Wind Integration Studies in the United States
美国风能并网研究

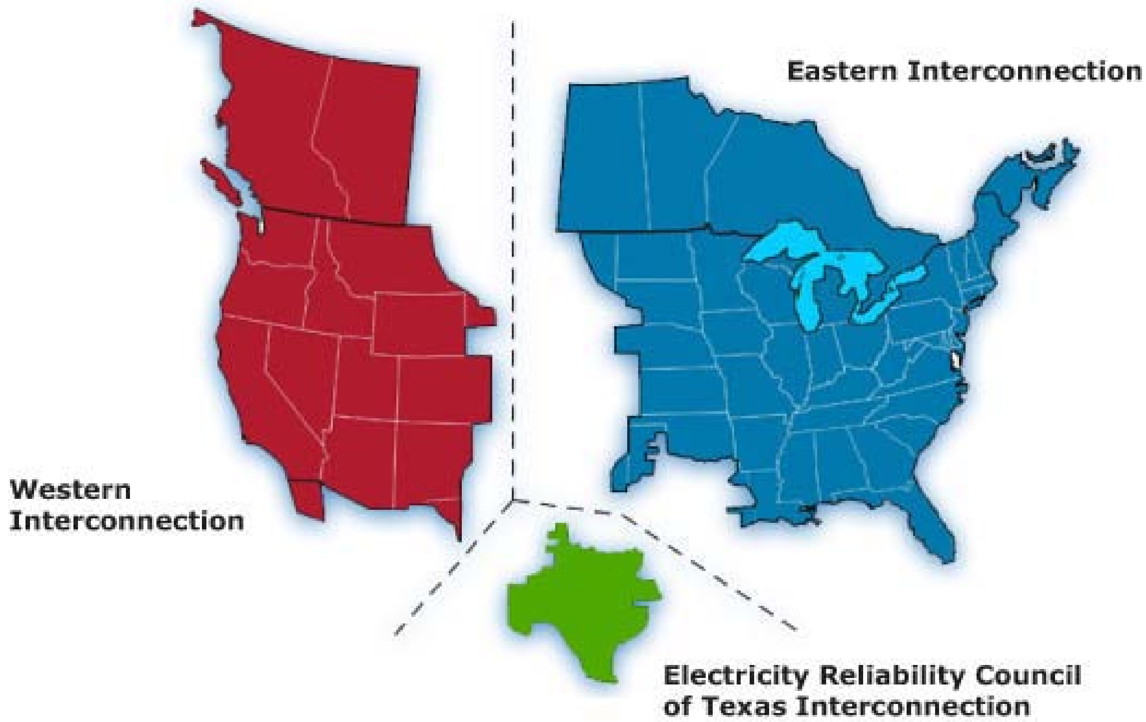
Lisa Schwartz, 丽莎·施瓦兹, RAP

Beijing, China – May 2010

The Regulatory Assistance Project

China ♦ EU ♦ India ♦ United States

US Transmission Interconnections
美国输电互连电网



Key Points From US Studies
美国研究要点

- Grids can accommodate high levels of wind and solar generation with:
  - Large operating systems, balancing areas or markets
  - State-of-art forecasting
  - Flexible generation, demand response and pricing strategies that encourage both
  - New operating strategies
  - Adequate transmission
  - Integrated planning for demand-side resources, generation and transmission

- 电网可通过以下措施提高风能与太阳能发电接入水平：
  - 大的运行系统，平衡地区或市场
  - 最新预测科技
  - 弹性发电、需求响应以及相应的电价鼓励策略
  - 新的操作策略
  - 充足的输电
  - 需求侧资源、发电与输电综合规划

Key Points From US Studies
美国研究要点

- Plug-in electric vehicles and demand response can help integrate wind
  - Night charging of PHEVs coincides with high levels of wind production
  - Demand response increases or decreases loads according to wind levels
- Beyond US
  - High wind penetration in Spain, Germany, Denmark without smart grids

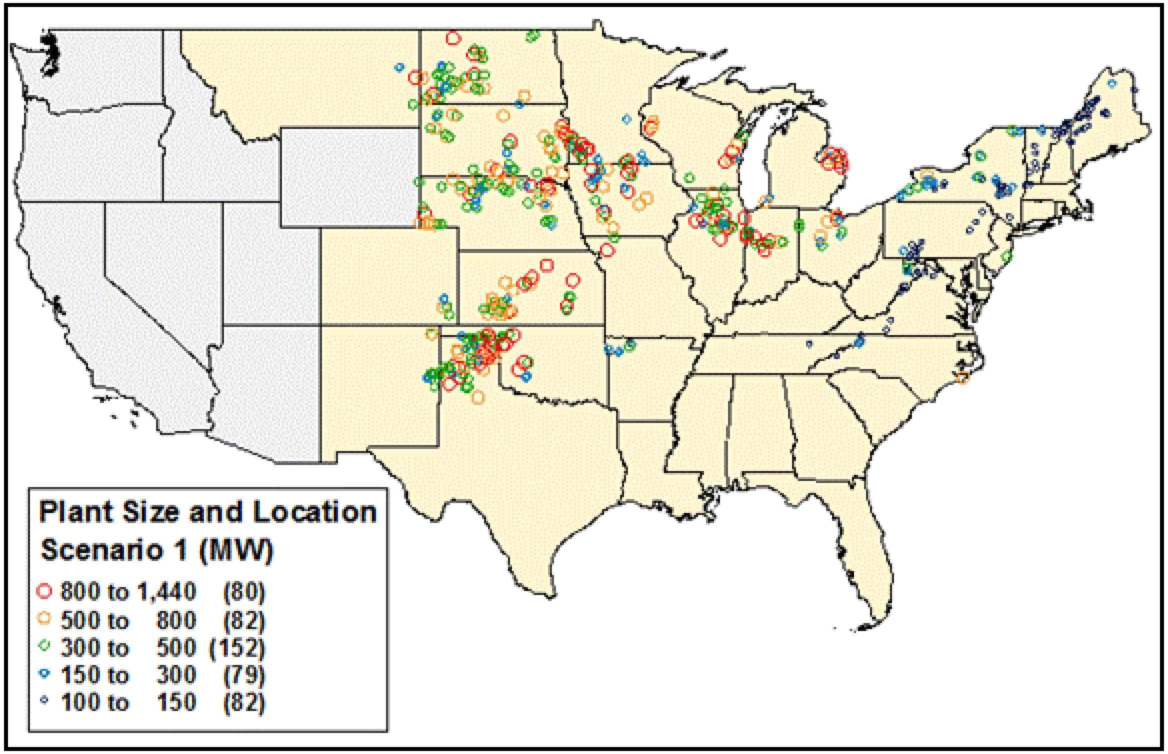
- 充电式电动汽车与需求响应可以帮助整合风能：
  - 外接充电式电油混合动力汽车在夜间充电，时间与风能高峰时期重合。
  - 需求响应根据风能水平增加或减少负荷
- 美国之外
  - 西班牙、德国、丹麦风能渗透率高，但没有智能电网。

