ARPA-E
Transmission Planning

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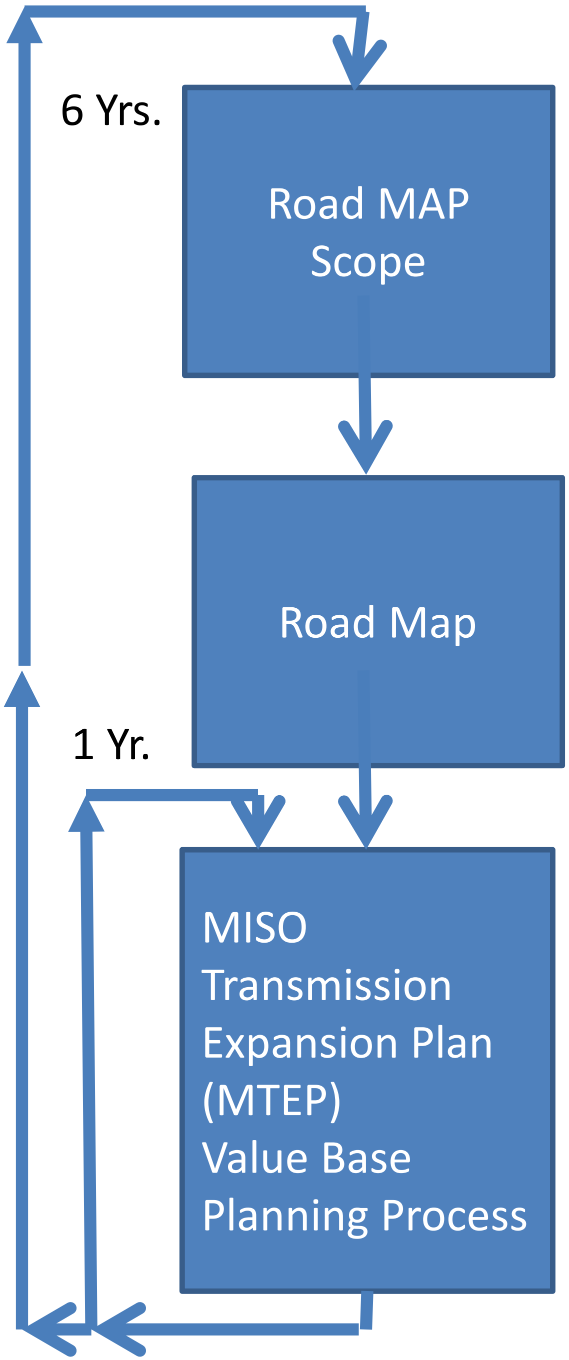
September 29,2016



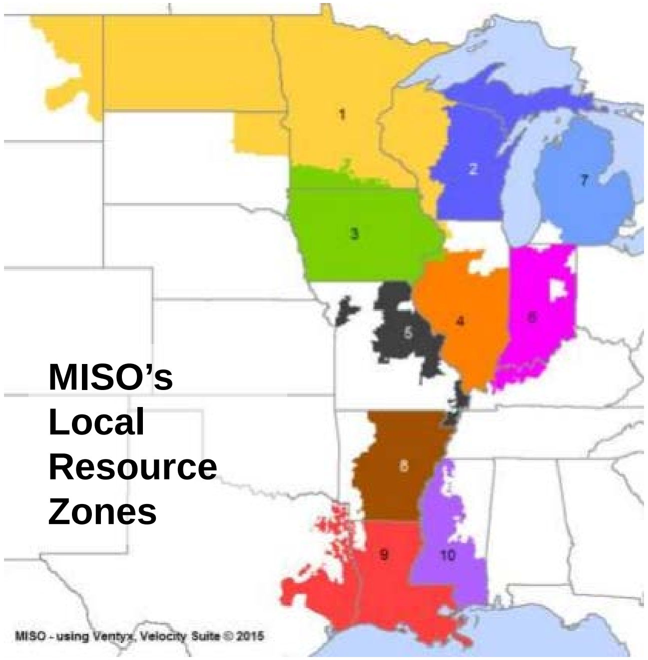
Definition of the future(s) with variable and alternatives,
Existing MISO inter regional power transfer capability
Generation alternatives
Transmission alternatives
Solution Constraints

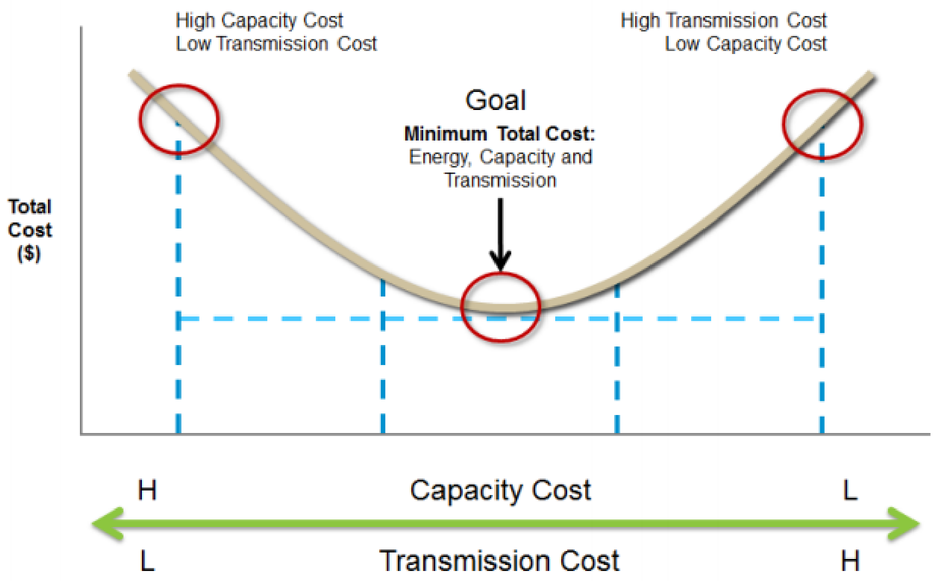
Carbon and Other Effluents
Max Renewables
Optimal Economic Generation Mix Forecast in lieu of Integrated Resource Plans
Location of Generation-Renewable Energy Zones input in lieu of exact site information
Value of Optimal Transmission
Optimal Inter MISO Regional Transmission

Transmission approved for construction
Generation Adequacy (LOLP)
Informational studies answering pertinent questions

Balancing the mix of renewable siting and transmission build-out

- RGOS found there is a balance between siting renewables in resource rich areas and building transmission to deliver them.
- MISO's mid-term analysis uses a new co-optimization technique to reevaluate this conclusion given current resource trends.
  - Transmission interface capacity between the MISO Local Resource Zones (LRZ) is examined.

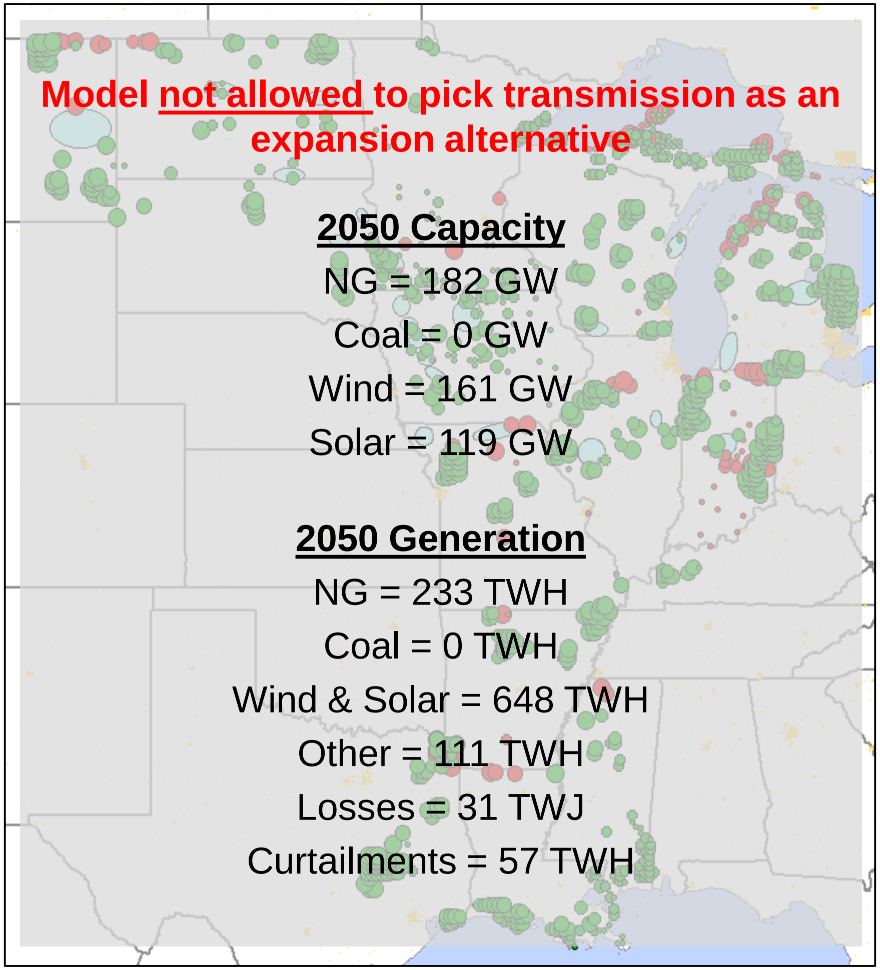


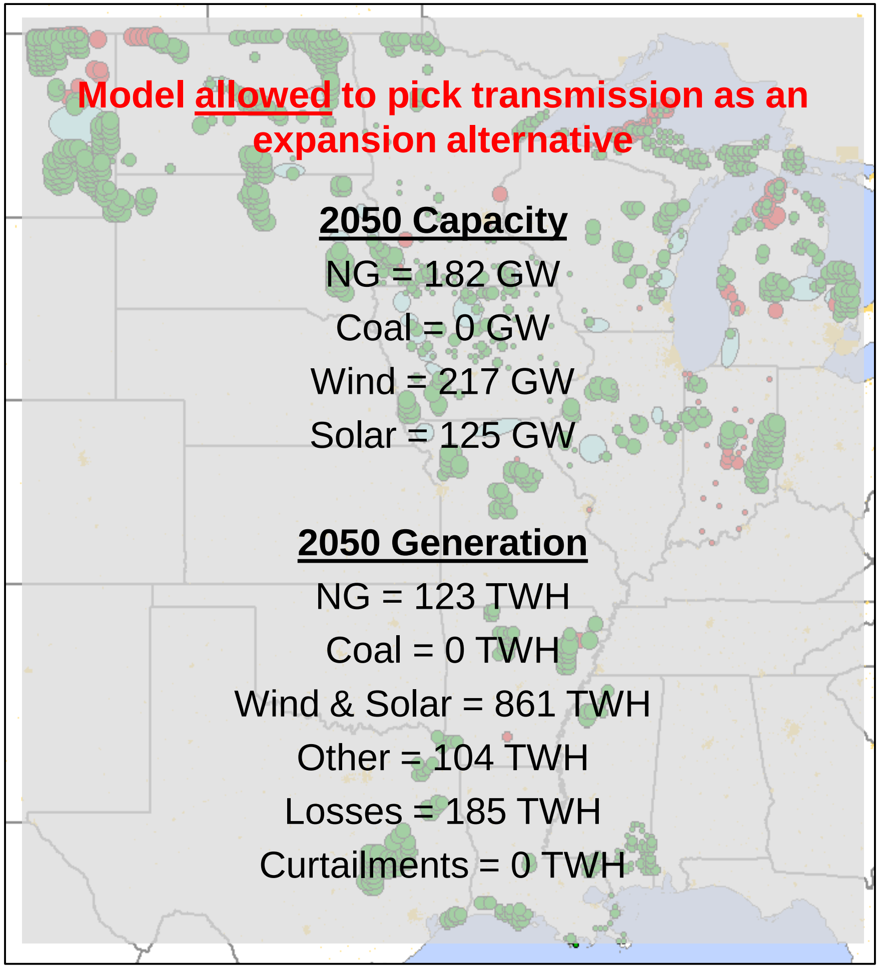


Co-optimization Generation Forecast and Transmission

- Three carbon dioxide reduction levels since 2005 were used
  - 30% by 2030
  - 50% by 2036
  - 80 % by 2050
- Optimal mixes of gas, wind and solar generation were sited for each carbon dioxide reduction level
- Cost of future energy was calculated-50% carbon reduction was the least cost scenario
- Inter-MISO regional transmission was identified

Study finding: an increase in transmission allows for more renewables to be built-out, while minimizing thermal generation

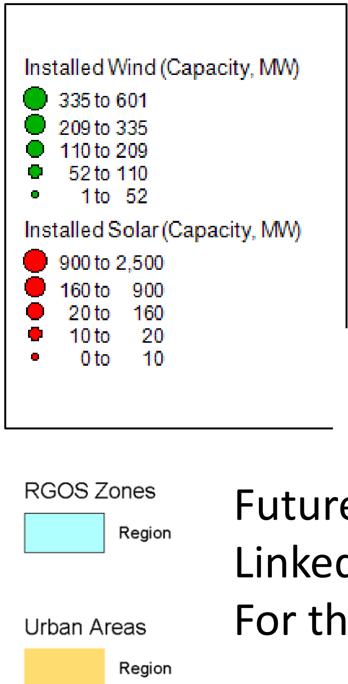




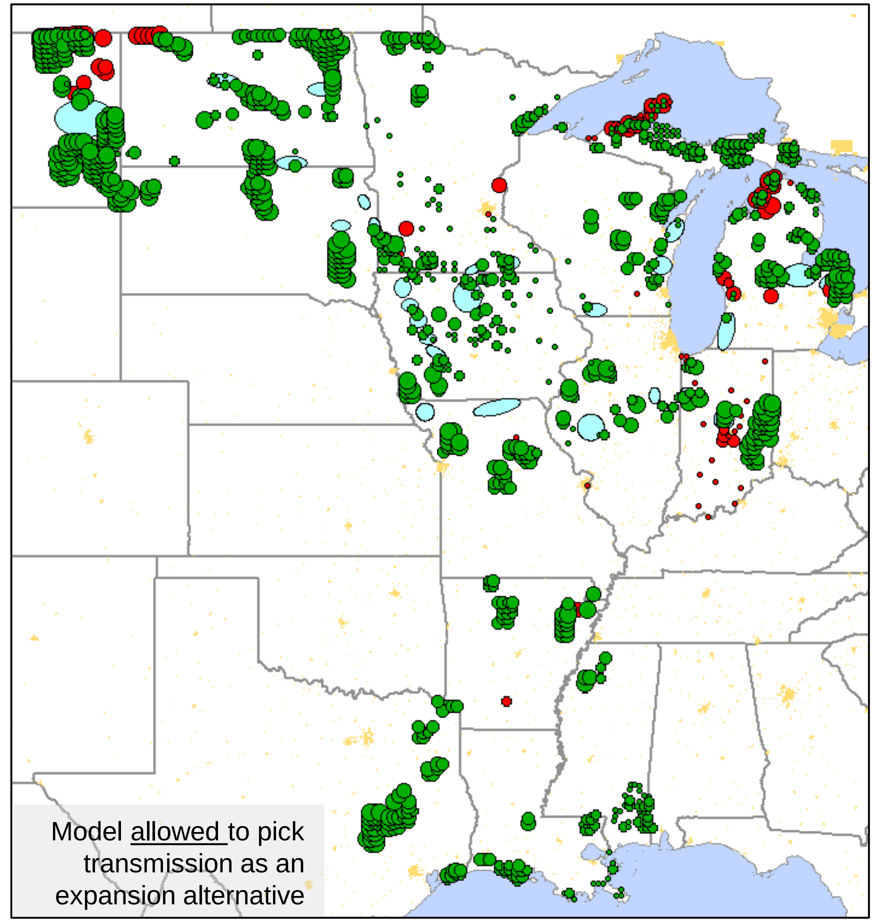
Results shown are from the load matching optimization which does not consider economics.

