EPRI | ELECTRIC POWER RESEARCH INSTITUTE

The Integrated Grid:

Energy Storage and Smart Grid Technologies and their Relationship to 2050 GHG Goals

Haresh Kamath
Program Manager, EPRI

Presentation to
The Bay Area Air Quality Management District
8 October 2014

Together…Shaping the Future of Electricity

EPRI's Mission

To conduct research, development and demonstration on key issues facing the electricity sector on behalf of our members, energy stakeholders, and society

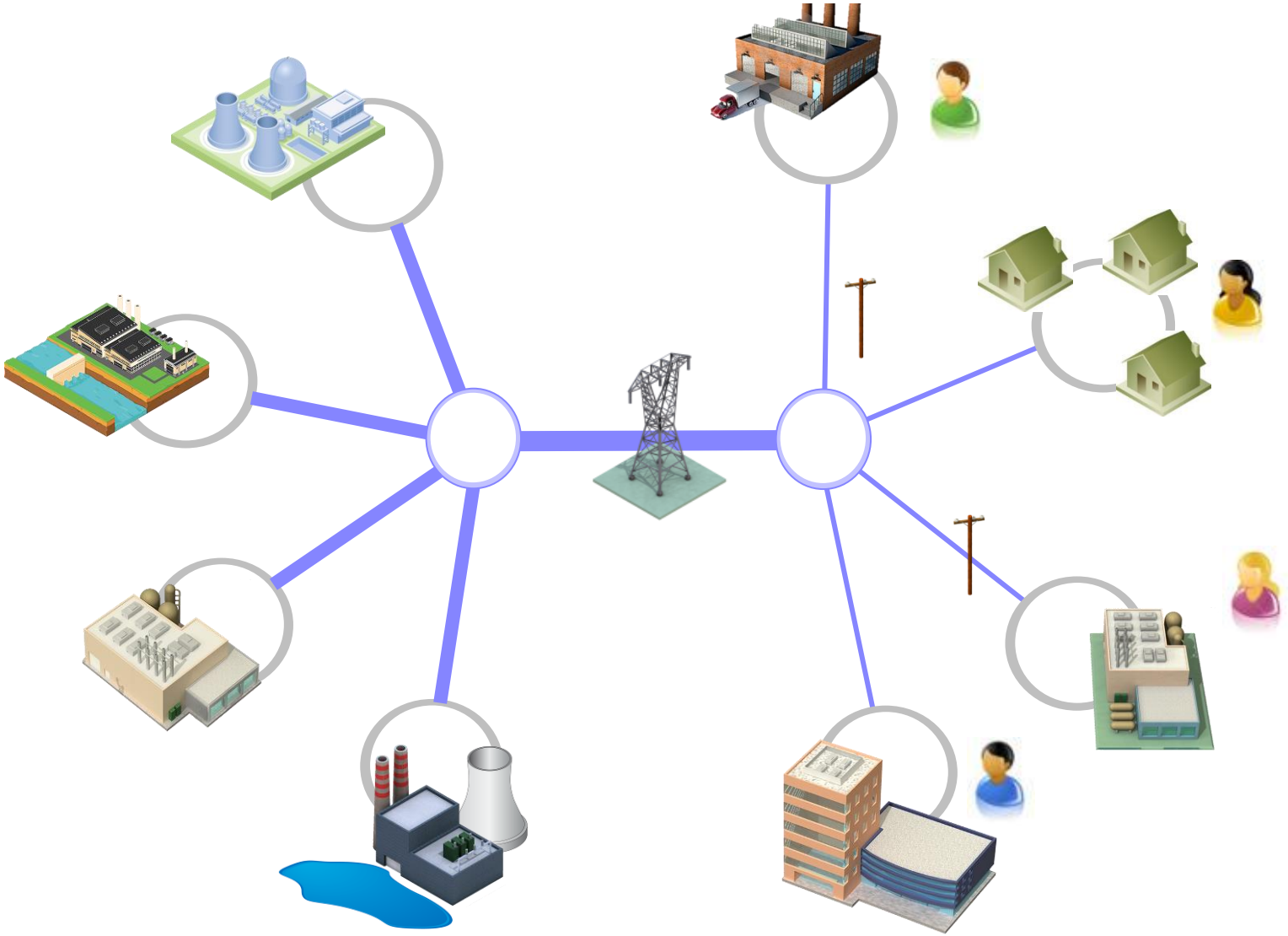
The Path Forward

- **We need an integrated approach to transform the power system**
- **EPRI's current research on The Integrated Grid is ready to be applied**
- **Industry and policy/regulatory leaders need to coalesce on key research imperatives for the transformation**

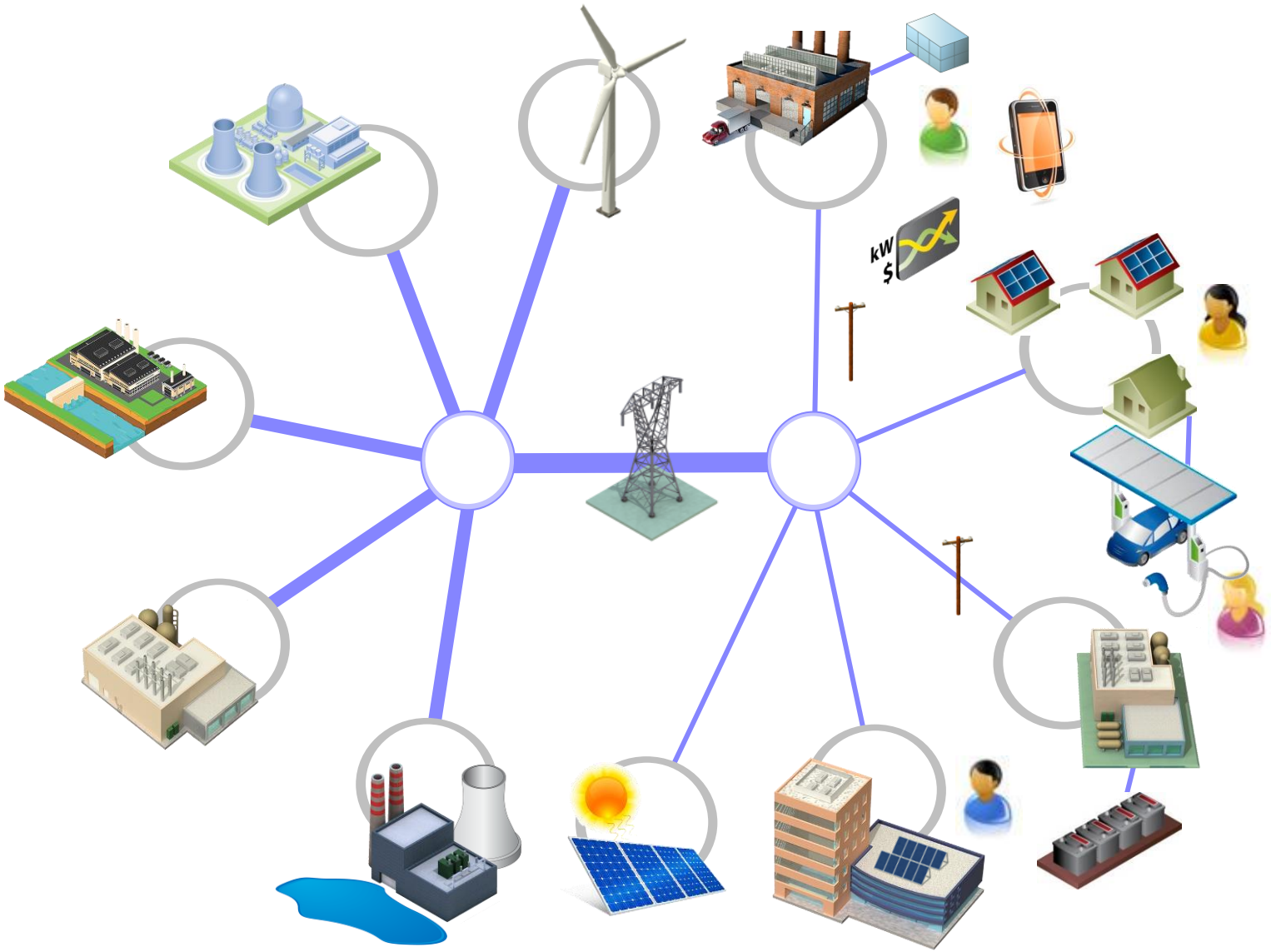
Integrated
The Whole is Greater than the Sum of its Parts

Transforming the Power System – It is a Journey not a Destination

Electric Power System – As it Was



Electric Power System – As it is Likely to Be



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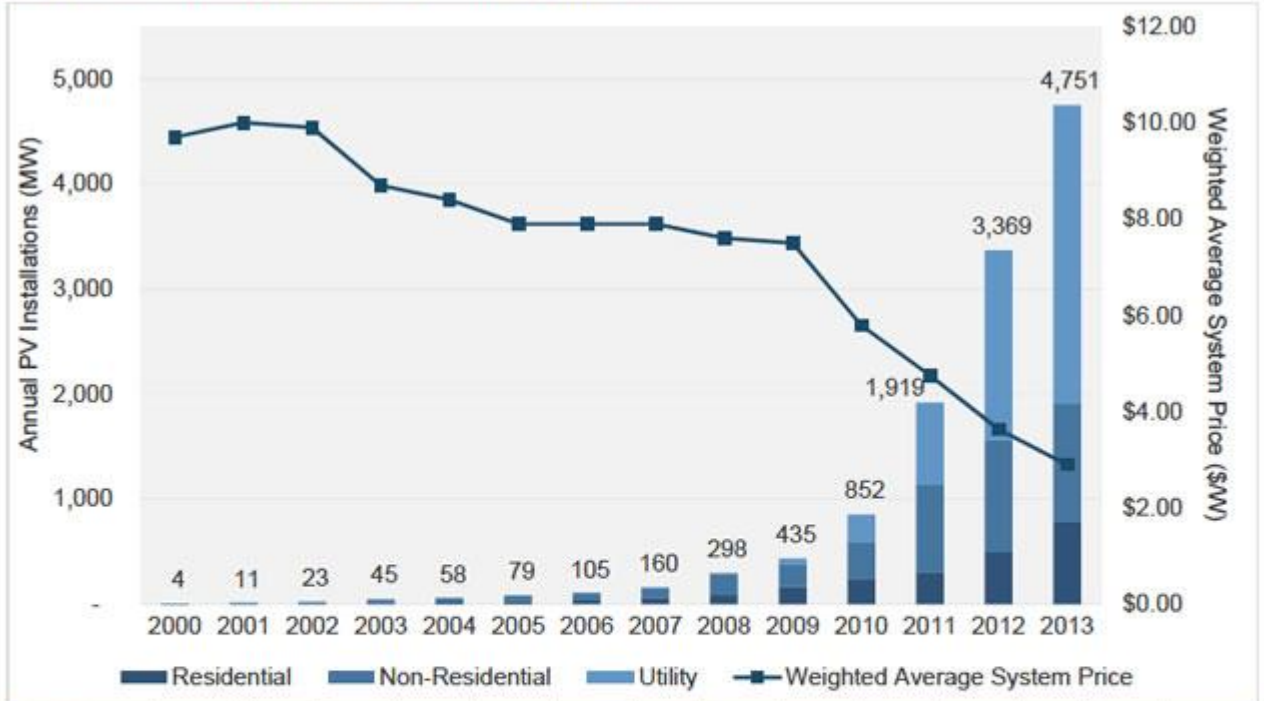
Distributed Resources - Solar

Figure 2.1 U.S. PV Installations and Average System Price, 2000-2013



Installations (MW)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Residential	1	5	11	15	24	27	38	58	82	164	246	304	494	792
Non-Residential	2	3	9	27	32	51	67	93	200	213	339	831	1,072	1,112
Utility	0	3	2	3	2	1	0	9	16	58	267	784	1,803	2,847
Total Installations	4	11	23	45	58	79	105	160	298	435	852	1,919	3,369	4,751

