New Electric Grid Technologies for New Challenges

IEEE Systems Council Coastal Los Angeles Section

2011 Green Energy Forum/Workshop

December 5, 2011

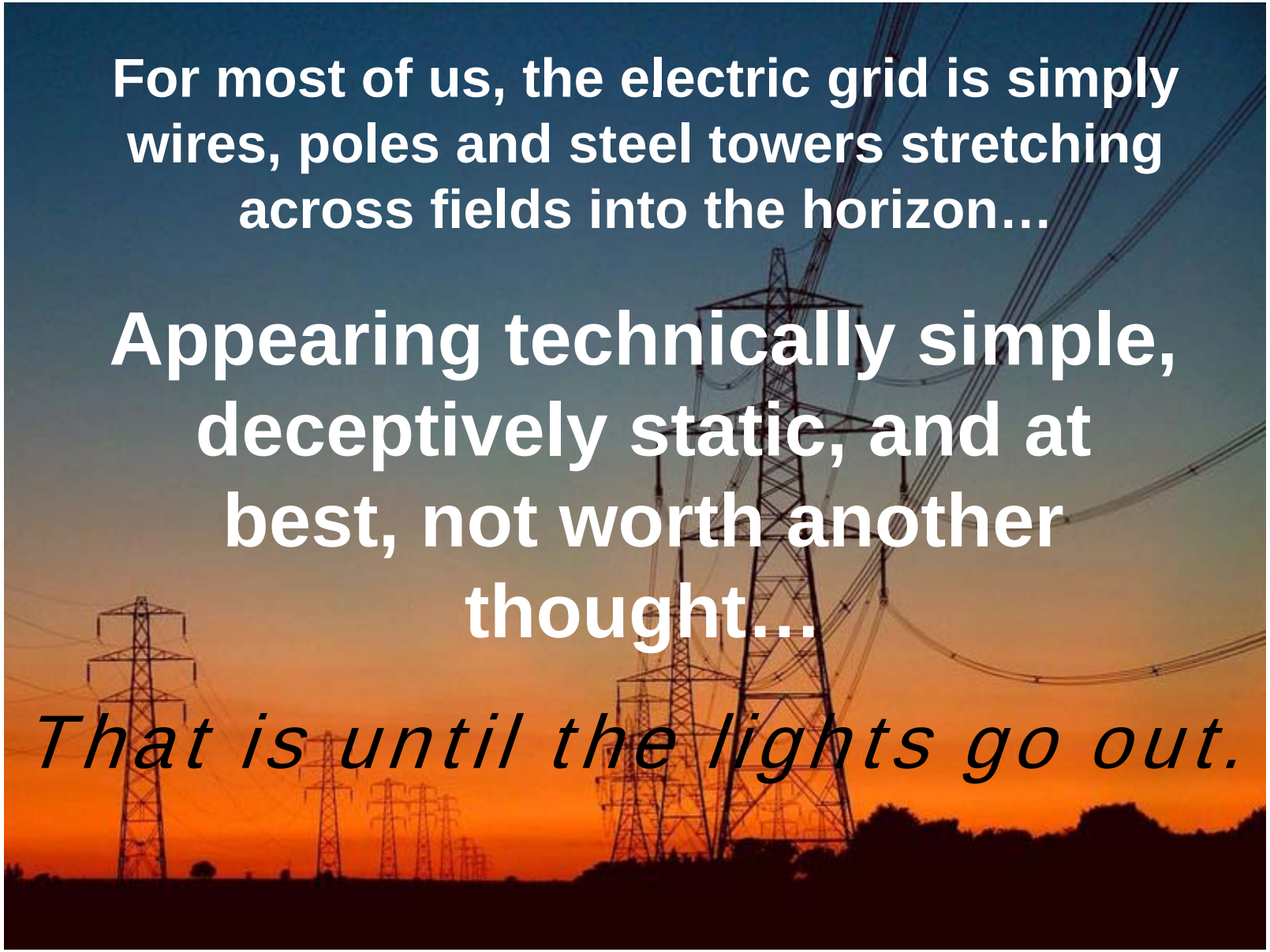
California State University, Long Beach, CA

Merwin Brown, PhD, Program Director

University of California ciee | *Electric Grid Research*

University of California

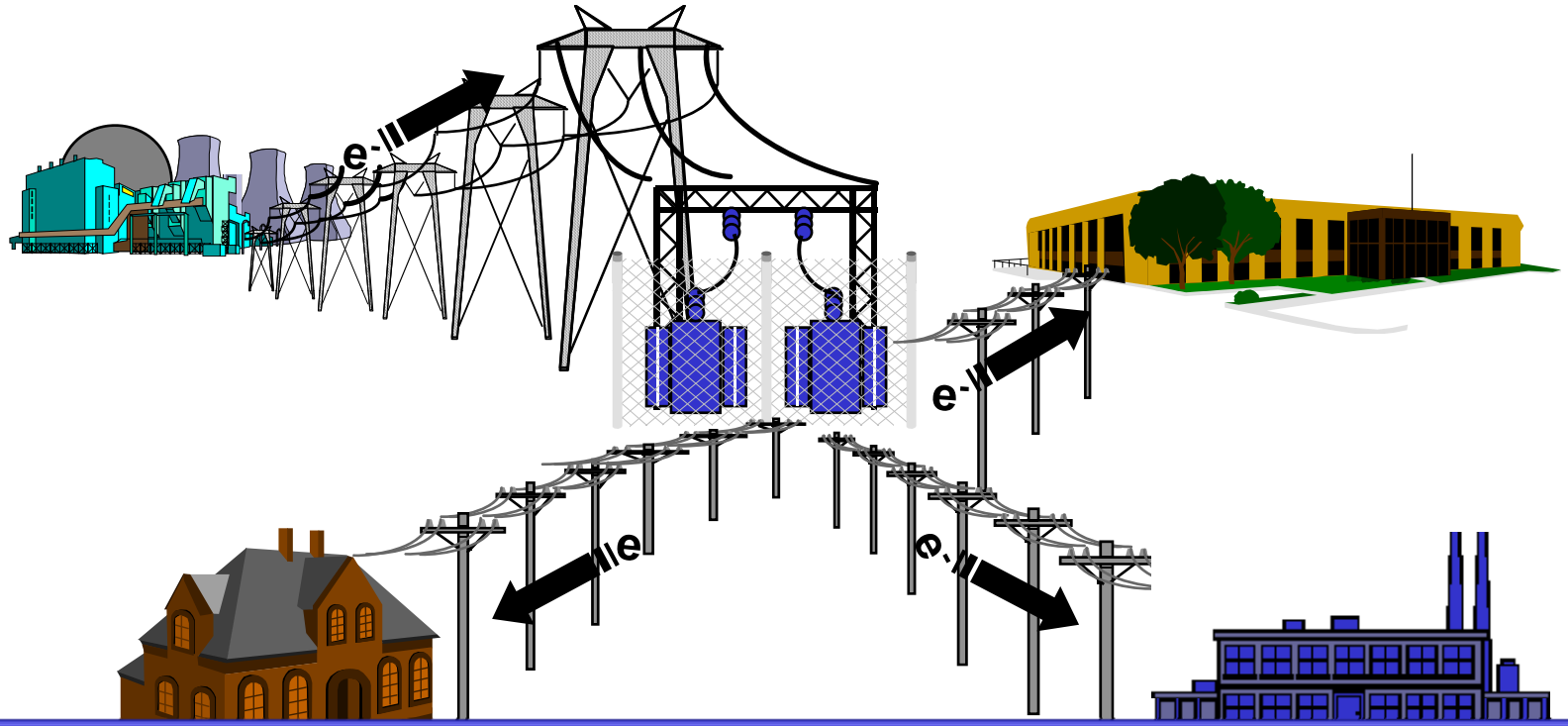
This presentation is based in part on work sponsored by the California Public Interest Energy Research (PIER) program administered by the California Energy Commission; it does not necessarily represent the views of, nor has it been approved or disapproved by, the Energy Commission.


For most of us, the electric grid is simply wires, poles and steel towers stretching across fields into the horizon…
Appearing technically simple, deceptively static, and at best, not worth another thought…
That is until the lights go out.

Power outages are expensive, a threat to human health, safety, and welfare, and to national security, and just plain inconvenient.

The 21st Century grid faces new, unprecedented challenges that threaten to increase the risk of power outages or higher costs, unless it is modernized.

For most of the 20th Century, the electric grid had a relatively simple role: moving electricity from central power plants to the consumers.



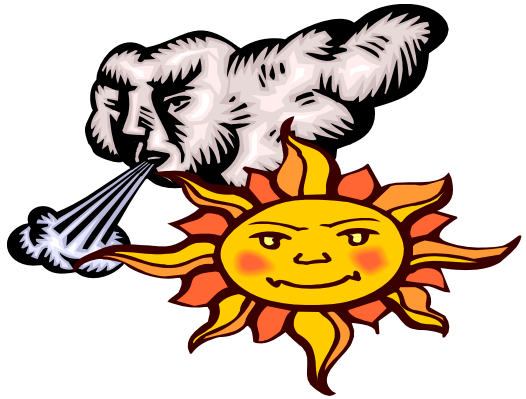
Its behavior was predictable, and under the close control of an operator - much like conducting an orchestra. ♬ ♬ ♬

But conducting the 21st Century electric grid is becoming hair raising:

- One of the world's largest machines, i.e., a multi-state, multi-country, brittle power delivery network
- Accommodating competitive power markets
- Serving growing and changing electric customer base that is becoming part of the "orchestra"
- Dealing with economic and public policy pressures

Being instrumental for meeting aggressive renewable energy goals

California's Renewable Energy Goals



- **Renewable generation to equal:**
  - **20% of retail sales Dec. 31, 2013**
  - **25% by Dec. 31, 2016**
  - **33% by Dec. 31, 2020**
- **20,000 MW of new renewable capacity by 2020**
  - **8,000 MW utility-scale renewables**
  - **12,000 MW of renewable distributed generation**

California's Renewables Portfolio Standard is one of the most aggressive in the US.

Source: 2011. *Staff Draft Report on Renewable Power in California: Status and Issues. California Energy Commission, August 2011, Publication No. CEC-150-2011-002.*

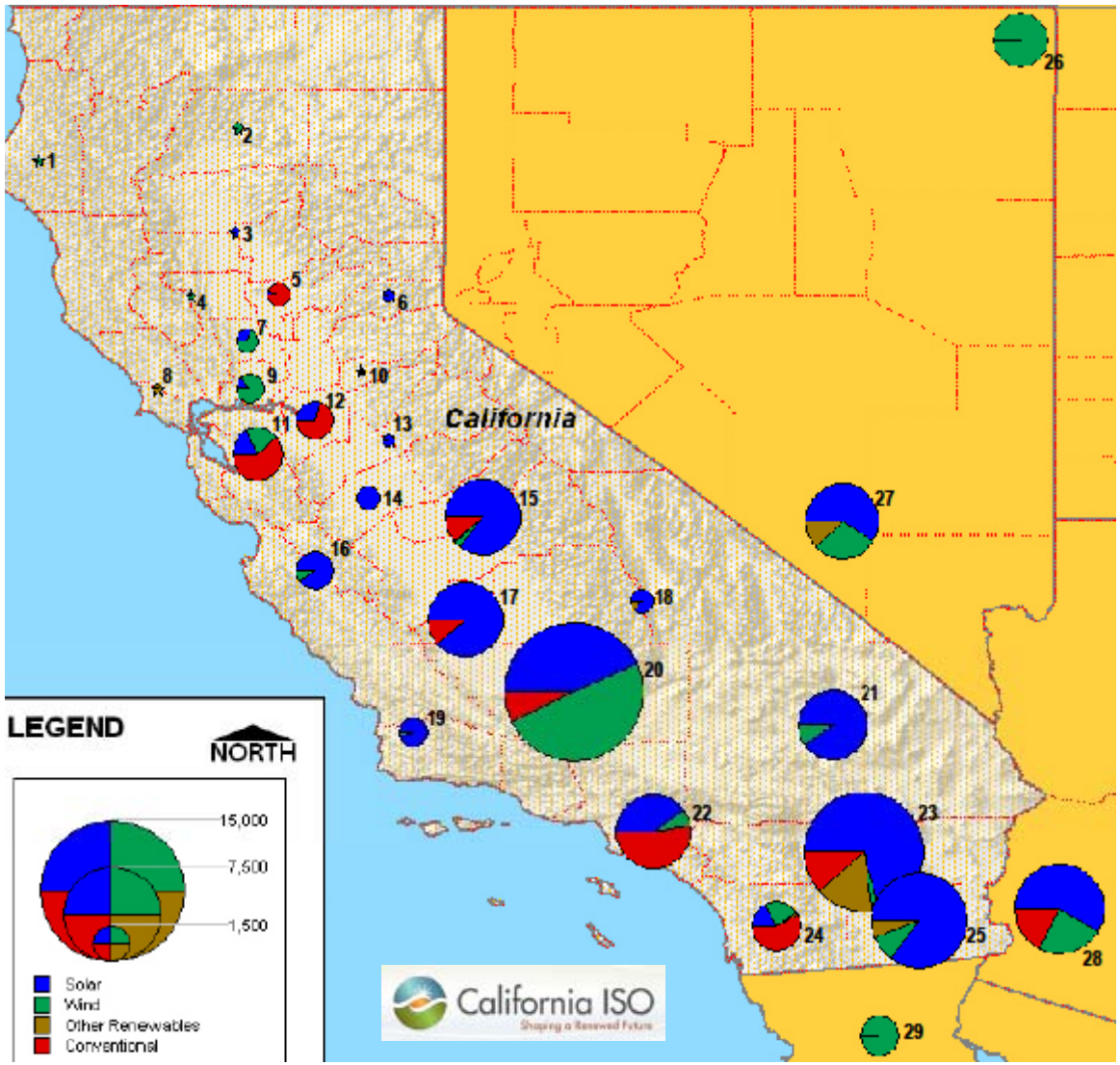
Why Such "Ambitious" Renewable Energy Goals?

When signing the California Renewable Energy Resources Act, Senate Bill (SB 2), April 2011, Governor Brown noted:

"This bill will bring many important benefits to California, including stimulating investment in green technologies in the state, creating tens of thousands of new jobs, improving local air quality, promoting energy independence, and reducing greenhouse gas emissions."

