Eastern Interconnection Wind Integration & Transmission Study

Project Overview

Prepared by:

Robert Zavadil

Enernex

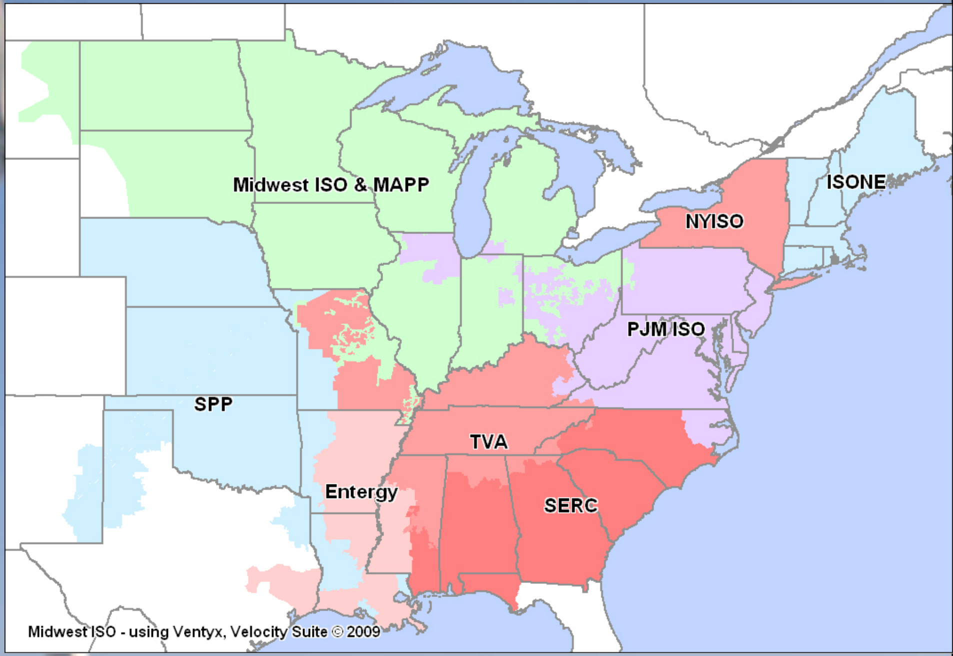
Presented by:

Charlie Smith

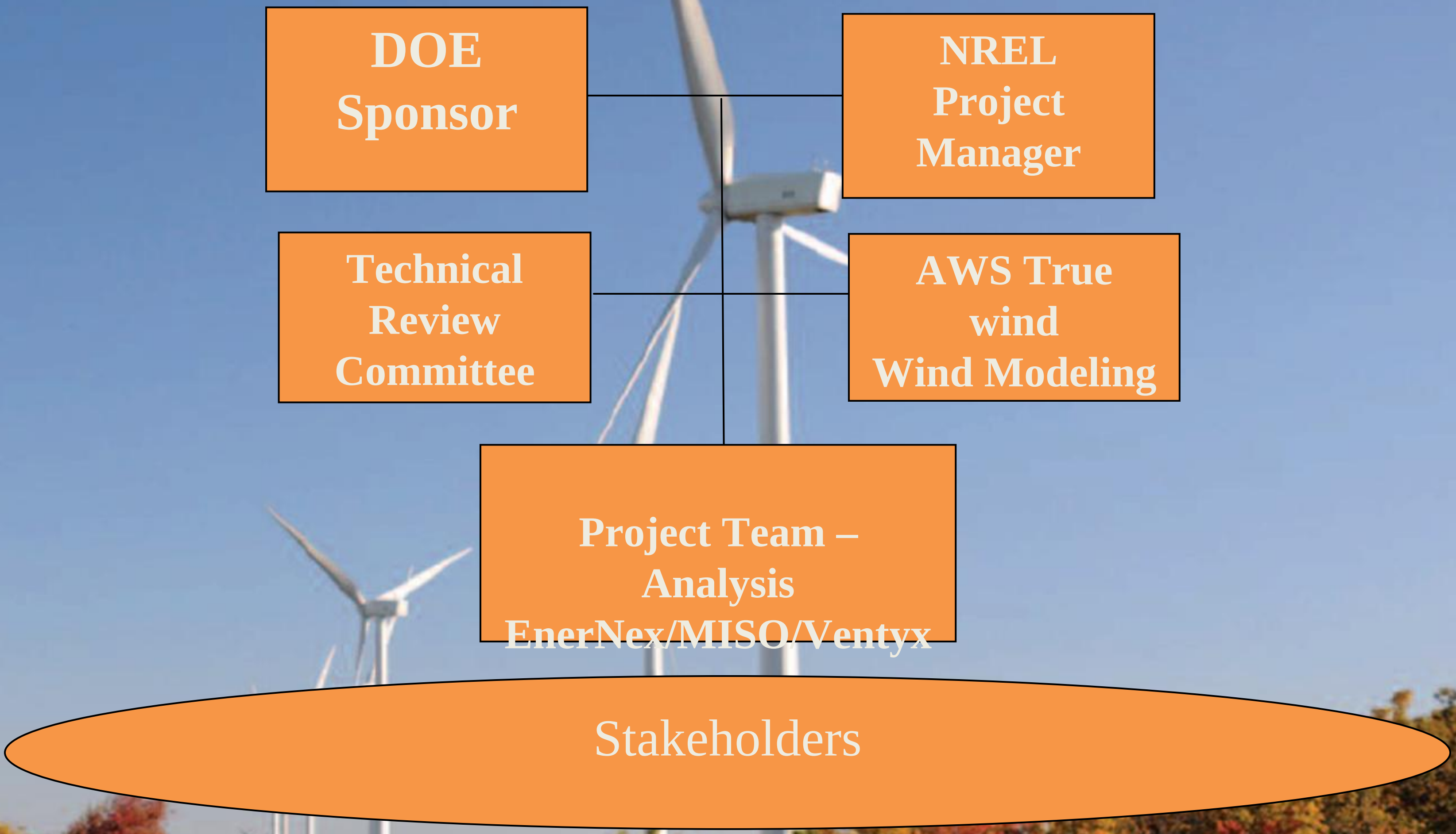
UWIG

What is Needed to Integrate 20% Wind in the Eastern Interconnect?

- Evaluate the power system operating impacts and transmission associated with increasing wind energy to 20% and 30%
  - Impacts include operating with the variability and uncertainty of wind
- Build upon prior wind integration studies and related technical work;
- Coordinate with current regional power system study work;
- Produce meaningful, broadly supported results
  - Technical Review Committee



EWITS Study Organization



Technical Review Committee

- Includes representation from the following organizations

New York Independent System Operator (NYISO) Xcel Energy Southern Company PJM Interconnection Southwest Power Pool(SPP) U.S. Department of Energy Midwest ISO (MISO) Michigan Public Service Commission Mid Area Power Pool (MAPP) American Wind Energy Association (AWEA)	Federal Energy Regulatory Commission (FERC) – observer status North American Electric Reliability Corporation (NERC) CapX 2020 (Great River Energy) Utility Wind Integration Group (UWIG) Windlogics National Renewable Energy Lab General Electric (GE) Regulatory Assistance Project University College Dublin Organization of MISO States (Wisconsin Public Service Commission)

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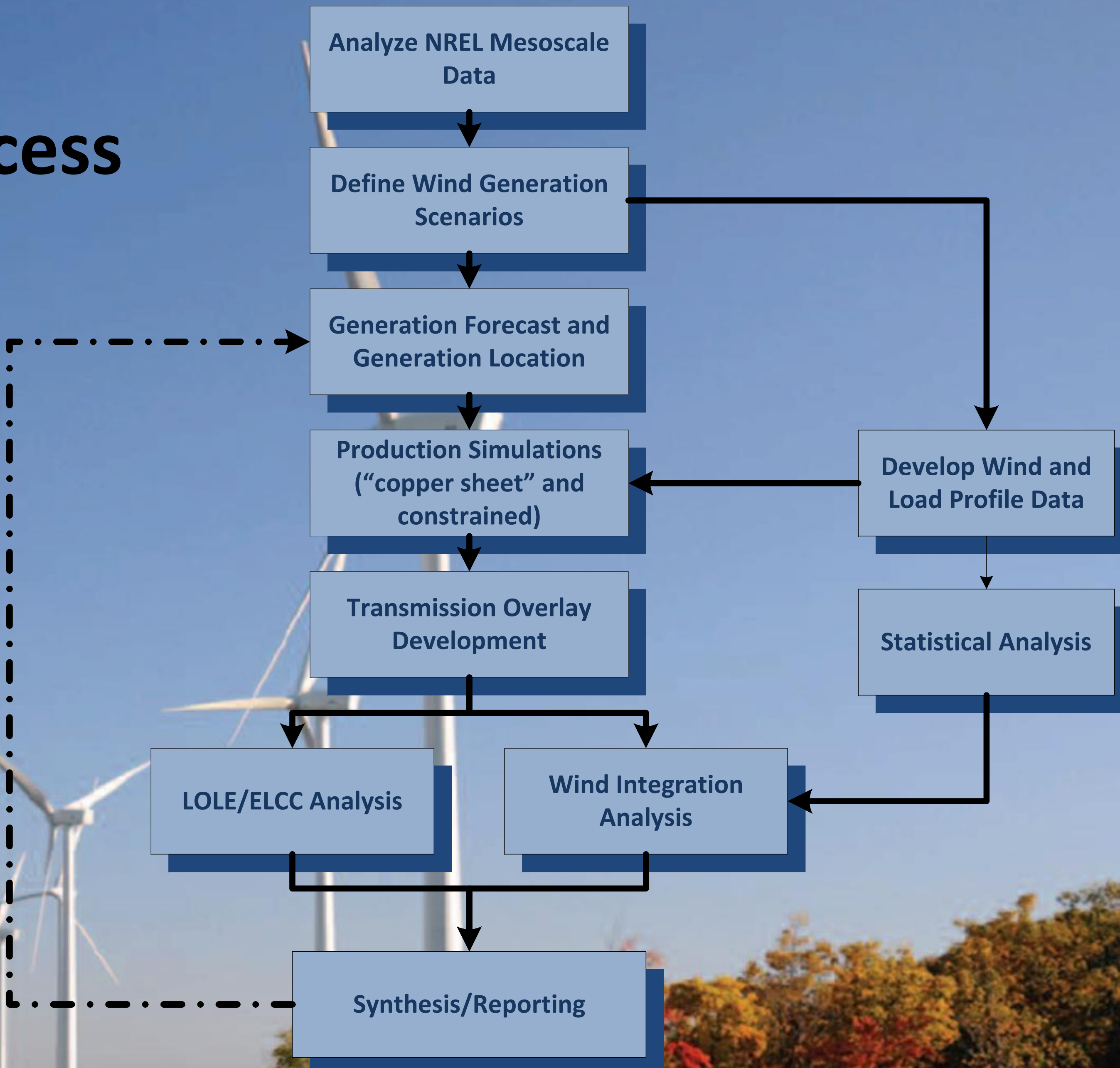
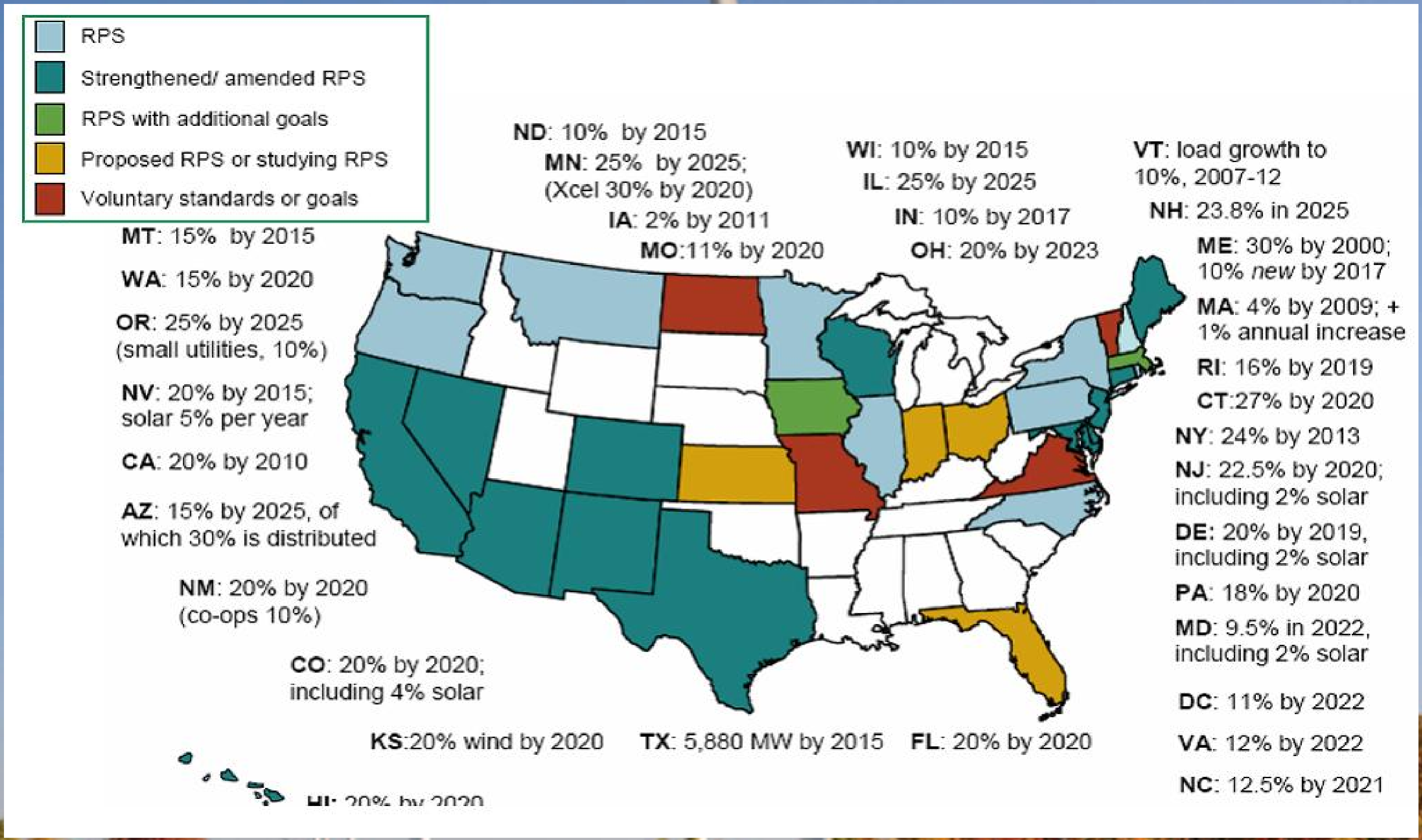
Study Process



