Keeping the Lights On - Today and Tomorrow

Jay Giri
IEEE Power & Energy Society (PES)
Governing Board Member

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Grid Management LANDSCAPE

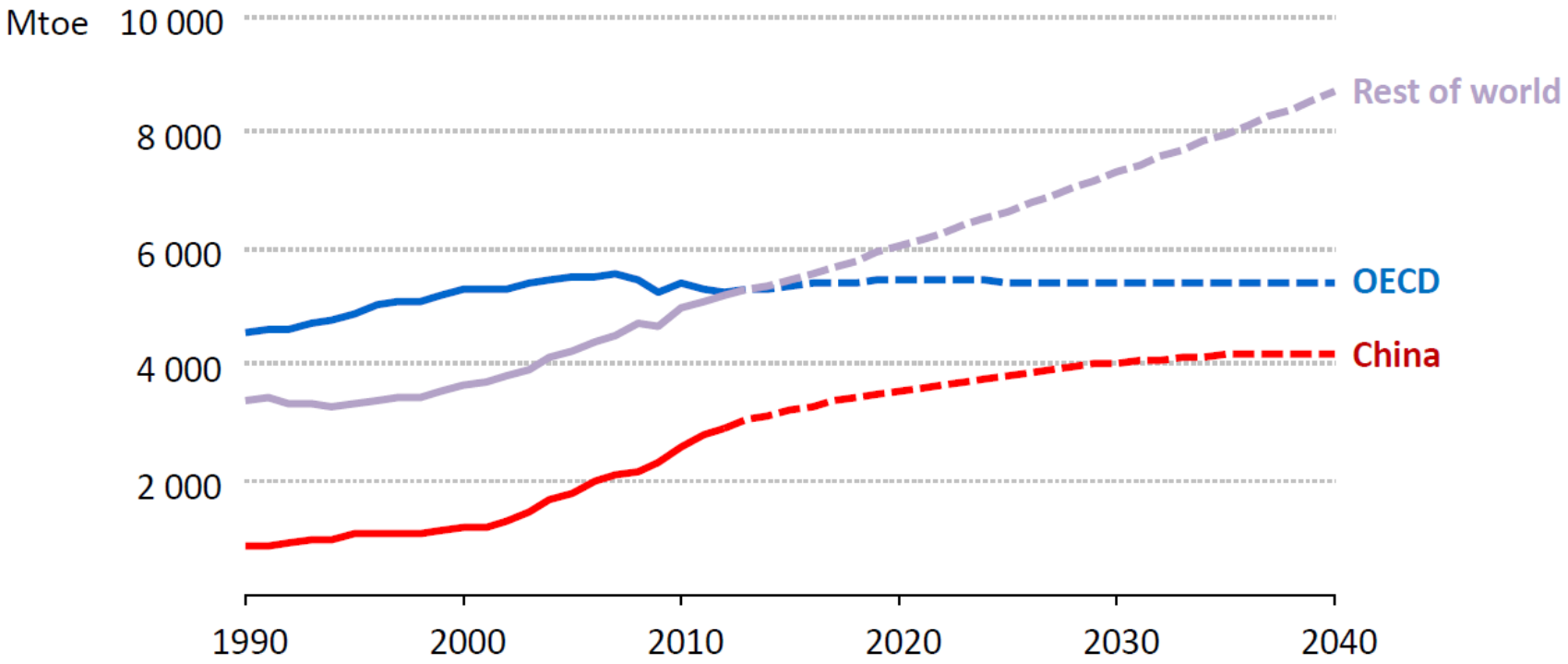
Grid Challenges

- Demand for energy is growing
- Greater risk of blackouts
- Increasing energy costs & price volatility
- Increasing renewable generation

Global Energy Demand

Projected to grow by 80% from 2012 to 2040

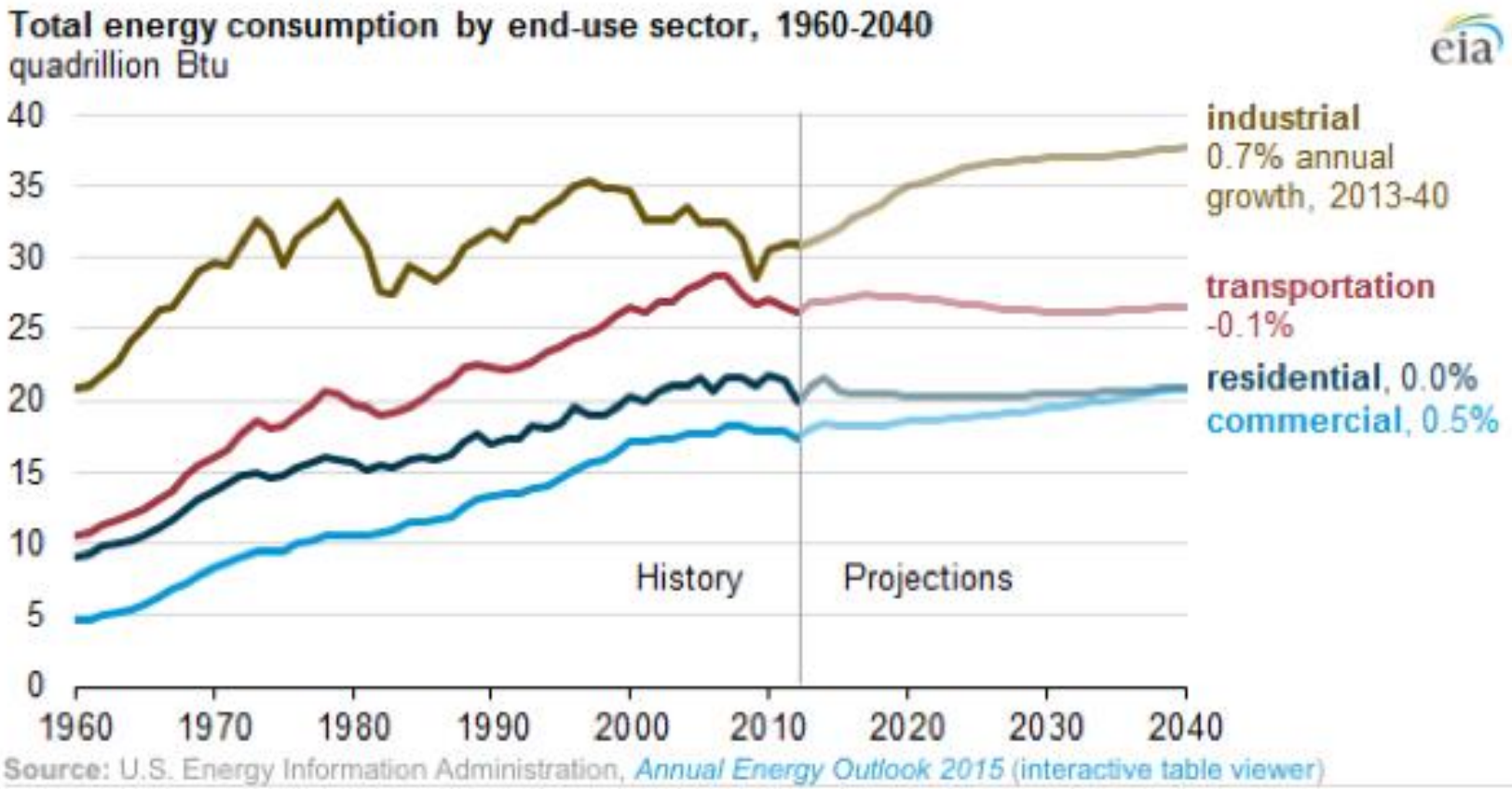
IEA World Energy Outlook 2014



Source: International Energy Agency (WEO 2014)