Eastern Wind Integration and Transmission Study
东部风电并网与输电研究

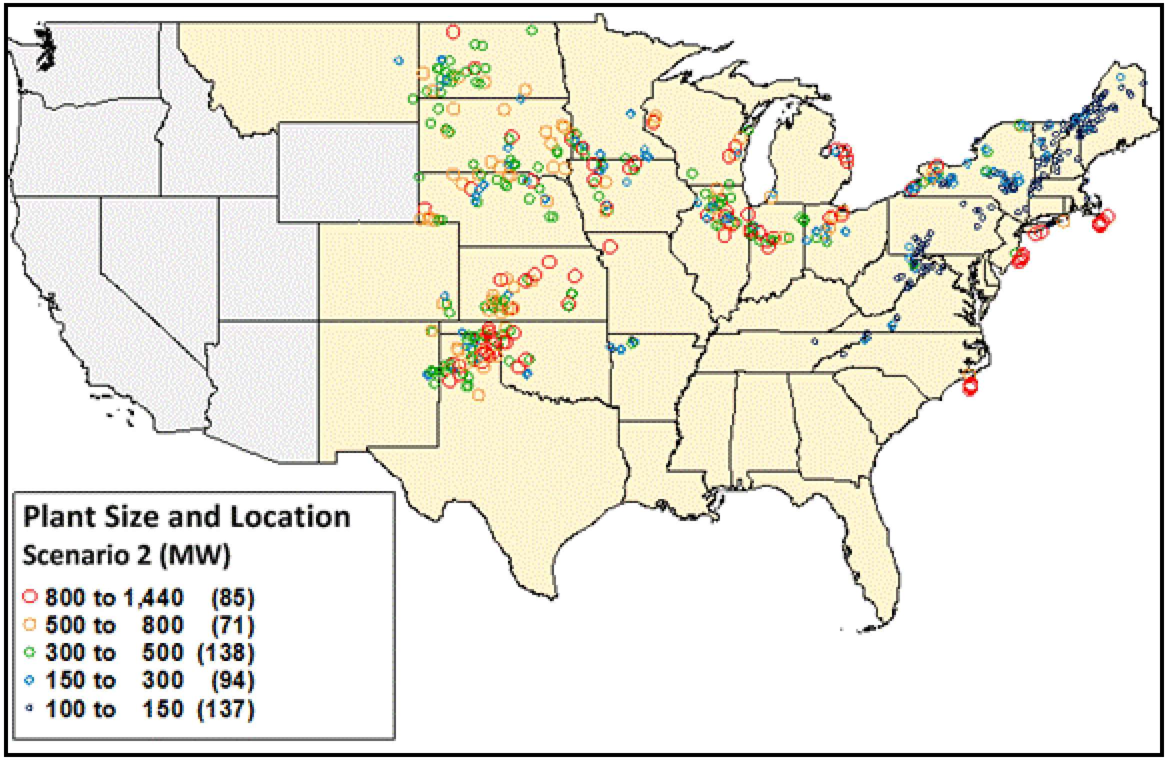
- Evaluate operating impacts and transmission to meet 20% of energy use with wind by 2024
- Four scenarios analyzed
  1. High capacity factor (CF) wind, mostly in Midwest
  2. Move some wind projects east, add off-shore wind
  3. More wind near eastern load centers, more off-shore
  4. Increase to **30% wind**, a lot of off-shore wind

- 为达到2024年风能占20%电量的目标，评估运营影响与输电能力
- 分析了四种情景
  1. 高容量因子风能，主要在中东部
  2. 将一些风能项目东移，增加离岸风能。
  3. 在东部负荷中心附近增加风能，更多离岸风能
  4. 增加至**30%风能**，很多离岸风能。

