Challenges and Opportunities in the Large Scale Integration of Renewable Energy into the Electric Grid

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BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science

U.S. DEPARTMENT OF ENERGY

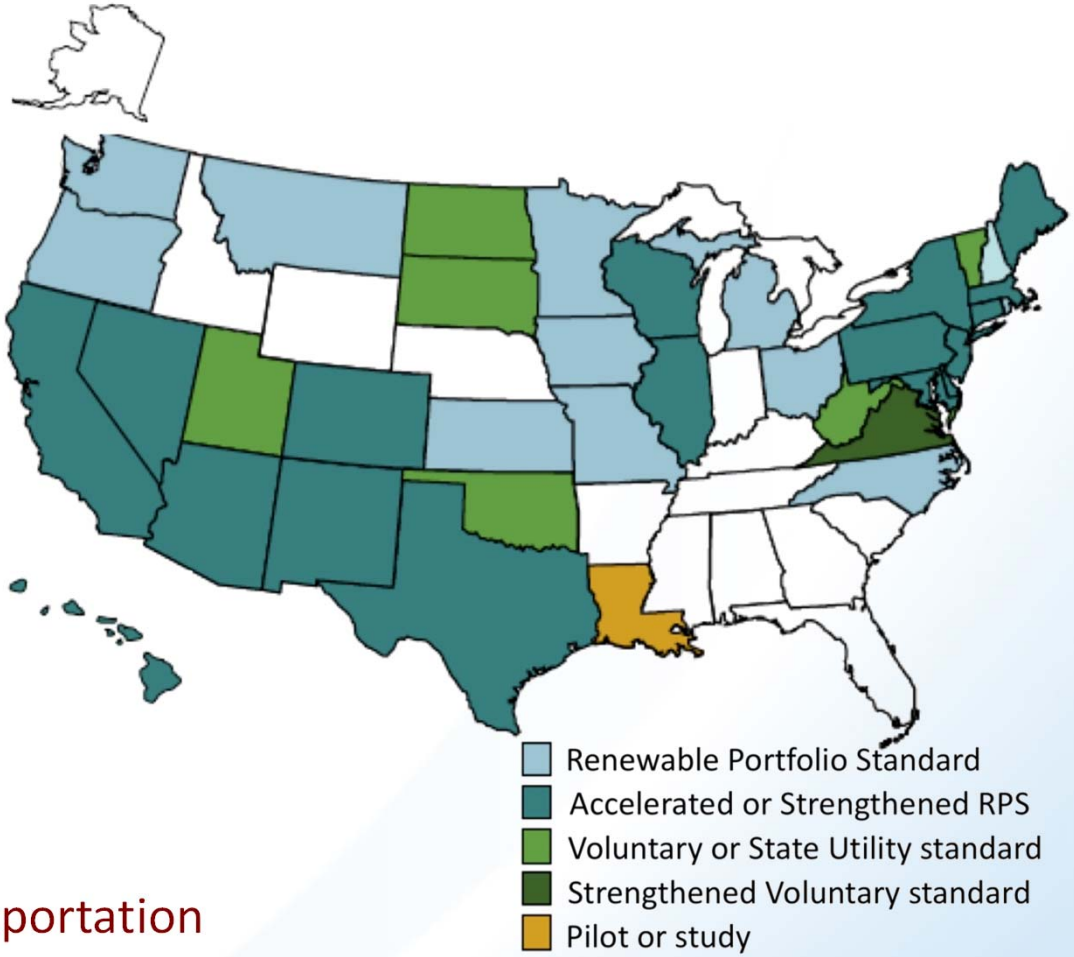
Renewable Portfolio Standards

30 states and DC have RPS

typically 20% renewable power by 2020 or 2030

most aggressive:
CA - 33% by 2020

NY – 30% by 2015, 80% by 2050



http://www.ferc.gov/market-oversight/othr-mkts/renew/othr-rnw-eeps.pdf

Drivers for RPS

reduced carbon emission

encourage alternative energy

prepare for electrification of transportation

replace foreign oil with renewable electricity

jobs and economic growth

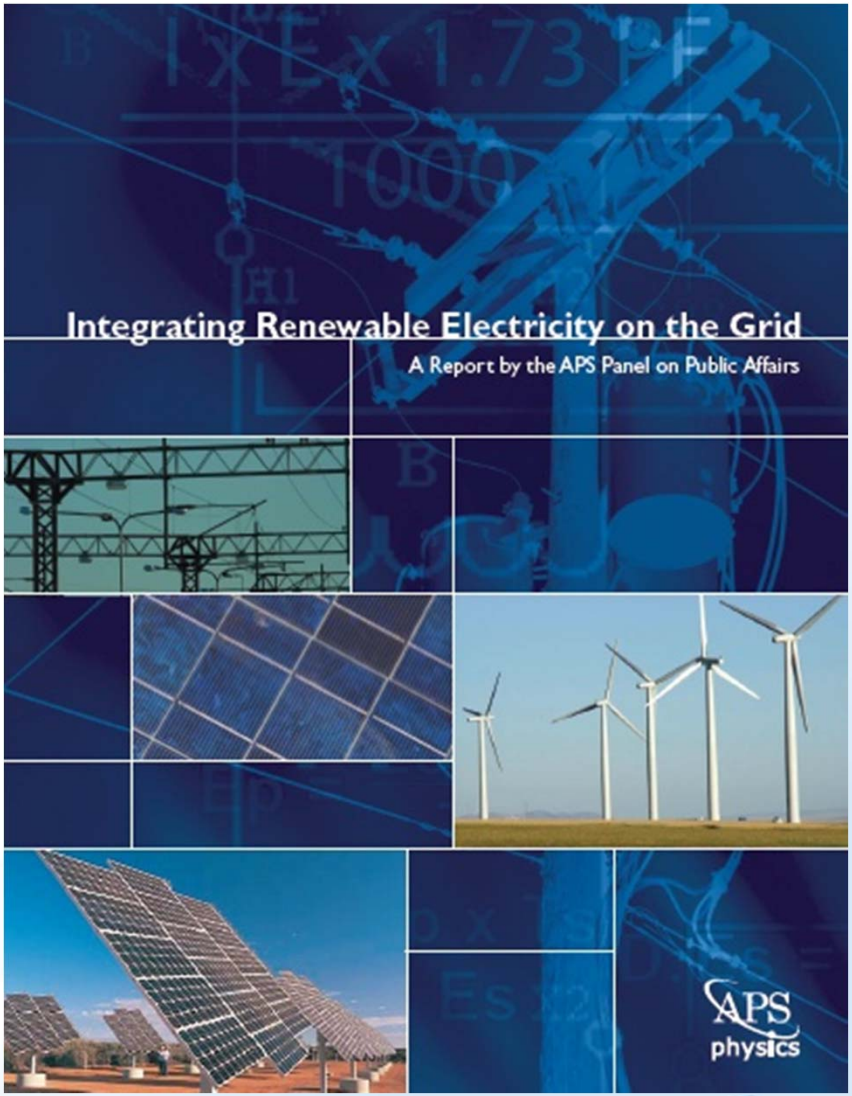
American Physical Society
Panel on Public Affairs (POPA)

Co-chairs:

George Crabtree (ANL) and Jim Misewich (BNL)

Committee:

Ron Ambrosio (IBM), Kathryn Clay (Auto Alliance), Paul DeMartini (Southern California Edison), Revis James (EPRI), Mark Lauby (NERC), Vivek Mohta (MA Dept of Energy Resources), John Moura (FERC), Peter Sauer (UIUC), Humayun Tai (McKinsey), Kris Larsen (APS), Jodi Lieberman (APS), Francis Slakey (APS)



Abundant Wind and Solar Resources

Concentrating Solar Power – Direct Sun

State	Available Area	Resource Potential
	(mi²)	(GW)
Arizona	19,300	2,468
California	6,900	877
Colorado	2,100	272
Nevada	5,600	715
New Mexico	15,200	1,940
Texas	1,200	149
Utah	3,600	456
Total	**53,900**	**6,877**

Mehos and Kearney (2007)

