

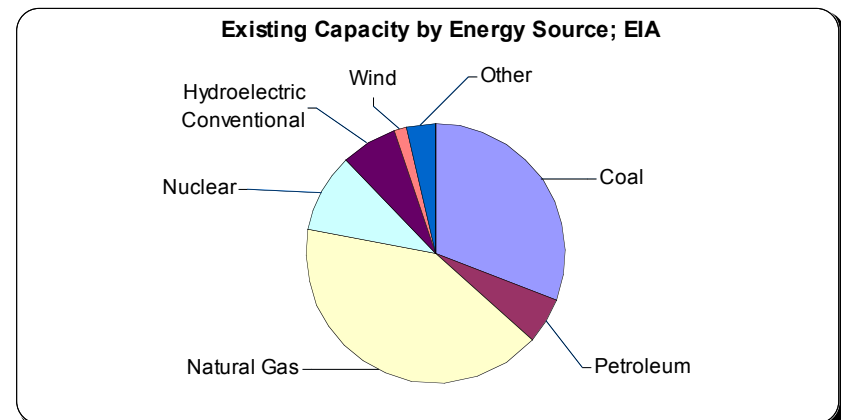
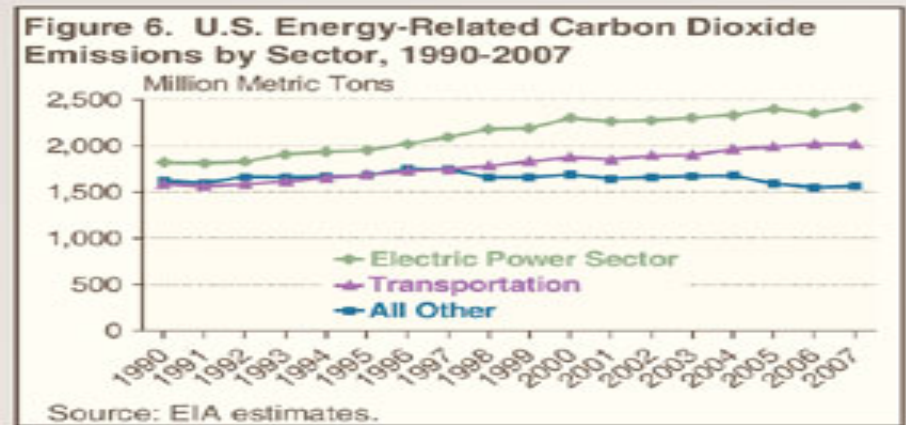
The Smart Grid Broadly Construed as a Cyber-Physical Electric Power System Business Platform