Eastern Scenario 1: High CF, On-shore Wind
东部情景1：高容量因子的陆上风能

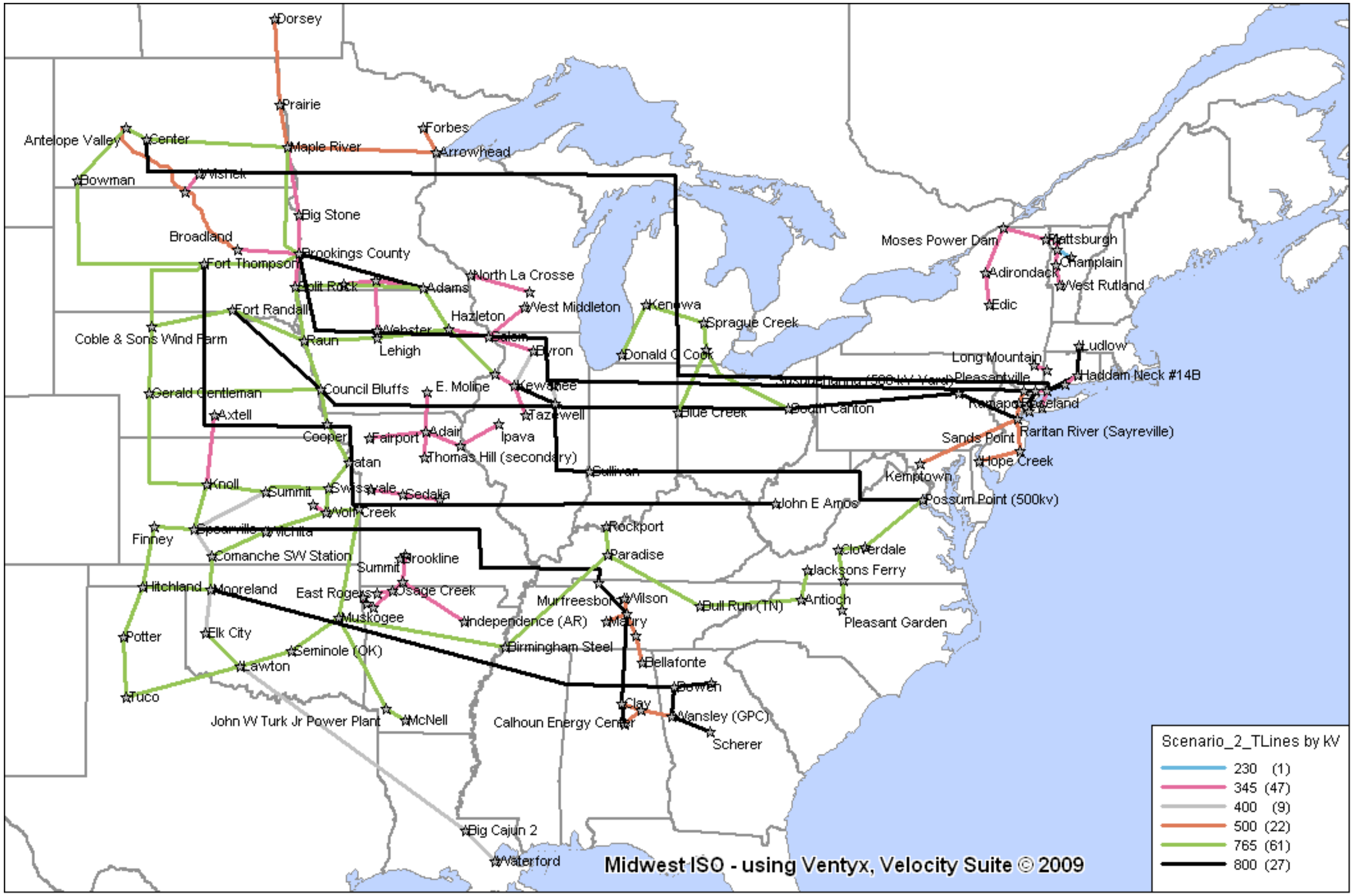


Eastern Scenario 2: Some Off-shore Wind
东部情景2：一些离岸风能



See maps of other scenarios in “Extra Slides”
其他情景地图请见“附加幻灯片”

Transmission Overlay for Scenario 2
情景2 输电覆盖图



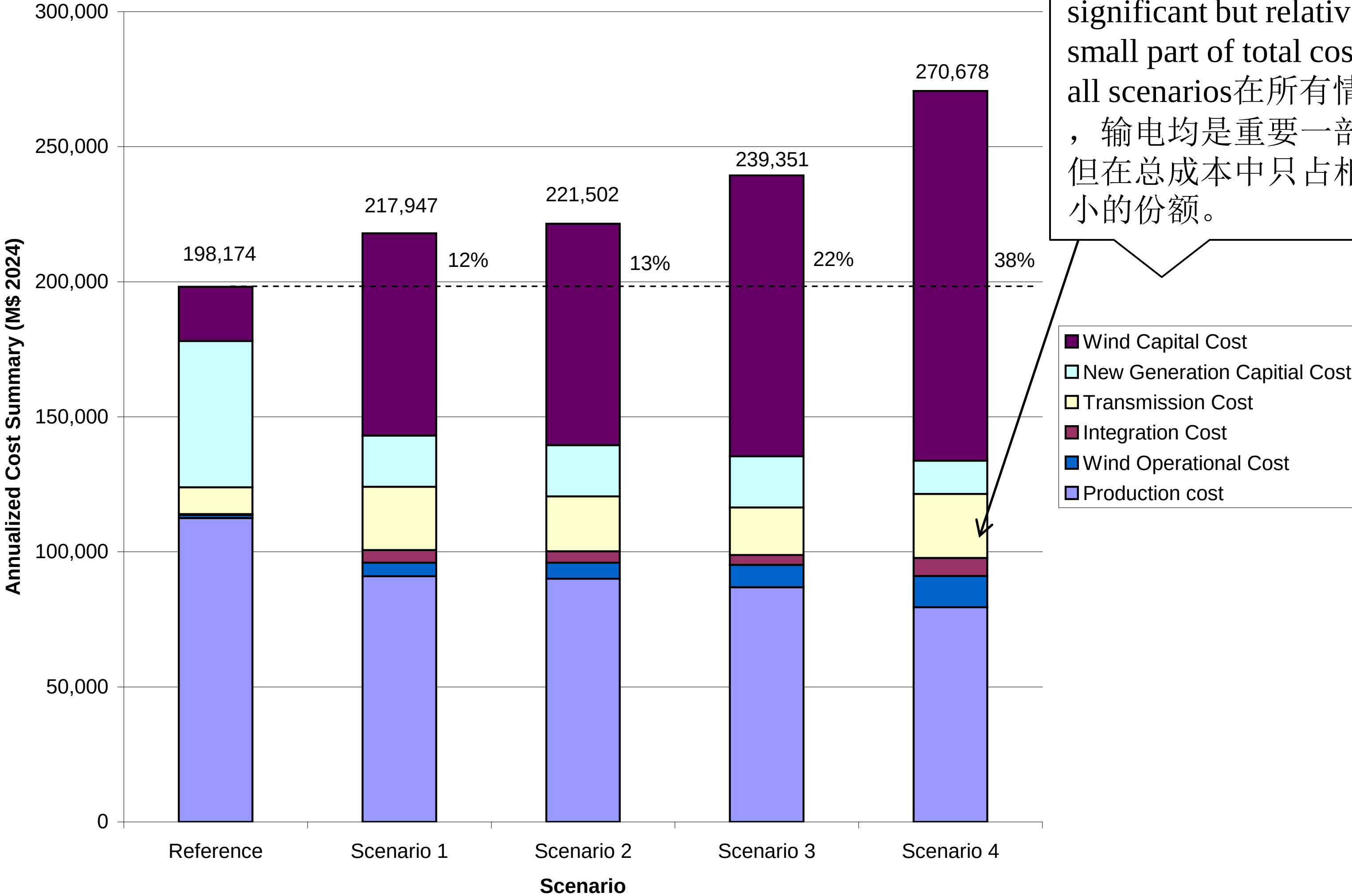
Eastern Study Conclusions
东部研究总结

- 30% wind is technically feasible with significant transmission expansion
  - Includes high-voltage DC and extra high-voltage AC lines
- Wind integration cost: $5/MWh
  - With large balancing areas and well-developed markets
- Large operating areas (loads, generating units and geography) and adequate transmission are the most effective measures for managing wind generation

- 通过大力扩展输电网络，30%风能在技术上是可行的。
  - 包括高压直流线和超高压交流线。
- 风电并网成本：$5/兆瓦时
  - 与大平衡区和发达的市场
- 管理风力发电最有效的措施是扩大运行区域（负荷、发电设施及地理）和足够的输电能力。

Total Annual Costs by Scenario
各情景的年度总成本

Transmission is a significant but relatively small part of total costs in all scenarios在所有情景中，输电均是重要一部分，但在总成本中只占相对较小的份额。



Note: Reference case is wind acquired under existing Renewable Portfolio Standards.