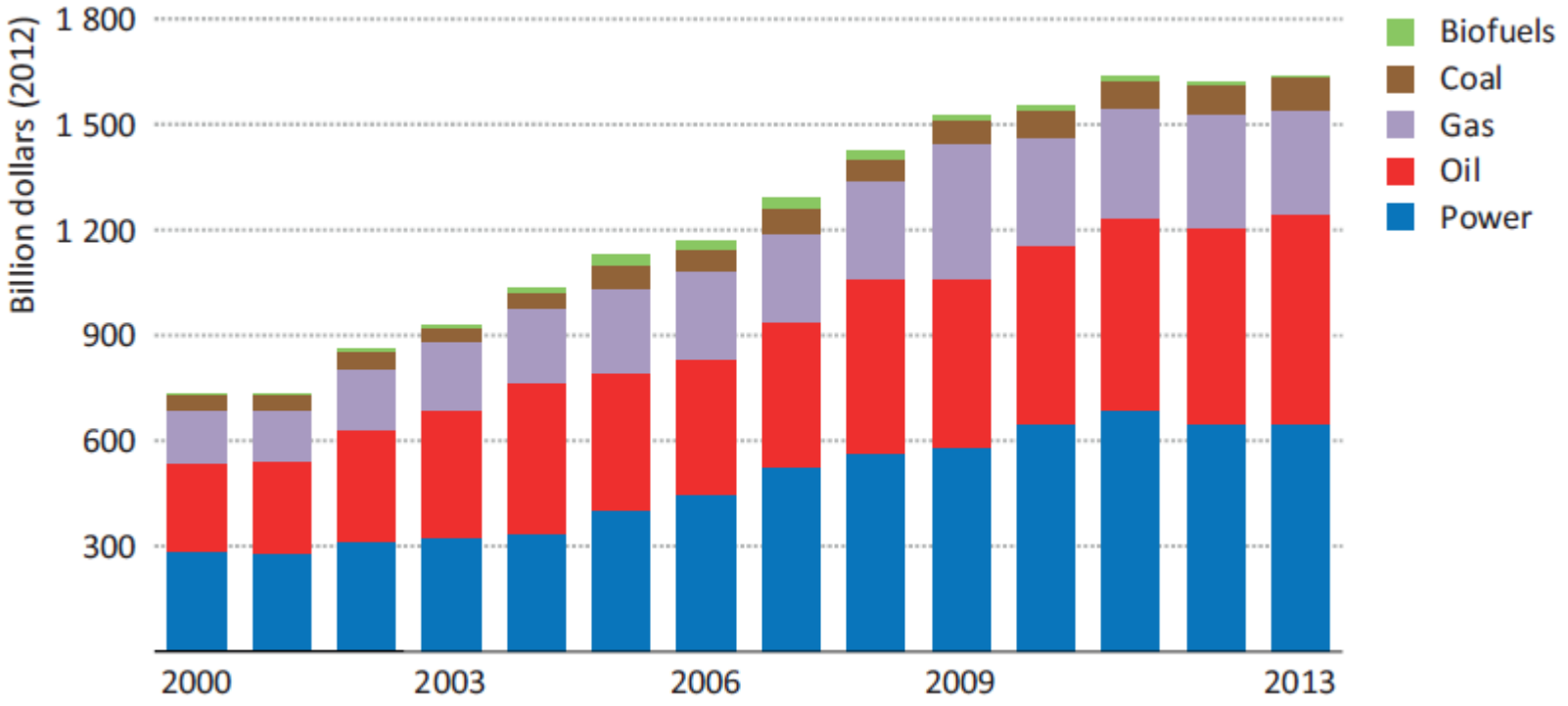
Energy Demand

US Energy Demand Slows



Global Energy Supply Investments

Doubled since 2000



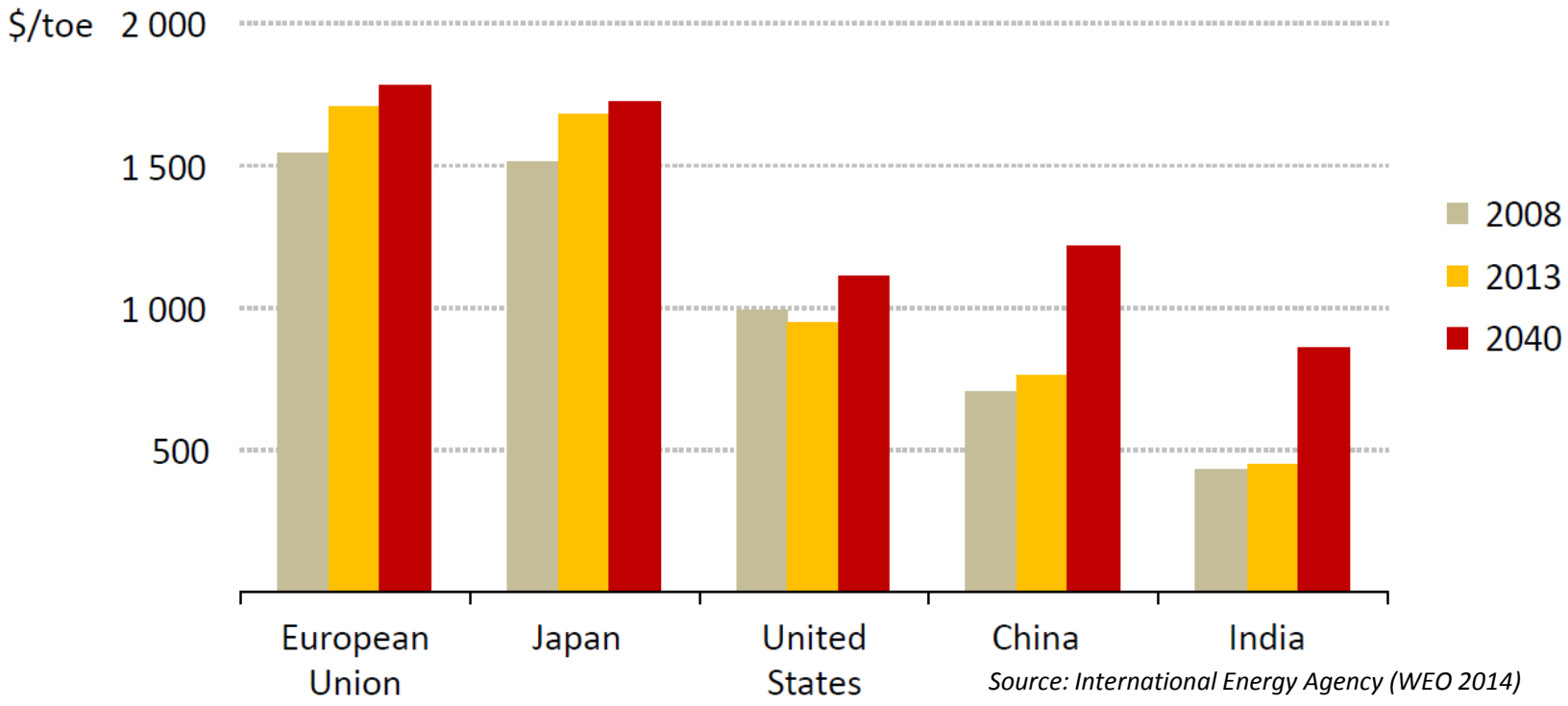
Blackouts are increasing worldwide

History of Blackouts	Region	Duration	People affected	Initiating Event
9-Nov-65	NE US, NYC	14 hours	25M	Faulty substation relay
13-Jul-77	NYC	25 hours	8M	Lightning
1-Mar-89	Quebec & NY State	9 hours	6M	Geomagnetic storm
11-Mar-99	Sao Paolo, Brazil	5 hours	97M	Lightning
14-Aug-03	NE US (8 states), Canada	upto a day	50M	Line overload problems
28-Sep-03	95% of Italy, Switzerland	18 hours	55M	Line fault
