University of Pittsburgh

Electric Power Grid Reliability in a New Era of Energy Development

MIT Energy Initiative
February 7, 2017 – Cambridge, MA

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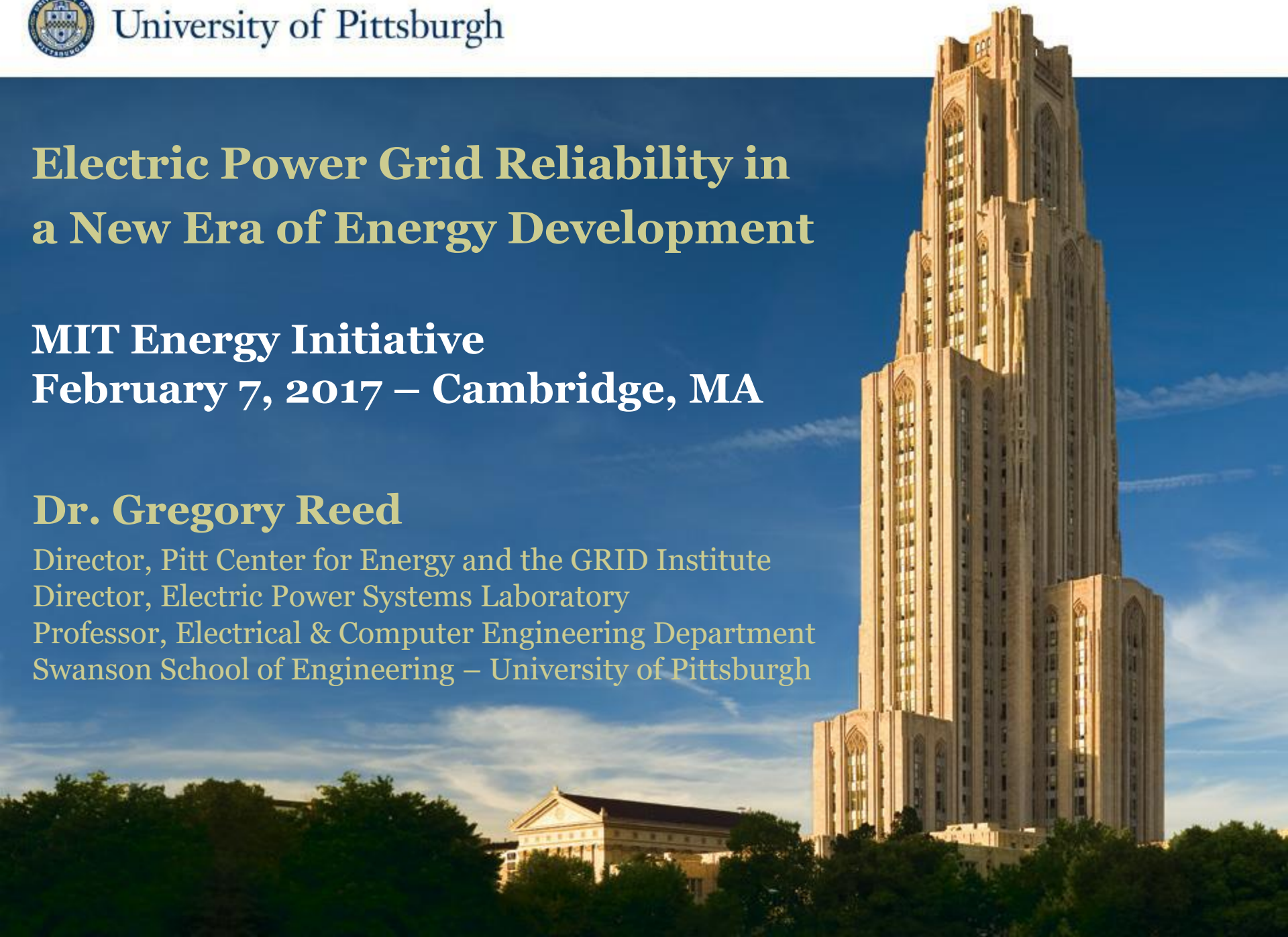

Energy and Electricity – Critical to Our Productivity and Quality of Life

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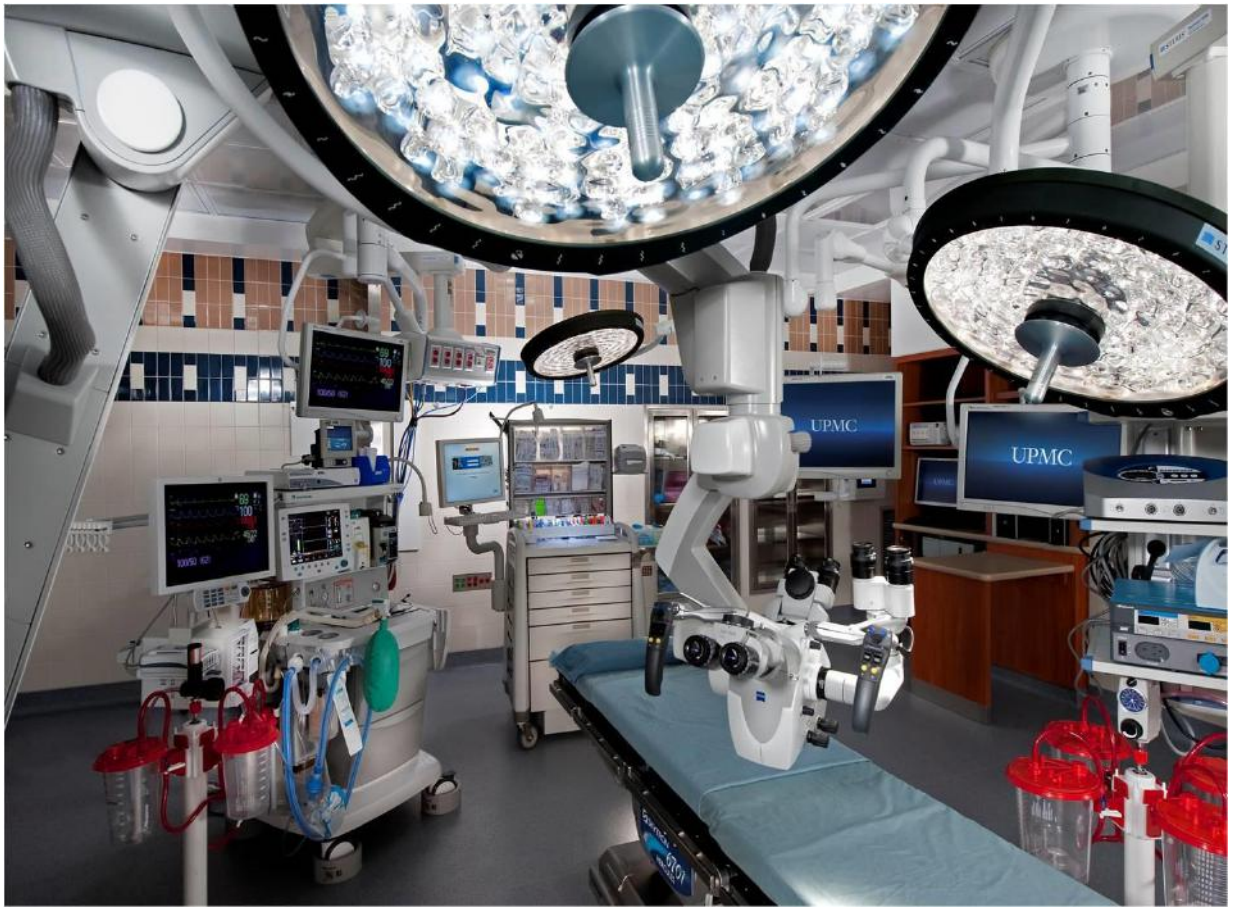
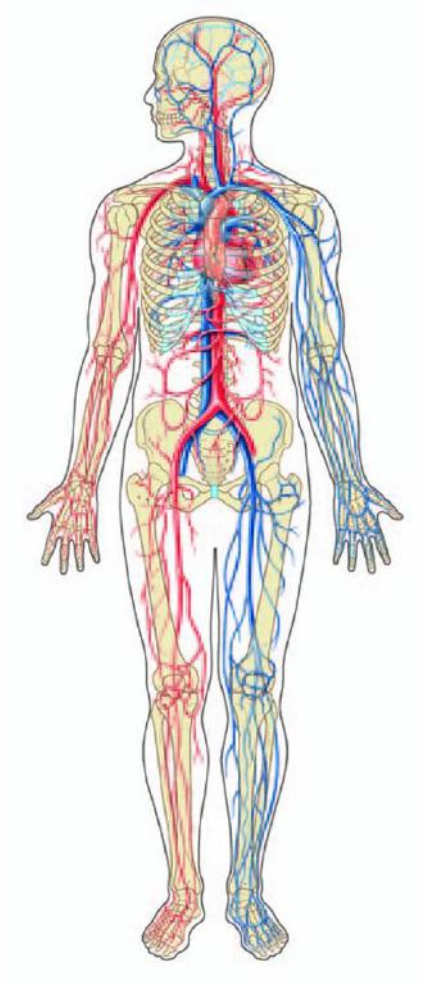
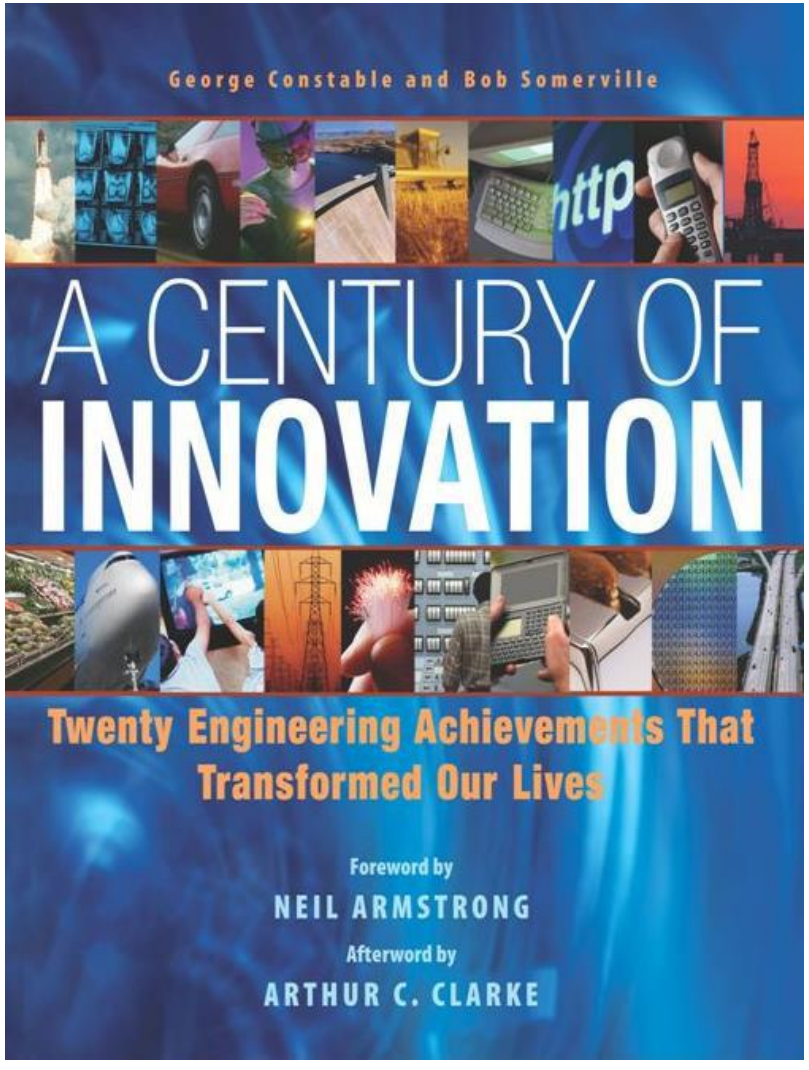


Energy and Electricity – Critical to Our Productivity and Quality of Life

Electricity – the Life Blood of Modern Society

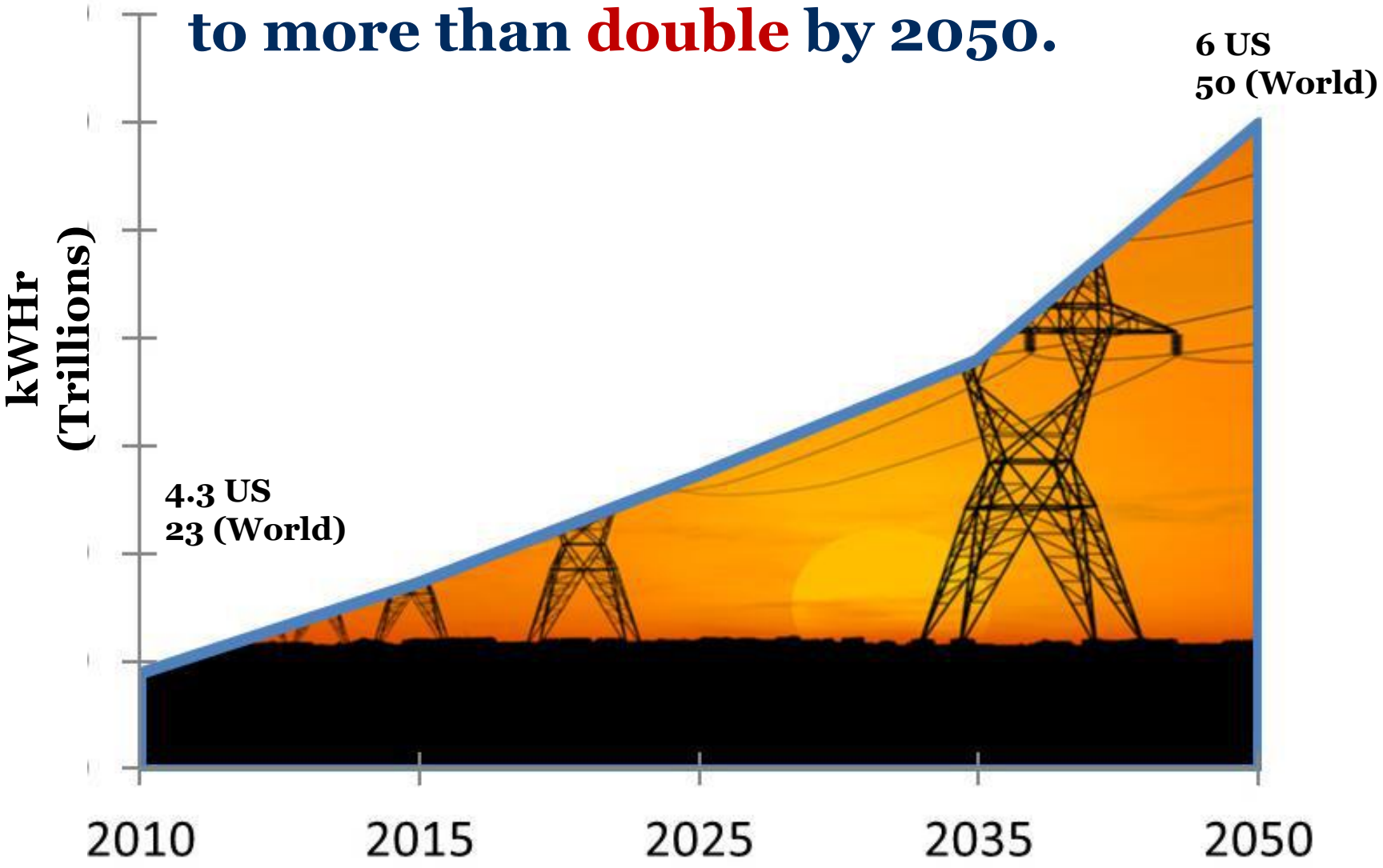


Greatest Engineering Achievement of 20th Century

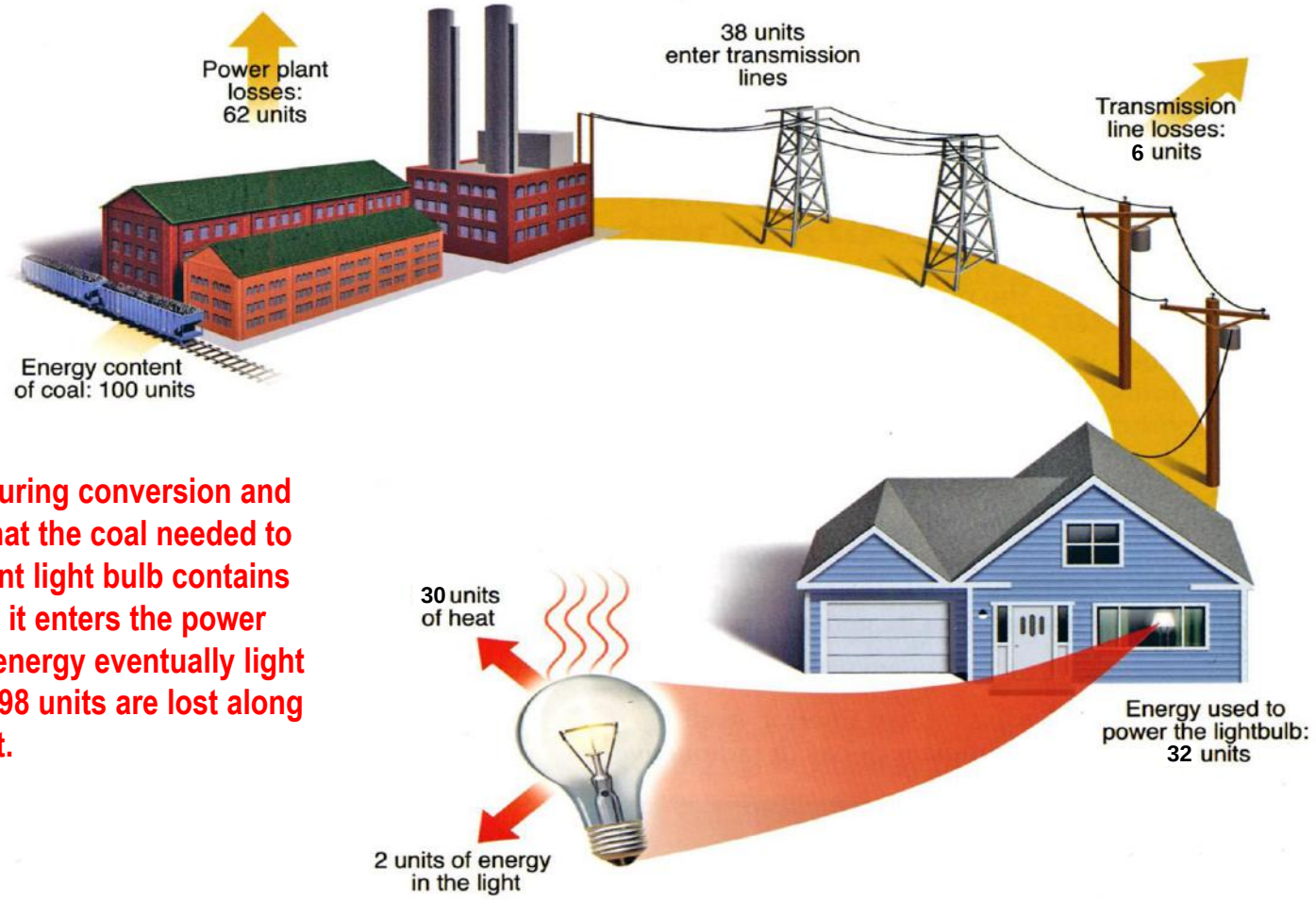


1. Electrification
2. Automobile
3. Airplane
4. Water supply & distribution
5. Electronics
6. Radio & TV
7. Agricultural mechanization
8. Computers
9. Telephone
10. Air conditioning & refrigeration

Electricity demand is expected to more than double by 2050.