GTM RESEARCH

40 YEARS SEIA Solar Energy Industries Association

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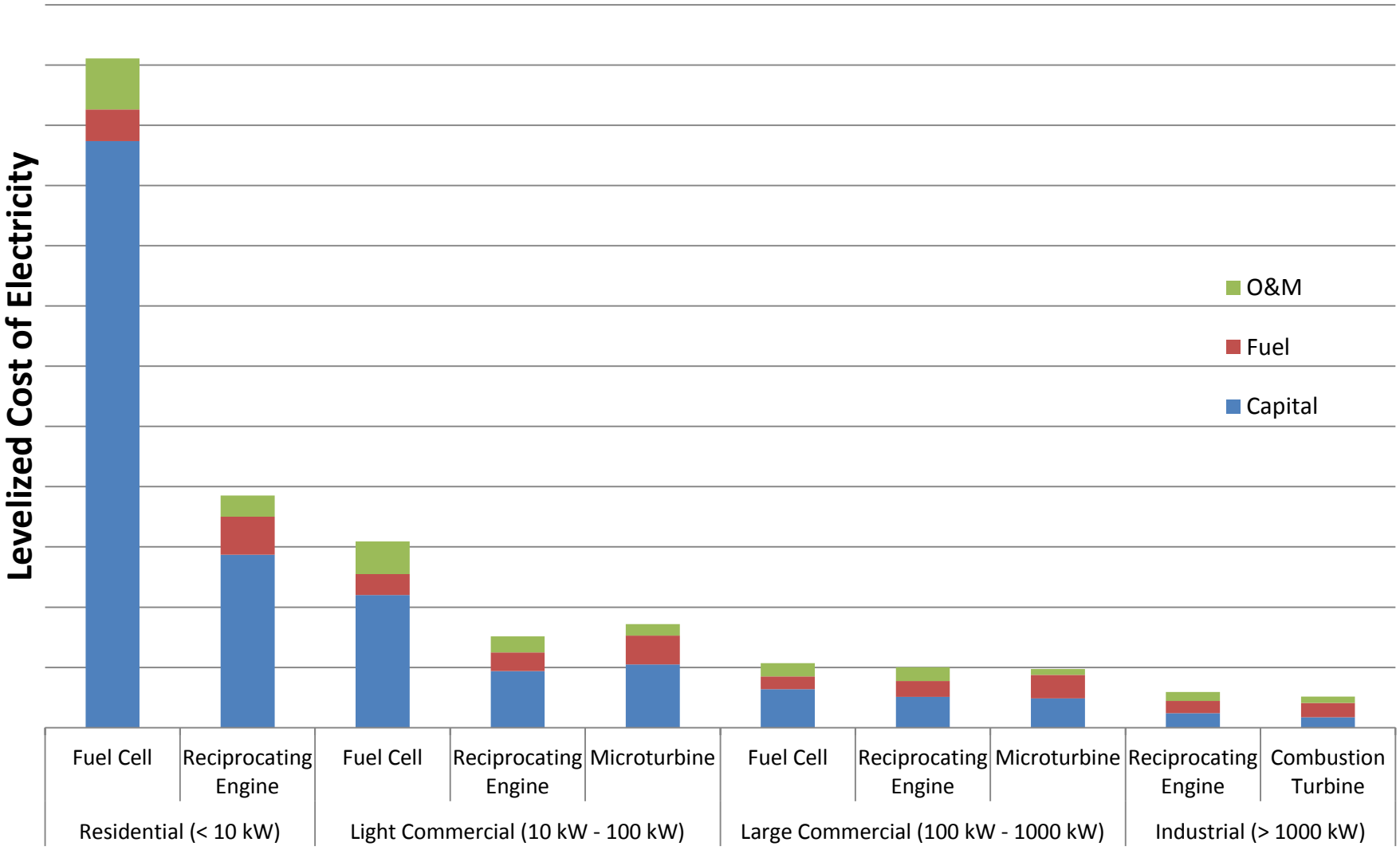
Distributed Generation

EPRI Distributed Generation Technology Comparison – In Progress



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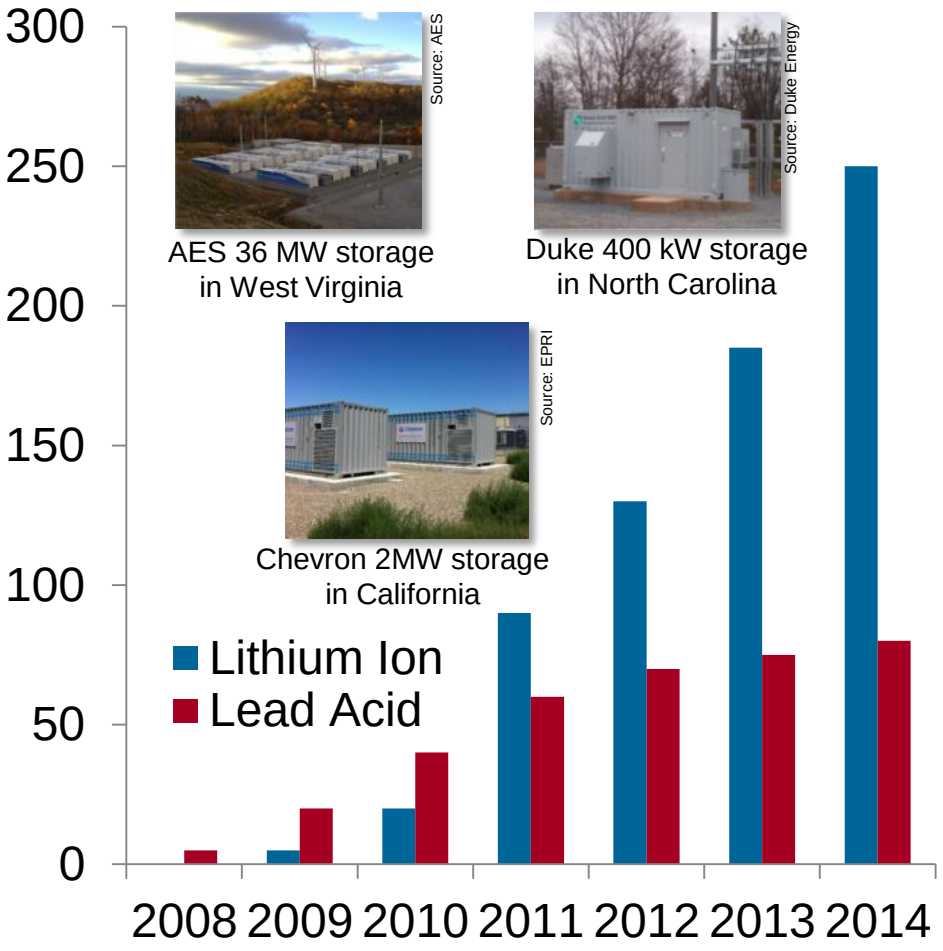
Energy Storage

- Investment in storage continues, particularly in lithium ion products for ancillary services
- Utilities are exploring options at the transmission and distribution level
- Some developers are installing systems on the customer side of the meter

Lithium Ion and Lead-Acid-based Storage Systems Installed Worldwide



Source: U.S. DOE, EPRI Estimates

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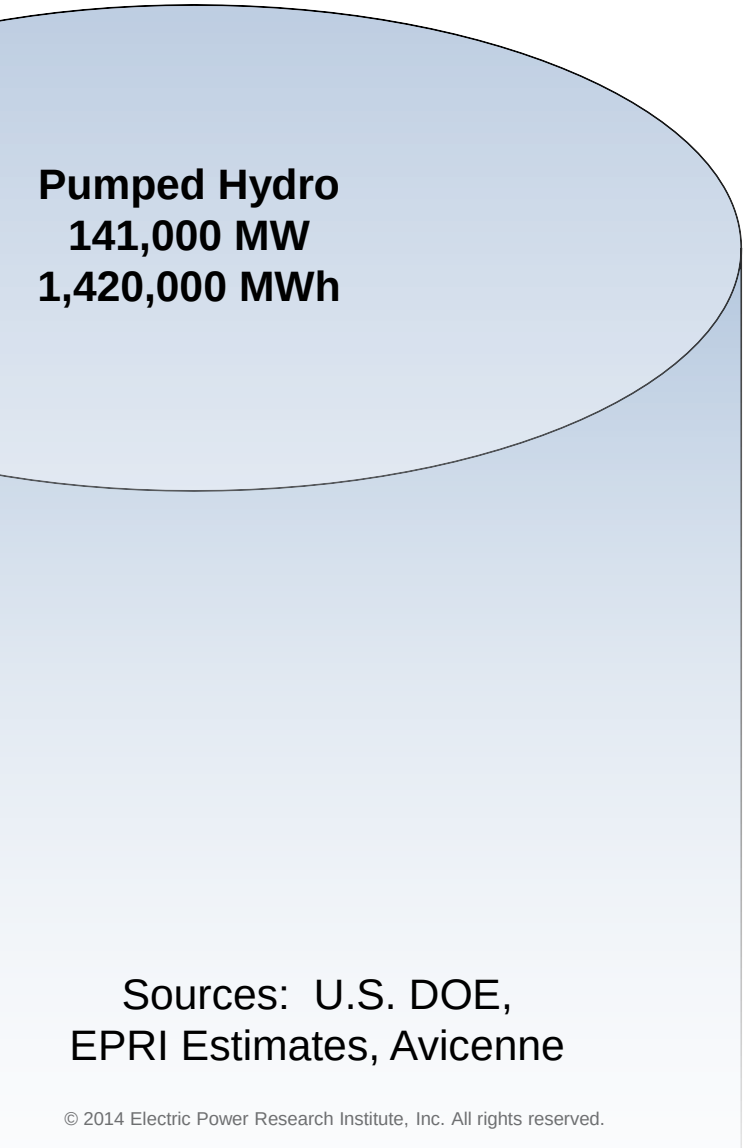
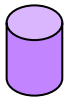
Total Deployed Grid Storage Worldwide, July 2014

