

Exceptional service in the national interest



Future Electric Power Grid Evolution and Resiliency

Abraham Ellis

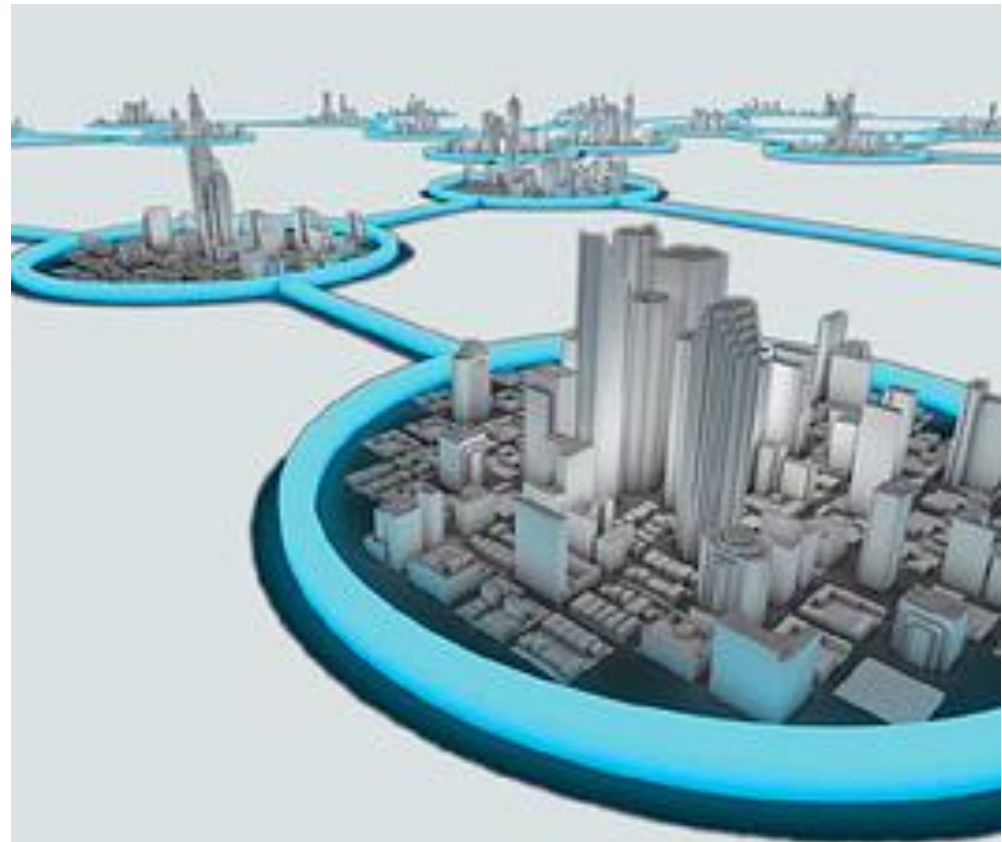
May 2013



Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

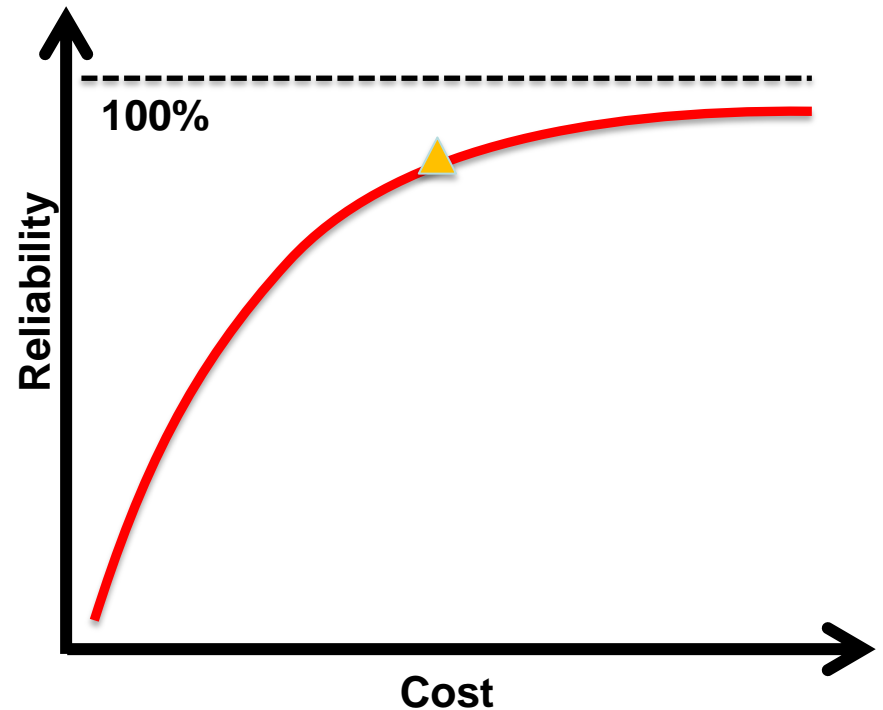
Topics

- Reliability and metrics
- Natural disasters
- Resiliency
- Future grid architectures
 - Smart Grid
 - Microgrids
 - SuperGrids
- Final thoughts



Reliability

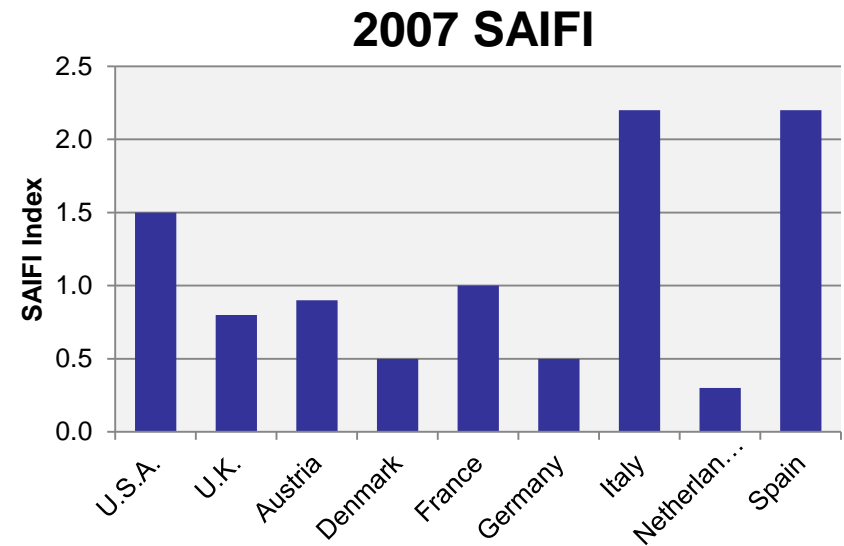
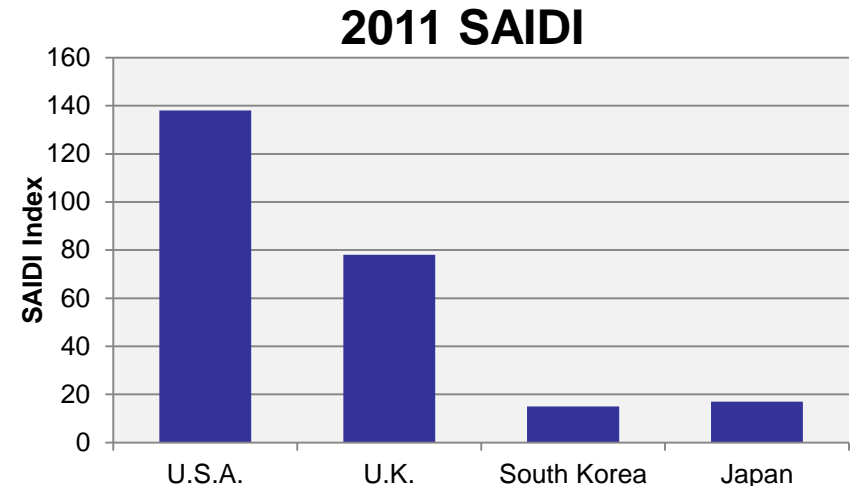
- Power Systems
 - Transmission is a Network
 - Distribution is mostly Radial
- Power System Reliability
 - 1 day in 10 years
 - 120 min in 1 year
 - 99.97% Reliability
- Is 99.97% good enough?
- How is this calculated?
- Do we really need and can we afford another “9” of reliability?