Energy and Electricity (In)Efficiency – Losses



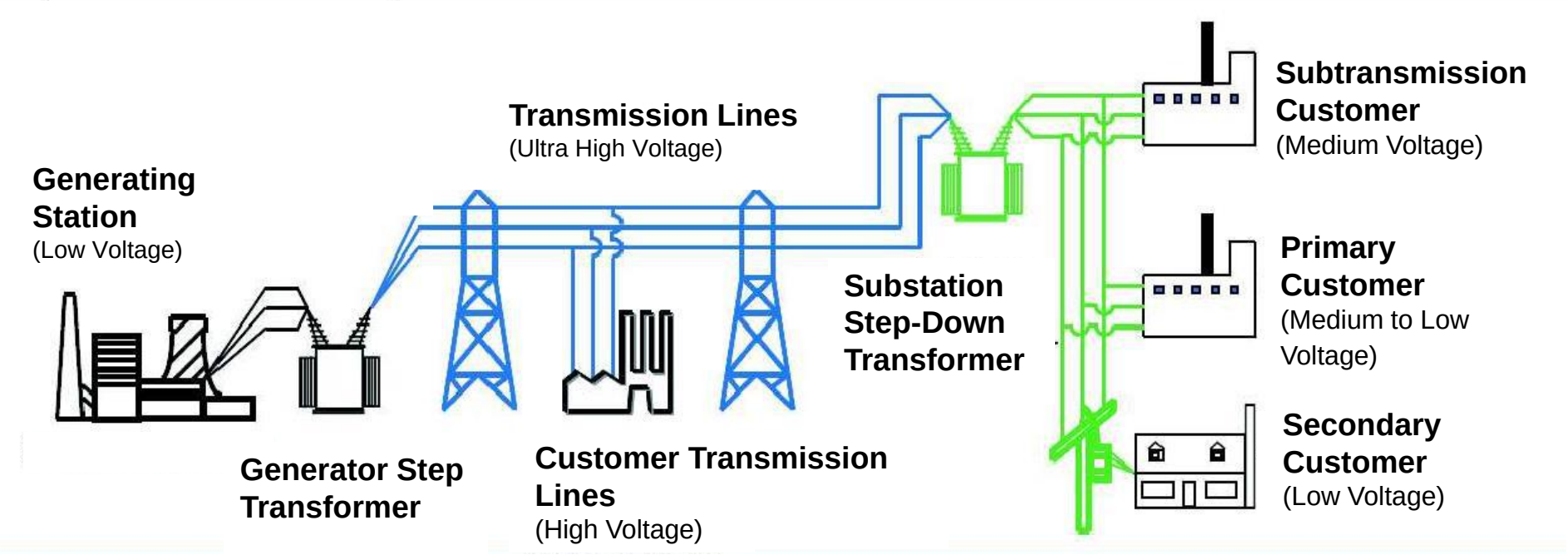
Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent light bulb contains 100 units of energy when it enters the power plant. Only two units of energy eventually light the bulb. The remaining 98 units are lost along the way, primarily as heat.

Power Grid Infrastructure and Reliability

What is the Power Grid?

Today's Electric Power Systems (AC Networks, One-Way Flow)

Generation → **Transmission** → **Distribution** → **Consumption**



T&D (the Grid) Delivers Electricity

Transmission

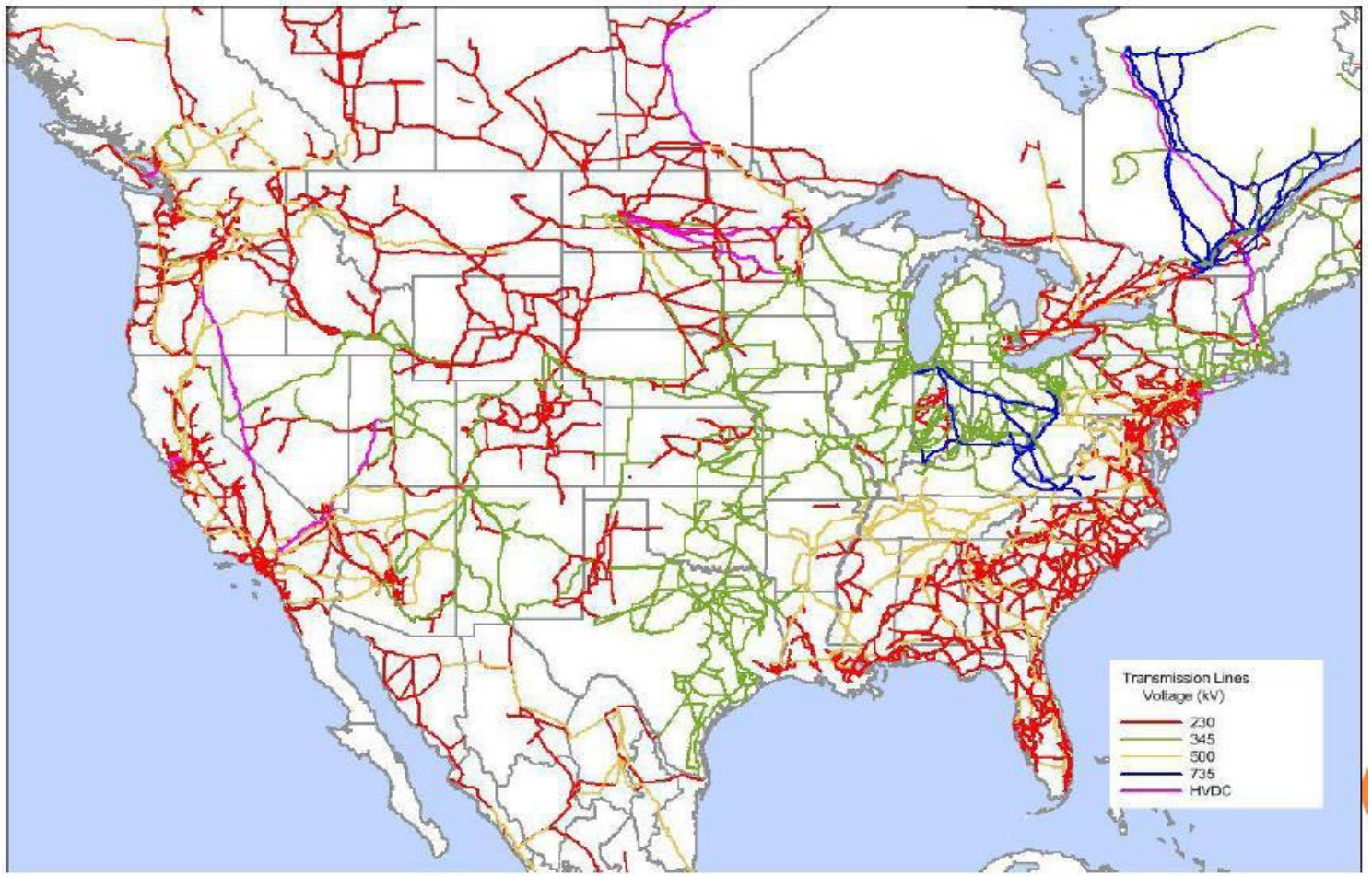
- High voltage
- 400,000 miles
- 16,000 substations

Distribution

- Lower voltage
- 5,000,000 miles
- 60,000 substations

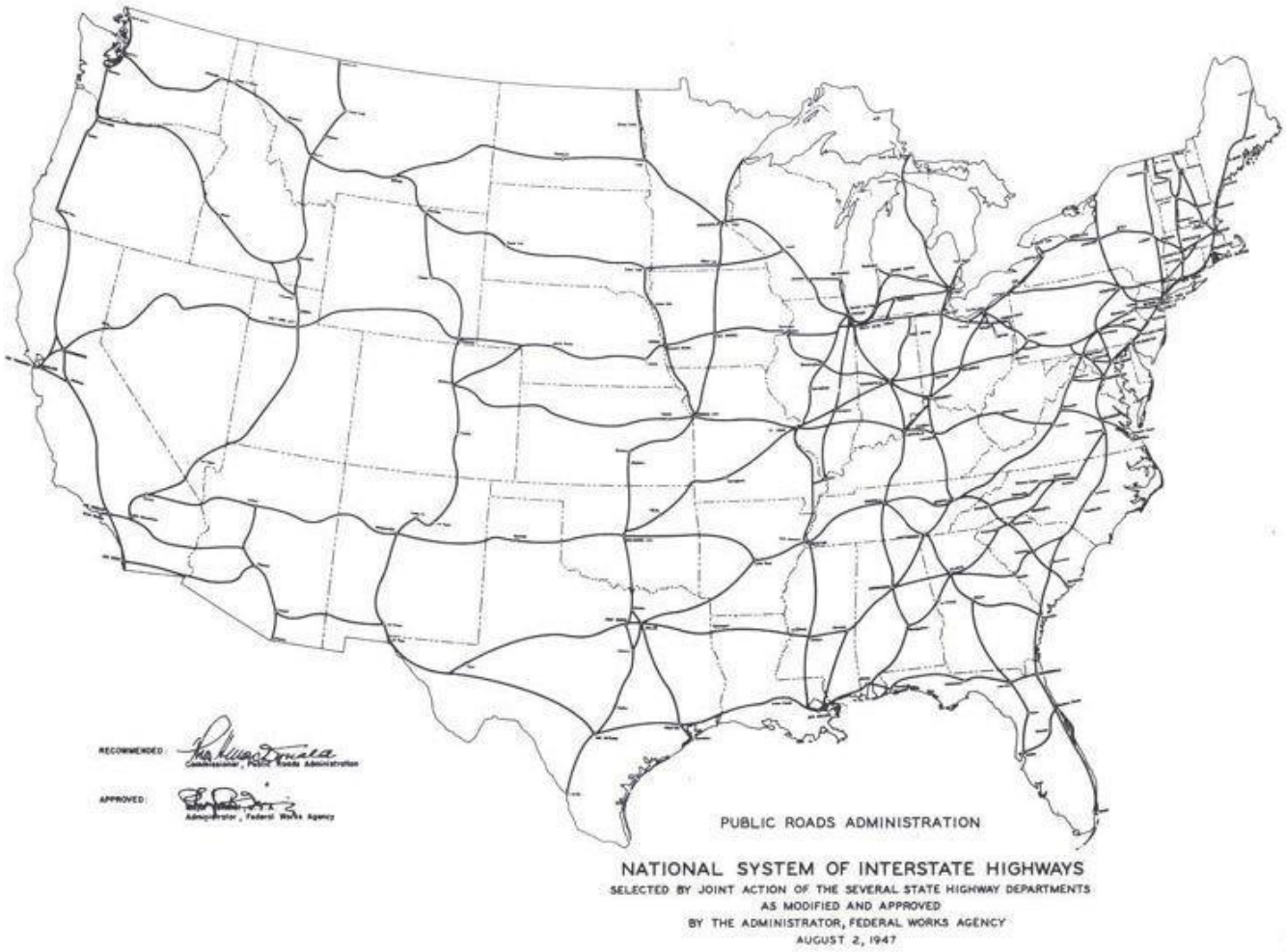
Grid Reliability

The U.S. Power Grid



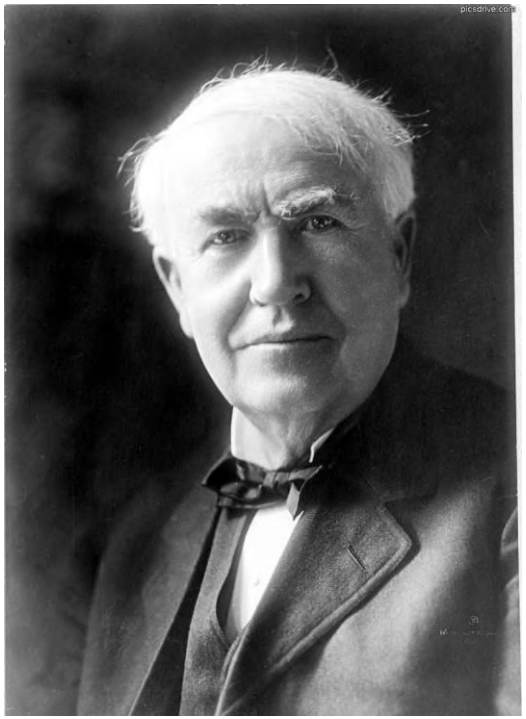
The U.S. Power Grid

The Grid was not planned like the U.S. National Interstate Highway System



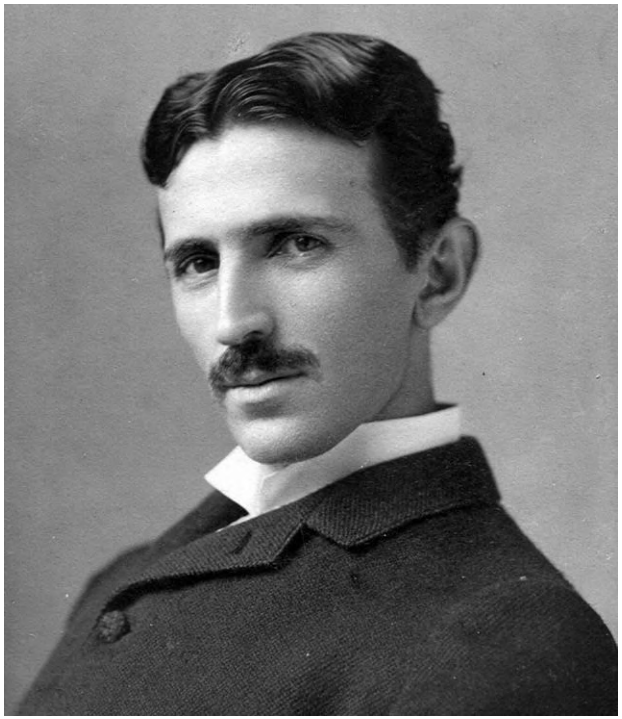
The U.S. National Highway System Today

In the late 1800s and early 1900s, Pittsburgh was at the center of the war of the currents — AC vs. DC electricity



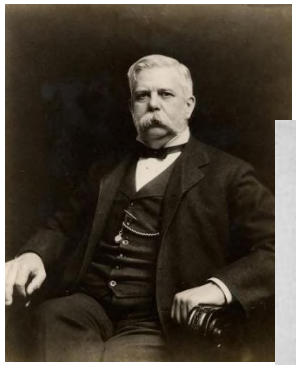
Edison

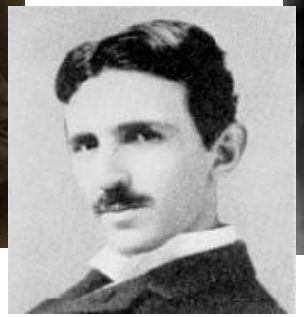
Westinghouse

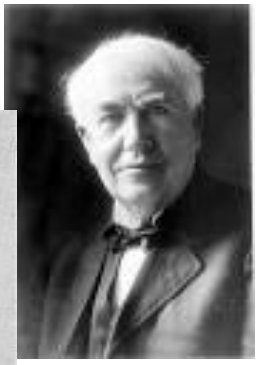


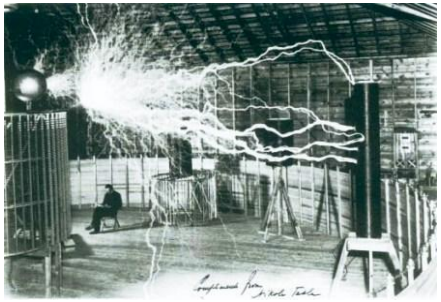
Tesla

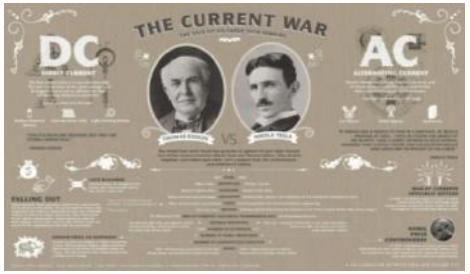
AC vs. DC – The Original "War of the Currents" (20th Century)