PV Solar Resource – Indirect Sun

Roof area ~ 6B m^2 ~ 600 GW

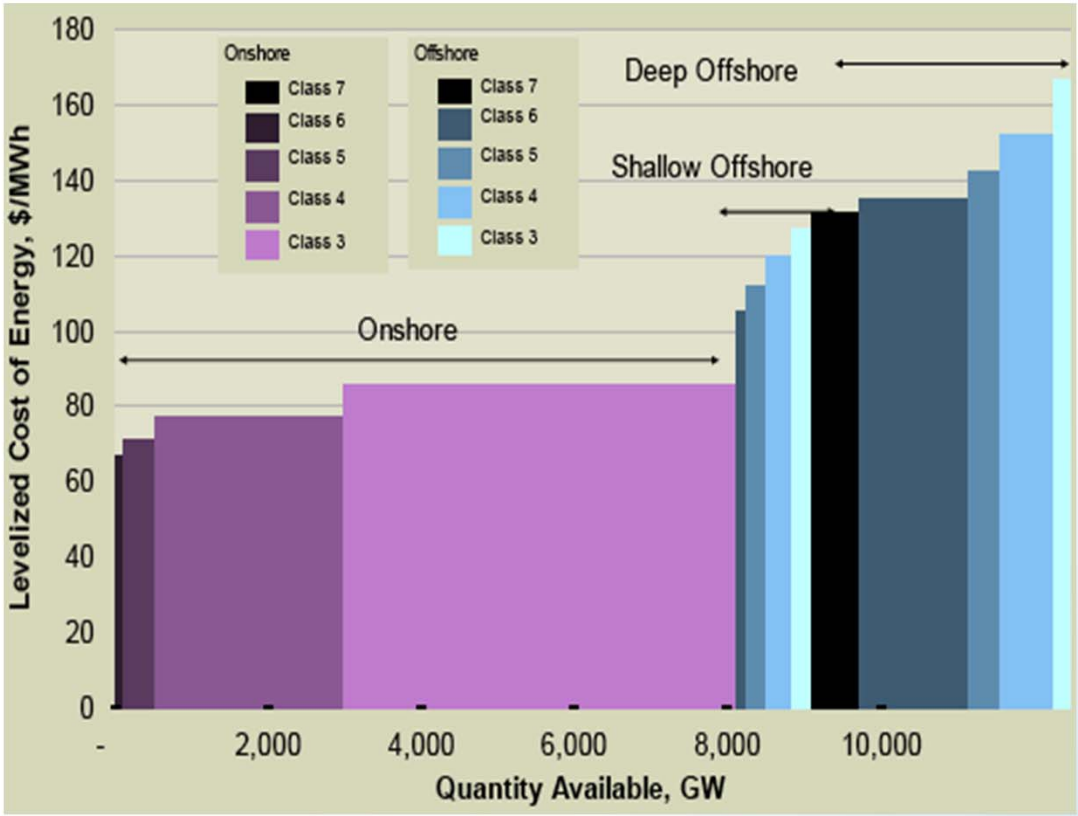
Urban footprint ~ 3% of land ~ 2300 GW

Solar Technologies Market Report EERE (2008)

2009 electricity use ~ 450 GW (ave)
~ 1000 GW (peak)

2030 projection ~ 660 GW (ave)

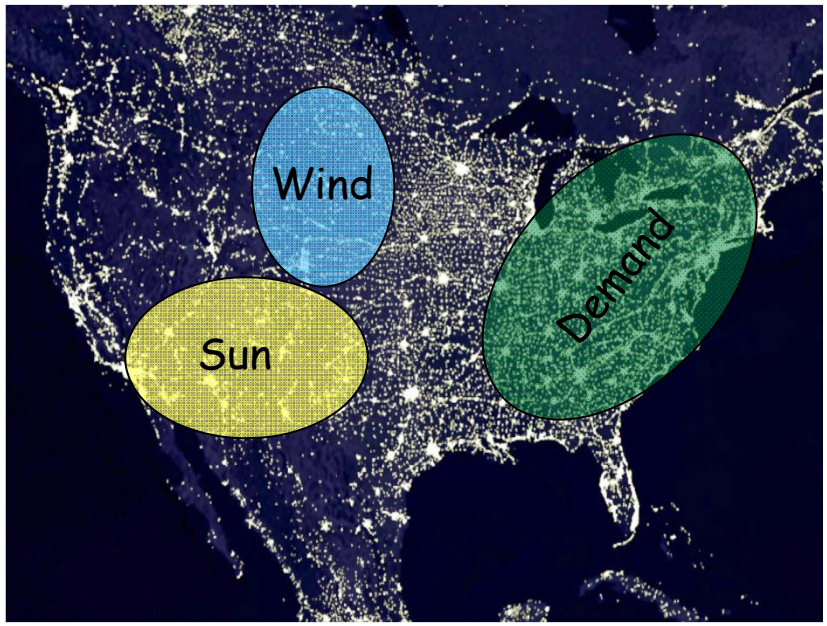
Wind Resource

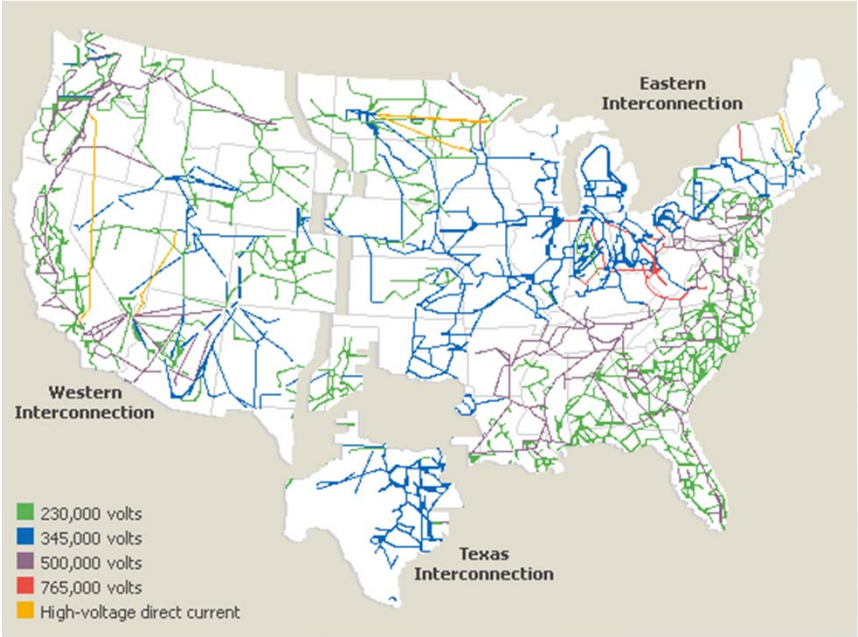


Black and Veatch (2007)

wind and solar resources far exceed RPS

Transmission





Fragmented US transmission network

Geographical separation of renewable sources from demand centers

Balkanized transmission network designed for local or regional use

Historically low investment in transmission

Need an interstate highway system for electricity

Existing Challenges for the Grid

Congestion

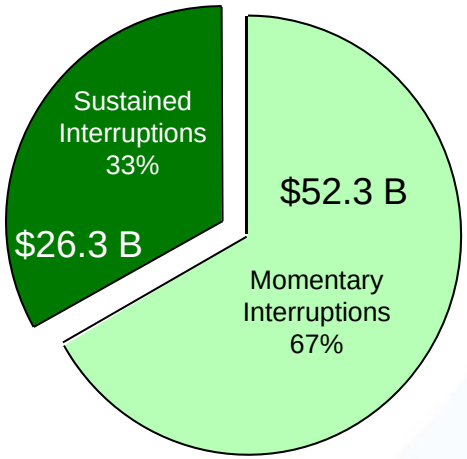
growing electricity uses growing cities and suburbs
high people / power density
urban power bottleneck