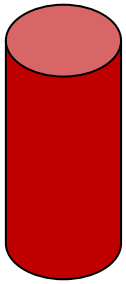




Batteries
387 MW
595 MWh

Flywheels
898 MW
9 MWh

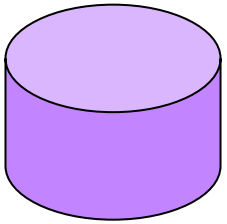
Hydrogen Storage
3 MW
35 MWh



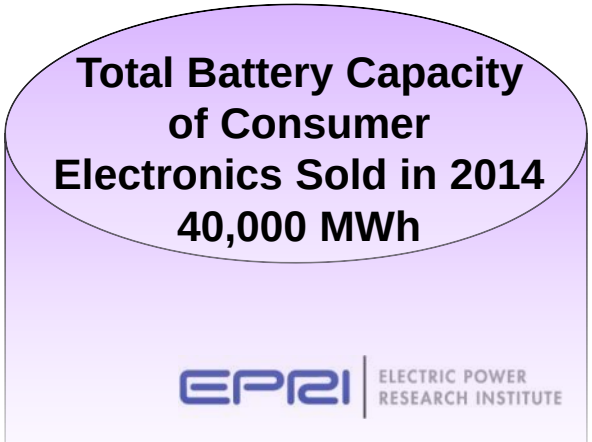
Thermal Storage
1,570 MW
3,734 MWh

Compressed Air
435 MW
4,010 MWh

California
Procurement Target
1325 MW



Total Battery Capacity
of U.S. Electric Vehicles
on the Road
5450 MWh



Sources: U.S. DOE,
EPRI Estimates, Avicenne

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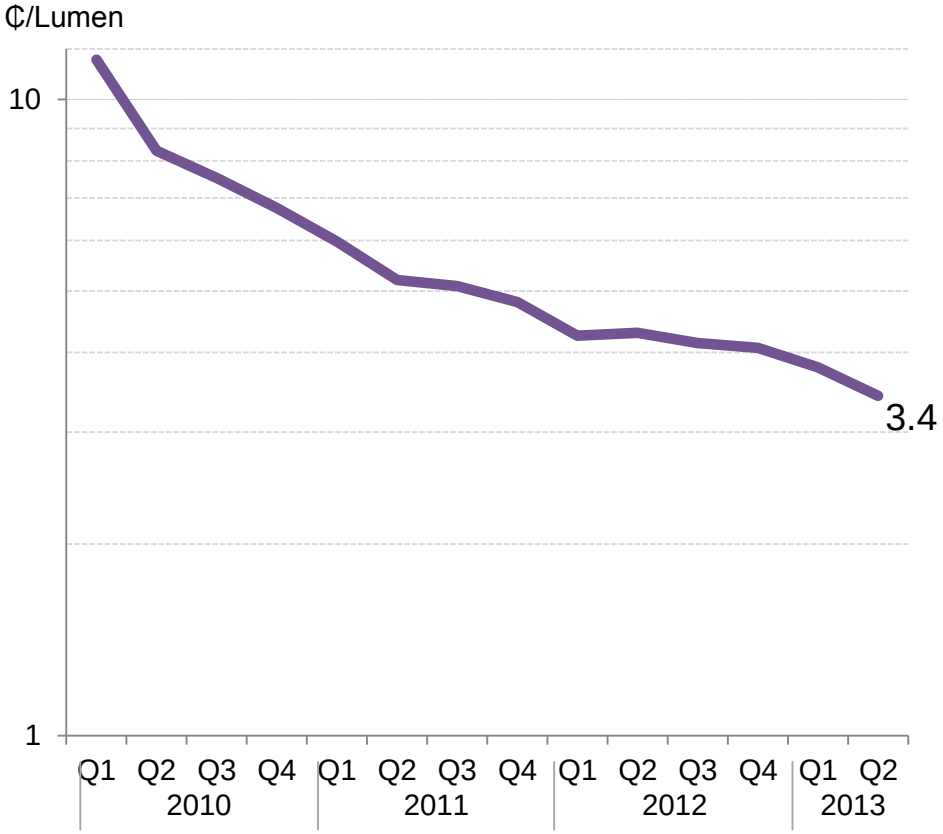
Technologies of Change

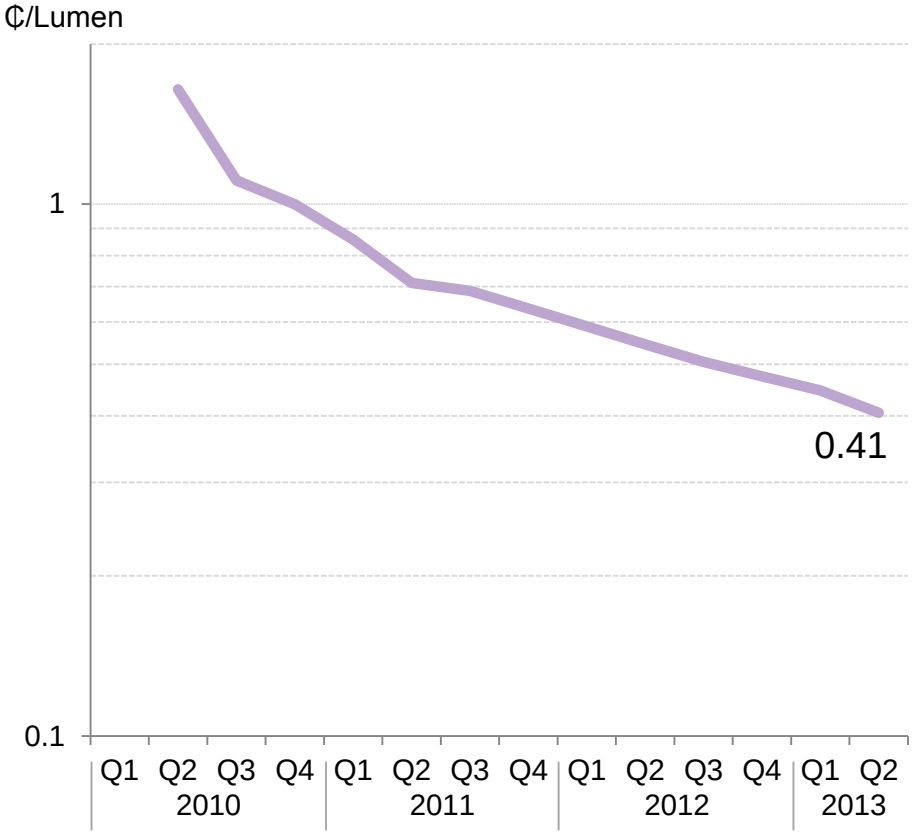
Consumer Market: LED Upstream and downstream price trends

PRICE PER UNIT LIGHT OUTPUT FOR LED CEILING BULBS, 2010-2013



Source: LEDInside, Bloomberg New Energy Finance. Note: LED bulb price refers to global average for 40W-equivalent bulbs before tax or subsidy.

PRICE PER UNIT LIGHT OUTPUT OF HIGH-BRIGHTNESS WHITE LEDS, 2010-13



Source: LEDInside, Strategies in Light, Bloomberg New Energy Finance. Note: “Ten-year trend” is used to help visualise the 30% per year cost reduction of the past ten years. It has been normalised to Q3 2010.

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Home Energy Management

Energy Efficiency
2007

Customer Engagement
2010

Thermostat Management
2012

Demand Response
2013

Hit energy efficiency targets

Build customer loyalty

Manage peak demand

Ilan Frank, Opower (EPRI Workshop: Evaluating EE and DR Potential of HEMS)

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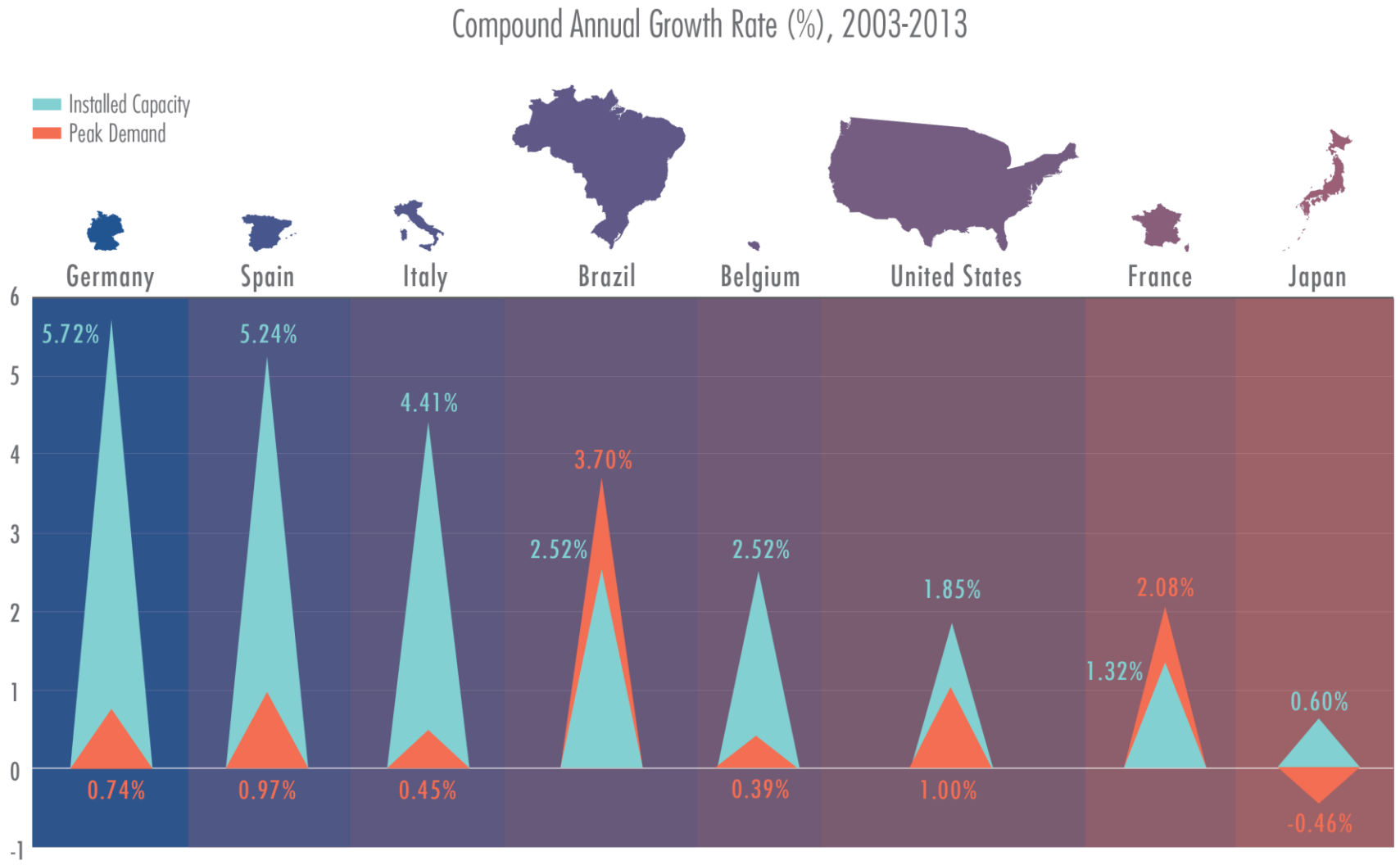
Diverging Trend