*RGOS = Regional Generator Outlet Study, see https://www.misoenergy.org/Planning/Pages/RegionalGenerationOutletStudy.aspx

This study identified cumulative potential for wind and solar build-out in MISO, which represents the upper limit of renewable expansion



Future Substation Locations
Linked by Transmission
For the 2010 Road Map

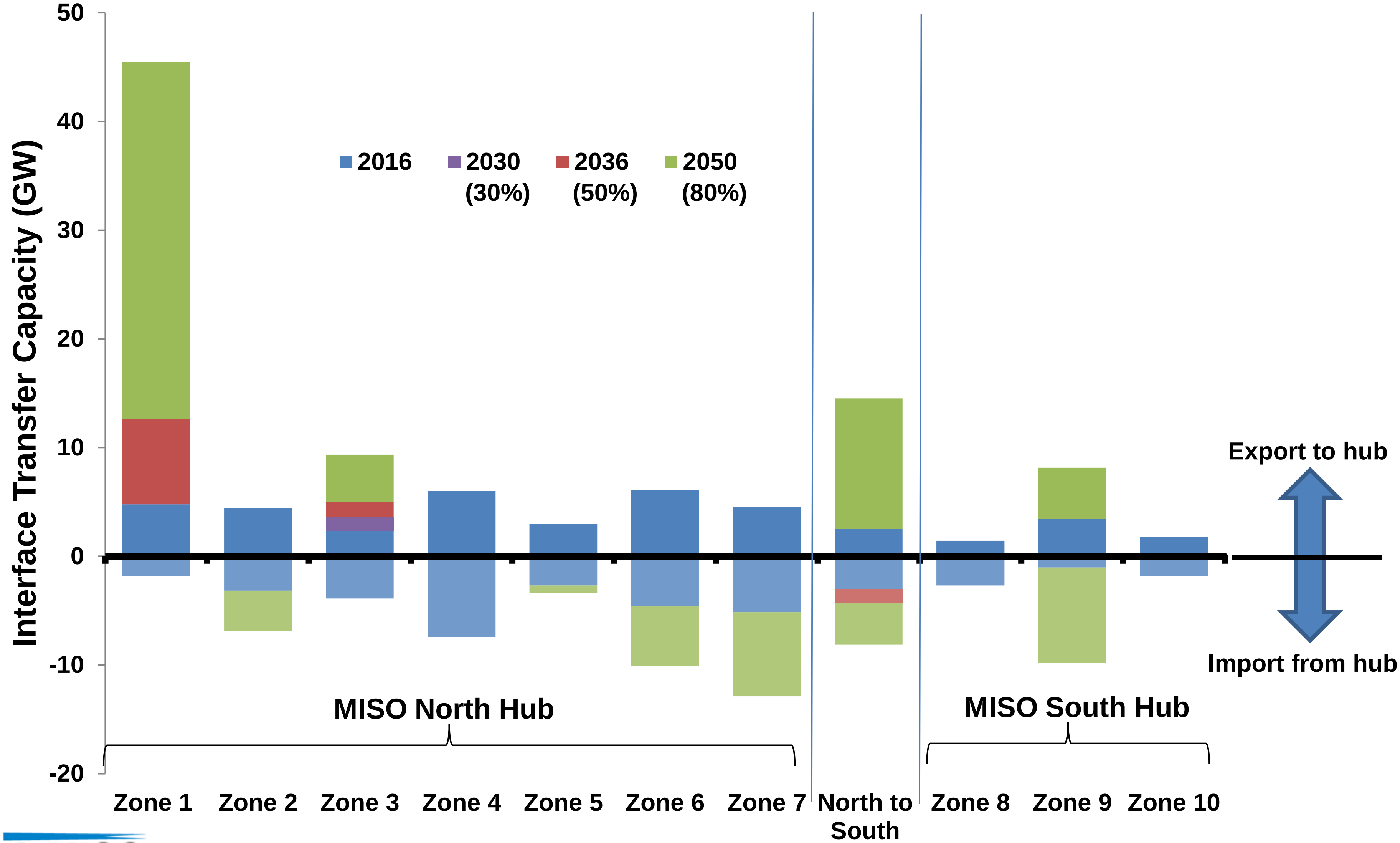


Constraining transmission expansion (left) drives a more distributed solar build-out; allowing transmission expansion (right) shifts renewable build-out to MISO North and replaces some solar expansion with wind.

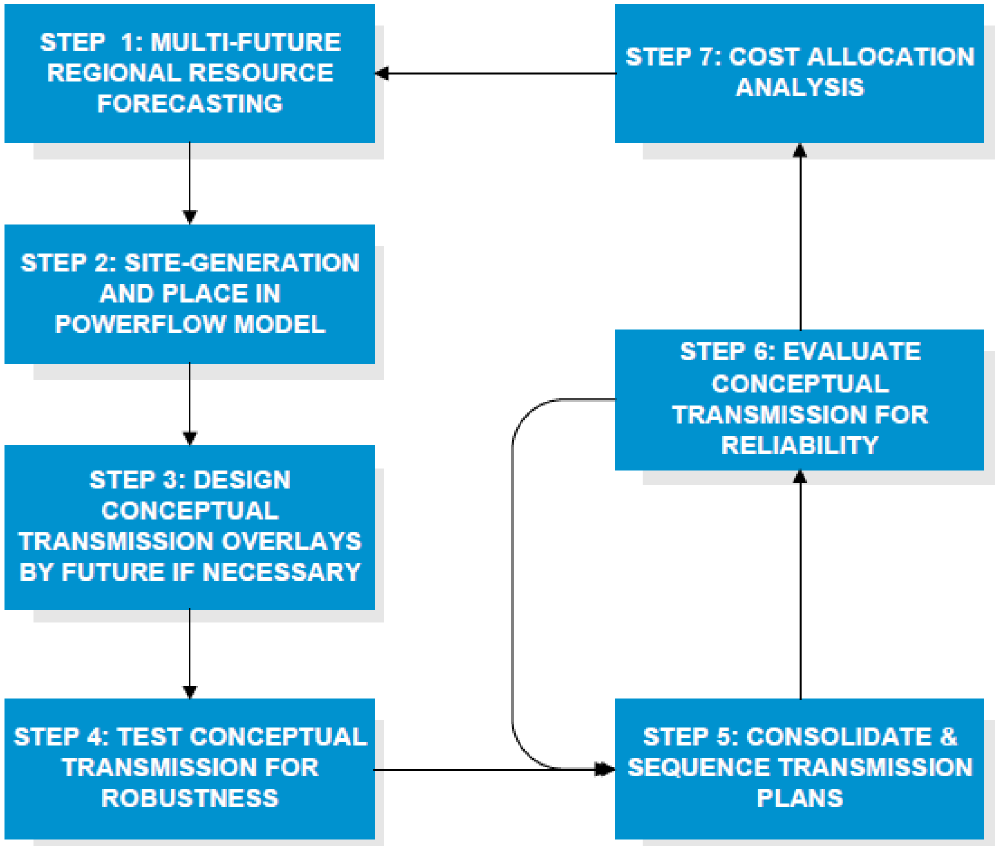
Both maps shows results of the load-matching optimization which does not consider economics.

*RGOS = Regional Generator Outlet Study, see https://www.misoenergy.org/Planning/Pages/RegionalGenerationOutletStudy.aspx

Study finding: High levels of wind build-out in Zone 1 by 2050 are facilitated by a large increase in export capacity



Value Based Planning Process



- Objective of value based planning is to develop the most robust plan under a variety of scenarios – not the least-cost plan under a single scenario
  - The “best” transmission plan may be different in each policy-based future scenario
  - The transmission plan that is the best-fit (most robust) against all these scenarios should offer the most future value in supporting the future resource mix

Load Forecast

- Utility bus by hour for the year
- Wind pattern matching the load pattern for a year
- Solar pattern matching the load pattern for a year
- Demand Response hourly for a year

EGEAS Generation Forecast

- Establish futures- 4
- Optimal selection of generation using a set of the road map alternatives
- Output is and input to the PROMOD production cost simulation program

Top Congested Flowgates in PROMOD Run*

Flowgate Name	Monitored Element Area (From - To)	2017 BAU			2022 BAU			2017 and 2022 BAU Combined		
		Binding Hours	Shadow Price (k$/MWh)	Congestion Cost ($)	Binding Hours	Shadow Price (k$/MWh)	Congestion Cost ($)	Binding Hours	Shadow Price (k$/MWh)	Congestion Cost ($)
10NTVL13 253581 SIGE 10NTVL16 253580 SIGE **	SIGE	3857	368.23	64,808	4443	493.26	86,814	8300	861.49	151,622
10802288 253552 SIGE 10ELOT13 253526 SIGE	SIGE	1051	85.95	24,667	962	82.35	23,633	2013	168.30	48,300
4NASON P 348835 AMIL 4INA 347280 AMIL	AMIL	843	134.19	21,335	636	101.12	16,078	1479	235.31	37,413
7JOPPA T 347325 AMIL 5JOPPA T 351003 EEI	AMIL-EEI	693	30.96	18,577	568	29.55	17,731	1261	60.52	36,308
16PETE 254529 IPL YBUS702 99296 IPL	IPL	631	47.70	14,310	596	47.00	14,100	1227	94.70	28,410
08WHITST 249529 DUK-IN 16GUION 254523 IPL **	DEI-IPL	151	6.54	6,251	463	22.75	21,750	614	29.29	28,001
10ABBRWN 253505 SIGE 10ABB345 253620 SIGE **	SIGE	1386	20.32	9,552	1559	30.15	14,170	2945	50.48	23,722

* Based on 2017 and 2022 BAU future PROMOD simulation
** Historically congested flowgates

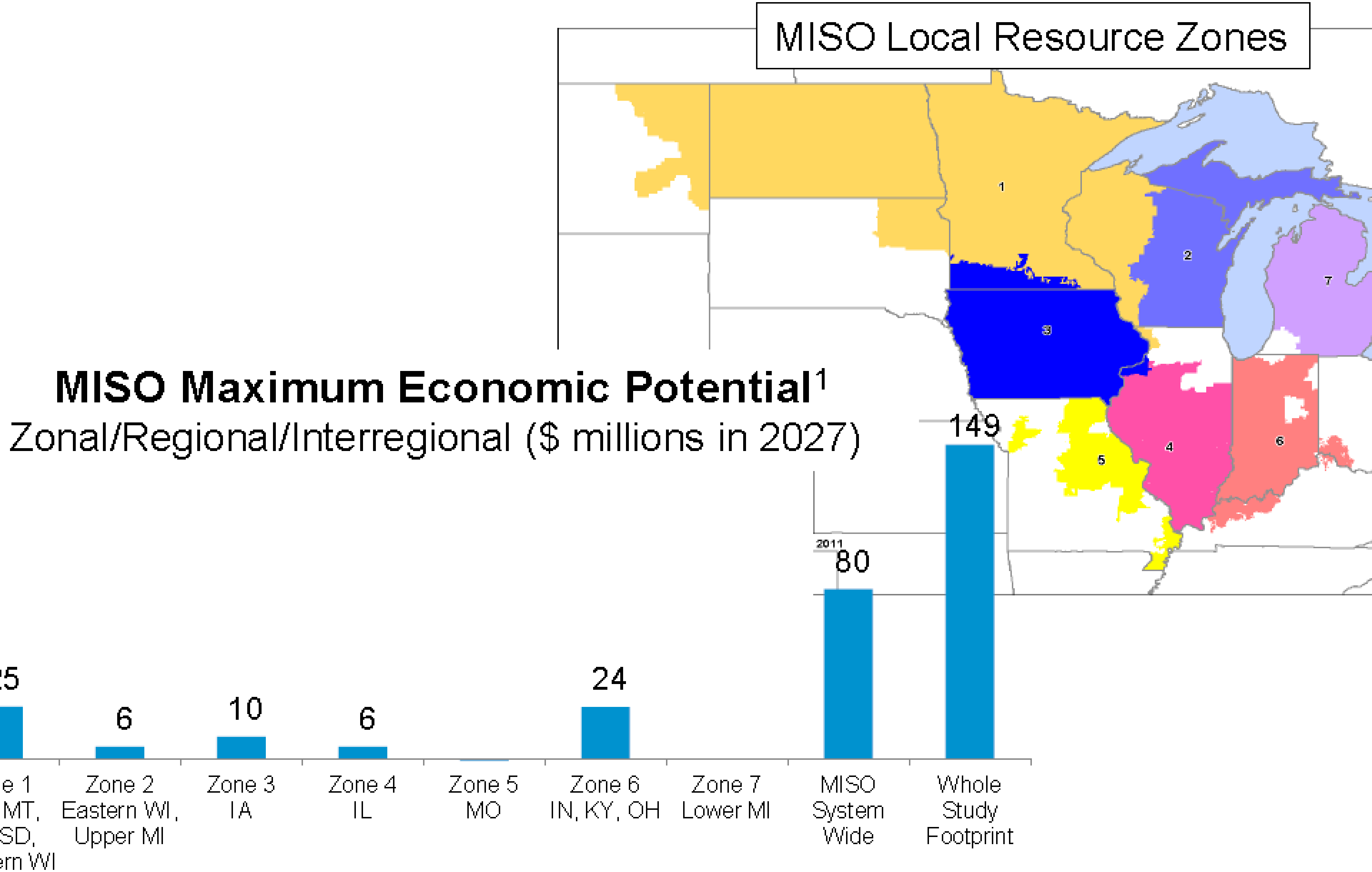
Summary of Historically Congested Flowgates

Flowgate Common Name	Monitored Element Area (From - To)	Day-Ahead		Real-Time		PROMOD Simulation			
						2017 BAU		2022 BAU	
		Binding Hours Ranking	Shadow Price Ranking	Binding Hours Ranking	Shadow Price Ranking	Binding Hours	Shadow Price (k$/MWh)	Binding Hours	Shadow Price (k$/MWh)
AB Brown 138/345KV Xfmr FLO Gibson-Francisco 345KV	SIGE	27	73	117	623	1386	20.32	1559	30.15
Adams 161/69kV Xfmr FLO Adams-Beaver Creek-Harmony/Rice 161kV	ALTW	14	24	76	21			2	0.06
Baldwin-Mt Vernon 345KV FLO St. Francois-Lutesville 345KV	AMIL	19	107	19	220	382	4.41	247	3.34
Benton Harbor-Palisades 345KV FLO Cook-Palisades 345KV	AEP	18	132	43	61	1	-		
Bunsonville-Eugene 345KV FLO Casey-Breed 345 KV	AEP-AMIL	9	58	32	213	989	12.65	77	1.07
Crete-East Frankfort 345kV FLO Dumont-Wilton Center 765kV	CE	172	410	4	51	201	0.94		
Crete-St Johns Tap 345kV FLO Dumont-Wilton Center 765kV	NIPS-CE	155	313	3	15	125	0.57	191	2.46

