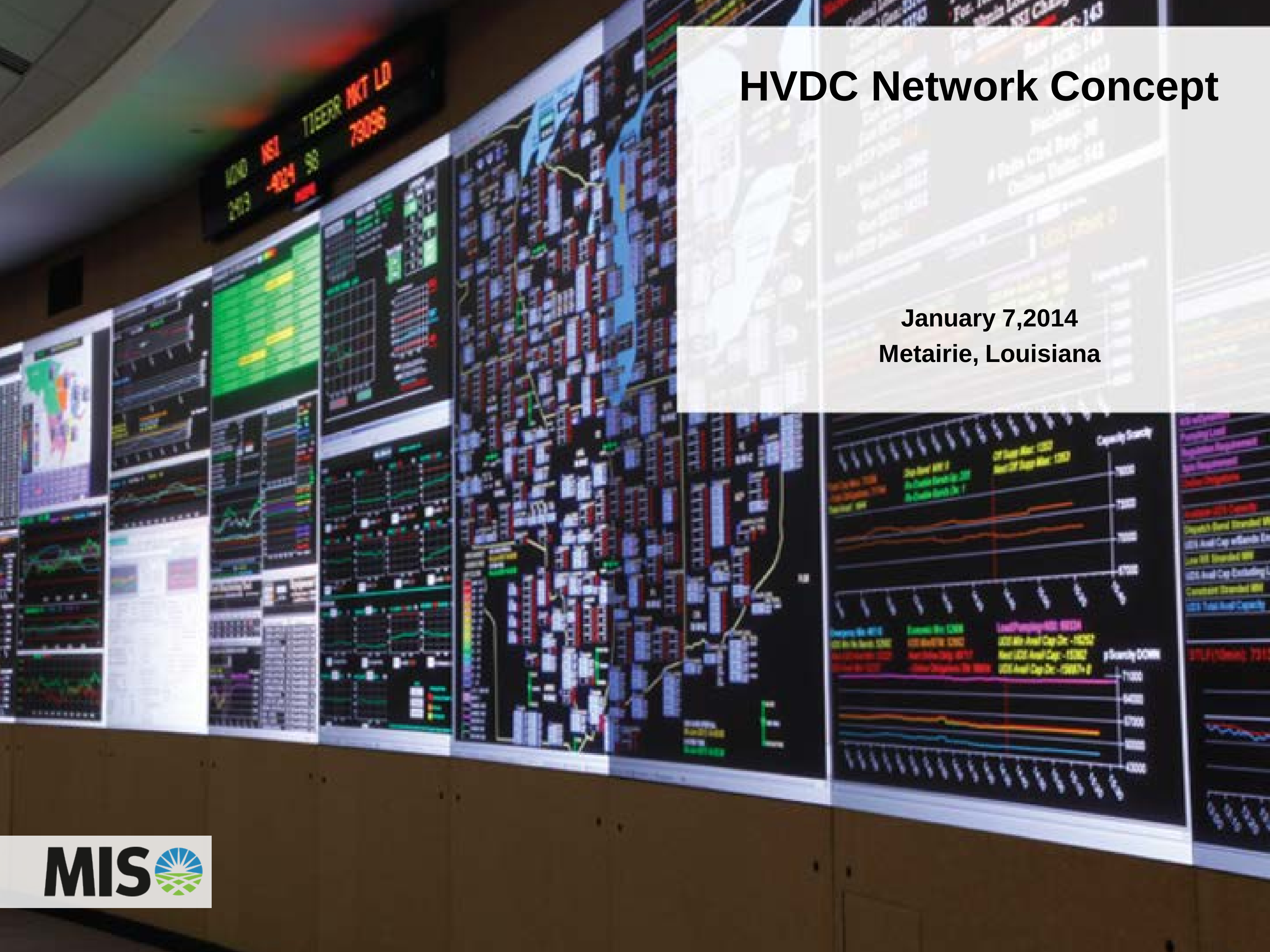
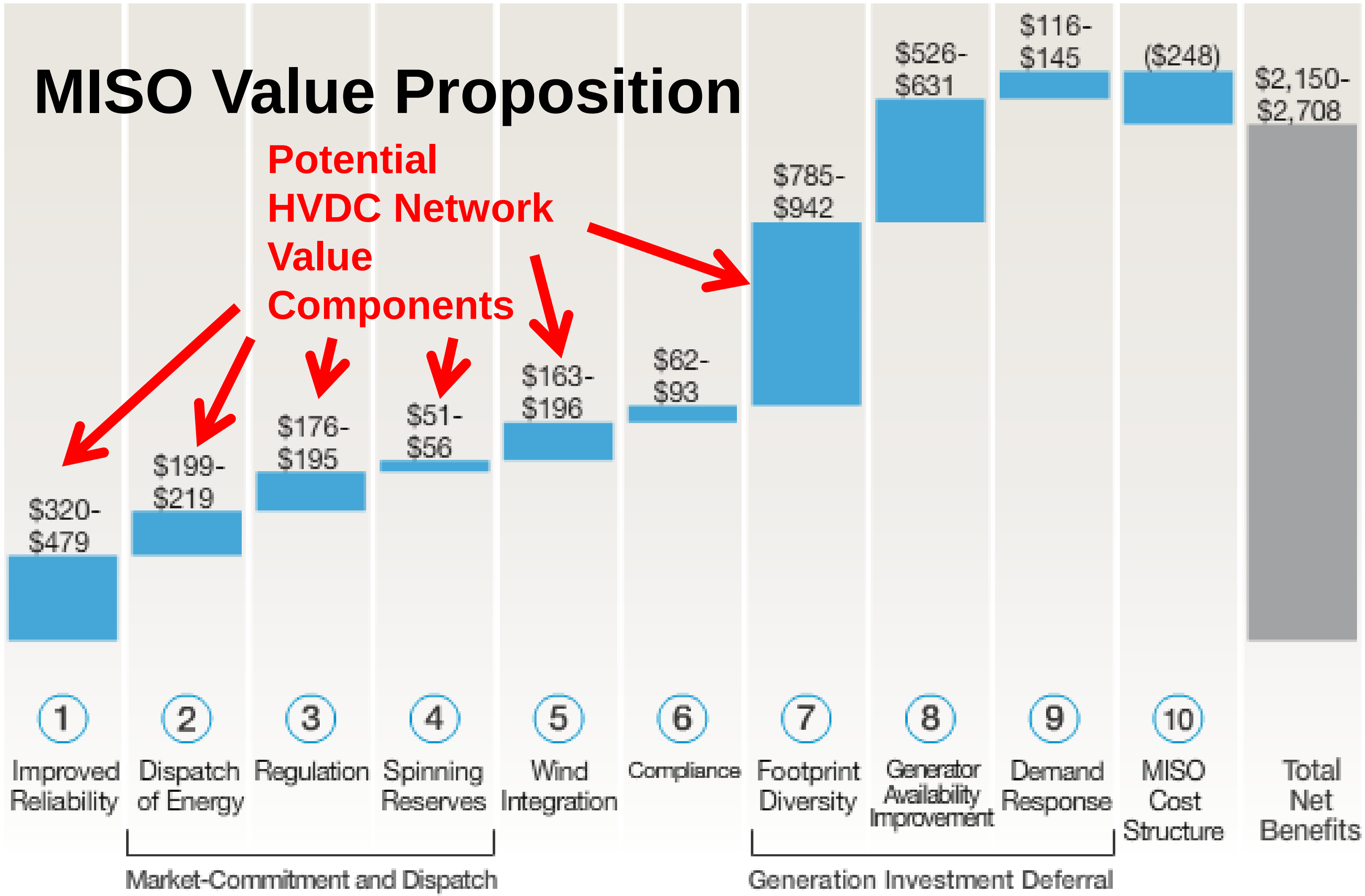
HVDC Network Concept

January 7,2014
Metairie, Louisiana



MISO Value Proposition



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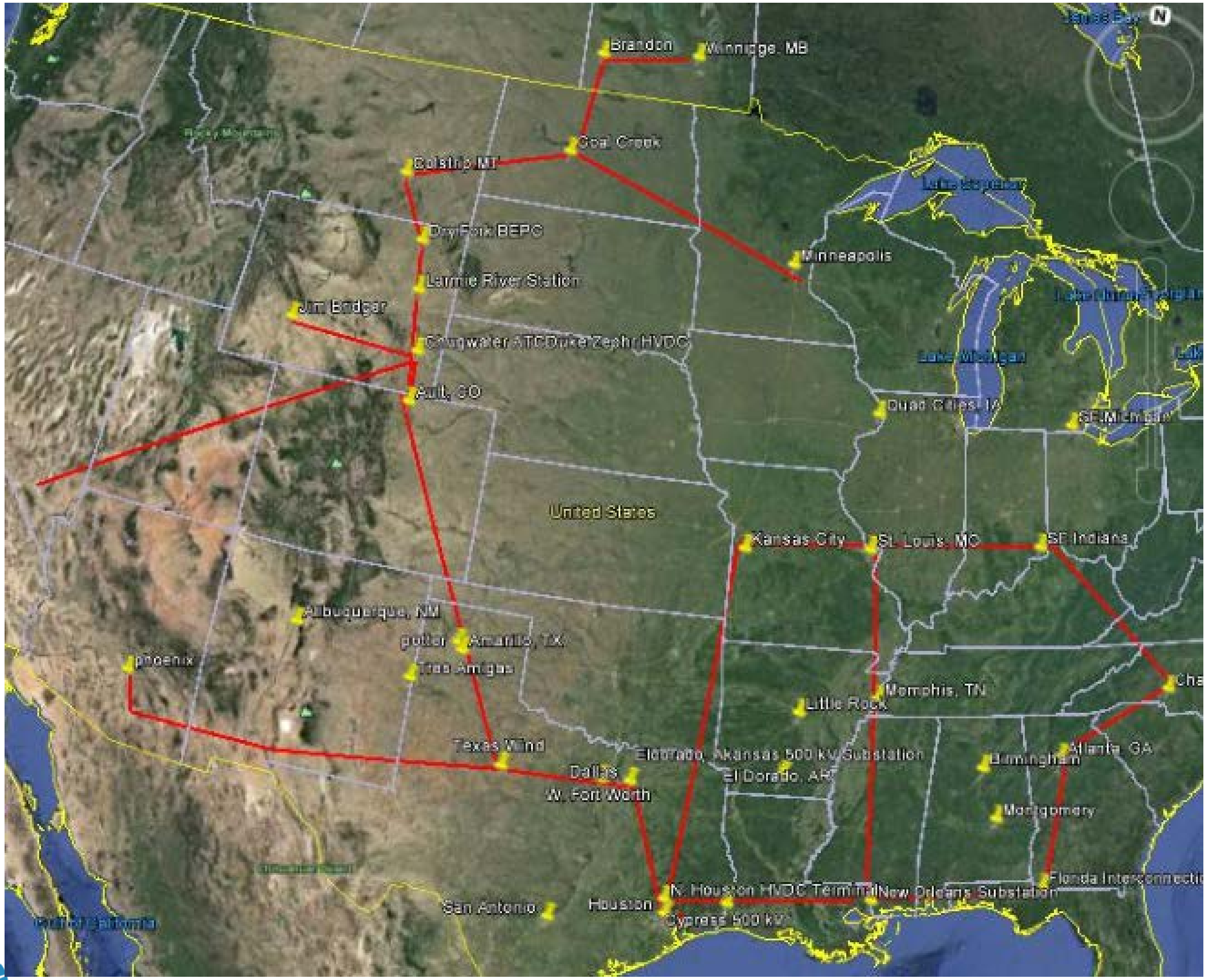
One Time Opportunity to Mine Unused Potential Benefits Spread over the U.S. and Canada

- **The estimated potential value is estimated to be approximately $50B is obtained from the following categories:**
  - Frequency Response — $5B from 7000MW spinning reserve
  - Load Diversity — $38B from 36,000MW load reduction
  - Wind Diversity — $3B from 4000MW capacity credit
  - Solar Diversity — $1B from 1500MW capacity credit
  - Area Control Error — $3B from 4000MW ACE improvement
  - Carbon Reduction — ?

- **Once the potential benefits are mined, the growth to support future transmission lines is small, possibly 0.06%/yr.**

A view of the potential mature HVDC network



Why is MISO sharing information and seeking study participants with this meeting?