Source: California Energy Commission website, http://www.energy.ca.gov/renewables/history.html

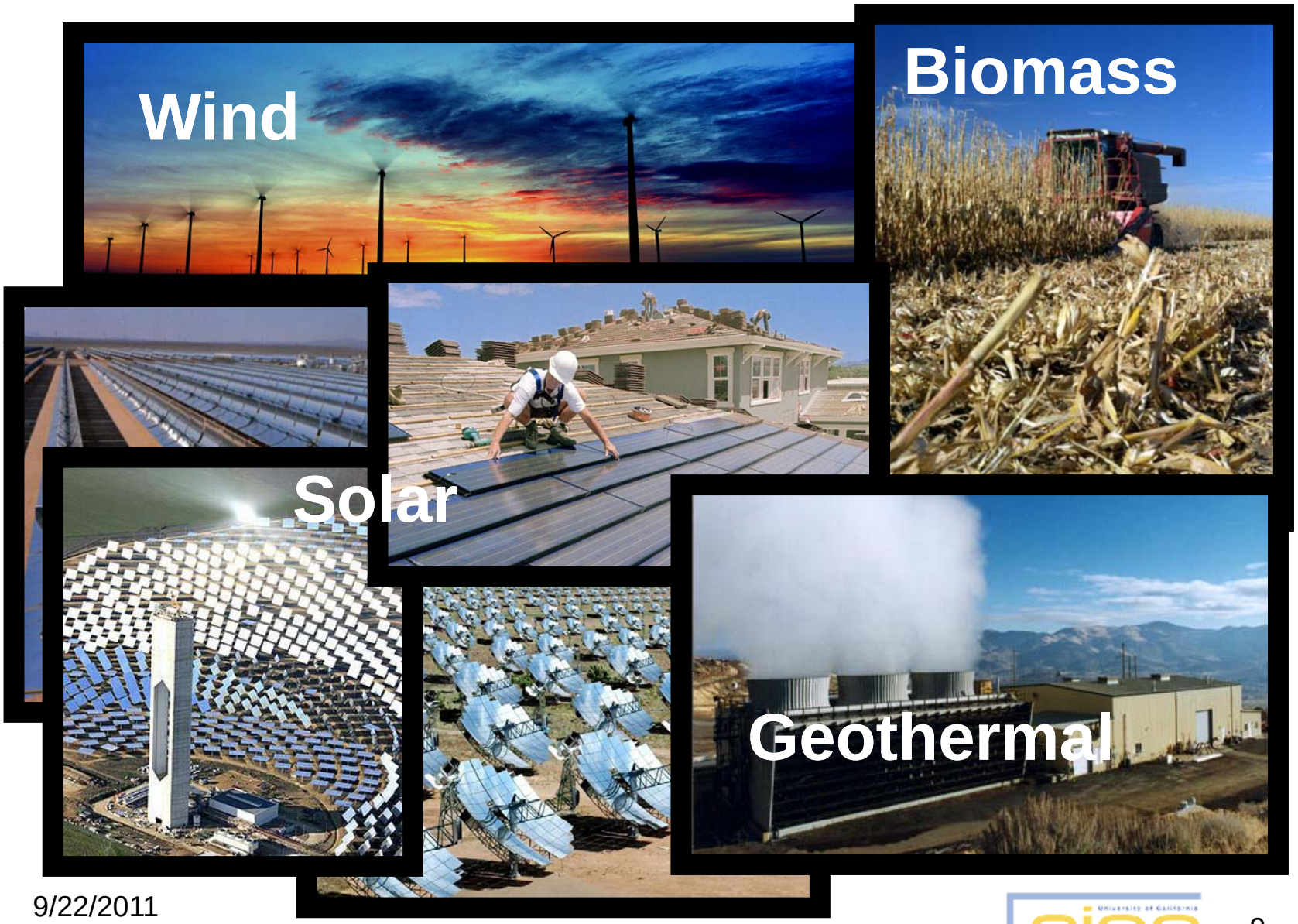
Renewable Projects in the CAISO Queue



Made up mostly of variable wind and solar resources.

Source: CAISO, *Briefing on Generation Interconnection Trends*, June 13-14, 2011 http://www.caiso.com/2bba/2bba799624040.pdf

By 2020 the public might see this…



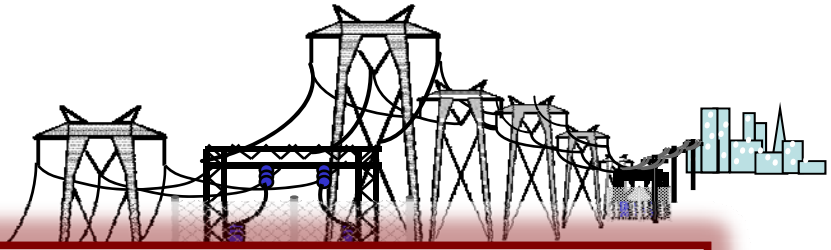
But to grid operators, 33% renewables looks more like this…

To better understand, let's explore…

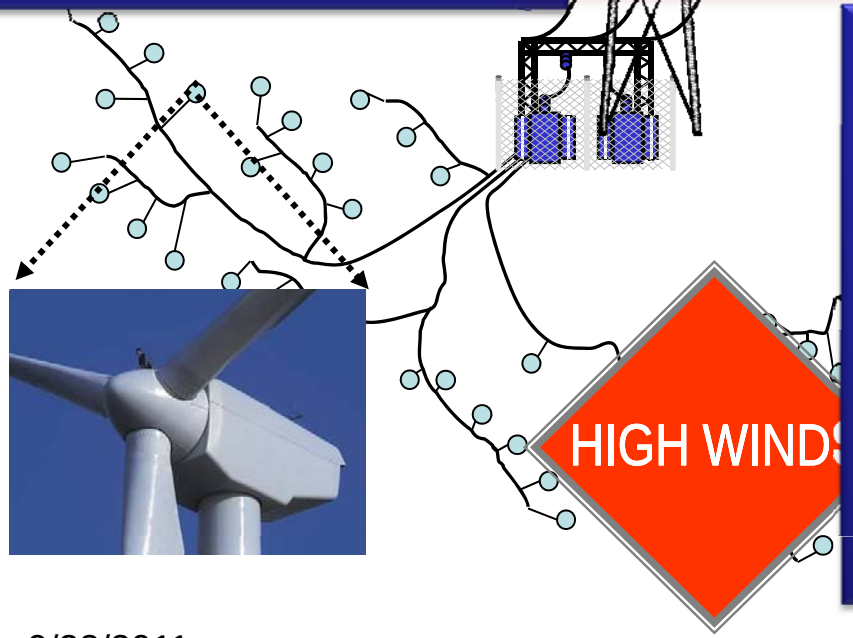
The Saga of Renewable Generation and Grid Integration.

The Saga of Renewable Generation and Grid Integration

Most central station renewable generation will be located remote from customers.



Grid must provide access.



Line extensions must be built to the power plants, but siting and permitting new transmission lines are becoming difficult.

Environmental impacts and financial concerns are biggest barriers to new transmission lines

- **Permitting and Siting**
  - **Aesthetic impacts**
  - **Environmental and land use impacts**
  - **Getting approval from multiple agencies and jurisdictions**
- **Planning and Cost Recovery**
  - **Proving need and value**
  - **Identifying benefits & allocating costs**

Delays can reduce reliability and economic efficiencies, and create barriers to meeting renewable generation policy goals.

Continuing *The Saga of Renewable Generation and Grid Integration*

Some renewables exhibit unique behaviors, for which the grid was not designed and the operator is ill equipped.

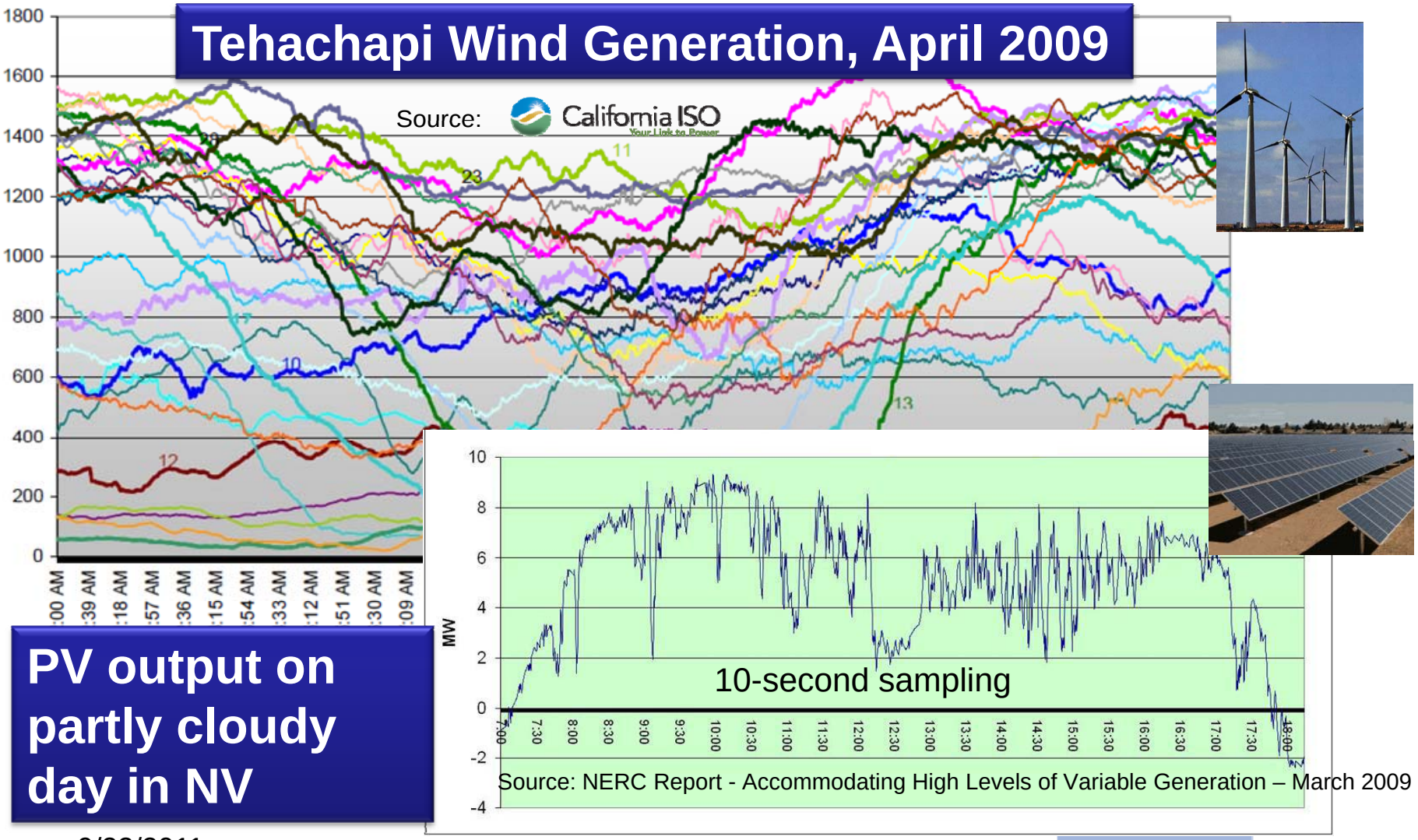
Grid must accommodate.

Renewable Power Plant

Some unique behaviors are:

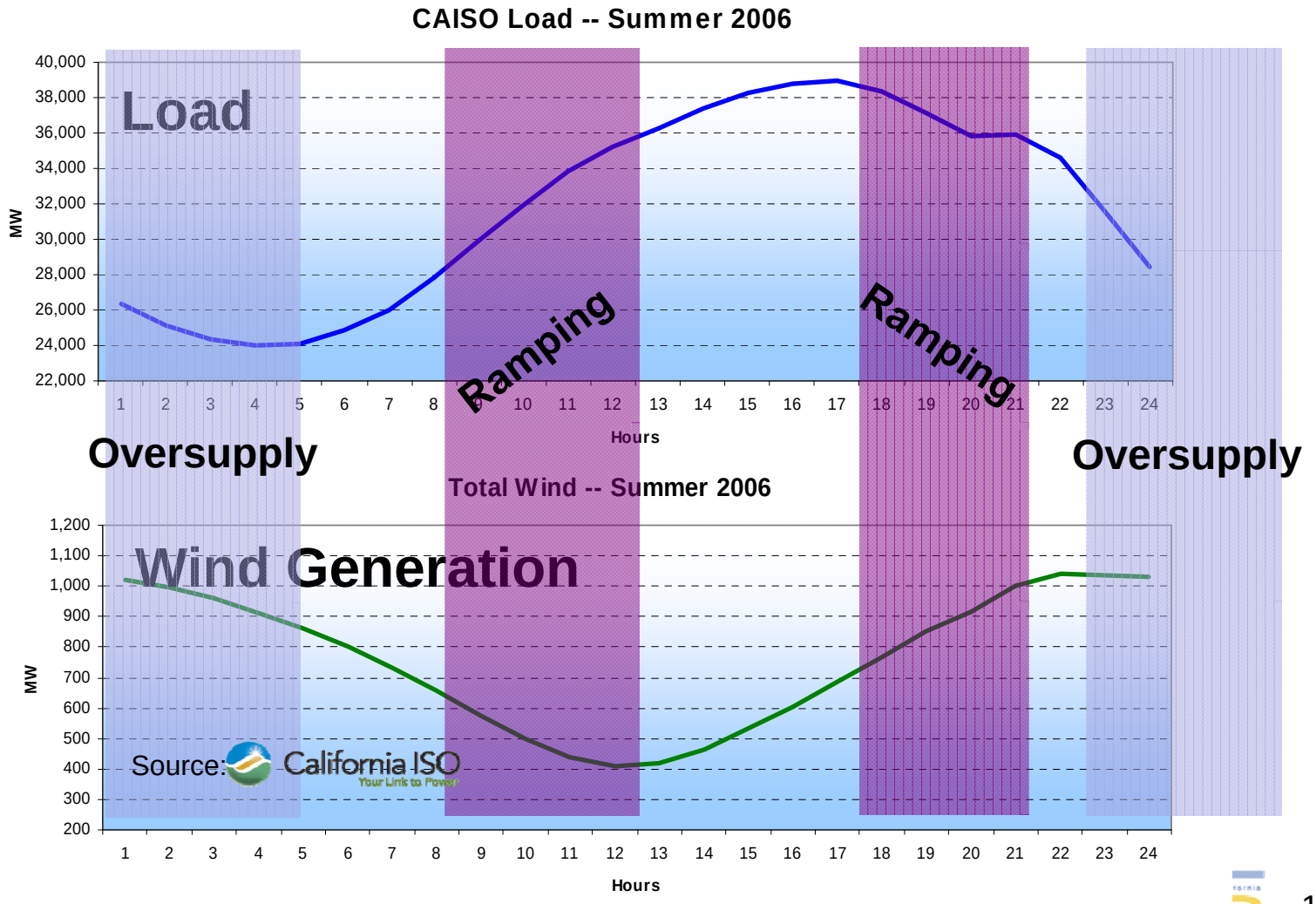
- ***Variability & Unpredictability***
- ***Fast Ramp-Rates***
- ***Over Supply***
- ***Low Inertia***

Wind and Solar can vary widely by the hour, and be a challenge to predict day to day.

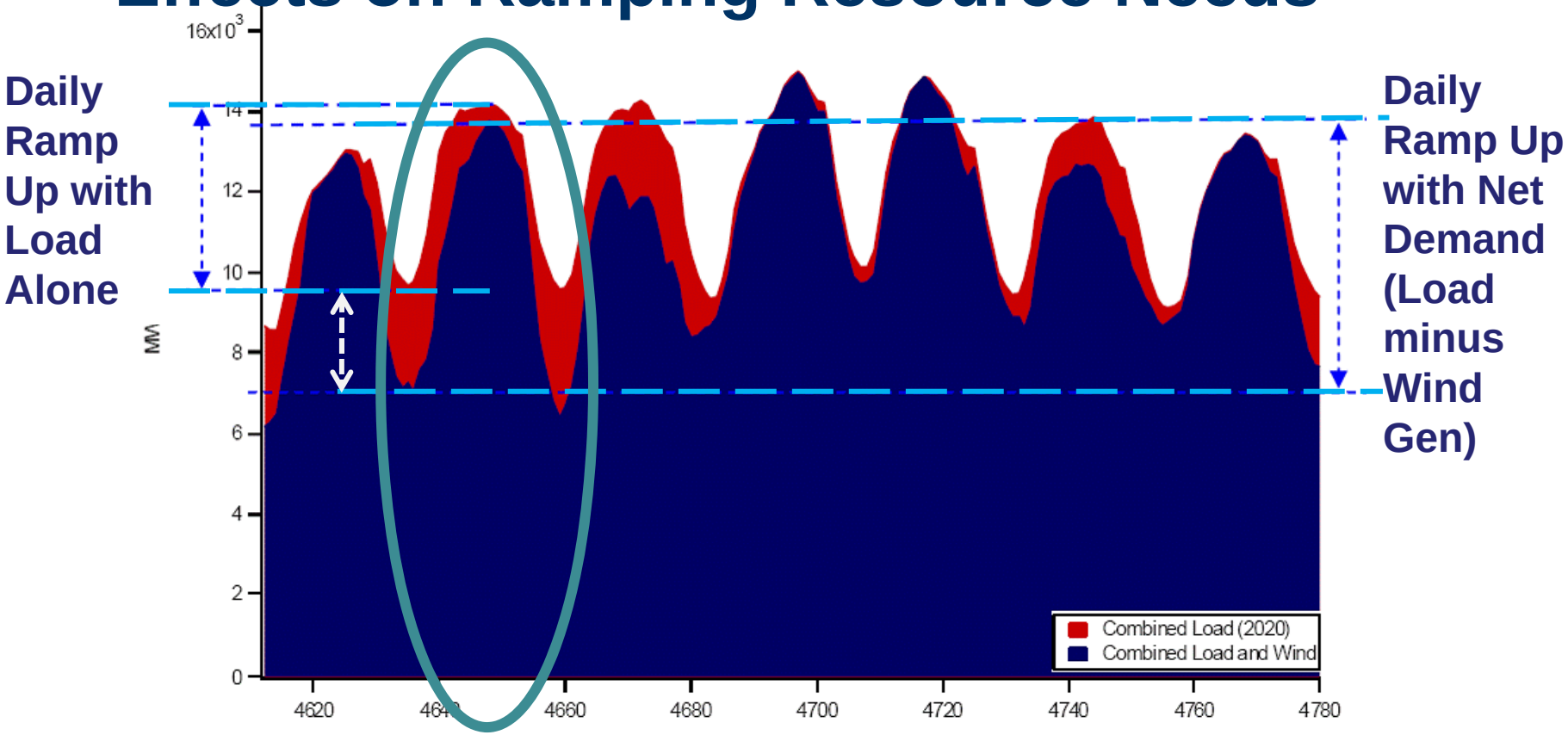


Source: NERC Report - Accommodating High Levels of Variable Generation – March 2009

Typical load & wind profiles are almost inverse, creating oversupply and ramping challenges.