Difference of Constrained and Unconstrained Production Cost Cases

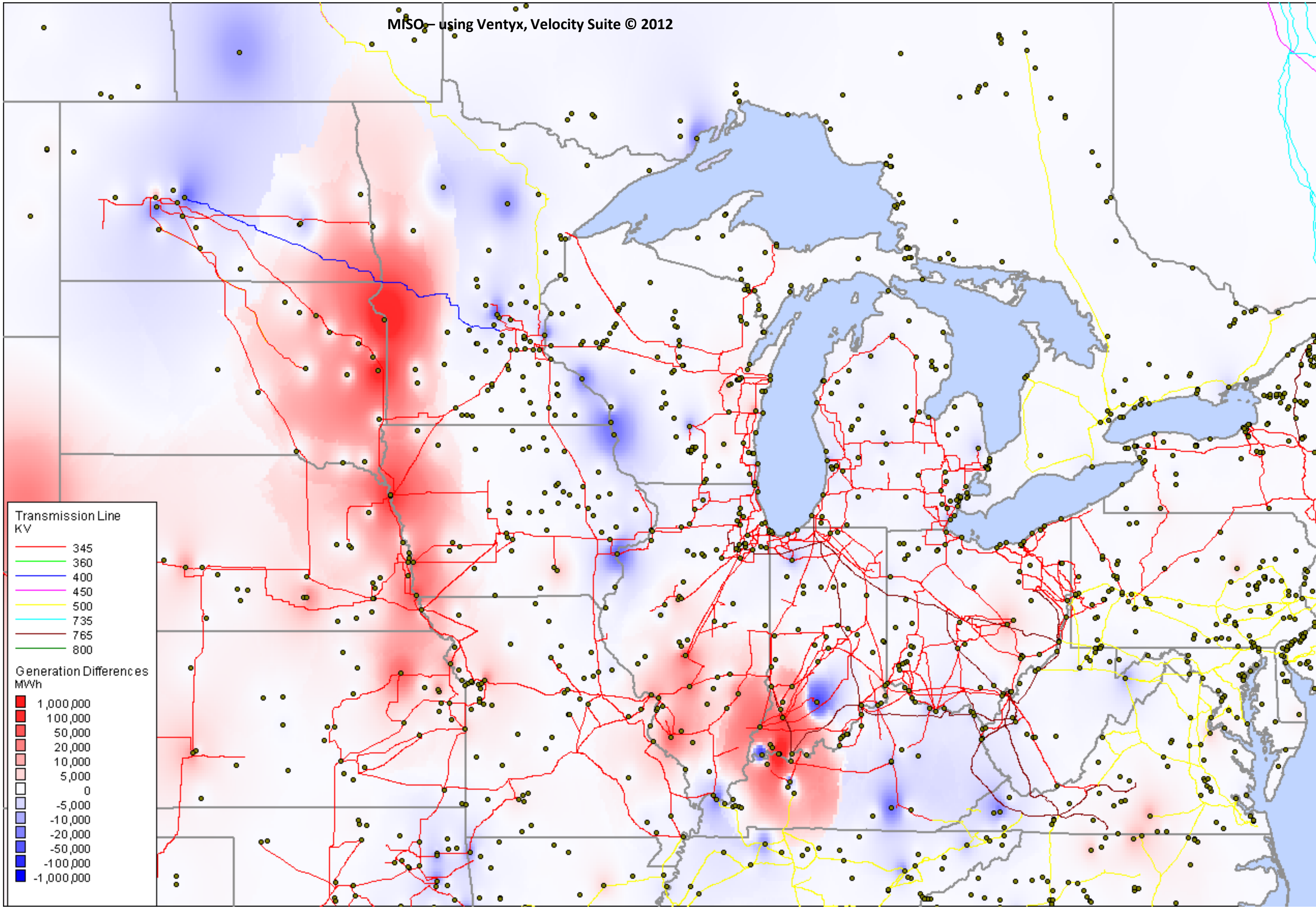
- Potential production cost savings
  - By area
  - MISO and neighboring areas

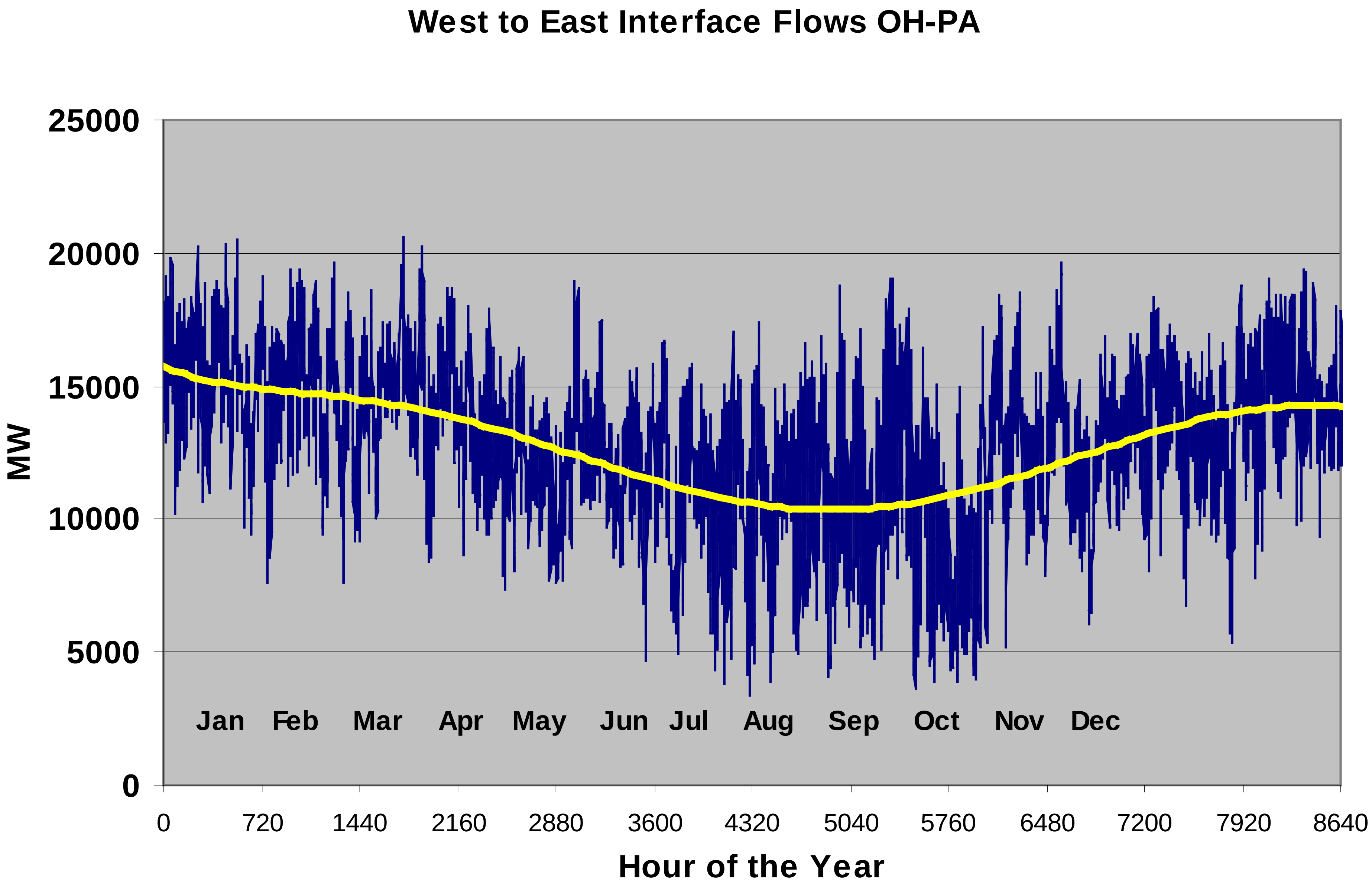
laximum Economic Potential in 2027 Derived from onal/Regional/Interregional Congestion Relief Analyse



gures shown represent maximum economic potential to MISO resulted from congestion relief on respective zonal/regional/interregional levels

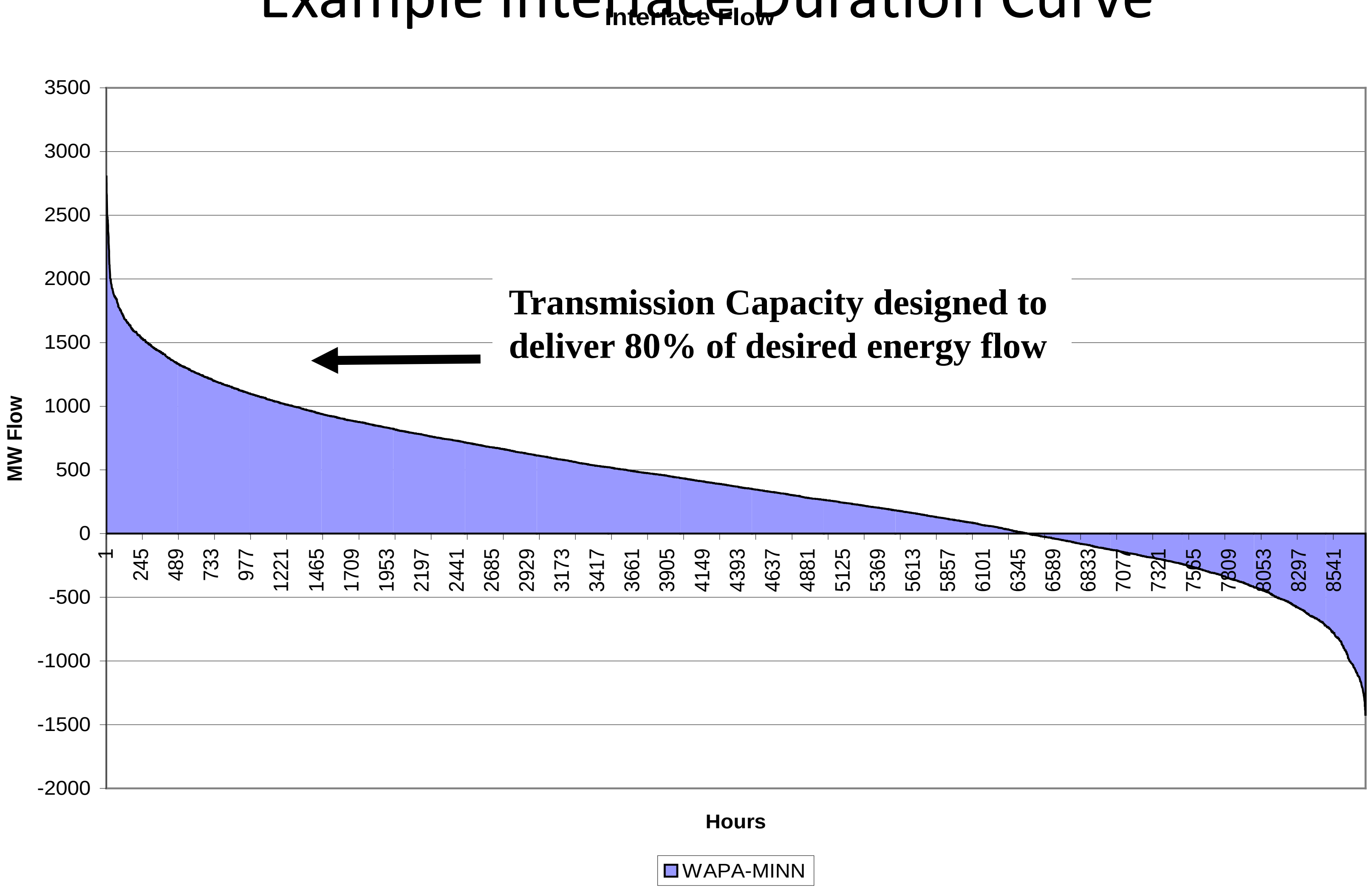
Energy Sources and Sinks



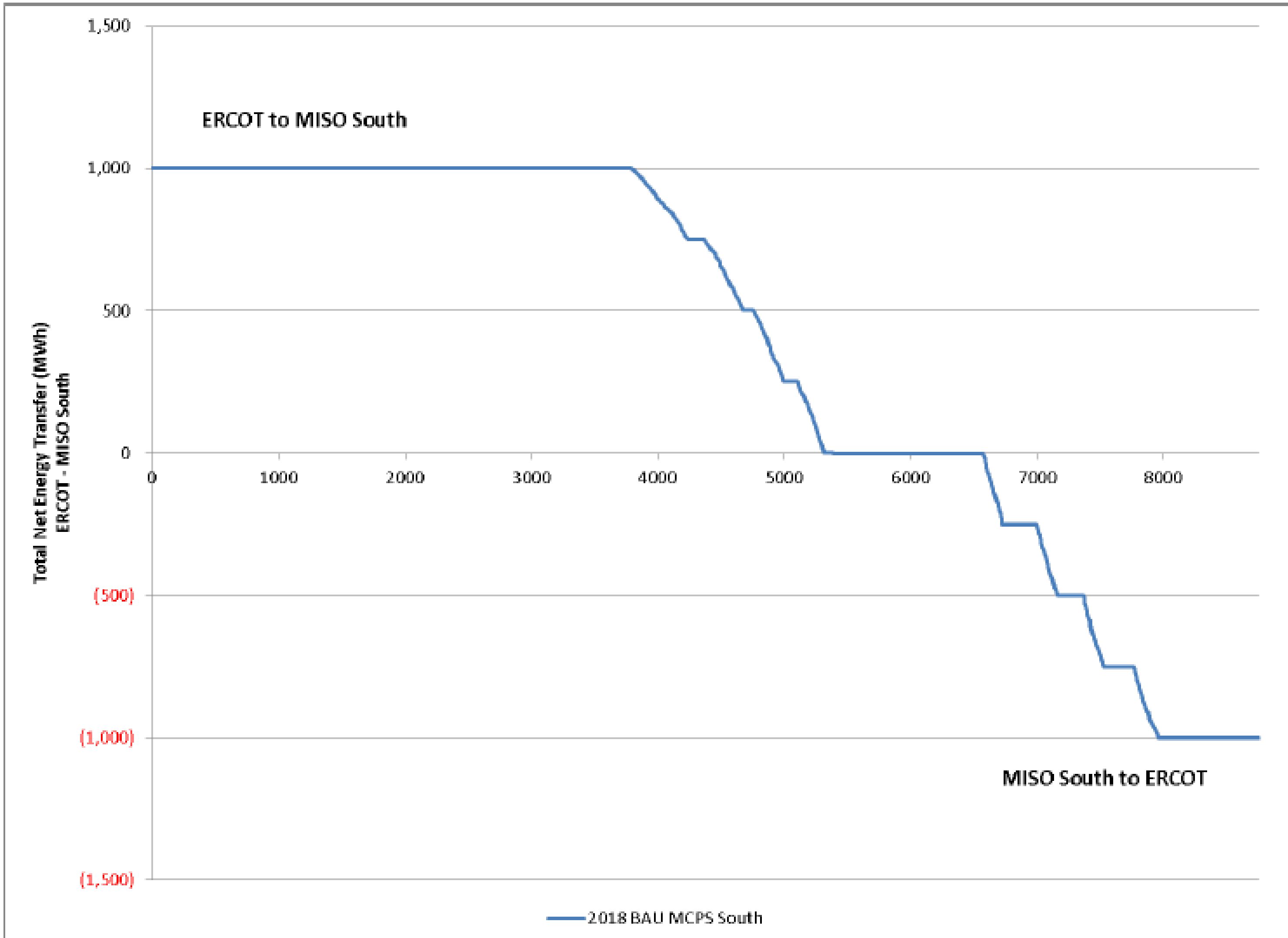


West to East Interface Flows OH-PA
25000
20000
15000
10000
5000
0
MW
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
720
1440
2160
2880
3600
4320
5040
5760
6480
7200
7920
8640
Hour of the Year