- MISO appears to benefit as well as many other Balancing Areas from a proposed HVDC Network.
- No one area or two areas have the diversity to justify significant transmission expansion. Potential study participants need to be identified. Better data is needed and more detailed justifications need to be developed.
- Every Balancing Area’s participation is not necessary to justify the HVDC Network, but economy of scale tends towards inclusion of as many Balancing Areas as is feasible. Information may help make a decision to participate in a future study.
- The HVDC Network may be started by building sections that can provide benefits on their own. These projects and participants need to be identified.
- Experience has shown that local stakeholder participation may increase the benefit capture by 20%. For the Sketch, this is about $4B present value.
- The concepts are new and take time to be understood.

MISO Guiding Principles

- **Guiding Principle 1 –** Make the benefits of a competitive energy market available to customers by providing access to the lowest possible electric energy costs
- **Guiding Principle 2** – Provide a transmission infrastructure that safeguards local and regional reliability
- **Guiding Principle 3** – Support existing state and federal renewable objectives by planning for access to all such resources (e.g. wind, biomass, demand side management
- **Guiding Principle 4** – Creates a mechanism to ensure investment implementation occurs in a timely manner
- **Guiding Principle 5** – Develop a transmission system scenario model and make it available to state and federal energy policy context and inform the choices they face

MISO Conditions to Justify Transmission

- A robust business case that demonstrates value sufficient to support the construction of the transmission project.
- Increased consensus on current and future energy policies.
- A regional tariff that matches who benefits with who pays over time.
- Cost recovery mechanisms that reduce financial risk.

Anticipated Next Steps

- **Work with potential participants –self funded**
  - Obtain better data
  - Mutually understand economic justification processes of Balancing Areas
  - Produce a projected HVDC Network Benefit/Cost calculation
  - Invite stakeholders and regulators to the Question
    - What are the Guiding Principles for each of the three layers of transmission design?
    - What would be the expectations of the HVDC Network
      - The HVDC Network is not expected to be an RTO
- **Form a set of participants by the end of 2014 or earlier that would be willing to participate with staff and or funds for a detailed study to design an HVDC network and set up the governance to manage the study.**

Expectations

- **Energy price differences are not large enough to justify major inter-regional transmission expansion as in the past due to gas setting the price for most Balancing Areas.**
- **Capacity Diversity already exists, has a high value that can justify transmission, is easy to determine, and has a low risk of not occurring-Capacity Diversity will primarily justify the HVDC Network.**
- **The HVDC Network will consist of three layers;**
  - Voltage Source Converters for fast response products as Frequency Response and Regulation-higher cost and higher performance needed
  - Classical HVDC for bulk energy transport for power sales and renewable energy delivery-lower cost
  - AC system changes will be modest-used for Transmission Service to access the HVDC system and deliver scheduled power and energy.

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Value Based Planning

- **Provides economic information used to design transmission systems to perform to economic and reliability criteria- principle used to design the Sketch.**
- **Has been proven to be able to design transmission systems on a national basis**
- **Is slightly modified to include capacity products**
- **Value Based Planning has been used by MISO since 2008 and was used to justify the $5.2B Multi Value Projects in 2011.**
  - MVPs increase the transmission capability to deliver 21,000 MW of wind generation the 25,000 MW MISO Renewable Portfolio Standard.
  - MVPs relieve congestion and increase the market efficiency of MISO
  - MVPs had a benefit to cost ratio of about 1.8:1 across the MISO footprint

Value of Capacity Diversity

- Capacity Diversity value is produced by sharing existing generation capacity by the use of a transmission system such that the cost of future generation is displaced
- The net result is a lower price of wholesale power to the load customer
- Increased revenue to existing and future renewable generation may be a benefit
- Lower cost of delivered energy through cooperation in the design and use of the HVDC Network
- Possible lower carbon production through increased efficiency of existing and future generation

Sketch Design Assumptions

- **Every Balancing Area in the Partial East, ERCOT and WECC would be able to access the HVDC Network as an economic option**
  - Direct HVDC terminal access
  - AC Transmission Service to the HVDC Costs proportional to potential benefits
  - HVDC Network costs include AC Transmission Service
  - Costs are based on system participation and benefits of the HVDC Network and not by line
- **Assumptions used until more detailed information is available**
  - Wind Capacity Credit increases, fixed price for generation displacement, Transmission Service Costs, one HVDC cost level estimate, etc.

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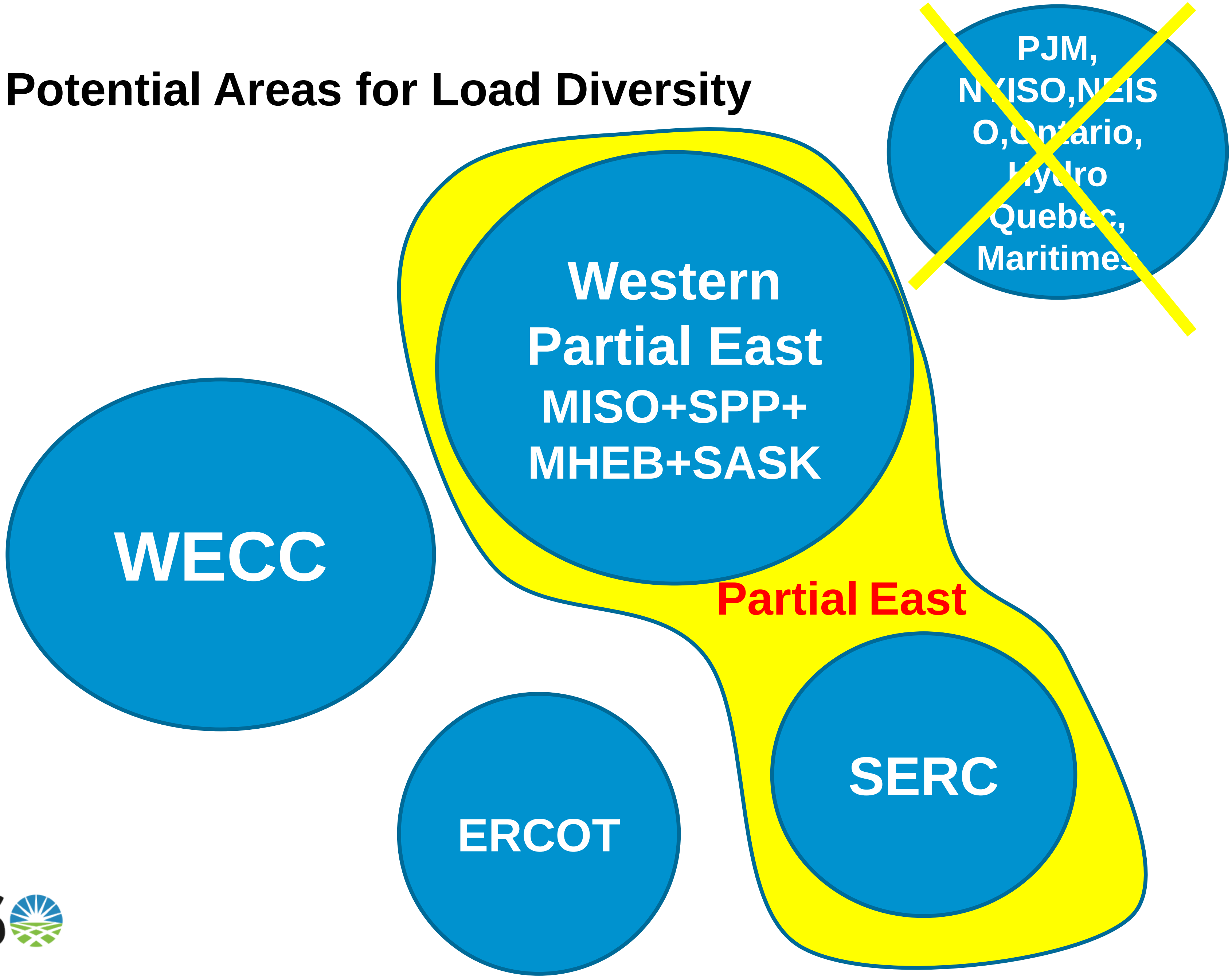
Component Maximum Sizes and Transmission Requirements

Potential Areas for Load Diversity



North East-HQ Potential

- **PJM, NYISO, NEISO, Ontario, Hydro Quebec and the Maritimes (North East) have a potential of about 17,000 MW of Load Diversity exchange**
  - Summer-Winter Peaking –high value
  - HQ may wish only to sell capacity and energy
- **North East- HQ have 850 MW potential for Frequency Response exchange**
- **Wind Diversity is unknown**
- **Indian Point is a logical HVDC terminus that could be a trading hub linked with other HVDC in the area**
- **No economically feasible transmission found in Sketches to link North East to Partial East**

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Load Diversity

- **Transmission requirement 50% of Load Diversity**
- **No transmission reserves are allocated as the diversity appears similar to a generator**
- **Value is the Load Diversity * the price of displaced generation:**
  - combustion turbine or
  - the cost change in the generation forecast
- **Example 25,000 MW * $700,000=$17.5B of potential benefits**

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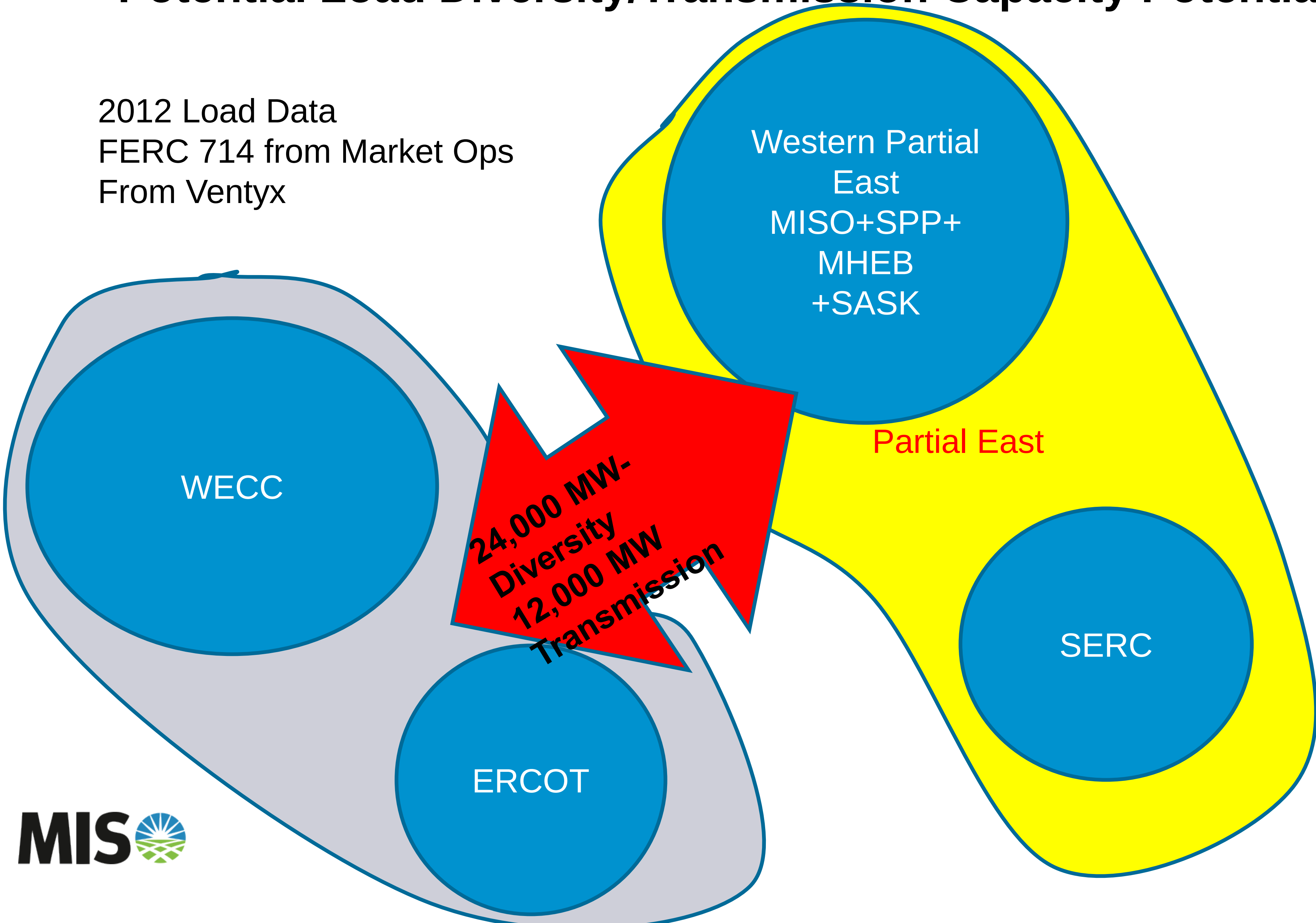
Potential Load Diversity/Transmission Capacity Potentia