Why 20% and 30% Wind?



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Wind Scenario Development

- Target was 20% of EI energy from wind in 2024
- Multiple scenarios, to explore tradeoff between low cost wind & transmission vs. local wind
- Develop 30% scenario for comparison
- Outcome
  - Three 20% and one 30% scenario developed
  - Collaborative process with project sponsors, stakeholders

Installed Capacity in MW

ScenarioID	Reference	Scenario 1	Scenario 2	Scenario 3	Scenario 4
ISO-NE	10,310	4,291	13,837	24,927	24,927
MAPP	1,361	13,809	11,655	6,935	14,047
MISO Central	5,211	12,193	11,380	11,380	12,193
Miso East	1,051	9,091	6,456	4,284	9,091
MISO West	12,109	59,260	39,953	23,656	59,260
NYISO	6,552	7,742	16,507	23,167	23,167
PJM ISO	22,402	22,669	33,192	78,736	93,736
SERC	4,009	1,009	5,009	5,009	5,009
SPP Central	3,882	44,055	46,272	25,997	44,705
SPP North	3,537	48,243	40,394	24,961	50,326
TVA	1,247	1,247	1,247	1,247	1,247
Totals	71,671	223,609	225,902	230,299	337,708

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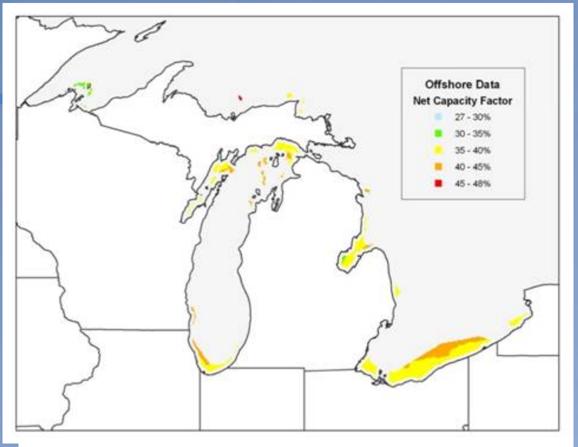
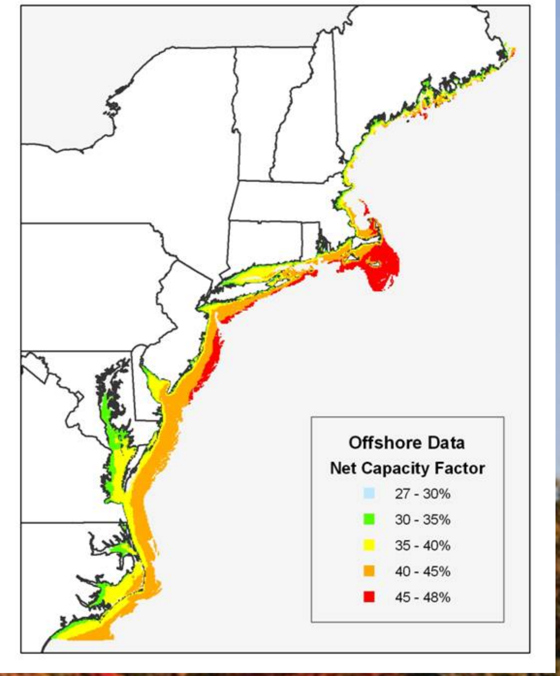
Offshore Wind

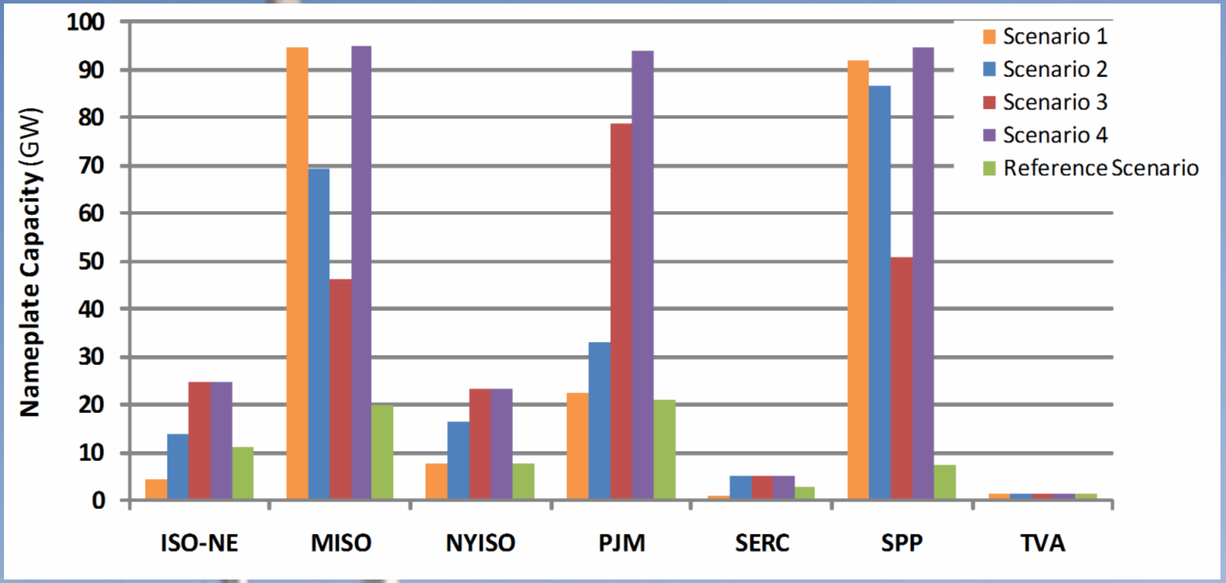
- Great resource
- Well correlated with load and close to load centers
- More expensive!





Regional Wind Penetration by Scenario

- Very high penetrations in SPP for all scenarios
- Atlantic off-shore amount increases substantially in S3 & S4.
- Installed wind generation capacity
  - 20% ≈ 230 GW
  - 30% ≈ 330 GW



Capacity Factor Comparisons:

West = MISO + SPP
East = ISO-NE + NYISO

Scenarios

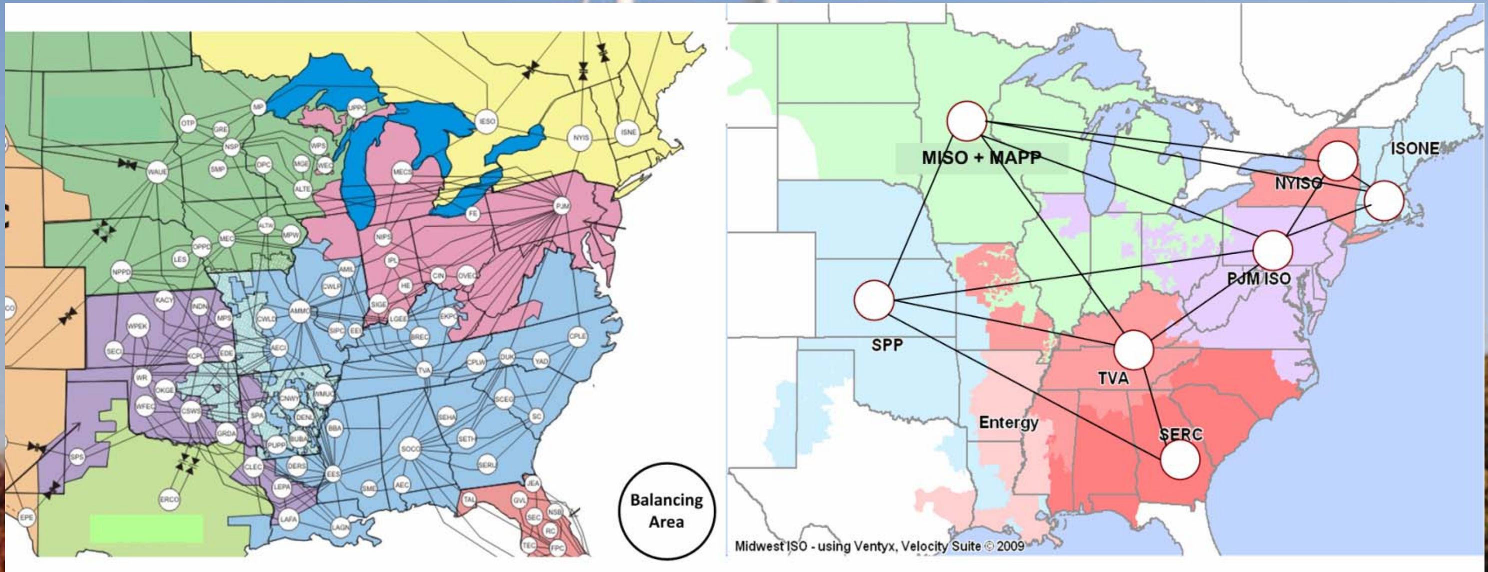
	East	West
Scenario 1	33%	40%
Scenario 2	34%	40%
Scenario 3	36%	39%
Scenario 4	36%	40%

Entire Database

	Land Only	W/offshore
West	38%	
East	31%	36%
East + PJM	30%	36%

Assumptions: Power System Model for 2024

- Loads escalated to 2024 based on regional projections
- 2018 power flow case, expanded to 2024
- Key assumptions
  - Per previous studies
  - Uniform structure assumed for 5 market footprints
  - No carbon tax or cap & trade as baseline

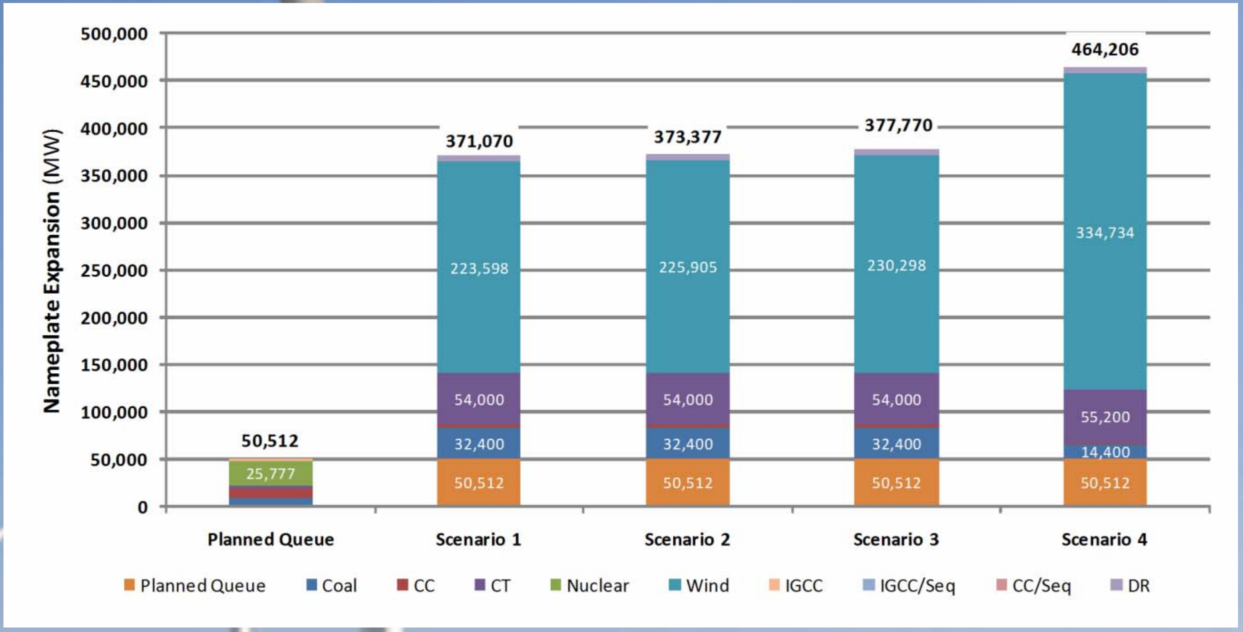


As of August 1, 2007 — Assumption for 2024

Conventional Generation Expansion

- Wind generation by scenario assumed to have 20% capacity value
- EGEAS expansion performed to identify regional generation needed for reliability
- Following LOLE/ELCC analysis, some of this generation could be deferred

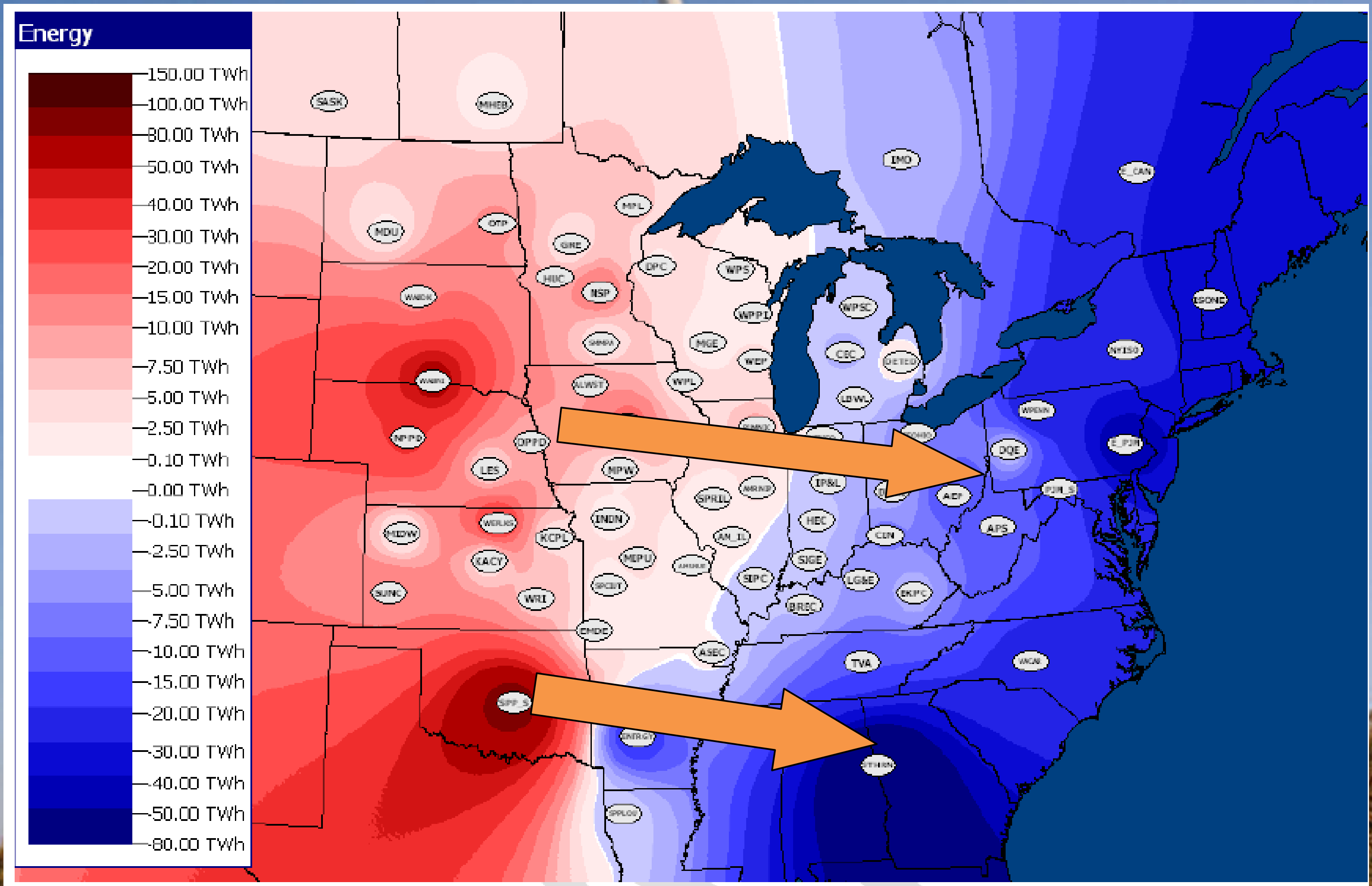
Generation Expansion to 2024



Developing Transmission Overlays

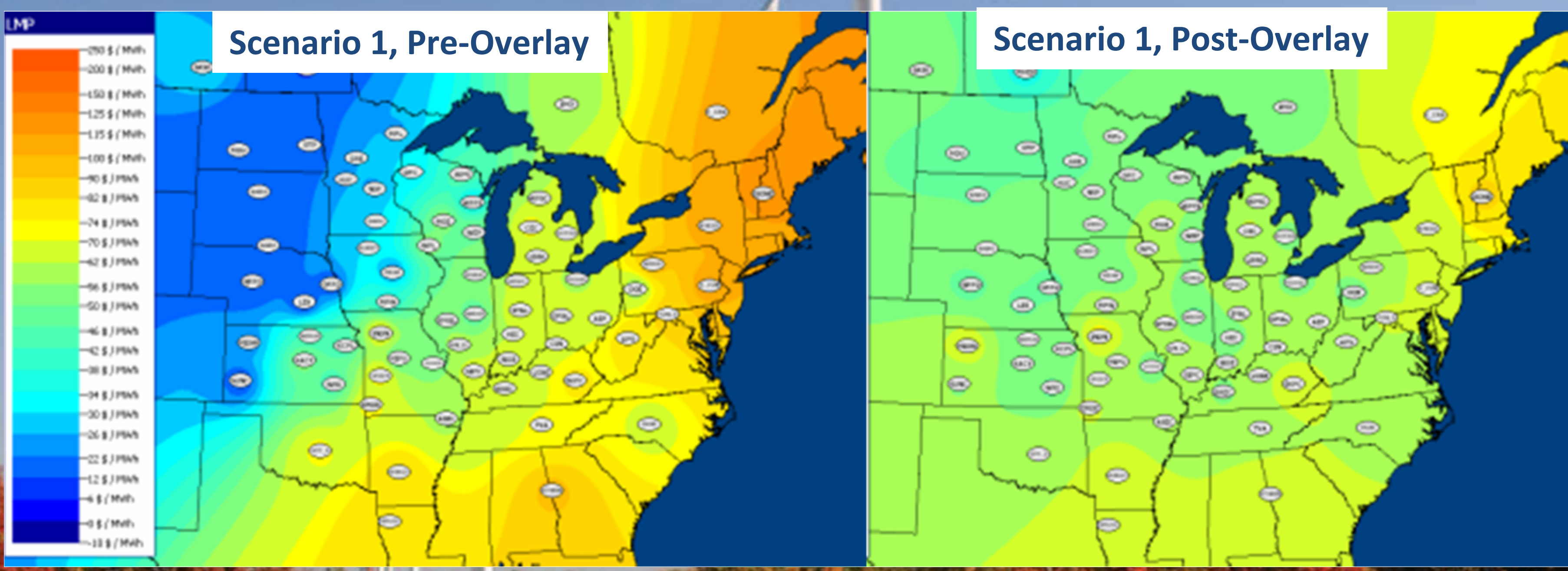
- Employed economic transmission expansion process – "top-down" view of Eastern Interconnection
- Conventional transmission expansion has been based on more of a "bottom-up" perspective
- Approach
  - Site new generation (including wind)
  - Run annual production simulations
    - "copper sheet" – no transmission constraints; LMPs equal across footprint
    - Constrained case
  - Analyze difference to determine location for new transmission
  - Congestion charges are "budget" for expansion