Michael Caramanis, Mechanical and Systems
Engineering, Boston University

IEEE, Demystifying the Smart Grid
Panel Presentation
November 21, 2009

Electricity Sector of Paramount Importance for Sustainable Future

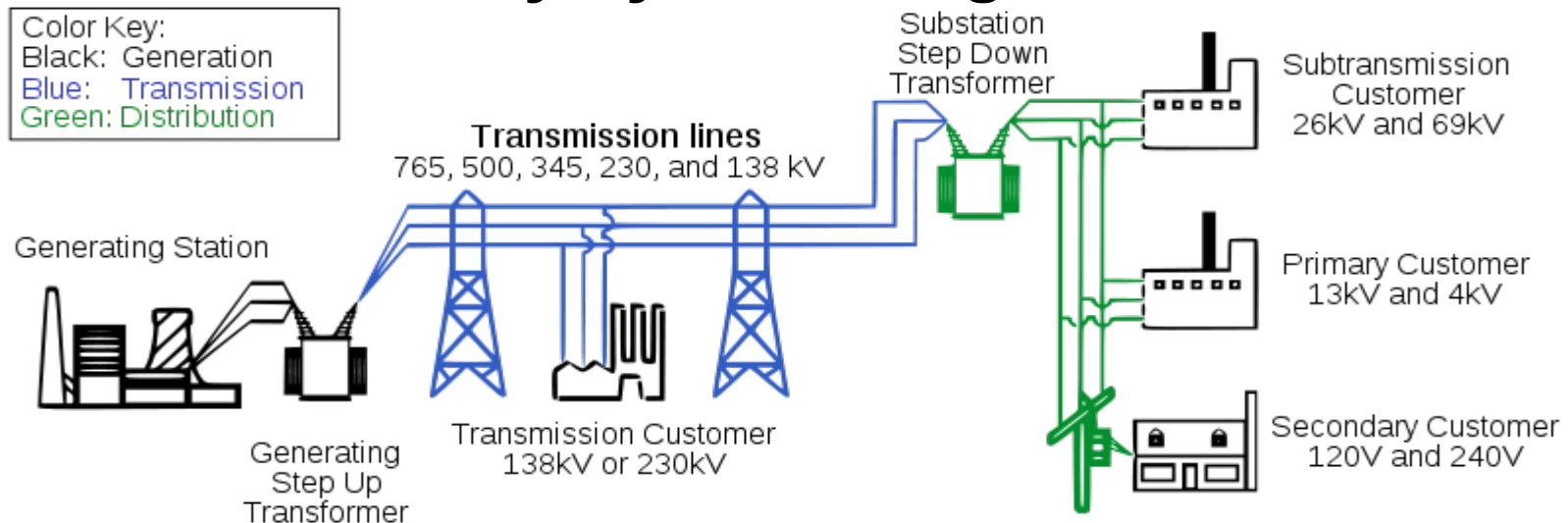
- Fossil Fuel Conservation. Stop using for heating (heat pumps & low enthalpy geothermal Energy 3-4x more efficient)
- Transportation Sector Electrification a Must!
- New Load met by Clean Generation, Not Fossil Fuel based Generation!



Instantaneous Energy Balance Required under Limited Transmission Flow Control (Kirchhoff): A Challenging Complex System Integration Problem

- Spatial and Temporal Congestion in
 - Energy Balance
 - Transmission Capacity
 - Distribution Capacity
- Congestion Must be Managed in (close to) Real Time!
- Presence of Uncertainty Requires Dynamic Scheduling of Contingency Resources for Robust System Security Control: Mix of Fast/Slow-Response Capacity Reserves Must be Secured Efficiently over Time and Space

Smart Grid encompassing Cyber/Physical Components provides a **Cyber-Physical-System (CPS) Platform for Efficient Electricity System Integration!**



- Gen, T&D, Metering with Embedded Automation & I.T.
- Decision Support and Control Software
- Market and Regulatory Framework (TPA, Competition)
- Distributed Resources (Roof top PV, DSM Microgrids, Storage,...)

PLATFORM OPEN TO COMPETING DEVELOPERS & USERS?