12-Jul-04	Greece	varied	7M	Heavy Load conditions
1-Aug-05	Indonesia	5 hours	100M	Grid imbalance
1-Nov-06	Germany, France, Italy, Spain	varied	10M	Line switching error
1-Feb-08	Chenzou, China	2 weeks	4M	Winter storms
10-Nov-09	Brazil & Paraguay	3 hours	67M	Storms
10-Jul-12	India North	24 hours	370M	Over-withdrawals, line overloads
31-Jul-12	India - 3 regions	several hours	620M	Over-withdrawals, line overloads

Global increase of energy costs

Price Volatility Increasing

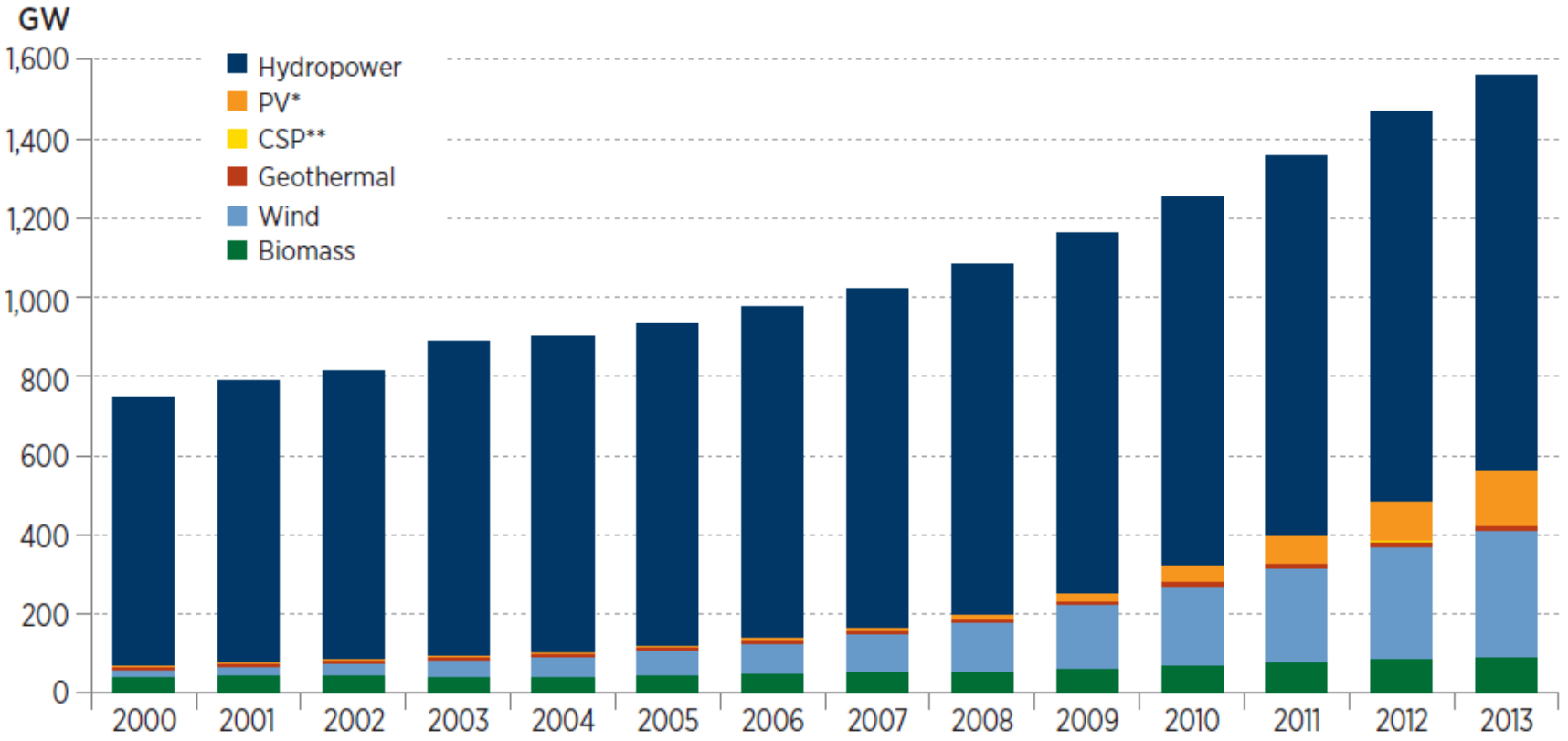
Weighted average customer cost



Source: International Energy Agency (WEO 2014)