Price and Quantity of Sources and Sinks Determine Transmission Requirements



How it works

- Define energy "sources" and "sinks"
- Compare unconstrained flow of energy ("copper sheet") to flow constrained by transmission limits
- Accumulate annual congestion costs; use as annual "budget" for transmission expansion



Transmission Concepts, not “Plans”

- Looks at the **end** of a planning horizon, rather than the **beginning**
- Significant additional analysis needed to engineer details of plan
  - AC analysis
  - Stability and dynamics
  - Further operational assessment
- Evolution from existing grid would also be a major question

Line-miles & Estimated Cost

- Not included:
  - off-onshore transmission cost (S3 & S4)
  - Some regional updgrades
- Scenario 1 most costly
- Many common elements across all four scenarios
- Economic benefits > cost*

TABLE 2. TRANSMISSION COST ASSUMPTIONS

Cost-per-Mile Assumption

Voltage Level	345 kV	345 kV AC (dou-ble unit)	500 kV	500 kV AC (double circuit)	765 kV	400 kV DC	800 kV DC
US$2024 (millions)	2,250,000	3,750,000	2,875,00	4,792,00	5,125,000	3,800,000	6,000,000

TABLE 3. ESTIMATED LINE MILEAGE BY SCENARIO

Estimated Line Mileage Summary

Voltage Level	345 kV	345 kV AC (double circuit)	500 kV	500 kV AC (double circuit)	765 kV	400 kV DC	800 kV DC	TOTAL
Scenario 1	1,977	247	1,264	243	7,304	560	11,102	22,697
Scenario 2	1,977	247	1,264	243	7,304	560	8,352	19,947
Scenario 3	1,977	247	1,264	742	7,304	769	4,747	17,050
Scenario 4	1,977	247	1,264	742	7,304	560	10,573	22,667

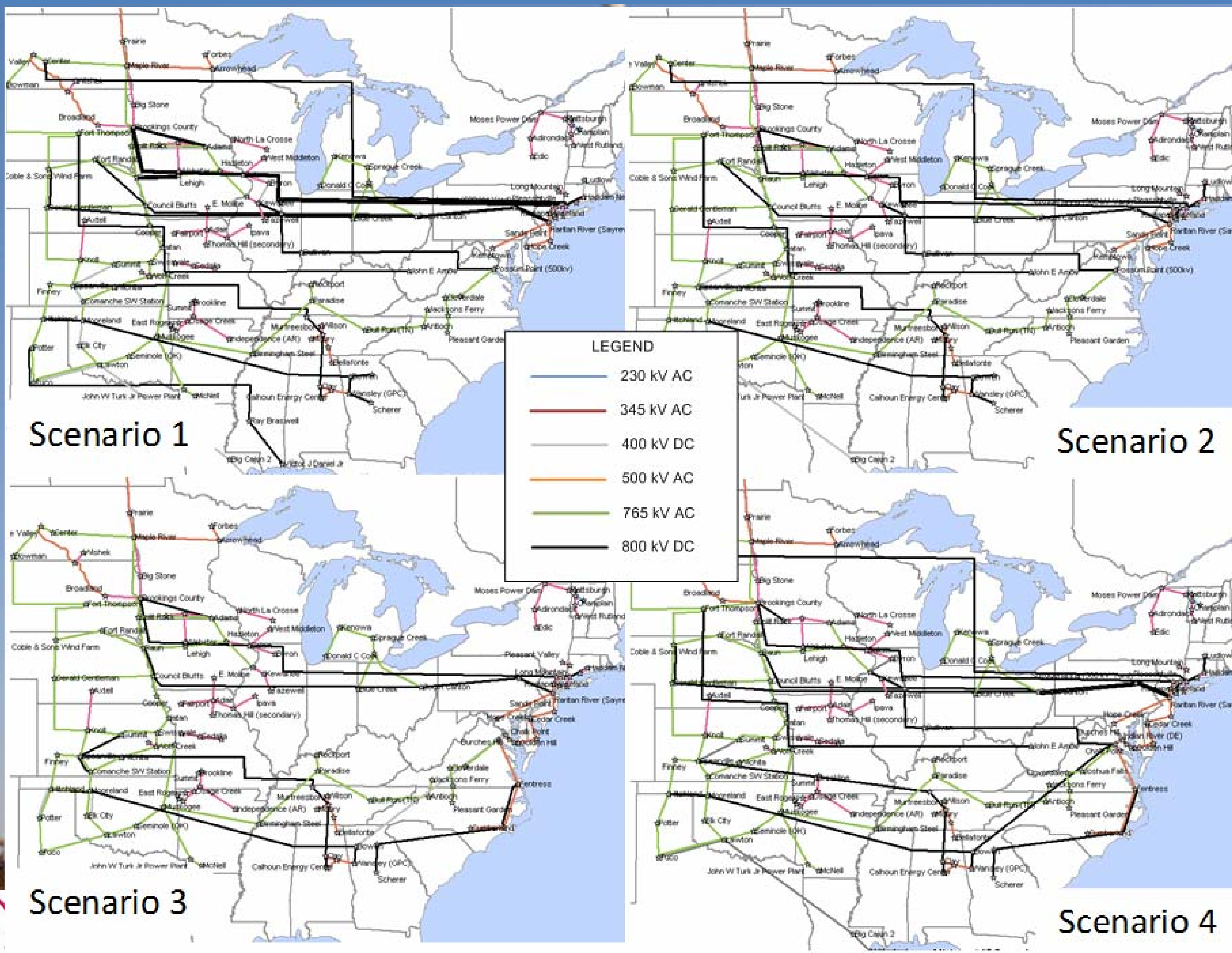
TABLE 4. ESTIMATED COSTS BY SCENARIO

Estimated Cost Summary (US $2024, millions)

Voltage Level	345 kV	345 kV AC (double circuit)	500 kV	500 kV AC (double circuit)	765 kV	400 kV DC	800 kV DC	Total
Scenario 1	5,560	1,158	4,543	1,456	46,791	2,397	83,265	145,169
Scenario 2	5,560	1,158	4,543	1,456	46,791	2,397	62,640	124,544
Scenario 3	5,560	1,158	4,543	4,445	46,791	2,957	35,603	101,056
Scenario 4	5,560	1,158	4,543	4,445	46,791	2,957	79,298	144,191

**Benefits consist of production cost savings only; costs based on overlay, and do not include details of engineering design.*

Overlays for 4 Scenarios



Transmission Requirements

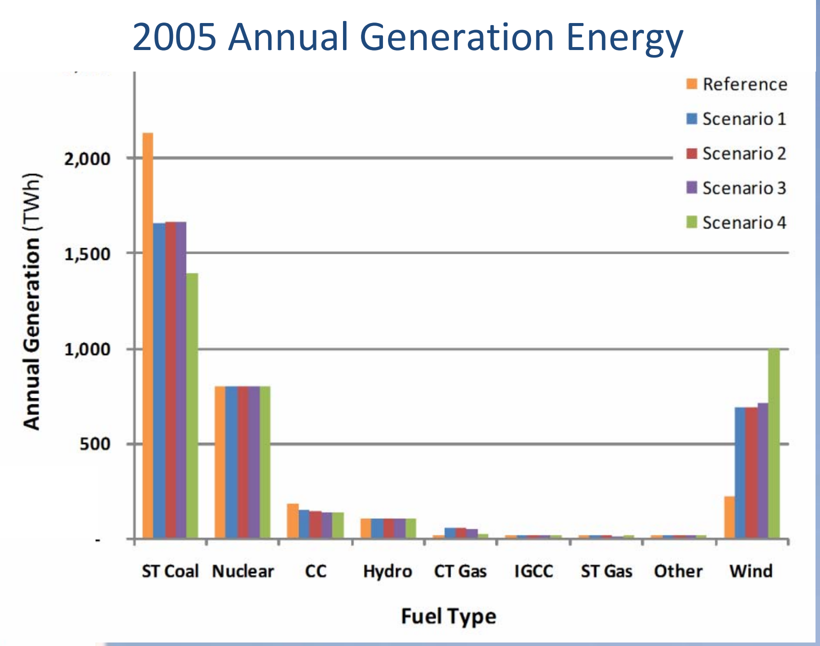
- The conceptual transmission overlays consist of multiple 800kV HVDC and EHV AC lines; regional AC upgrades also needed
- Similar levels of new transmission are needed across the 4 scenarios; some transmission elements are common to all overlays
- The modeling indicates that a fair amount of wind can be accommodated provided that adequate transmission is available.
- Transmission provides capacity benefits in its own right, and enhances the reliability contribution of wind generation by a measureable and significant amount.
- The EHV DC transmission in overlays could provide other operational and reliability benefits not evaluated here

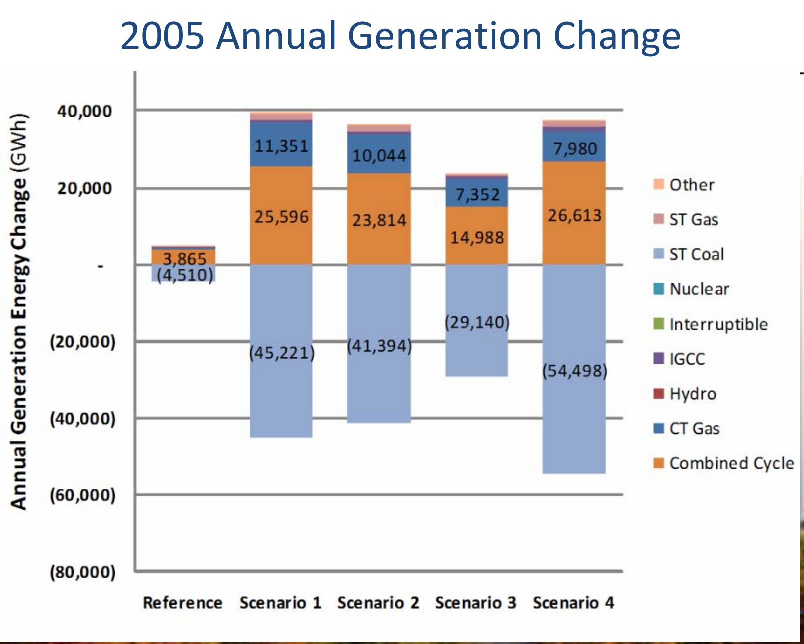
Evaluating Operating Impacts

- Based on chronological production simulations (PROMOD)
  - Hourly granularity
  - Mimic market operation
    - » Day-ahead commitment to forecast load and forecast wind generation
    - » Re-dispatch to actual load and actual wind
    - » Carry additional regulation and other reserves to address increased variability and uncertainty due to wind generation
- Analyzing impacts within the hour
  - Use high-resolution wind and load data
  - Apply mathematical and statistical techniques to estimate incremental requirements