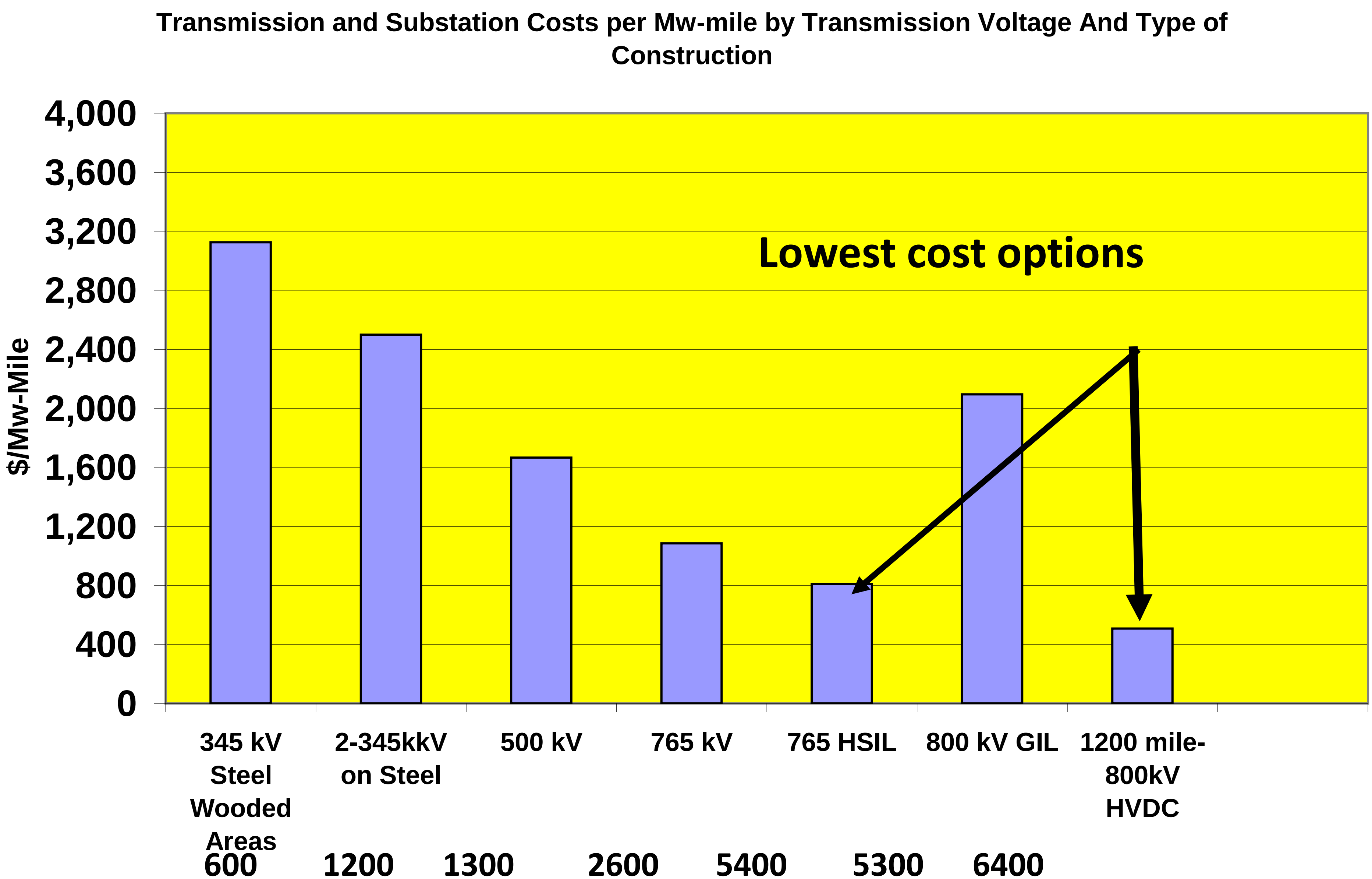
Transmission Overlay Design Workshop
Example Interface Duration Curve



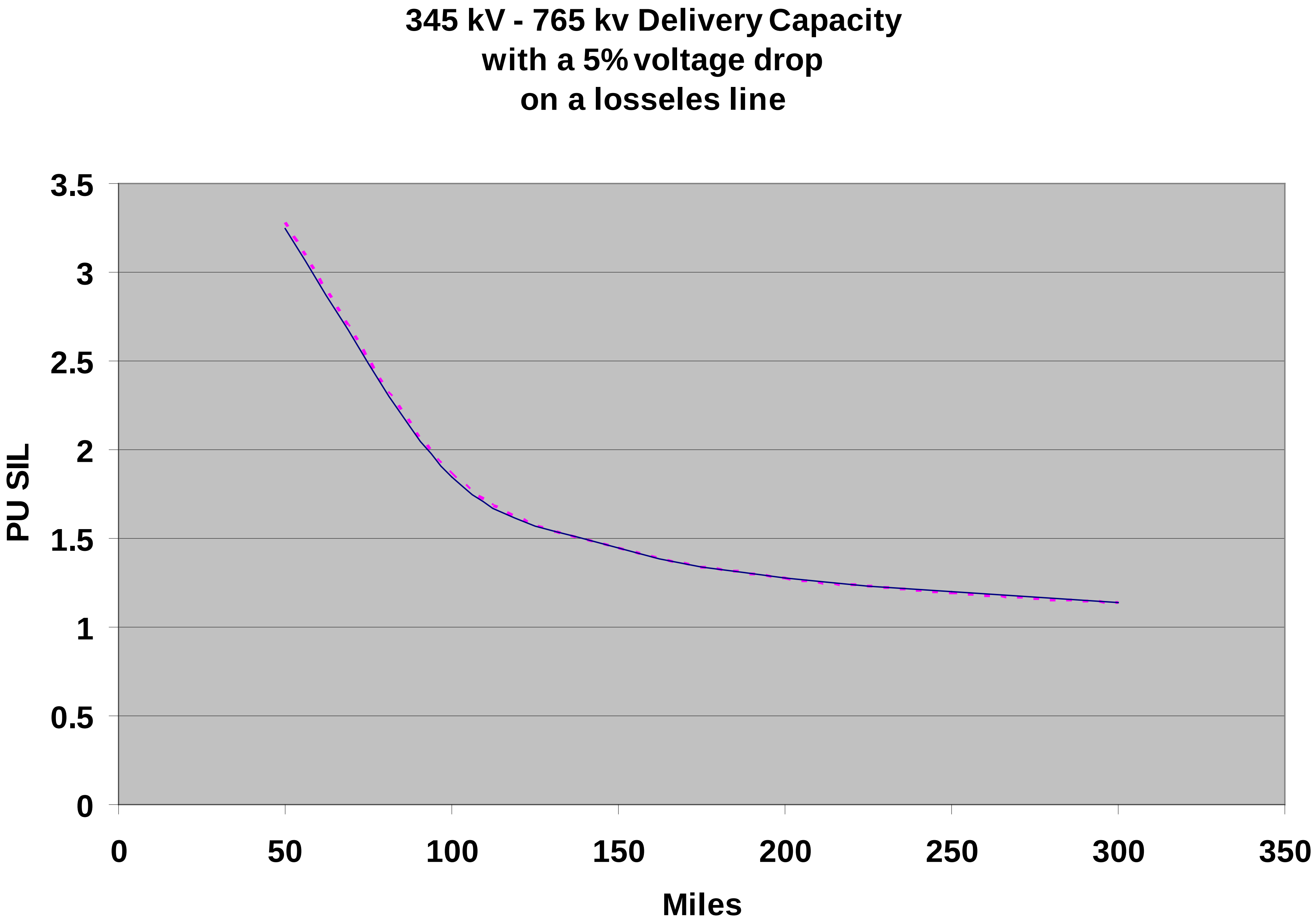
HVDC Line Loading: Duration Curve



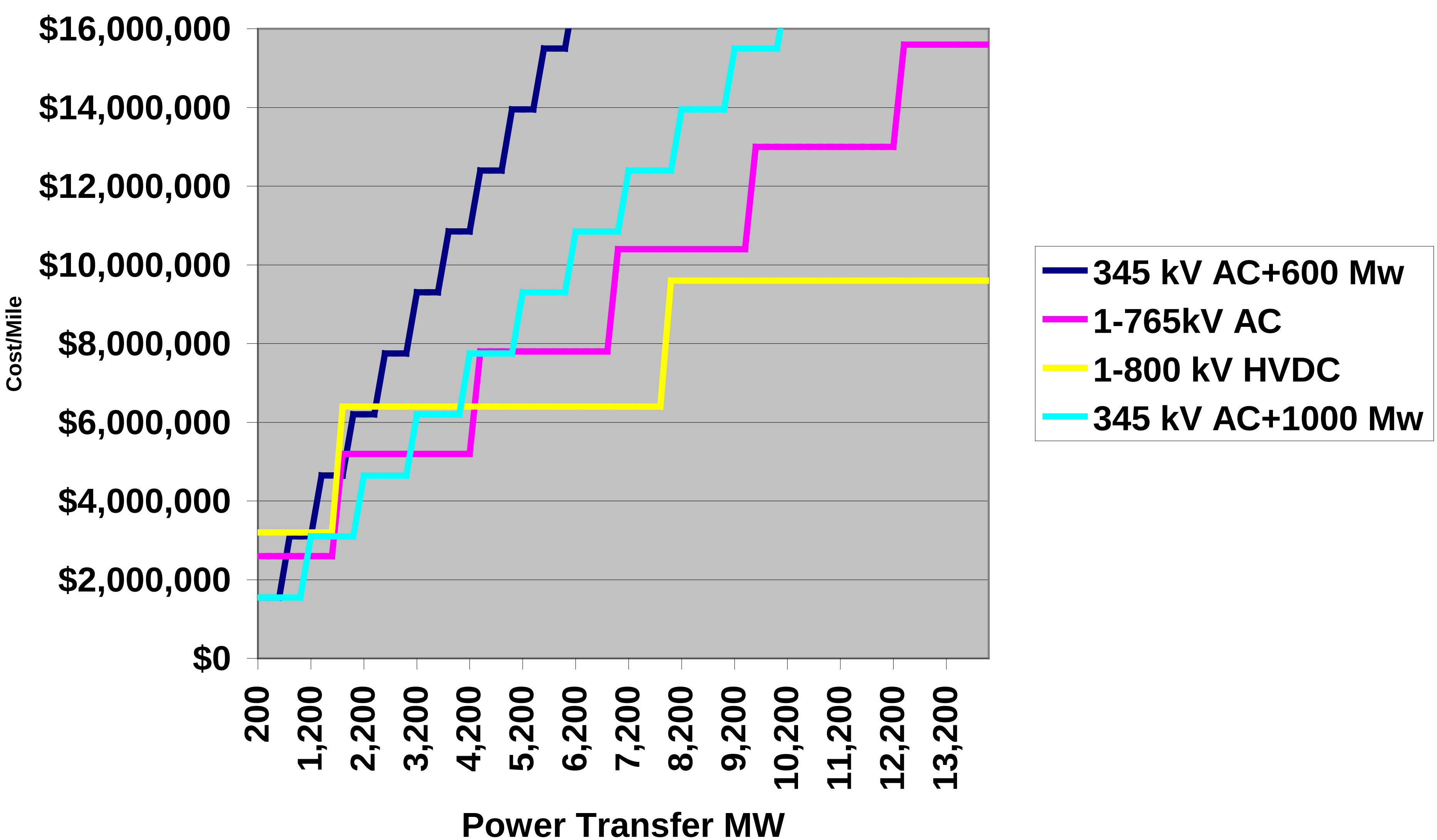
Capacity Factor is approximately 70%



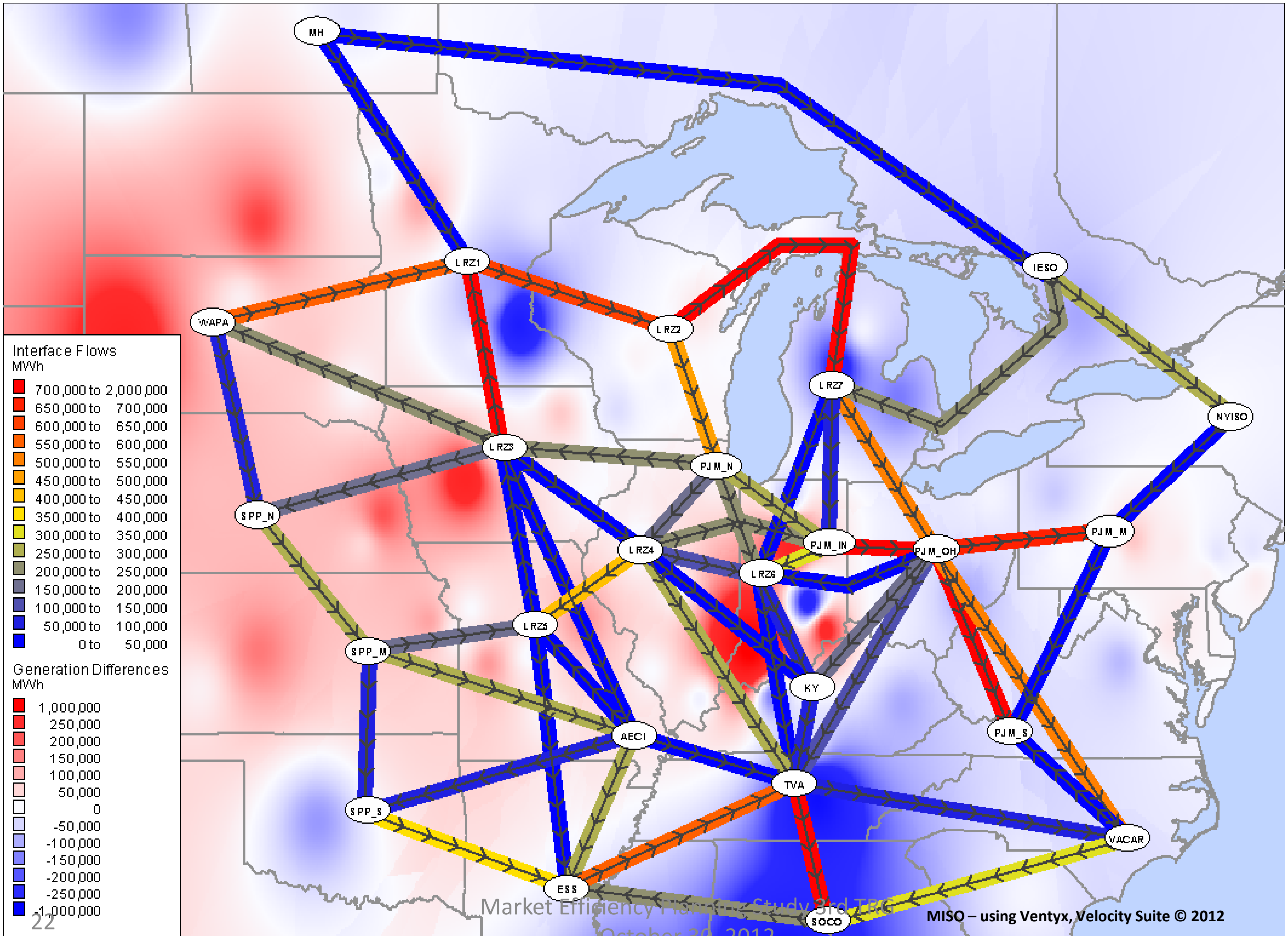
Transmission and Substation Costs per Mw-mile by Transmission Voltage And Type of Construction
$/Mw-Mile
4,000
3,600
3,200
2,800
2,400
2,000
1,600
1,200
800
400
0
Lowest cost options
345 kV Steel Wooded Areas
2-345kkV on Steel
500 kV
765 kV
765 HSIL
800 kV GIL
1200 mile-800kV HVDC
600
1200
1300
2600
5400
5300
6400