Installed Capacity Surpassing Peak Demand



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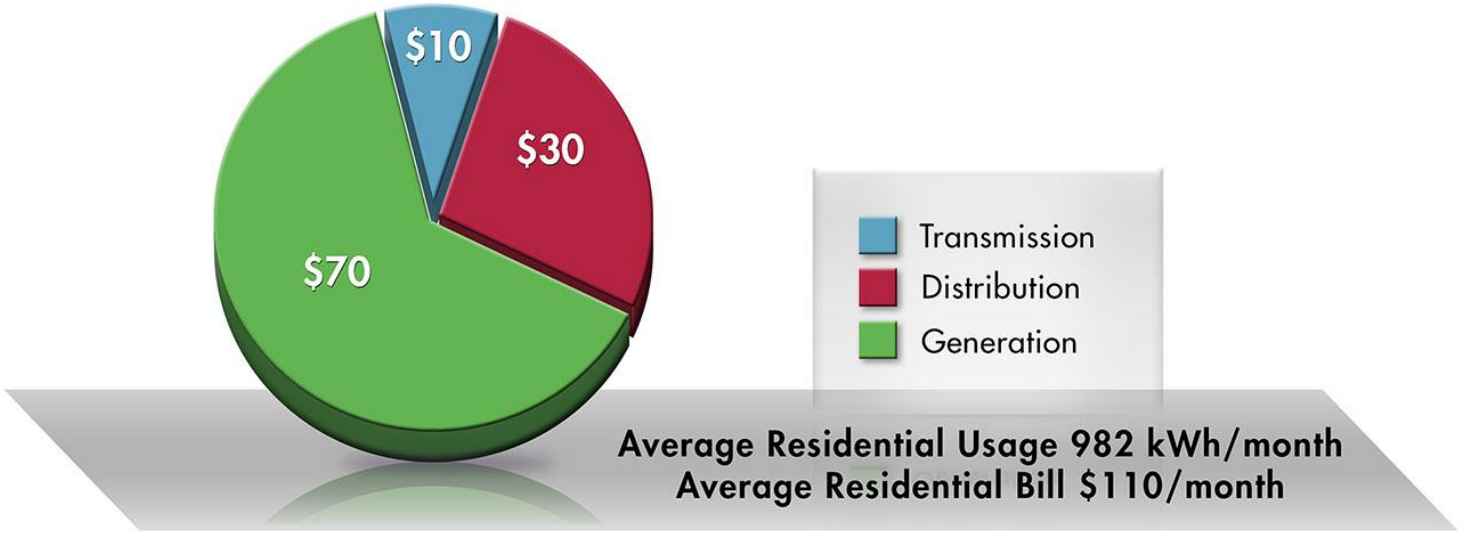
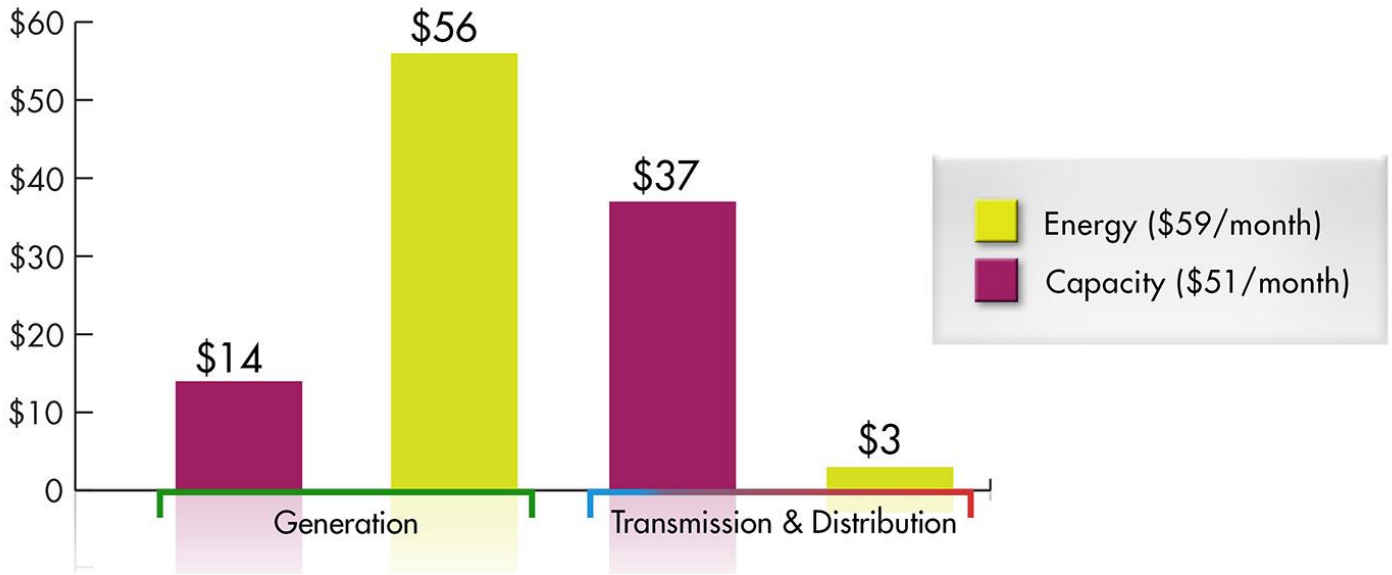
U.S. Average Cost to Consumers





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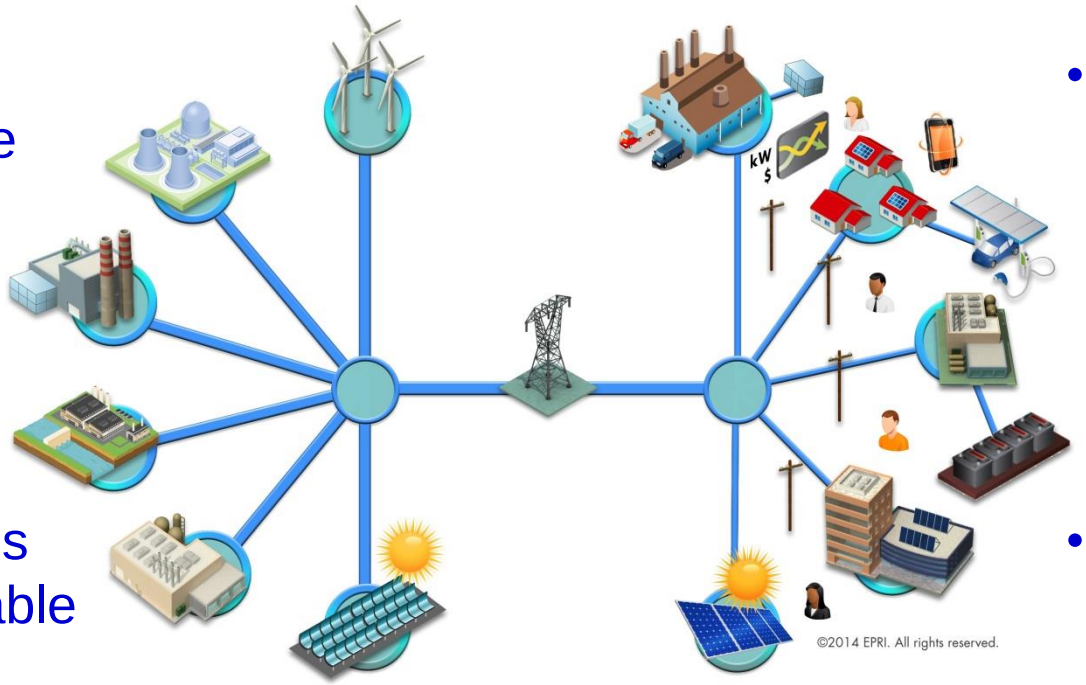
The Future Power System – Integrated

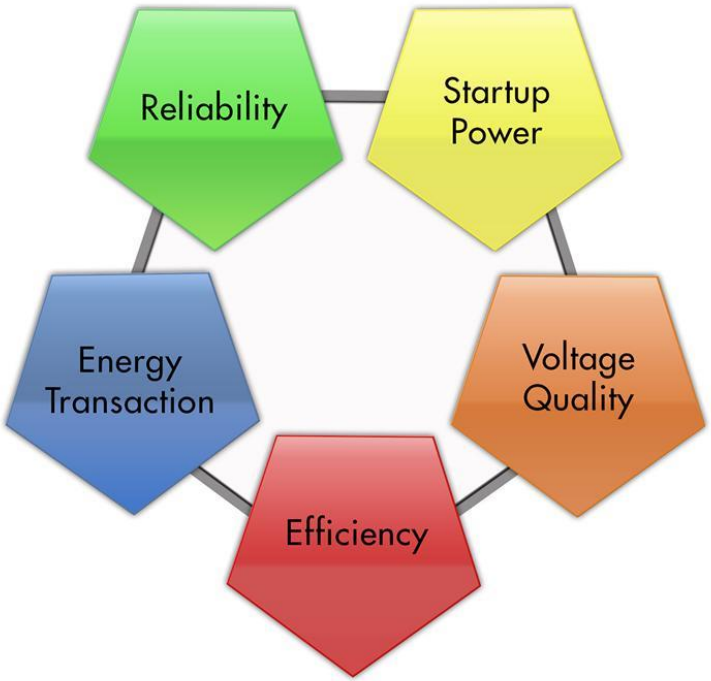
- Generation Becomes More Flexible
- T & D Becomes More Controllable and Resilient



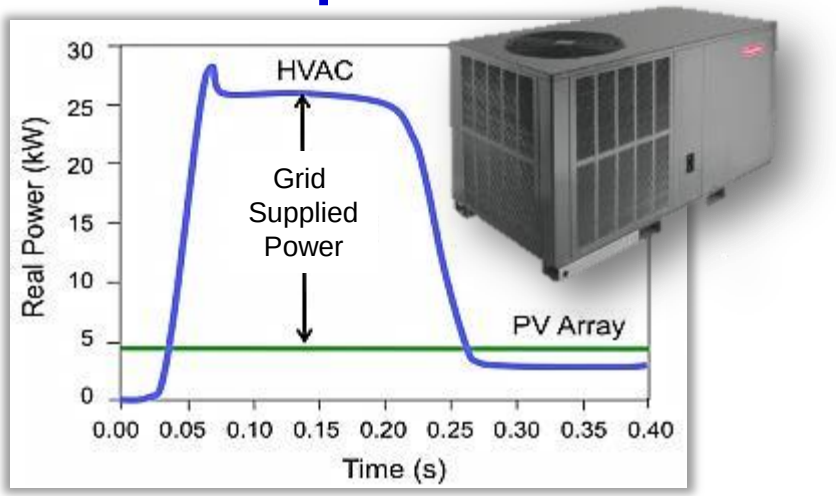
- Consumers Become Energy Producers
- Loads Become More Interactive and Dynamic

A More *Dynamic* End-to-End Power System

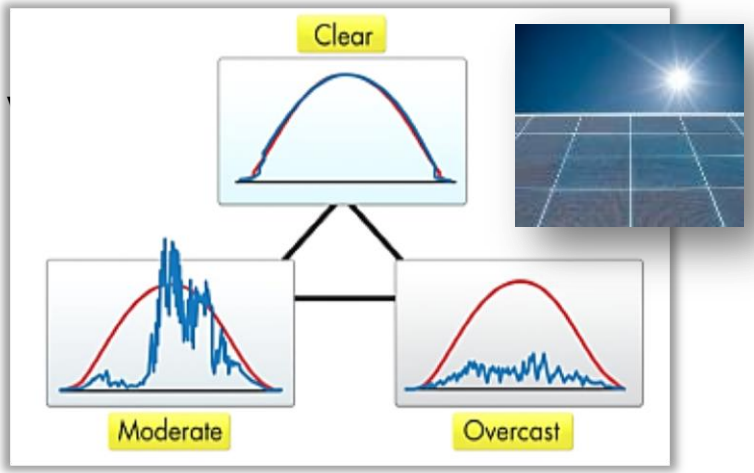
Interconnected



Startup Power



24 by 7 Electricity



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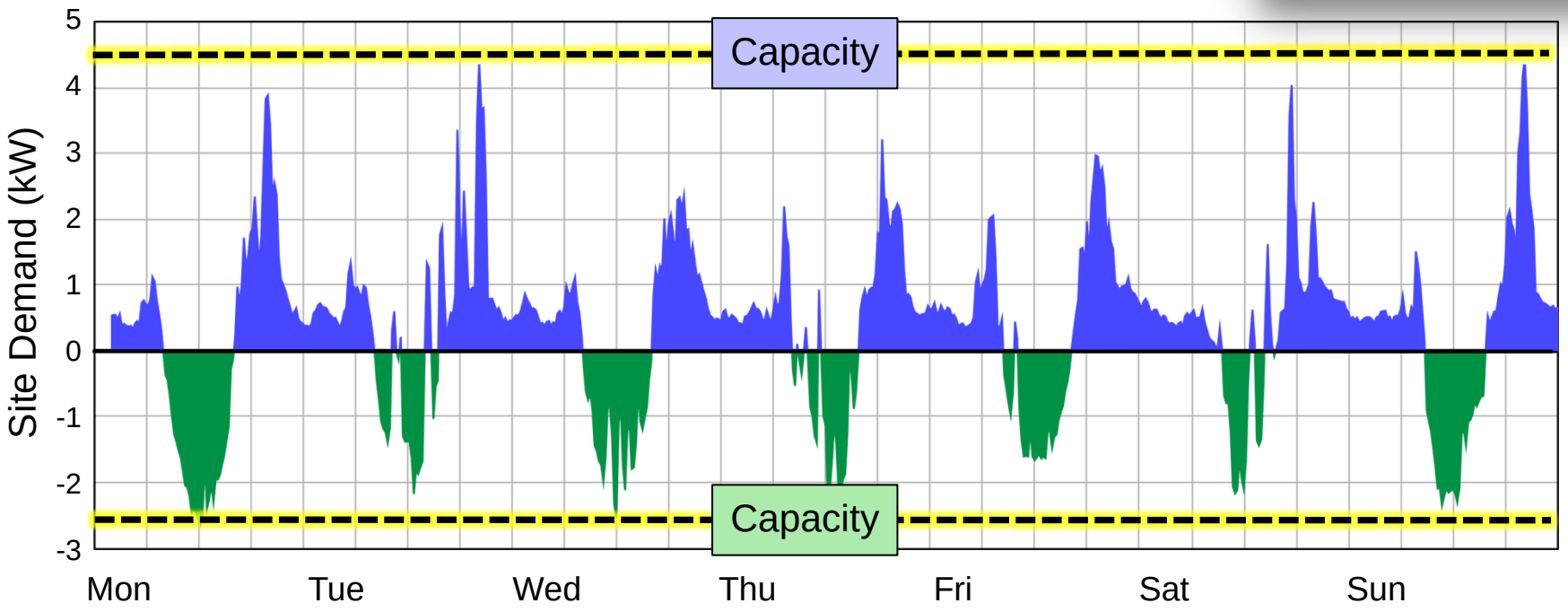
Zero Energy Homes