注意：参考案例是根据可再生能源配额制获取的风能。

Eastern Study Conclusions
东部研究总结

- Transmission has many benefits
  - Reduces wind variability impacts
  - Reduces wind integration costs
  - Increases grid reliability
  - Uses generating sources efficiently
- Adjusted production cost (APC) savings indicate potential budgets for transmission
  - Represents difference between unconstrained & constrained cases

TABLE 4-6. BENEFIT AND COST COMPARISON (US $2024, MILLIONS)			
SCENARIO	2024 ANNUAL TRANSMISSION COST	2024 APC SAVINGS	2024 B/C RATIO
1	23,437	28,648	1.22
2	20,320	22,194	1.09
3	17,567	13,095	0.75
4	23,758	18,676	0.79

B/C = Benefit/cost; in this case, APC savings in 2024 divided by transmission cost in 2024

- 输电有很多好处：
  - 减少风能不稳定性的影响
  - 减少风能整合成本
  - 增加电网可靠性
  - 有效地利用发电来源
- 调整的生产成本节约表明了输电的潜在预算
  - 阐明了无约束案例与有约束案例的区别

表4-6 收益与成本比较（美国，2024，百万美元）			
情况	2024年输电成本	2024调整的生产成本节约	2024收益/成本比
1	23，437	28，648	1.22
2	20，320	22，194	1.09
3	17，567	13，095	0.75
4	23，758	18，676	0.79

本例中，收益/成本比为2024年调整的生产成本节约除以2024年输电成本。

Western Wind and Solar Integration Wind and Solar Integration Study
西部风能与太阳能集成研究

- Analyze operating and cost impacts of meeting 35% of energy use in 2017 from wind and solar*
- Five Western states
- *Not* a transmission study

- 分析达到2017年风能与太阳能占能源利用总量35%这一目标的运营与成本影响*
- 西部五州
- *不是*输电研究

*70% concentrating solar power (6 hours thermal storage) and 30% distributed photovoltaics

*70%聚光太阳能（6小时蓄热）和30%分布式太阳能发电

Western Study Scenarios
西部研究情景

- Geographic locations tested:
  - *In Area* – Each state meets its target with in-state resources
  - *Mega Project* – Concentrate projects in best resource areas for economic efficiency
  - *Local Priority* – Balance of in-state and best resource areas
- Four wind/solar levels tested

Case Name	In Footprint Energy Penetration			Rest of WECC	
	Wind + Solar	Wind	Solar	Wind	Solar
10%	11%	10%	1%	10%	1%
20%	23%	20%	3%	10%	1%
20/20%	23%	20%	3%	20%	3%
30%	35%	30%	5%	20%	3%

Note: In footprint = Five WestConnect states; WECC = Western Interconnection

- 测试的地理位置
  - *地区内*-各州通过州内资源达到其目标
  - *大型项目*-出于经济效益考虑，项目集中在最佳资源区域
  - *本地优先级*-平衡州内与最佳资源区域
- 测试的四个风能/太阳能级别

案例名称	西部五州能源比例			其他WECC	
	风+太阳	风	太阳	风	太阳

注意：西部五州=西部电网五个州
WECC=北美西部大电网

Western Study Conclusions
西部研究结论

- 5-state area can integrate 30% wind plus 5% solar assuming:
  - Balancing Area cooperation to reduce net load variability
  - Sub-hourly generation scheduling
  - Greater transmission utilization
  - Coordinated generation dispatch
  - Best wind/solar forecasts for unit commitment and operations
  - More dispatchable generation and demand response
  - Some additional operating reserves

- 西部电网五个州地区可以集成30%风能加5%太阳能，假定：
  - 平衡地区合作，减少净负荷不稳定性
  - 安排时间间隔少于1小时的发电计划
  - 更好地利用输电系统
  - 协调发电调度
  - 通过最佳风能/太阳能预测改进机组组合与操作
  - 增加可调度发电与需求响应
  - 增加一些额外的运行备用。

Western Study Conclusions
西部研究结论

- 5-state area already has enough reserves to cover variability 95% of the time
  - Displacement of fossil-fuel resources frees up reserves
- Energy storage not needed
  - Dispatched generation cheaper
- 30% wind scenarios yield $20 billion in savings/year*
- Operating savings similar across resource locations

- 西部电网五个州地区的储备已经足以应付95%时间内的不稳定性。
  - 替代矿物燃料资源释放储备
  - 不需要能源储备
  - 发电调度更便宜
  - 30%风能的各情景每年可节省200亿美元*
  - 各资源位置运营节约相似

*Equates to $80/MWh of wind or solar produced. Study only analyzed operating costs, *not* capital costs.

*相当于生产风能或太阳能$80/兆瓦时。研究仅分析运营成本，*不分析*资本成本。

Regional Transmission Planning
地区输电规划

- Long-term transmission plans for 3 interconnections
- Identify transmission needs and model scenarios to:
  - Reliably serve demand
  - Meet public policy directives
  - Minimize cost and environmental impact
- Involve states, stakeholders
  - Improve plans, gain support for transmission siting & costs
- Includes efficiency, demand response and renewables

- 3大互连电网长期输电计划
- 确定输电需求与模型情景，以：
  - 可靠地满足需求
  - 达到公共政策指令要求
  - 最小化成本与环境影响
- 使各州、利益相关者参与
  - 改进计划，为输电选址与成本获取支持
- 包括效率、需求响应与可再生能源

Renewable Energy Zones
可再生能源区域

- Western Interconnection
  - Map of zones with large, high-quality renewable resources
  - Resource supply curves by zone
  - Model estimates cost to deliver resources in zones to load centers
- Next steps in Western US
  - Identify grid co. preferred zones
  - Coordinate procurement from zones by multiple grid co.
  - Reach agreement on trans-state lines—cost and siting.
- Work starting in Eastern US