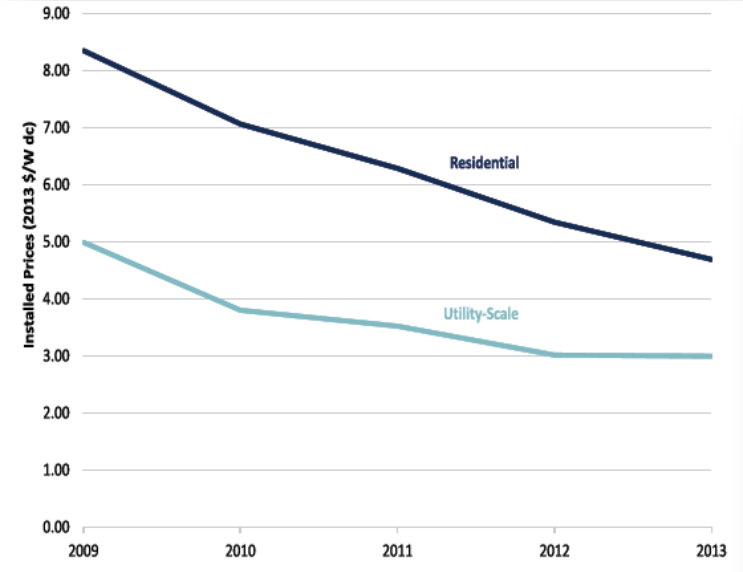
Renewable generation growth Global

source: DOE NREL

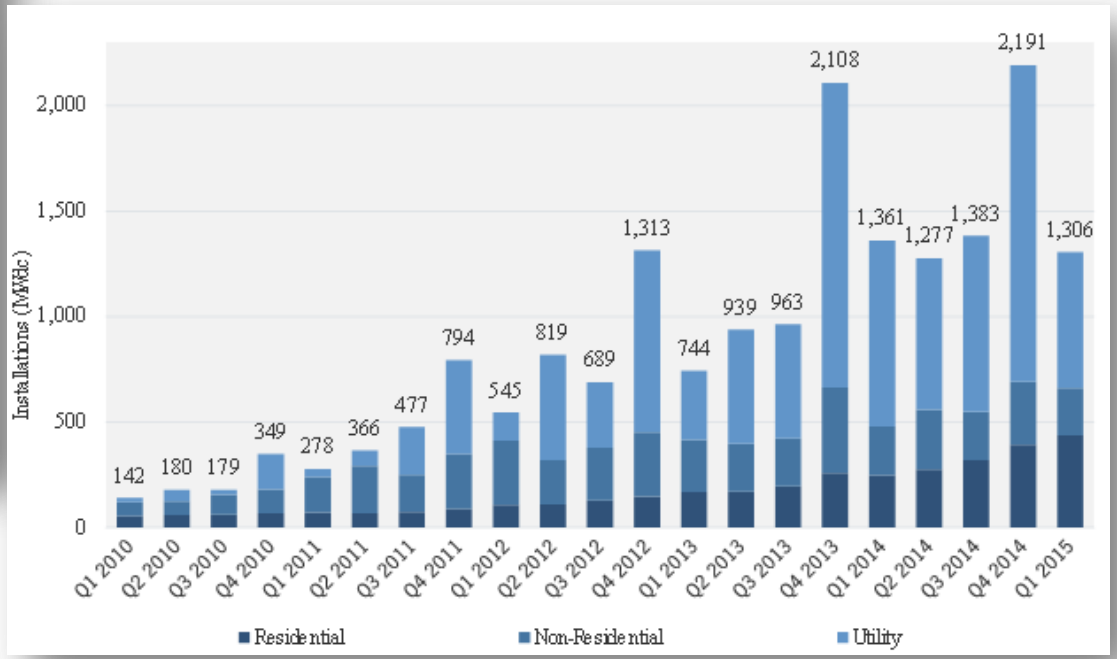


Solar generation growth US

As Solar Costs decrease, Installations increase



Source: Lawrence Berkley National Laboratory

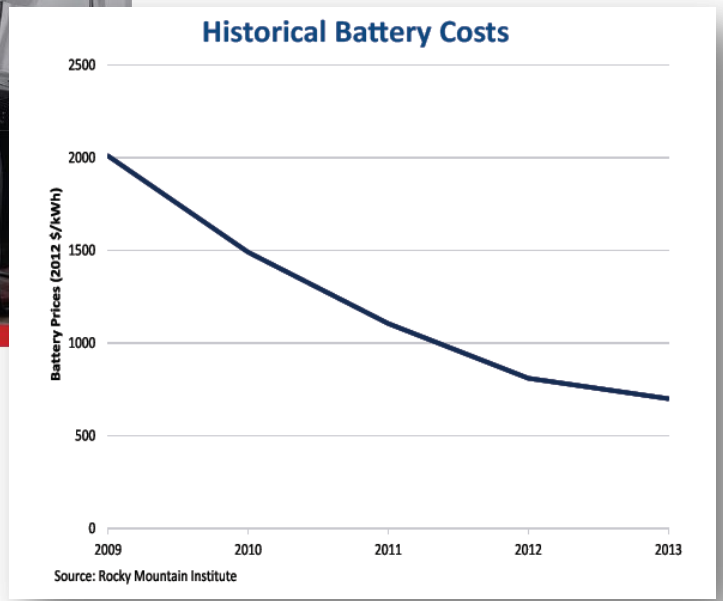


Source: GTM Research / SEIA U.S. Solar Market Insight report

Also, Battery costs are decreasing

Tesla Powerwall

10kWh for backup power, $3,500
7kWh for daily cycling, $3,000
Can be paralleled and aggregated/dispatched
10 year warranty



Our imperatives

Reliable power

Affordable power

Renewable power

for a stable grid

for an efficient grid

for a clean grid

Today's grid management challenges

Plan, Model, Measure, Monitor, Mitigate

Retiring
Workforce

Meters, PMU, …
Big Data

Critical mission
Communication

Environment
Public Safety
Storm Restoration
GHG

Cyber-Security

Sustainability
Renewable
Deployment
& CO2 free energy
New Generation Mix

Control Room
IT Architecture & Services

New Electrical Equipment
(FACTS, HVDC, …)