***Capacity* . . . Reliably *Deliver Energy* Every Second, Every Place**

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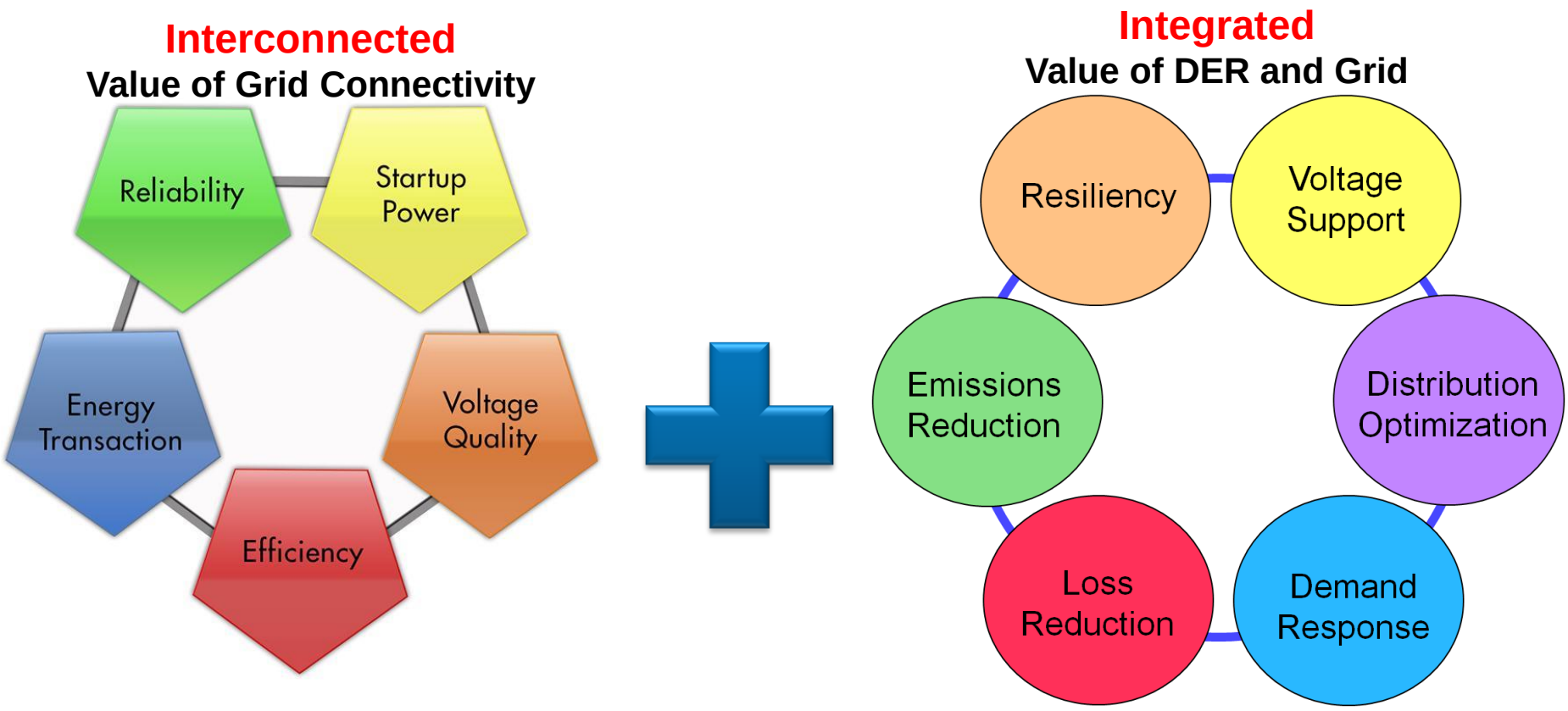
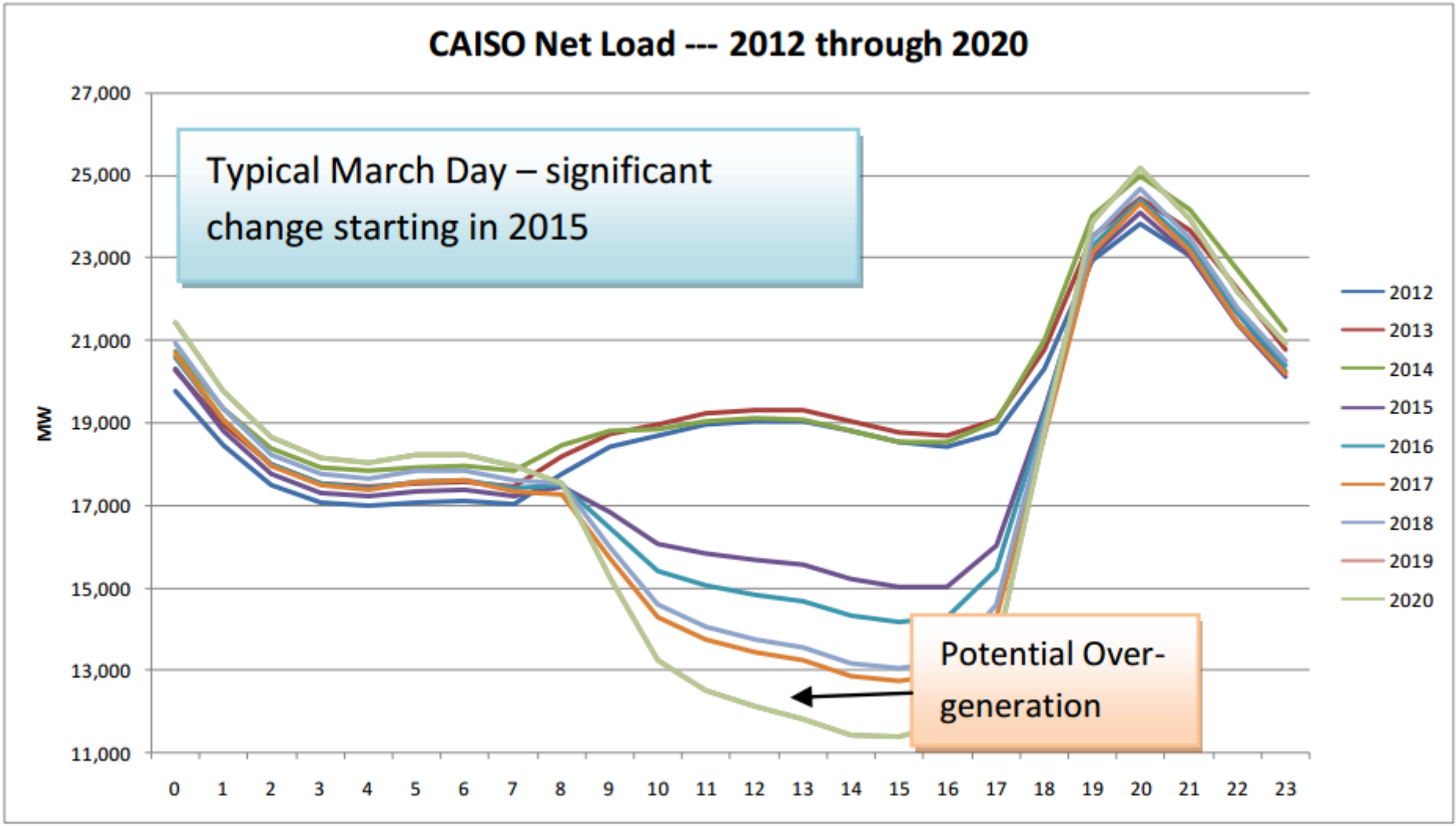
Interconnection vs. Integration



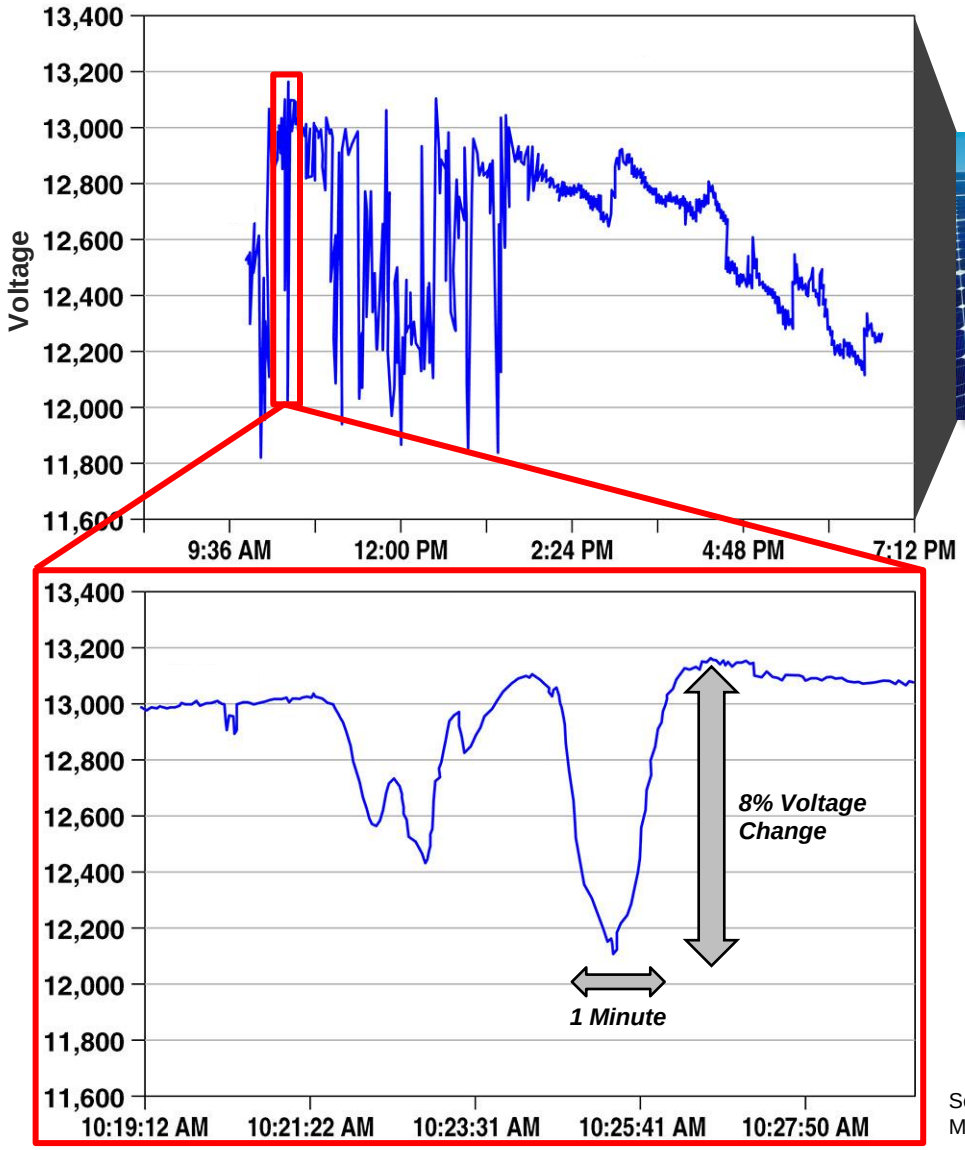
Integration Enables Values of all Resources