Reliability

- Reliability Indices
 - System Average Interruption Duration Index (**SAIDI**) – avg. minutes per customer per year that power supply
 - System Average Interruption Frequency Index (**SAIFI**) – avg. number of interruptions per customer per year
- But wait, these indices do not include natural disasters (!!??)

<http://www.fas.org/sgp/crs/misc/R42696.pdf>
http://www.smartgrid.com/wp-content/uploads/2011/09/1-110117_Intl_Biz_Offering_Related_to_ISGT-KEPCO-to-Bruce.pdf



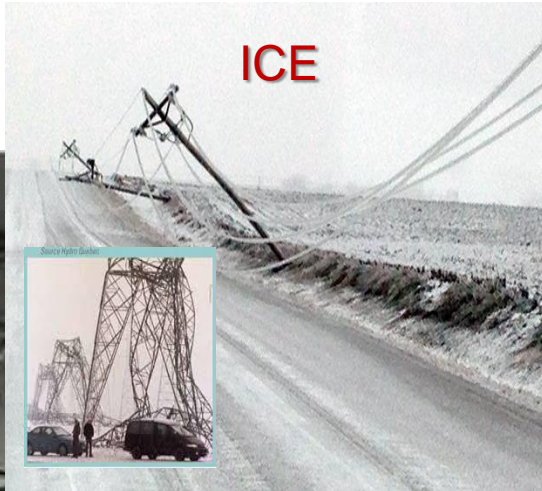
NOTE: Comparison is difficult due to different in calculation method

Grid Exposure to Natural Disasters

FLOODS



ICE



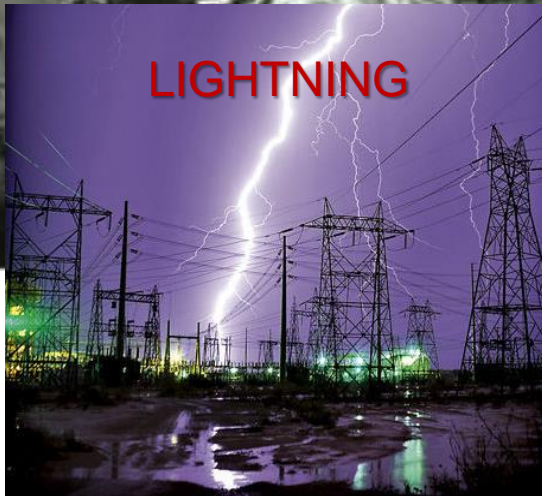
FIRE



WIND



LIGHTNING



EARTHQUAKE

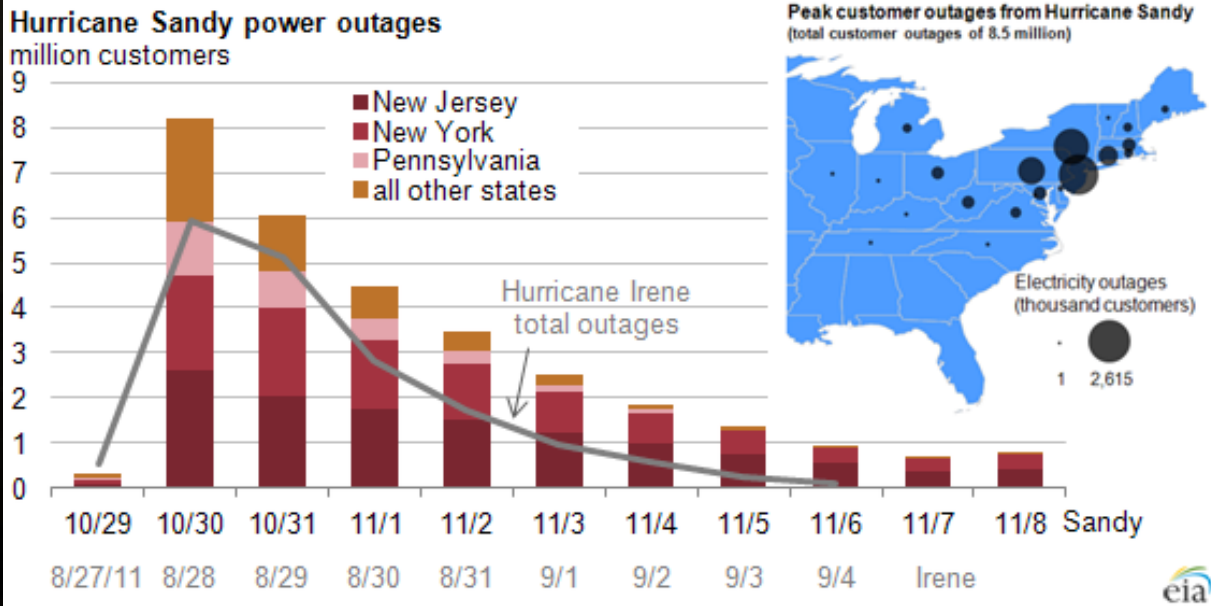
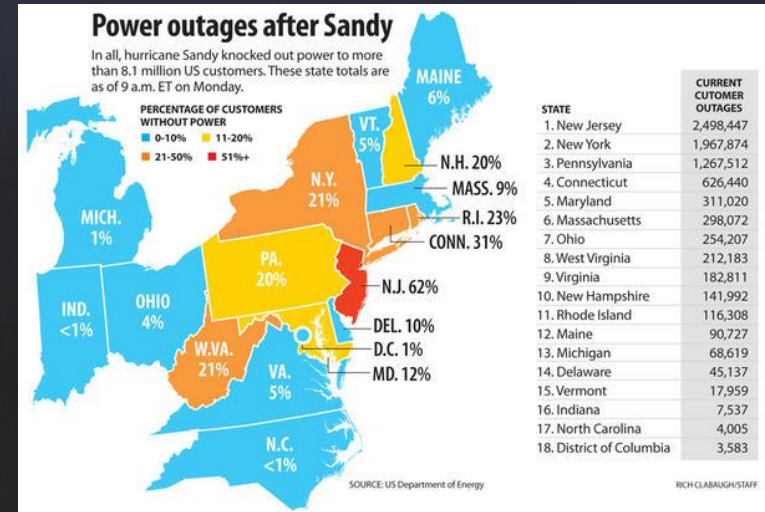


Hurricane Sandy



Hurricane Sandy

- Largest disruption in history (EEI)
 - 24 states affected
 - 110 deaths (U.S.)
 - \$63 billion in cost
 - 8.7 million affected by power outage
- Could we have done better?