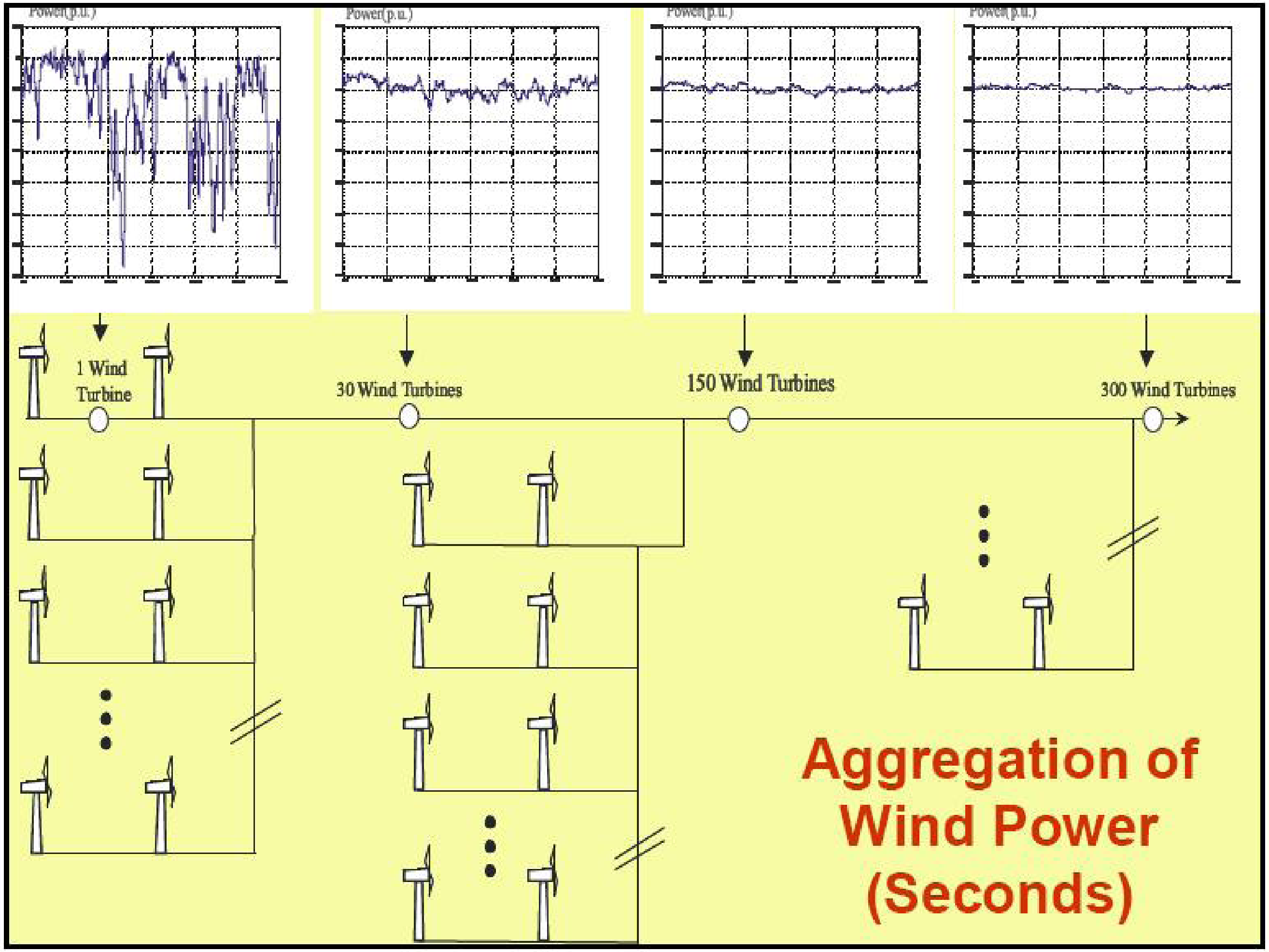
- 北美西部大电网
  - 大型、高质量可再生资源区域地图
  - 各区域资源供应曲线
  - 用模型估算将各区资源运送到负荷中心的费用
- 在美国西部接下来的步骤
  - 确定公共事业公司喜欢的区域
  - 协调多个公共事业公司在各区域的采购
  - 跨州的输电线的位置确定与成本分配
- 在美国东部启动项目

For More Information

- Eastern Wind Integration and Transmission Study:
  http://www.nrel.gov/ewits
- Western Wind and Solar Integration Study:
  http://www.nrel.gov/wind/systemsintegration/wwsis.html
- Western Interconnection Transmission Planning:
  http://www.wecc.biz/Planning/TransmissionExpansion/RTEP/Pages/default.aspx
- Western Renewable Energy Zones Initiative:
  http://www.westgov.org/index.php?option=com_content&view=article&id=219&Itemid=81