Business Model Change
New regulation

System Dynamics
Operating near to True real Time Limits

System Scalability
From energy cluster to large Interconnected Grids

critical
severe
high
normal

Courtesy – EPRI & Terry Boston, CEO PJM

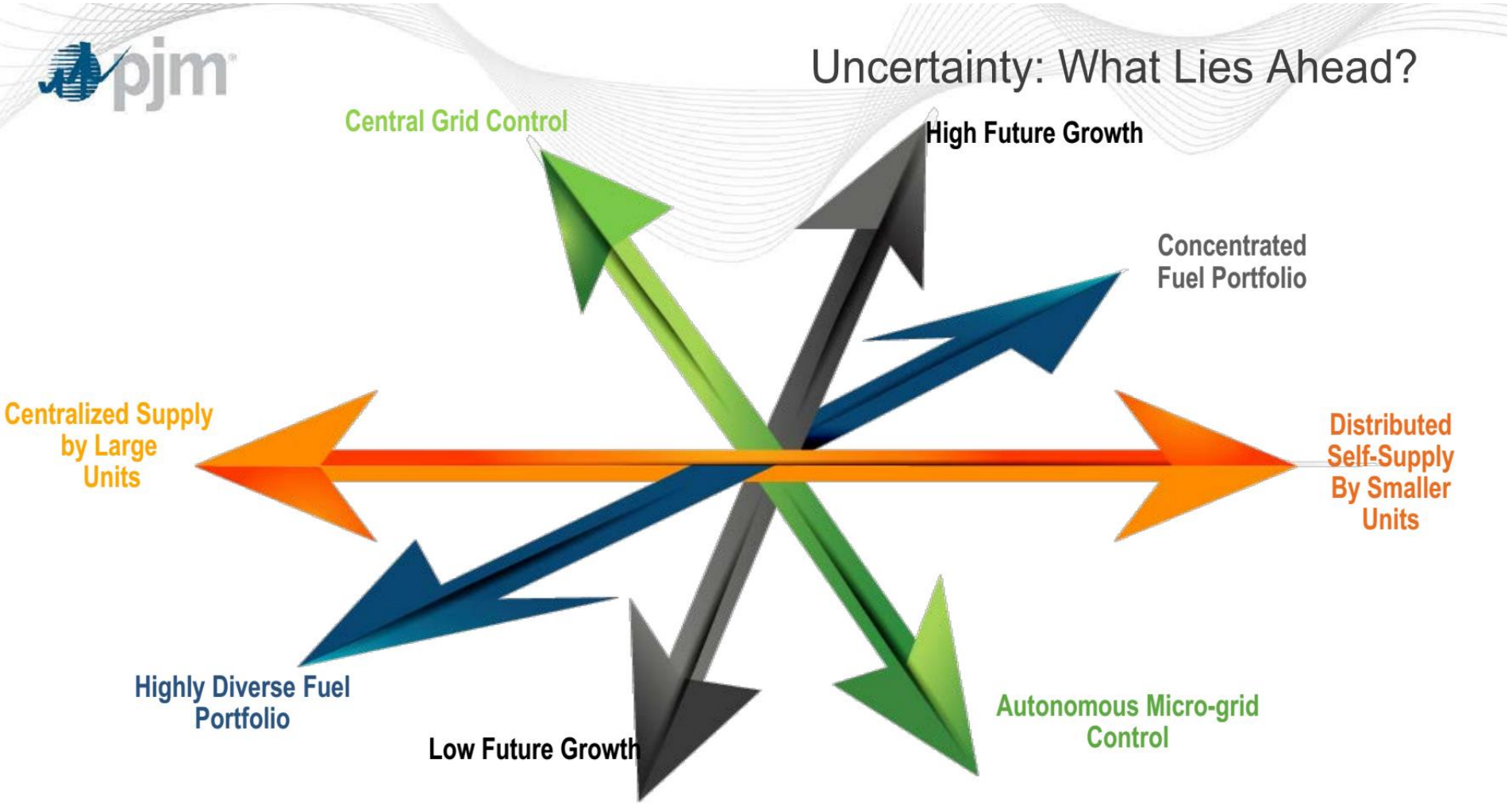
The Future Aint What it Used to Be

Long-Term Research Needs vs. Near-Term Trends

	Natural Gas	Nuclear Power	Digital Technology	Distribution	Carbon Capture	Wind and Solar
2000	Avoid gas-fired plants; fuel prices high, volatile	Nuclear power poised for a renaissance	Digital tech driving more powerful processors & hard drives	Boring. Just run it safely and reliably	CCS grabs global focus and investment	Not in long-range plans or capital budgets
						
2015	Gas is king	Nuclear renaissance stalled in US	Digital tech focusing on batteries and energy	Distribution system platform is the key enabler	CCS research funding and interest on the decline	Lion's share of new plants; front and center in planning

Keep all options open in the long term; maintain a balanced portfolio

Courtesy – Terry Boston, CEO PJM



Future Projections

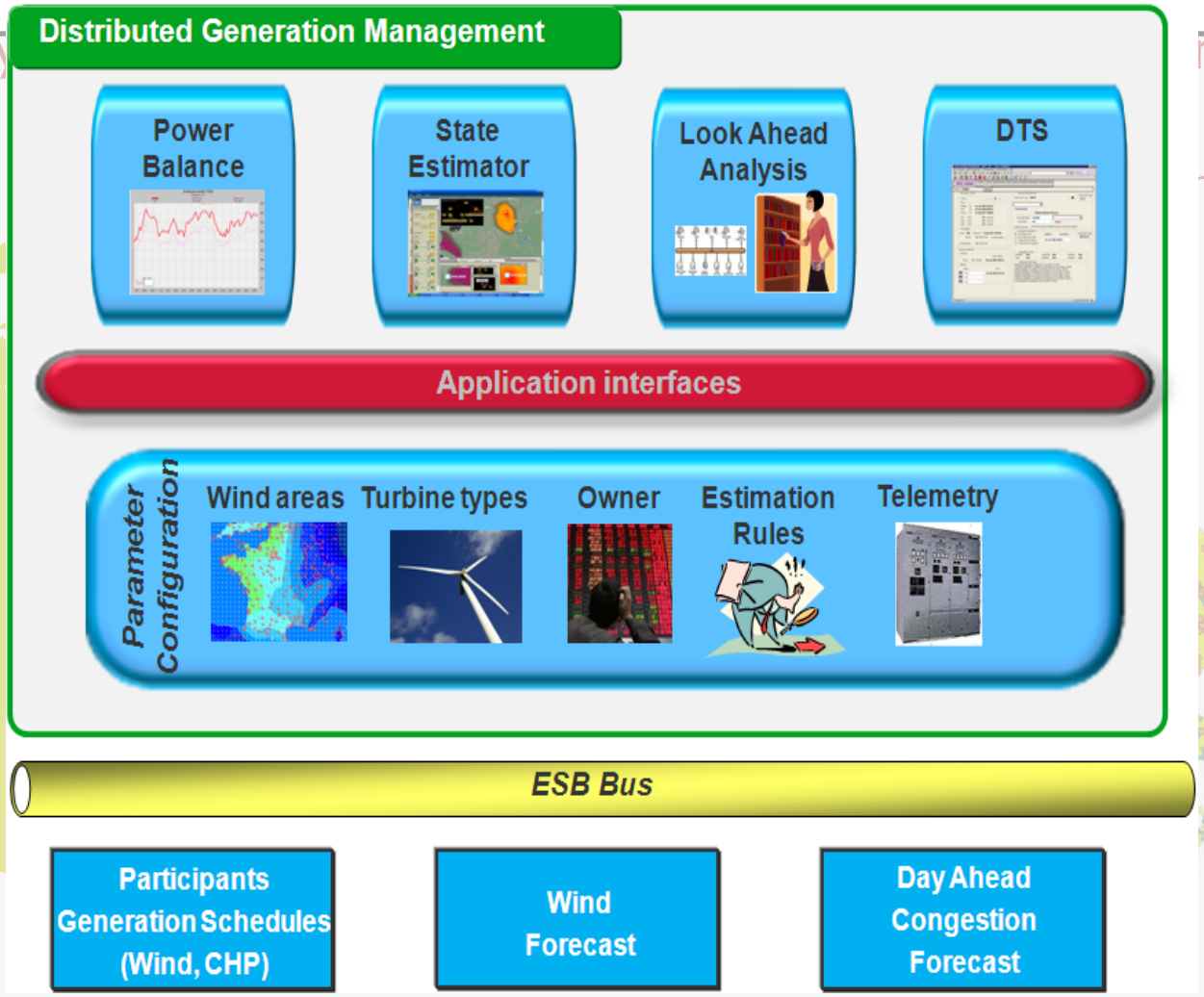
Monitor Trends…Hard and Soft

- Book Reference: Daniel Burrus,
  "Flash Foresight: How To See The Invisible and Do The Impossible"