Natural Disasters & Cost Raising...

- High-consequence natural disasters are more frequent
- Avg. \$1B events by decade:
 - 80-89: 2.0 events/year
 - 90-99: 4.7 events/year
 - 00-09: 4.8 events/year

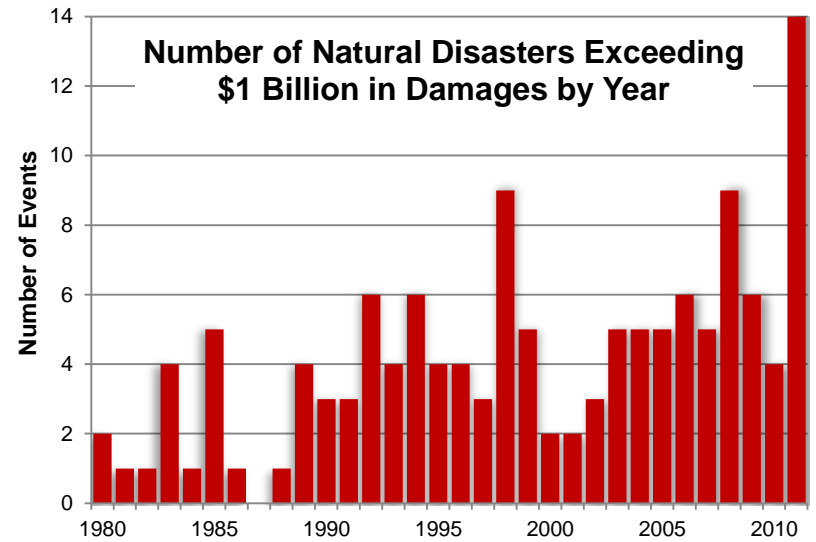
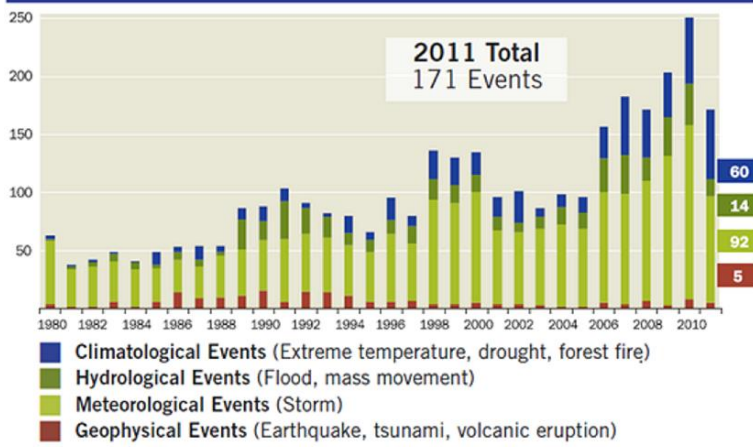
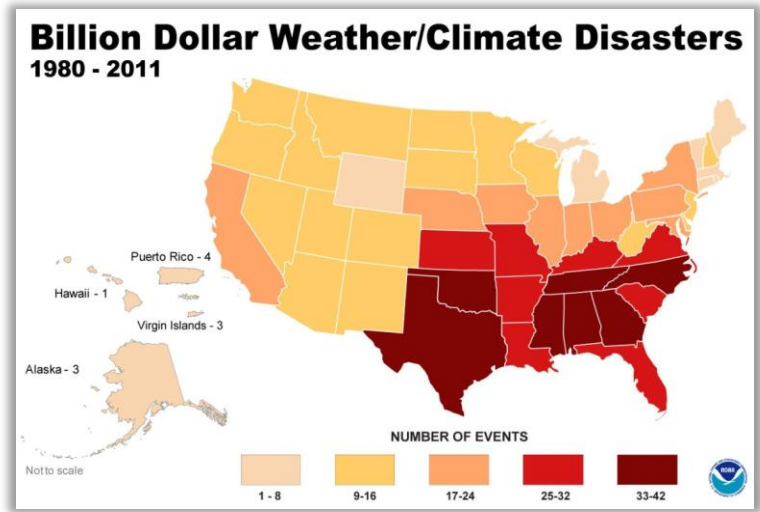


Figure 5: Natural Disasters in the United States, 1980 - 2011, Number of Events, Annual Totals

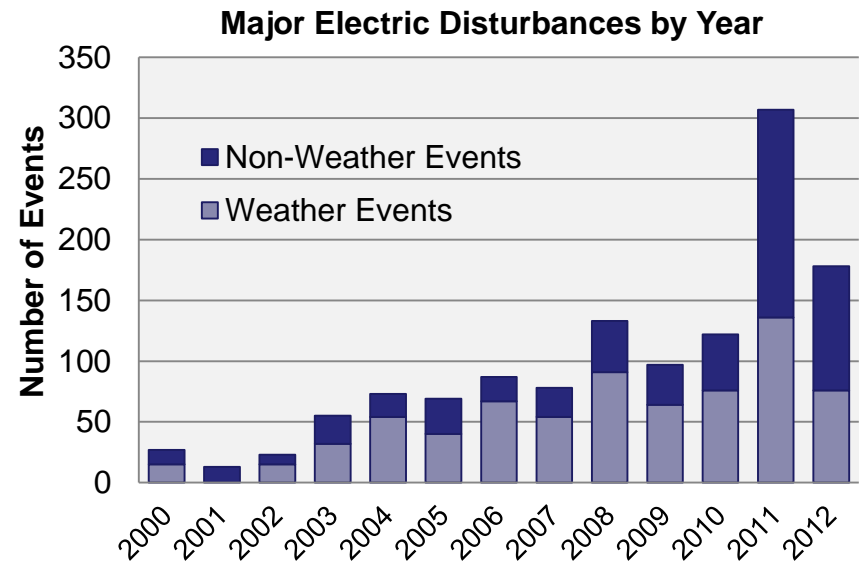


Source: Munich Re, "2011 Natural Catastrophe Year in Review," January 4, 2012.



Power Outages & Cost also Raising...

- Electricity interruptions cost Americans ~\$150B/yr
- For every \$1.00 spent on electricity, we spend at least another \$0.50 to cover the cost of power failures.