2012 Load Data
FERC 714 from Market Ops
From Ventyx



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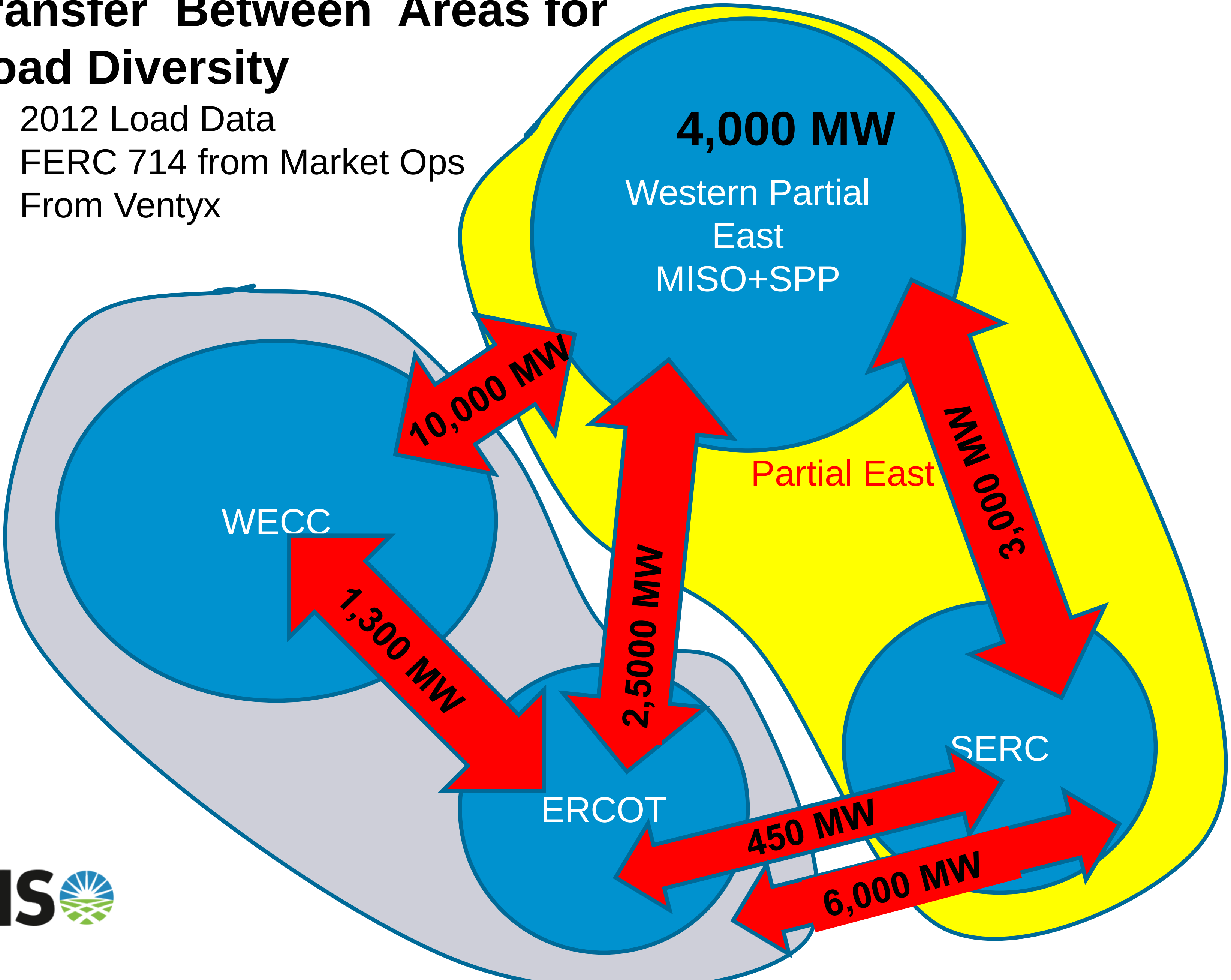
Area Pairs Potential Power Transfer Between Areas for Load Diversity

2012 Load Data
FERC 714 from Market Ops
From Ventyx

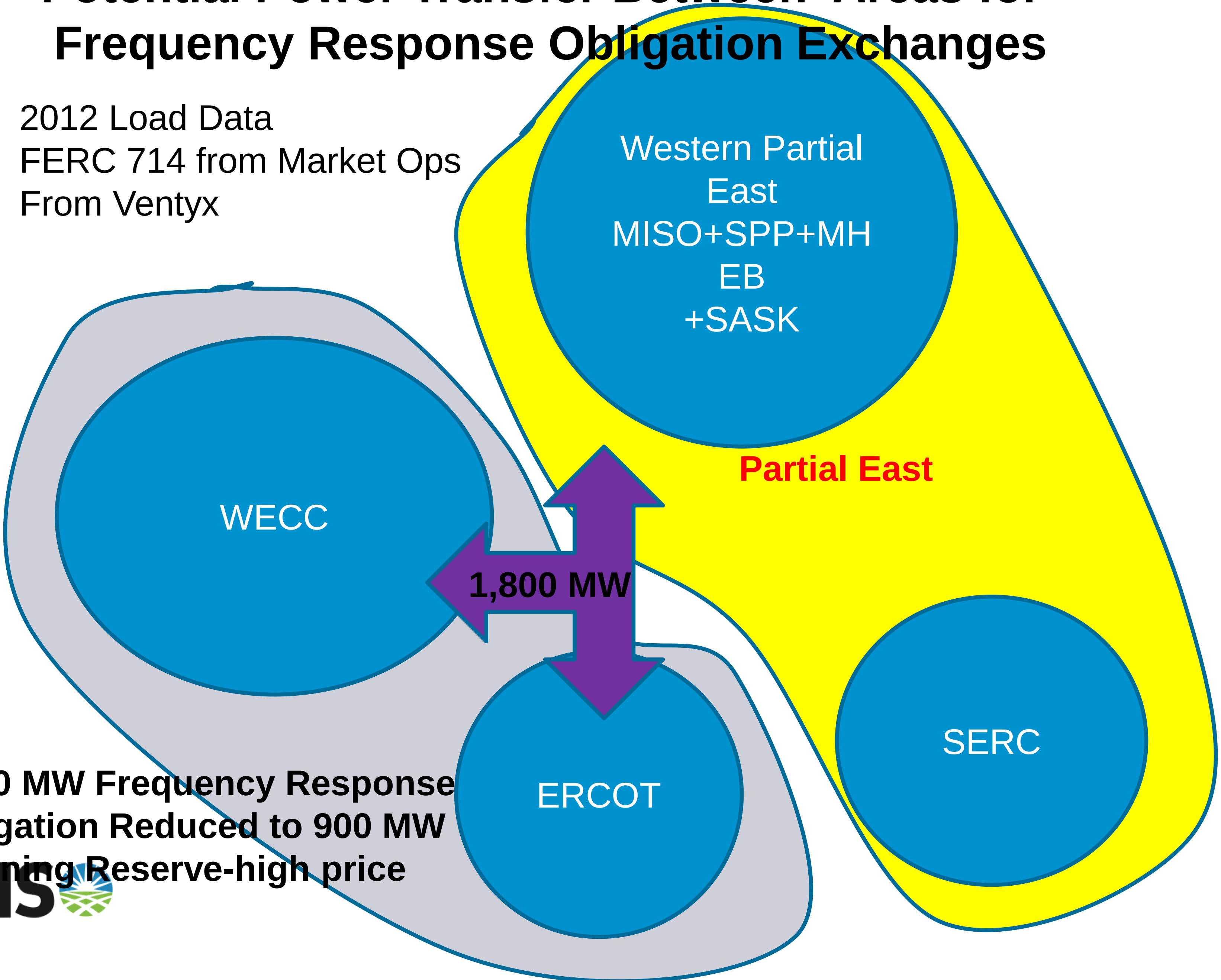


Frequency Response Obligation Sharing of Generation Reserves

- The Partial East, WECC and ERCOT have about the same level of Frequency Response Obligation is about 2,700 MW
- The Spinning Reserves used for Frequency Response can be reduced by a factor of three for each area or by 1,800 MW. Each area would carry 900 MW.
- The transmission capacity is 900 MW firm.
- Transmission reserves must be supplied.

Potential Power Transfer Between Areas for Frequency Response Obligation Exchanges

2012 Load Data
FERC 714 from Market Ops
From Ventyx



2,700 MW Frequency Response Obligation Reduced to 900 MW Spinning Reserve-high price

Transmission Reserves for Frequency Response Obligation Sharing

- At least three HVDC lines tie the Partial East, WECC and ERCOT
- The HVDC Network Sketch is designed to be N-1 self contingent for the Frequency Response Sharing Obligation transmission capacity.
- For an 1800 MW total Frequency Response Obligation Sharing delivery, 900 MW would be reserved on each line for Frequency Response allowing for the loss of one line or terminal.
- The low outage rate of HVDC and the generation resources from a pool of generation and not individual generators provide a highly reliable resource.

Frequency Response Dynamic Performance

- **Typically the present governor response to large generation disturbances before the frequency starts to recover is 3 seconds.**
- **With the HVDC Network the response is 2/3 from other asynchronous areas and is delivered near the area with the generation outage with 3 cycles or 60 times faster.**
- **The net result is that the frequency response in the system with the generation outage is one third the frequency deviation and the frequency drop in the other areas is one third of the frequency drop if the disturbance were in their area.**
- **In addition the Voltage Source Converter HVDC terminals near the generation outage support voltage that helps the AC system recover faster also.**
- **The inertia of WECC, ERCOT and the Partial East is available and used to mitigate Frequency events. Only one interconnection inertia is available today and it has a traveling wave time constant and governor response of several seconds before aid is applied.**

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Transmission and Benefits

- **The total HVDC transmission capacity would be 2,700 MW including transmission reserves.**
- **Benefits for the Sketch were assumed to be:**
  - $3/MWH premium for Spinning Reserve on an assumed lost opportunity energy price of $30/MWH
  - As the transmission offers capacity, planning reserves are reduced and the associated cost of generation
  - Energy prices were assumed to be reduced about 0.1% due to a lower operating point on the price-supply curve.