Bulk-System Operating Challenges



Source: CAISO

Distribution Operating Challenges



1 MW PV

= Substation

= Line Regulators

Source: Feeder Measurements, 2011

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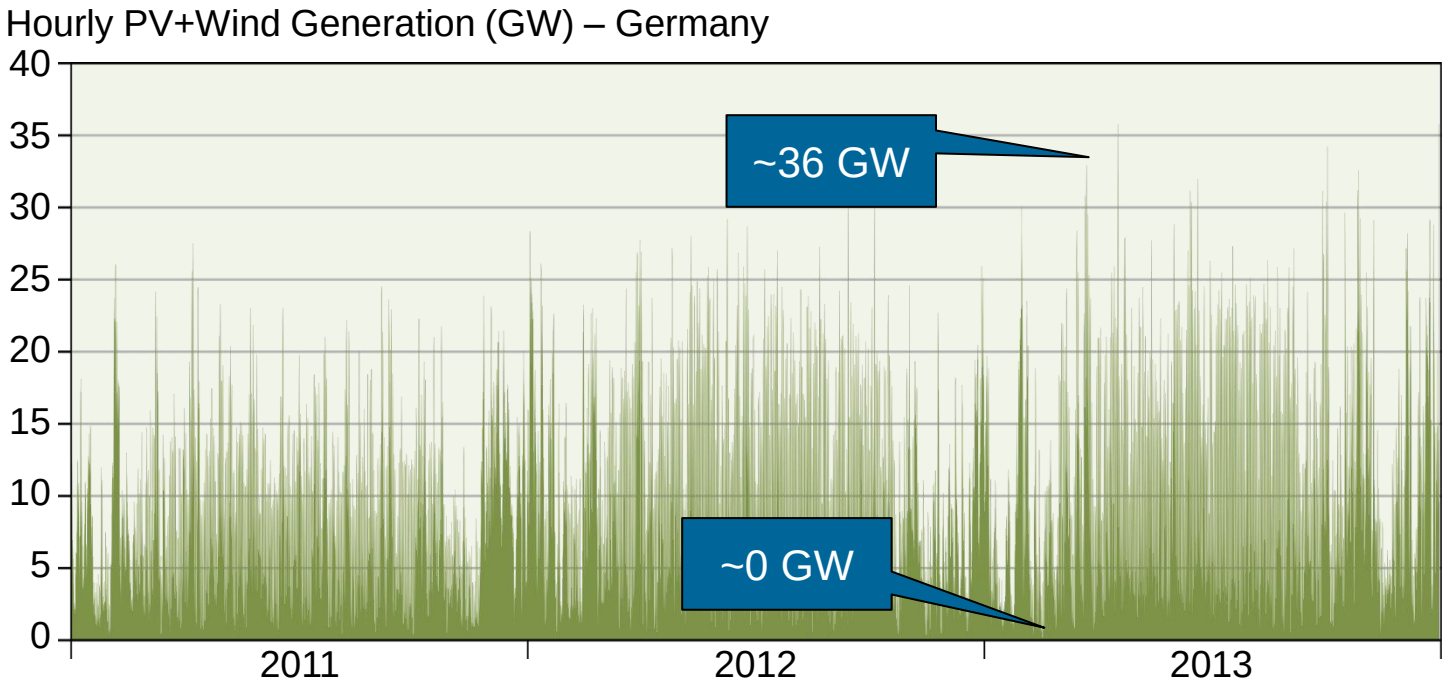
Insights From a Real Power System



Insights from a Dynamic System

~80 days/yr variable generation at below 5% of installed capacity

Maximum Hourly Ramp ~10 GW

Maximum Hourly Down Ramp ~7 GW

When the Scale of Balancing Becomes Unpredictable and Dynamic

Data from Klaus Kleinekorte, Amprion, German TSO.

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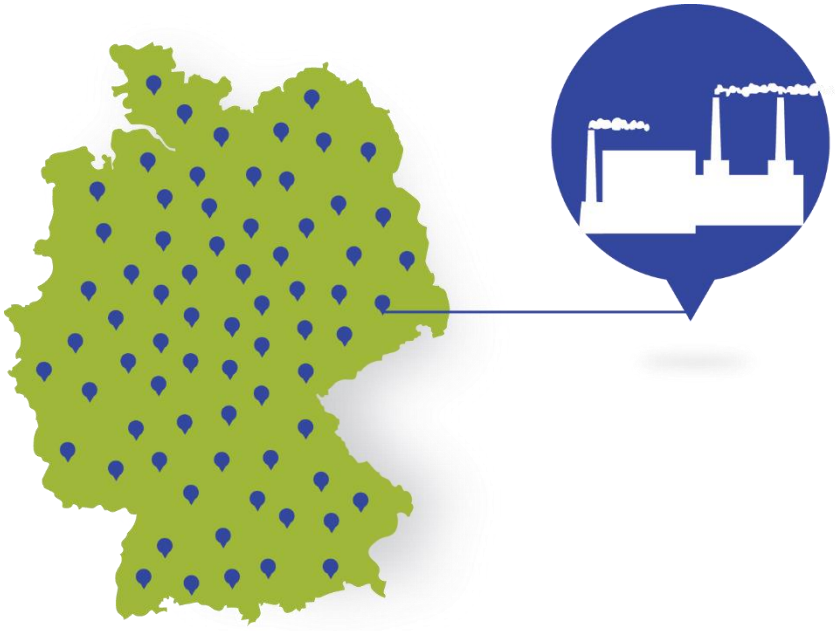
Balancing the System…
With Central Generation



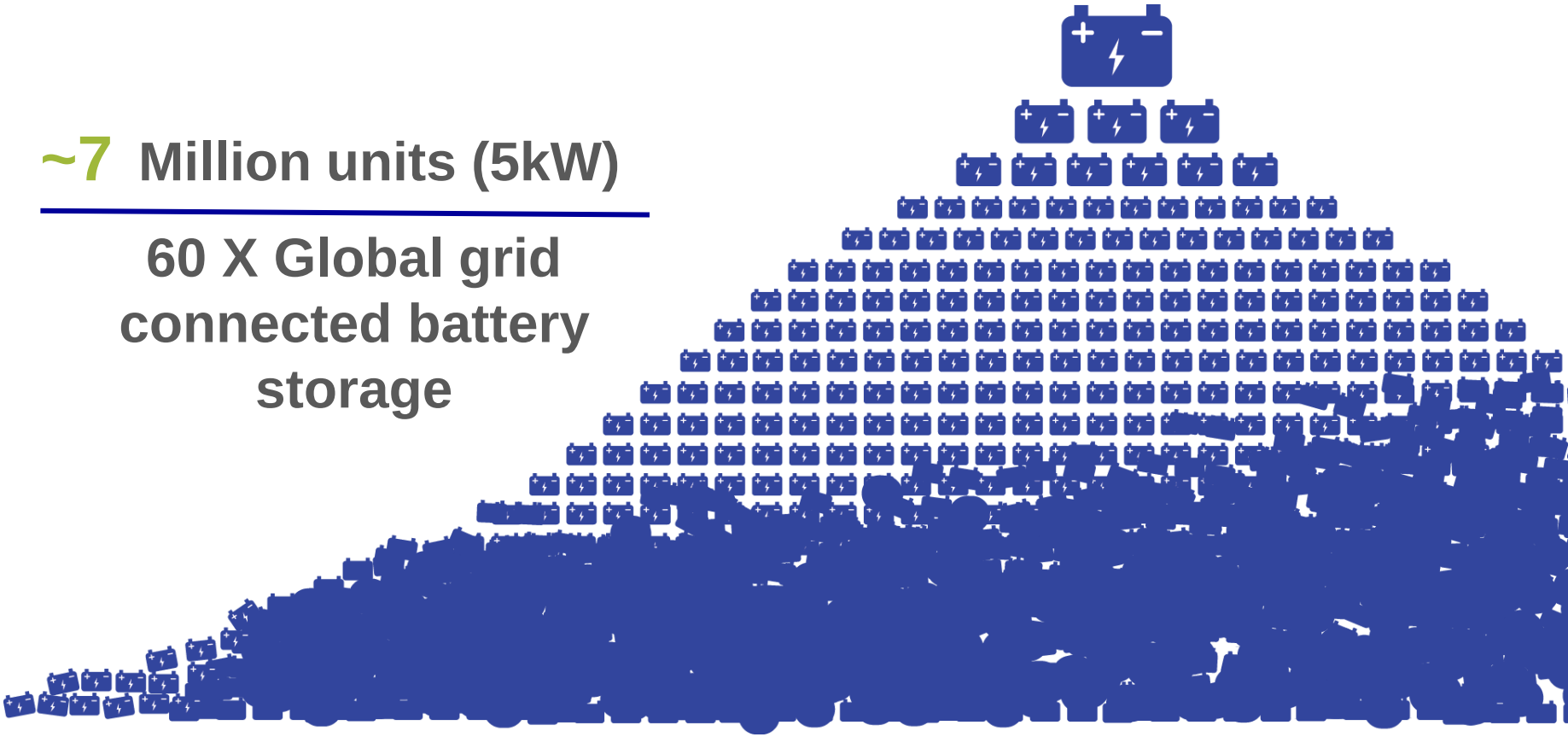
~72

Central generation plants (@ 500 MW each) needed on days with minimum PV + Wind.

Balancing the System…
The Scale of Energy Storage Needed

~7 Million units (5kW)

60 X Global grid connected battery storage



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Balancing the System…
The Scale of Customer Resources Needed

(Supplied Homes)