345 kV - 765 kv Delivery Capacity
with a 5% voltage drop
on a losseles line
PU SIL
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
Miles

Power Transfer Breakover by Voltage

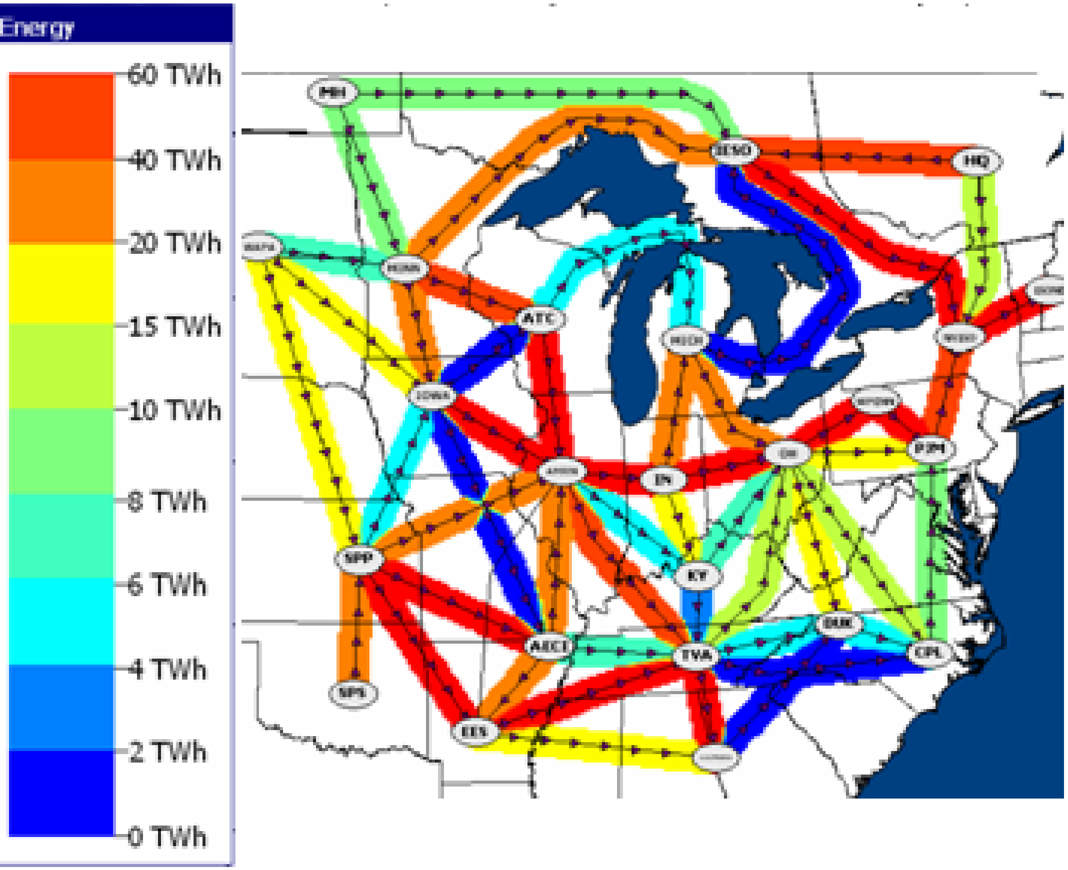


Interface Contour: Annual Energy Difference Unconstrained Case Minus Constrained Case

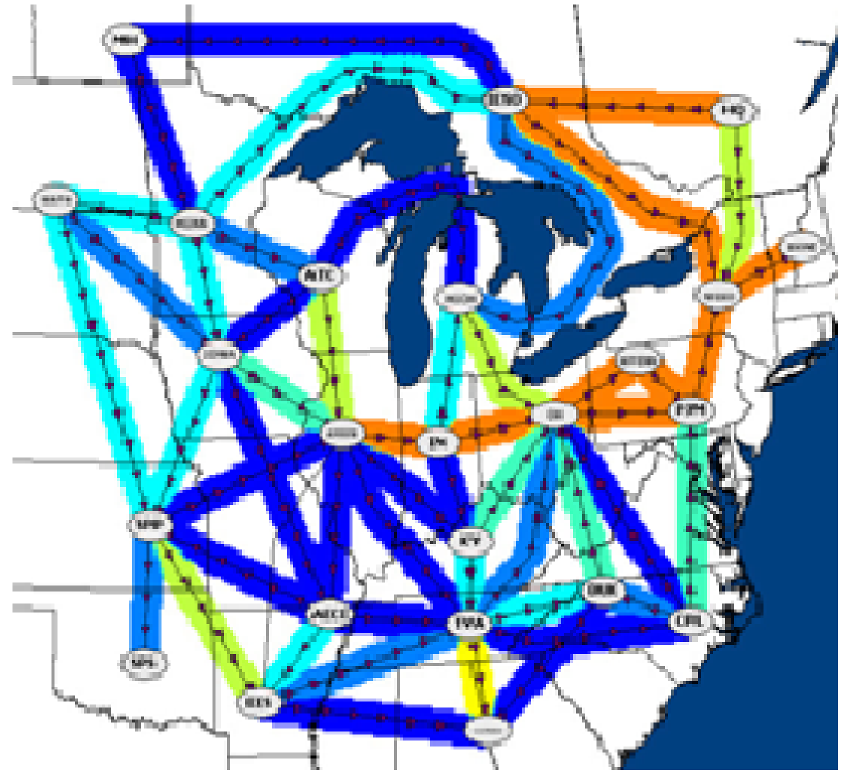


Loop Flow Patterns

Interface AC Flows without an Overlay



Interface Flows with an Overlay including HVDC



Benefit Components

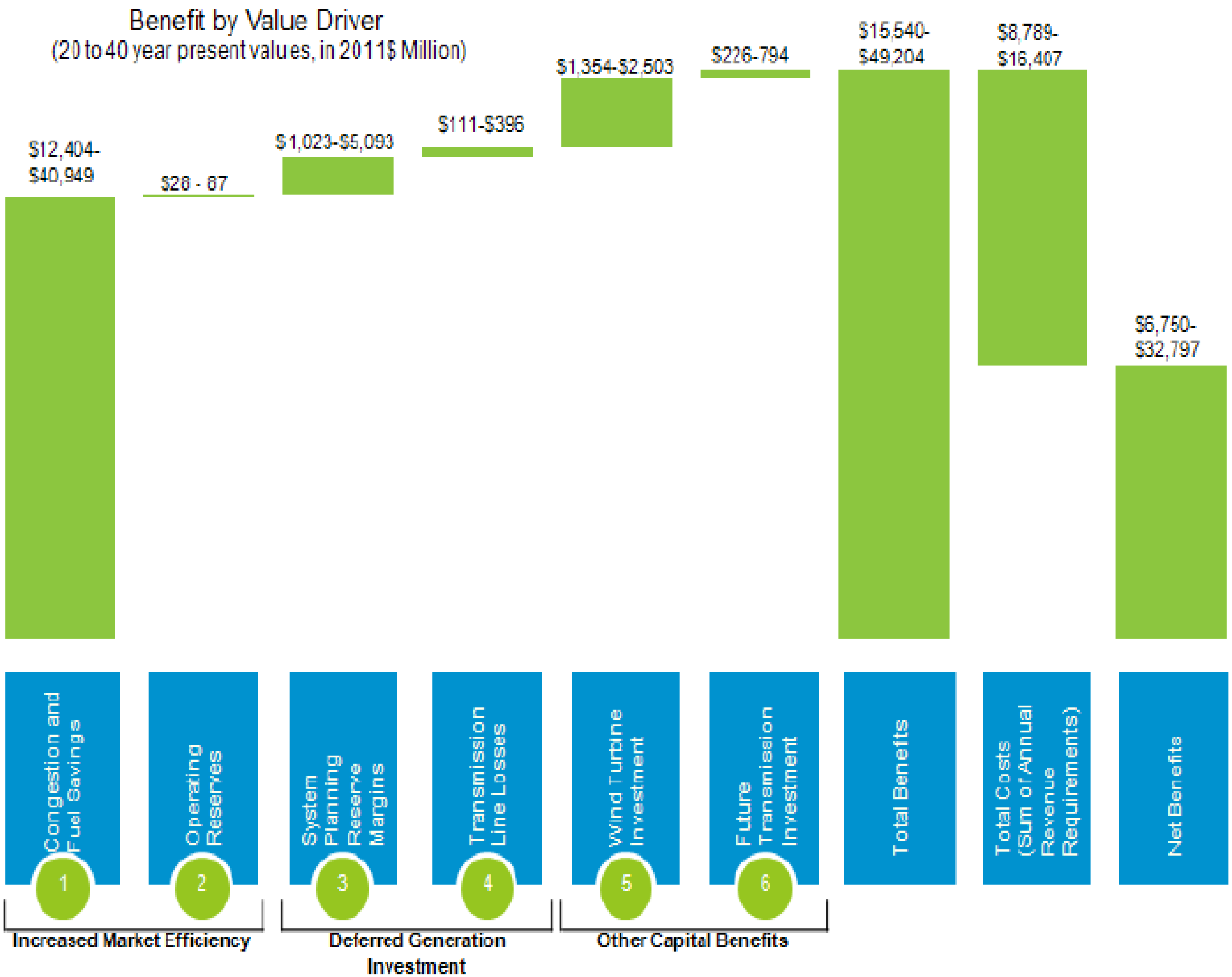
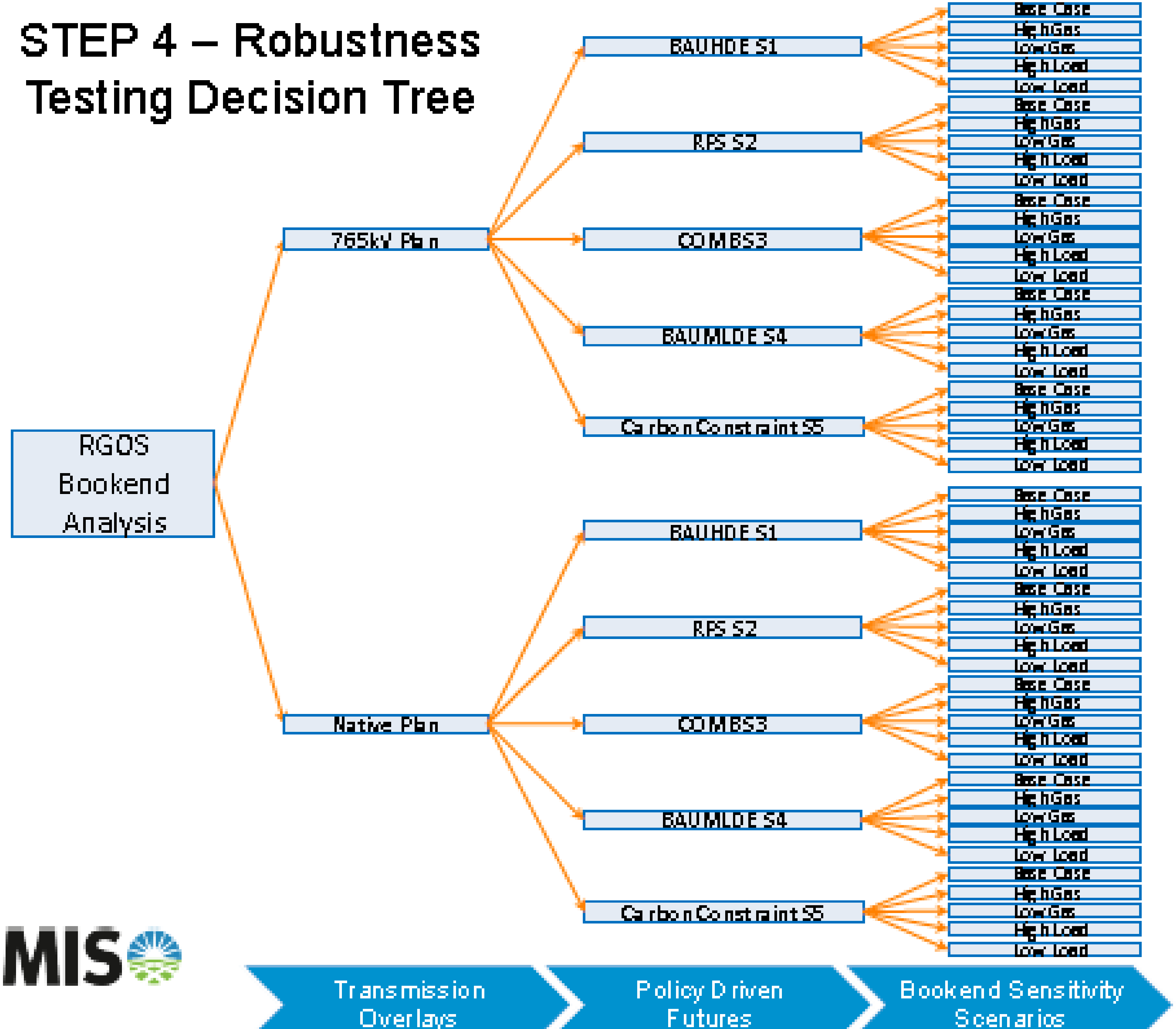