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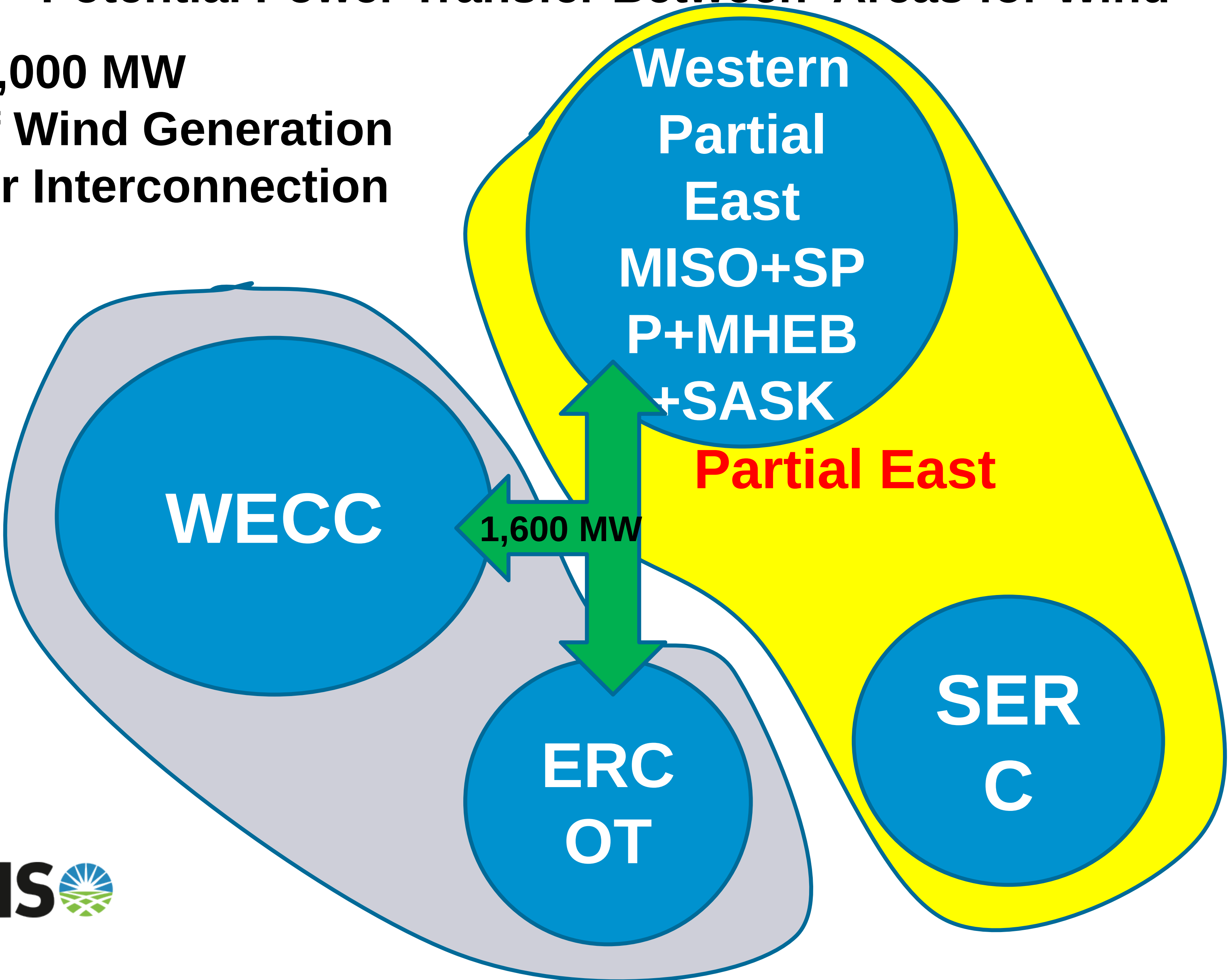
Potential Power Transfer Between Areas for Wind

**25,000 MW
of Wind Generation
Per Interconnection**



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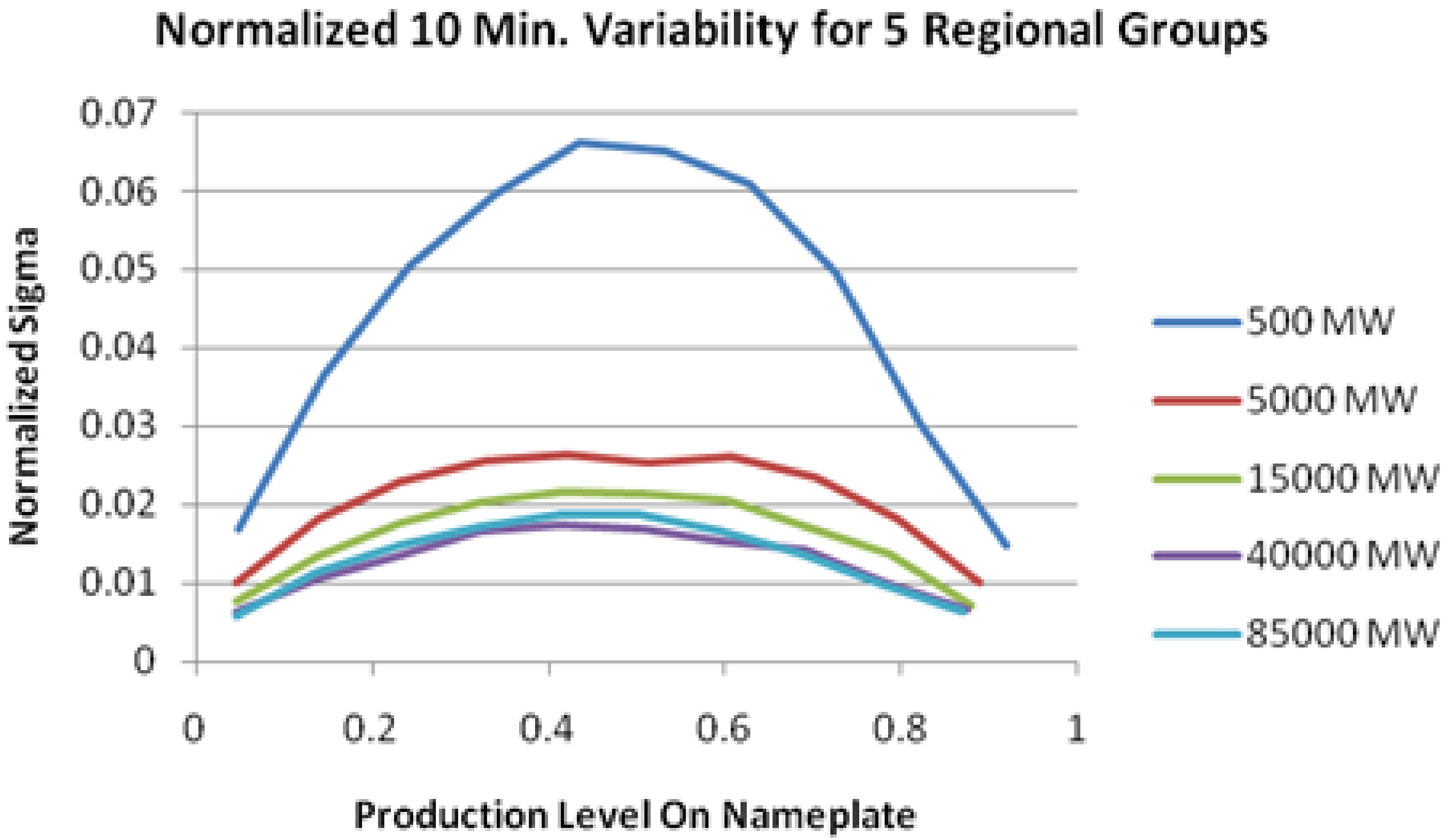
Wind Diversity



Wind Variation Reductions

- **The HVDC Network could be used to lower Standby Reserves associated with Wind Variability and may produce value from displaced generation needed for reserves if some other factor is not larger**
- **Actual wind data and forecasts would be preferred for this type of analysis for potential benefit analysis.**
- **Multiple years of actual data should be used for economic justifications. Forecasted data is good for the first pass.**

Capacity Credit versus Increased Capacity

- **Capacity Credit increases with geographic diversity- decreased correlation coefficient**
- **Capacity Credit decreases with increased generation of the same characteristics that are already in the resource mix**
  - Adding more wind or solar in a location that already is included in the resource mix, decreases
    - Capacity Credit
    - Value of **all** wind or solar in the resource mix not just the incremental
- **Selections of HVDC terminal locations and the number of locations can change the total value of the resource mix**