2030
50% demand growth (US)
100% demand growth (world)

Reliability
Power Quality

Average Power Loss/Customer (min/yr)

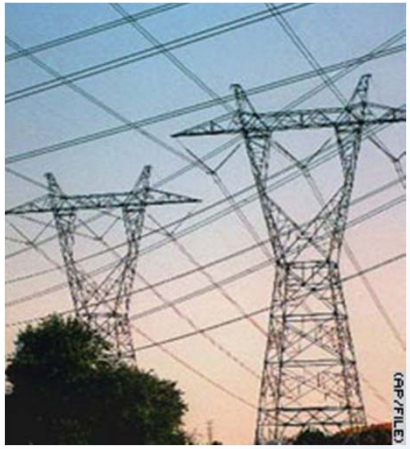
US	214
France	53
Japan	6



$79 B economic loss (US)

LaCommare & Eto, Energy 31, 1845 (2006)

Efficiency



62% energy lost in production / delivery

8-10% lost in grid

40 GW lost (US)
~ 40 power plants

2030: 60 GW lost
340 Mtons CO_2

THE WALL STREET JOURNAL.
WSJ.com

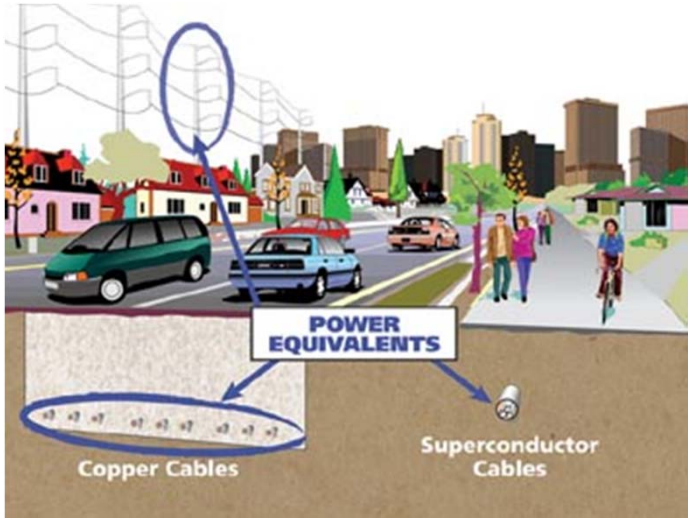
ASIA TECHNOLOGY | DECEMBER 9, 2010, 11:15 A.M. ET

Brief Power Outage Threatens Toshiba Chip Shipments

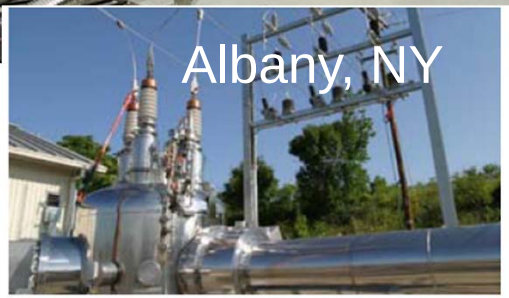
0.07 second outage ➔ 20% chip reduction for 2 months

Superconducting Materials for the Grid

TRANSMISSION: NY State testing



LIPA commissioned the first high temperature superconducting power transmission cable (138 kV) system on June 25, 2008 at Holbrook site, Long Island, NY, capable of carrying 574 megawatts of power.



Superconducting Cables

- Increasing the efficiency and capacity of the grid

Long Island Power Authority

- Longest cable live on the grid

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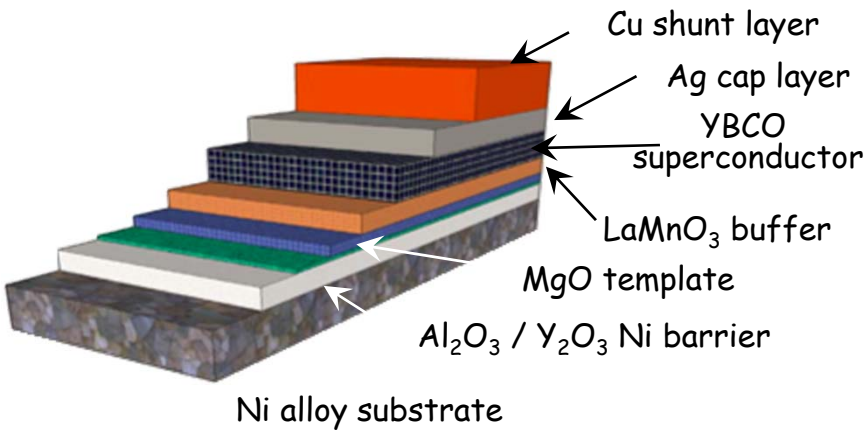
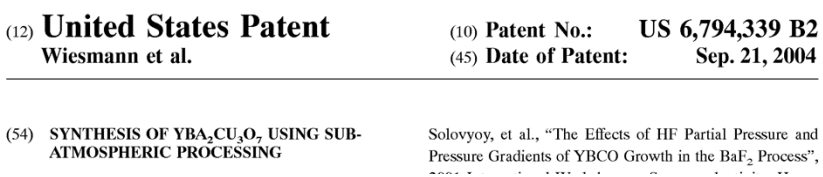
SuperPower Inc.