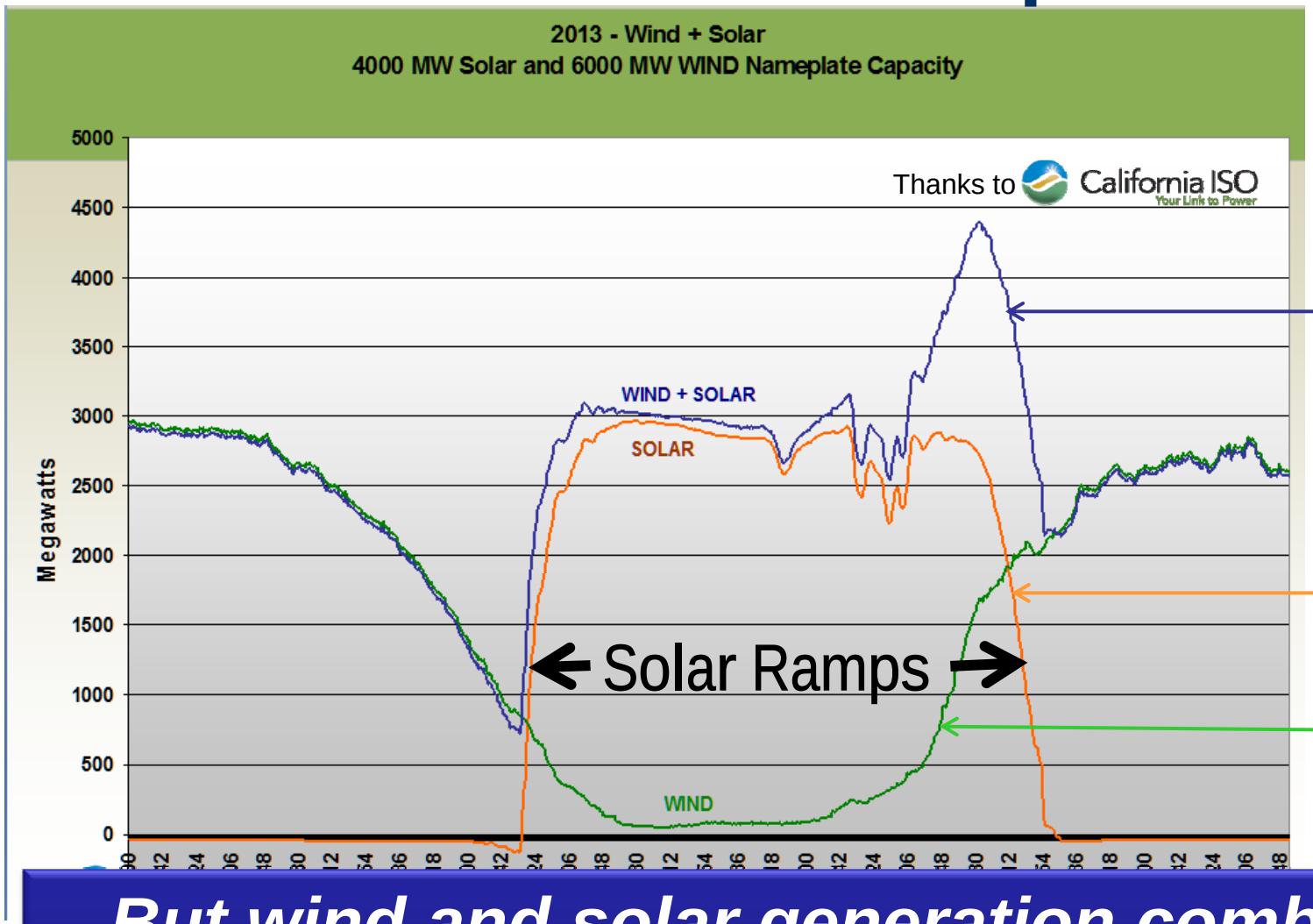
Power Profiles with and w/o Wind Show Effects on Ramping Resource Needs



~2,500 MW of new dispatchable generation required for ramping.

Source: NERC Report - Accommodating High Levels of Variable Generation – March 2009

Wind + Solar seem complementary…



…But wind and solar generation combined <u>appear</u> to make ramping worse.

Renewable integration analyses agree that additional ancillary services will be needed.

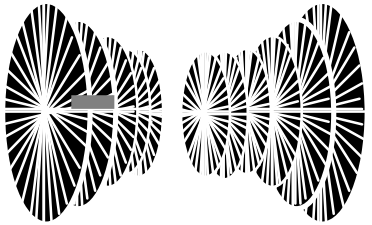
CAISO NYISO ERCOT NREL SPP

- Increased need for regulation, spinning reserves, and load-following
- Steeper system ramping requirements
- More frequent and serious over-generation events
- Less efficient dispatch of conventional resources
- Suppressed energy market prices

Source: Judy Chang, The Brattle Group, Renewable Energy Integration Issues and Analysis, EUCI Conference on Renewable Energy Development and Transmission Expansion, August 11, 2010

The power grid is designed and operated under the influence of inherent inertia.

- **The rotational mass of the turbine-generators in traditional (thermal) power plants create inherent inertia in the grid.**

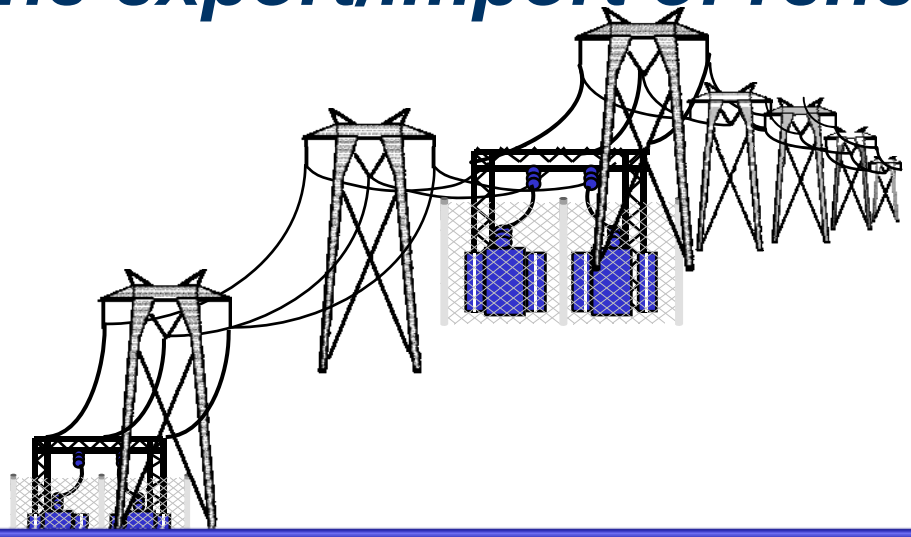


- **Some renewables exhibit traditional inertia because they use turbines.**

- **But wind and some solar power plants exhibit little or no inertia.**

A growing concern is that increasing renewable deployment will reduce inertia, causing grid instabilities to worsen.

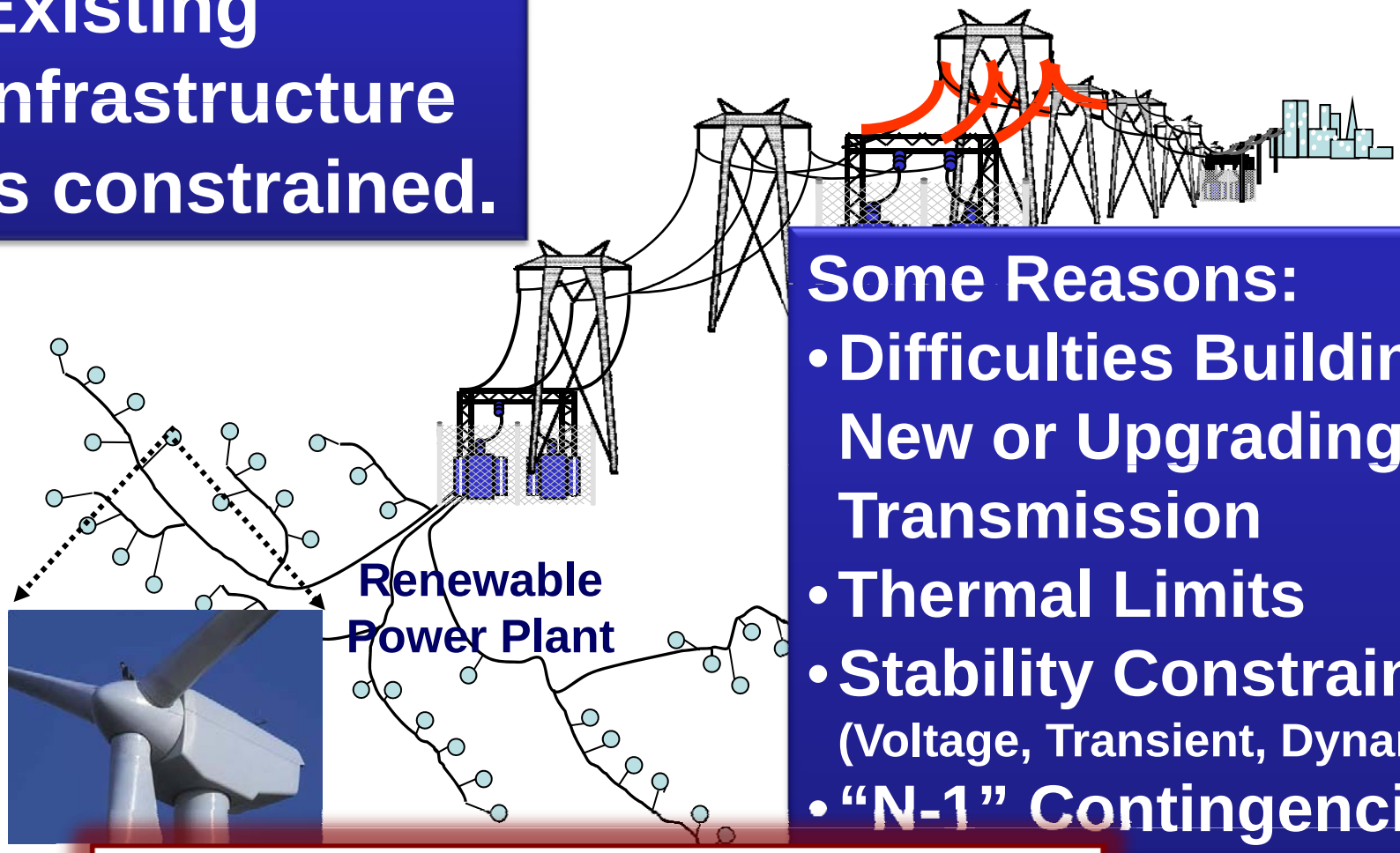
Western transmission deratings of 1000s of MW, put into practice to reduce threats to reliability from grid instabilities, are already costing millions of dollars a year, and restricting the export/import of renewable power.



Will high penetrations of wind and solar force even higher deratings or risks to grid reliability? Can lower inertia be exploited to benefit grid stability?

Continuing The Saga of Renewable Generation and Grid Integration

Existing infrastructure is constrained.



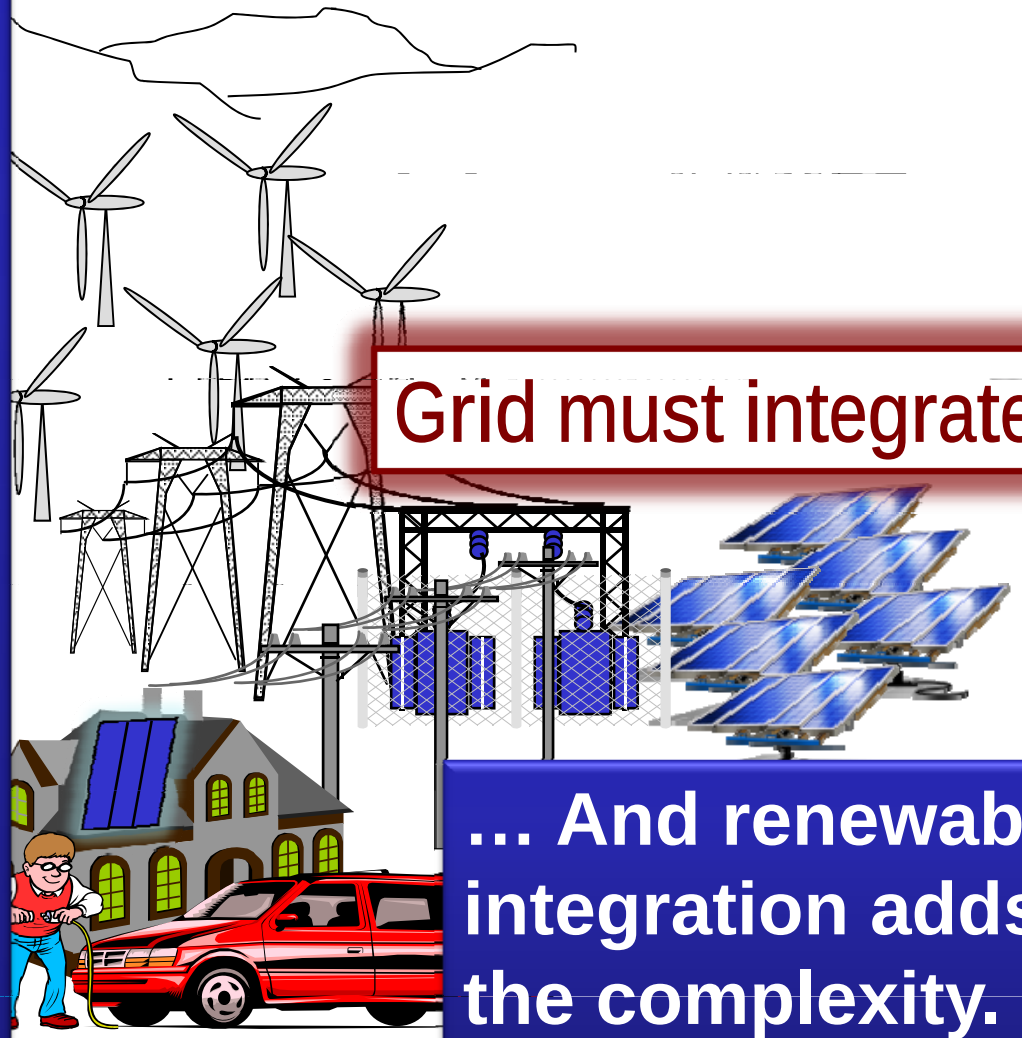
Some Reasons:

- **Difficulties Building New or Upgrading Transmission**
- **Thermal Limits**
- **Stability Constraints (Voltage, Transient, Dynamic)**
- **"N-1" Contingencies**

Grid capacity must be increased.