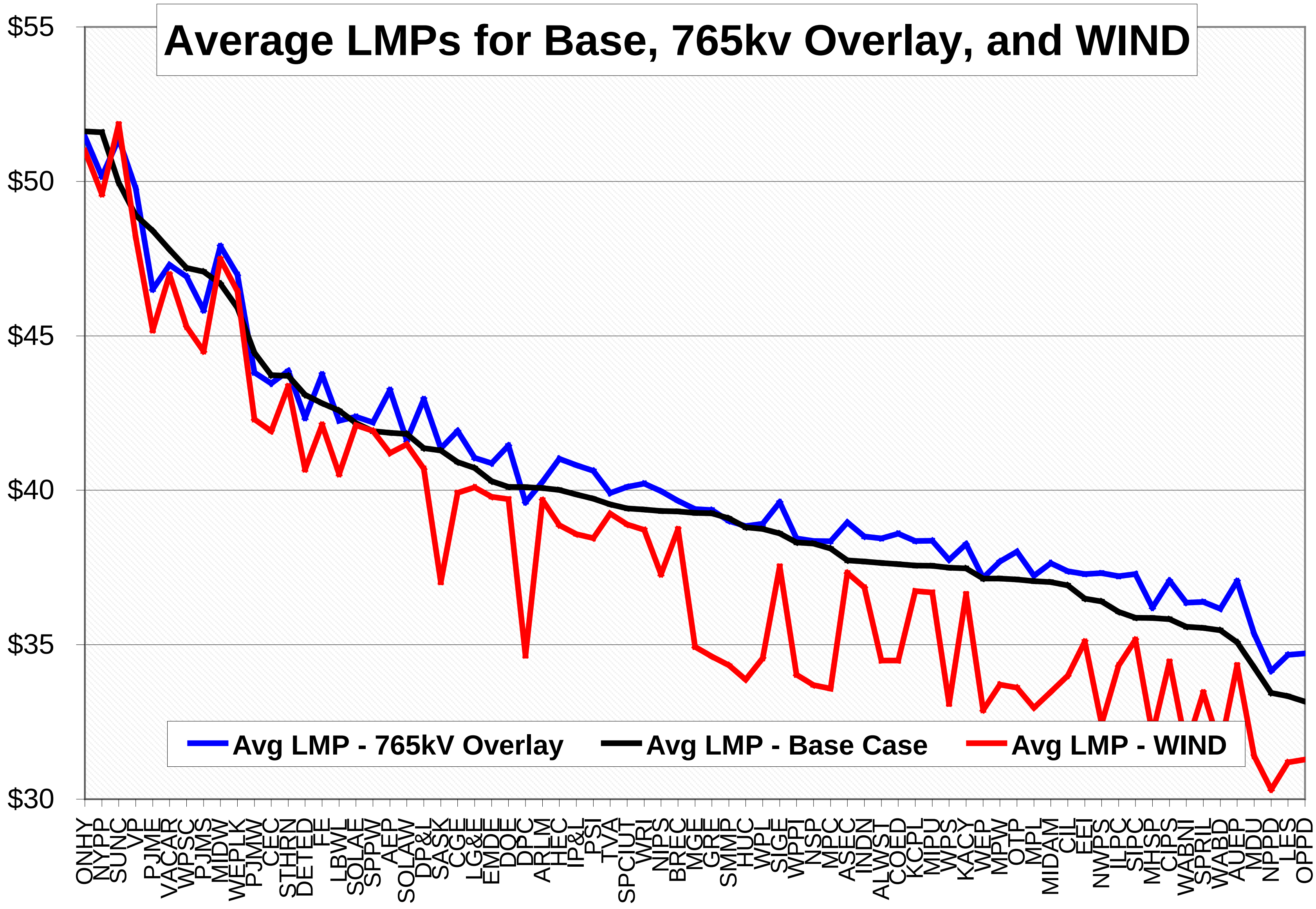
Figure 4.1-13: Proposed MVP portfolio economic benefits

STEP 4 – Robustness Testing Decision Tree

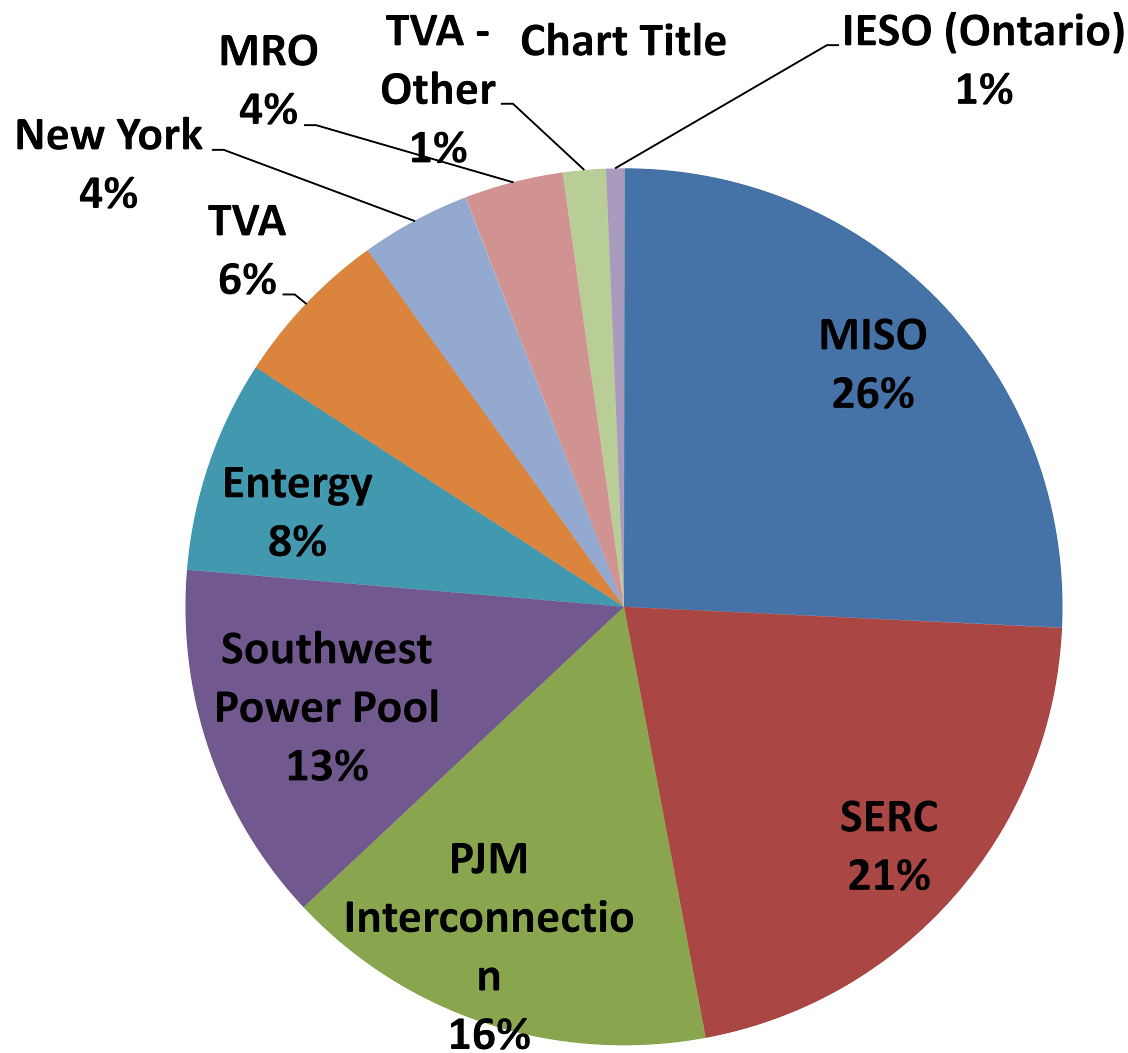


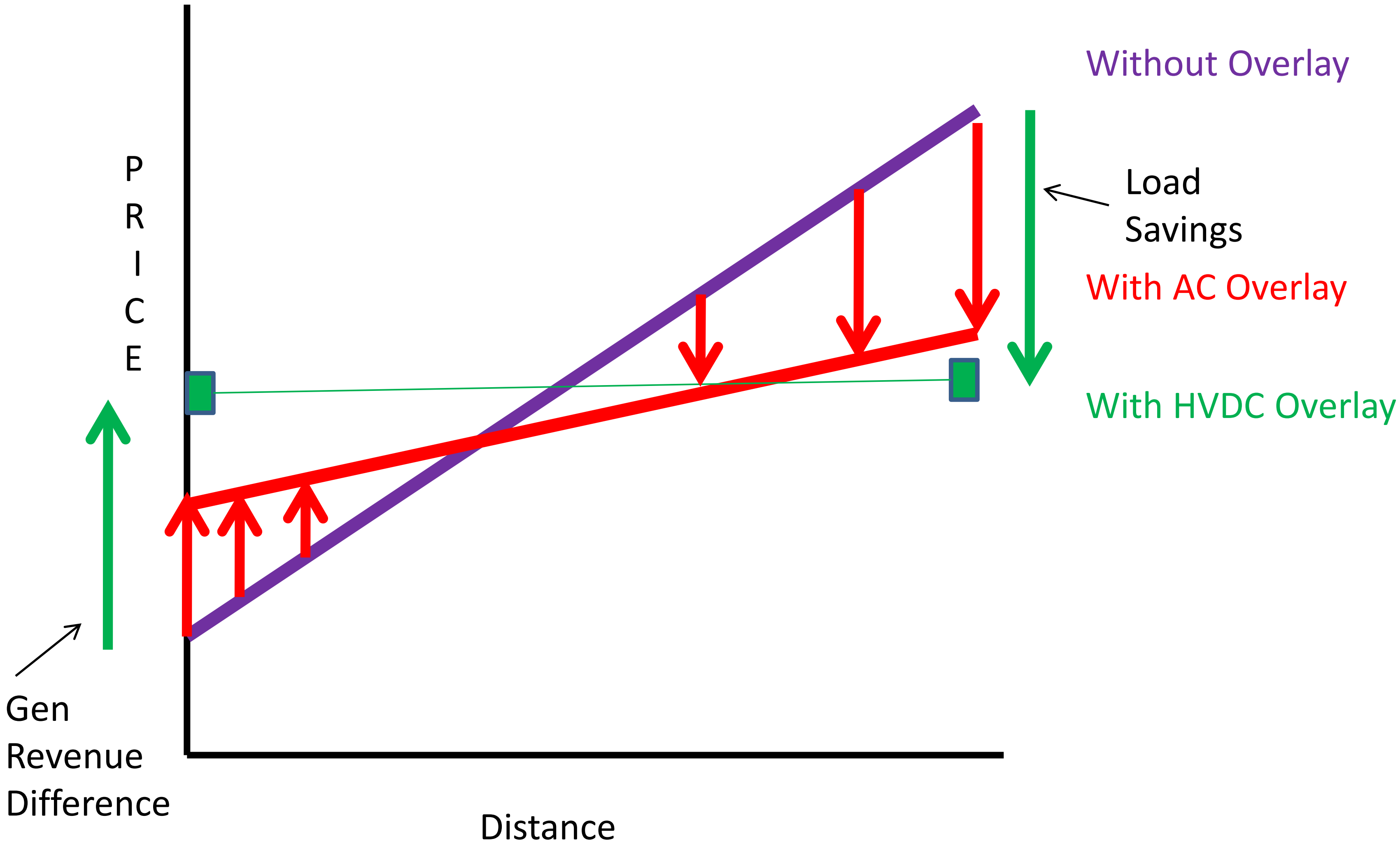
Robust Transmission Plan

- Then tested for reliability
- Cost allocated
- Sent to Board of Directors for Approval


Average LMPs for Base, 765kv Overlay, and WIND
$55
$50
$45
$40
$35
$30
Avg LMP - 765kV Overlay
Avg LMP - Base Case
Avg LMP - WIND
ONHY
NYPP
SUNC
VP
PJME
VACAR
WPSC
PJMS
MIDW
WEPLK
PJMW
CEC
STHRN
DETED
FE
LBWL
SOLAE
SPPW
AEP
SOLAW
DP&L
SASK
CGE
LG&E
EMDE
DOE
DPC
ARLM
HEC
IP&L
PSI
TVA
SPCIUT
WRI
NIPS
BREC
MGE
GRE
SMMP
HUC
WPL
SIGE
WPPI
NSP
MPEC
ASEC
INDN
ALWST
COED
KCPL
MIPU
WPS
KACY
WEP
MPW
OTP
MPL
MIDAM
CIL
EEI
NWPS
ILPC
SIPC
MHSP
CIPS
WABNI
SPRIL
WABD
AUEP
MDU
NPPD
LES
OPPD

MISO Pays 100%, 34% Benefits For MISO Central to Entergy Transmission



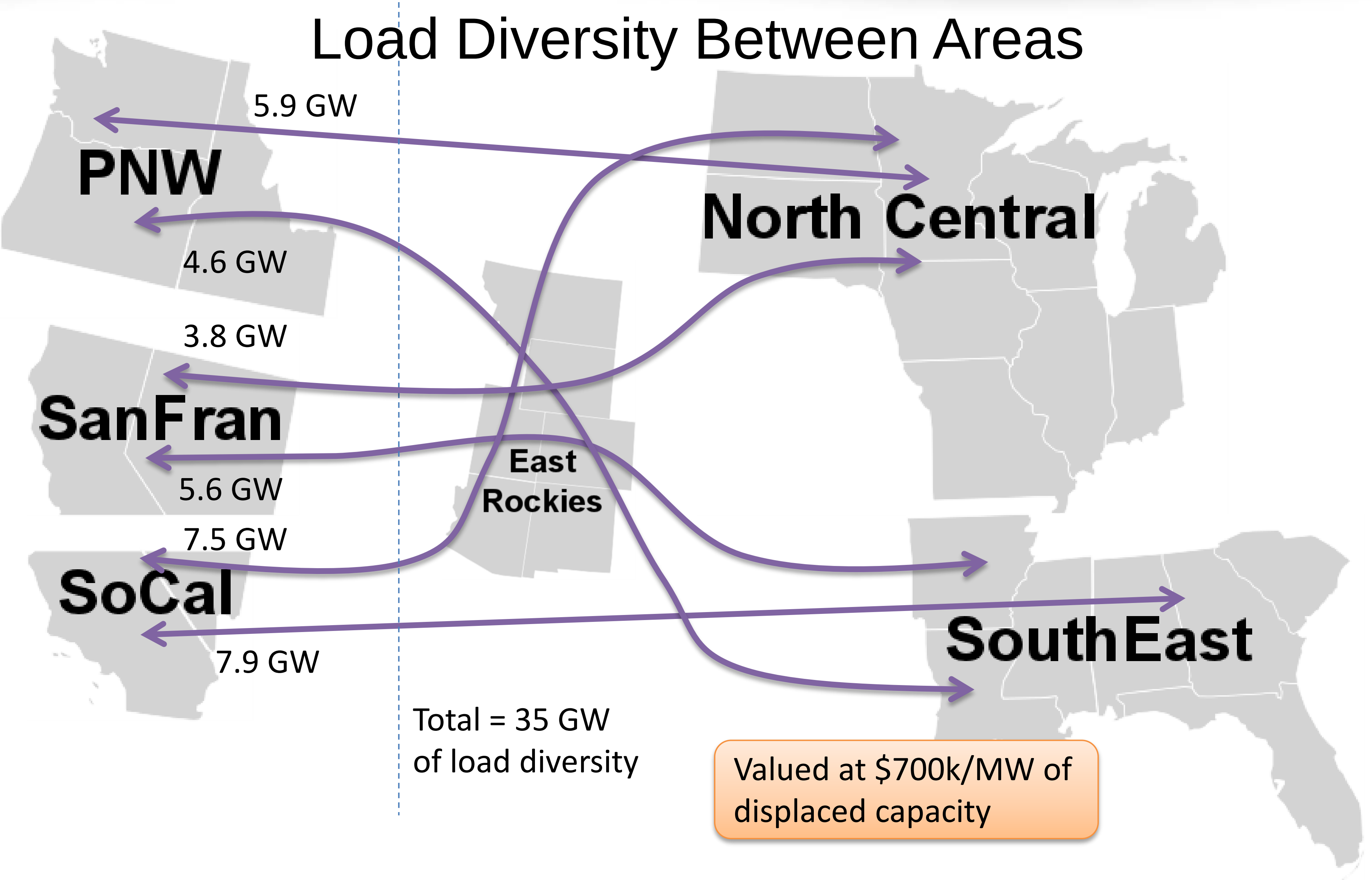


Without Overlay
P
R
I
C
E
Load
Savings
With AC Overlay
With HVDC Overlay
Gen
Revenue
Difference
Distance