Operational Impacts

- Generation displacement depends on location/amount of wind generation
- Fossil units are displaced due to the additional variability and uncertainty introduced by wind generation





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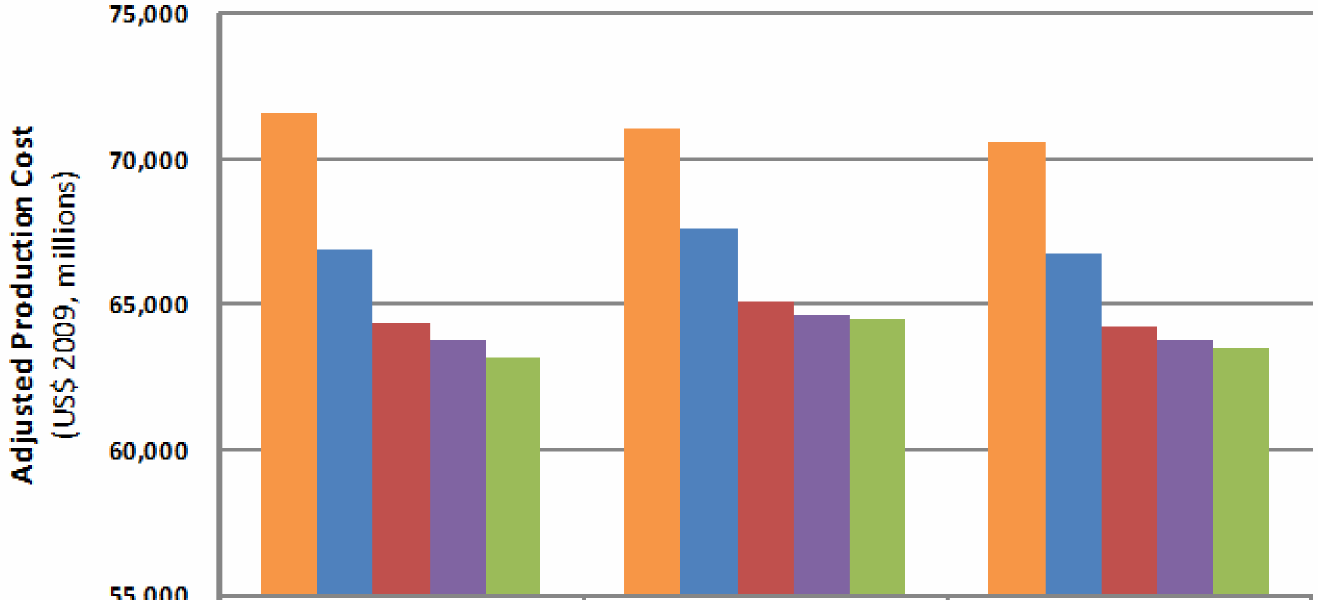
Impacts on Production Cost

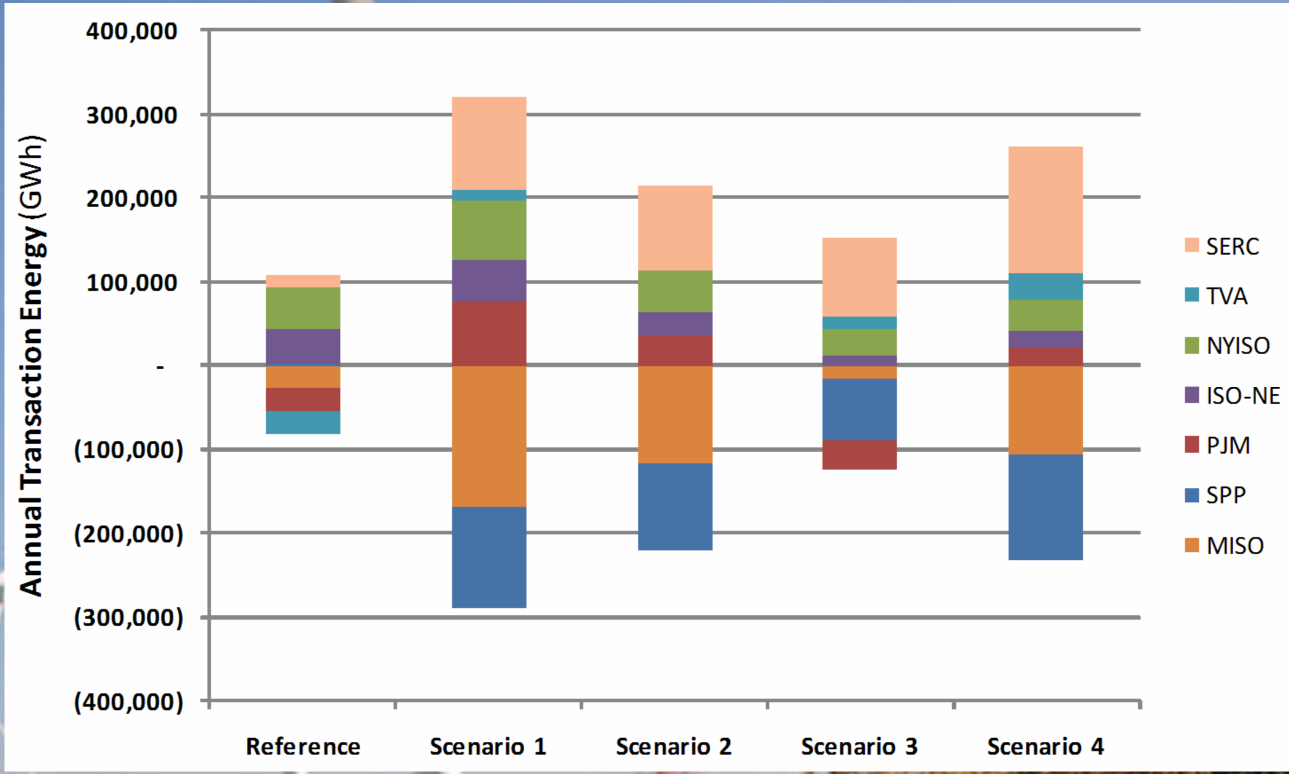


	2004	2005	2006
Reference	71,642	71,042	70,623
Scenario 1	66,834	67,571	66,700
Scenario 2	64,380	65,059	64,226
Scenario 3	63,769	64,653	63,754
Scenario 4	63,219	64,509	63,474

Year

Effects on Regional Energy Transactions

- MISO & SPP are net exporters in all scenarios
- PJM is net exporter in Scenario 3
- Scenario 3 has lowest transaction energy



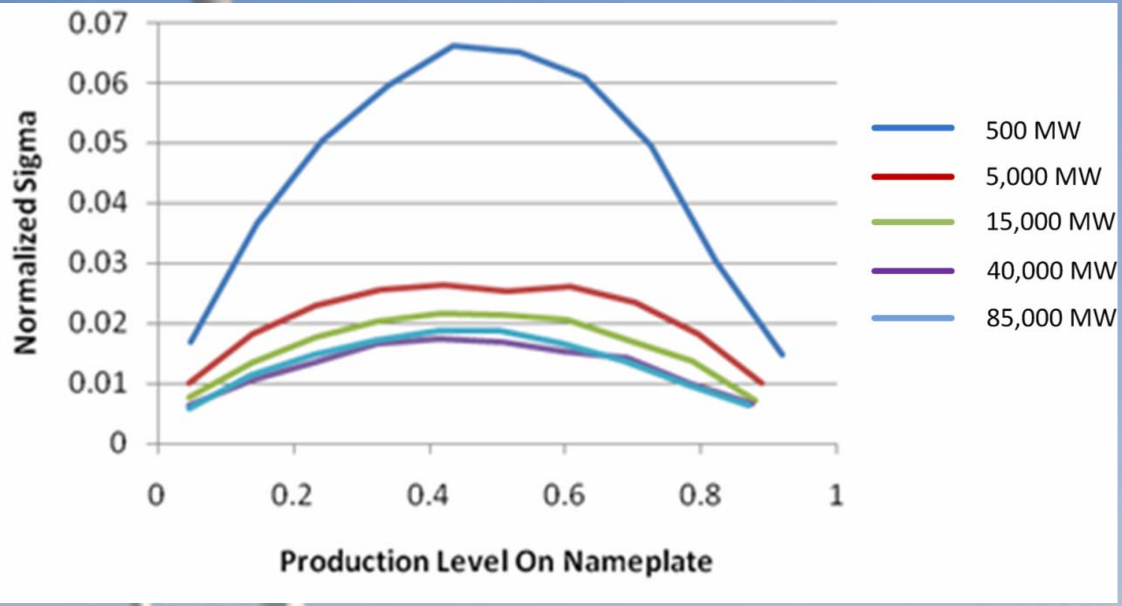
Assessing Wind Integration Impacts

- Operational cost for managing wind is assessed through comparative production simulations
  - Actual wind generation, including DA uncertainty and incremental reserves
  - "Ideal" wind generation, which requires no incremental reserves and is known perfectly for all forecast horizons
- Large, multi-area model introduced some new challenges
- No practical experience with very high penetrations of wind to use as a guide for analysis

Diversity Benefits

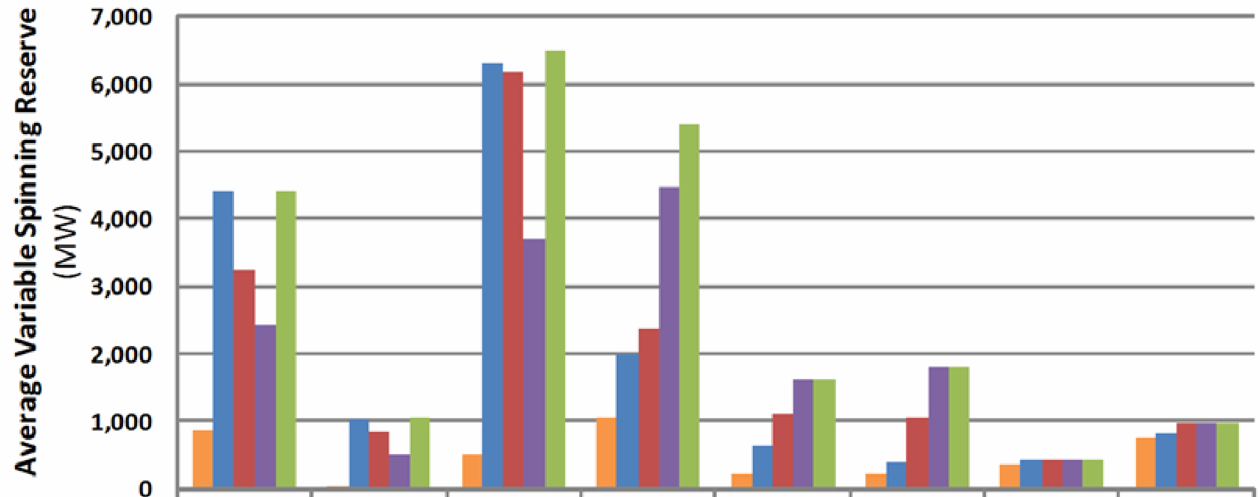
- Both variability and uncertainty of aggregate wind decrease percentage-wise with more wind, more geographic area
- Both can be characterized for a defined scenario with NREL meso-scale data
- Characterizations are useful for estimating incremental reserve requirements