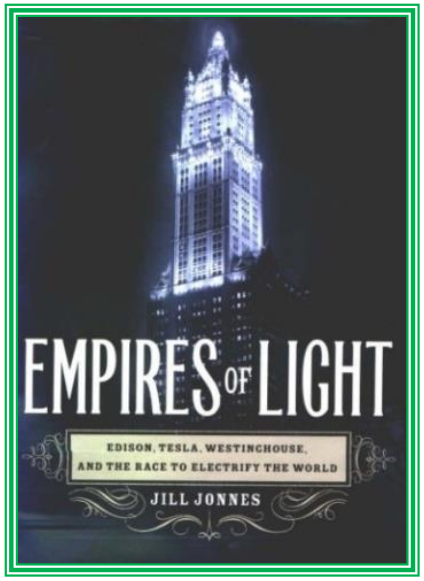






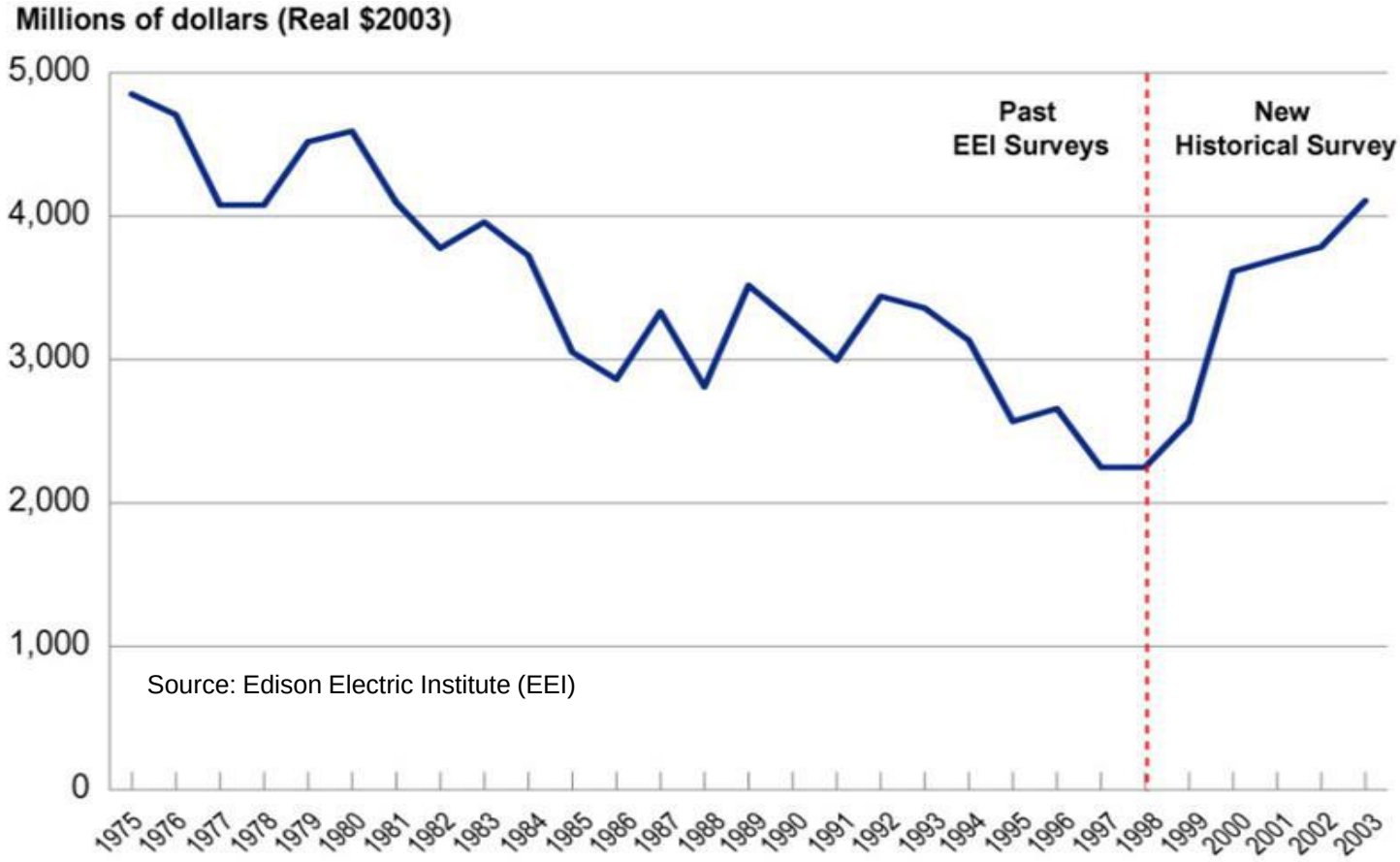




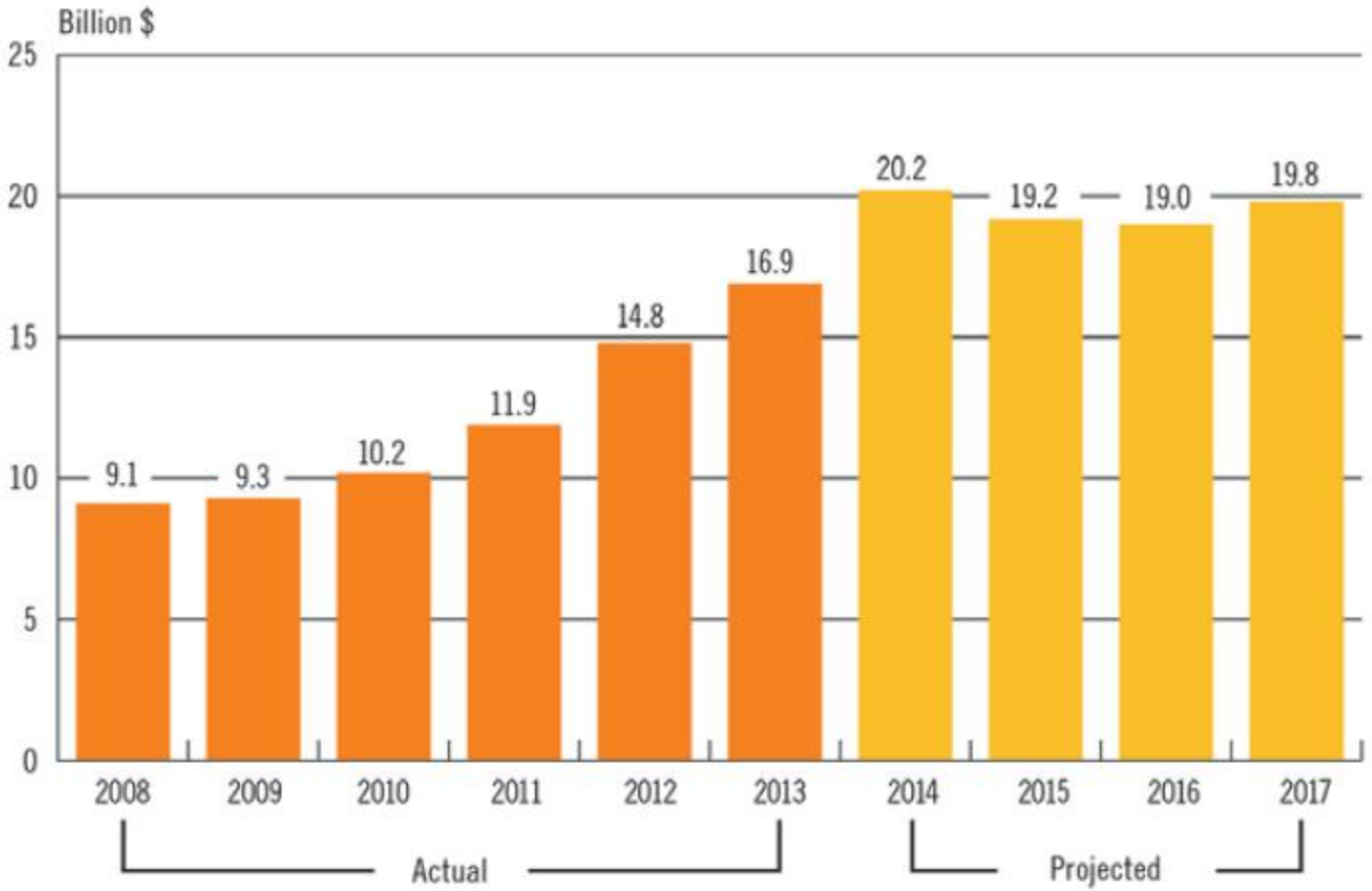


Transmission Investments

Transmission Investments by Investor Owned Utilities (IOUs) and Stand-Alone Transmission Companies (1975-2003)



Recent Transmission Investments



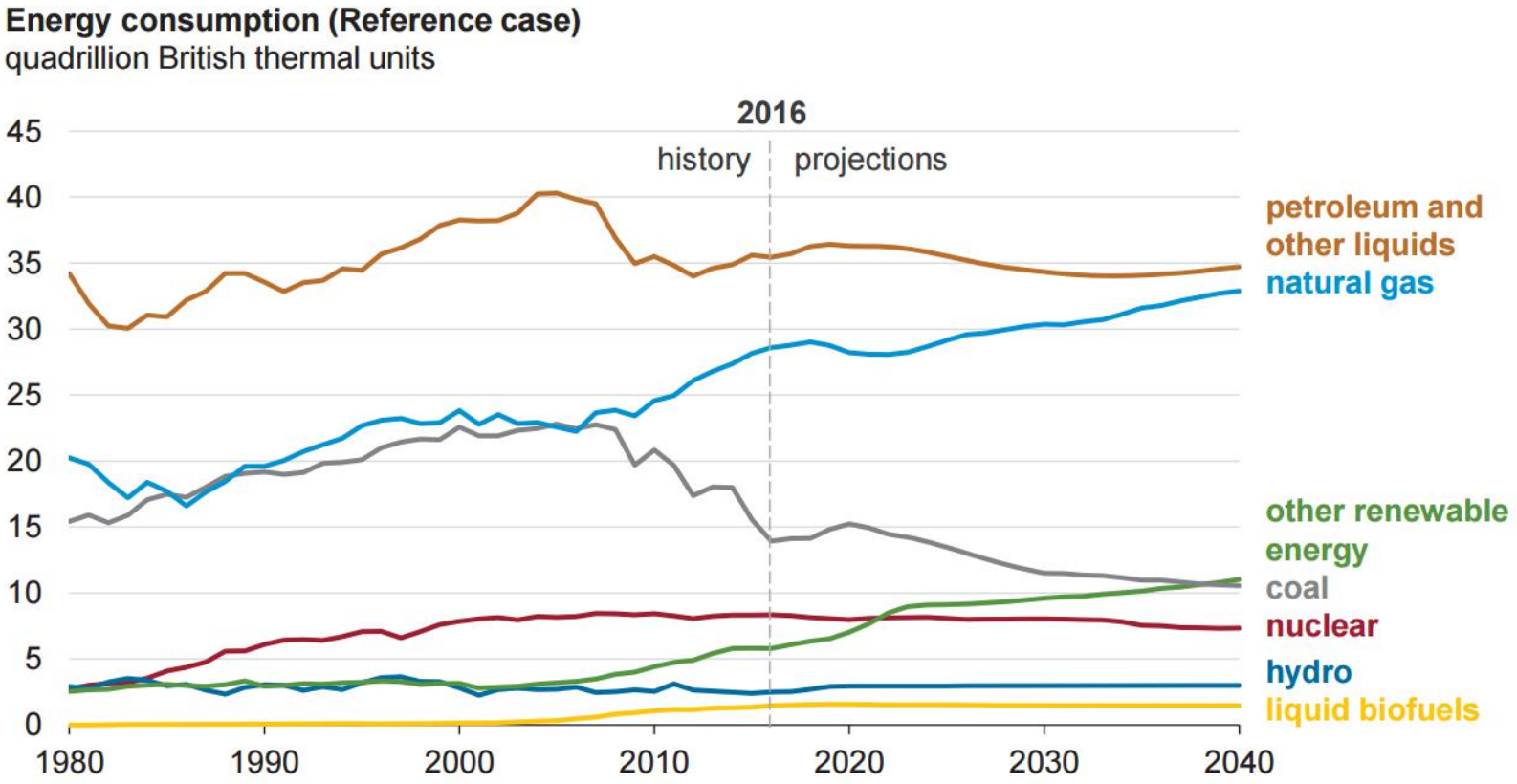
Edison Electric Institute member investments by year. Courtesy of EEI.

Challenges for Today's Power Grid

Resource Transition

Consumer Participation

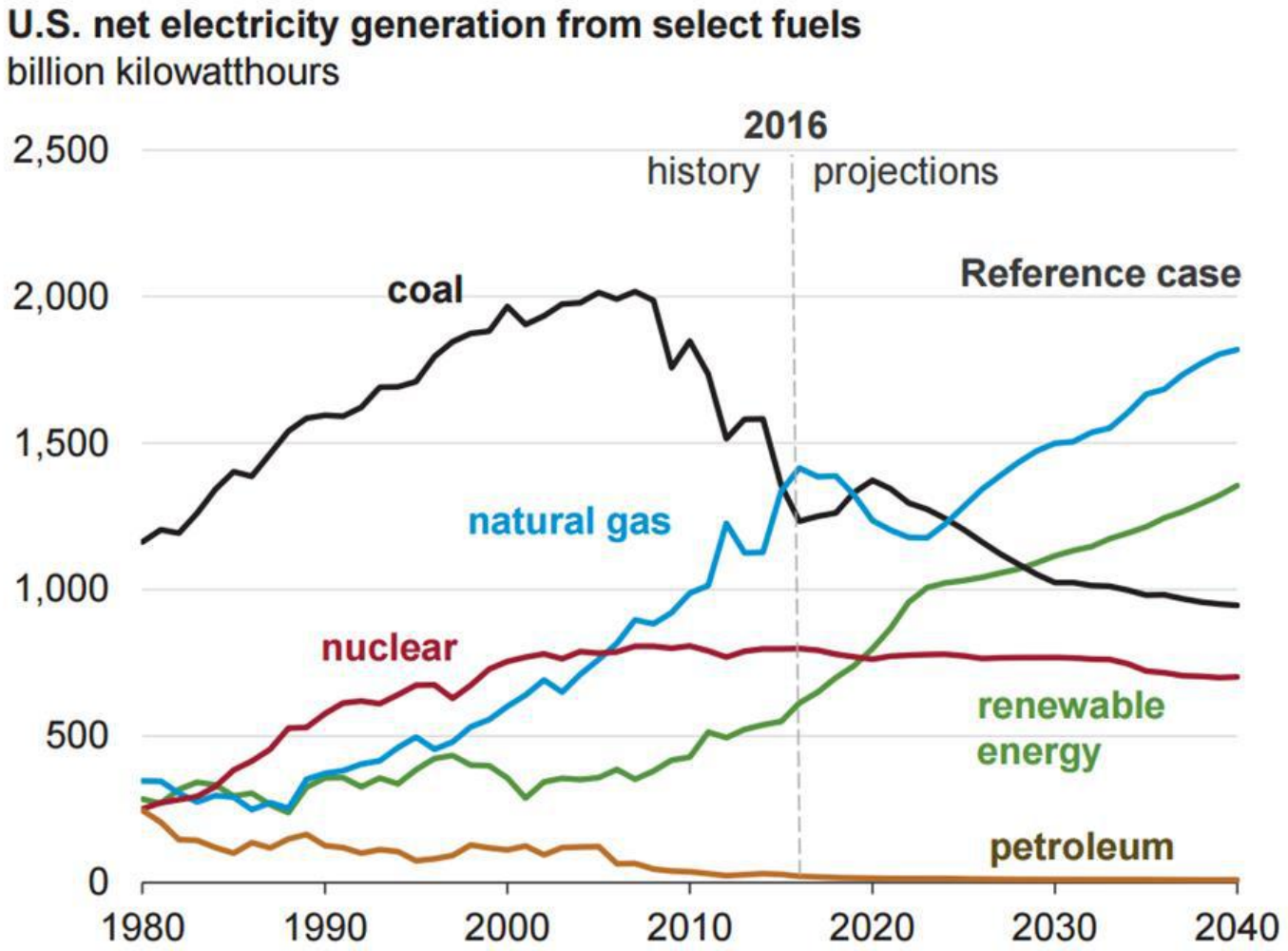
Energy Utilization



Primary Energy Use by Fuel (quadrillion Btu)

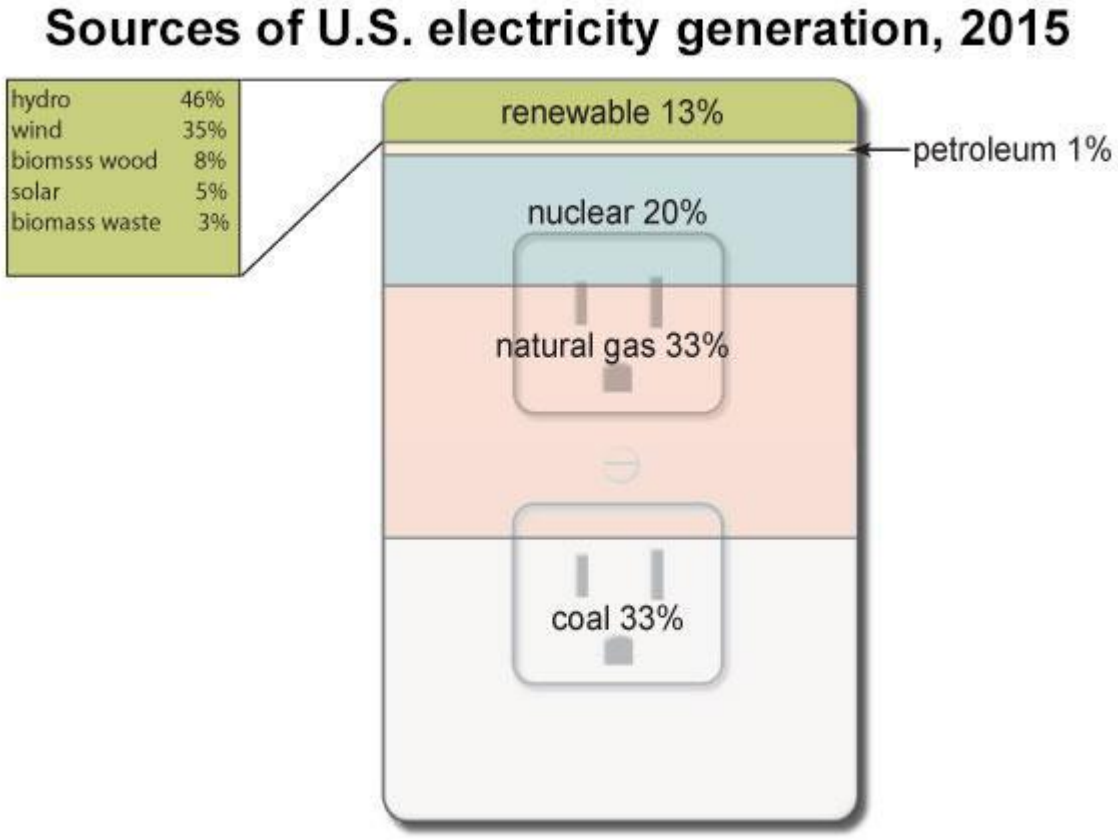
(U.S. DOE EIA, report)