Capacity Diversity

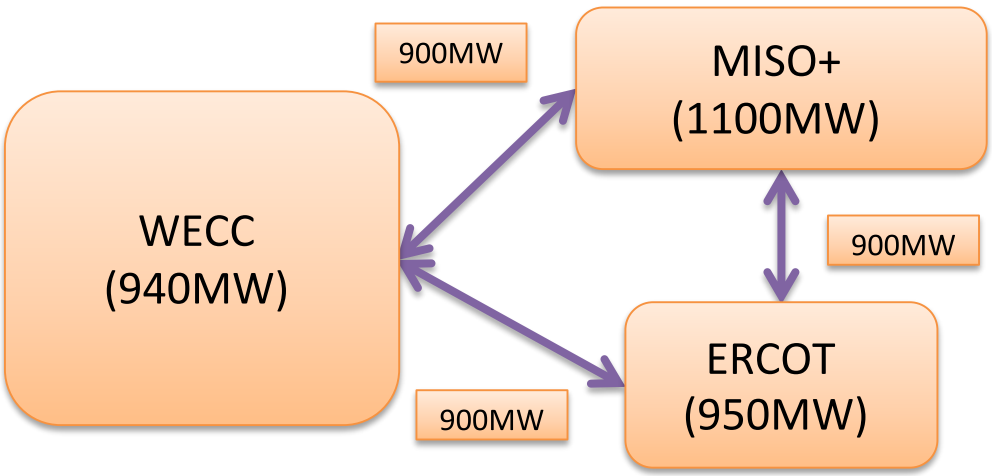
- Between Balancing Areas
- Time zone differences is the main driver
- North-South load pattern differences is a secondary driver
- Study
  - Determine the economic potential
    - Generation displacement
    - Energy payment and market product premium displacements
  - Design a transmission system to capture the value for a targeted benefit/cost ratio

Load Diversity Between Areas



Valued at $700k/MW of displaced capacity

Frequency Response

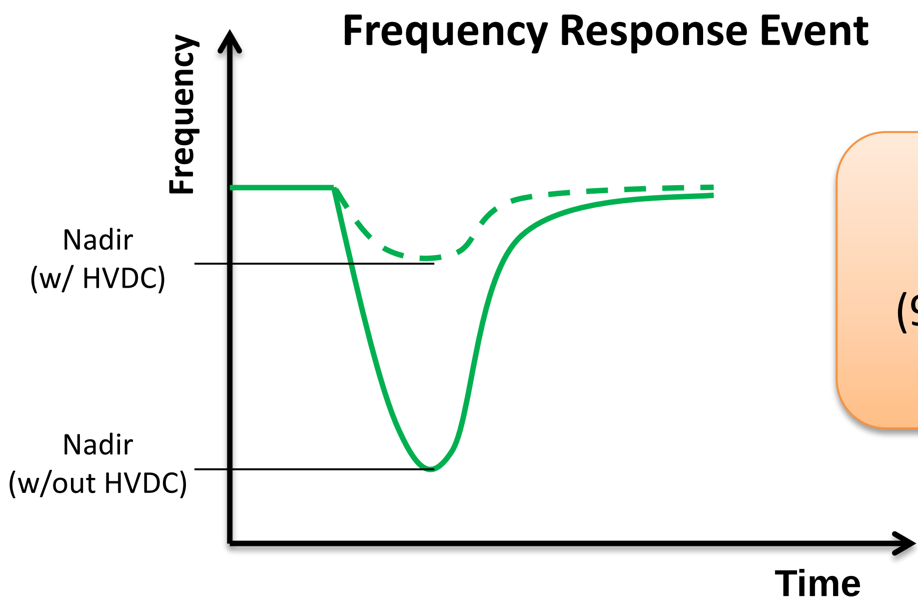


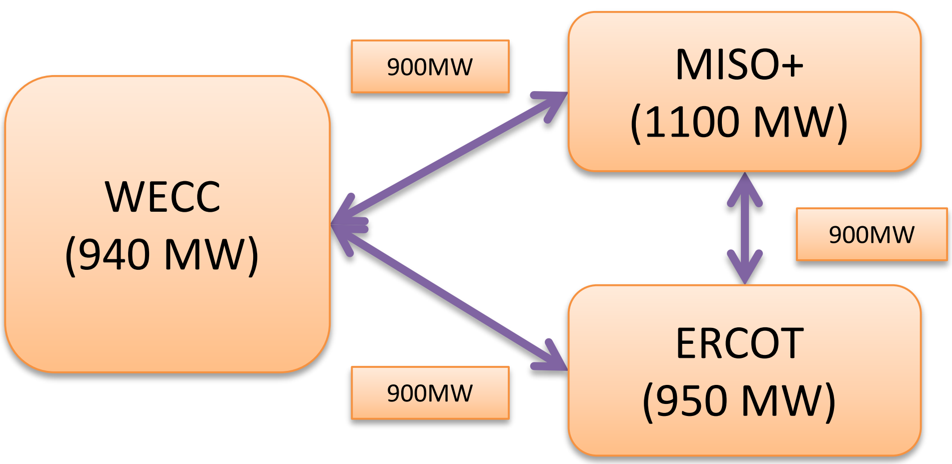
Zone	Reserves (MW)
East	4500
→ MISO+	2900
WECC	2740
ERCOT	2750

- Sharing frequency response reserves through interregional secure power transmission
  - ~950 MW of local reserve, ~2750 total reserves
  - 2x900 MW of secure transmission
  - Net benefit 5400 MW of displaced capacity (3x1800 MW)
- Approximately 1 in 30 years there will be an outage in two regions simultaneously

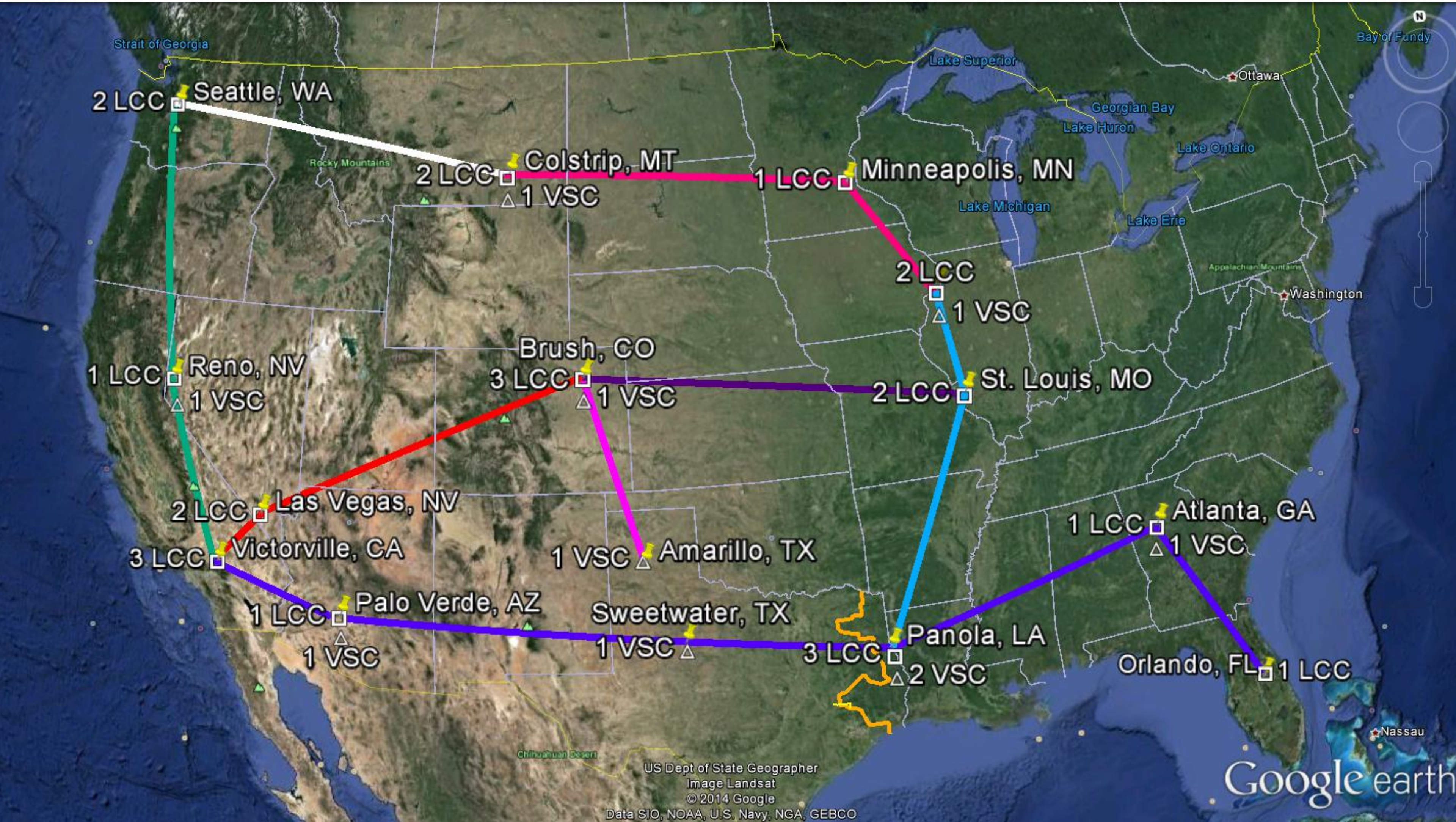
Frequency Response (cont.)

- Improved frequency response performance
  - Current governor control responds in 3-5 seconds
  - VSCs allow for response in 0.1 seconds
  - Raises frequency event nadir



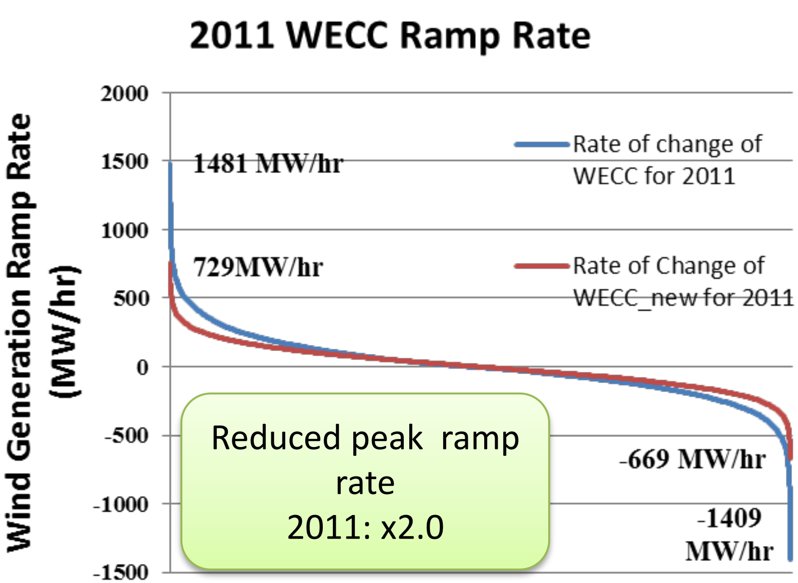


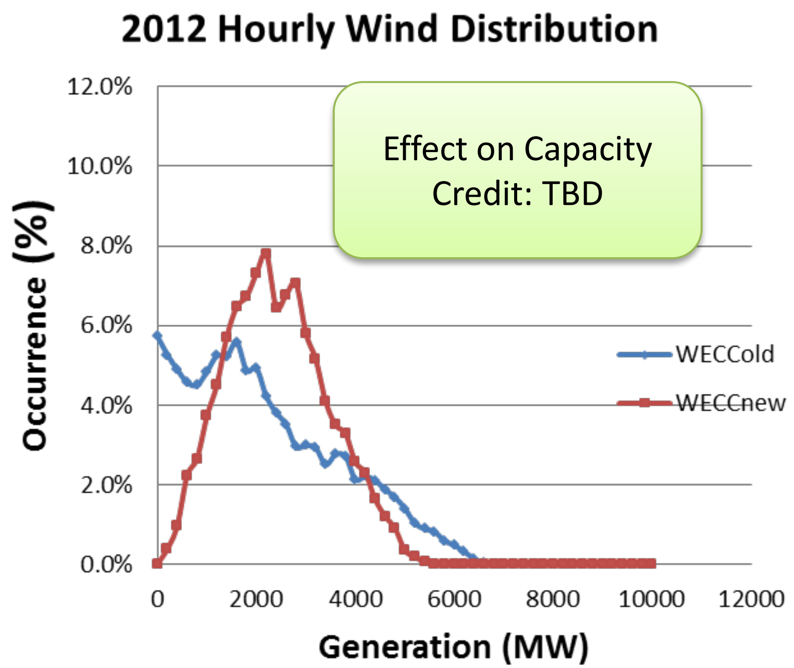
HVDC Network Concept



Wind Energy Benefits for WECC

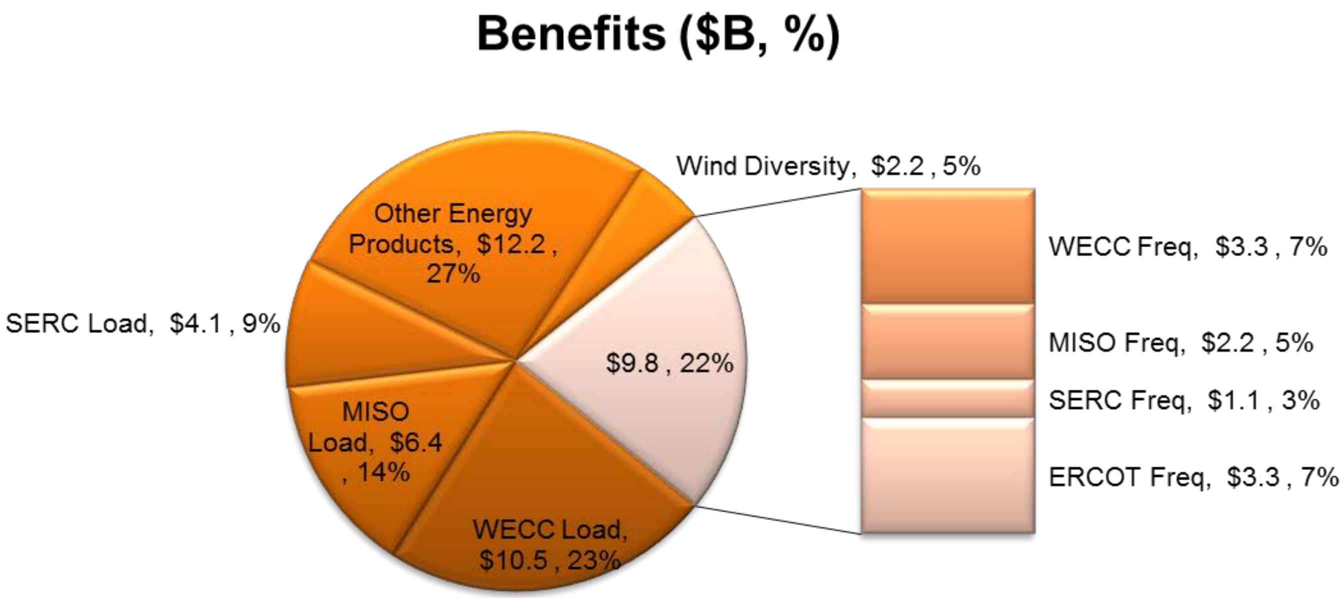
- Add all wind generation across MISO, ERCOT, and WECC
- Re-distribute wind based on peak capacity





- Benefits
  - Reduced ramp rate
  - Reduced variability (and thereby potentially increased capacity credit)