Unbundled Cost of Electricity: Averages

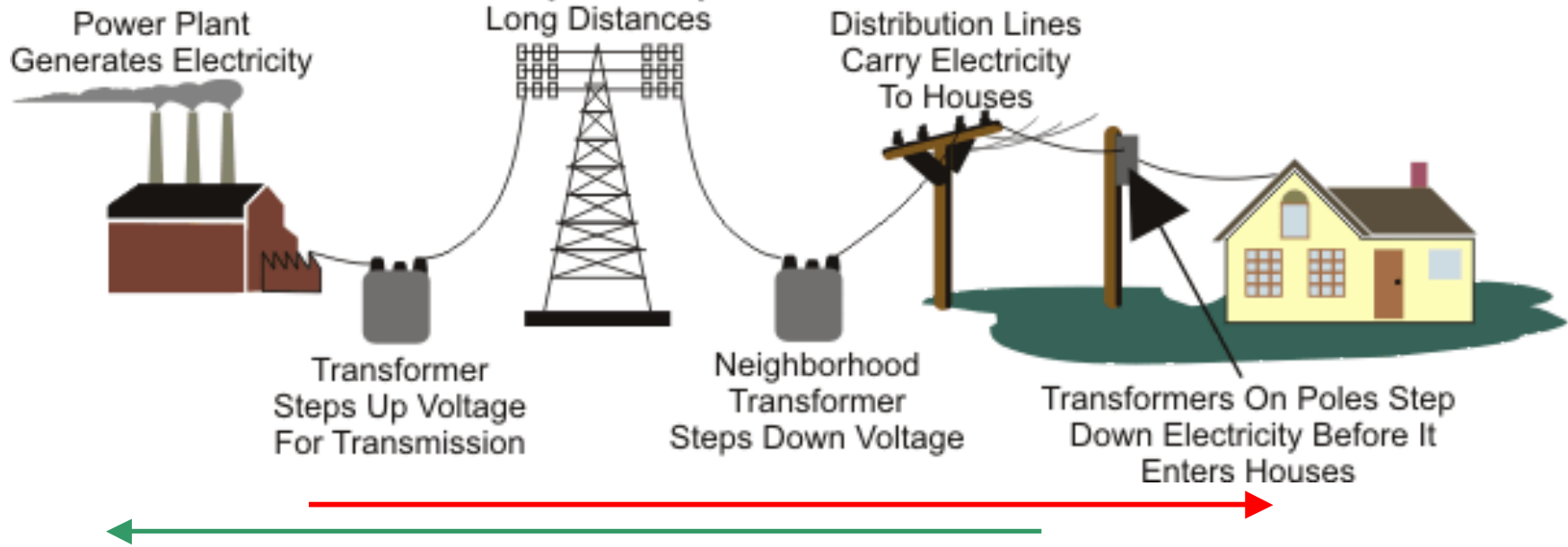
60%: Cyber ✓ Market ✓

5%: Cyber ✓ Market

35%: Cyber ? Market ?

AMI, S.I., Dynamic Reconf., GFAs,...

SCADA → PMU+



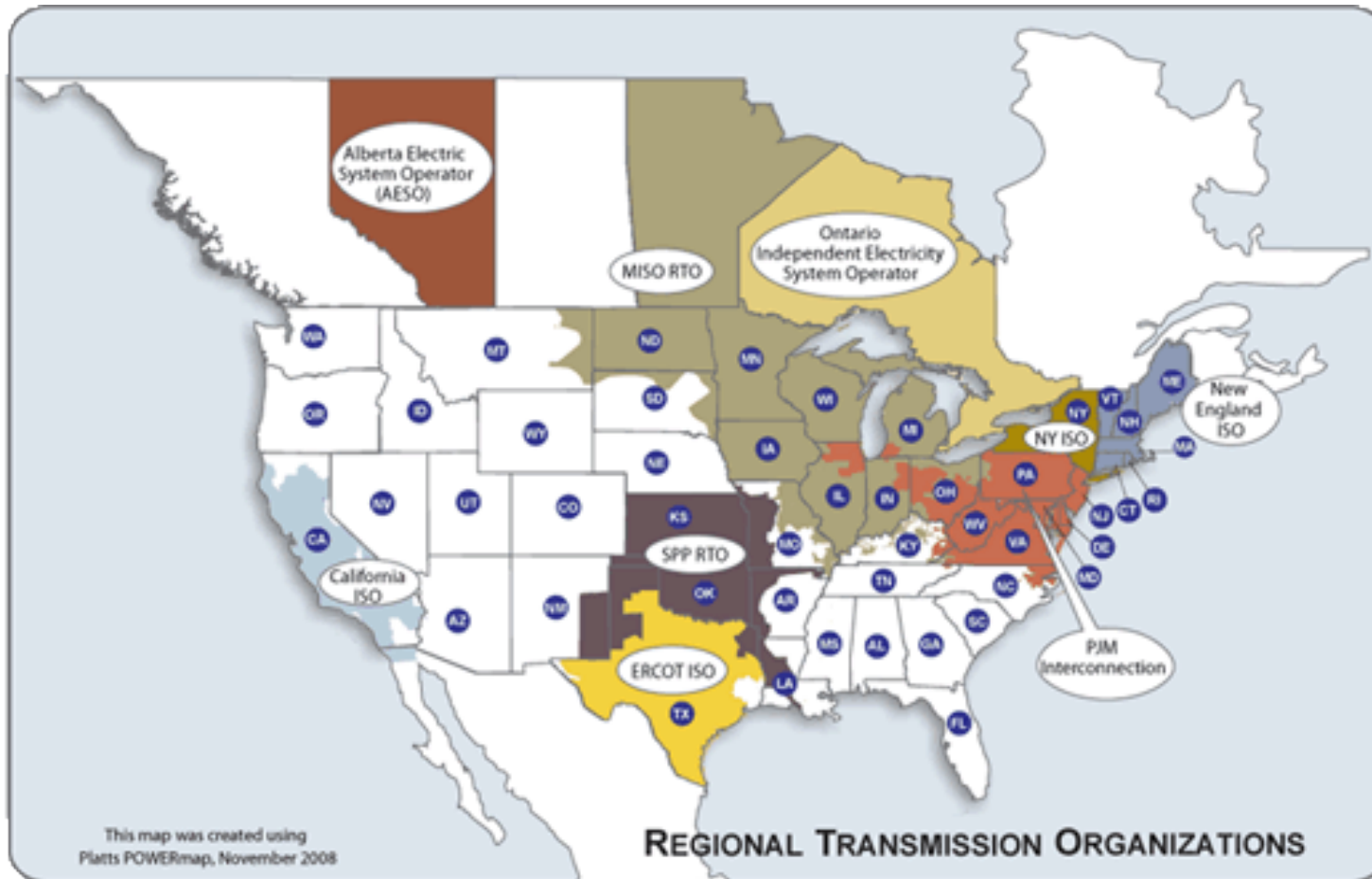
**Direction of Power Flow no Longer Unidirectional!
The “Cyber” Smart Grid Component Can Reduce
EACH Cost Component!**