Industry	Average Cost of 1-Hour Interruption
Cellular communications	\$41,000
Telephone ticket sales	\$72,000
Airline reservation system	\$90,000
Semiconductor manufacturer	\$2,000,000
Credit card operation	\$2,580,000
Brokerage operation	\$6,480,000

Need a better way to measure grid “Reliability”

<http://galvinpower.org/resources/library/fact-sheets-faqs/electric-power-system-unreliable>

Reliability → Resiliency

- The concept of Reliability and associated metrics are becoming inadequate.
- New concept: Resiliency
 - Encompass reliability
 - Include natural and manufactured threats
 - Include consequences of grid disruption
 - Inform operations in real time
 - Provide guidance for investment decisions

Resilient Grid

A grid that is planned and operated to minimize risk and consequences power outages, by anticipating, adapting, and optimally recovering from failure caused by natural or manufactured threats

$$R = \int_{t=0 \rightarrow r} (T - M) C dt$$

R = Risk

T = Threat

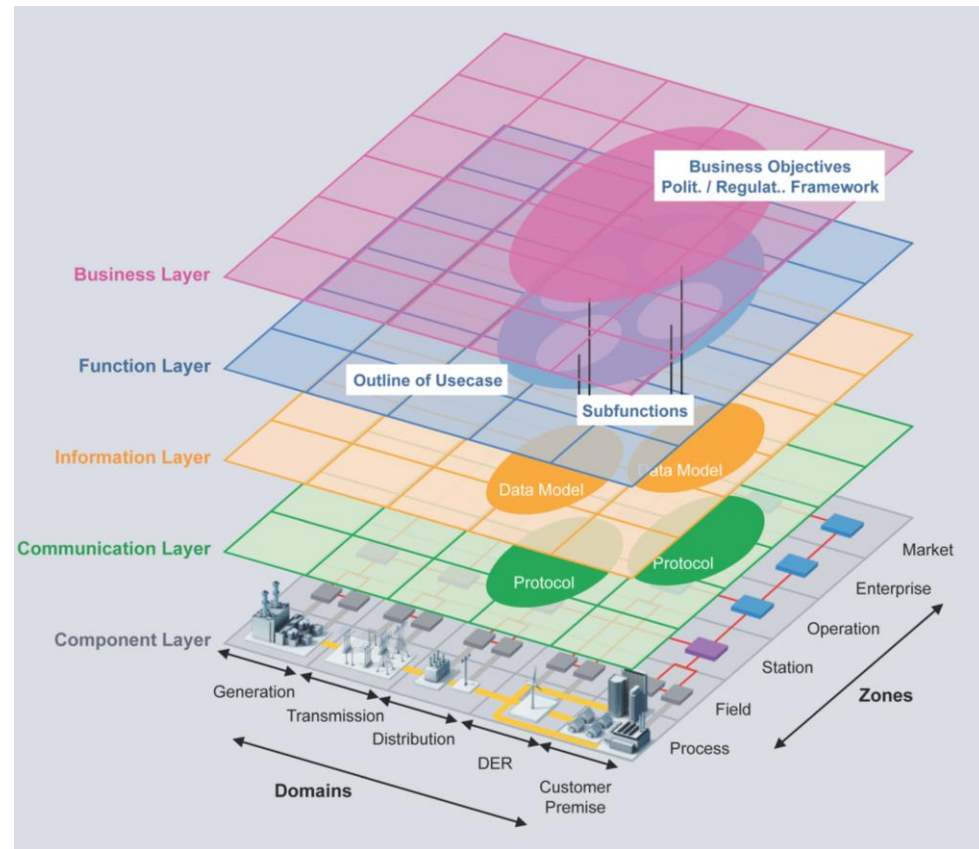
M = Mitigation

C = Consequences

r = recovery time

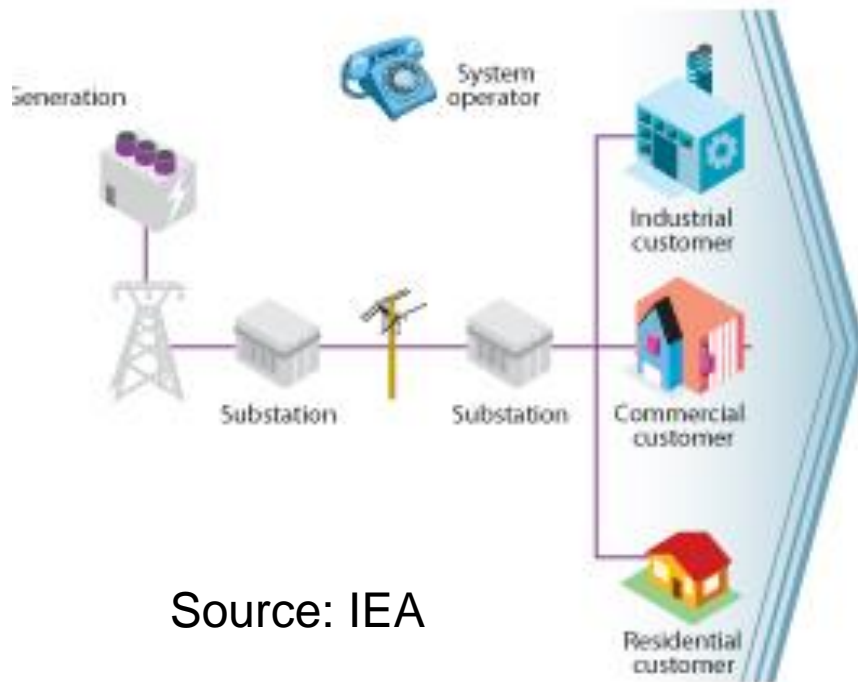
How Will the Grid Evolve?

- The existing grid is very large and complex
- Evolutionary change along several dimensions
- Different visions for revolutionary change

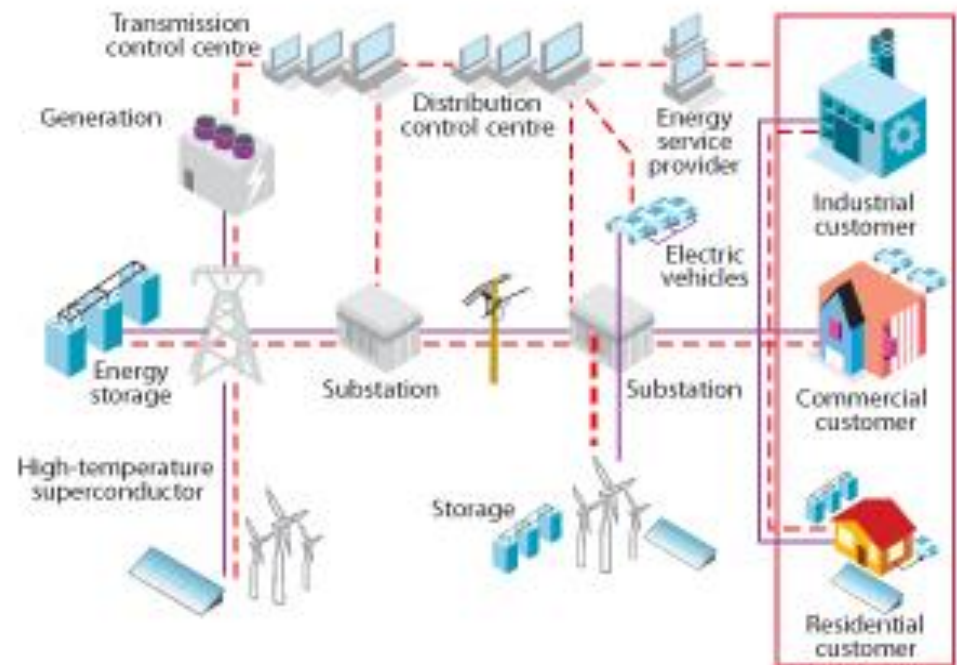


Revolutionary: Smart Grid

- Significant changes in all grid layers, especially
 - AMI, Smart Homes/buildings
 - DER, Storage, Renewable Energy
 - Communication-aided measurement, control, automation