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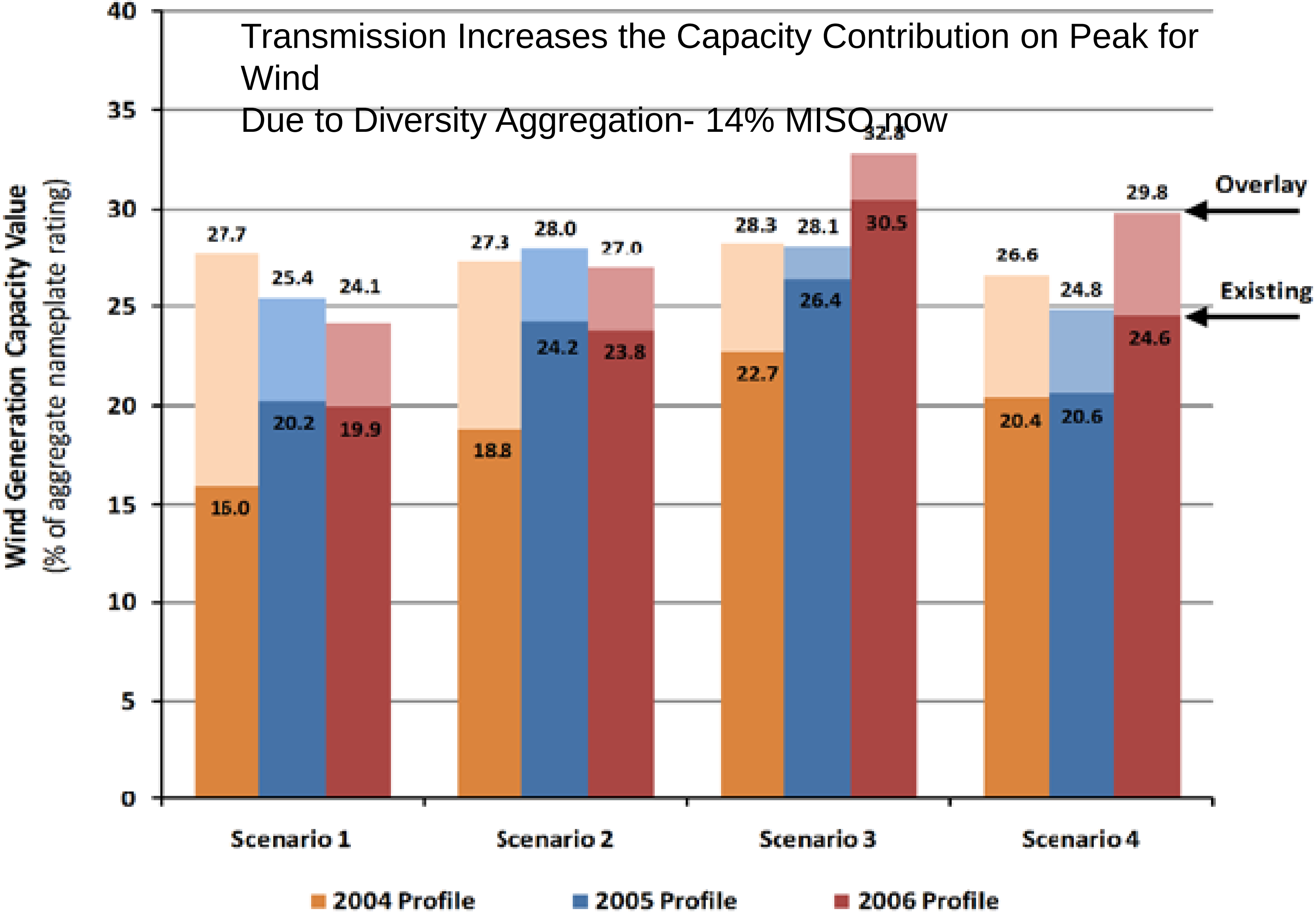
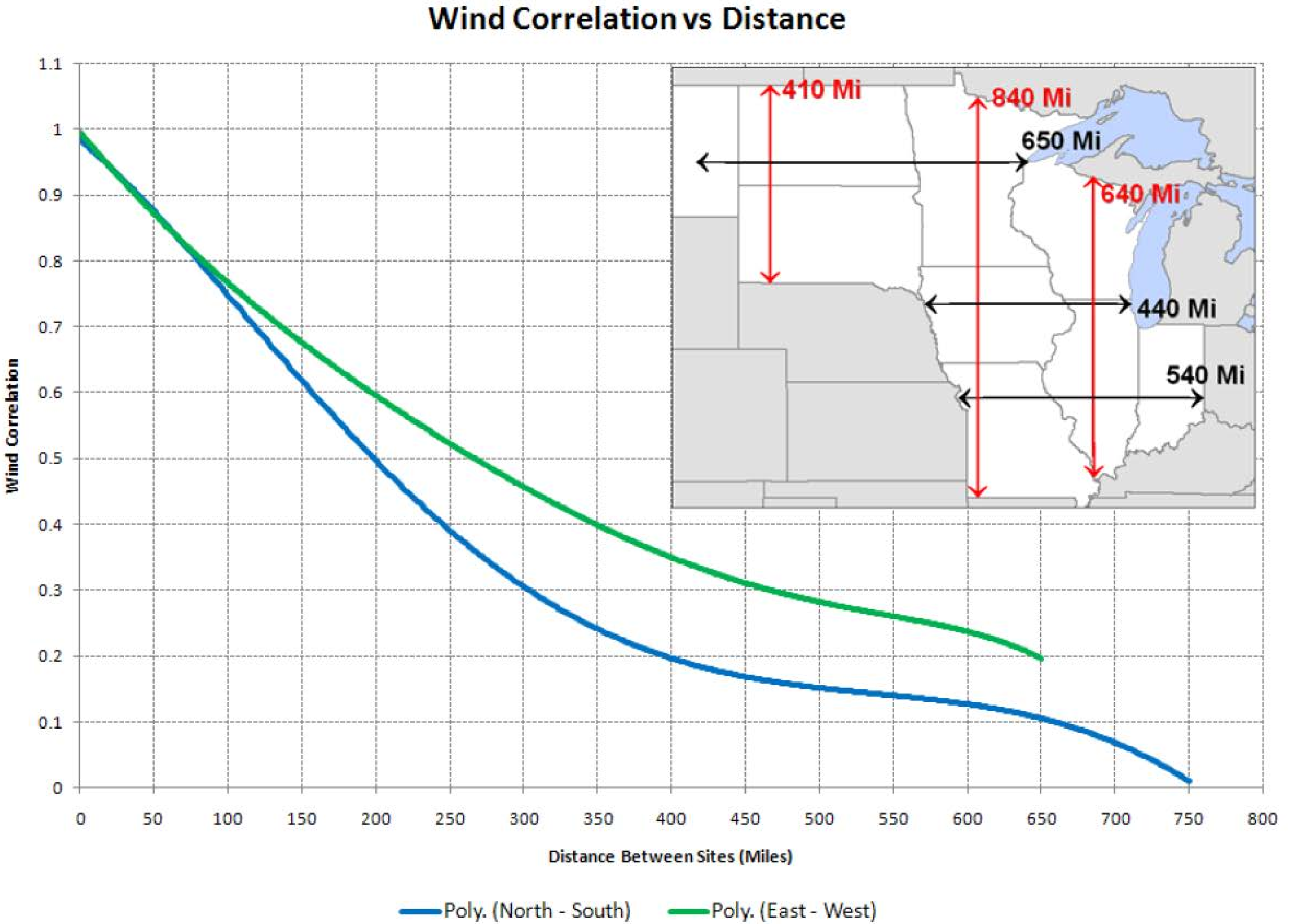
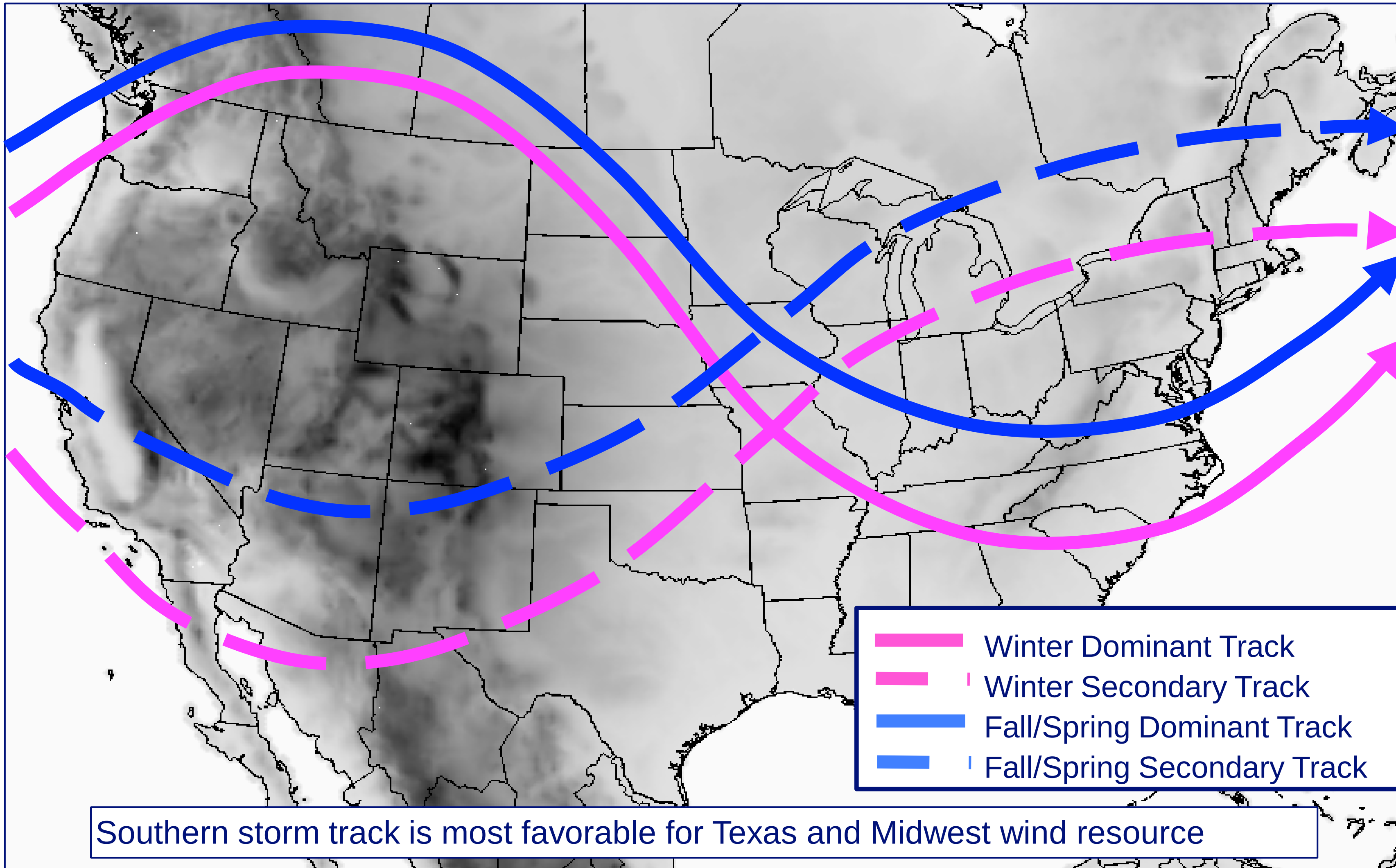
Transmission Increases the Capacity Contribution on Peak for Wind
Due to Diversity Aggregation- 14% MISO now



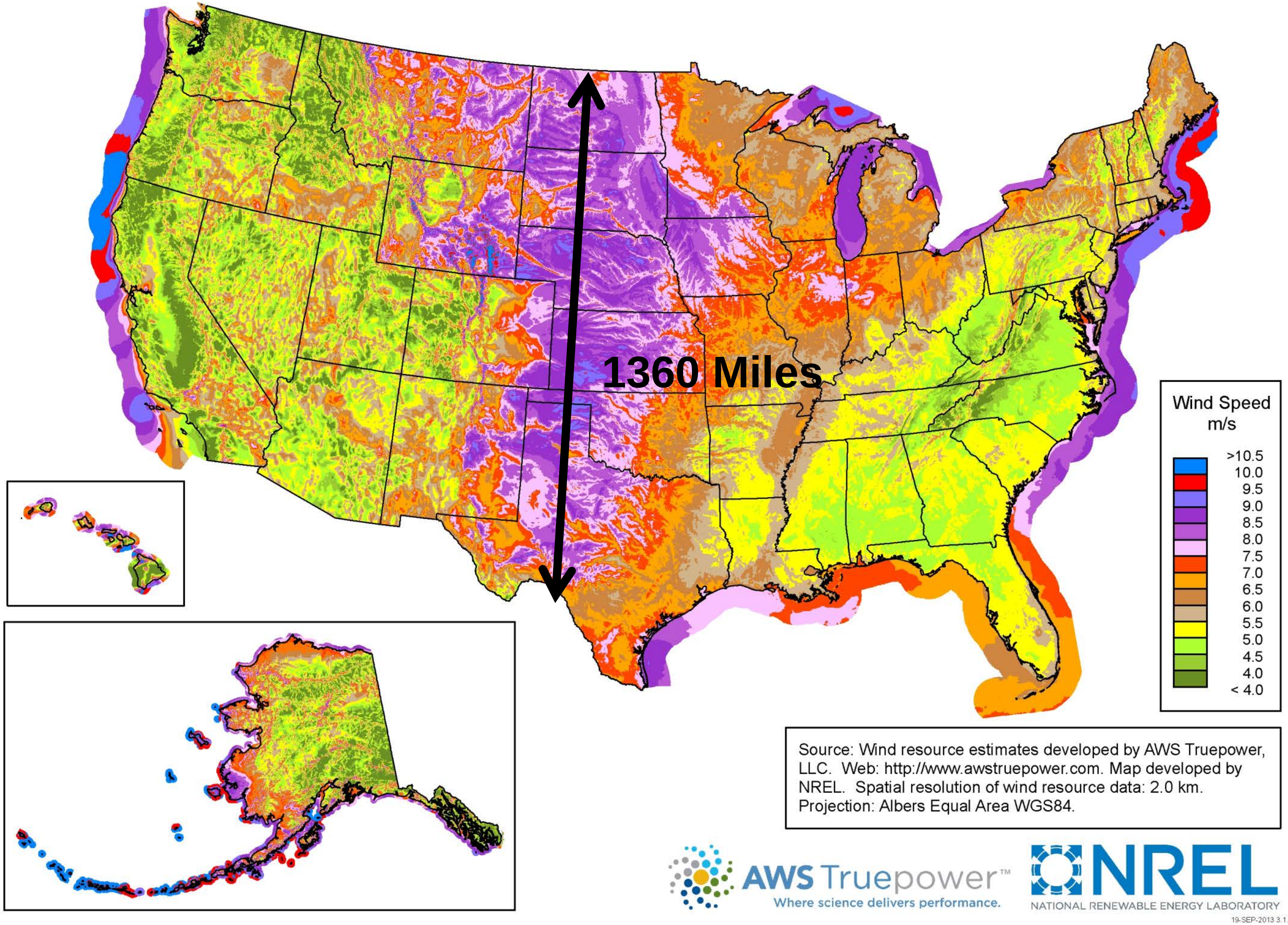

Wind Correlation vs Distance
Wind Correlation
Distance Between Sites (Miles)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
410 Mi
840 Mi
650 Mi
640 Mi
440 Mi
540 Mi
Poly. (North - South)
Poly. (East - West)

Storm Tracks Typically Cross the U.S.