Synergies to be Realized by CPS Platform

over and above: Reduction of non-technical losses, Expeditious location of outages, network reconfiguration, Improved maintenance, ...

- (i) Intermittency [Clean Energy +Nuclear!], + (ii) New HEV Loads => congestion in Energy Generation, Capacity Reserves, T&D Network.
- Load Response/Conservation and Distributed Resources (Generation, Storage,...) can be Managed Synergistically to Mitigate Congestion.
- CPS and Market Design must facilitate Load and Distributed Res. participation in BOTH:
 - *Wholesale* Market; LMP, Ancillary Services
 - *Retail* Market; Losses, Congestion, Equipment aging and Degradation, Local Voltage Control,...

>50% of consumers in US in Regional Liberalized Whole-Sale Markets! ~0% in Retail Markets!



Real-Time Congestion Price/Cost Discovery

- In Liberalized Wholesale Markets
 - Energy Balance (MWh)
 - Transmission Equipment Capacity Needed for Contingency Planning
 - Generating Capacity Reserves (MW)
- In Potential (?) Retail/Distribution Markets
 - Distribution Network Equipment Capacity
 - Marginal Losses
 - Equipment Life Degradation
 - Voltage Control (FAPER/VAPER?)

Clean Generation Problems/Issues

- Wind Output Forecast Error (at 90% confidence interval)
 - Day ahead ~20% (stand. Dev ~10%)
 - Hour Ahead ~ 5% (stand. Dev ~2.5%)
- Regulation Service currently on the order of .5-1% of Peak Load, at an average cost of \$50+ per MW per hour
- Operating Reserve Reqs higher but at lower cost
- Wind Generation~20% of energy=> Regulation Service 2-3% of Peak Load. SHOW STOPPER?
- Similar Issues with PV. Current Rates Inappropriate! California Utility Example...

Issues with Mass Adoption of Hybrid Electric Vehicles (HEVs)

- Full conversion to HEVs => ~20-25%
Increase in Load Centered around Residential and Urban areas!
- How about Costs of Scaling up the Distribution Network? Could it put the Breaks on HEV Adoption?

Cyber component of Smart Grid may
Enable Market Development.

However, Regulatory Reform is a MUST

- CYBER: Decision Support, Micro-grids, Sub-metering, Control, GFAs, Consumer Preferences
- Retail Market Development: Cost and Requirements Information to consumers and consumer response/participation
- Regulatory Reform:
 - Reform Distribution Network Regulated Rates to Provide the Correct Incentives?
 - Open CPS Platform to Developers and Users?
Think of Telecom Analogies. Non Obvious Apps?