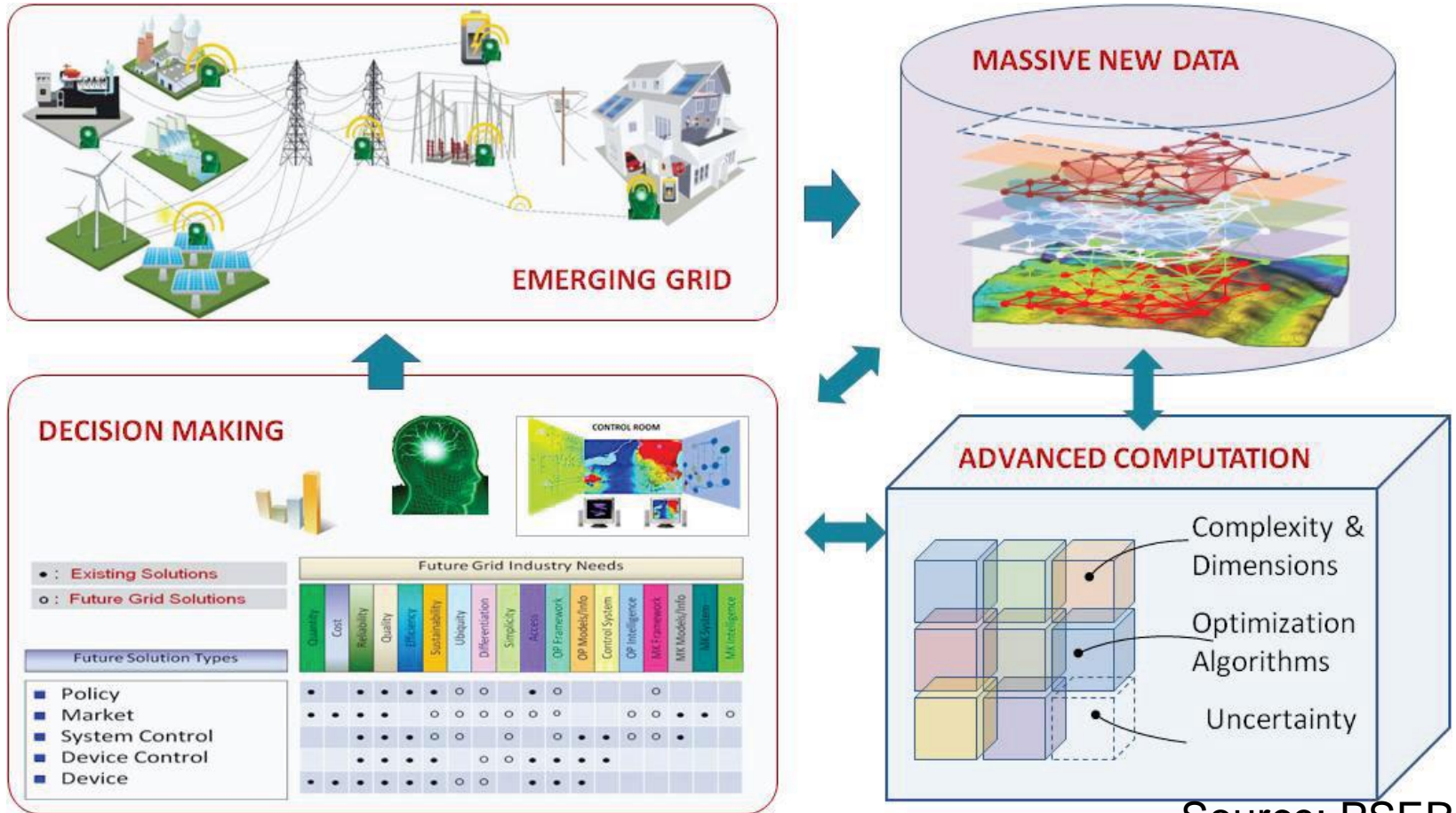


Source: IEA



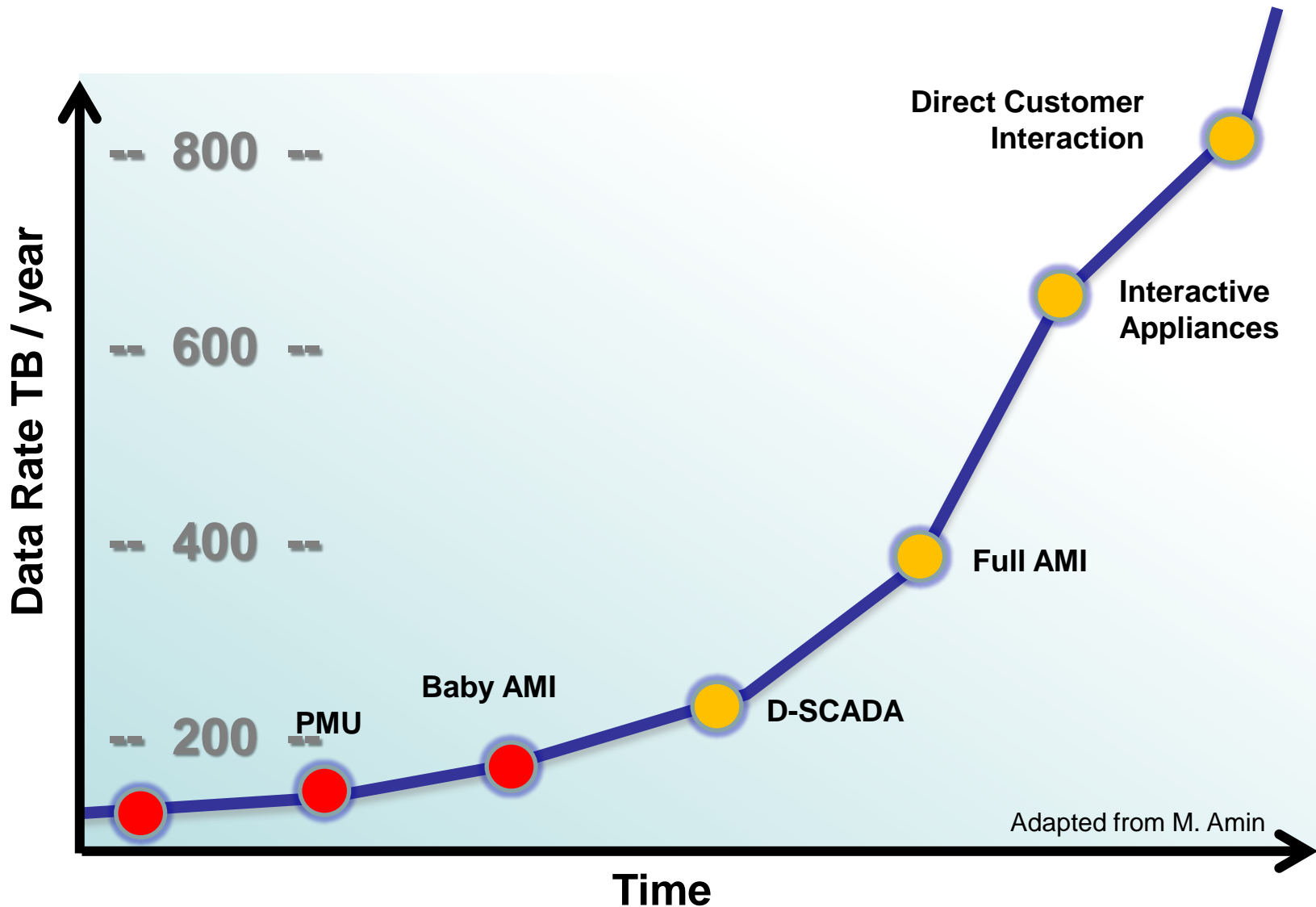
Revolutionary: Smart Grid

- Higher level of complexity



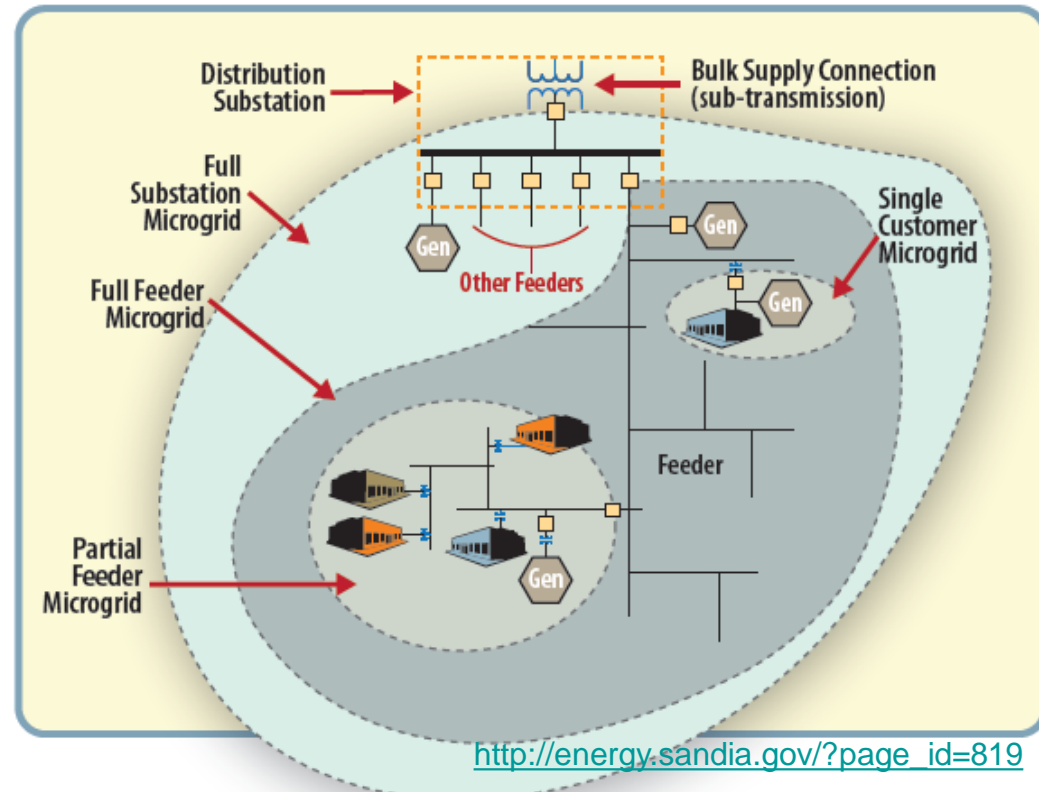
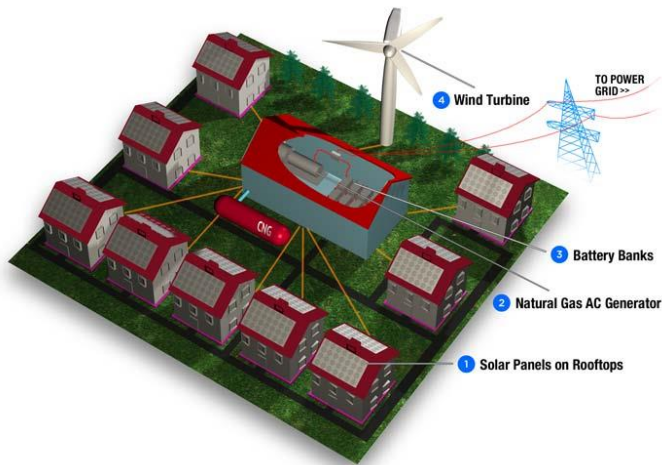
Source: PSERC

Much More Data to Process...



Architecture: Microgrids

- Incorporates DG, local control/protection, possibly storage
- Key Attributes
 - **Defining: Grid interactive, but able to island when grid is down**
 - Inherently resilient
 - Can be scalable, self organizing