Gen 2 Superconducting Cables

Gen 2 Wires: Functional Multilayers




(12) **United States Patent**
Wiesmann et al.

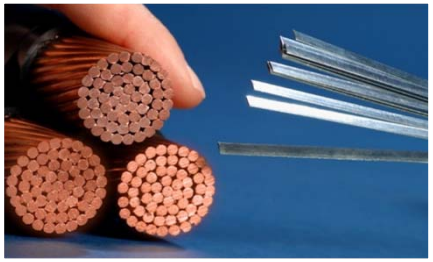
(10) Patent No.: US 6,794,339 B2
(45) Date of Patent: Sep. 21, 2004

(54) SYNTHESIS OF $YBA_2CU_3O_7$ USING SUB-ATMOSPHERIC PROCESSING

Solovyoy, et al., "The Effects of HF Partial Pressure and Pressure Gradients of YBCO Growth in the BaF_2 Process",

Transmission

- 3 million meter order



Cu, HTS
1000A equivalents

Distribution

HTS Triax cable

- Project HYDRA
- ~300 m cable, 13.8 kV, 4 kA (96 MVA)
- Critical ConEd need: limit fault currents
- Strengthen grid by linking substations

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SuperPower Inc.

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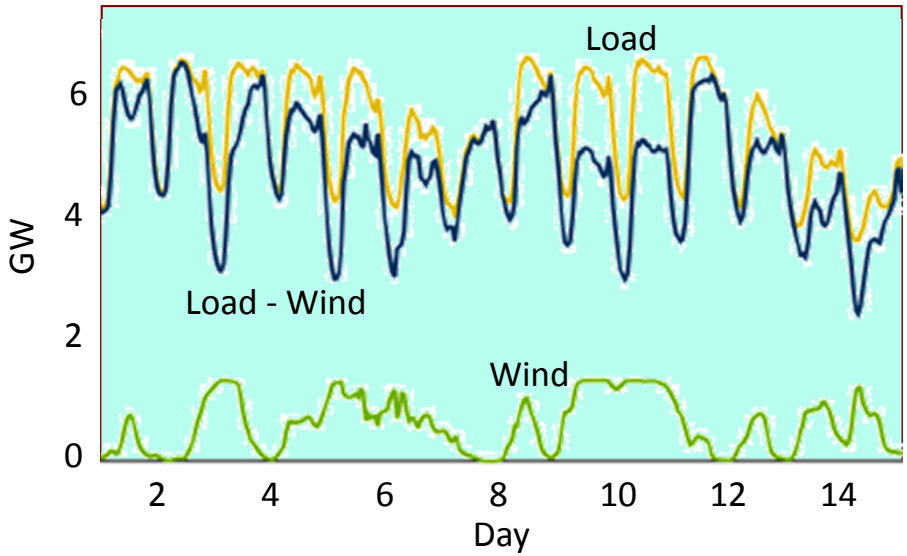
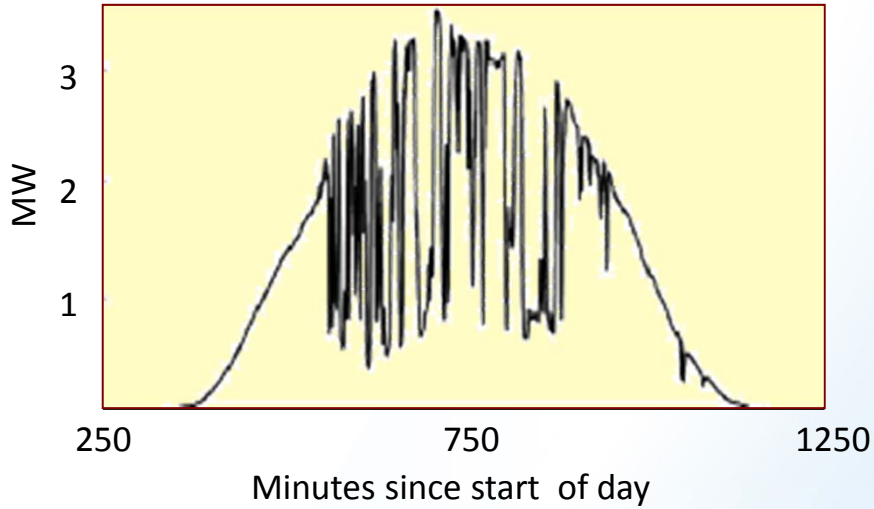
Variability