Electricity Generation

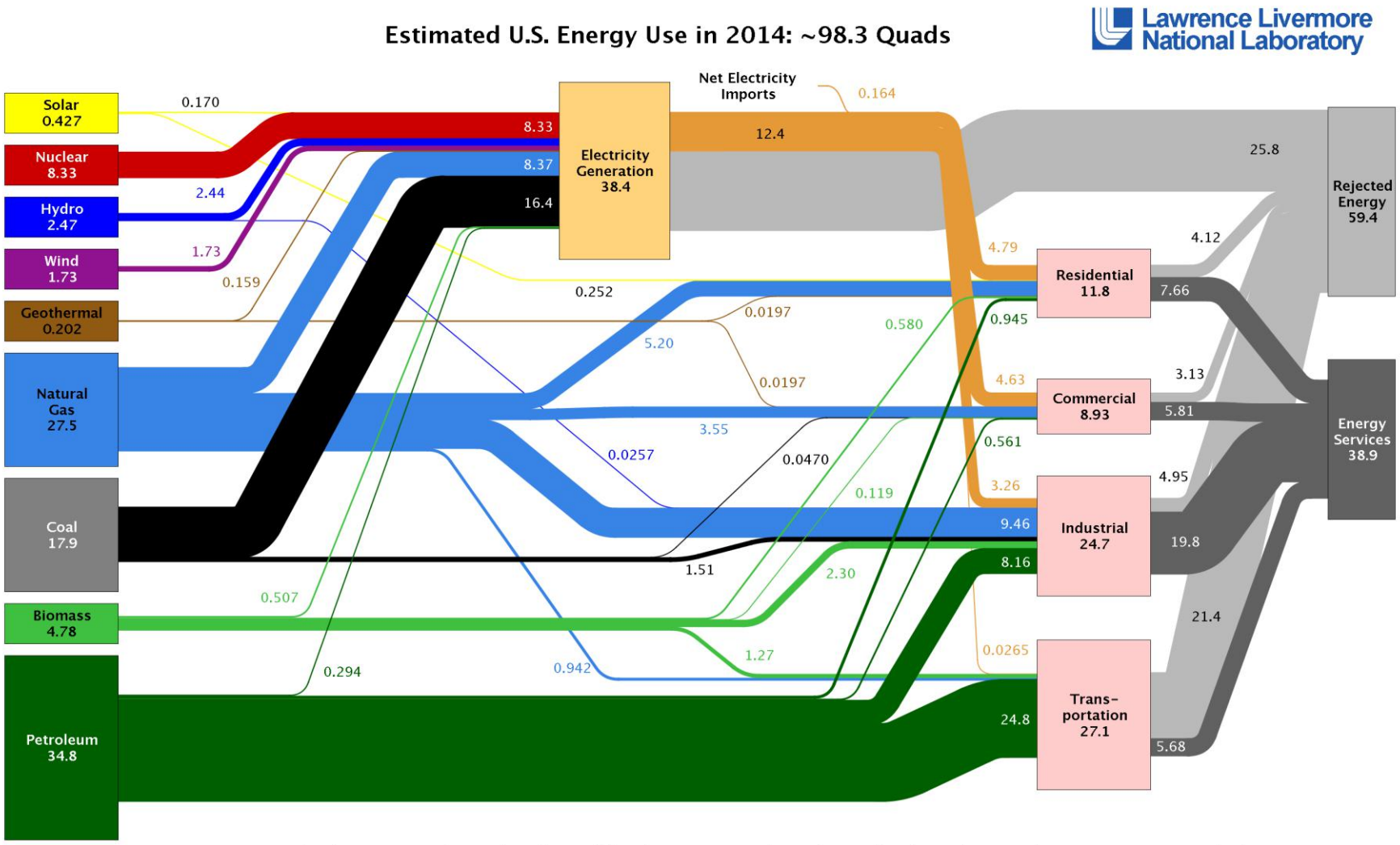


(U.S. DOE EIA, report)

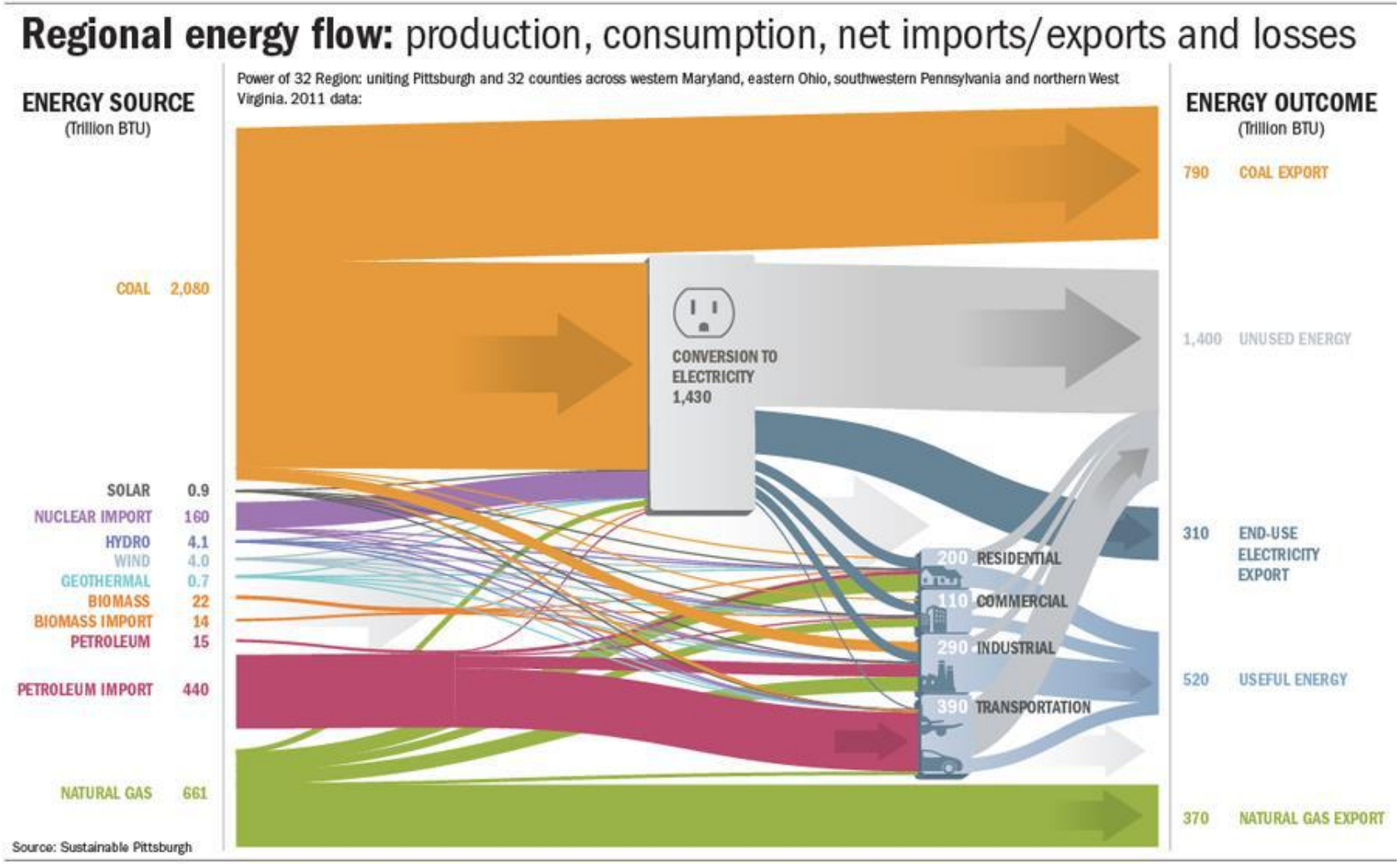
Electricity Generation



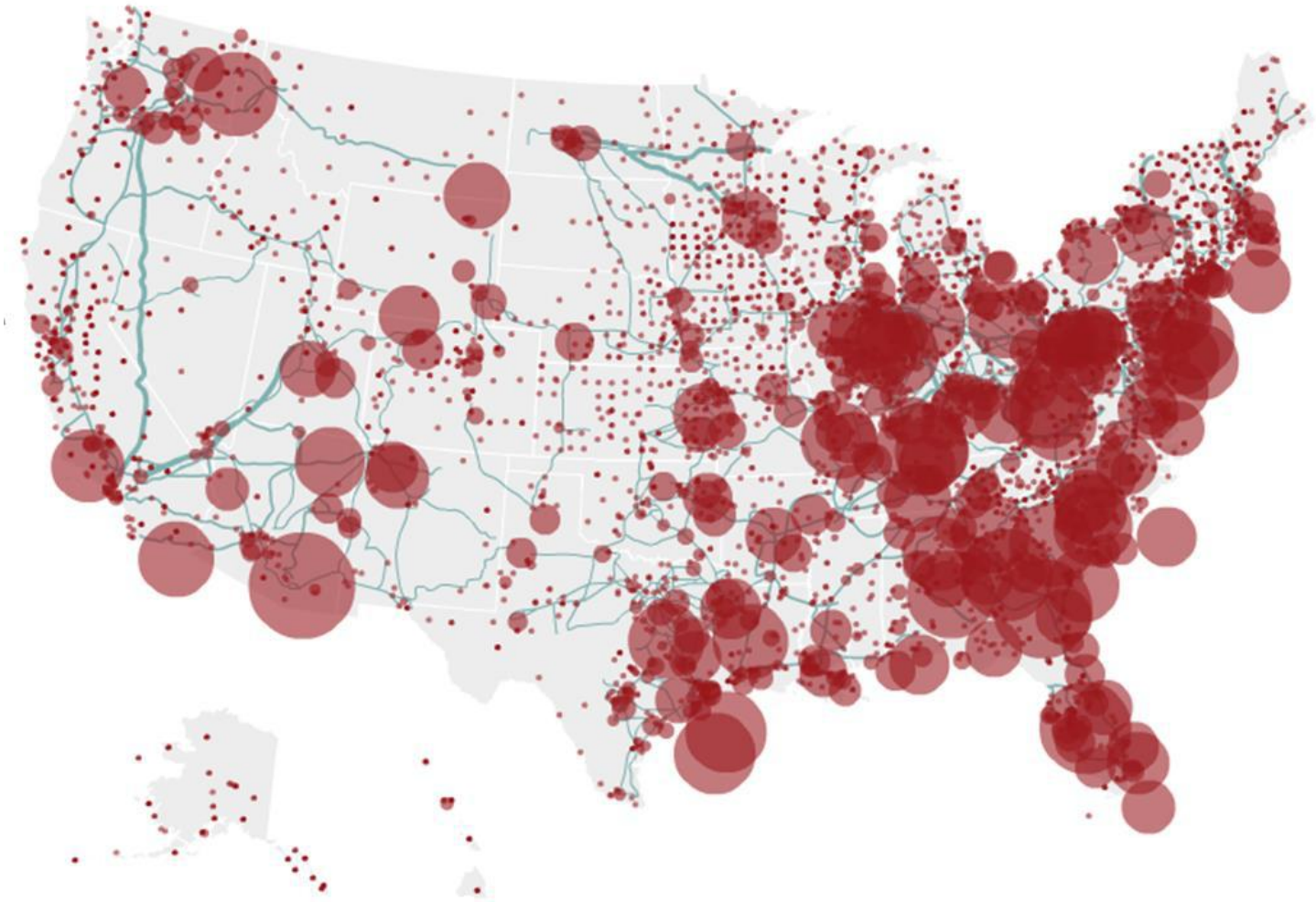
U.S. - Energy Production to End-Use



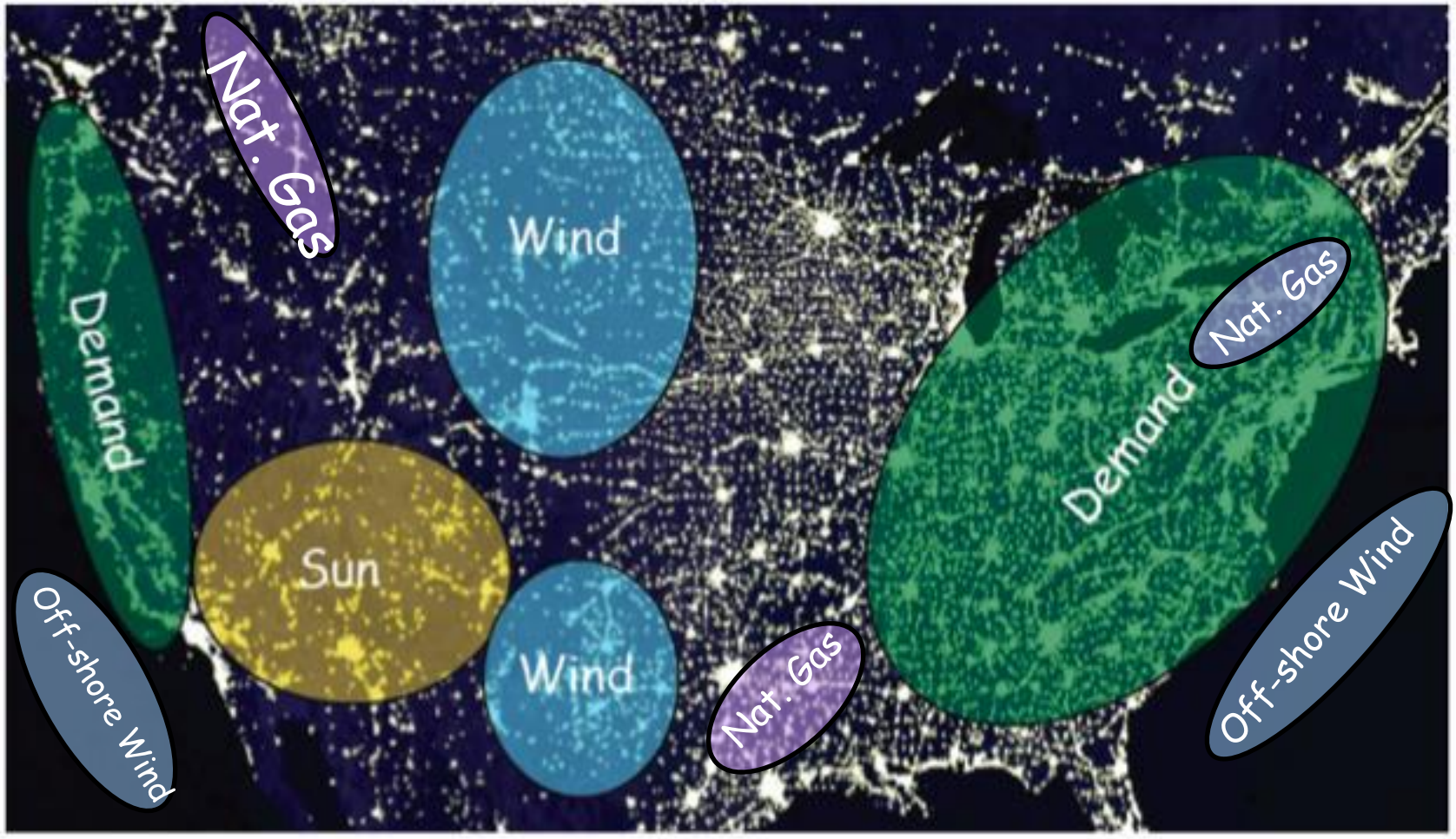
E4P32 - Energy Production to End-Use



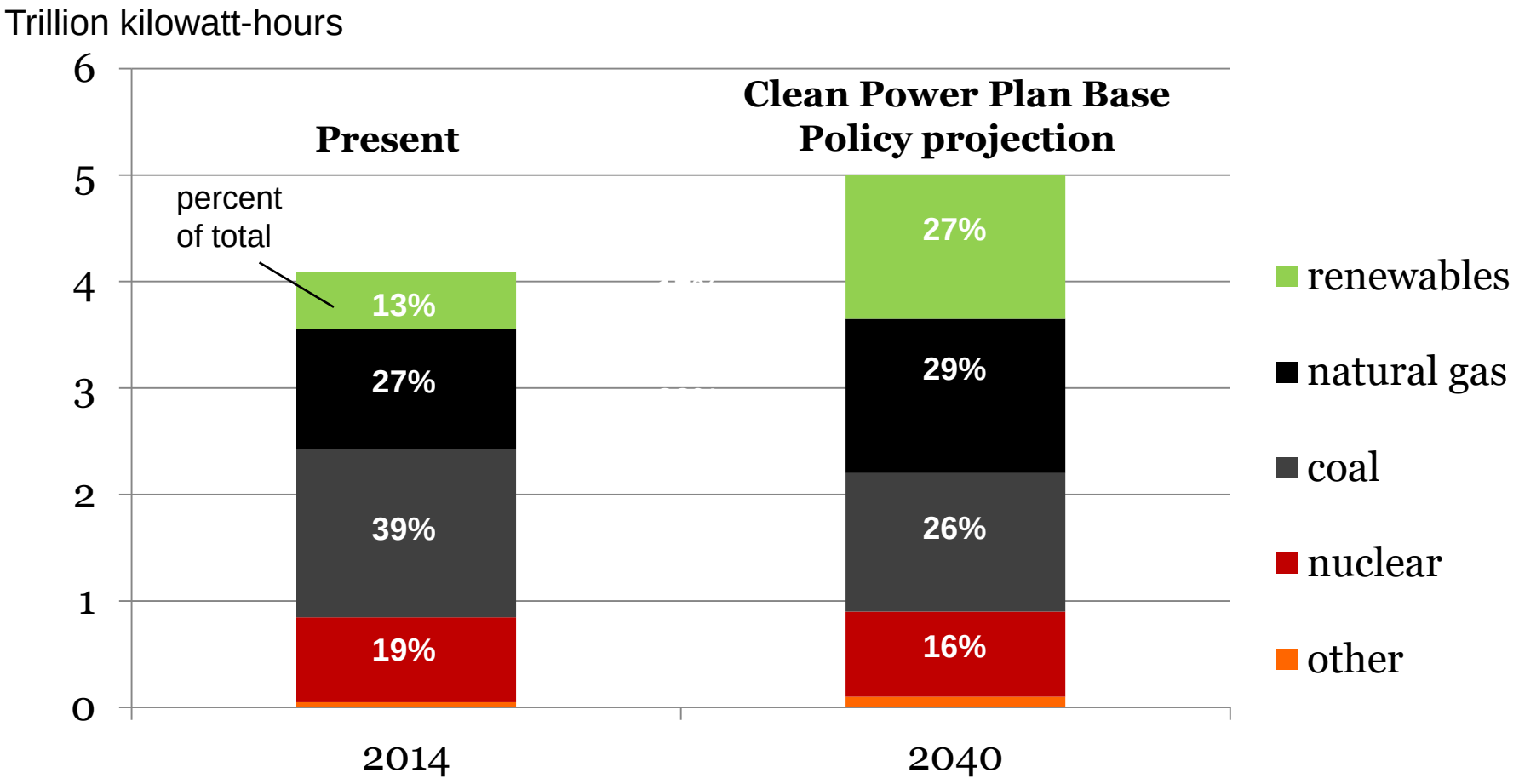
Electricity Generation Portfolios are Changing