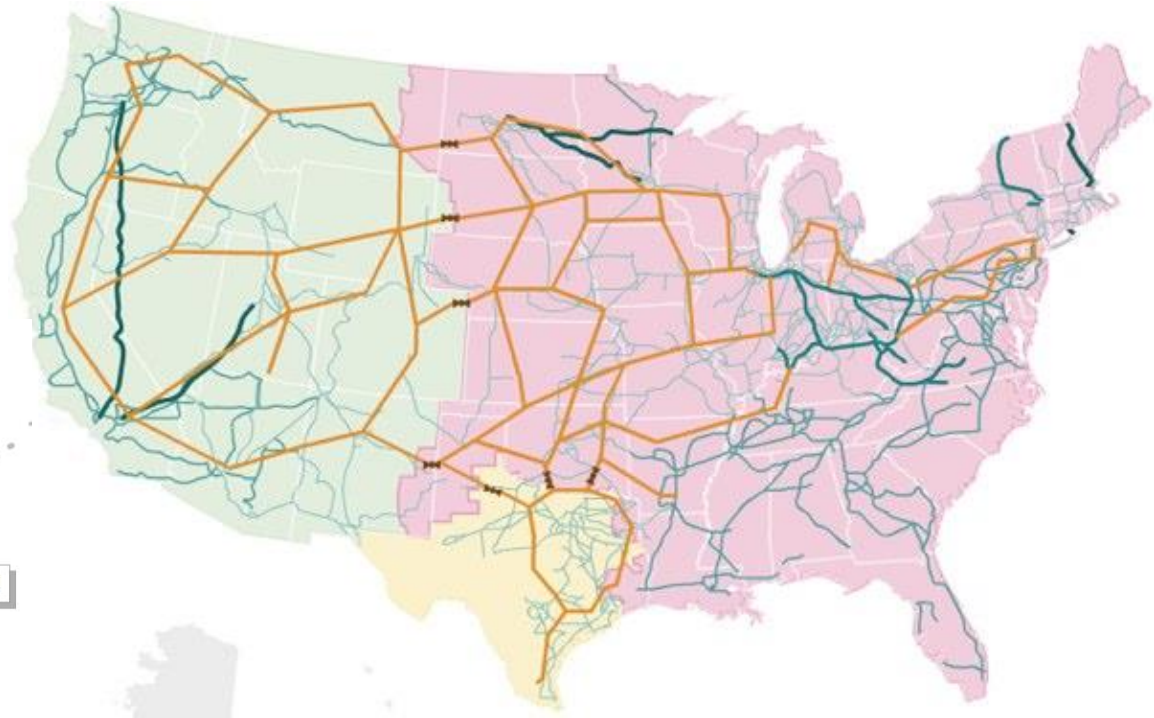
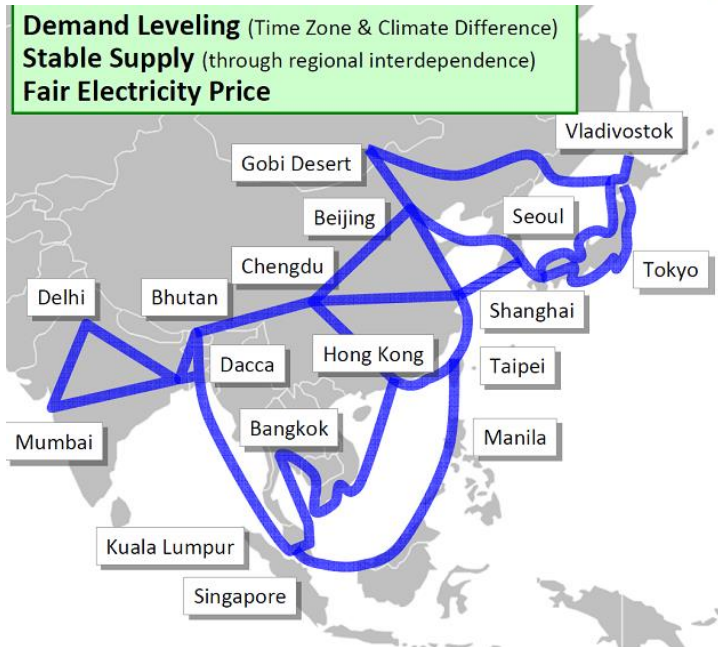
Architecture: Microgrids

- Business case
 - Limit extent of outage
 - Maintain critical and emergency services
 - Expedite recovery
- An expensive fix to a low probability event!
- To improve ROI, use it while grid-connected!
 - Demand reduction
 - Better power quality
 - Sell grid services (black start, voltage/frequency support, ...)