Costs allocated by % of benefits



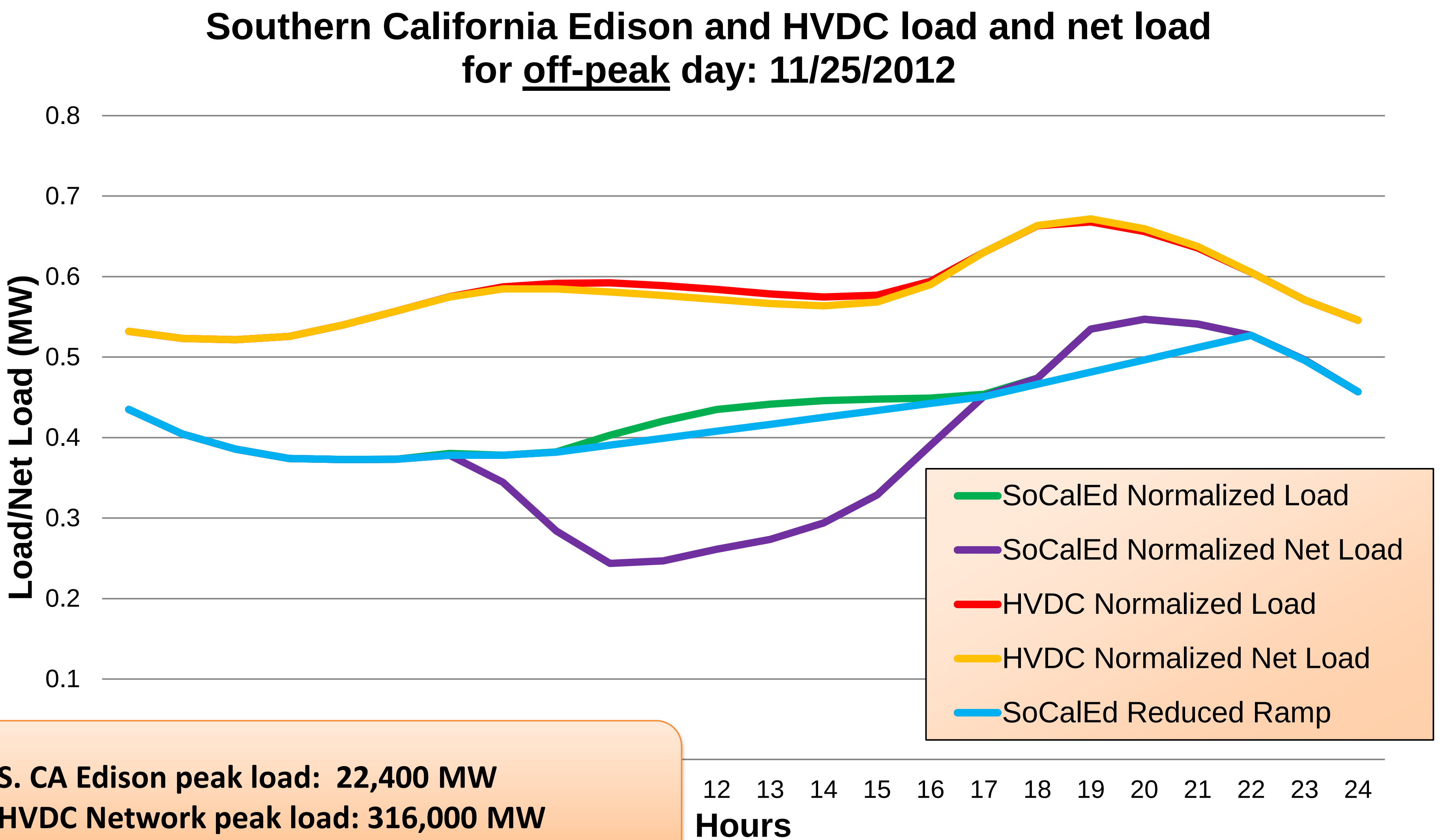
Value Drivers	
Load diversity	46%
Frequency response	22%
Wind diversity	5%
Other Energy Based Products	27%

Example:

SERC Load Cap. Cost = $36.2B * 9% = $3.3B

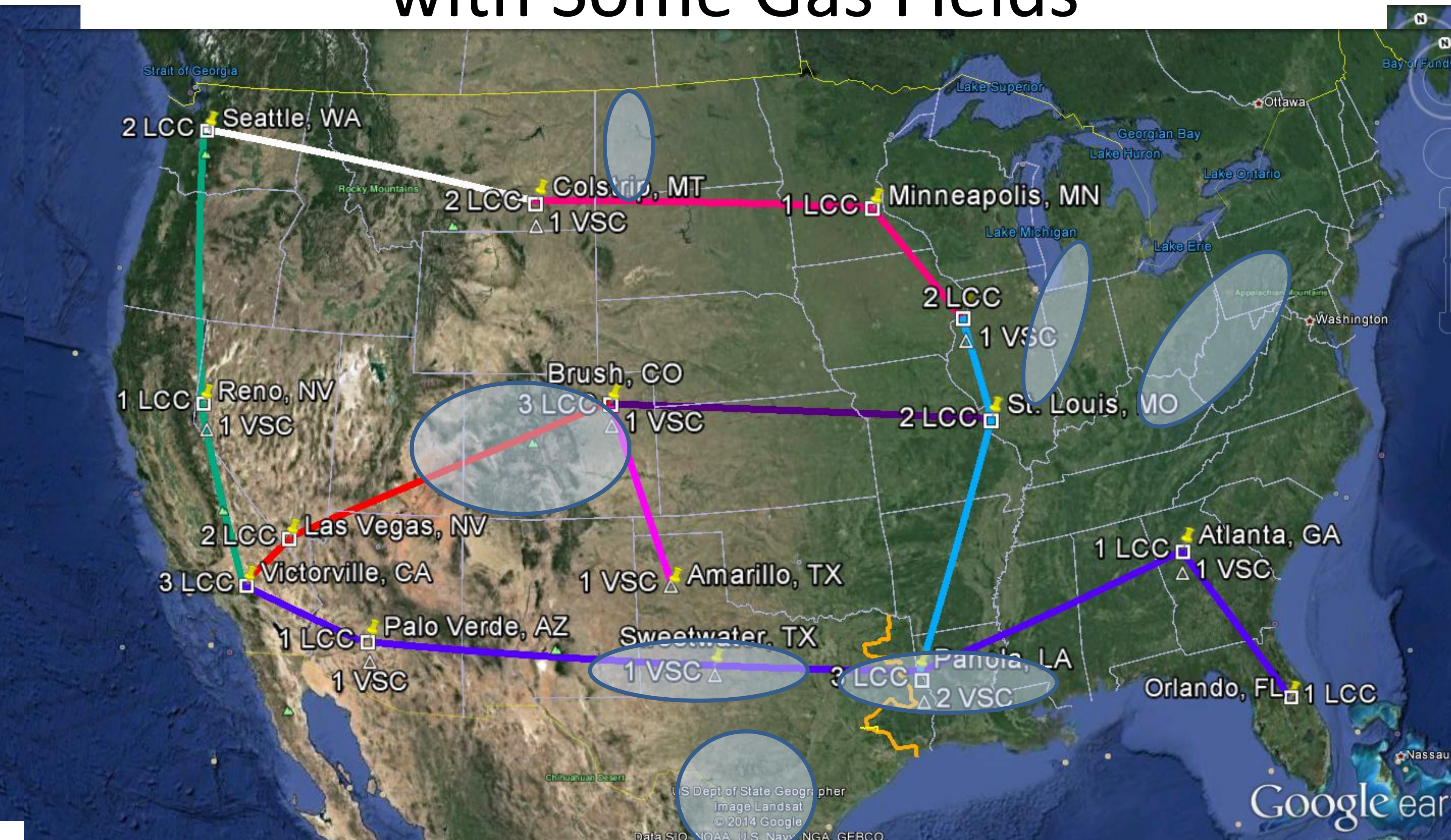
SERC Freq Reg Cost = 36.2B * 3% = $1.1B

High Solar Generation Impact

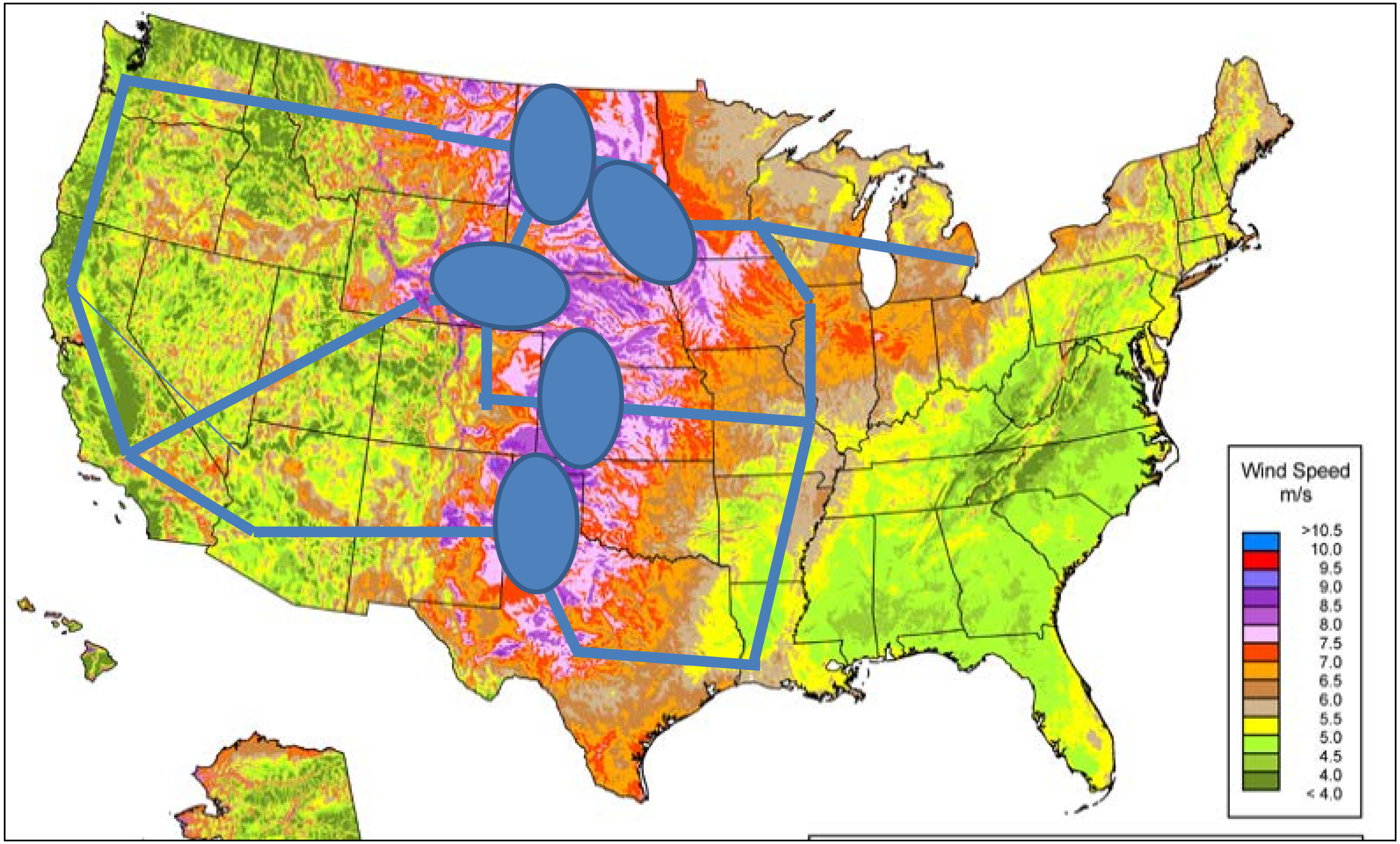


S. CA Edison peak load: 22,400 MW
HVDC Network peak load: 316,000 MW

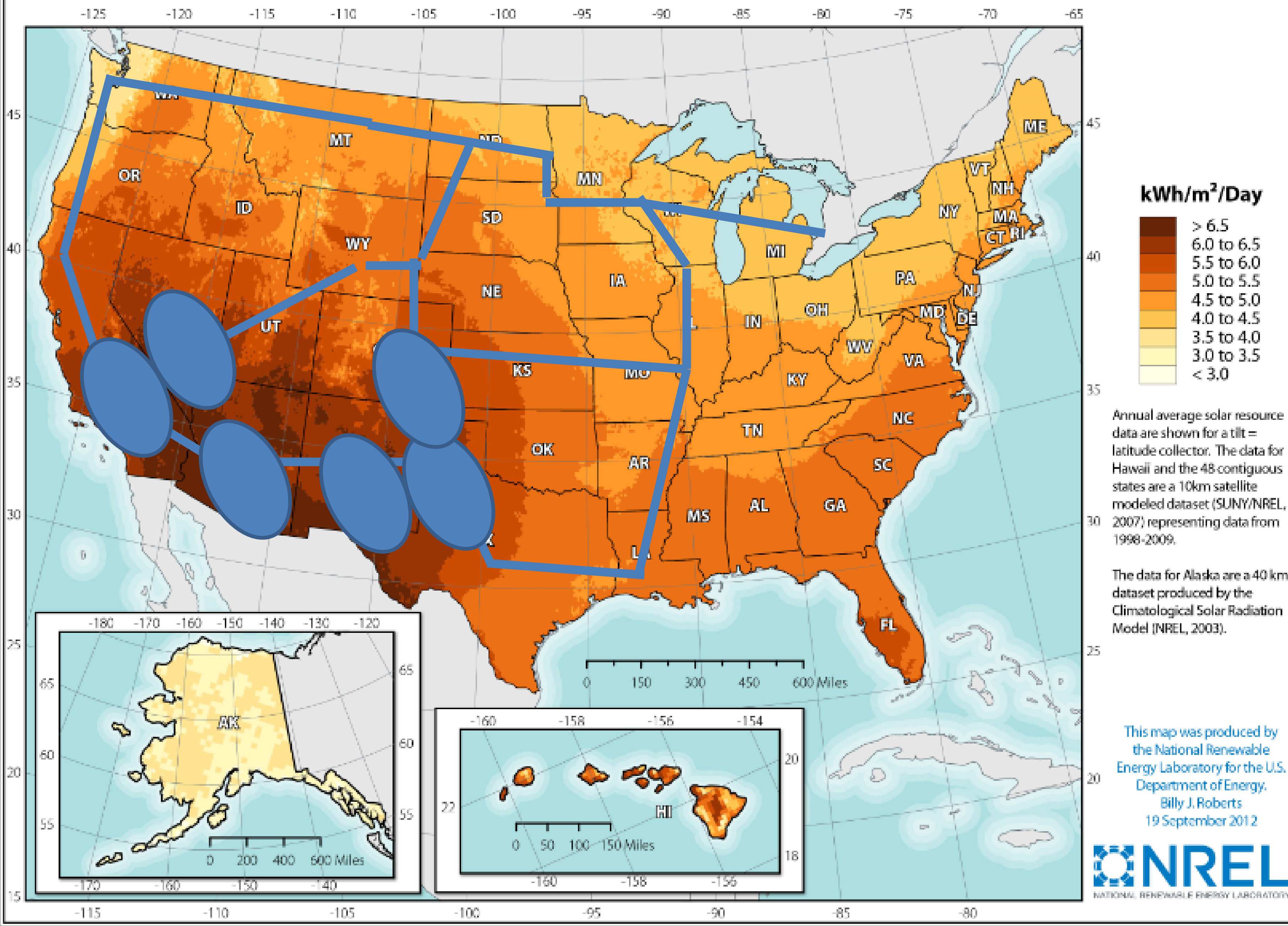
HVDC Network Concept with Some Gas Fields



Cost to Deliver Wind Energy with the Macro Grid is 25% of the cost of individual HVDC lines proposed currently because of sharing the cost and more fully utilizing the lines.



Photovoltaic Solar Resource of the United States



Questions

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