10-minute Variability of Aggregate Wind Generation



Results – Reserve Requirements

- Wind variability (as function of generation level and scenario) use to calculate incremental regulation amount
- Results is a profile that varies hourly with the amount of wind generation



	MISO	MAPP	SPP	PJM	NYISO	ISO-NE	TVA	SERC
Load Only	885	43	514	1055	217	202	365	741
Actual Wind S1	4,424	1,020	6,308	1,994	618	399	420	816
Actual Wind S2	3,245	835	6,176	2,359	1,118	1,046	418	955
Actual Wind S3	2,419	503	3,695	4,463	1,614	1,789	418	955
Actual Wind S4	4,423	1,038	6,487	5,410	1,614	1,789	418	955

Region

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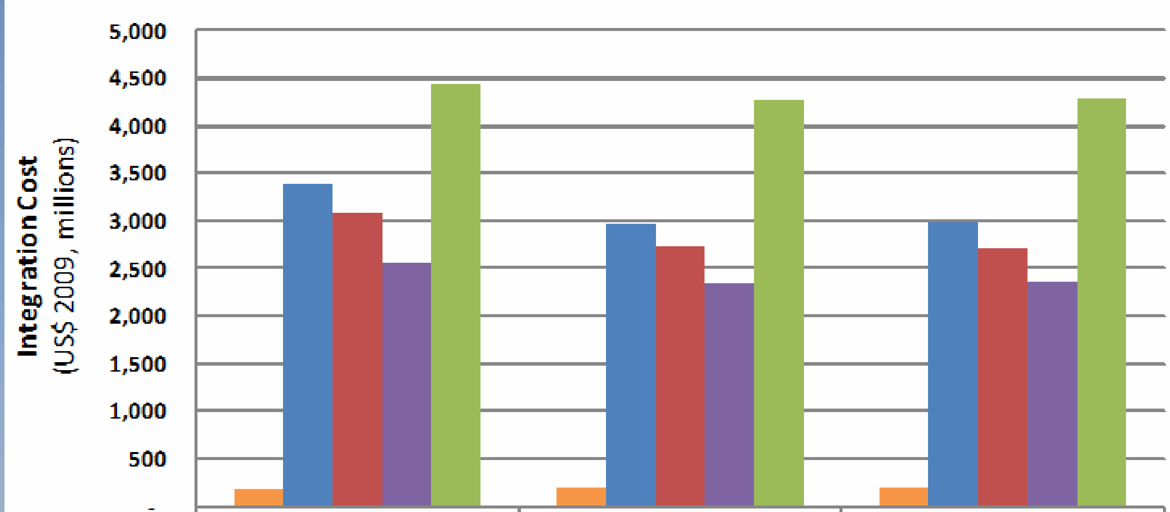
Wind Generation Impact on Reserves

- Operational assumptions for 2024 played important role in reducing reserve requirements
- The geographic size of the market areas assumed in the study allows substantial benefits of geographic diversity to be realized.
- The pooling of larger amounts of load and discrete generating resources via regional markets also realizes the benefits of diversity.
- With sub-hourly energy markets, changes in load and wind than can be forecasted over a short interval are compensated for in a very economic manner.

Integration Cost Results

- Some variation by year
- Reducing wind in west reduces integration cost
- Incremental spinning reserves have more influence on cost



	2004	2005	2006
Reference	174	189	199
Scenario 1	3,396	2,967	2,989
Scenario 2	3,078	2,728	2,720
Scenario 3	2,560	2,337	2,359
Scenario 4	4,439	4,269	4,285

Year

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Wind Integration Costs & Impacts

- Because the production simulation model contains multiple operating areas, and transactions between these areas are determined on an economic basis, variability from wind in a given area will be dispersed through economic transactions to other areas.
- Costs for integrating wind across the interconnection vary by scenario. For the 20% cases, Scenario 1 shows the highest cost at $5.13/MWh (US$2009) of wind energy; Scenario 3 shows the lowest integration cost at $3.10/MWh (US$2009).
- Integration costs average $4.54/MWh (US$2009) for the 30% scenario, which is roughly a combination of scenarios 1 and 3.

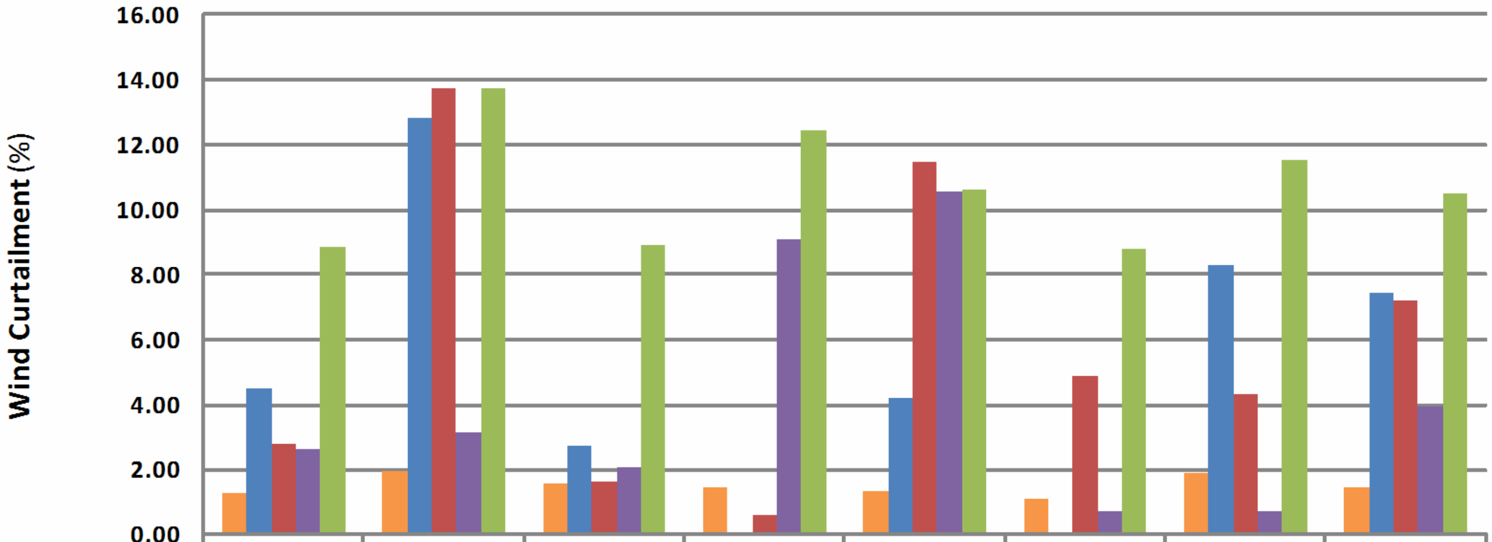
Wind Integration Costs & Impacts (cont.)

- The integration cost results for the 20% scenarios show that spreading the wind more evenly over the footprint reduces the cost of integration… (more in the east, where there is more load and a larger number of resources to manage variability…)
- Using the actual shape as the proxy resource (with no intra-hour variability or uncertainty over any forward time frame) eliminates any issues related to the "value" of wind energy between the "actual" and "ideal" cases.
- The actual shape proxy, however, does potentially mask or leave out some true operational costs, e.g. backing down or possibly even de-commitment of fossil units to accommodate wind generation

Model Assumptions and Curtailment

- Wind generation curtailment observed and investigated
- Effects on curtailment of "Must Run" status for fossil units, dispatch price for wind
- Sensitivity cases compared to "copper sheet" case where transmission constraints are removed
- Findings
  - Removing "Must Run" flags from coal units had very little impact on wind generation curtailment (decrease of 0.27%)
  - Setting dispatch price of wind generation to -$40/MWH reduced curtailment by just under 50% (6.38% to 3.51%)
  - "Copper sheet" case shows curtailment level of 0.12%, which is likely due to minimum generation constraints
  - Increasing MinGen levels to 50% on coal plants increased curtailment by only 2%
- Conclusion: Transmission congestion is major cause of curtailment