Continuing the Saga of Renewable Generation and Grid Integration

At the distribution end of the grid, distributed generation integration offers a significant class of challenges…



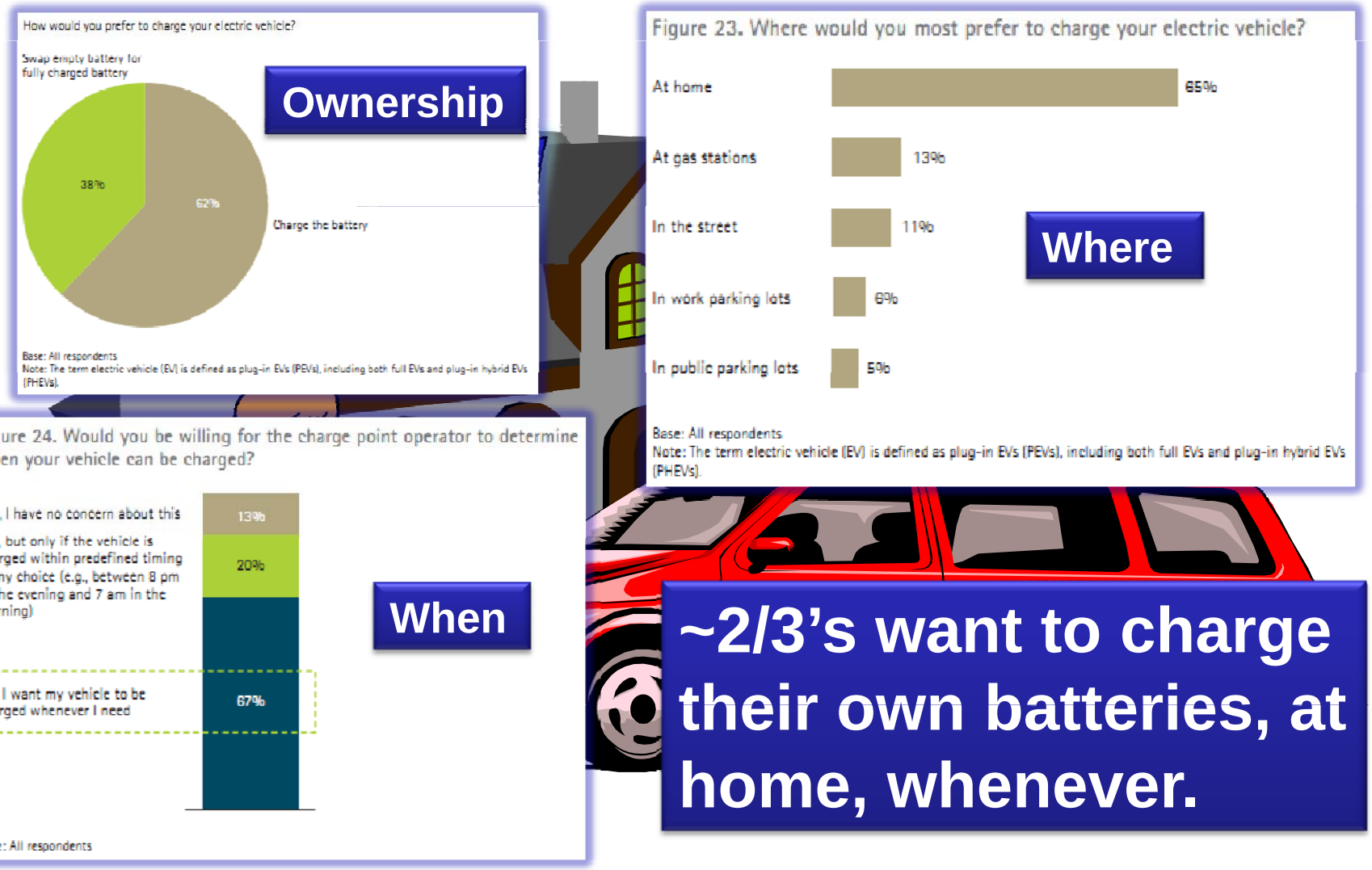
Grid must integrate DG.

… And renewable DG integration adds to the complexity.

While the technical effects of renewable DG are grid-wide, they tend to be felt most locally.

- Clustering - uneven DG penetration
- Islanding/Safety
  - preventing unintentional islanding
  - variable power quality and reliability
  - application of microgrid concept
- Modeling - masking load with generation
- Transformers - local capacity limitations
- Protection
  - back-feed (reverse power flow)
  - fault current contribution from DG
  - relay desensitization
- Voltage regulation
  - maintaining voltage in permissible range
  - voltage ride-through
  - wear on existing voltage regulation equipment
  - reactive power (VAR) support

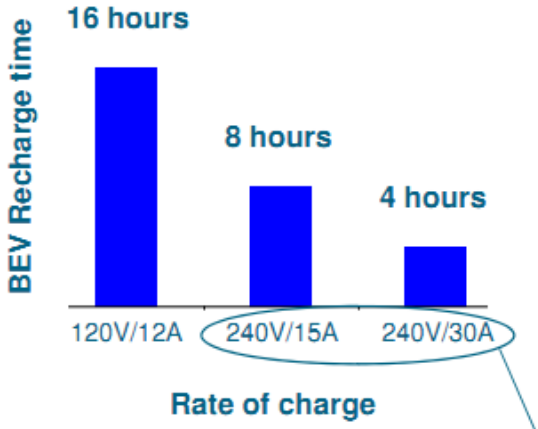
How consumers want to charge their EVs*

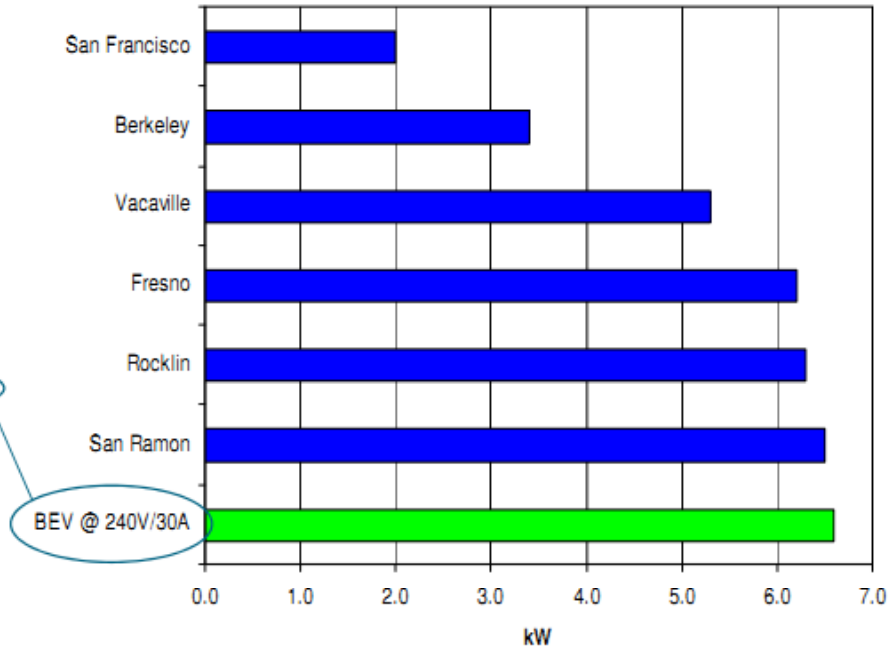


***Reference**: Accenture, "Plug-in Electric Vehicles: Changing Perceptions, Hedging Bets," an end-consumer survey on the electrification of private transport, 2011

PEV Charging Creates A Significant Increase In Load

Customers will prefer a 240V charge to shorten recharge times → **PEV charging is a large load for PG&E customers, comparable to average peak summer load of a single home**





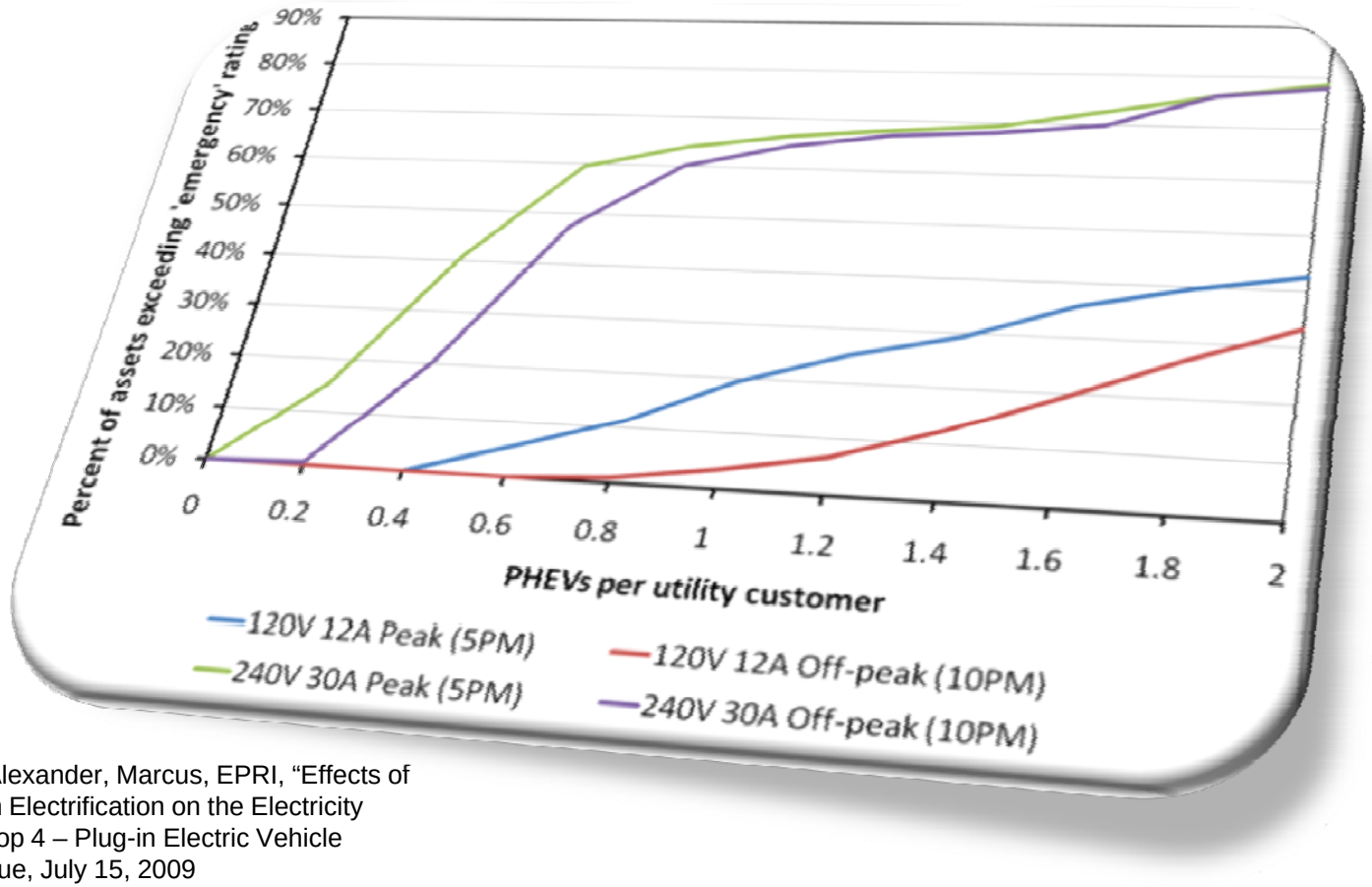
Slide from: Tang, Andrew, "Smart Grid: Vision, Opportunity and Effectiveness," Berkeley-Stanford CleanTech Conference Series, Nov 13, 2009

Source: http://www.nissanusa.com/leaf-electric-car/#/charging, August 14, 2009

7

In short, each new EV is ~ a new household load.

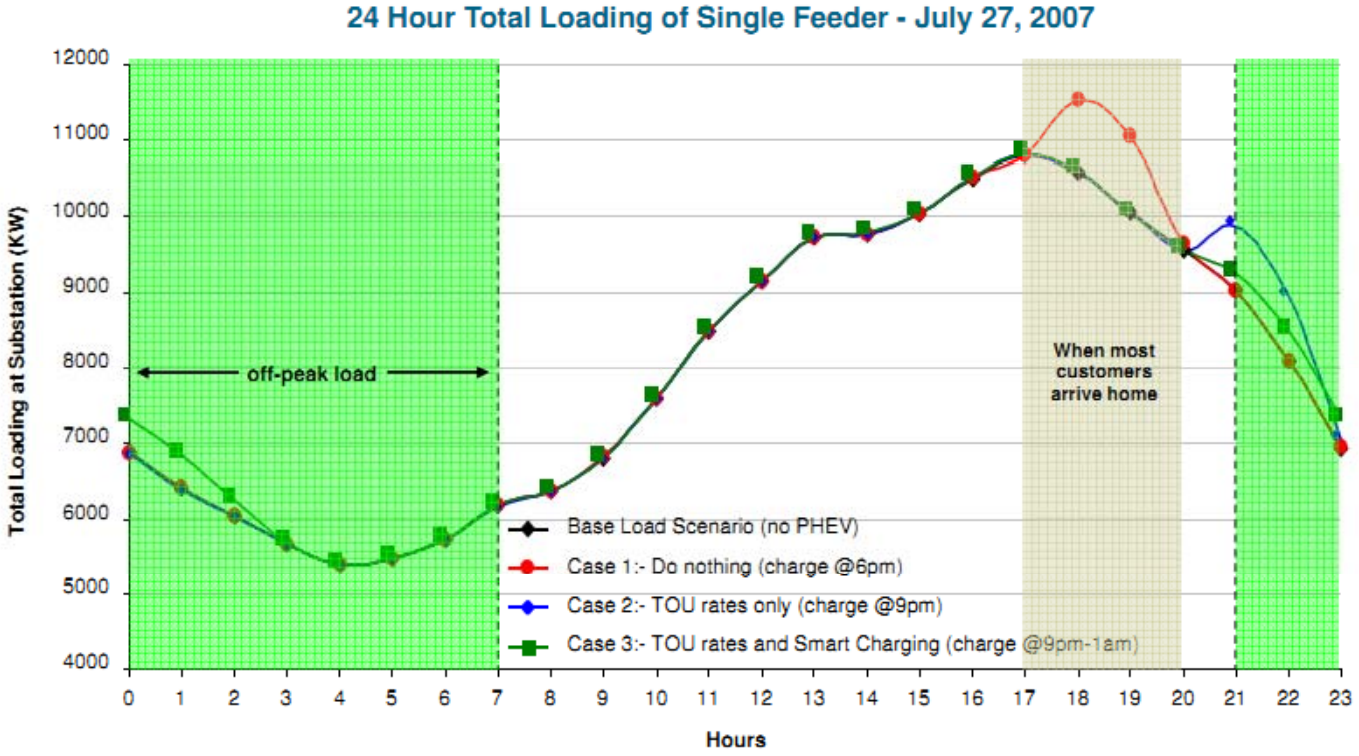
Asset overloading can increase quickly.*



***Reference**: Alexander, Marcus, EPRI, "Effects of Transportation Electrification on the Electricity Grid," Workshop 4 – Plug-in Electric Vehicle Integration Issue, July 15, 2009

At medium charging rate, < one PHEV/house can significant increase overloading.