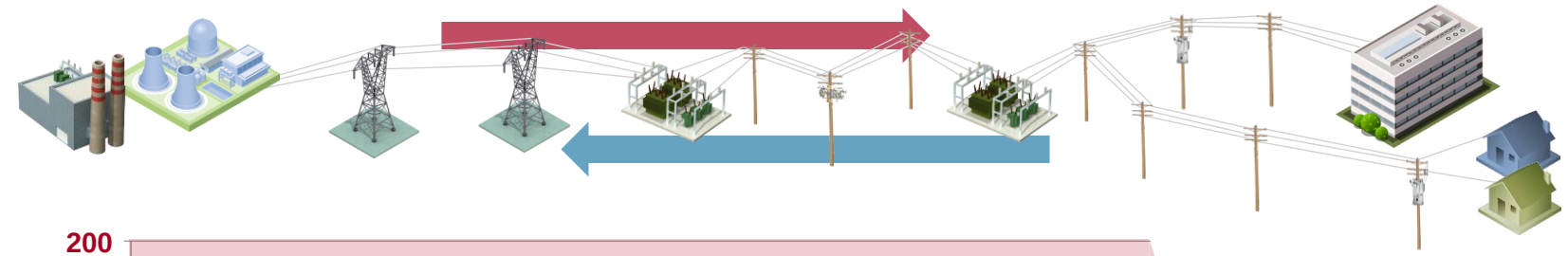
35,620,000

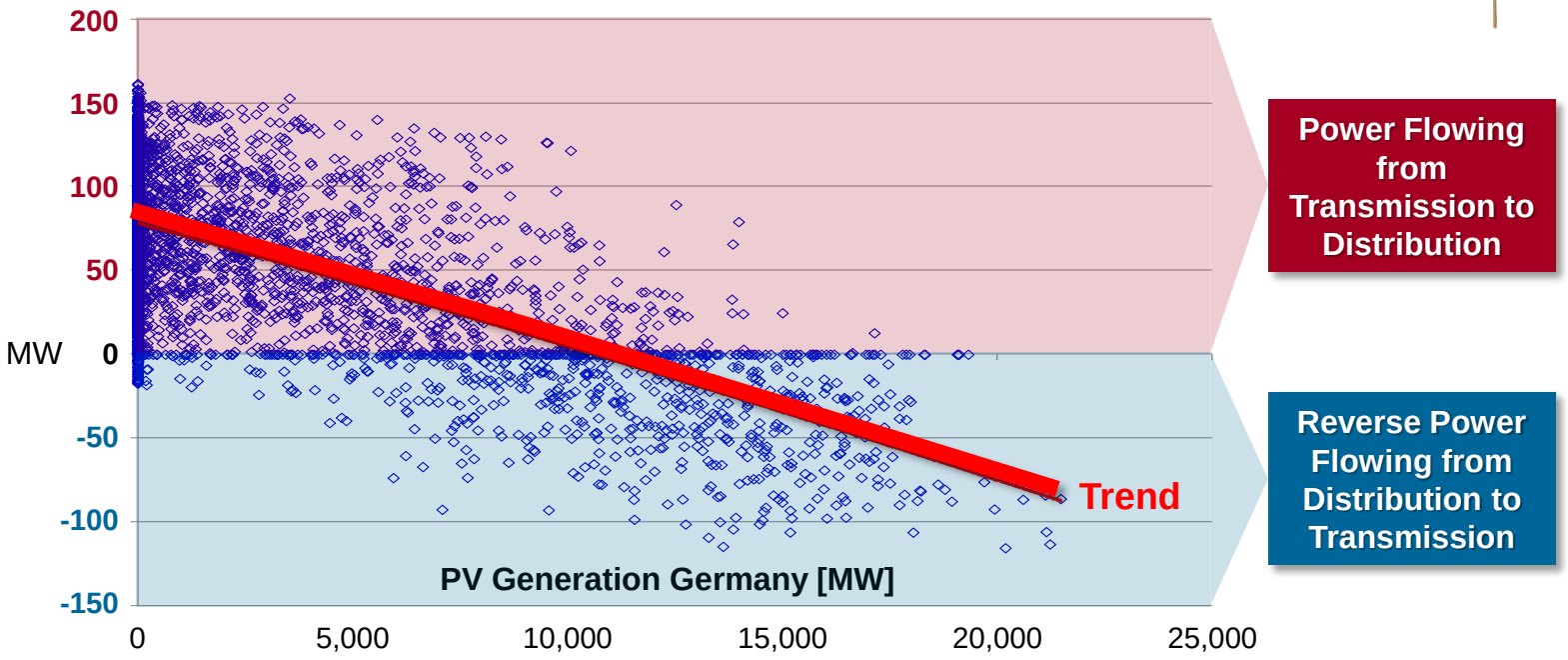
40,076,000

(German Households)

~89 out of every **100** homes needed to supply resource, assuming each contributes 1kW.

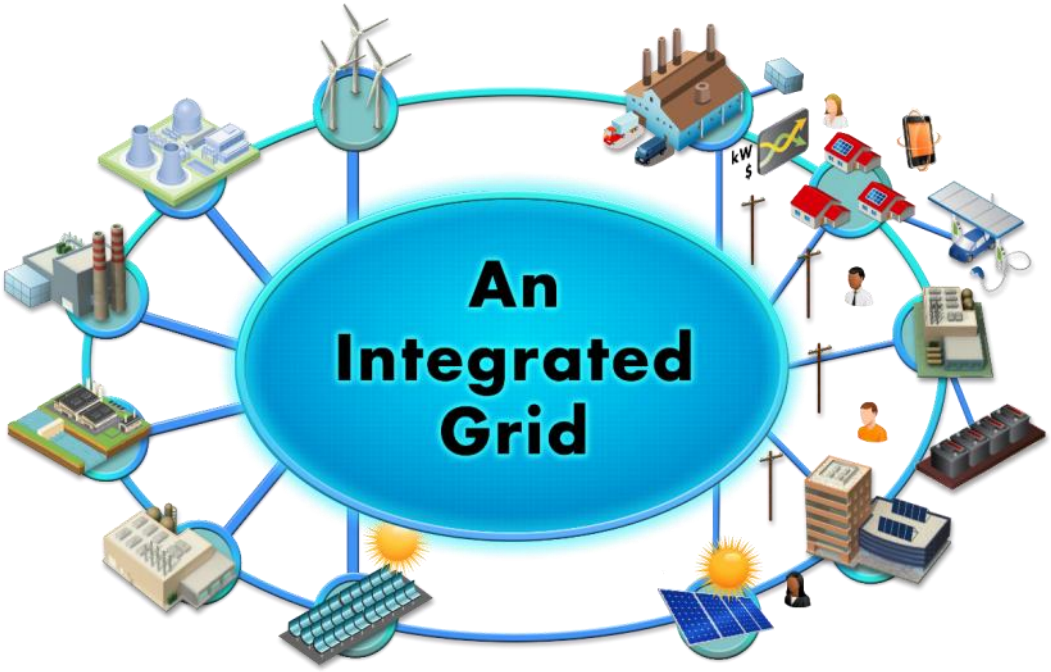
A Real Power System…
When T&D System Becomes Dynamic





Data from Klaus Kleinekorte, Amprion, German TSO.

The Optimum Balance – An Integrated Grid



German Energy Policy moves toward an Integrated Grid

1. Refine DER interconnection rules to support grid reliability
2. Value energy and capacity resource
3. Upgrade and modernize T&D infrastructure
4. Market integration of variable resources
5. Equitable cost allocation

Opportunity to Learn and Act Now

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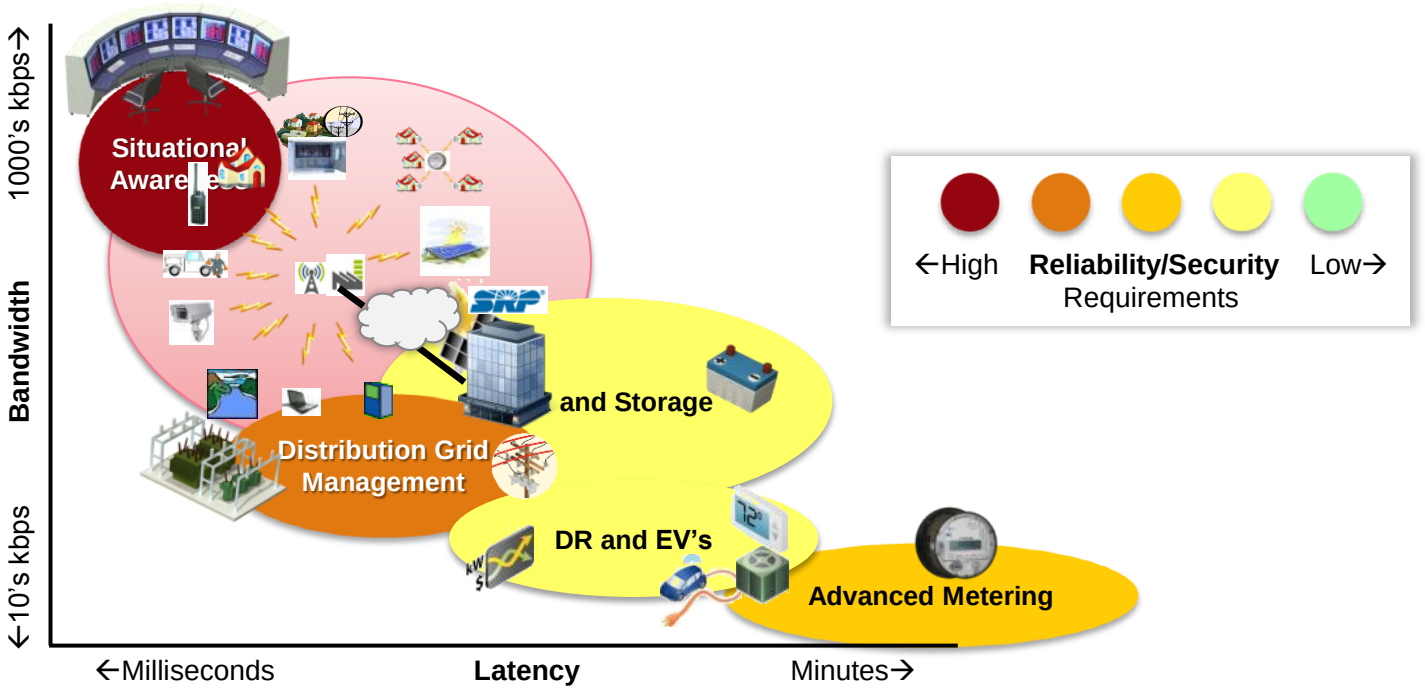
Integrated Approach to Grid Modernization

Communication Requirements



Opportunity for an Integrated Communication System of the Future

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Integrated Approach to Deploying Demand and Energy Efficient Resource

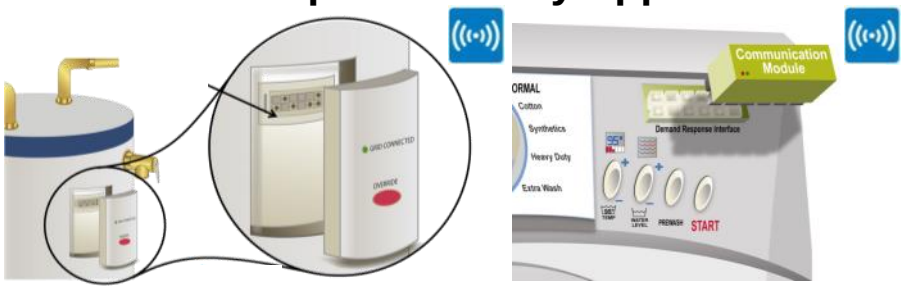
~$5.0B/yr

End Use Energy Efficiency Program Investment in U.S.

Opportunity for an Integrated Deployment

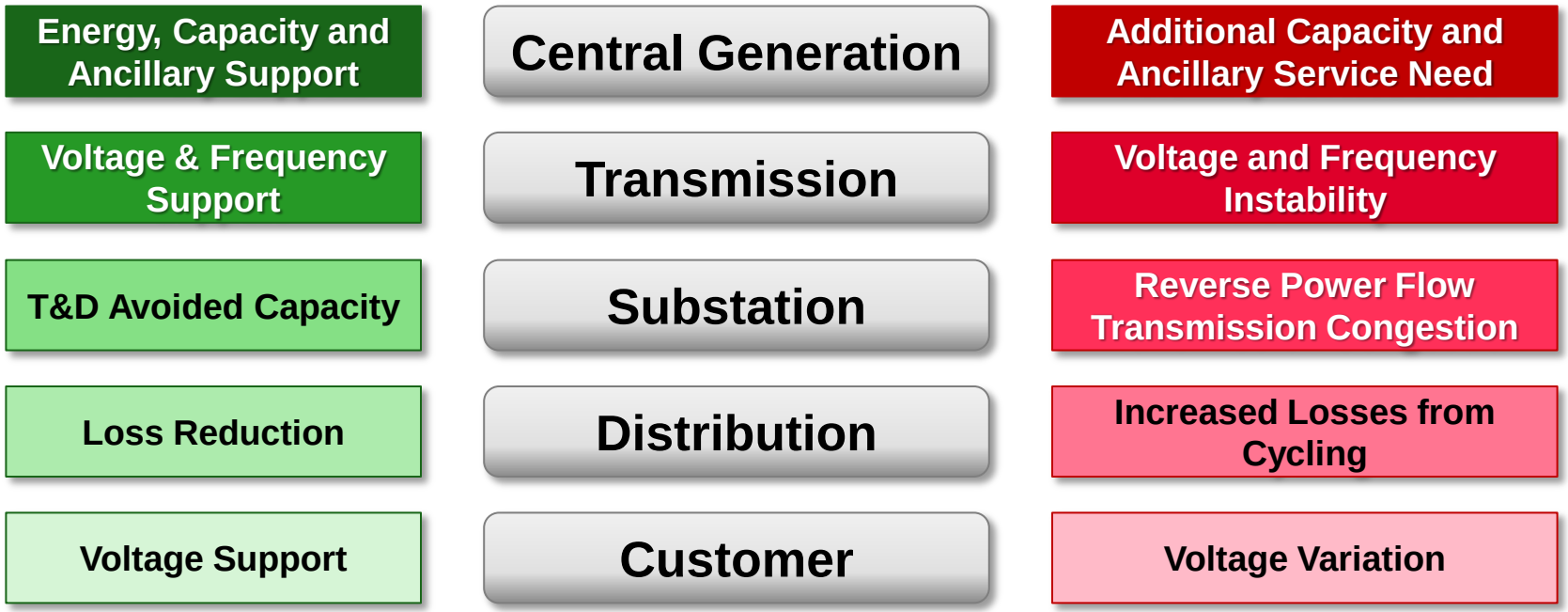
End-to-End Energy Efficiency

Demand Response-Ready Appliances



EPRI Research Ready to Apply for End-to-End Efficiency and DR Ready Appliance

Benefit and Cost of an Integrated Approach for DER Deployment



EPRI Benefit Cost Assessment Method and Distribution System Simulator (DSS) Tool Provides a Consistent, Repeatable & Transparent Framework