Smart Grid
TECHNOLOGY & SOLUTIONS

Smart Grid Technology & Solutions
Enhancing the 'brain and the nervous system' of the grid

Denmark Renewable Energy 1980 vs 2008

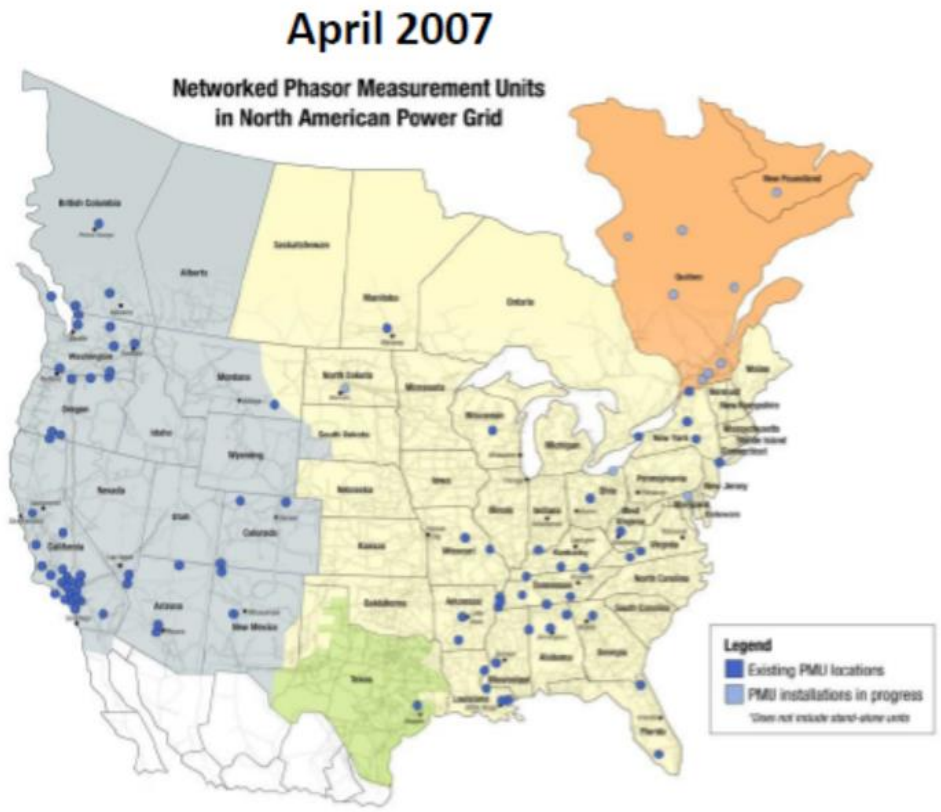


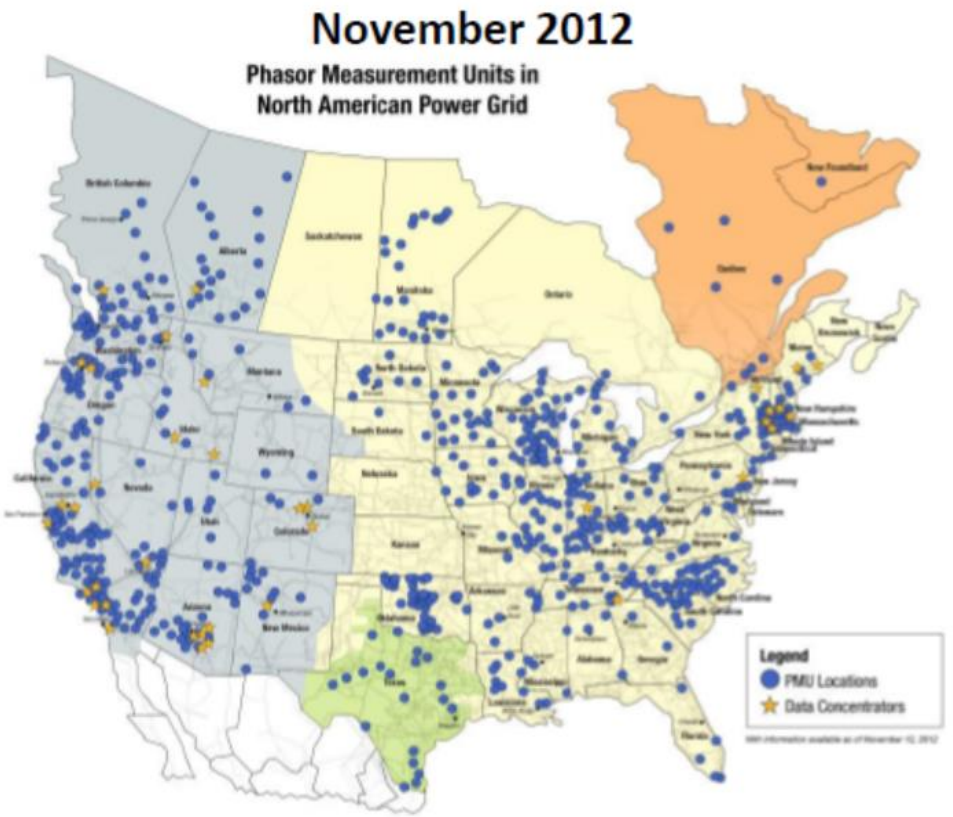
> 20% of Energy Supply

Synchrophasor Deployment in North America

Source: NASPI Website (www.naspi.org)

A Rapidly Changing Landscape





Approx. 200 PMUs in 2007

Over 1700 PMU deployed as of 2015
(over 10TB/Month of "raw" PMU data)