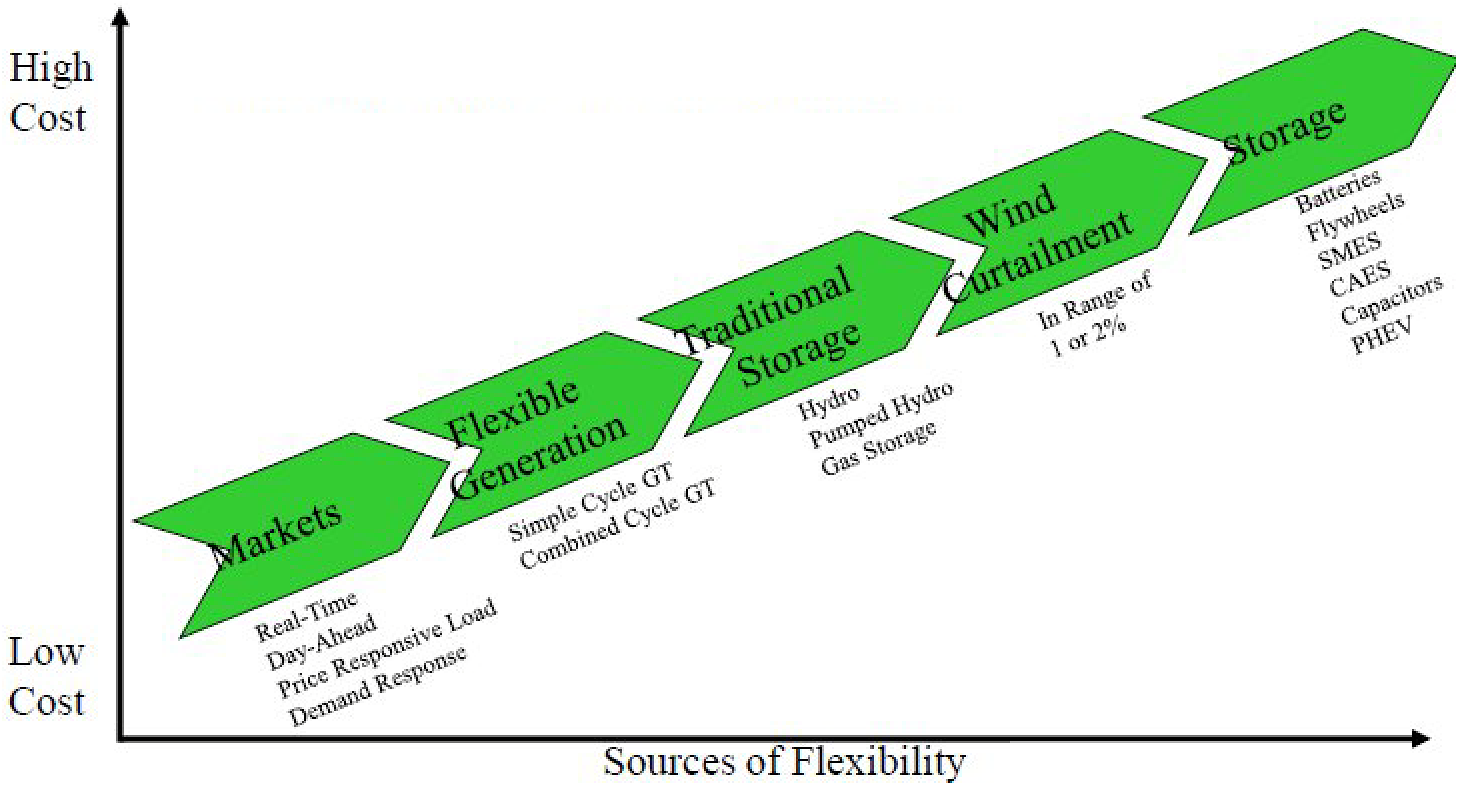
EXTRA SLIDES
附加内容

The Power of Aggregation and Geographic Diversity
集合的力量与地域分布多样性



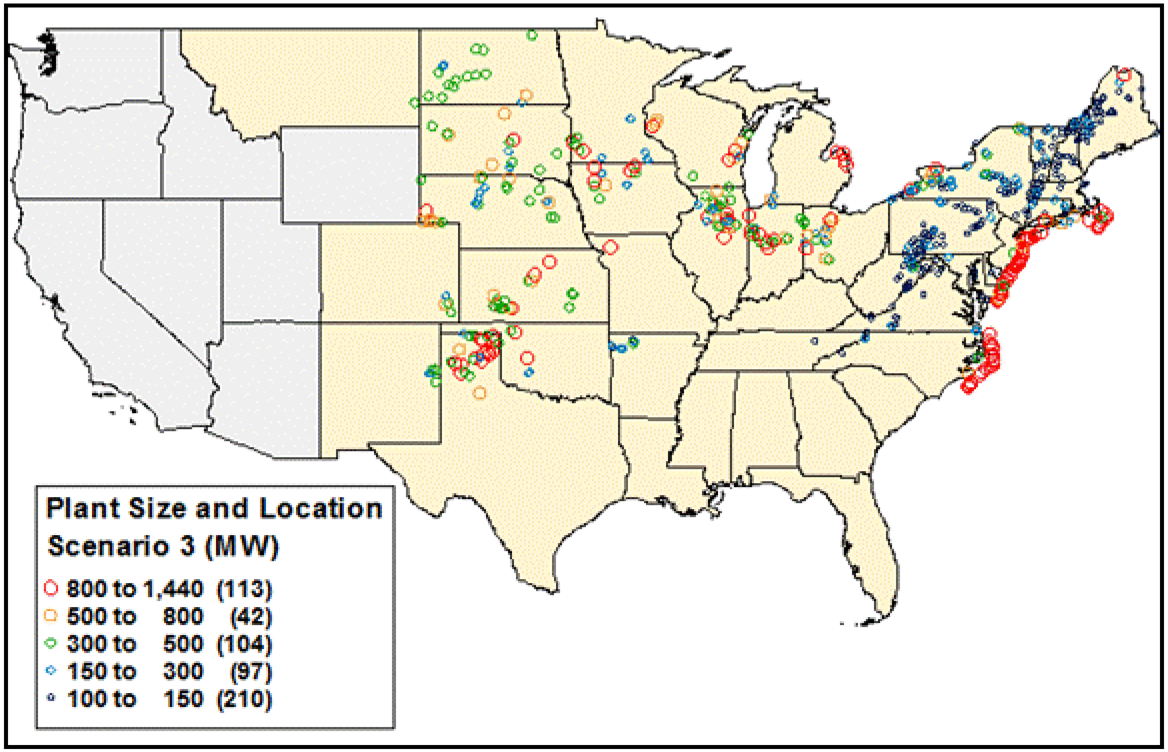
Source: National Renewable Energy Laboratory
来源：美国国家可再生能源实验室