Left Unmanaged, PEV load will add to peak electric demand



Slide from: Tang, Andrew, "Smart Grid: Vision, Opportunity and Effectiveness," Berkeley-Stanford CleanTech Conference Series, Nov 13, 2009

Source: EPRI.

Note: Feeder of Northeastern utility feeder during urban summer peak with 2,778 residential customers. PEV penetration = 10%. Case 1 – 3 charge @ 240V, 12A

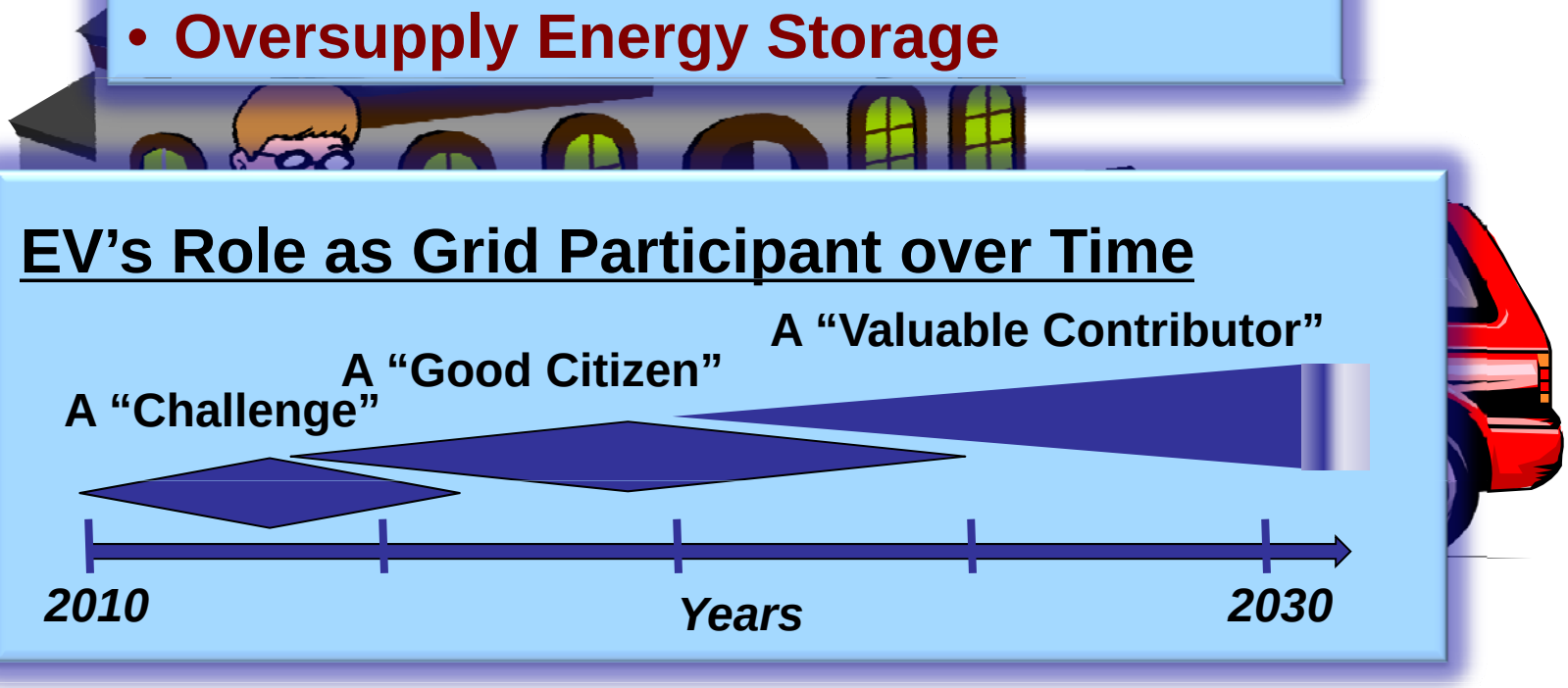
9

Unmanaged charging = problem;
Managed charging = opportunity

Today the electric grid is a resource for EVs, tomorrow EVs might be a resource for the grid.

V2G: Possible Services to Electric Grid

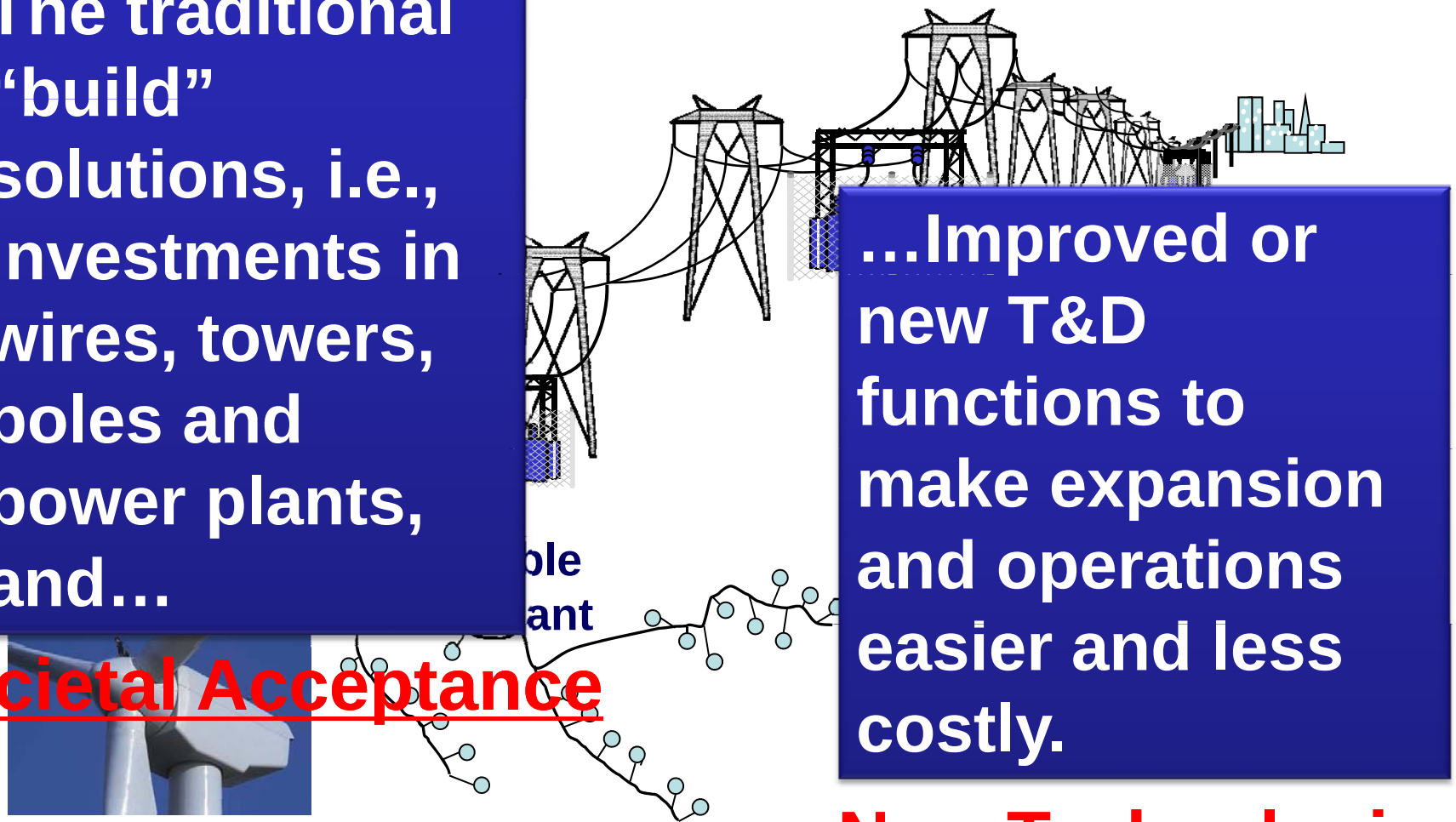
- Regulation
- Spinning Reserve
- Emergency Reserve or Load Shed
- Oversupply Energy Storage



EV's Role as Grid Participant over Time

There are essentially two options for successful expansion and operations of T&D:

The traditional "build" solutions, i.e., investments in wires, towers, poles and power plants, and…



…Improved or new T&D functions to make expansion and operations easier and less costly.

Societal Acceptance

New Technologies

Assertions: For now we can "build" our way out of these problems, but at higher renewable penetrations…

- …traditional "build" solutions, i.e., investments in wires, towers and power plants, can't do it alone.

- New technologies will be needed to make renewable integration easier and less costly…

…especially technologies that make the grid smarter.

New technologies needed to…

Provide faster *access* for new renewable plant

… by putting new power lines in a better light.

***Accommodate* renewable & distributed generator behaviors**

… by making the grid smarter and more flexible.

Increase grid power *capacity*

… by optimizing the grid for greater power flow.

Technologies come in many flavors: hardware, communications, and analytics.

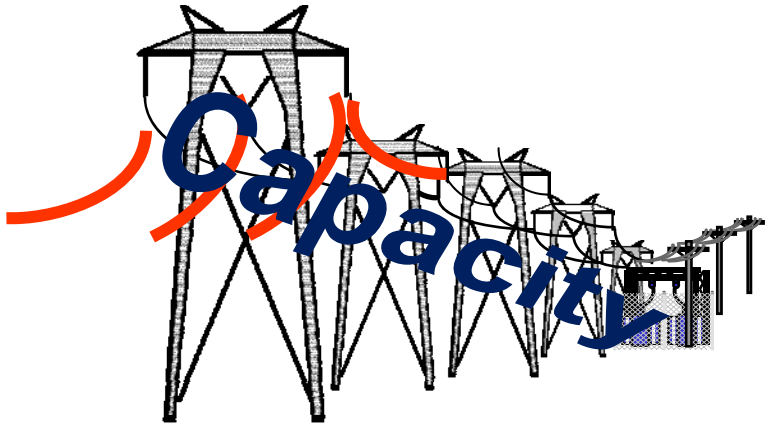
Putting New Power Lines in a Better "Light"

- ***Aesthetics*** **- Reduce or eliminate T&D visual footprint**
  - **Compact Corridors**
  - **Underground Transmission**
  - **Distributed Renewables & Demand Response**
- ***Values*** **- Improve the benefit/cost via more knowledge, insight and transparency**
  - **Web-based Interactive Stakeholder Siting Tools**
  - **Cost Allocation & Strategic Benefit Analysis Tools**

A Smarter, More Flexible Grid

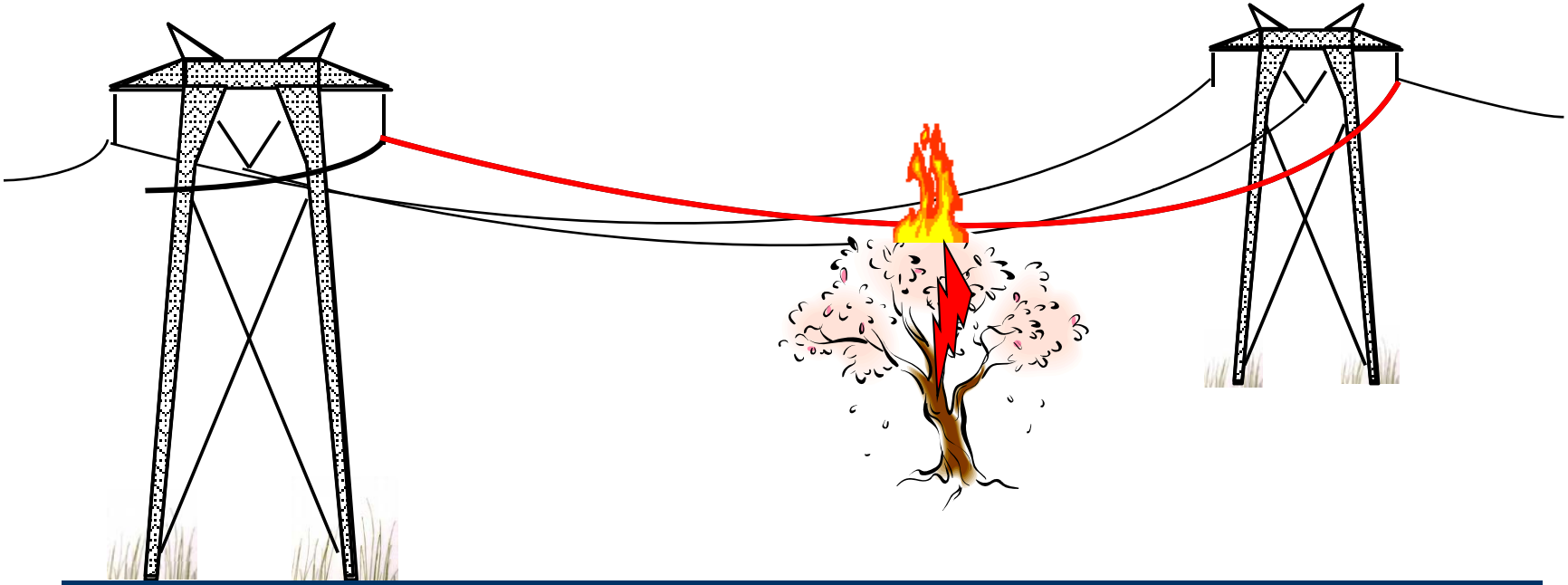
- **Situation Awareness**
  - **Wide-Area, Real-Time Monitoring**
  - **Visualization**
  - **“Smart Meters”**
  - **Telemetry**
- **Planning & Forecasting**
  - **Solar and Wind Forecasting Tools**
  - **Generator and Load Modeling**
  - **Statistical/Probabilistic Planning Tools**
- **Control**
  - **Energy Storage (temporal power flow control)**
  - **Ancillary Services Devices**
  - **Advanced Power Electronics**
  - **Advanced Intelligent Protection Systems**
  - **Demand Response**
  - **Distributed Generation (non-variable, variable)**

Optimizing the Grid for Greater Power Flow



- Situation Awareness
  - Dynamic Thermal Ratings
  - Wide-Area, Real-Time Monitoring
  - Visualization
  - “Smart Meters”
- Planning & Forecasting
  - Statistical & Probabilistic Planning Tools
- Control
  - Energy Storage
  - Power Flow Control (spatial)
  - Ancillary Services Devices
  - Advanced Intelligent Protection Systems
  - Advanced Fast, High-bandwidth Communications and Computations
  - Demand Response
  - Distributed Generation
- Physical Plant
  - Advanced Transmission Line Conductors and Designs
  - Advanced Grid Components
  - Fault Current Controllers

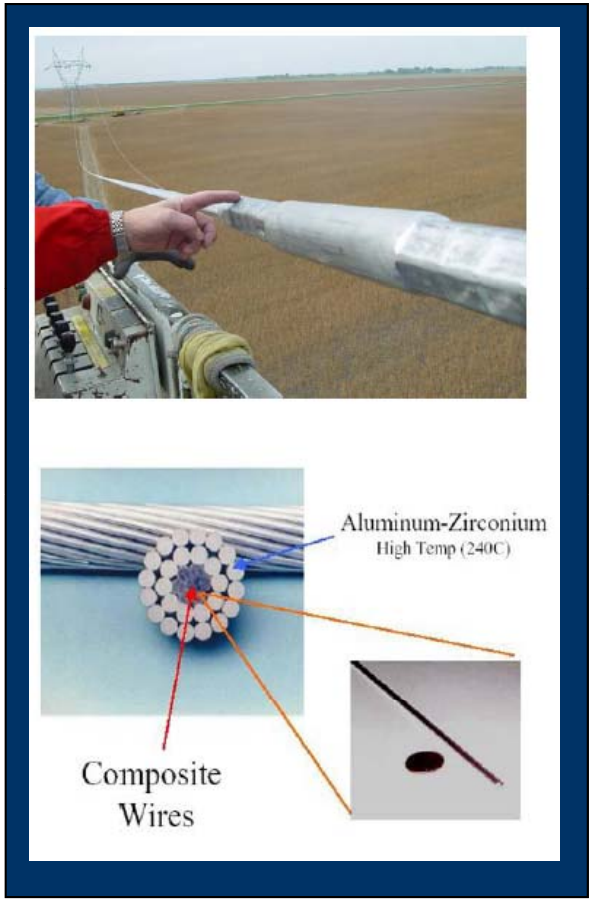
Transmission capacity limited by high line temperatures caused by I^2R.