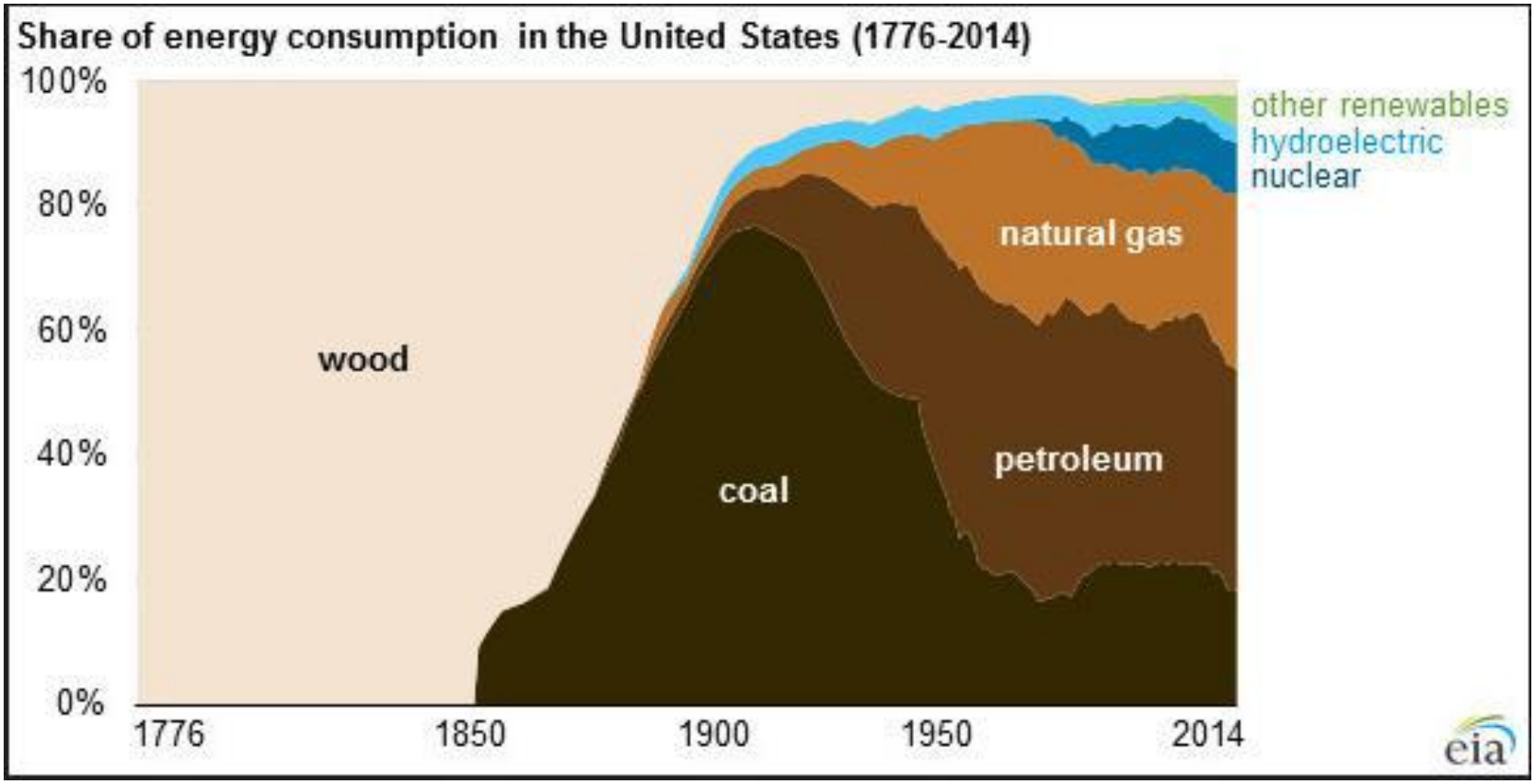
Future Energy Supply and Demand Trends



Proposed Clean Power Plan

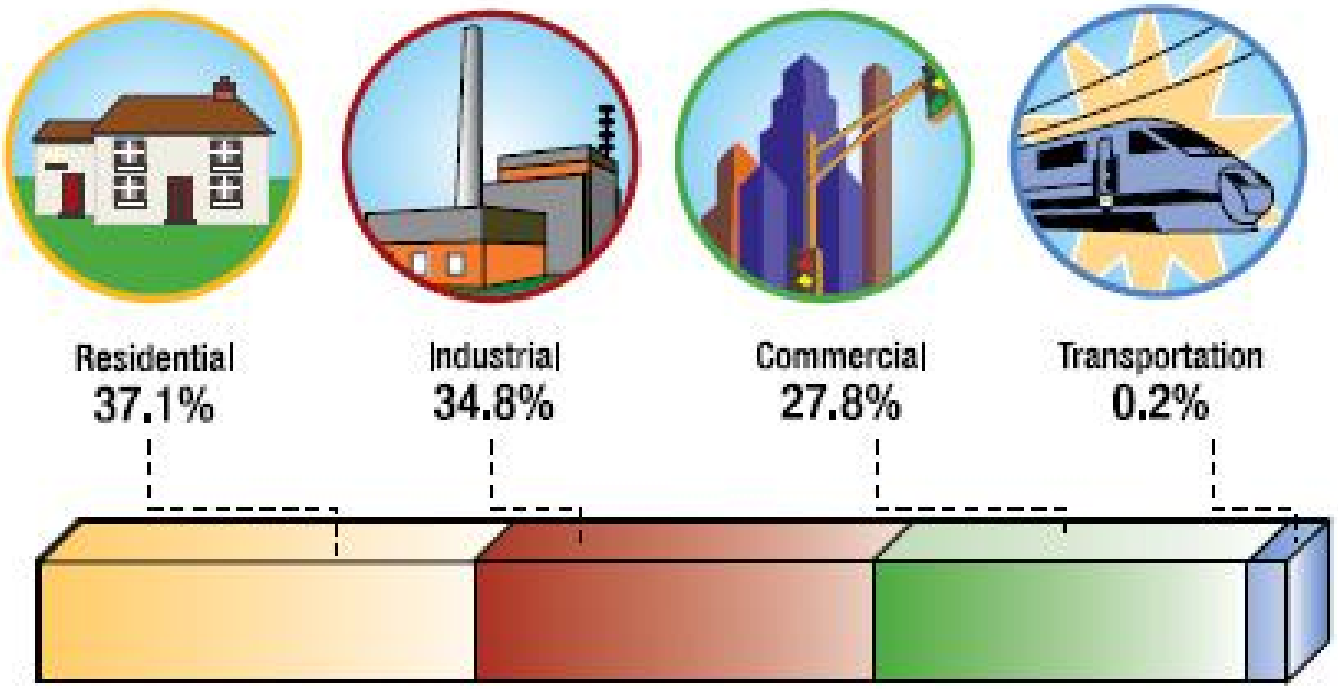


Energy Mix has Evolved Over Time



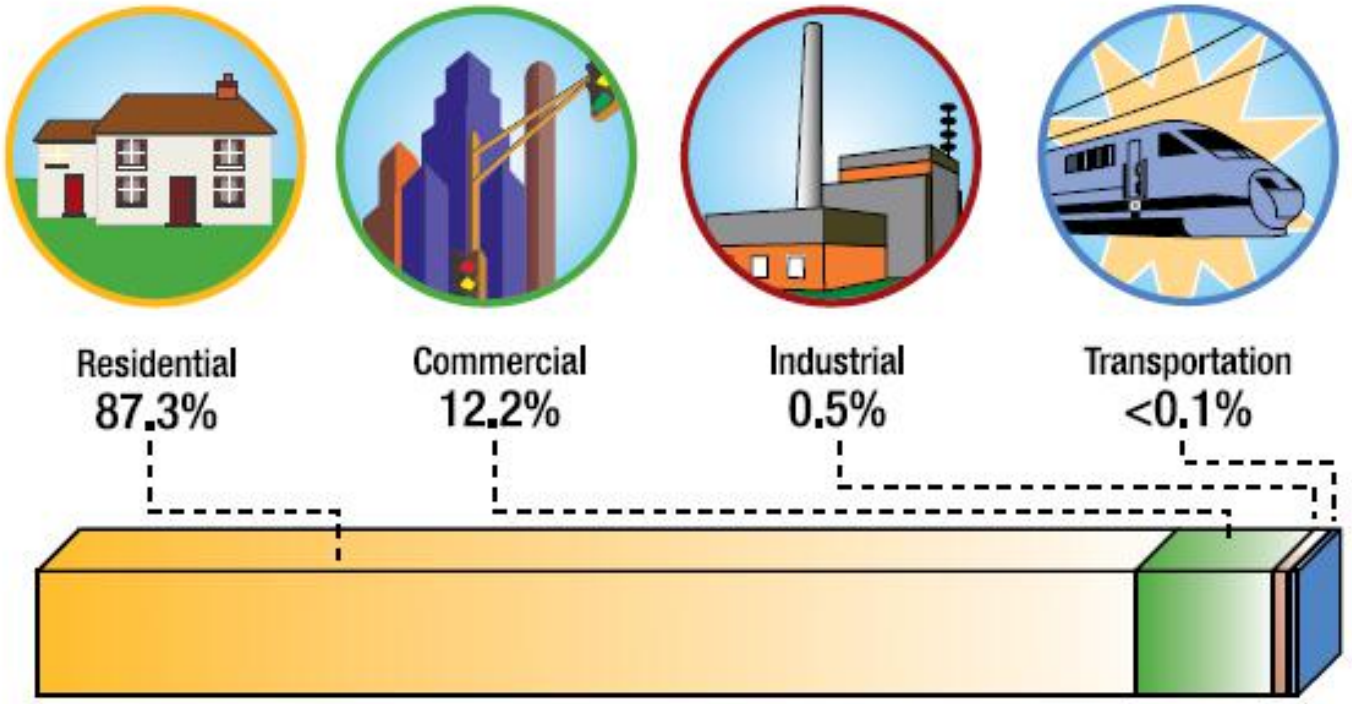
Consumer Participation is Increasing

Four primary consumer sectors – electrical consumption



Source: Edison Electric Institute (EEI)

Four primary consumer sectors – number of customers (meters)



Source: Edison Electric Institute (EEI)

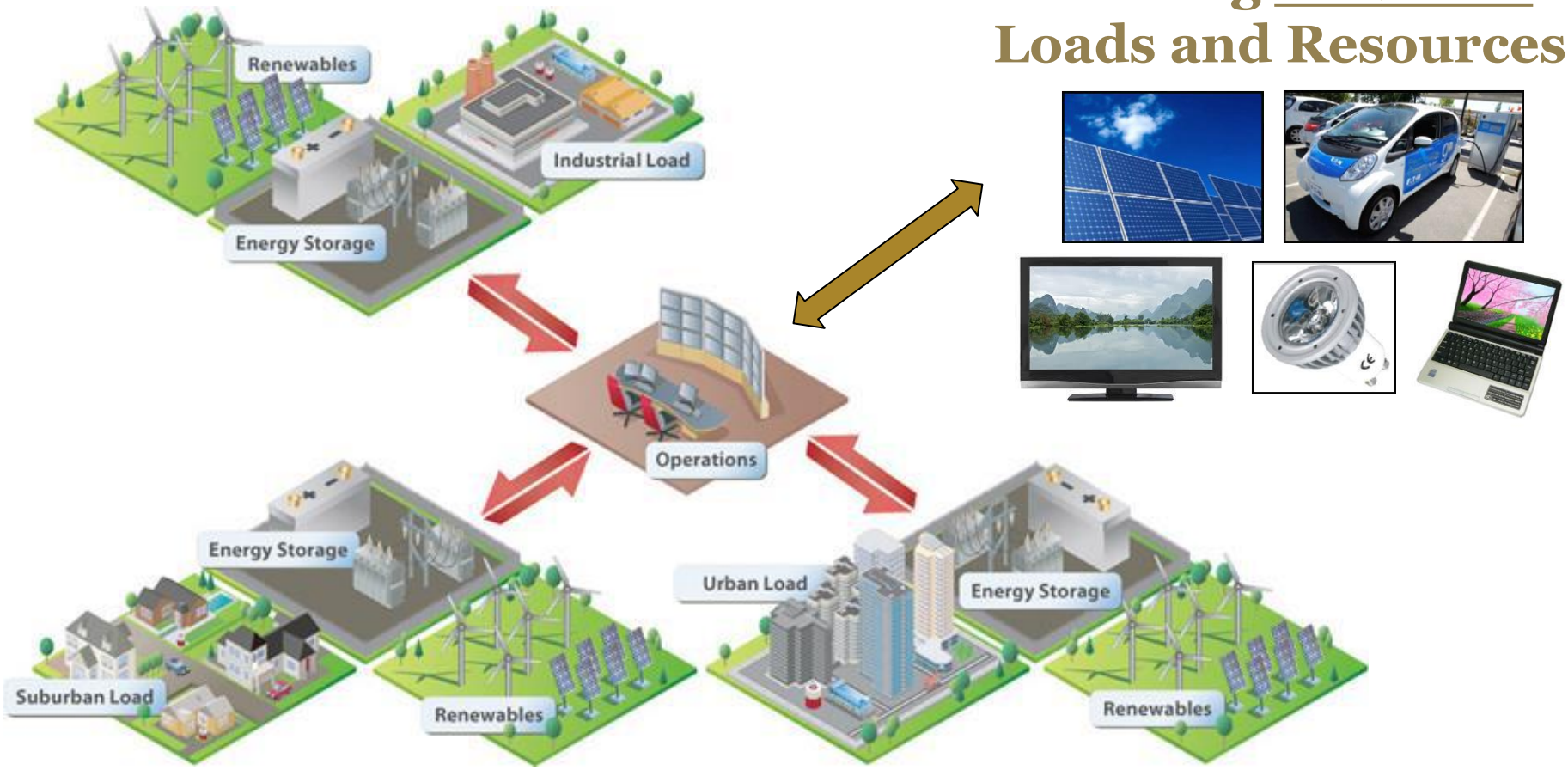
Grid Impacts from Powerful Weather Events

Hurricane Sandy

Cascading Blackout Scenarios

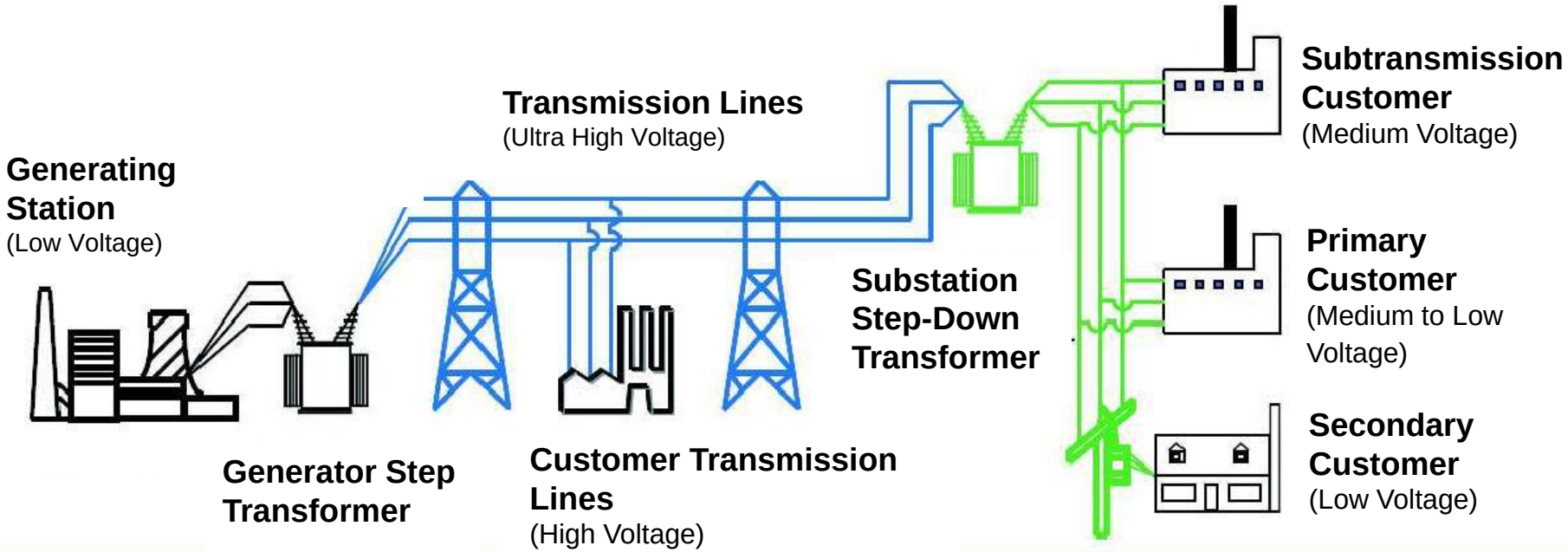
Distributed Energy Resources and Microgrids

Evolving DC-based Loads and Resources

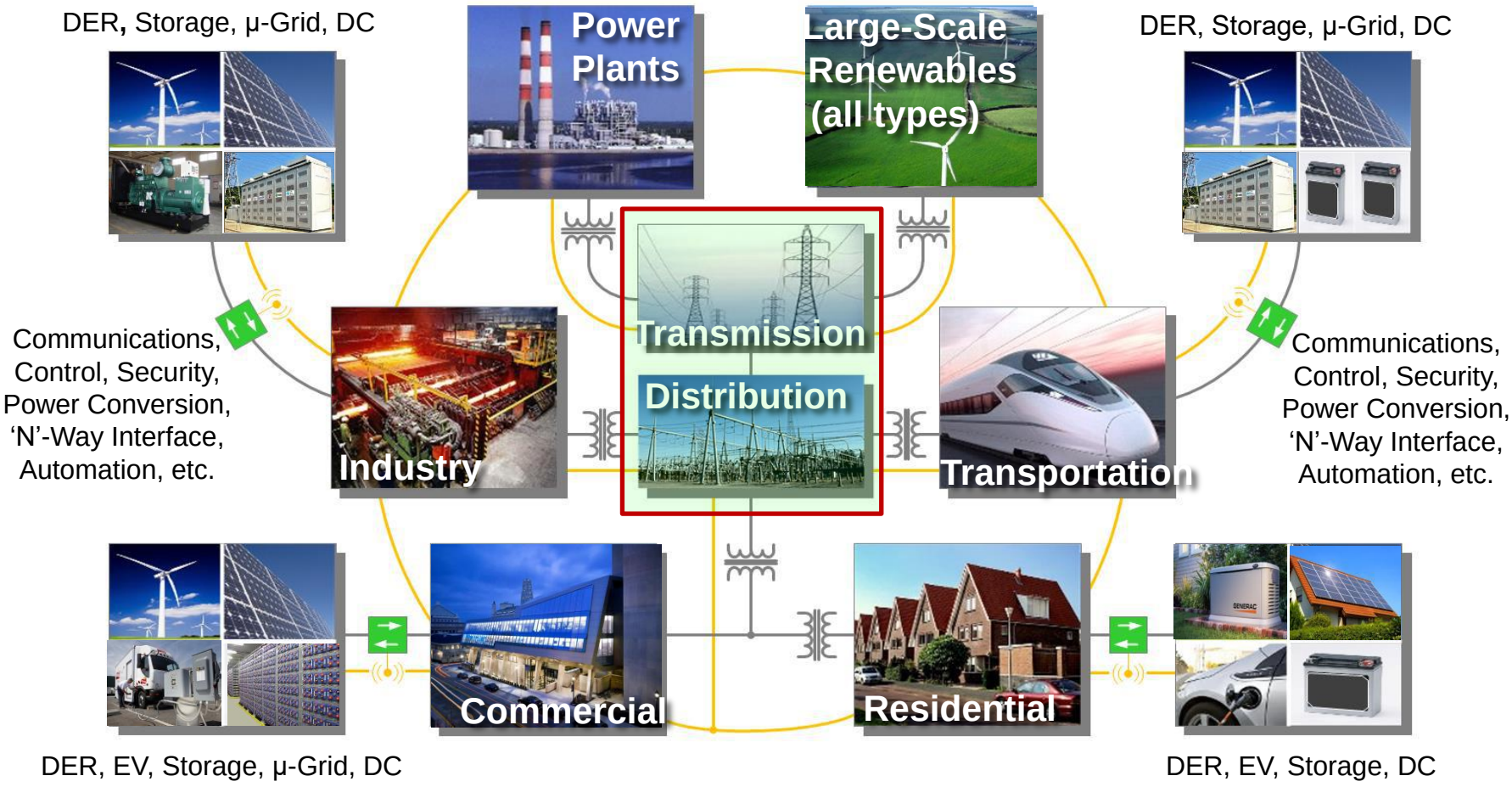


Tomorrow's electric power systems will have hybrid AC-DC networks and multi-way flow