Curtailment by Scenario and Region

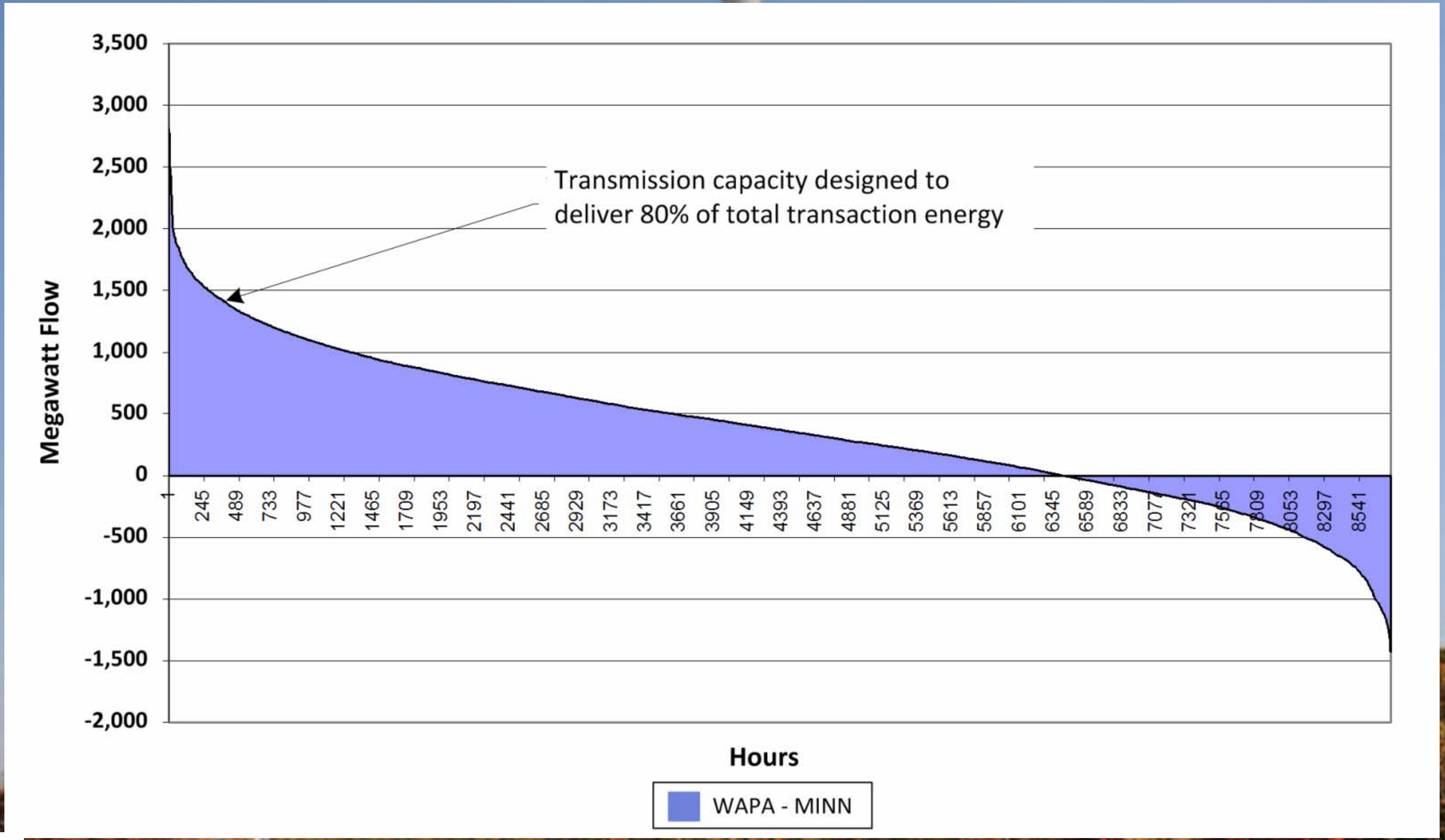


	MISO	SPP	PJM	ISO-NE	NYISO	SERC	TVA	Total Footprint
Reference (%)	1.27	1.94	1.56	1.43	1.30	1.08	1.86	1.46
Scenario 1 (%)	4.52	12.79	2.76	0.02	4.20	0.08	8.28	7.46
Scenario 2 (%)	2.77	13.75	1.62	0.60	11.44	4.87	4.29	7.21
Scenario 3 (%)	2.62	3.16	2.05	9.06	10.57	0.72	0.71	3.94
Scenario 4 (%)	8.87	13.73	8.90	12.44	10.61	8.76	11.53	10.51

Region

Curtailment is expected result

- Transmission overlays sized to deliver most, but not all, of transaction energy from “copper sheet” model

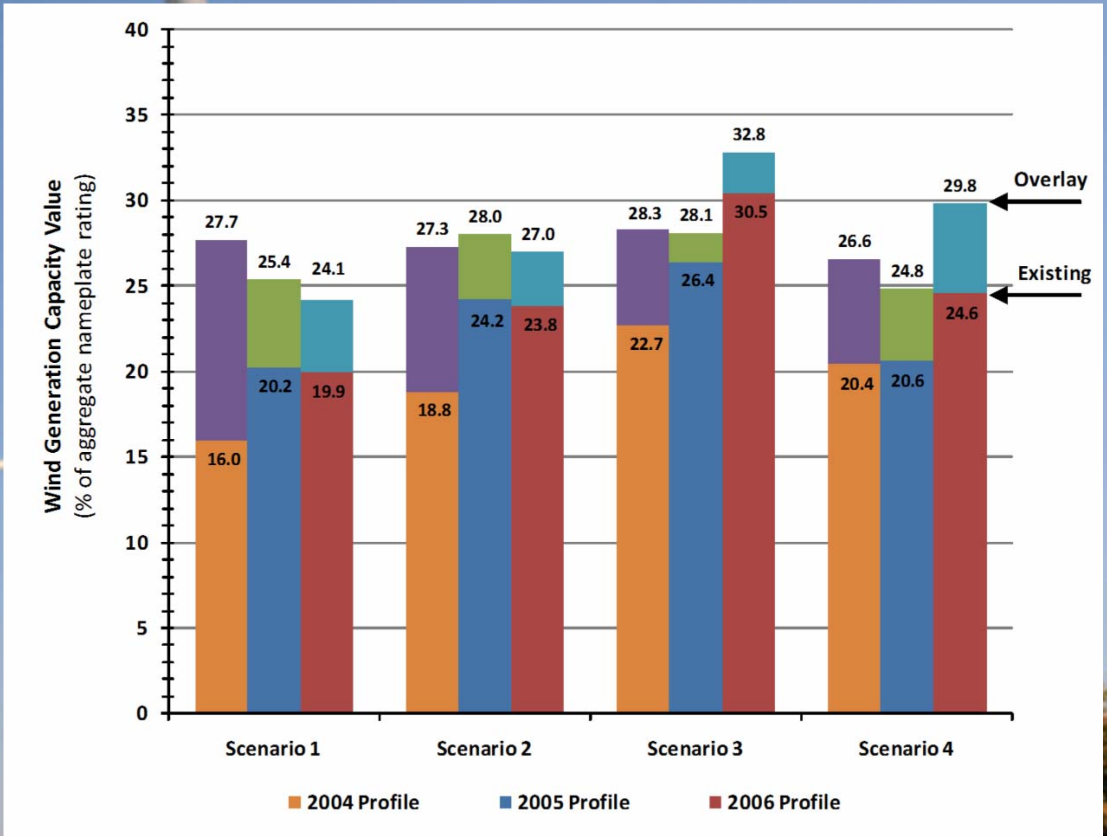


Wind Generation contribution to Resource Adequacy

- LOLE analysis of the Eastern Interconnection with wind generation and the transmission overlays as developed in this study show the Effective Load Carrying Capability **(ELCC)** of the wind generation to range from **24.1% to 32.8%** of the rated installed capacity.
- The LOLE analysis performed for this study shows that the existing transmission network in the Eastern Interconnection contributes roughly **50,000 MW** of capacity benefits. With the transmission overlays developed for the wind scenarios in this study, the benefit is increased by up to **8500 MW**.
- The **transmission overlays increase the ELCC** of wind generation anywhere from a few to almost **10 percentage points** (e.g. 18% to 28%).
- The ELCC of wind generation can vary greatly geographically depending on which historical load and wind profiles are being studied. Inter-annual variations were observed; however, these variations were much smaller than had been observed in previous studies (e.g. Minnesota 2006).

Transmission and Overlay Effects on Wind Generation Capacity Value

- Overlay increases capacity value of wind generation by a few to almost 10%
- Some inter-annual variability, although smaller than observed in some previous studies
- Difference between ELCC with overlay and 20% is conventional generation that could be deferred

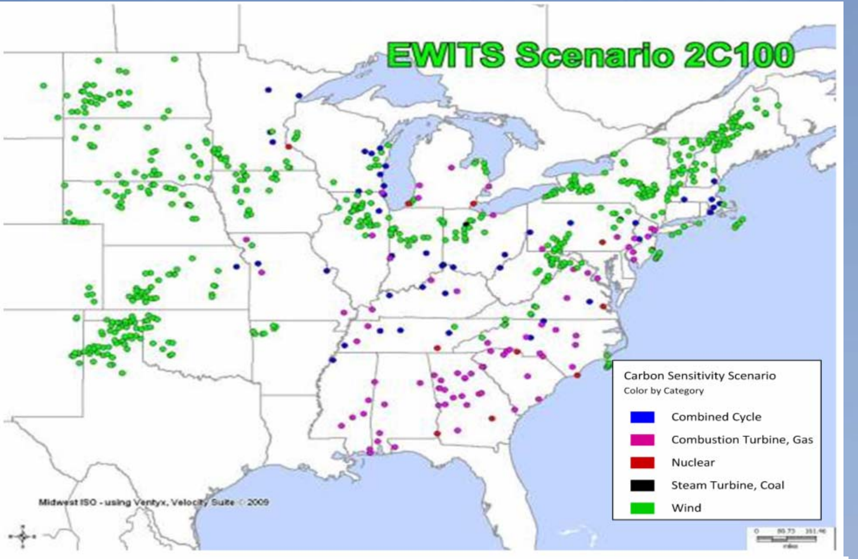


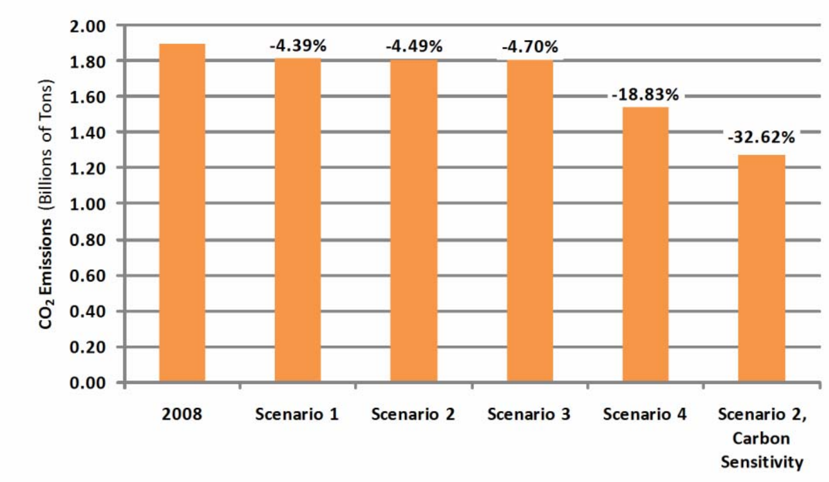
PROMOD Modeling Sensitivities

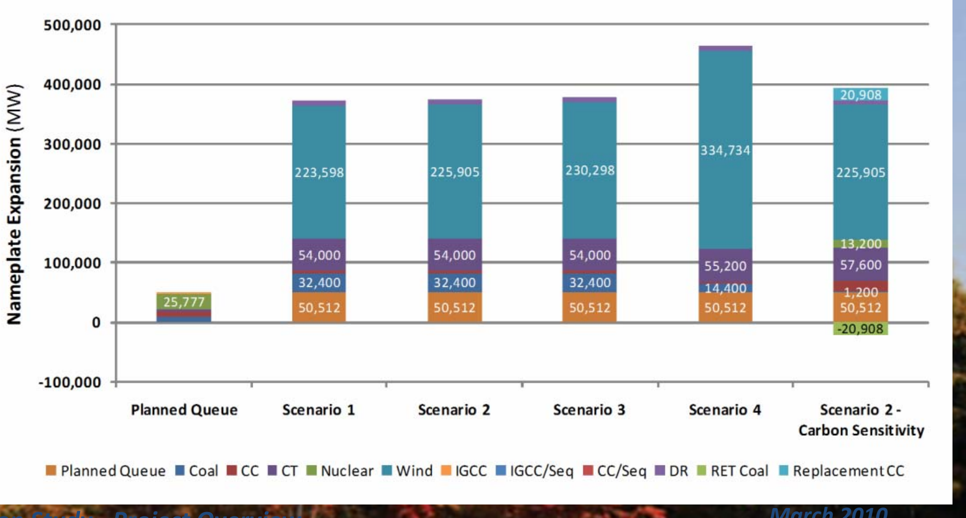
- Opportunities for sensitivity cases was limited by scope and schedule
- However, some additional cases run to assess effects of PROMOD features or nuances
- Focus areas
  - Effects of PROMOD modeling on wind generation curtailment
  - Effect of PROMOD “bid logic” on unit commitment and production cost
  - Influence of inter-regional hurdle rates on integration cost