Xcel Wind Farm, Minnesota
1.5 GW Wind in 10 GW Peak System



Solar PV



Wind variability: up to 100% of capacity on calm days

Load variability: 30% - 50% of peak predictable to a few percent

Solar variability: up to 70% of capacity due to clouds

Generation variability < load variability: compensate ~ with existing reserves

Generation variability > load variability: reserves ~ renewable capacity

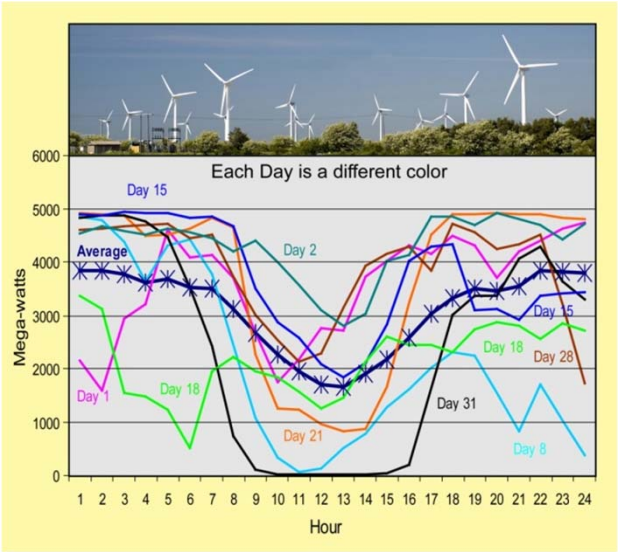
Penetration beyond load variation requires high reserves

Accurate weather forecasts are critical

20% Wind Energy by 2030, Energy Efficiency and Renewable Energy, DOE/GO-102008-2567 (2008)

Johan Enslin, Quantum Technology, *Grid Impacts and Solutions of Renewables at High Penetration Levels*, APS Grid Study (2009)

Large-scale energy storage is critical for renewable penetration and grid stability and reliability

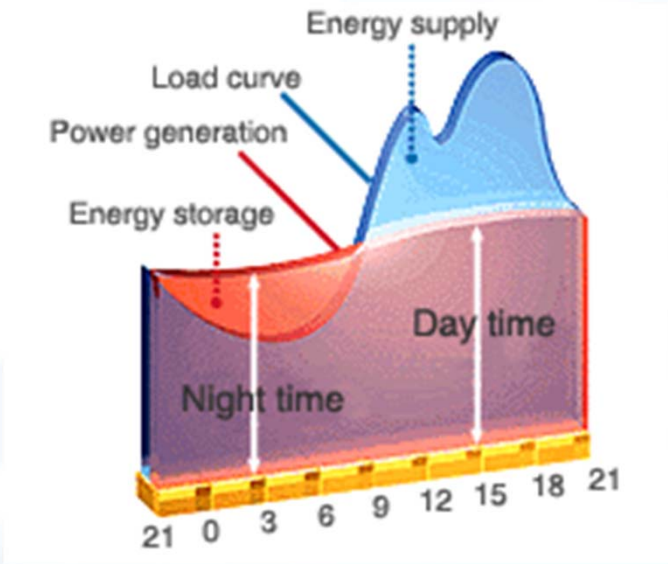


Drivers for Large Scale Energy Storage

- Renewable Generation
- Grid Reliability Management
- Power quality
- Load leveling, shifting

Size of the challenge – How much storage is needed?

- Over 200GWh of balancing resource (e.g. storage) needed to meet DOE 20% Wind by 2030 goal (20% of wind output)
- 15,000 PHEV batteries required to shift 4 hours of wind from one 100MW project



Energy Storage Options

Okinawa Seawater Pumped Storage

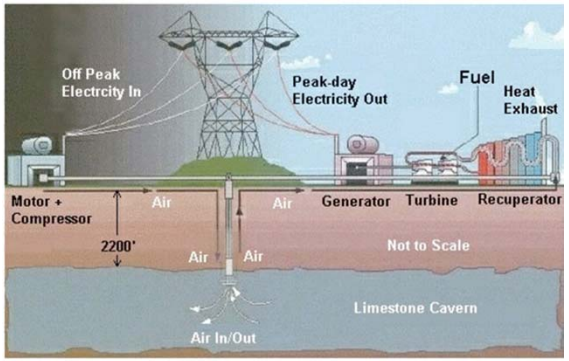


Photo Courtesy of CAES Development Company

Compressed Air Energy Storage

Huntorf Germany (290 MW), McIntosh Alabama (110 MW)