Flexibility Supply Curve
弹性供应曲线

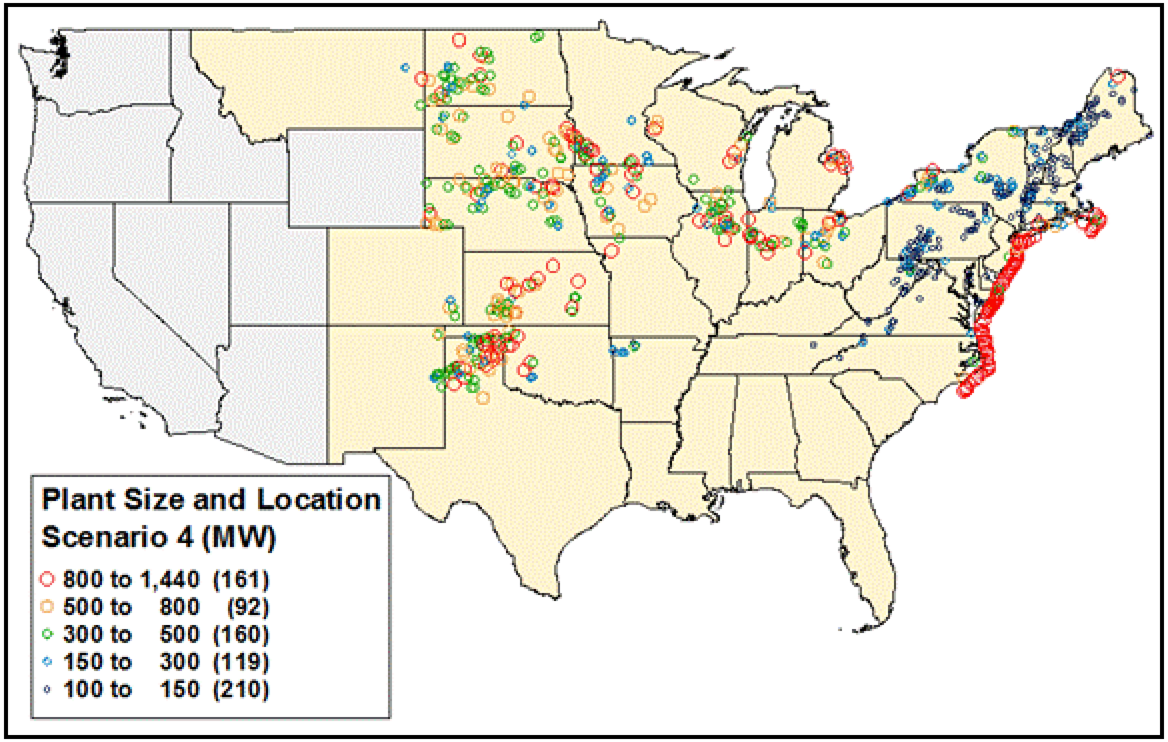


Source: National Renewable Energy Laboratory
来源：美国国家可再生能源实验室

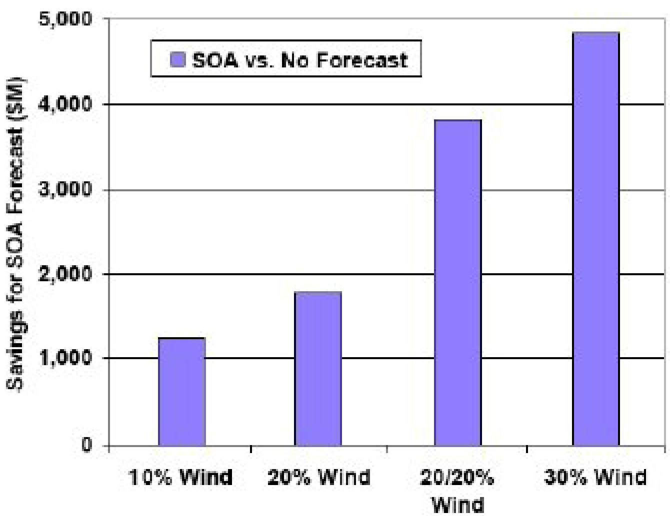
Eastern Scenario 3: Local + More Off-shore Wind
东部情景3：当地+更多离岸风能

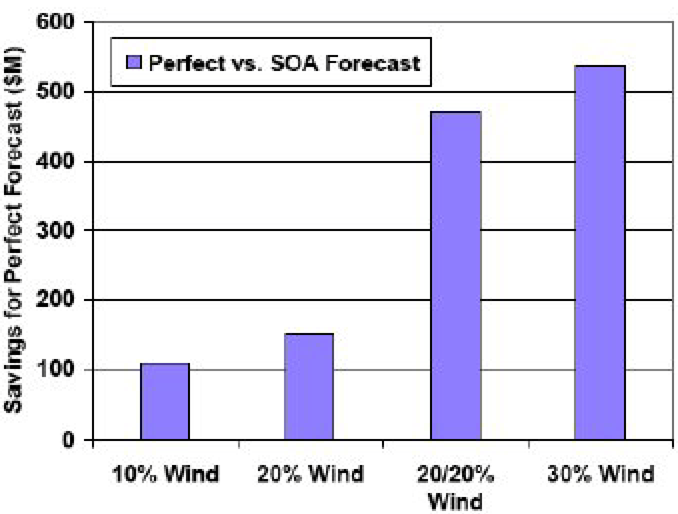


Eastern Scenario 4: 30% Wind, Much Off-shore
东部情景4：30%风能，多数离岸



Western Study: Wind Forecasting Is Important
西部研究：风力预测很重要





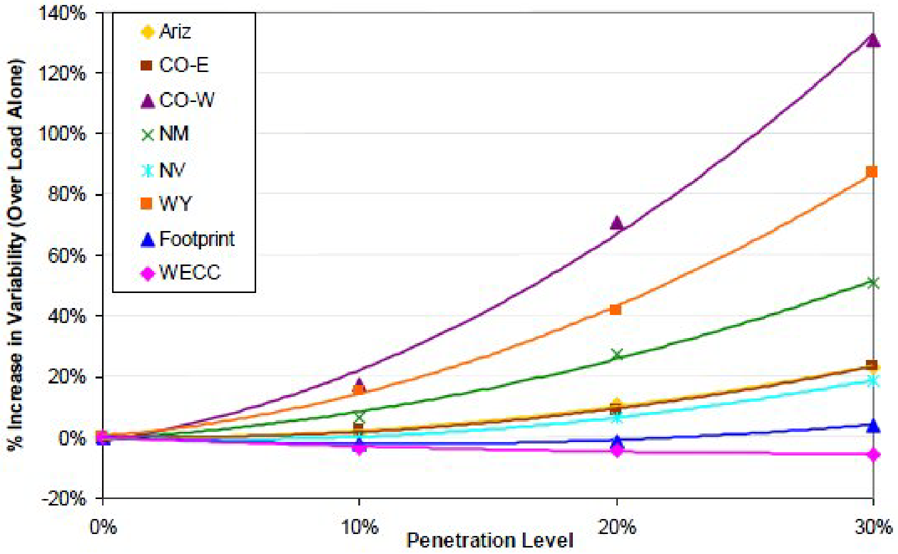
- Using day-ahead wind forecasts for unit commitment saves $12 to $20 per MWh
- Could save another $1 to $2 per MWh if forecasts were perfect

- 为机组组合采用提前一天的风力预测，每兆瓦时节约$12 到$20 。
- 如果预测非常准确的话，每兆瓦时可以再节约$1到$2。

Note: SOA = State-of-art wind forecast

注意： SOA = 最新技术风力预测

Large Balancing Areas Minimize Variability
大平衡区最小化不稳定性



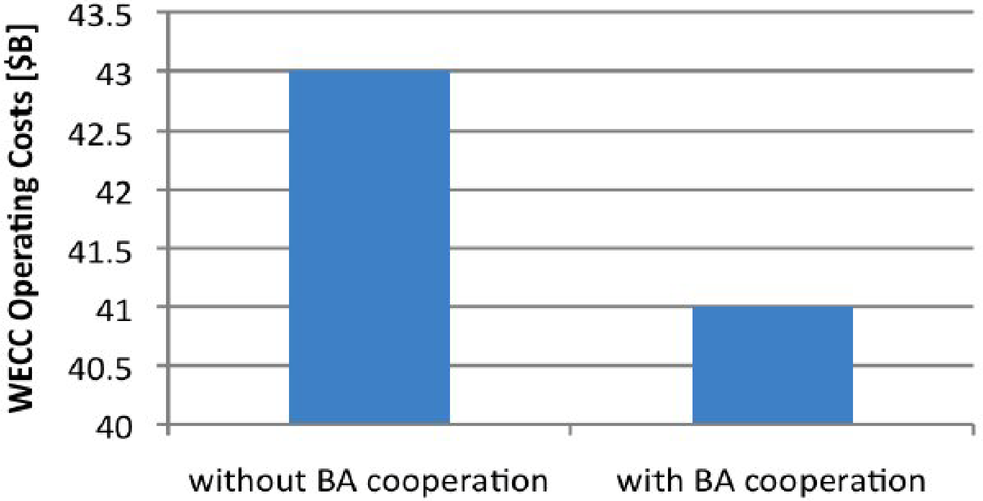
- Net load variability increases with increasing penetration of wind.
- Geographic diversity mitigates this increase.

