build, but with careful Fed-State coordination and cooperation.

Conclusions

A national transmission overlay has potential to offer significant net benefits to the nation, but….the political, regulatory, and procedural difficulties associated with initiating it are formidable.

Development of a national transmission overlay merits further attention through discussion and analysis regarding benefits, issues and concerns, and possible paths forward.

The next step in the effort will be to convene a group of experts spanning various dimensions of the issues who would expand and refine the work reported here and who would provide recommendations on the extent to which a national transmission overlay should be further pursued.

Specific objectives of such a group could be to

- Identify overlay designs that make sense under several of the most likely futures;
- Assess benefits and issues/concerns, nationwide and regionally
- If benefits are attractive relative to issues/concerns, then initiate exploration of "paths forward".