Supplied by Mark Alhstrom of Wind Logics

United States - Land-Based and Offshore Annual Average Wind Speed at 100 m



Wind Capacity Credit Increase

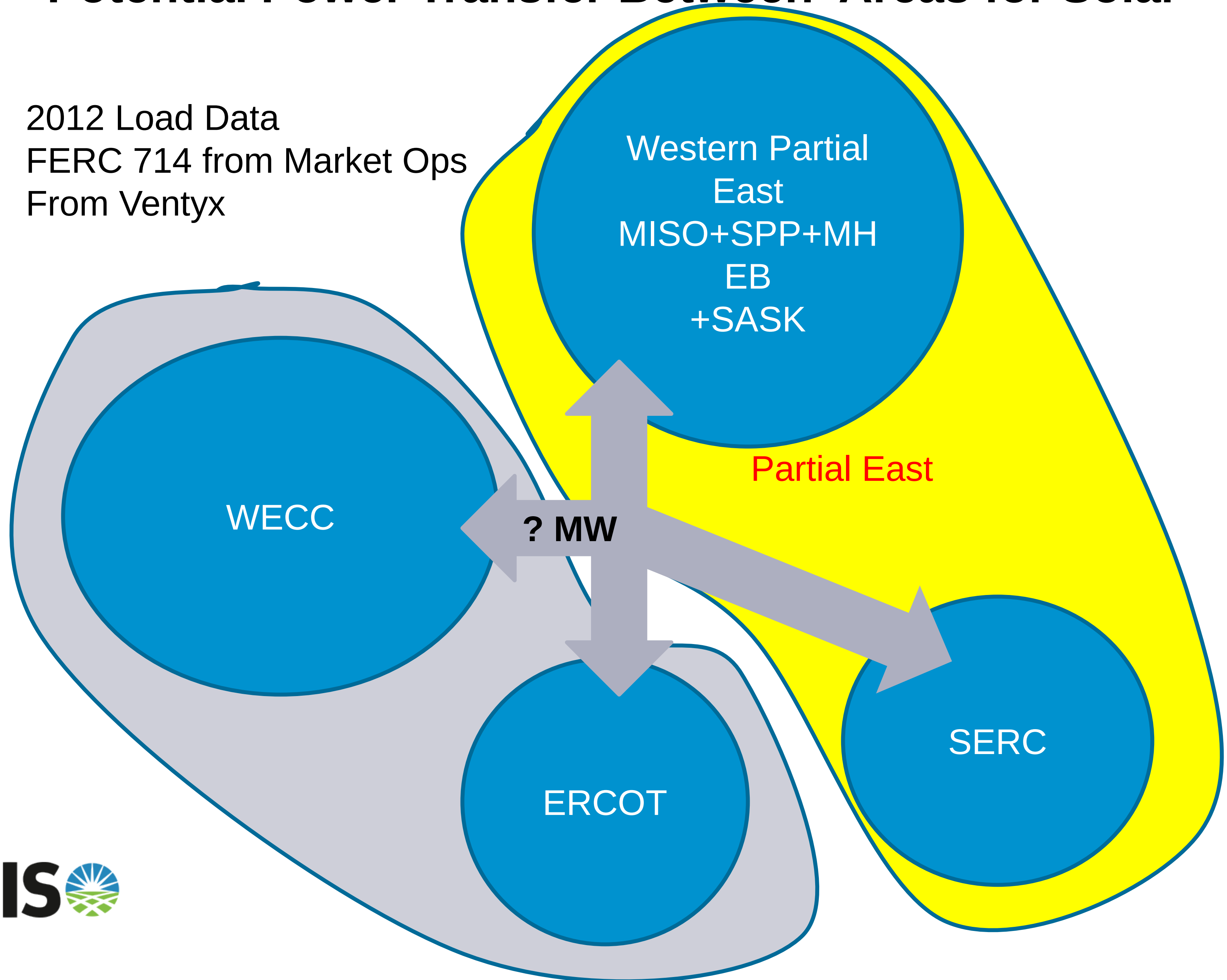
- The NREL Eastern Wind Integration and Transmission Study (EWITS) showed that the capacity credit may increase about 10% over the present MISO 14%.
- Multiple years of wind data are required to evaluate the potential benefit.
- Actual wind data may be added to NREL data.

Transmission and Benefits for Wind Capacity Credit

- **If the increase in Wind Capacity Credit is increased by 10% and there is 25,000 MW of wind in each area**
- **Transmission capacity would be 2,500 MW and no reserves as the exchange would appear to be a generator or load**
- **Value is the Load Diversity * the price of displaced generation:**
  - combustion turbine or
  - the cost change in the generation forecast
- **Example 25,000 MW *0.1* $700,000=$1.8B of potential benefits**

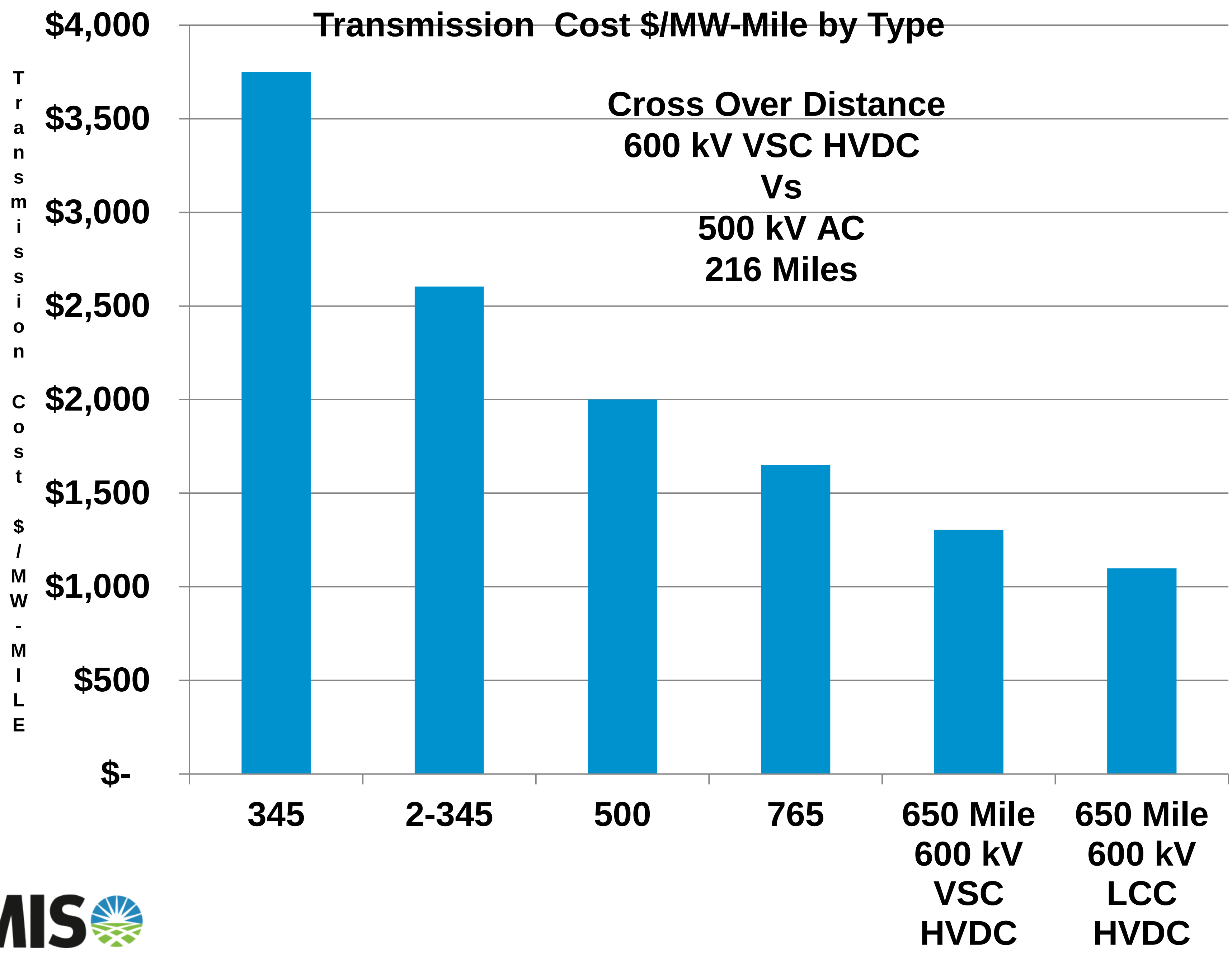
Potential Power Transfer Between Areas for Solar