High temperatures can damage line material or cause line to sag too low, creating safety hazards and/or outages.

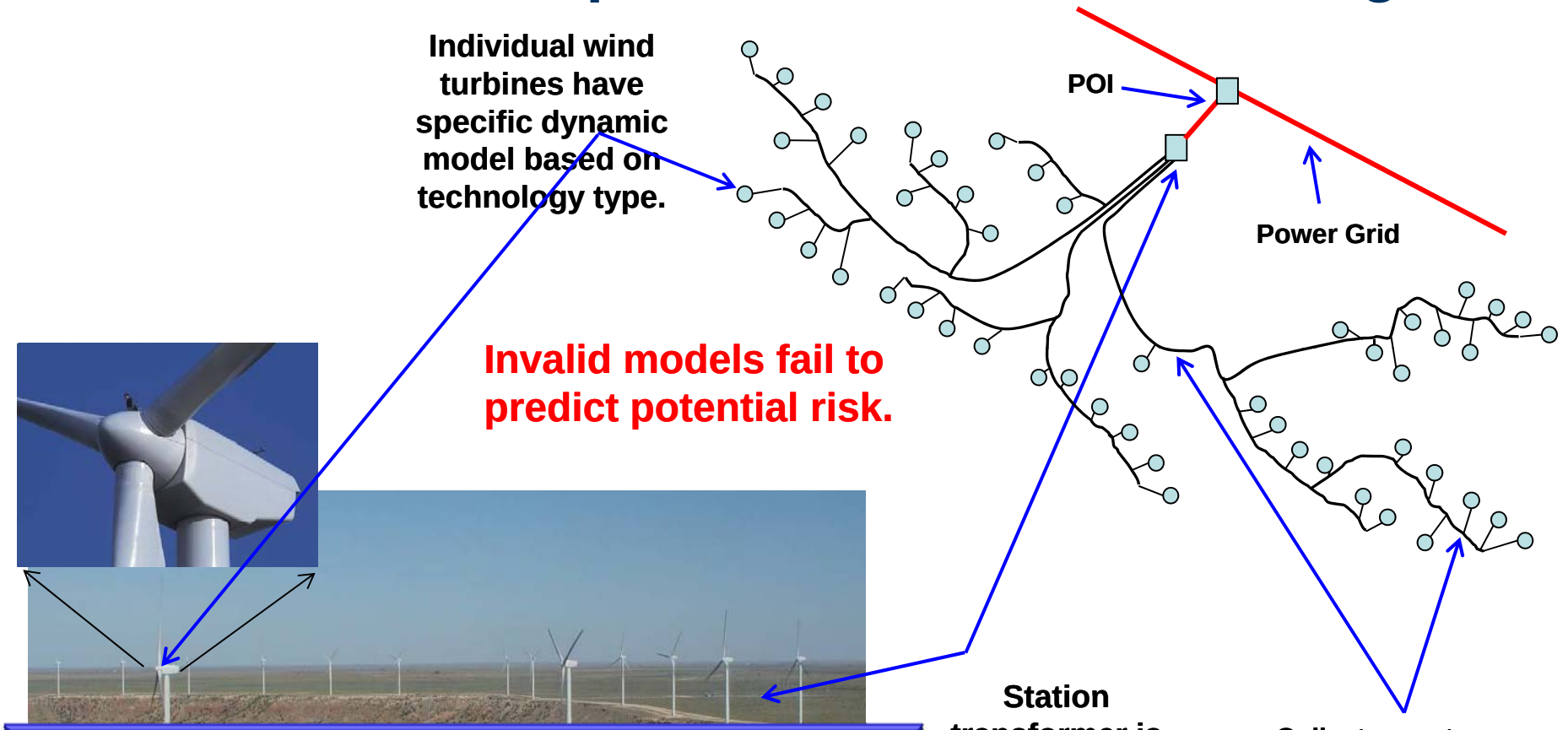
Example: Increase Capacity of Transmission Corridors via New Line Materials.

- **High-Temperature, Low-Sag Conductors: New composite core materials replace steel.**
- **> 2X power flow through transmission corridor.**
- **Upgrade transmission conductor without rebuilding transmission towers**
- **3M's version being tested at San Diego Gas and Electric.**



3M High-Temperature Low-Sag Conductor

Example: Accommodate Renewable Generation Unique Behaviors via Modeling

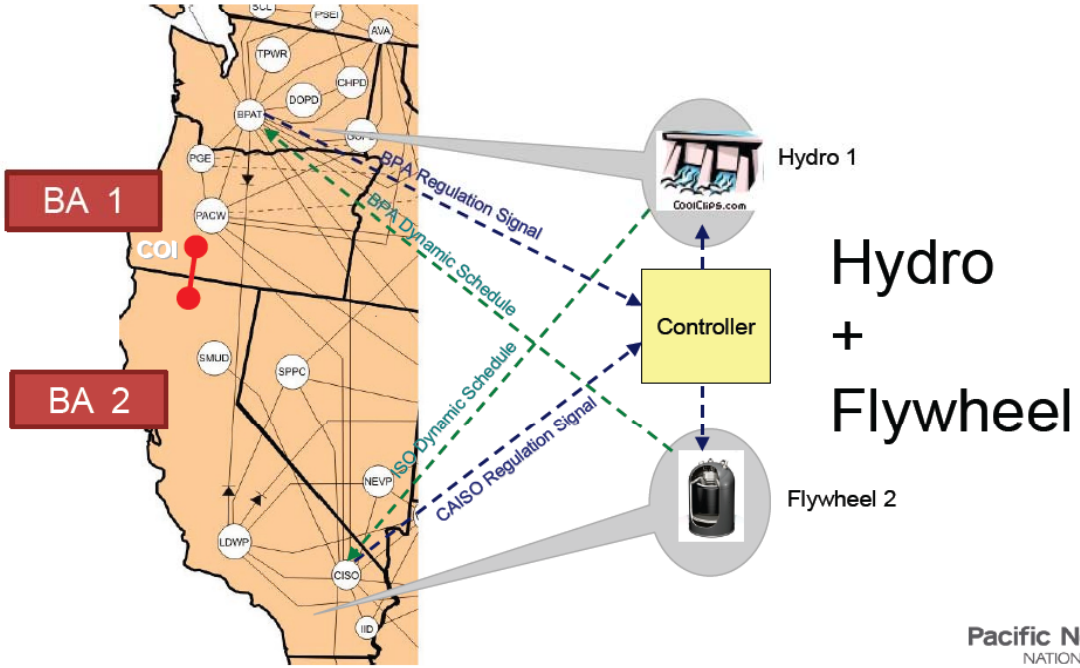


Updating dynamic wind power plant models reduces chances of grid problems.

Example: Accommodate Renewable Generation Unique Behaviors via Energy Storage

Wide Area Energy Storage Management System (WAEMS)

A WAEMS is a centralized control system that operates energy storage devices (ESDs) located in different places to provide energy and ancillary services that can be shared among balancing authorities (BAs).



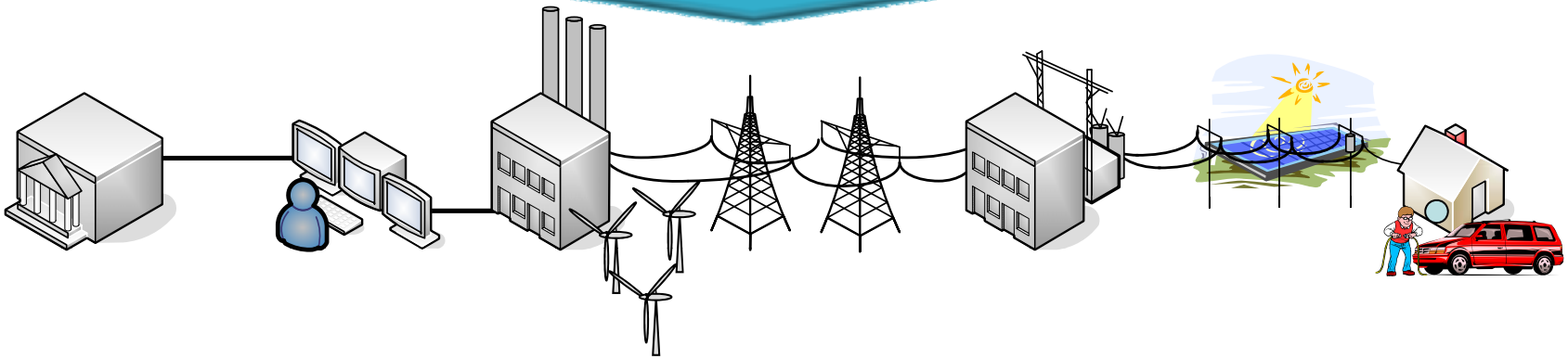
Combined flywheel/hydro resources shared between 2 control areas effectively … reduced total regulation requirements by ~$220M/yr. in 2020 w/33% renewables. **(PNNL)**

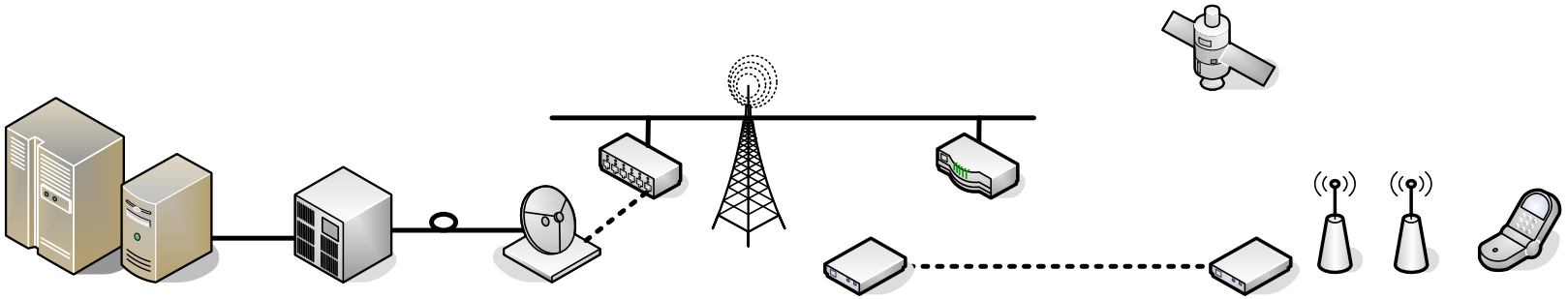
Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Example: Accommodate Renewables & Increase Capacity by Joining 2 Infrastructures

Electrical Infrastructure

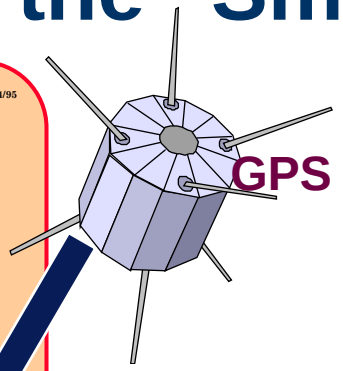




"Intelligence" Infrastructure

Equals the "Smart" Grid

Synchrophasor Measurements – The Basis of the "Smart Grid" Transmission

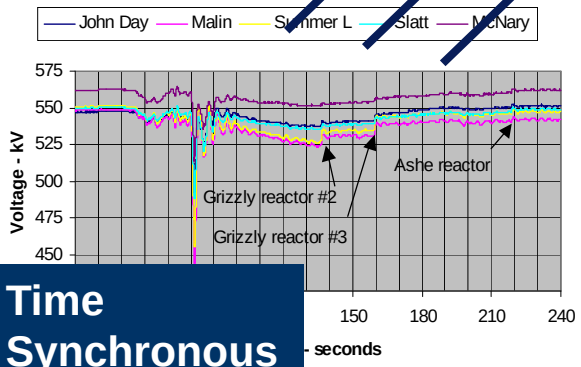


GPS Satellite

Time-Stamp

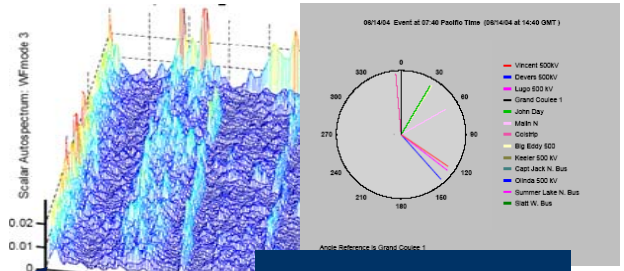
PMUs (Phasor Measurement Units)

Data

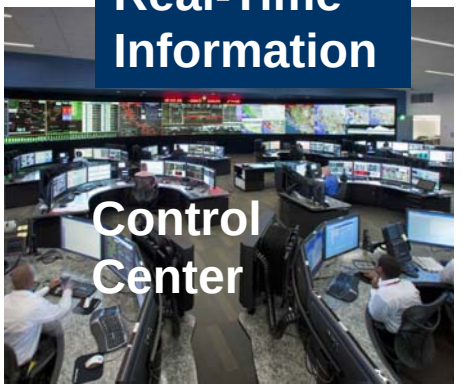


Time Synchronous Data

Data



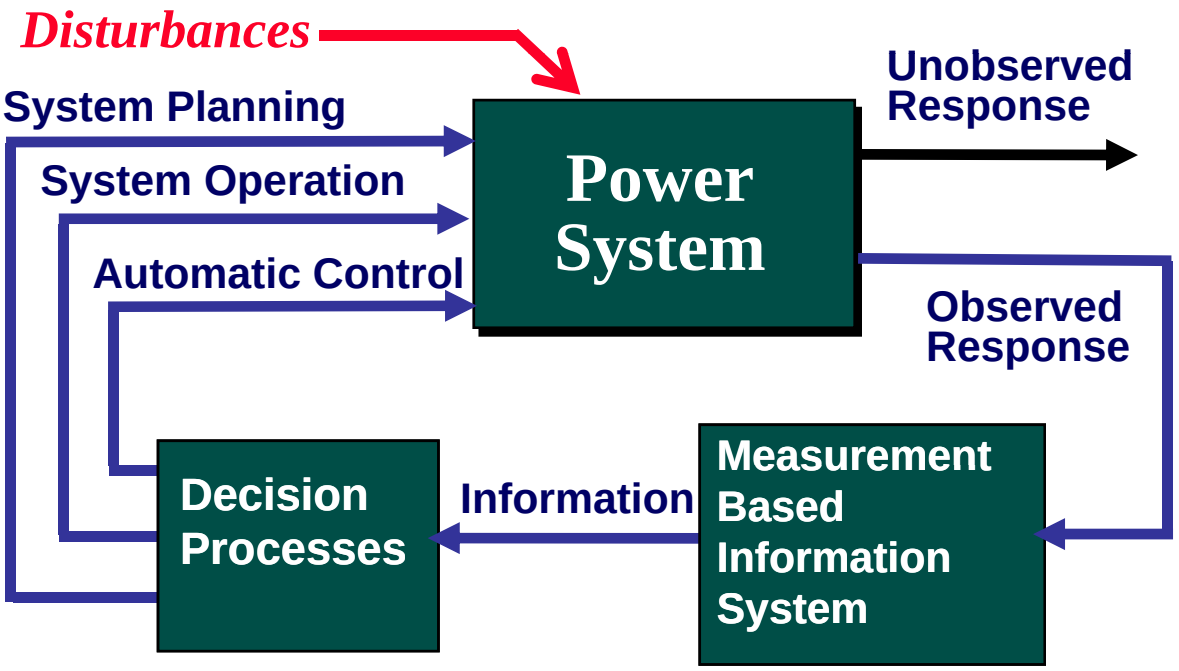
Useful Real-Time Information

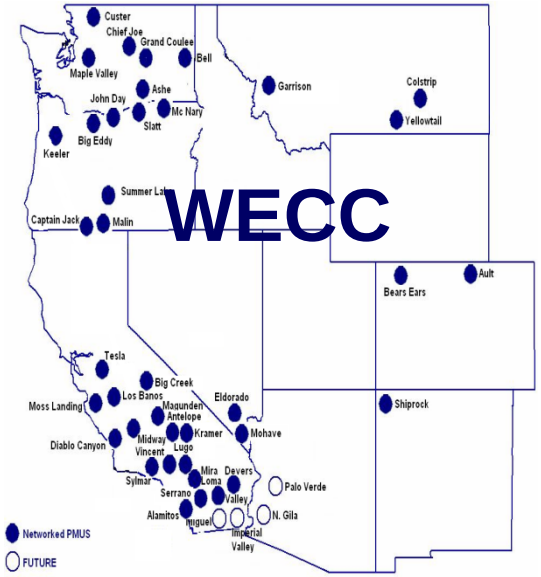


Example: Accommodate Renewable Generation and Increase Grid Capacity via Real-Time Wide-Area Monitoring and Control.