Generation ⇒ **Transmission** ⇒ **Distribution** ⇔ **Consumption**

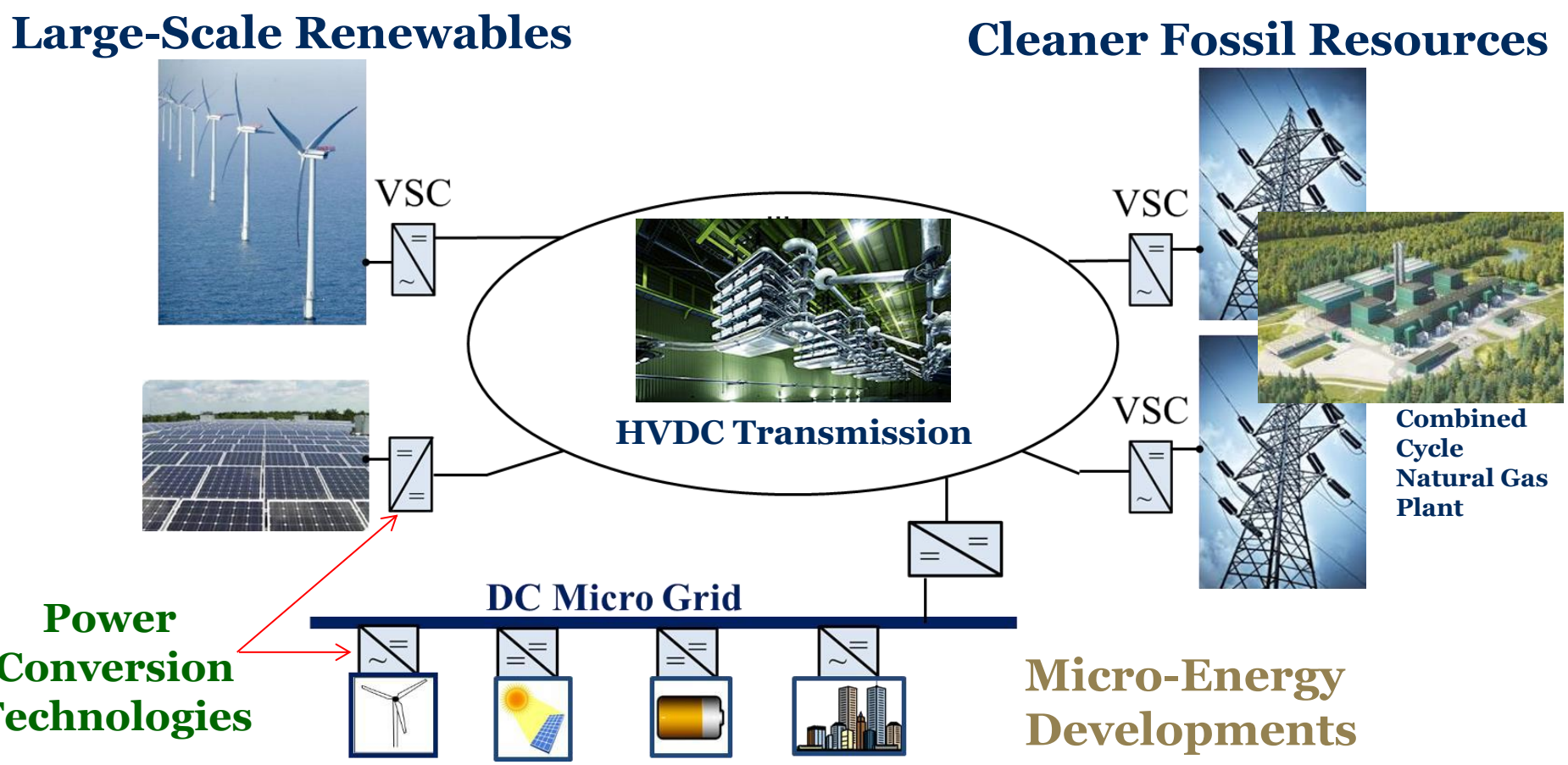


The 21st Century Grid and Its Interactions

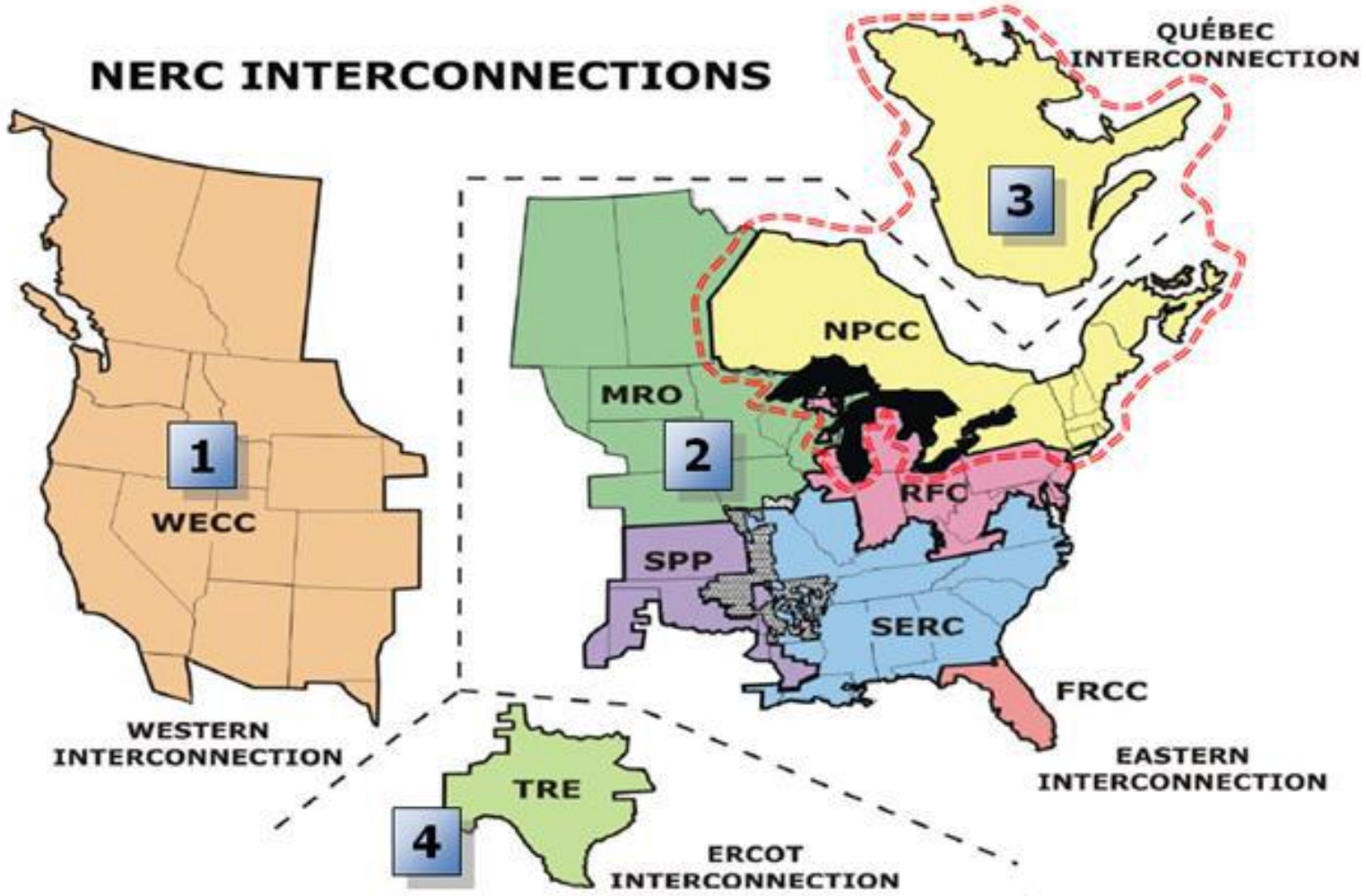


Opportunities – Grid Modernization

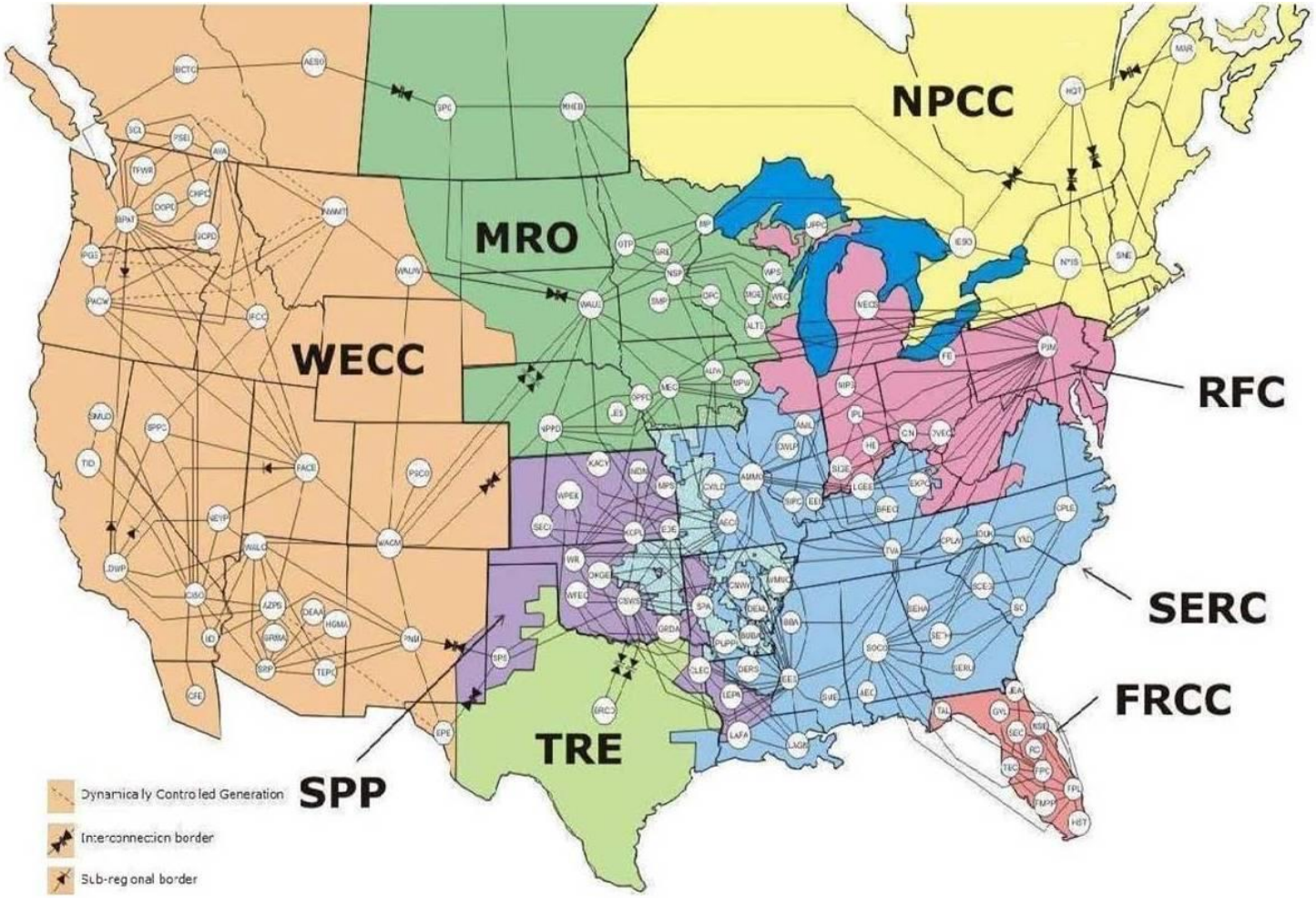
DC Solutions and Power Electronics Technology



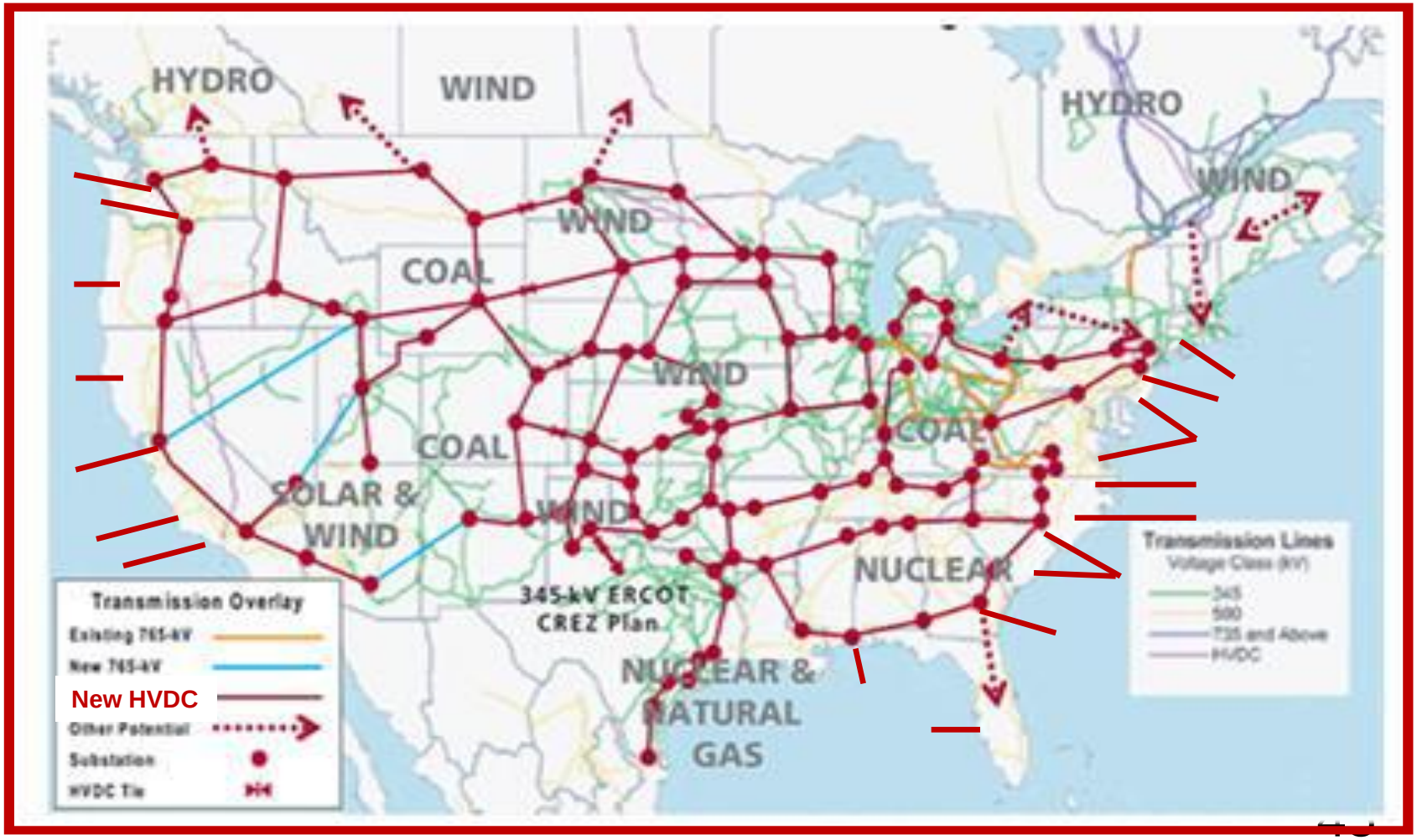
North American Grid Interconnects



North American Grid 'Control Areas'

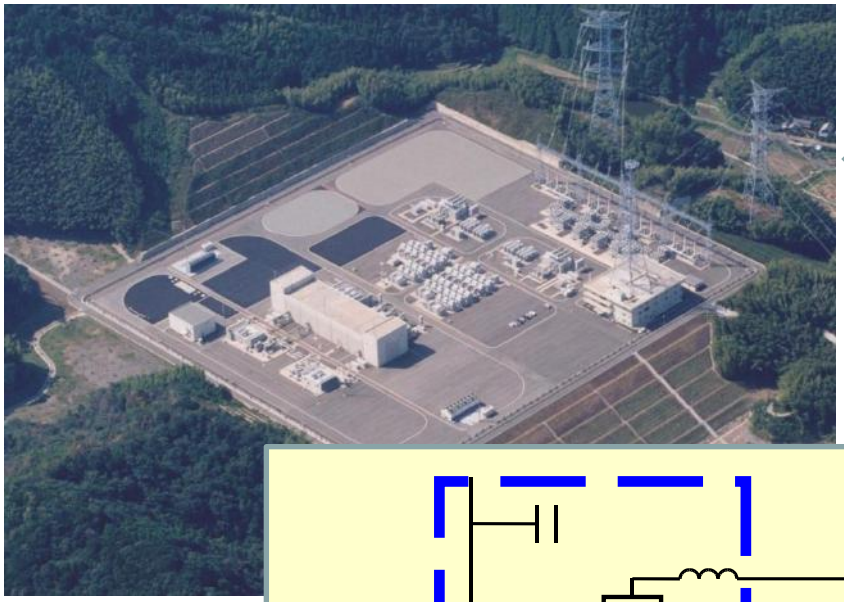


High Voltage Hybrid DC/AC Super Grid Concept for the U.S.