2012 Load Data
FERC 714 from Market Ops
From Ventyx

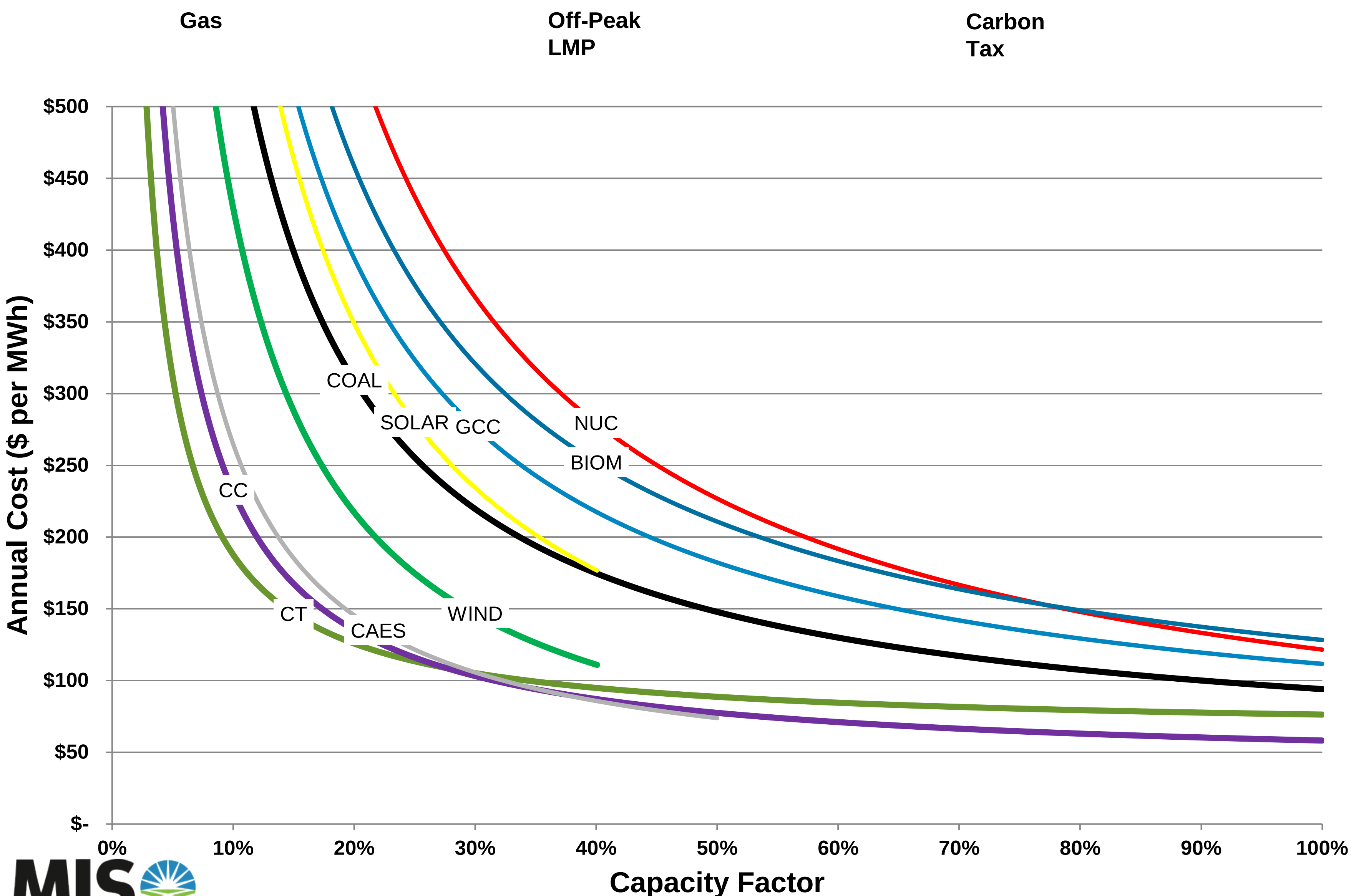


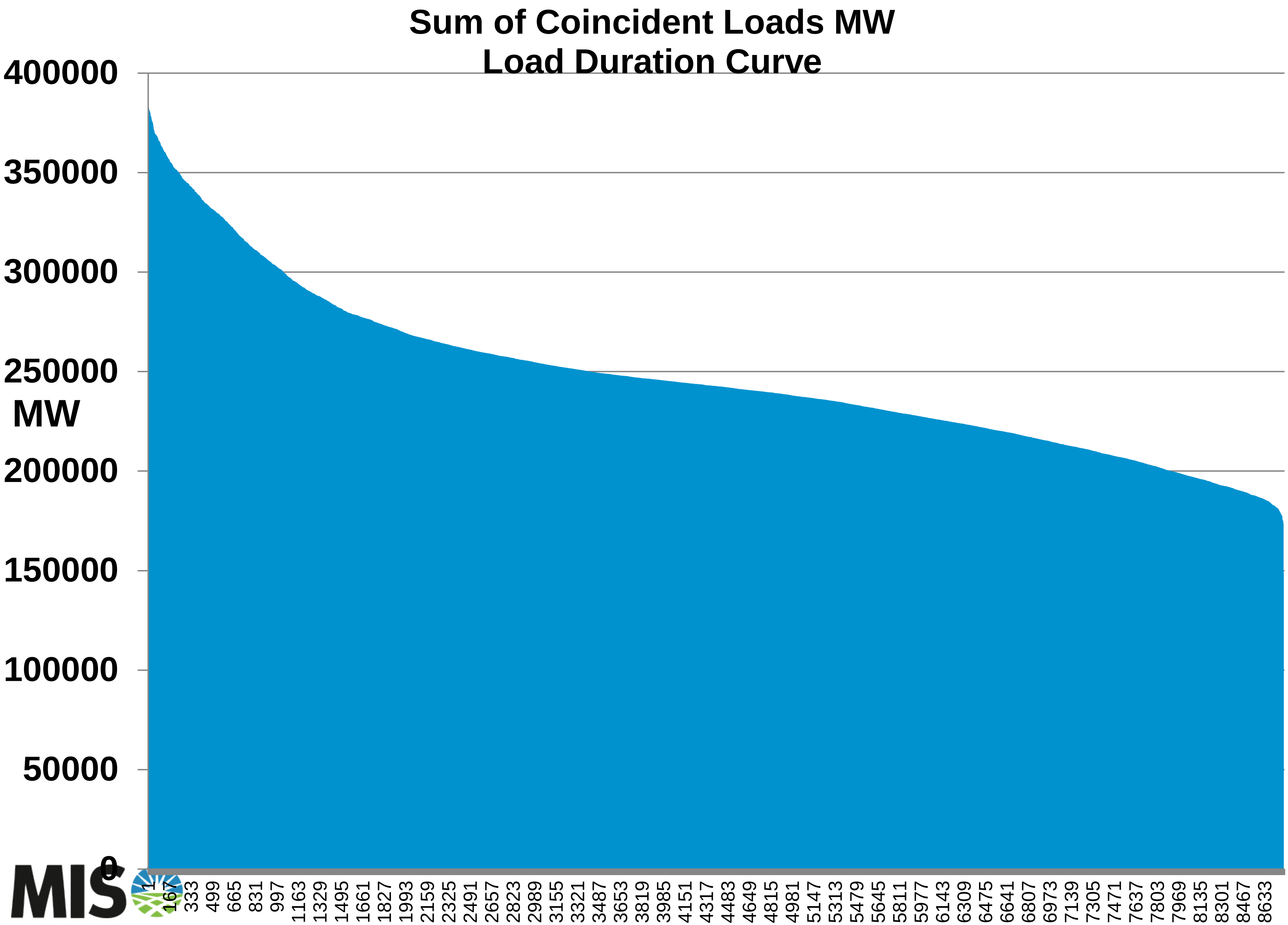
Solar Capacity Credit

- Solar data is insufficient to determine the capacity credit and variability reductions
- NREL is to have a forecasted data base in 2014
- Actual data will probably only be available on a limited basis
- Benefits cannot be estimated at this time

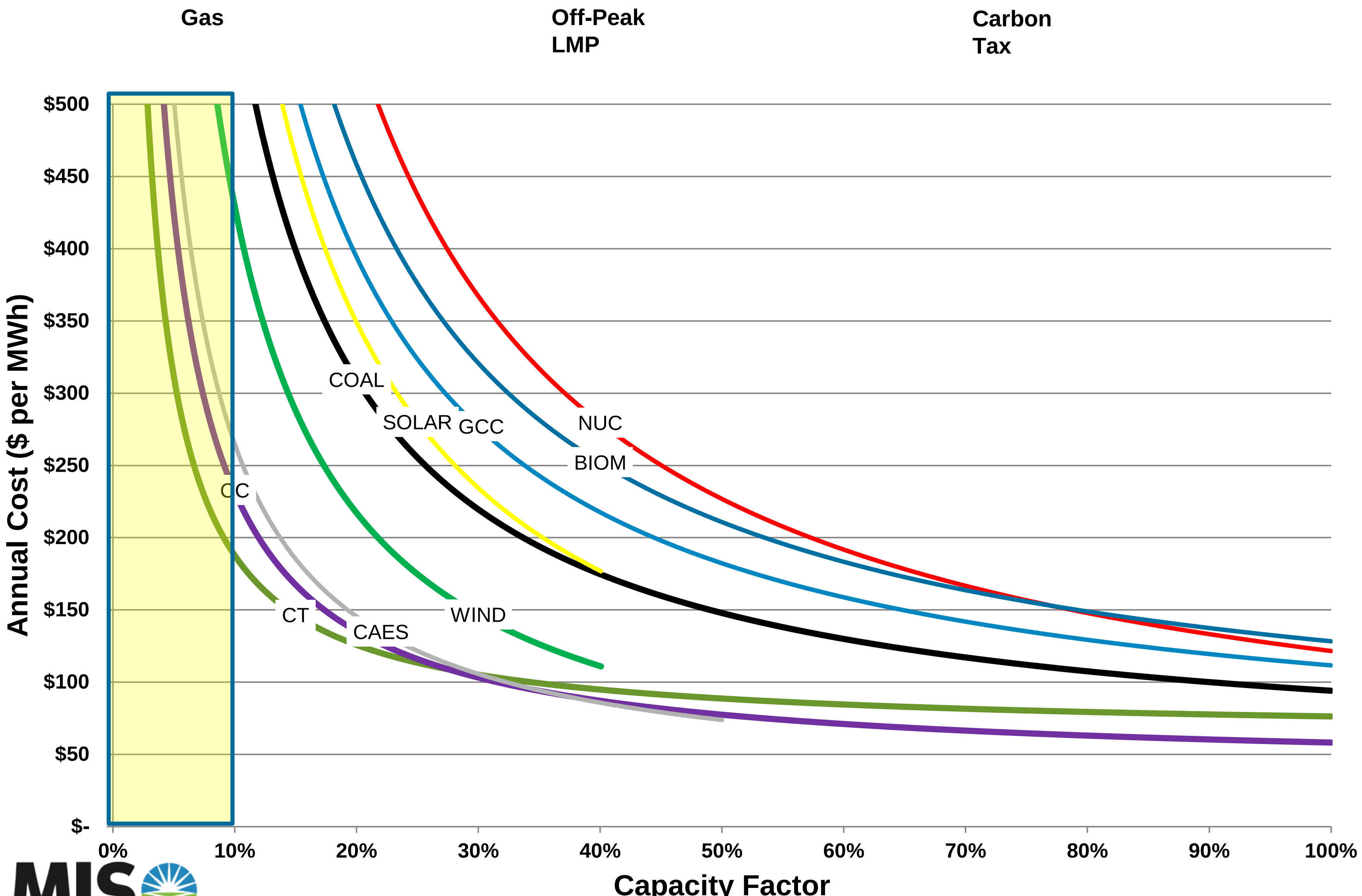

Transmission Cost $/MW-Mile by Type
Cross Over Distance
600 kV VSC HVDC
Vs
500 kV AC
216 Miles
Transmission Cost $/MW-MILE
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$-
345
2-345
500
765
650 Mile 600 kV VSC HVDC
650 Mile 600 kV LCC HVDC

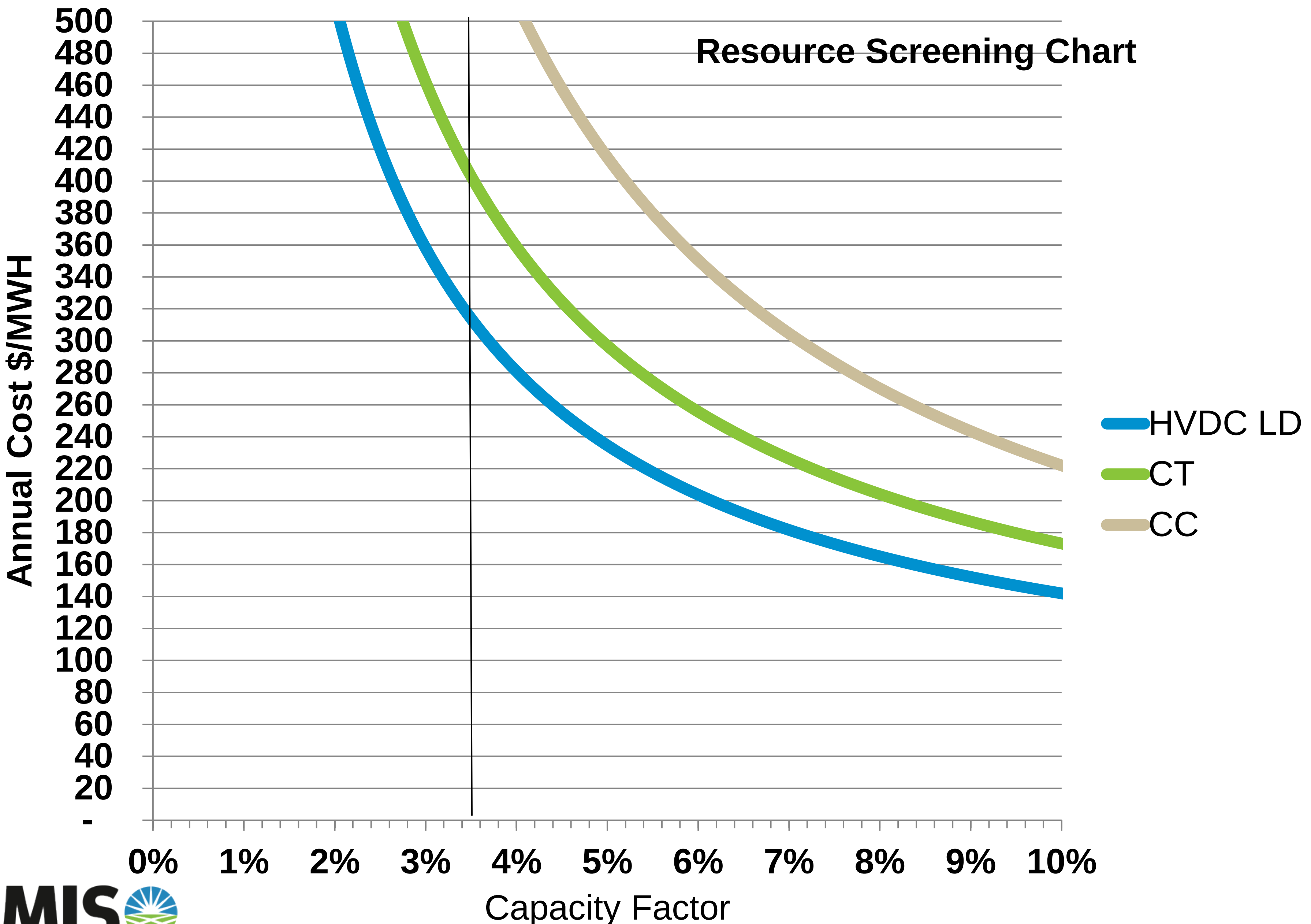
Interactive Generation Resource Screening Chart




Sum of Coincident Loads MW
Load Duration Curve
400000
350000
300000
250000
MW
200000
150000
100000
50000
0
1
167
333
499
665
831
997
1163
1329
1495
1661
1827
1993
2159
2325
2491
2657
2823
2989
3155
3321
3487
3653
3819
3985
4151
4317
4483
4649
4815
4981
5147
5313
5479
5645
5811
5977
6143
6309
6475
6641
6807
6973
7139
7305
7471
7637
7803
7969
8135
8301
8467
8633