The Before and After of Synchrophasor Measurements

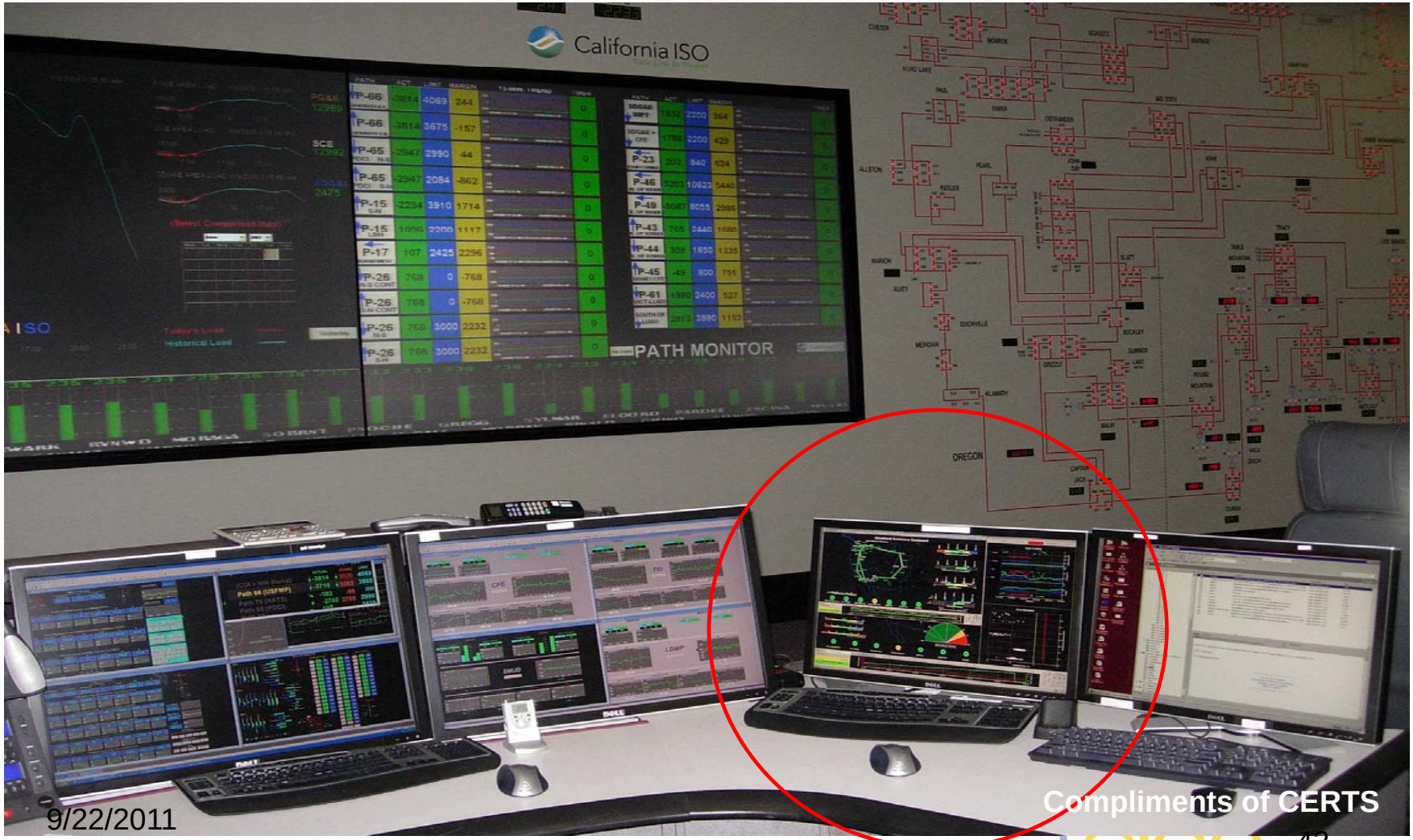
Synchrophasors ^ Traditional Real-Time Data Rate = Every 4-5 seconds ^ 30/second





An unprecedented ability to see, know, plan and control.

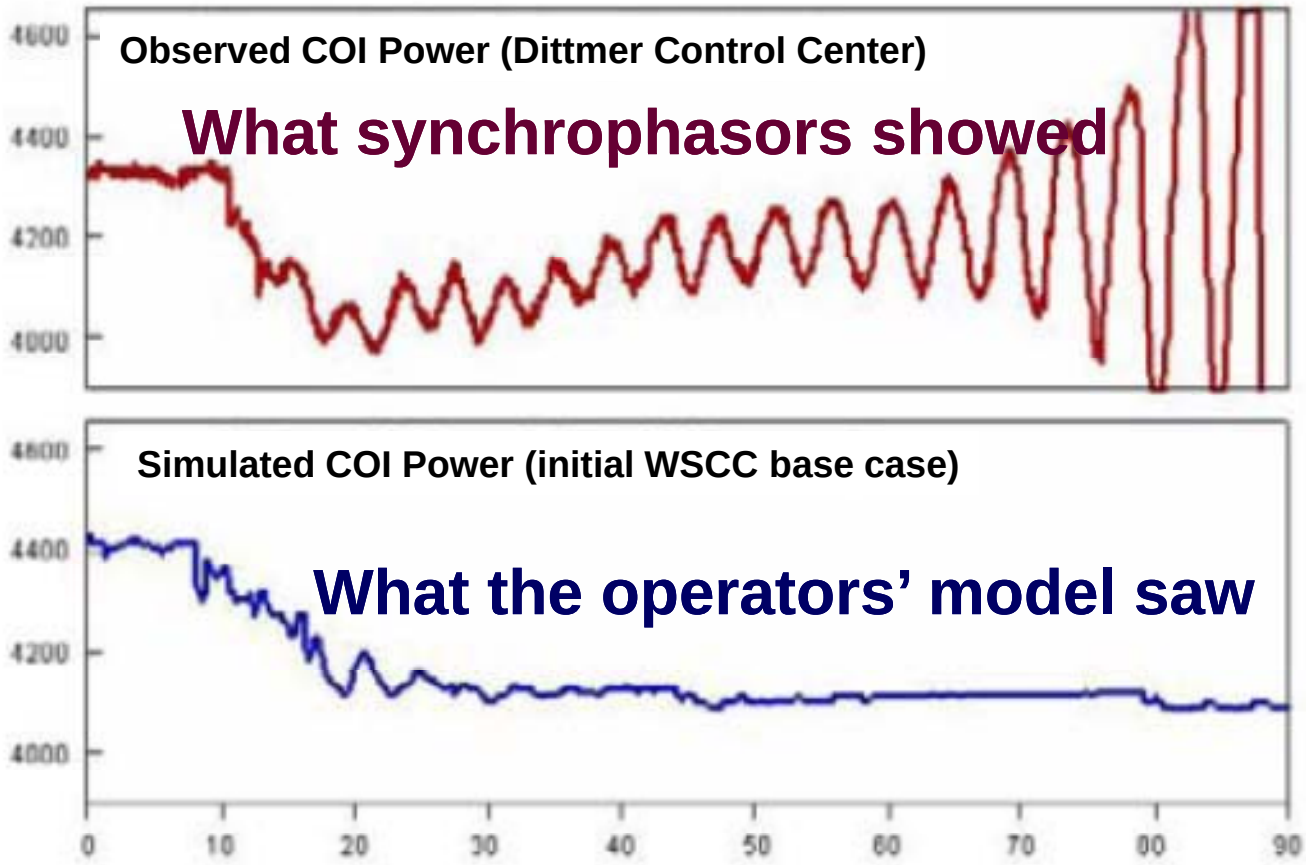
CAISO, SCE, PG&E, and SDG&E Are Pioneering the Use of Synchrophasor Technologies in California



Compliments of CERTS

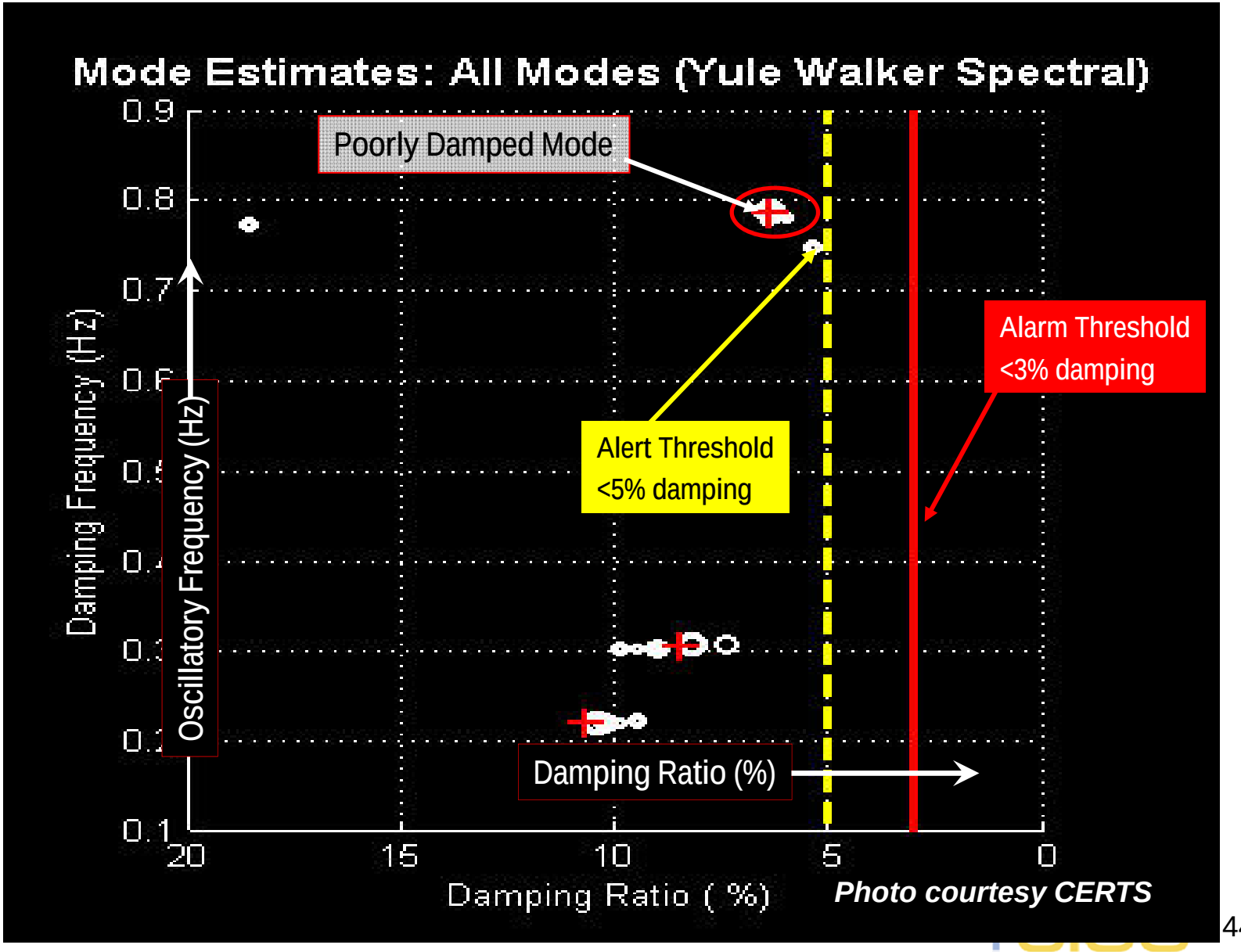
Two Views: California-Oregon Intertie

August 10th, 1996, Power Flow During Generator Trip



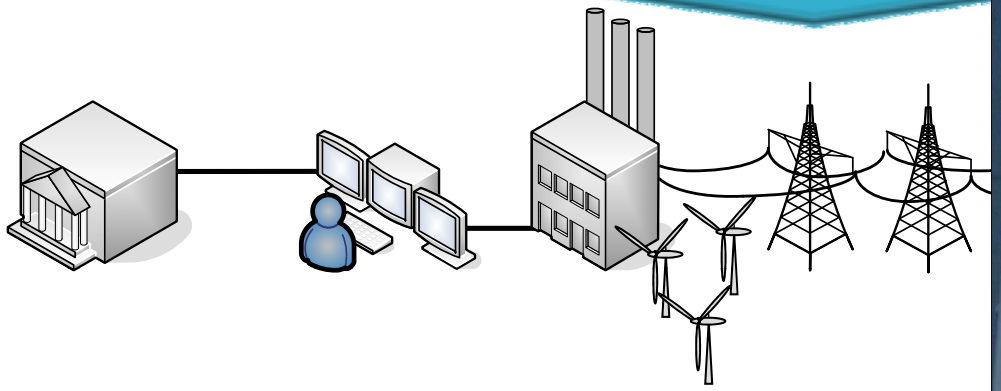
This event triggered an inter-area power oscillation and ended in a wide-area power outage in western US.