Carbon Sensitivity

- No carbon cost or penalty in base scenarios
- 5th scenario created based on high cost of carbon, based on Scenario 2

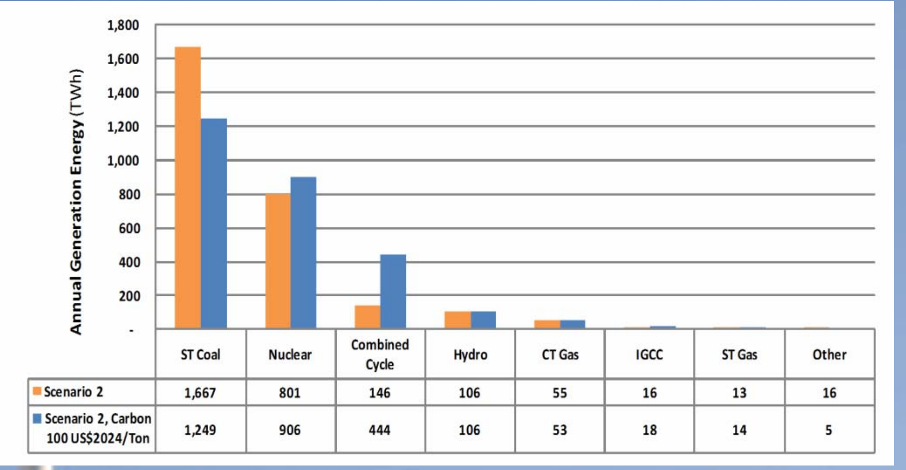




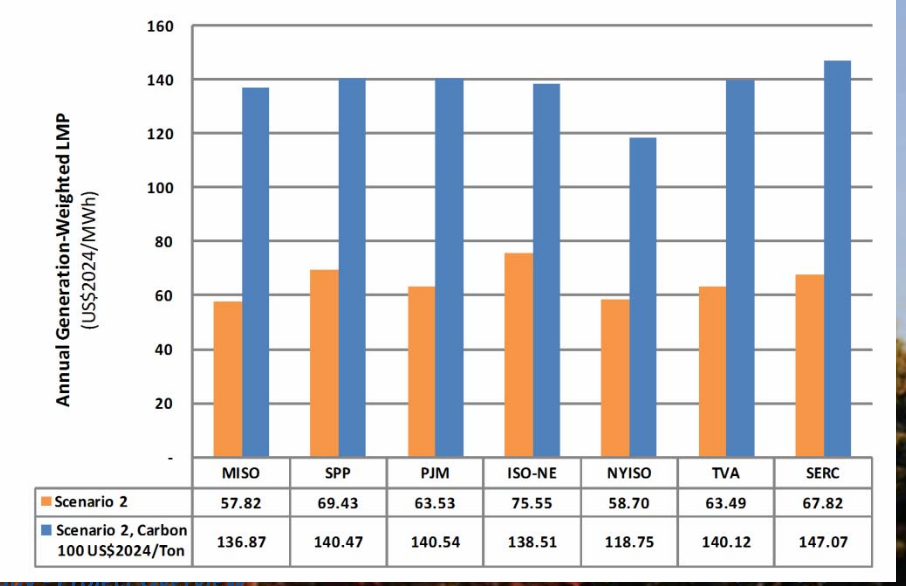


Carbon Sensitivity Results

- Findings
  - Carbon emissions reduced substantially over even Scenario 4
  - Carbon penalty increases production cost significantly
  - Little impact on wind curtailment or integration cost



	ST Coal	Nuclear	Combined Cycle	Hydro	CT Gas	IGCC	ST Gas	Other
Scenario 2	1,667	801	146	106	55	16	13	16
Scenario 2, Carbon 100 US$2024/Ton	1,249	906	444	106	53	18	14	5



	MISO	SPP	PJM	ISO-NE	NYISO	TVA	SERC
Scenario 2	57.82	69.43	63.53	75.55	58.70	63.49	67.82
Scenario 2, Carbon 100 US$2024/Ton	136.87	140.47	140.54	138.51	118.75	140.12	147.07

Annual Coal Generation TW-Hrs

Region	ST Coal S1	ST Coal S2	ST Coal S3	ST Coal S4
PJM	465	464	422	345
MISO	457	472	469	415
TVASUB	171	172	170	158
MAPPCOR	48	51	52	40
SPP	87	87	140	86
SERCNI	392	387	383	328
ISONE	21	20	16	14
NYISO	15	14	12	10
TOTAL	1,657	1,667	1,664	1,397

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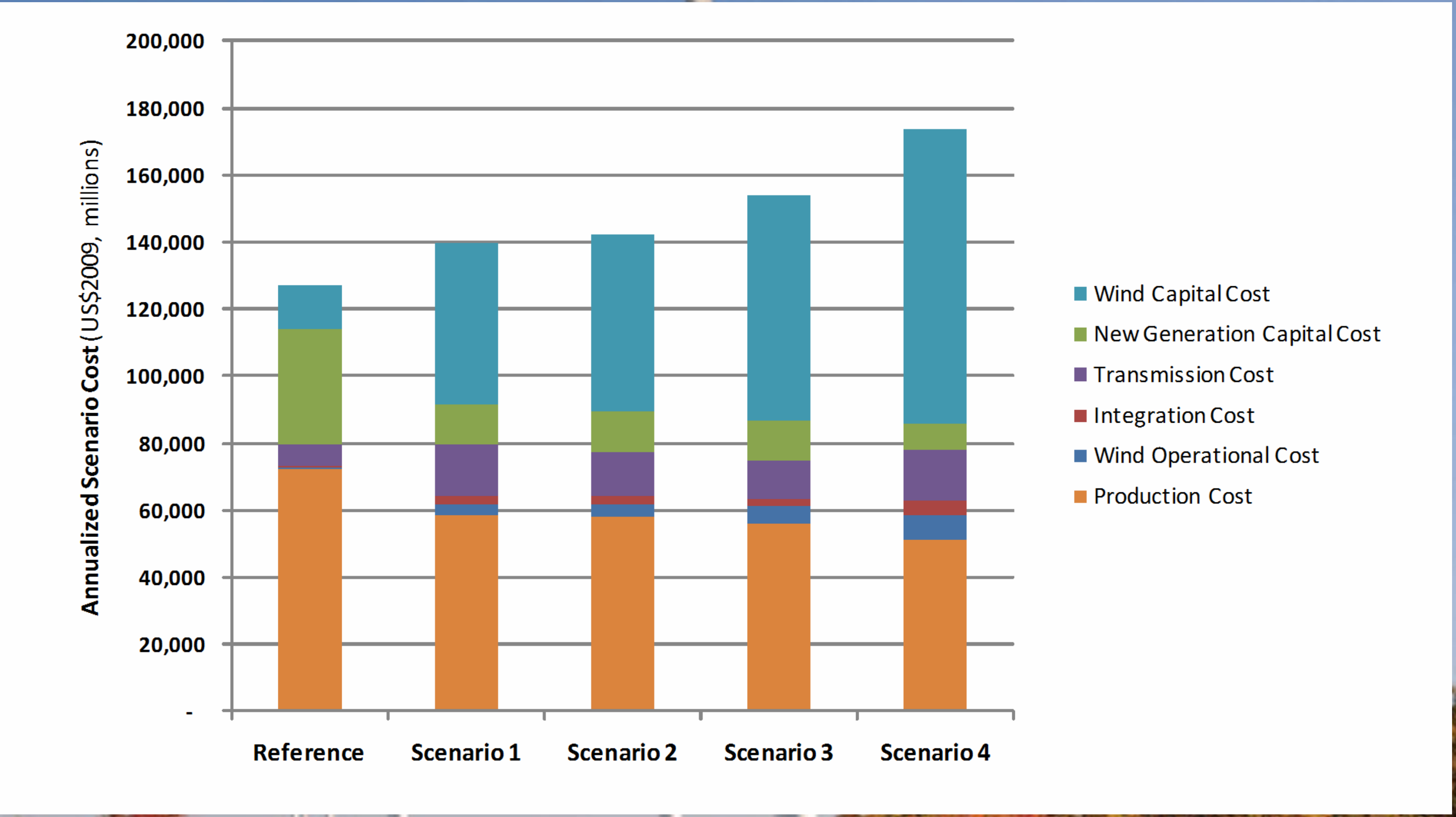
Scenario Cost Comparisons



EWITS Conclusions

- 20 and 30% wind penetrations are technically feasible with significant expansion of the transmission infrastructure.
  - New transmission will be required for all the future wind scenarios in the Eastern Interconnection,
- Without transmission enhancements, substantial curtailment of wind generation will occur
- Interconnection-wide costs for integrating large amounts of wind generation are manageable with large regional operating pools, where benefits of load and wind diversity can be exploited and large numbers of supply resources are efficiently committed and dispatched.

EWITS Conclusions

- Transmission helps reduce the impacts of the variability of the wind and….
  - Reduces wind integration costs
  - Increases reliability of the electrical grid
  - Helps make more efficient use of the available generation resources
- Costs for aggressive expansions of the existing grid are significant, but they make up a relatively small piece of the total annualized costs in any of the scenarios studied
- Wind generation displaces carbon-based fuels, directly reducing carbon dioxide (CO_2) emissions

Some Other Findings and Conclusions

- Achieving 20% energy penetration across the Eastern Interconnect will require very substantial wind development and therefore significant grid expansion.
- A single iteration of the economic transmission expansion methodology provides useful results and insights
- Further iterations would allow overlays to be improved, wind curtailment to be minimized
- Costs should be considered rough estimates based on a singe iteration of the process. Further engineering evaluation would be necessary to sharpen capital cost estimates and develop chronological plan to evolve existing grid

Finale…

- There are no fundamental technical barriers to the integration of 20% and 30% wind energy into the electrical system, but…
- There needs to be a continuing evolution of transmission planning and system operation policy and market development for this to be achieved

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The End, or just the First Step?

- **Sensitivity analysis was limited by schedule and budget**
- **A number of important considerations, alternatives, and variations suggested by TRC throughout process:**
  - **Further analysis of production-cost simulation results**
  - **Smart Grid implications and Demand Response sensitivities**
  - **PHEVs**
  - **Commitment/optimization with high amounts of wind**
  - **Fuel price sensitivity**
  - **The role and value of electrical energy storage**
  - **Transmission overlay enhancement**
  - **Sequencing of transmission overlay development**
  - **Wind generation curtailment and control**

Future Work

- Further analysis of regional results
- Demand response and smart grid load sensitivities
- Fuel sensitivity, unit commitment/optimization
- Plug in electric vehicle charging
- Sequencing of transmission
- Include more detailed representation from Canada
- Curtailment under transmission constrained scenarios and storage analysis

EnerNex CORPORATION

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