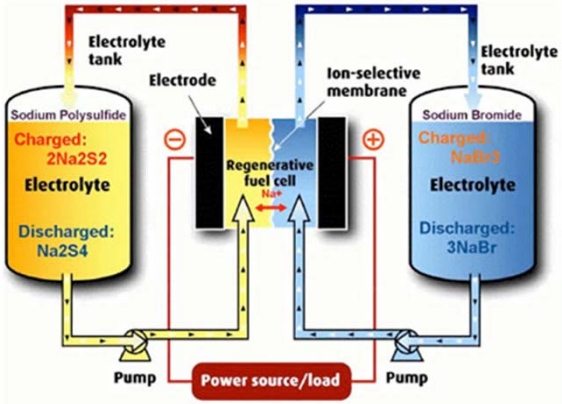
Sodium Sulfur batteries at Wind Farm

Xcel Energy, Luverne, MN

Molten salt thermal storage

Andasol, Spain

http://www.scientificamerican.com/article.cfm?id=how-to-use-solar-energy-at-night



Flow batteries

Conventional batteries: Lead acid

Southern California Edison Chino facility

(10 MW, 4 hr)

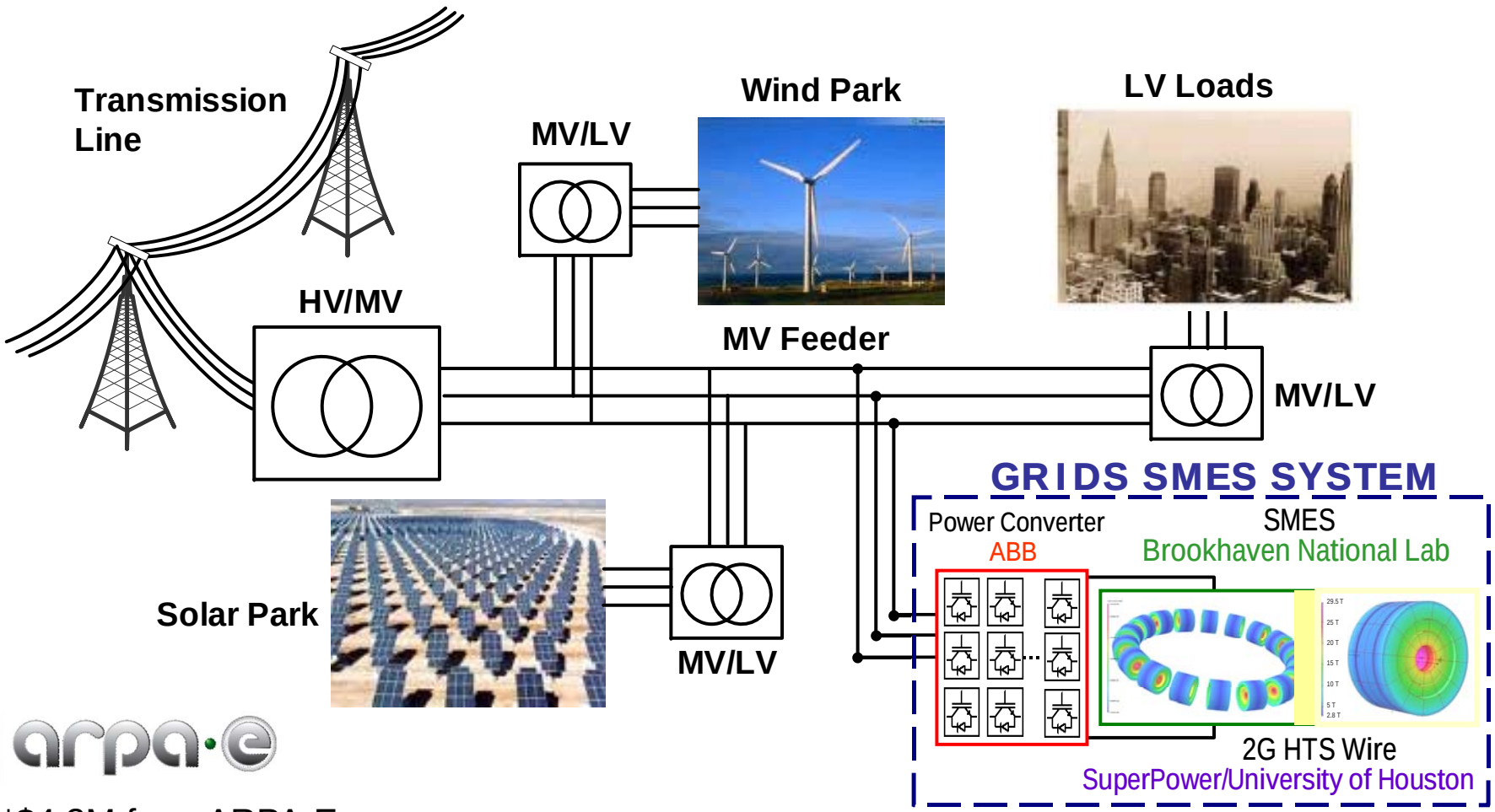
develop an overall strategy for storage

options, regulatory guidance, value for generation and transmission

conduct technological review of battery chemistries

increase R&D in basic electrochemistry

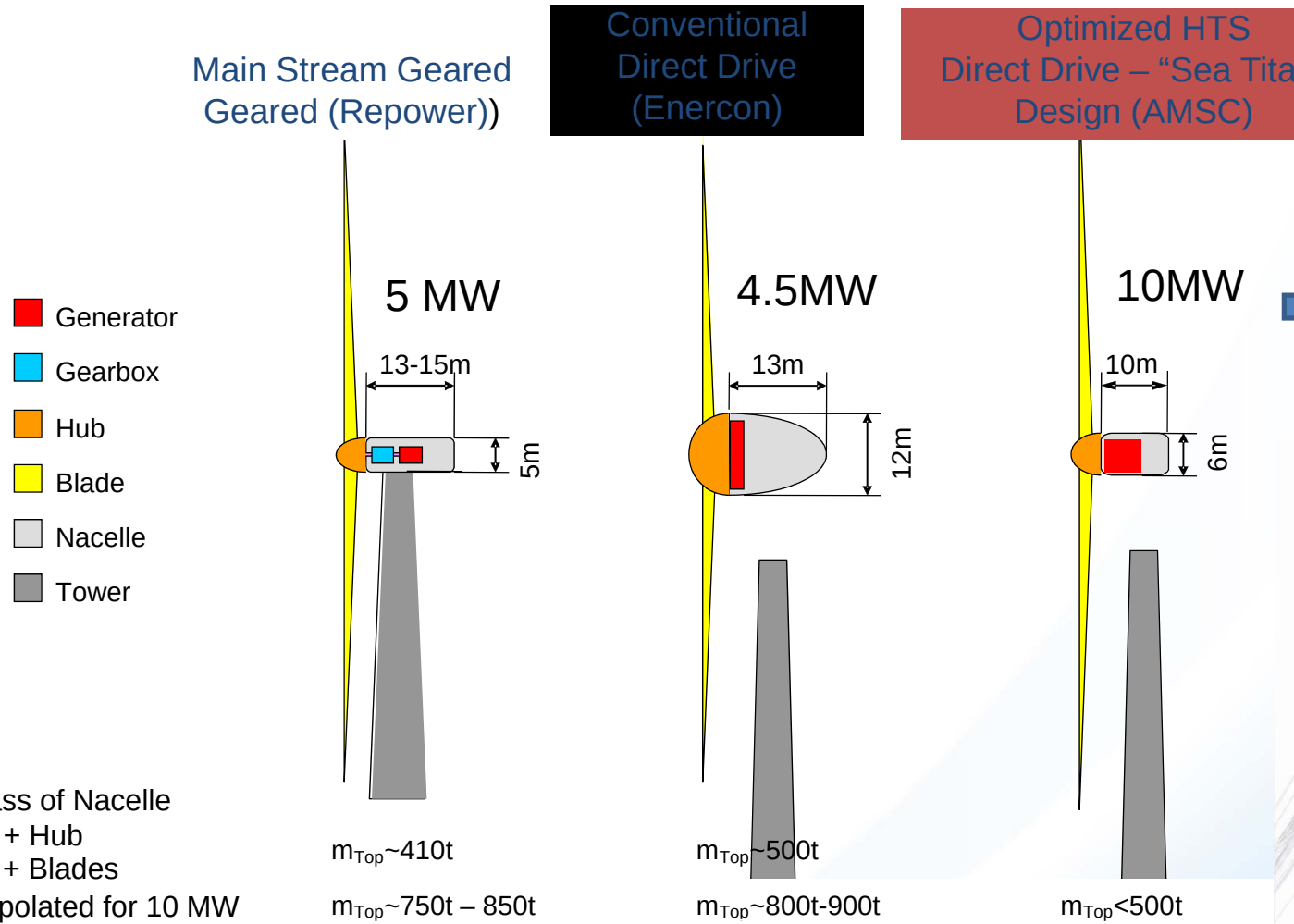
Superconducting Magnet Energy Storage (SMES) System with Direct Power Electronics Interface for GRIDS ($5.3M)*