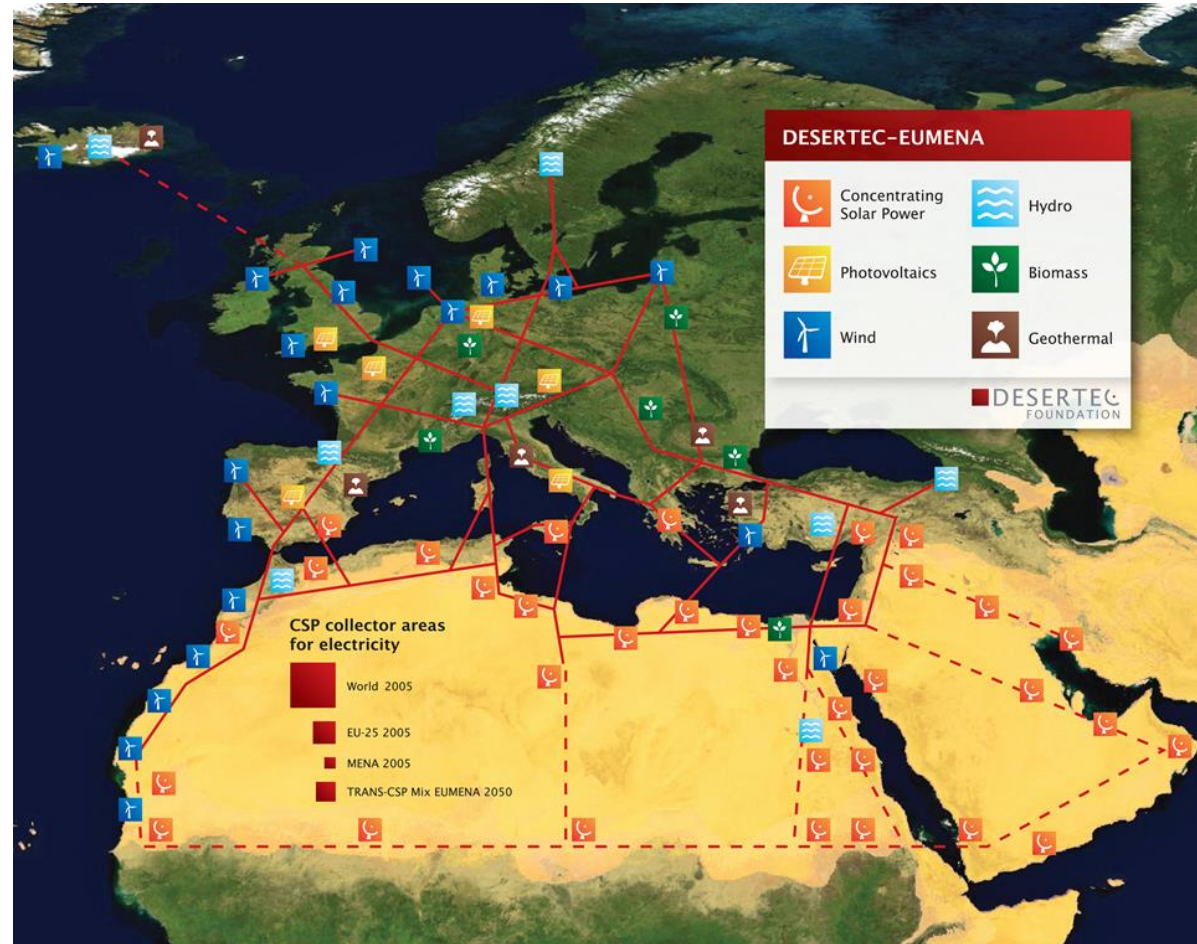
Architecture: Supergrids

- National/Regional Transmission Overlays
 - AC and/or DC



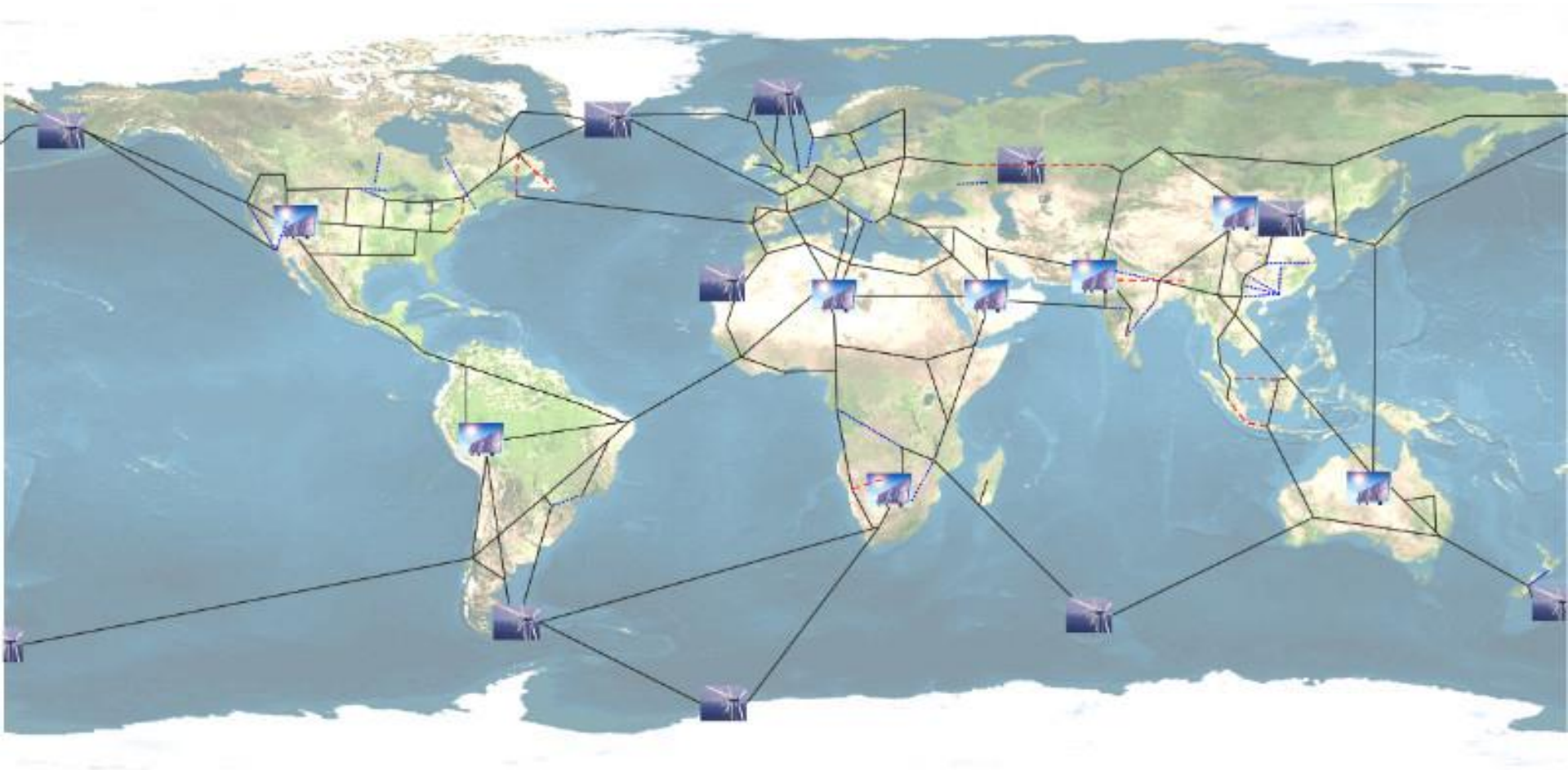
Architecture: Supergrids

■ Green Super Grids



Architecture: Supergrids

- Why Not?

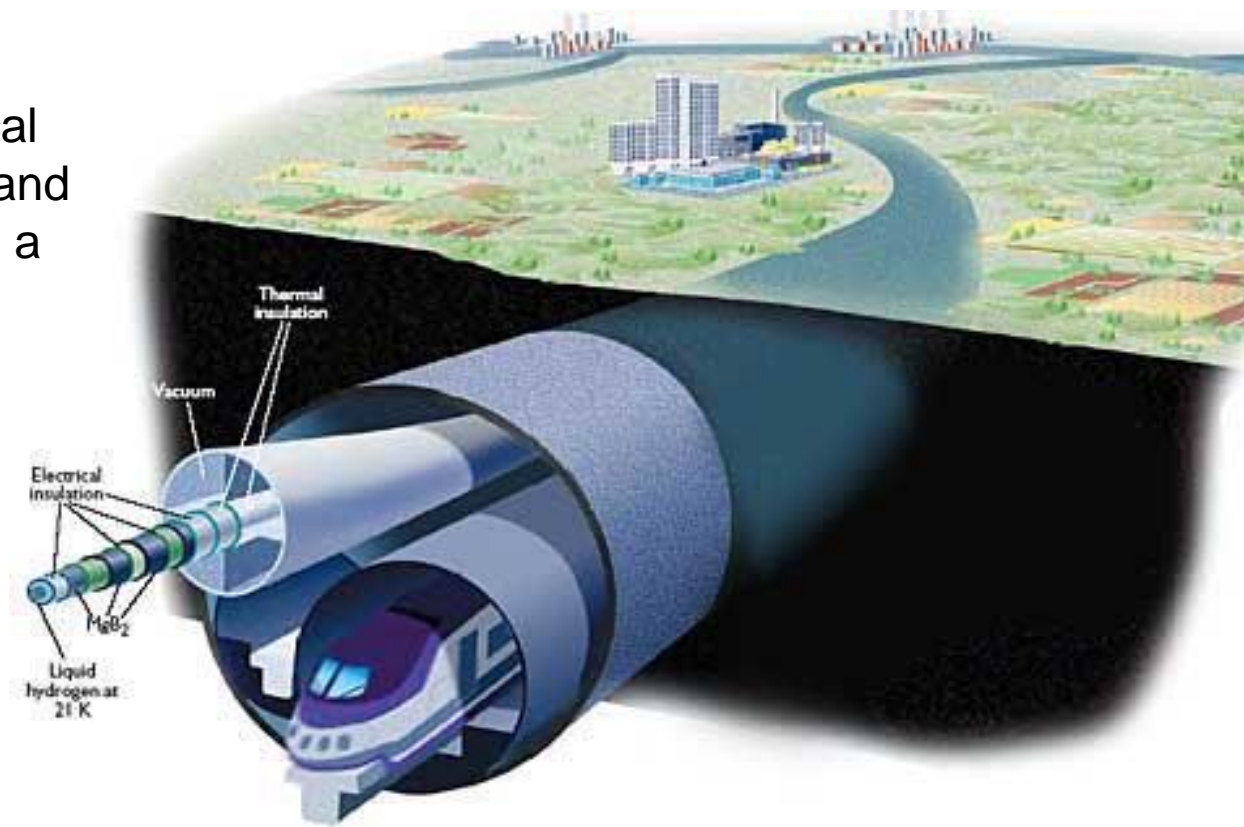


Architecture: Supergrids

- Continental Supergrid

<http://www.aip.org/tip/INPHFA/vol-10/iss-5/p20.html>

An energy pipe with liquid hydrogen at its core, surrounded a superconductor, electrical and thermal insulation, and a vacuum. Could share a tunnel with high-speed, long-distance trains.



Final Thoughts

- The grid is very reliable; however reliability metrics exclude natural disasters
- More frequent and severe weather events are causing more frequent and more expensive power interruptions
- To guide future investment, we need a new paradigm that factors in consequences: Resiliency
- The grid is very large and complex, changing before our eyes
 - Several dimensions: Equipment, communications, controls, markets...
 - Near term evolution: Smart-er, more capable grid
 - Longer term revolution: Microgrids, SuperGrids
- Big challenges: Cost and cost allocation...