Note: WECC = Western Interconnection;
Footprint = Five WestConnect states

- 净负荷不稳定性随着风能渗透率的增加而增加。
- 地域分布多样性可以缓和这种不稳定性的增加。

注意： WECC = 北美西部大电网
Footprint=西部电网五个州

Consolidating Reserves Could Save $2B/yr
整合储备可以节约$20亿/每年

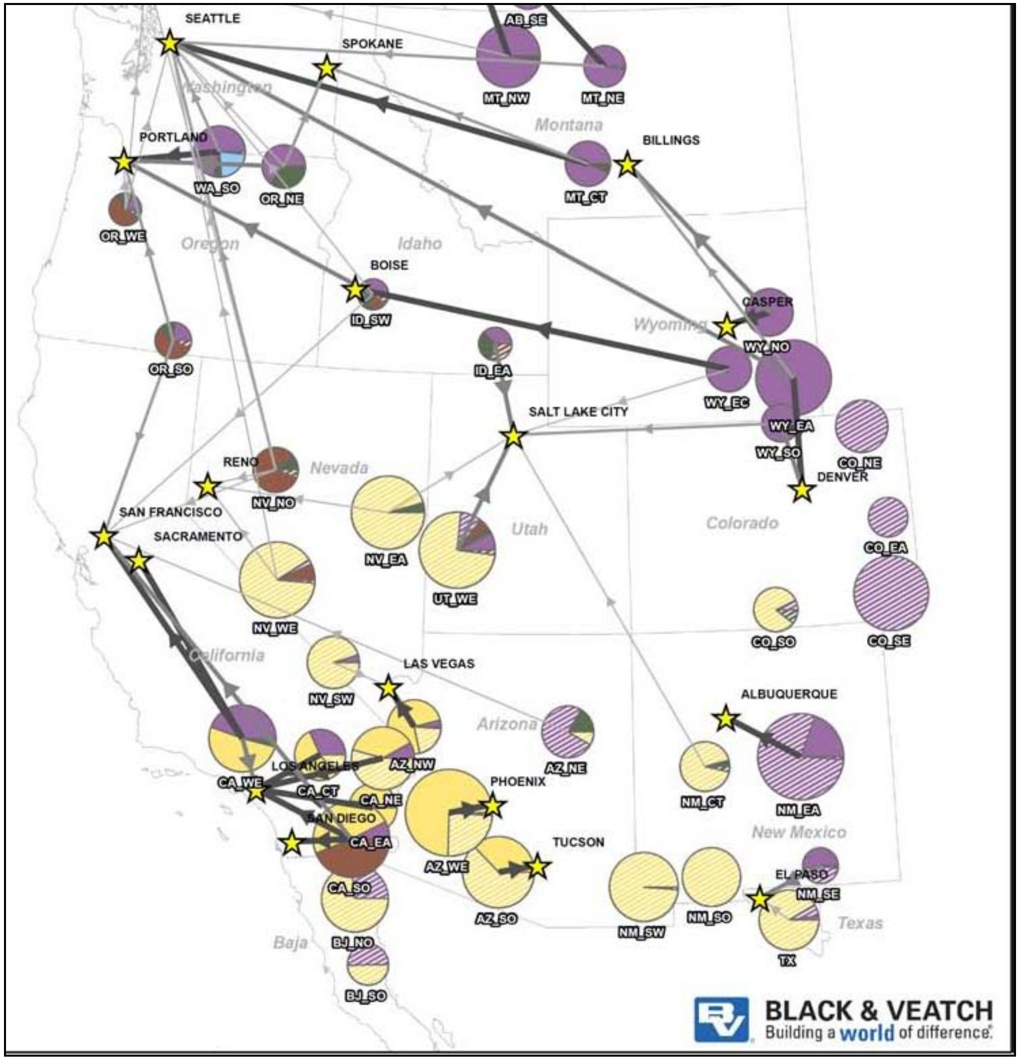


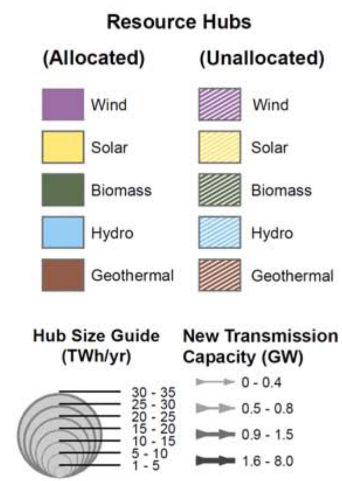
- Shows potential savings in Western Interconnection operating costs in the 10% case (10% wind/1% solar) by consolidating the number of balancing areas from 106 (left) to 5 (right)
- Savings estimated at about $2 billion per year

- 通过将平衡区从106个（左边）联合为5个（右边），展示了北美西部大电网10%案例（10%风1%太阳能）运营成本的潜在节约。
- 估计大约每年可节约$ 20亿。

Transmission and Least-Cost Resources in Western Renewable Energy Zones to Meet a Potential 33% Renewables Target in 2029

为达到2029年潜在33%可再生能源目标，西部可再生能源区域的输电与最低成本资源





Circle size indicates total resource potential; solid portion indicates amount procured. Map by Black & Veatch, based on modeling by USDOE Lawrence Berkeley National Laboratory.
圆圈大小表示总的资源潜能；阴影部分表示采购的数量。本图由博莱克威奇公司根据美国能源部劳伦斯伯克力国家实验室的相关模型提供。

Lisa Schwartz
Senior Associate
541-967-3077
lschwartz@raponline.org

RAP is committed to fostering regulatory policies for the electric industry that encourage economic efficiency, protect environmental quality, assure system reliability, and allocate system benefits fairly to all customers.
RAP致力于在电力行业中发展和促进可以鼓励经济效率、保护环境质量、确保系统可靠性以及让所有用户公平地享有系统效益的监管政策。