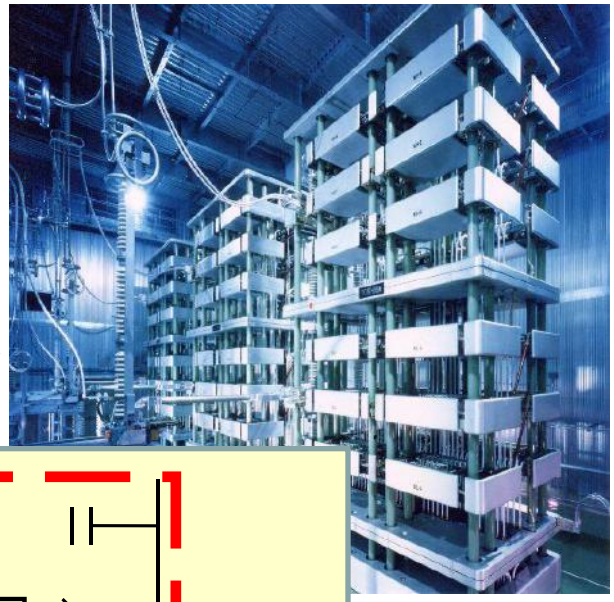
High Voltage Direct Current (HVDC) Systems

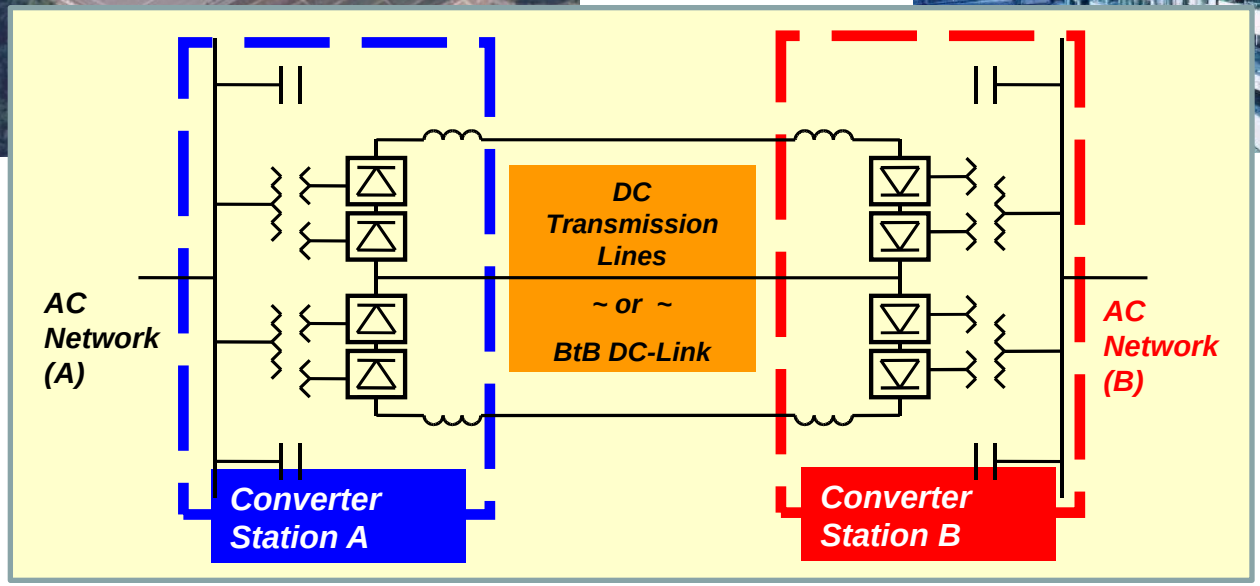
Transmission and Back-to-Back Link Configurations



CONVERTER STATION

THYRISTOR VALVE HALL





Advantages of DC and Power Electronics

- HVDC -- Greater Capacity per Right of Way (x6)
- Improved Controllability of T&D Networks
- Less Costly Infrastructure – both O/H and U/G
- Increased Efficiency and Lower Losses
- Reduced / Eliminate Risk of Major Blackout Events
- Enhanced Resiliency of Grid Infrastructure
- Integration of DC and AC/DC Microgrid Solutions
- Better Match of Supply (renewables/storage) and Demand (consumer devices)
- **Technology Development and Economic Growth, Leadership, and Workforce / Jobs**

Pitt Center for Energy
Off-Campus Research Facilities

Laboratory/Facilities Plans for the Pittsburgh Energy Innovation Center (EIC)

Establishing "The Energy GRID Institute"

(Grid Research and Infrastructure Development)

The Pitt Center for Energy

- **University-wide Research Center**
  - $35 Million R&D portfolio ($23.5-M new grants, FY-2016)
  - 100+ Faculty and 250-300 Graduate Student Researchers
- **Dedicated to improving energy technology research, development, and implementation, including:**
  - Resources
  - Delivery and Infrastructure
  - Utilization
  - Materials and Storage
  - Markets
  - Education and Training

The Pitt Center for Energy – 2016 Highlights

- $23.5 million in new University research grants
- Established the Energy GRID Institute at the Energy Innovation Center (EIC)
- $9.0 million of investments in Phase I construction for labs and facilities at EIC
- $5.1 million in in-kind equipment / sponsored programs for the GRID Institute
- Sponsored 8 RK Mellon graduate student research (GSR) fellowships
- Recruited and placed 5 new Center for Energy staff personnel in key positions
- Hosted 6 major university-based energy conferences and symposia
- Hosted 2 major US Department of Energy meetings and workshops
- Expanded the certificate programs in power, nuclear, and safety engineering
- Engaged in 15 city/regional district energy initiatives and projects
- Formed Tri-State University Energy (TrUE) Alliance: PITT, CWRU, CMU, WVU
- Sponsored several regional K-12 STEM events, including PJAS and PRSEF
- Supported 2 PROMAG (Preparation of Major Grants) efforts
- Financed other capital investments (including cost-share) for campus-based labs and major equipment

The Pitt Center for Energy

- **Areas of Strategic Growth**
  - INDUSTRY and COMMUNITY PARTNERSHIPS
  - Power Electronics and Energy Storage Technologies
  - Microgrids and Resilient / Secure Energy Systems
  - Renewable Energy Technology Development and Integration
  - Direct Current (DC) Infrastructure, Technologies, and Standards
  - Hybrid AC/DC Systems and Integrated Energy Networks
  - Electric Vehicle-to-Grid / Transportation Electrification Concepts
  - Power Systems Operation, Control, and Security
  - Energy Materials Development and Testing
  - Energy Policy, Regulation, and Economics
- **Need for New/Expanded Facilities and Operations**
  - On-Campus and Off-Campus Options
  - **Off-Campus focus at the Pittsburgh Energy Innovation Center**
    - **Establishing the Energy GRID Institute (June 2016)**

The Pitt Energy GRID Institute

The Challenge:

1 – Legacy-based aging electrical power and energy infrastructure in the U.S. and OECD nations

2 – Dynamic period of change and uncertainty across the utility industry

3 – Proliferation and growth of:

distributed and renewable energy resources;

microgrids and related developments (DC, power electronics, storage);

increased consumer participation and new market developments;

many other disruptive technological and regulatory paradigms that are affecting utility planning, design, engineering, operations, business practices, economics, and policy

The Pitt Energy GRID Institute

The Goal:

1 – A modern, reliable, resilient, sustainable, and secure grid

2 – Innovative customer solutions

3 – Clean energy technology development

The Pitt Energy GRID Institute

The Vision:

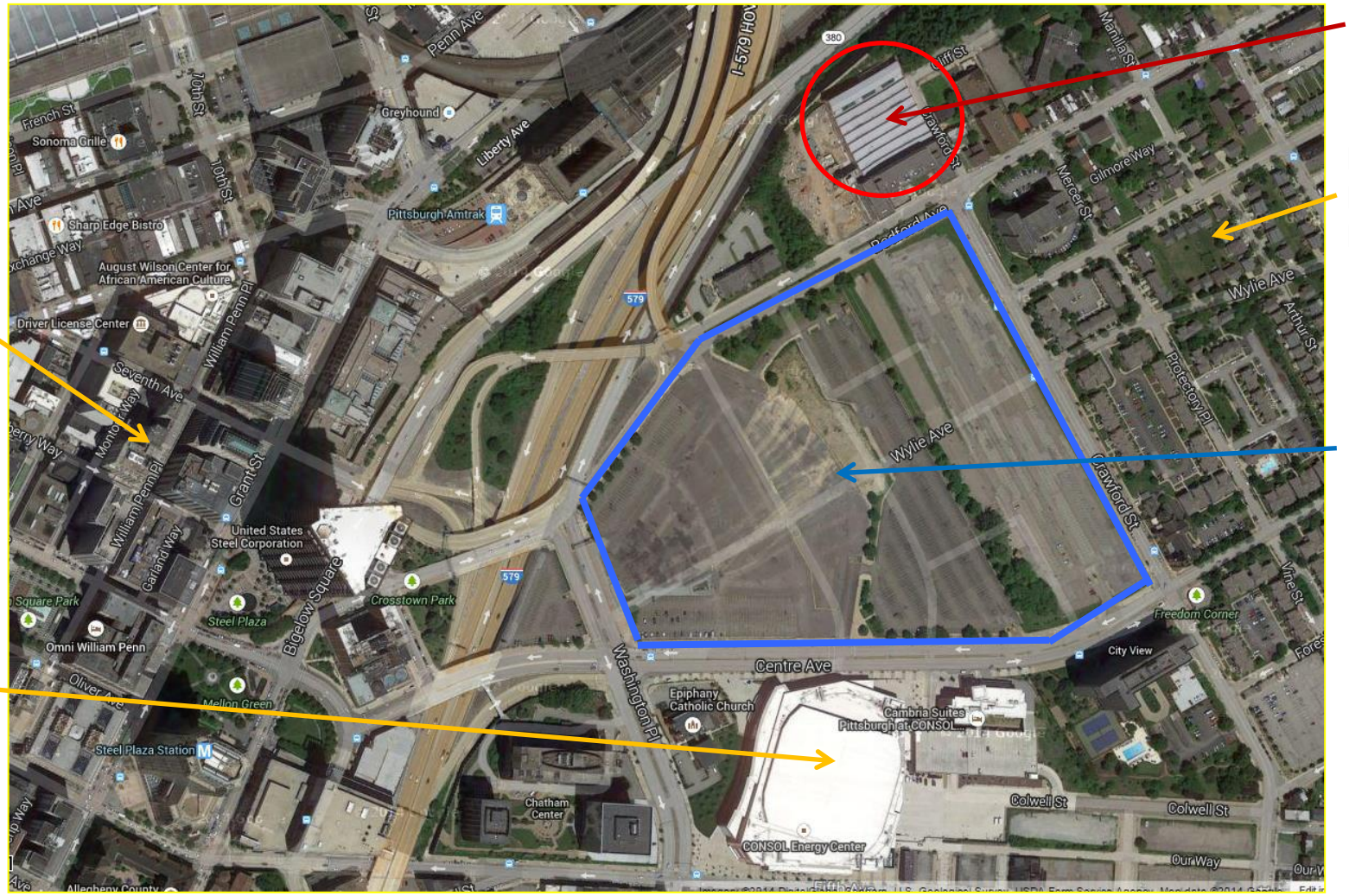
1 – Create a national/international consortium focused on serving the electric utility industry.

2 – Evaluate and assess both major industry-wide and individual utility issues and grand challenges.

3 – Work in collaboration with various partners towards the development, demonstration, and first-generation deployment of solutions across a broad area of grid technologies, systems, designs, operations, and regulation, as well as addressing market forces and business considerations.

Pittsburgh Energy Innovation Center

Energy Innovation Center - Location



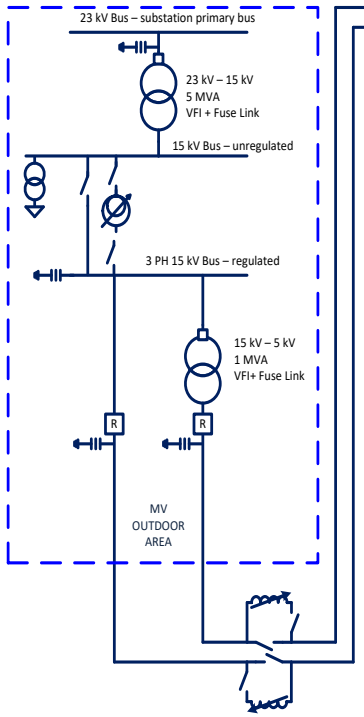
The Energy GRID Institute (est. June, 2016)

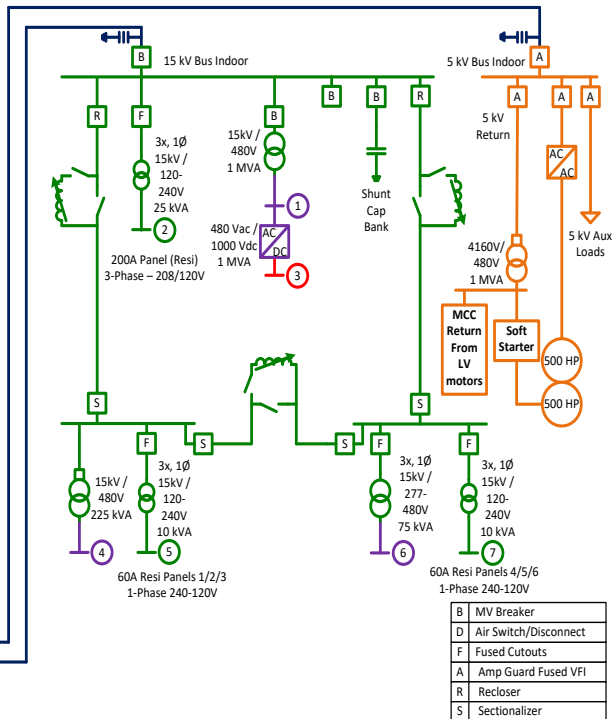
University research & development; and independent industry/community activities

- **Focus will be on the ELECTRIC UTILITY INDUSTRY**
- **Key Facility/Lab: High-voltage and high-capacity capability and multiple use facility**
  - **15 kV-ac, 5 MVA** and **1.5 kV-dc, 1 MVA** capacity
  - Ring-Bus configuration and dedicated DC area
  - AC and DC Energy Environments at Utility Distribution Level
  - Distributed Energy Generation, Grid, and Load Integration
  - Operation and Control Center, Smart Grid Interfaces

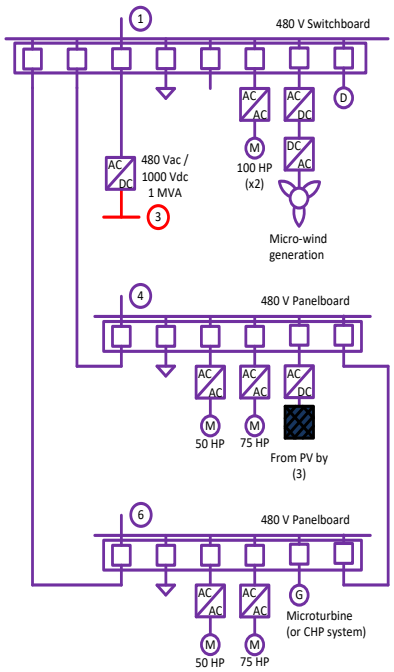
Energy GRID Institute

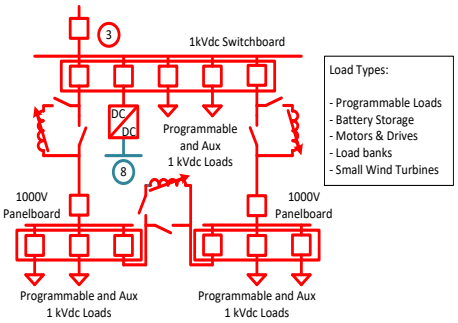
- 20,000 ft² of new labs/facilities
- Electric Power Technologies Lab
- High voltage AC/DC capabilities





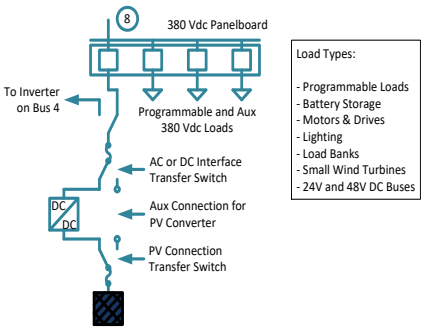
B	MV Breaker
D	Air Switch/Disconnect
F	Fused Cutouts
A	Amp Guard Fused VFI
R	Recloser
S	Sectionalizer





Load Types:

- Programmable Loads
- Battery Storage
- Motors & Drives
- Load banks
- Small Wind Turbines



Load Types:

- Programmable Loads
- Battery Storage
- Motors & Drives
- Lighting
- Load Banks
- Small Wind Turbines
- 24V and 48V DC Buses

MV INDOOR AND OUTDOOR AREAS	LV AC BUSES	LV DC BUSES

Energy GRID Institute

Electric Power Lab

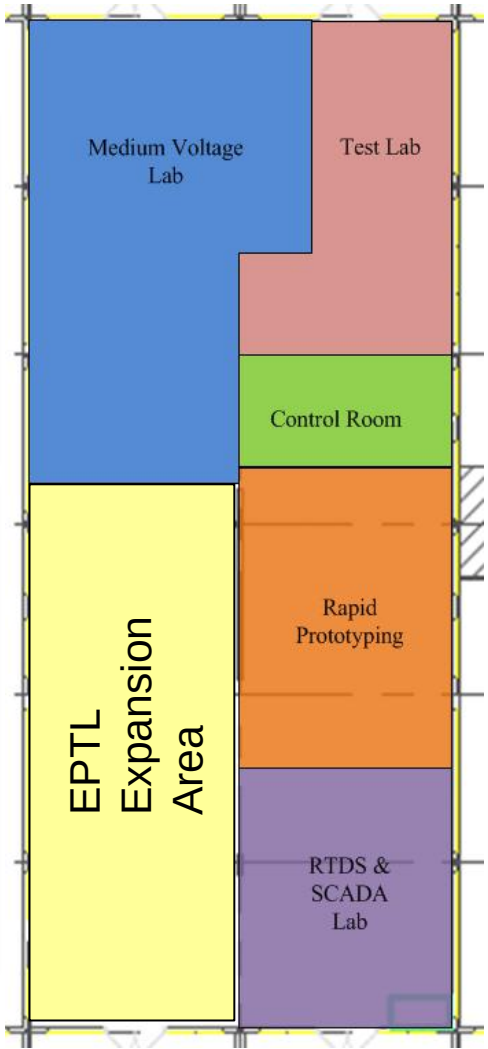
Proposed EPTL Layout

Power Distribution Areas

- **MV Grid Lab**: Reconfigurable lab for traditional or microgrid projects. Designed using utility-grade distribution equipment.
- **Test Lab**: Isolated testing facility for safe testing of industry technologies, and EPTML research projects.
- **AC and DC**: Flexible power architecture capabilities – AC, DC, and hybrid systems

Specialty Areas

- **Rapid Prototyping**: Advanced machine shop for development of professional grade components and projects.
- **SCADA Center**: Automation, metering, and control for distribution network.
- **Relaying and Controls**: Protective relaying technologies, Phasor-measurement, and advanced control
- **RTDS Center**: Real-Time Digital Simulator and hardware in the loop capabilities – research and testing on industry leading equipment.