Indian Synchrophasor project

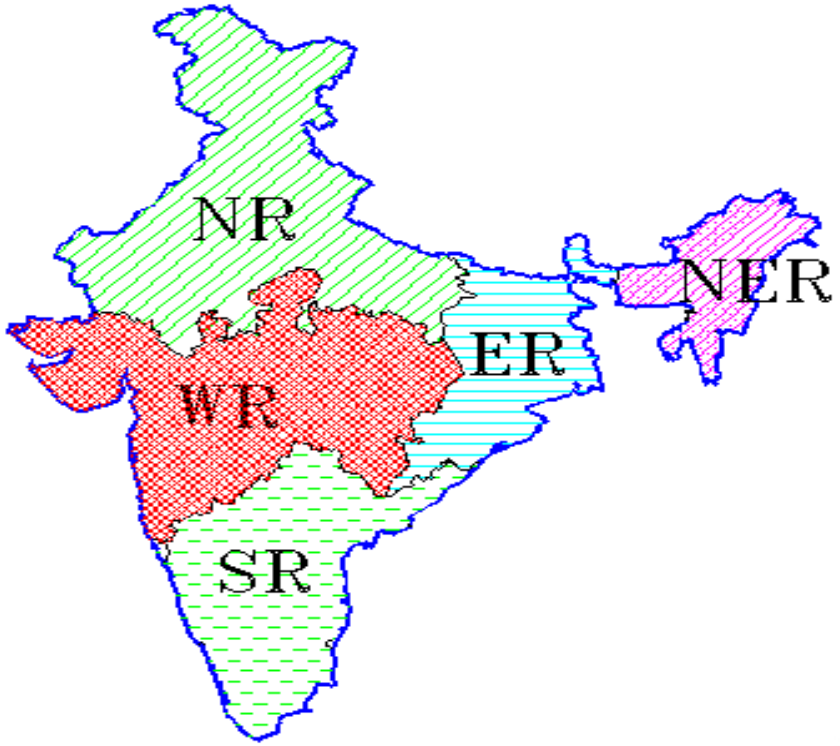
Full observability of the Indian Power system in real time