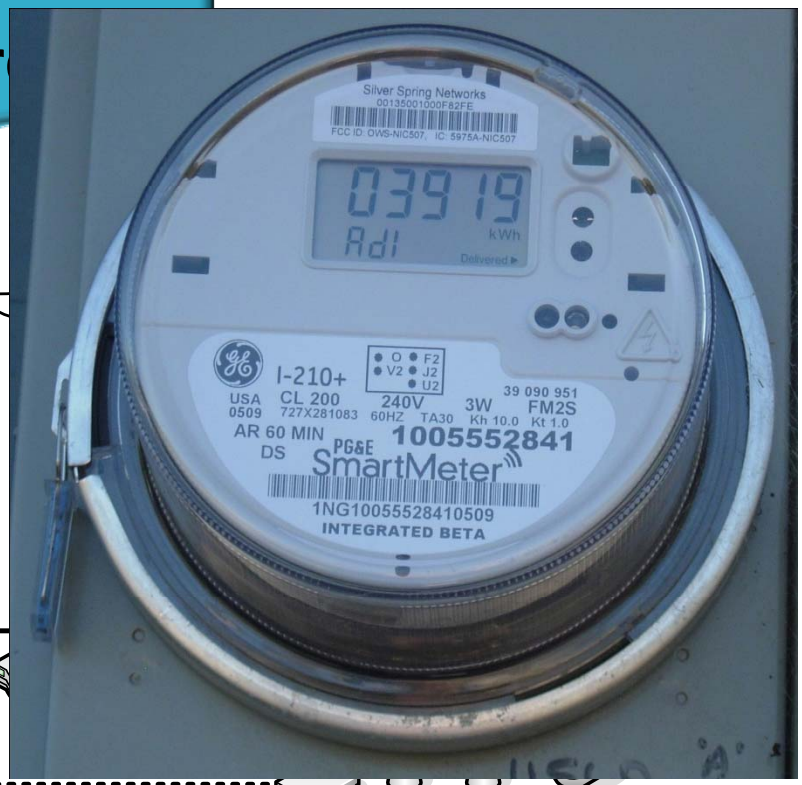
Mode Estimate: Visualization Example

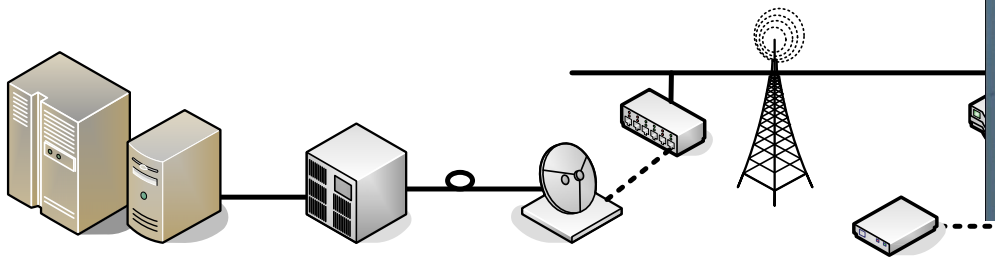


Example: Accommodate Renewables & Increase Capacity by Joining 2 Infrastructures

Electrical Infrastructur





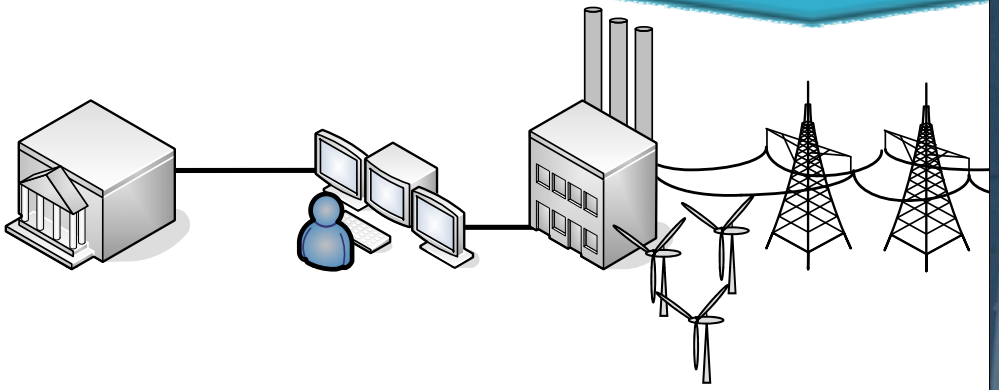


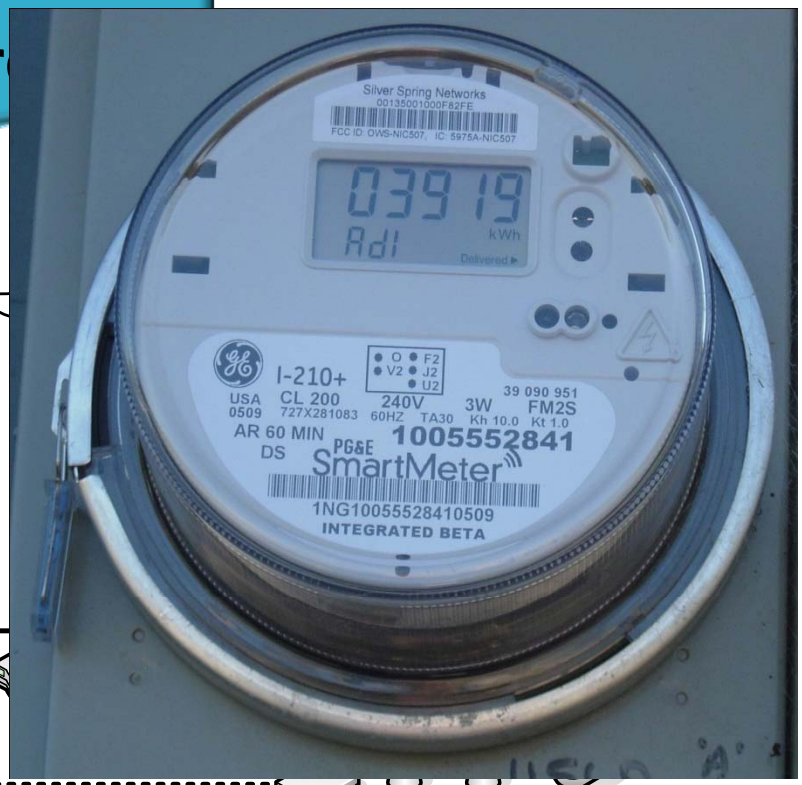
"Intelligence" Infrastructure

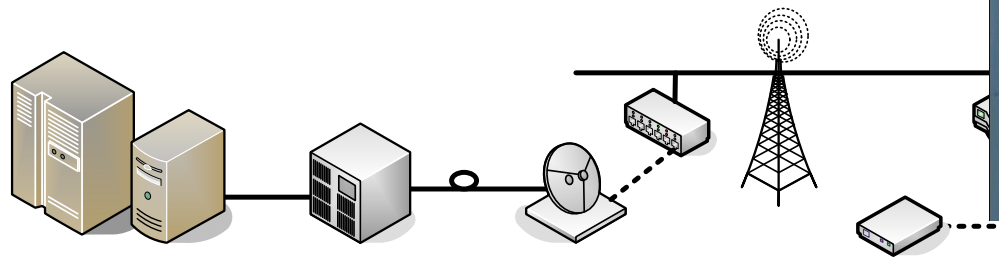
Equals the "Smart" Grid

Example: Accommodate Renewables & Increase Capacity by Joining 2 Infrastructures

Electrical Infrastructure







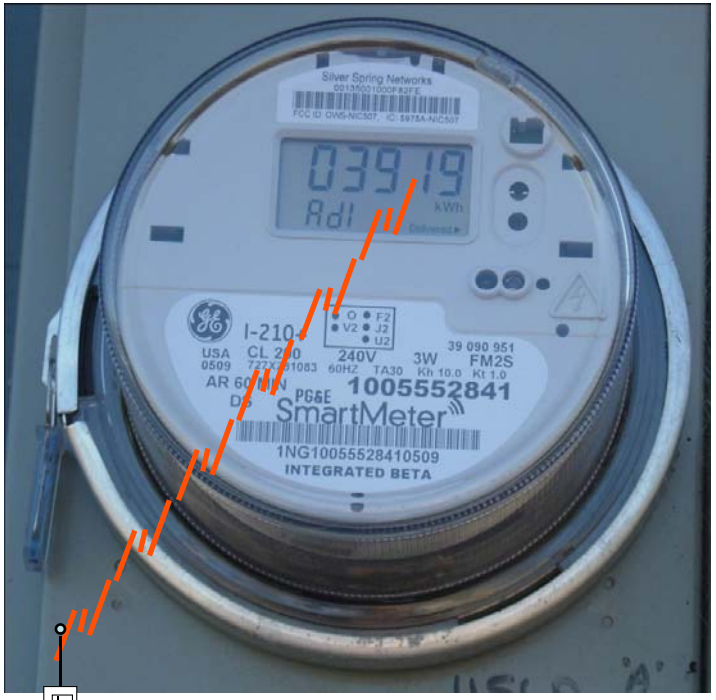
"Intelligence" Infrastructure

Equals the "Smart" Grid

The digital “smart meter” makes the customer an integral part of the “smart” grid.

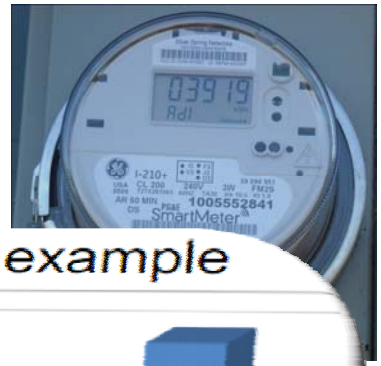
Past...

Present ~~Future...~~



Smart Meter can measure, remotely switch on/off and limit maximum electricity use; and communicate frequently

The Benefits of Smart Meters*

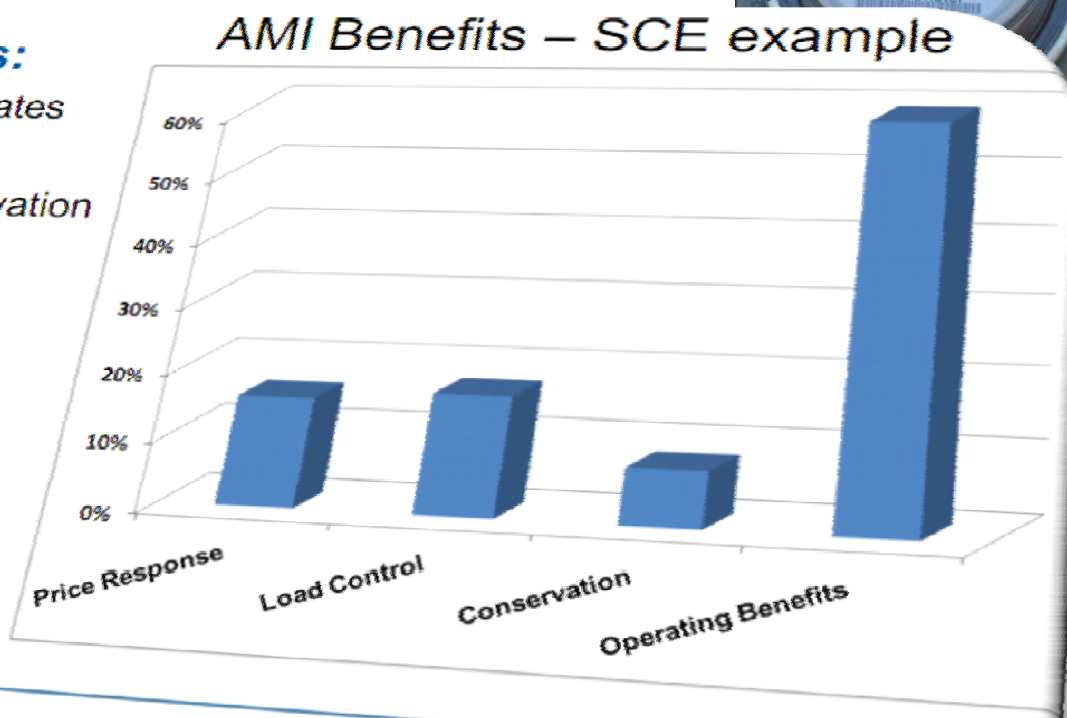


Quantifiable benefits:

- Demand response/smart rates
- Direct load control
- Information-induced conservation
- Operating Benefits
  - Remote meter reading
  - Automated outage detection
  - Remote connect/disconnect

Other benefits:

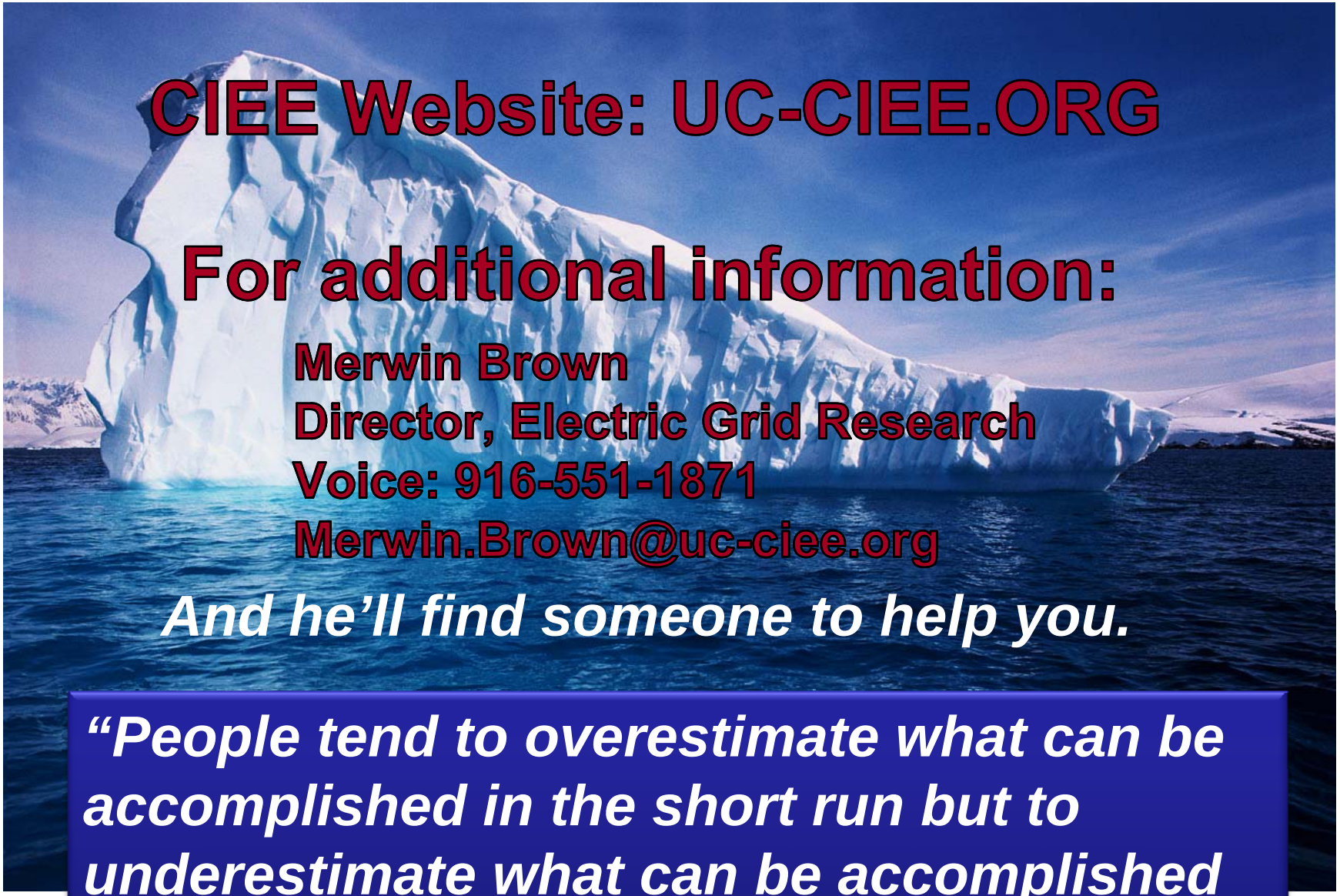
- Building block to Smart Grid, PHEVs, and DG
- Gateway for home area networks (HAN)/smart apps



The Edison Foundation | Institute for Electric Efficiency

*Reference: Wood, Lisa, Institute for Electric Efficiency, "Mart Meters Provide Multiple Financial Benefits to Consumers," UTE TELECOM 2010, May 24, 2010

"Smart" grid must have "smart" customers.



CIEE Website: UC-CIEE.ORG

For additional information:

Merwin Brown
Director, Electric Grid Research
Voice: 916-551-1871
Merwin.Brown@uc-ciee.org

And he'll find someone to help you.

"People tend to overestimate what can be accomplished in the short run but to underestimate what can be accomplished in the long run." **Arthur C. Clarke**