Interactive Generation Resource Screening Chart



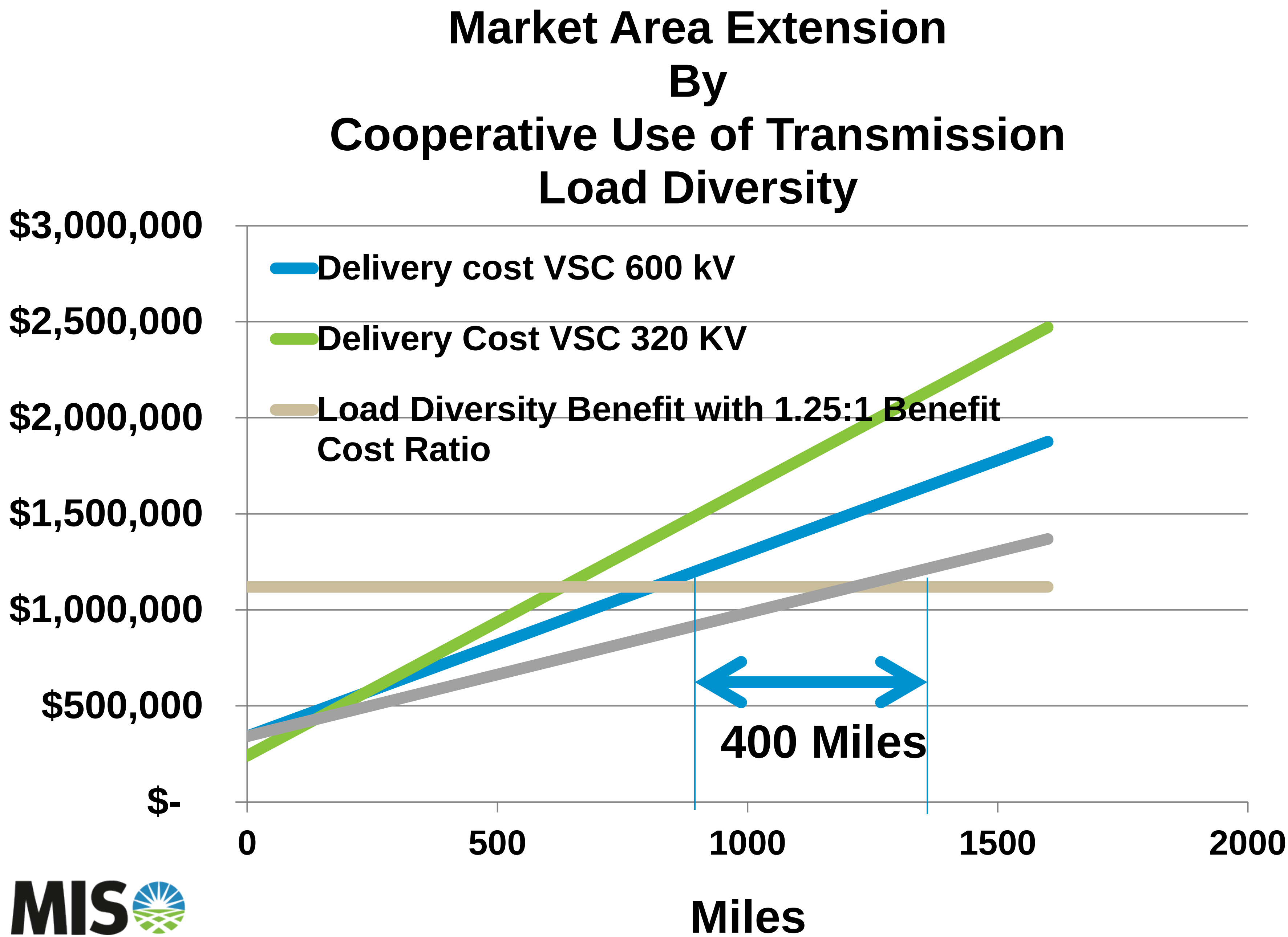

Resource Screening Chart
Annual Cost $/MWH
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
-
0%
1%
2%
3%
4%
5%
6%
7%
8%
9%
10%
Capacity Factor
HVDC LD
CT
CC

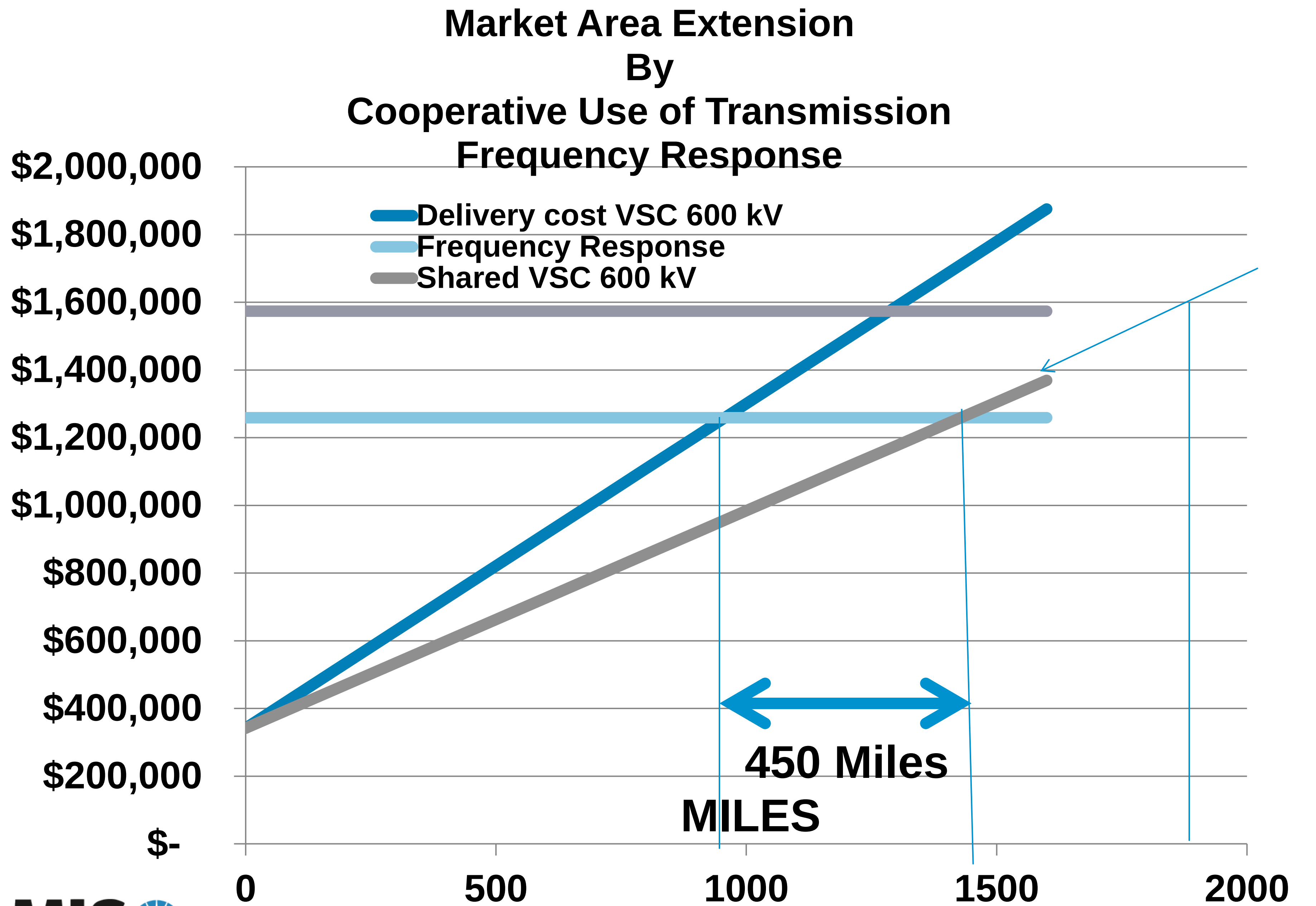
Transmission Design Concept

- **Voltage Source Converters may be operated in parallel to Classical Load Commutated Converters using an upgraded transmission line.**
- **Cooperative use of lines may extend the HVDC Network concept economic justification to reach California where there is major load and renewable resources**
- **Solar resources rated at peak load and wind generation rated at 50% load meet about 80% of the energy needs of the aggregated load profile**
  - better data needed for economic justification

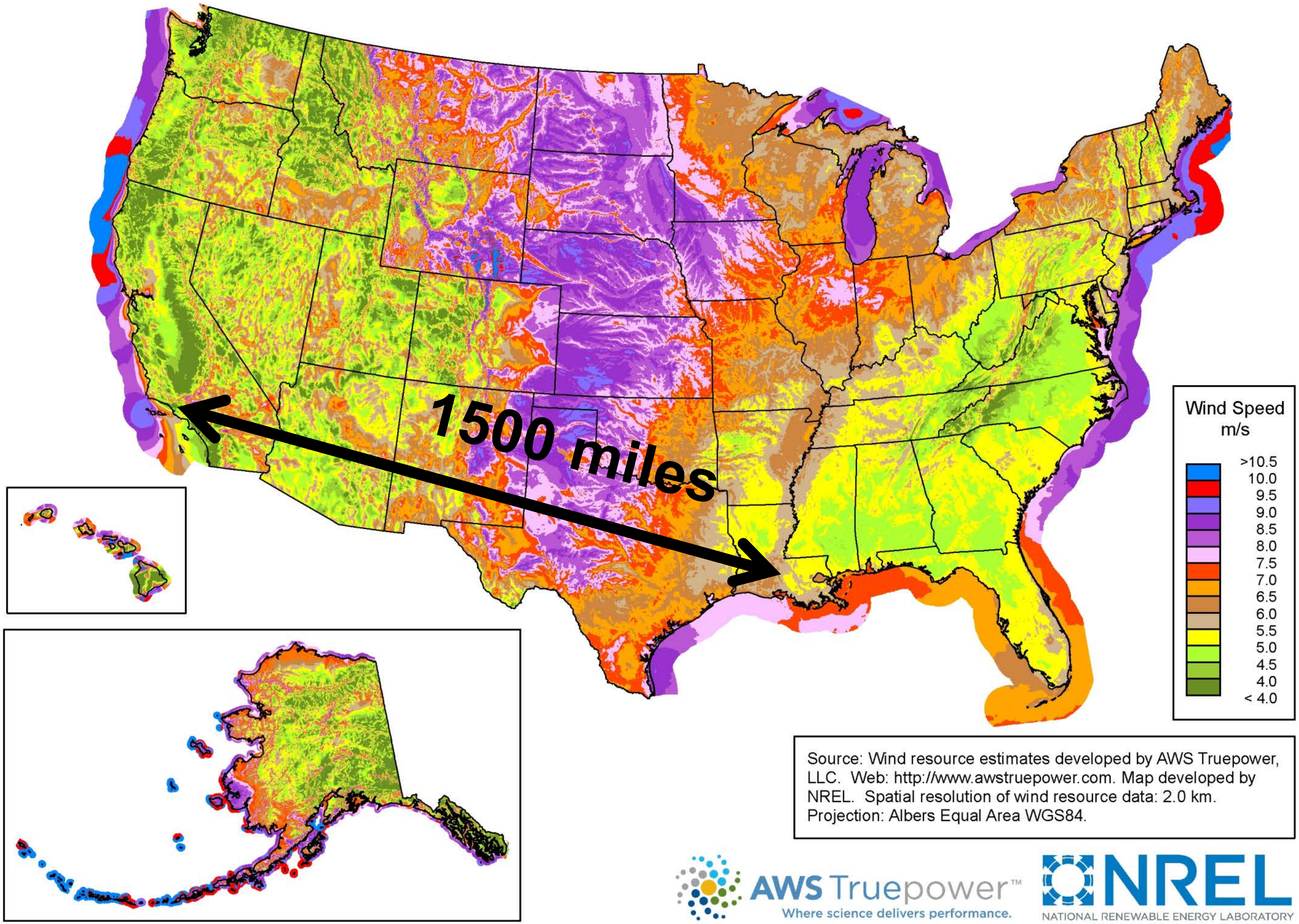
Cooperative Use of Transmission Assumptions

- Voltage Source Converters are about 25% higher in cost than Classic Load Commutated Converters
- Transmission capacity can be doubled for a 50% increase in cost by raising voltage 50%.
- Doubling current ratings may cost 75% more
- Engineering design is needed to refined these assumptions to economic justification levels
- Economic distances for transmission can be increased with transmission use cooperation


Market Area Extension
By
Cooperative Use of Transmission
Load Diversity
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$-
Delivery cost VSC 600 kV
Delivery Cost VSC 320 KV
Load Diversity Benefit with 1.25:1 Benefit Cost Ratio
400 Miles
0
500
1000
1500
2000
Miles
MISO


Market Area Extension
By
Cooperative Use of Transmission
Frequency Response
Delivery cost VSC 600 kV
Frequency Response
Shared VSC 600 kV
$2,000,000
$1,800,000
$1,600,000
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$-
450 Miles
MILES
0
500
1000
1500
2000

United States - Land-Based and Offshore Annual Average Wind Speed at 100 m



Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.

Questions

- **Contact:**
- **Dale Osborn**
- **Consulting Advisor**
- **Policy and Economic Studies**
- **MISO**
- **Email: dosborn@misoenergy.org**
- **Phone: 651-632-8471**

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