Scenarios to Apply the Benefit Cost Framework

Cost

Efficiency

Reliability

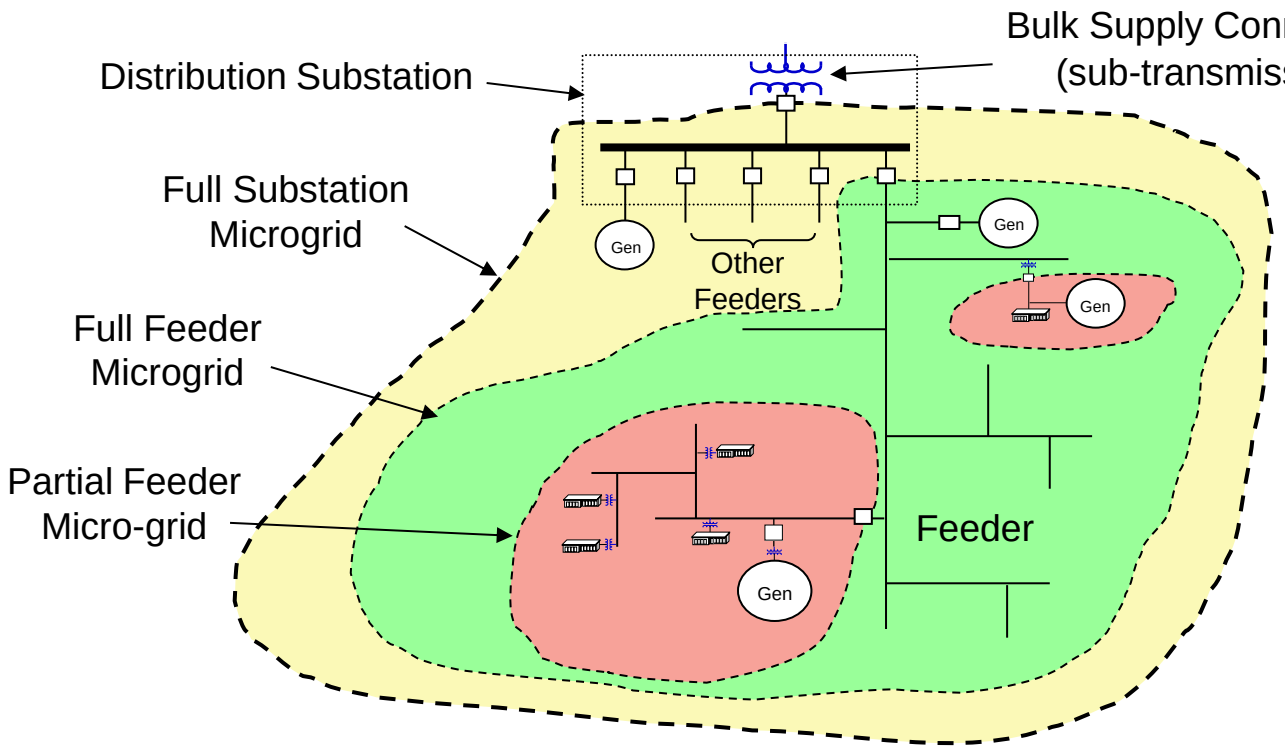
Power Quality

Resiliency

Asset Life

What is the Value for Integrated Central PV Deployment?

Scenarios to Apply the Benefit Cost Framework



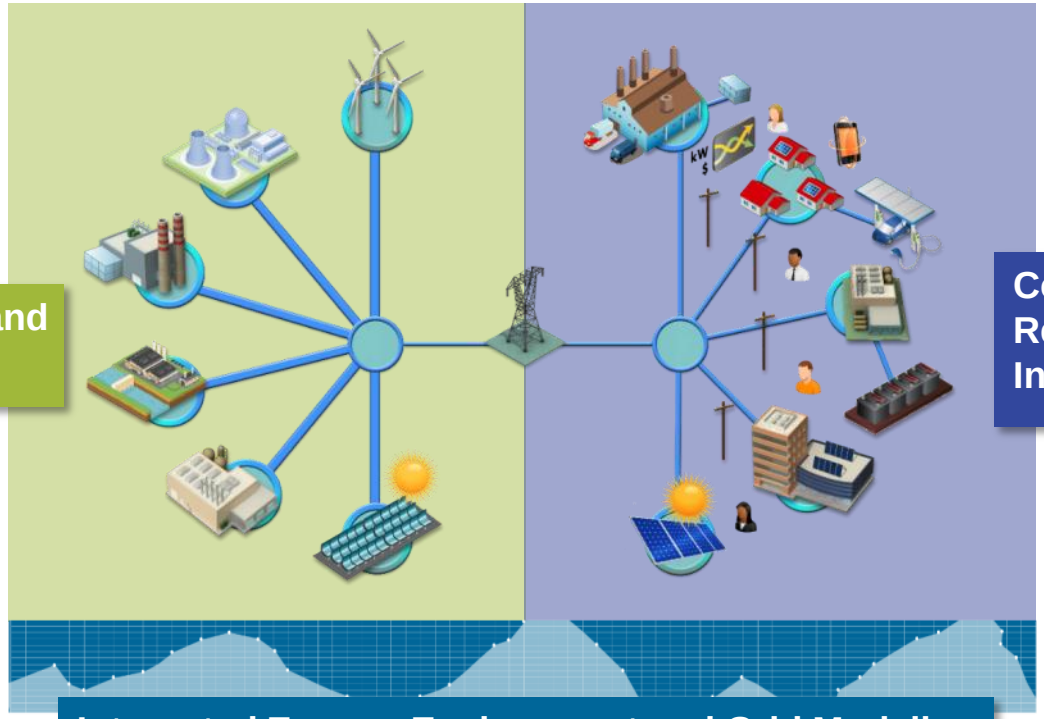
A critical first step in this process is completing a pilot project in the State that would serve as a model for future deployment.

Maryland Governor Micro Grid Taskforce Report. June 2014

What is the Value of Integrated Micro Grid Deployment?

Near-Term Power System Transformation

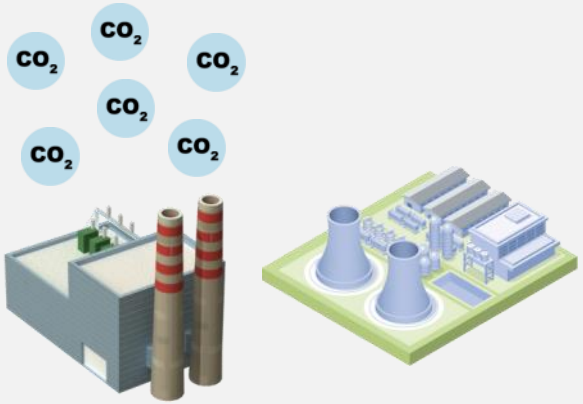
Generation Flexibility and Cost Optimization



Consumer Resource Integration

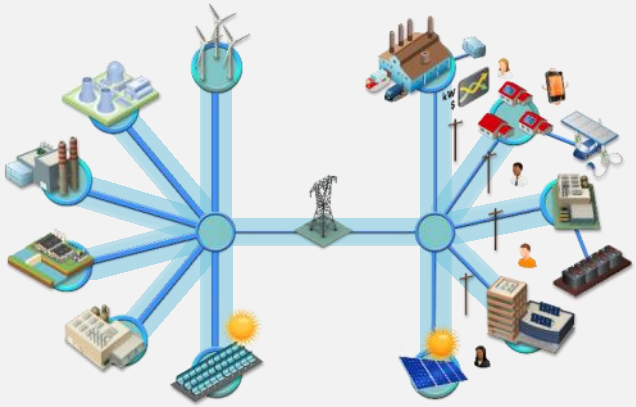
Integrated Energy, Environment and Grid Modeling

Long-Term Power System Transformation



CCS – Beyond Amines

Nuclear: Long-Term Operations and Advanced Nuclear Technology



Interactive, Two Way Fully Integrated T&D Infrastructure

Electrification for Emissions Reduction

The Path Forward

- **We need an integrated approach to transform the power system**
- **EPRI's current research on The Integrated Grid is ready to be applied**
- **Industry and policy/regulatory need to coalesce on key research imperatives for the transformation**

Integrated
The Whole is Greater than the Sum of its Parts

Transforming the Power System – It is a Journey not a Destination

Questions

Questions? Comments? Suggestions?

Please contact

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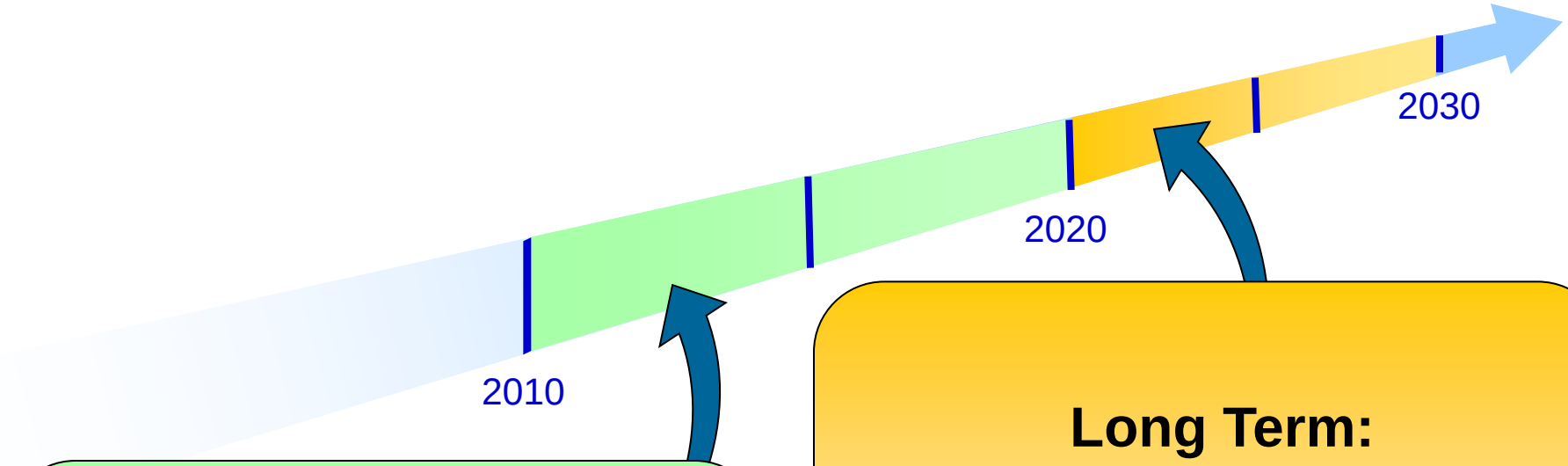
(650) 855-2268

Together…Shaping the Future of Electricity

The Future of Energy Storage



Near Term:
Establish Expectations and Develop Products for Niche Markets

Long Term:
Creating More Effective Storage Technologies

Key Performance Metrics for Storage Technologies

Cost

- Low materials and manufacturing costs
- Low integration costs
- Low recycling and disposal costs

Reliability

- Durable, long-life components
- Operable under wide range of conditions
- Well-defined failure characteristics and expected life

Efficiency

- High coulombic efficiency with low polarization
- Low self-discharge losses
- Minimal parasitic loads from cooling and other functions

Control

- Well-defined use cases
- Effective and well-established control algorithms

Storage Technologies:
Risk and Reward for the Utility Enterprise