Laboratory Ratings and Features

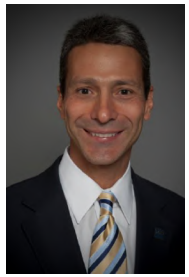
- 15 kV-ac, 5 MVA and 1 kV-dc, 1 MVA capacity
- Micro-Grid/Micro-Energy Environment at Electric Utility Distribution Level
- Distributed Energy Resource and Load Integration
- Renewable Technologies (Solar PV, Wind, etc.)
- Energy Storage, Electric Vehicle-2-Grid
- Distribution Feeder Infrastructure
- Real Time Digital Simulator (RTDS)
- SCADA and Systems Operations
- Protective Relaying and Substation Automation
- Advanced Control and Communications, PMU
- Modeling, Simulation, and Analysis
- FACTS and HVDC Control Systems
- Power Electronics Converters (and other power technologies development, prototyping, and testing -- e.g., IEEE 1547 certification)
- DC standards development (IEC SG 4)
- Integration of feeder analytics
- Technology testing and certification

The Energy GRID Institute Laboratories

- **Electric Power Technologies Lab**
  - Dr. Gregory Reed – ECE
  - High-Voltage/Capacity AC/DC Grid Facility and Ops Center
- **Energy Storage Technologies Lab**
  - Dr. Prashant Kumta –ChemE
  - Nano-Materials for Energy Conversion and Storage
- **High-Temperature Corrosion Testing Lab**
  - Dr. Brian Gleeson – MEMS
  - Harsh-Environment Materials Testing
- **Energy-Related University Incubator Space**
  - Dr. Mark Redfern – University
  - Lab Spaces for Start-up/Commercialization Activities

The Energy GRID Institute Laboratories

- **Electric Power Technologies Lab**
  - Dr. Gregory Reed – ECE
  - High Voltage/Capacity AC and DC Grid Facility



- **Energy Storage Technologies Lab**
  - Dr. Prashant Kumta – BioE, ChemE
  - Nano-Materials for Conversion/Storage

- **High-Temperature Corrosion Testing Lab**
  - Dr. Brian Gleeson – MEMS
  - Harh-Environment Materials Testing

- **Energy-Related University Incubator Space**
  - Dr. Mark Redfern – University
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The Pitt Energy GRID Institute

Value Proposition for Partners and Users:

- Collaborative R&D programs
- Utility investigations and testing
- Technology development, prototyping, and demonstration
- Commercialization opportunities
- Joint utility-vendor-government collaborations
- Various levels and constructs of partnerships
- Fee-for-service and contract R&D options
- Independent testing/certification and third-party operations
- Student development and access
- Education and training

The Pitt Energy GRID Institute

Current (Initial) Partners:

Duquesne Light

ANSYS

Dominion Virginia Power

Emerson

Pitt-Ohio Express

Siemens Energy

HL Hillman Foundation

Eaton

EPRI

FirstEnergy

Opal-RT

Sargent Electric

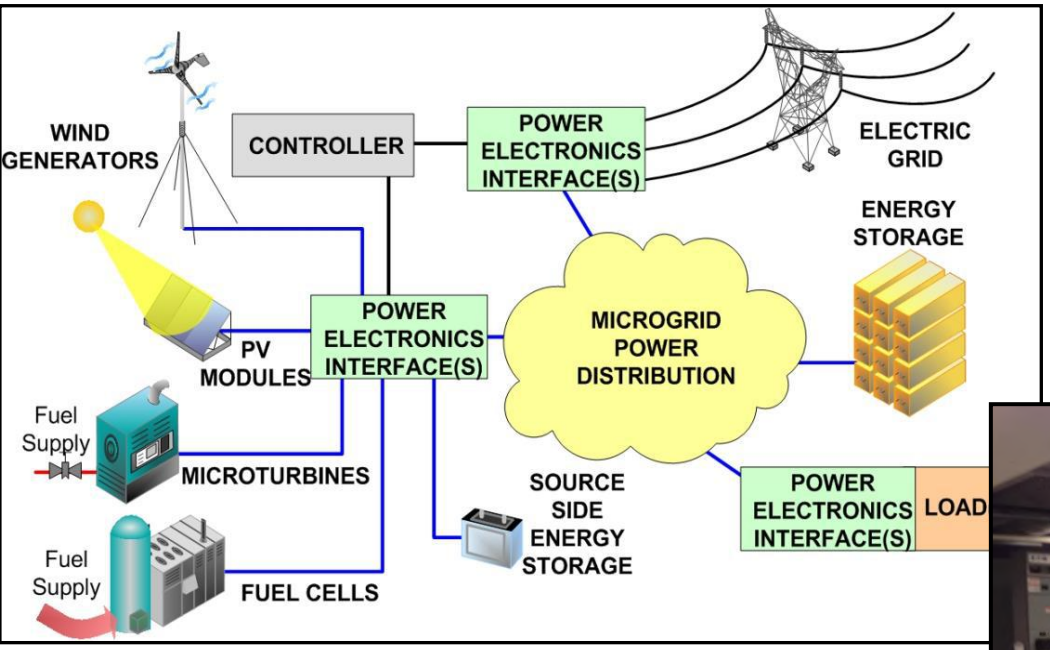
Universal Electric

RK Mellon Foundation

The Energy GRID Institute

A Few Examples of Our Industry and Community Partnerships

The Pitt Electric Power Systems Lab

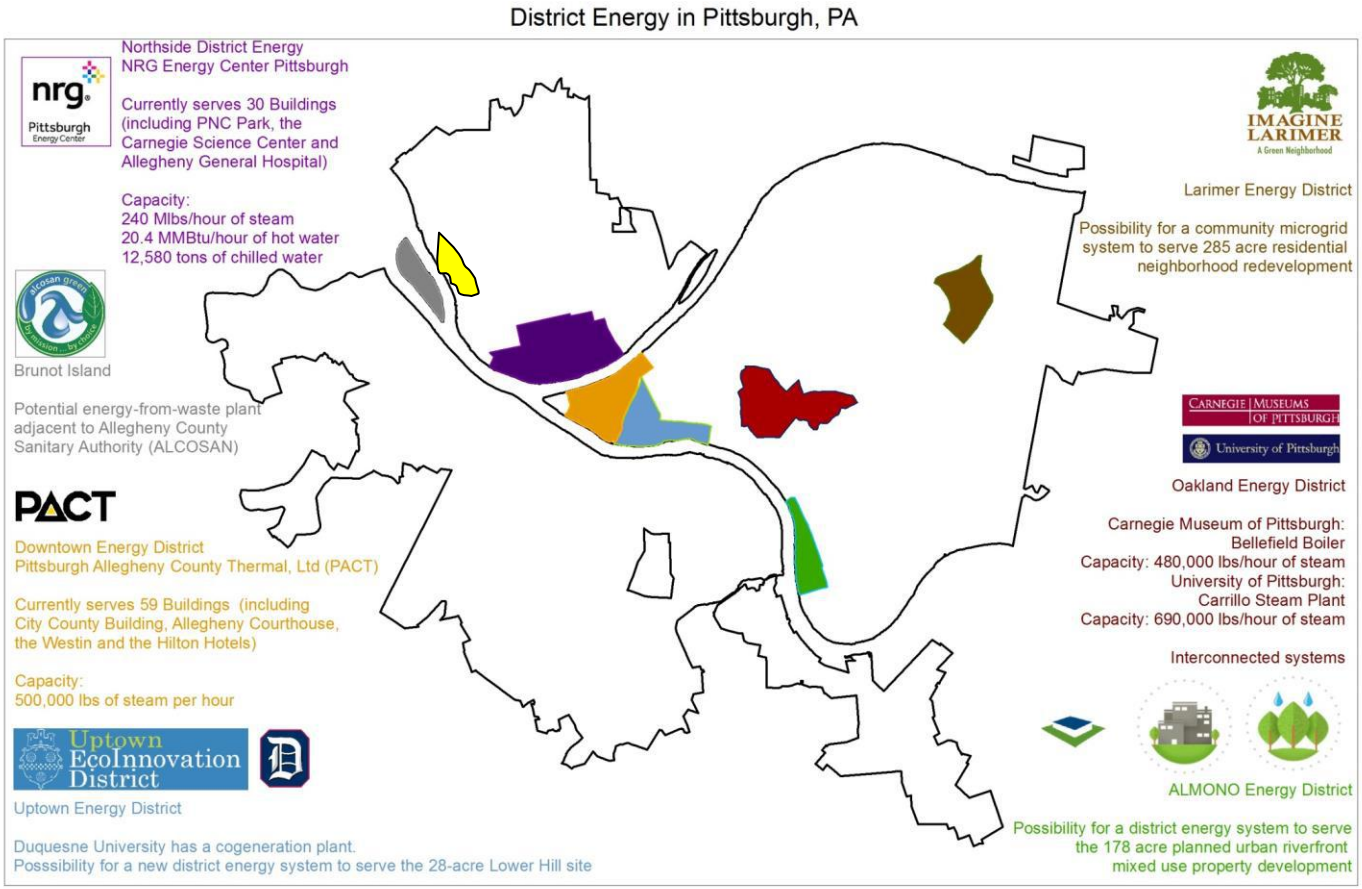


Smart Grid / Microgrid (EATON-sponsored)

Benedum Engineering Hall

Pittsburgh District Energy Initiative

- Goal: Largest District Energy Eco-System in N.A.
- Resiliency, Reliability, Sustainability, Security, Economics



Duquesne Light
Our Energy...Your Power

PEOPLES NATURAL GAS

HENRY L. HILLMAN FOUNDATION

Richard King Mellon Foundation

DLC Woods Run Microgrid Project

- Pitt CfE – Duquesne Light collaboration
- Full microgrid buildout plan at DLC's Wood's Run Operations Facility*
- Distributed generation, including renewables, natural gas, and diesel
- Advanced distribution network and control
- Full islanding capabilities
- AC and DC hybrid solutions
- R&D, demonstration elements

DUQUESNE LIGHT CO.

UNIVERSITY OF PITTSBURGH VERITAS 1787 VIRTUS

* Pending PA PUC Approval

Pitt-Ohio Express Harmar – DC Microgrid

- Renewable DC Energy (Solar/Wind) and Storage System

PITT OHIO
SUPPLY CHAIN • GROUND • LTL • TL

PITT | SWANSON ENGINEERING
ELECTRIC POWER SYSTEMS LAB

UNIVERSAL ELECTRIC CORPORATION

WindStax™ Wind Power Systems

ASR ADAM SOLAR RESOURCES

PCTI A Power Conversion Company

EATON Powering Business Worldwide

AQUION ENERGY

Sargent Electric Company

BDA Engineering, Inc.

Eaton-Pitt Partnership in Electric Power Engineering

- 7 Key Initiatives Summary:

1) Electric Power Systems Engineering Laboratory
   - Facility dedicated January, 2014, Benedum Hall

2) Undergraduate Capstone Senior Design Projects
   - 45 EE and ME completed projects to-date (101 students), many conducted at the Eaton Power Systems Experience Center

3) Power System Engineering Curriculum Support
   - 4 new course developments, adjunct professor support, numerous guest lecturers, lab section developments

4) Joint Research Program Developments
   - Collaboration with business groups, innovation center

5) Professional Society Contributions
   - IEEE, ASEE, others -- joint papers, panels, trade shows
   - Pitt EPIC participant -- sponsor, exhibitor, keynotes, etc.

6) Community Service and Outreach
   - K-12 STEM activities, EPIC sponsorship, volunteerism
   - Various local and national media events

7) Student Recruiting
   - 172 total: co-ops (73), interns (45), FTE's (54) since 2008
   - Leadership training, seminars, job fairs, campus events, etc.

EATON
Powering Business Worldwide

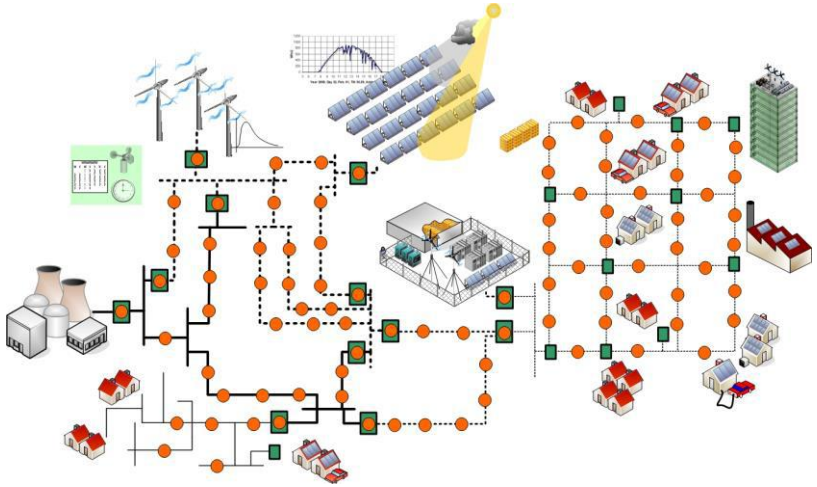
Partnership Signing Ceremony – March 10, 2009


EPSL Dedication Ceremony– January 9, 2014

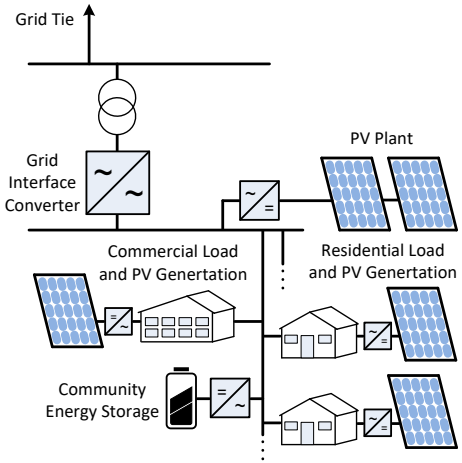
DC-AMPS Program

HILLMAN FAMILY FOUNDATIONS

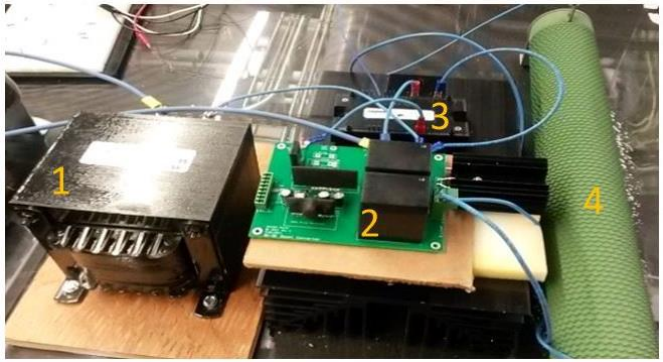
- Direct Current Architecture for Modern Power Systems



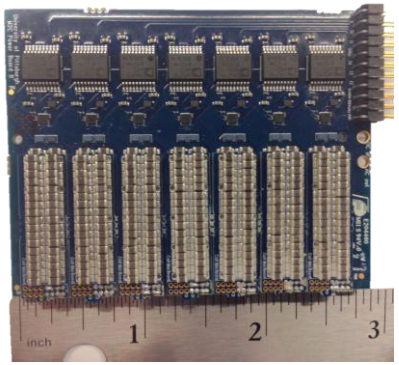
Advanced Microgrid and DC Architectures
(Feasibility and uGrid Design Studies)



Power Conversion Equipment Design, Fault Detection, and Reliability Assessments



Newly-developed Prototypes for DC Power Conversion

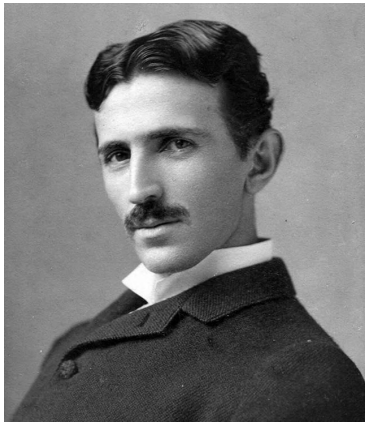


The Pitt Energy GRID Institute

Continued Leadership:

Positioning Pittsburgh and Western PA as the Nation's Leader in Grid Technology Research, Development, Demonstration, and Deployment

Westinghouse

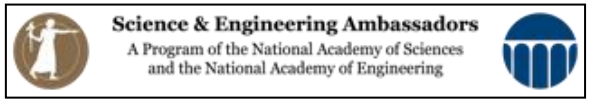


Tesla

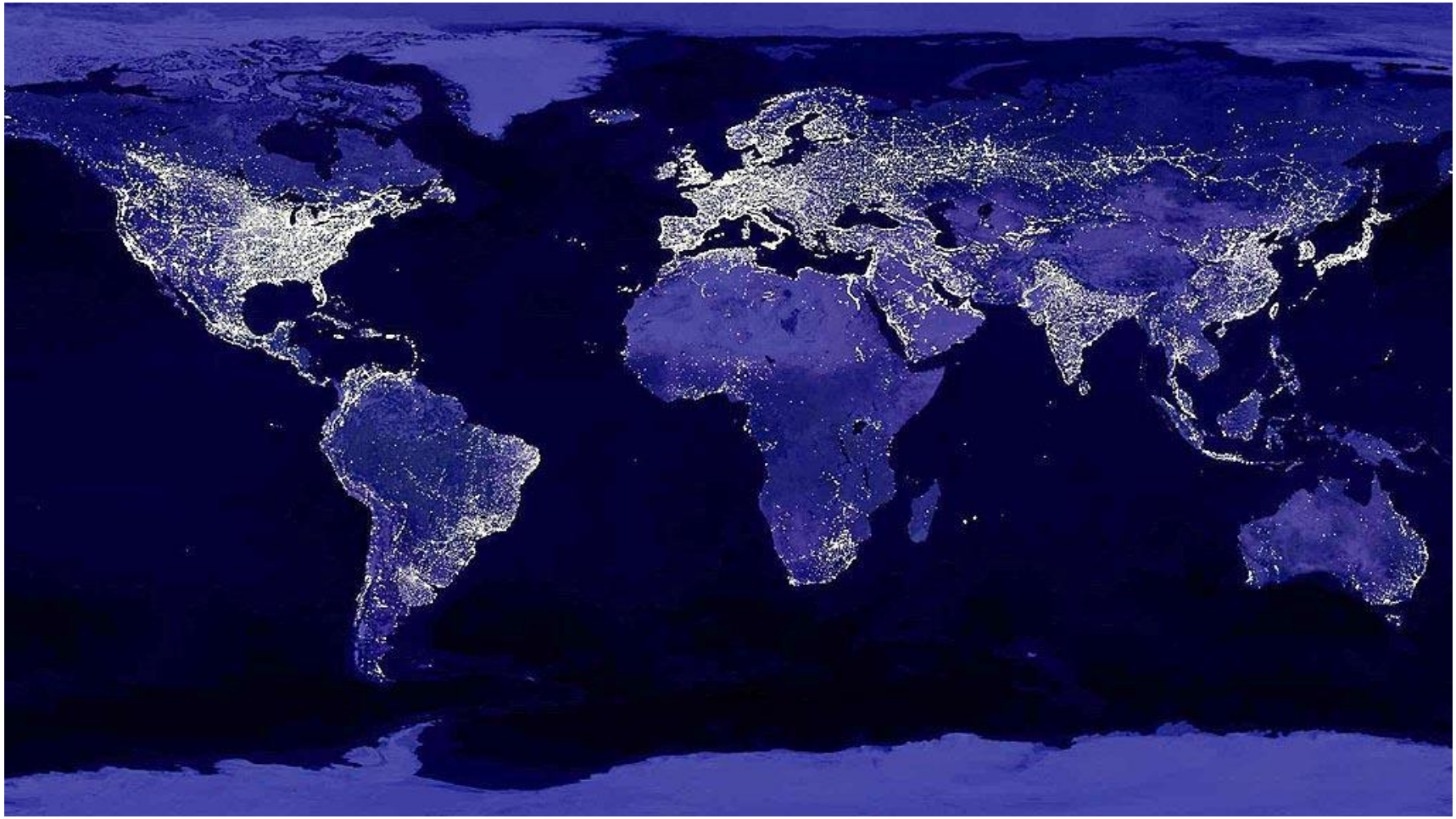
Leadership in this sector is part of our region's <u>Heritage</u>; and advancing this legacy is now part of our <u>Responsibility</u>

<u>The Pitt Energy GRID Institute is taking the Lead</u>

Center for Energy and GRID Institute Constituents



A Brighter Future with Global Implications



Thank You

Contact Information

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http://www.engineering.pitt.edu/power