Serving over a Billion people

The world largest WAMS for a single interconnection

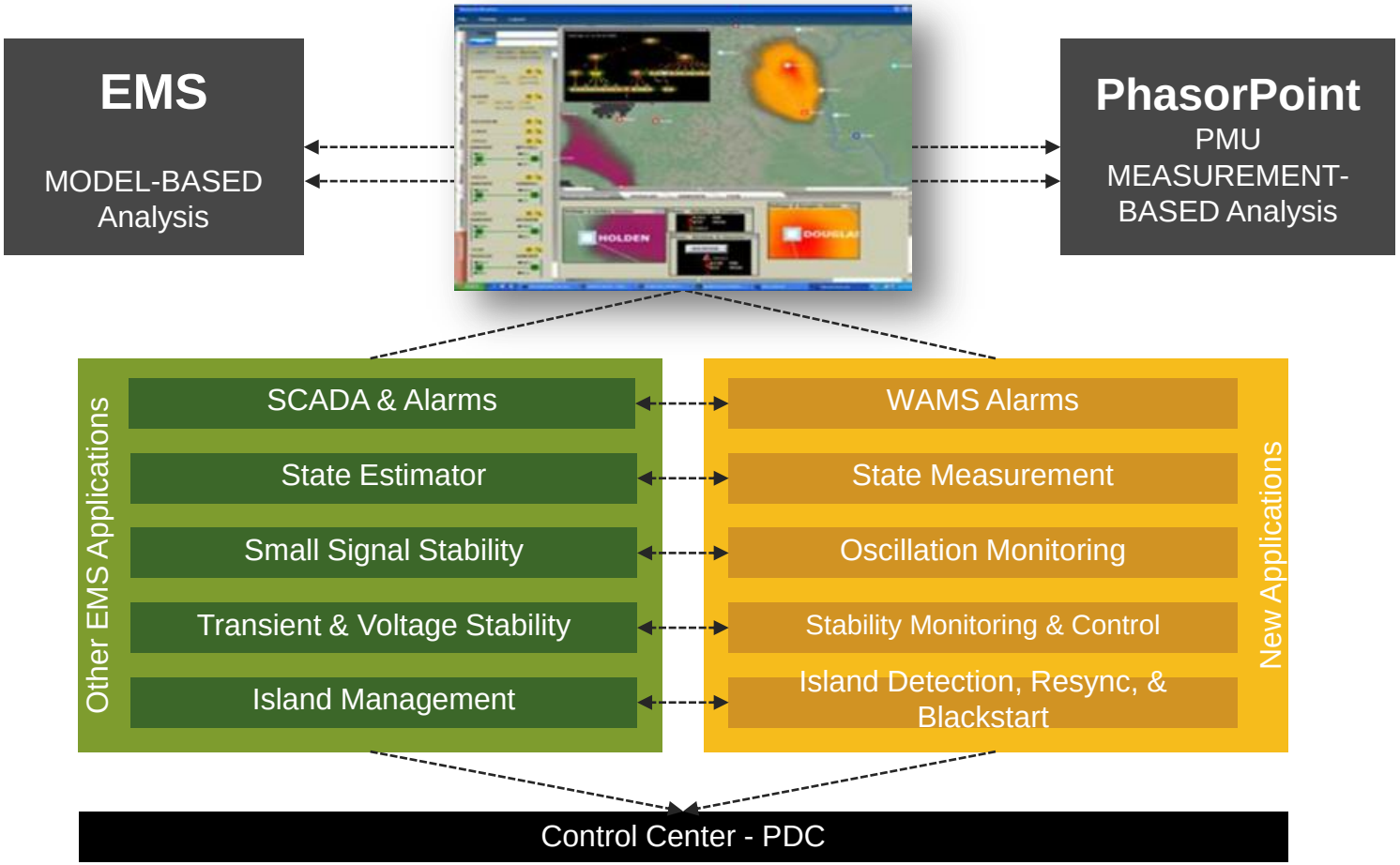
Local, Regional and National System

1800 PMUs in 351 substations, 34 control centers at 5ms resolution

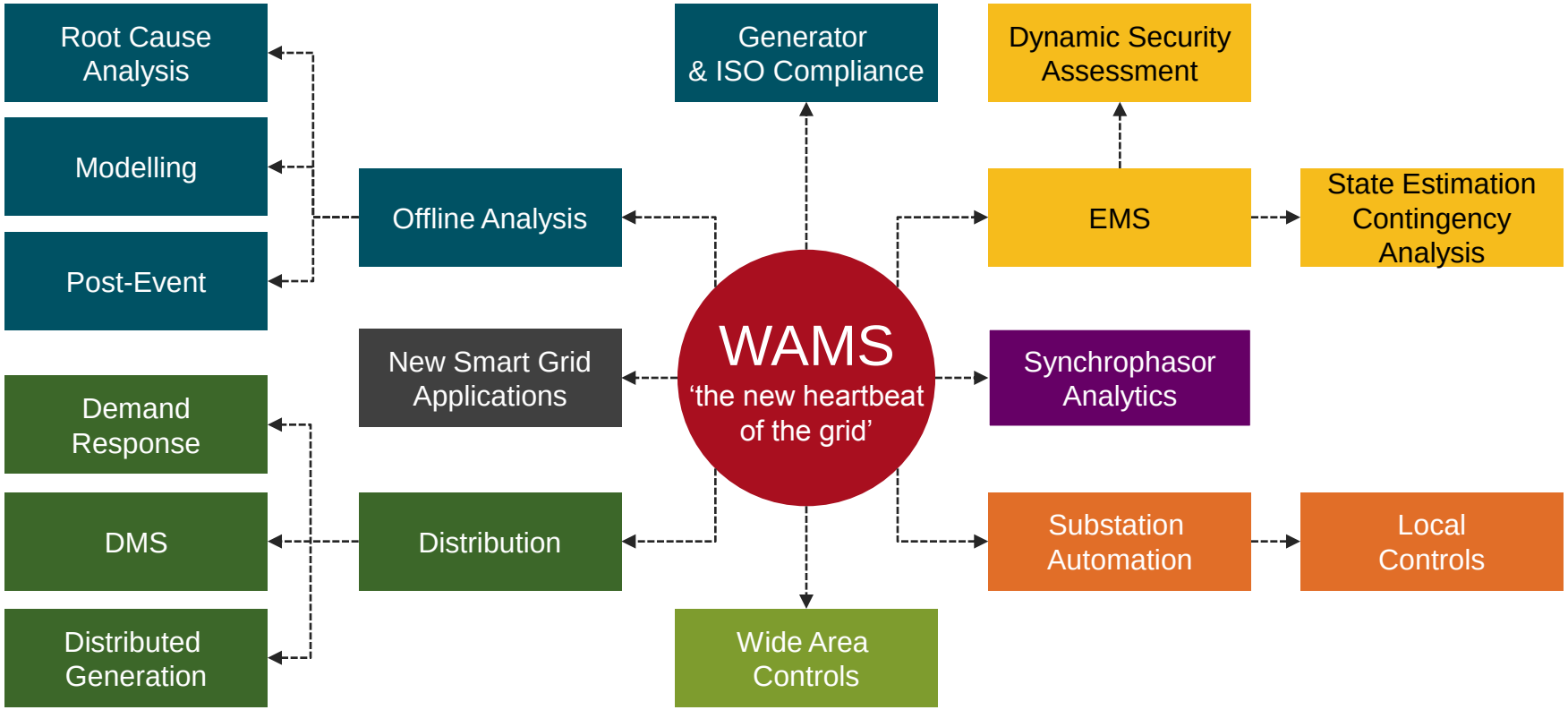


Control Room Operations Are Changing

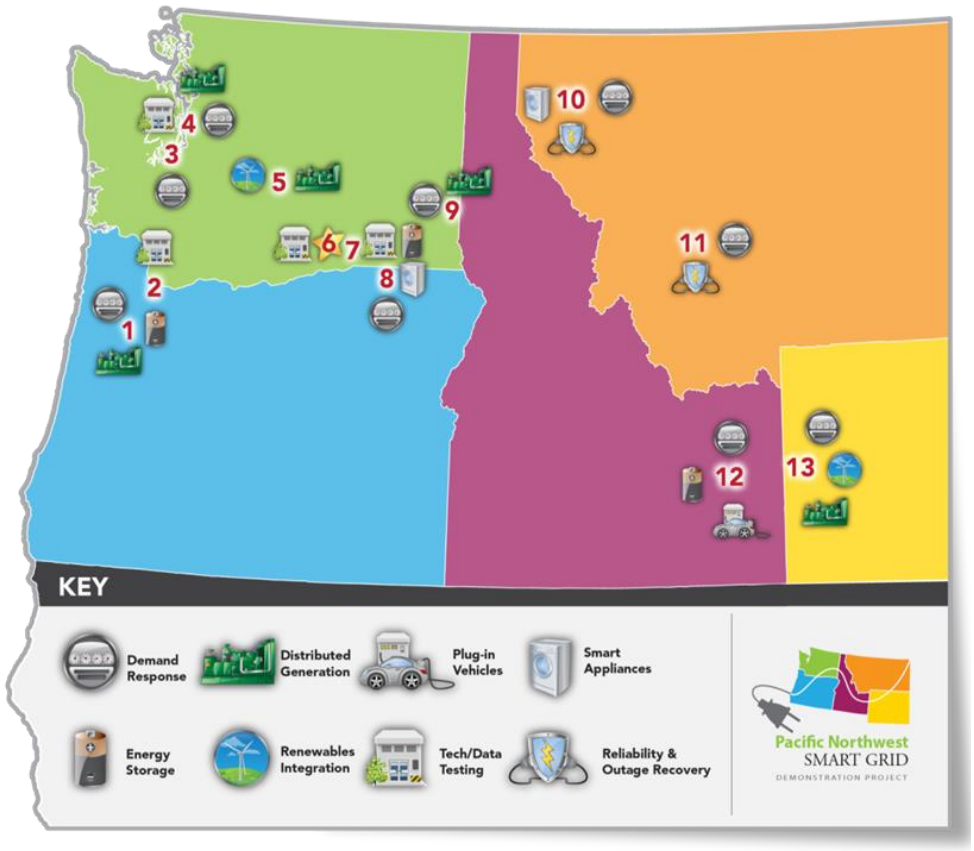
Transitioning from traditional "steady-state" view to enhanced "dynamic" situational awareness.



Wide Area Monitoring Systems (WAMS)



Pacific Northwest
Smart Grid Demonstration Project



Pacific Northwest
SMART GRID
DEMONSTRATION PROJECT

AVISTA
BONNEVILLE POWER ADMINISTRATION
Flathead Electric
BENTON P.U.D.
Idaho Falls Power
NorthWestern Energy
Battelle
The Business of Innovation
LOWER VALLEY ENERGY
NETEZZA
IBM
PGE
Portland General Electric
Peninsula Light Co.
3TIER
ALSTOM
Spirae
QualityLogic
Putting Technology to the Test
City of Ellensburg
WASHINGTON
UNIVERSITY of WASHINGTON
WASHINGTON STATE UNIVERSITY

Future Grid Management

Examples of practical nascent solutions

- **Evolve from a Reactive paradigm to a Proactive paradigm!**
  - From 'Load Following' to 'Generation Following'
- **Dispatch transmission MW using FACTS devices**

$$P = \frac{V_1.V_2.\sin(\delta)}{X_{line}} \quad + \text{P (HVDC/FACTS)}$$

- **Develop new Grid Automation control schemes**
  - Integrate sub-second synchrophasors with FACTS

Keeping the Lights On..

Some Final Takeaways..

- **Uncertainty is increasing..**
  - Challenges & Opportunities!
- **Monitor trends continually…**
  - Past not always a good indicator of the future
- **Develop creative solutions to innovate & leverage technology advances**

Jay Giri
jay.giri@alstom.com