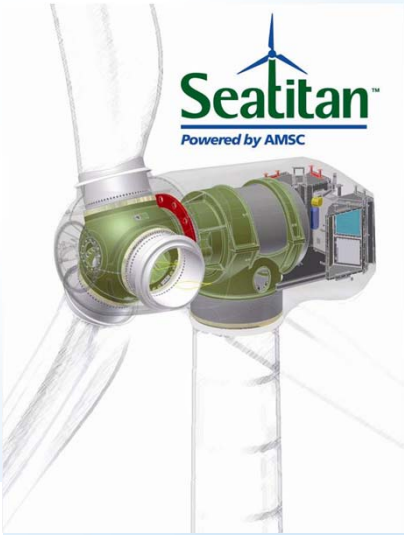
*$4.2M from ARPA-E

Team: ABB (V.R. Ramanan), Brookhaven Lab (Q. Li), SuperPower/U of Houston (D.Hazelton)

Comparison of Off-Shore Wind Turbines



Possible to go as large as 20MW with HTS



Power density of HTS generators allows for 10MW in a 5MW top head weight

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Summary

- Renewable Generation Integration Challenges:
  - Location of resources
  - Variability
  - Efficiency
- Existing Grid Challenges
  - Congestion
  - Reliability
  - Efficiency
- *Superconducting materials have enormous potential to mitigate these challenges*
  - *Progress in critical properties essential*