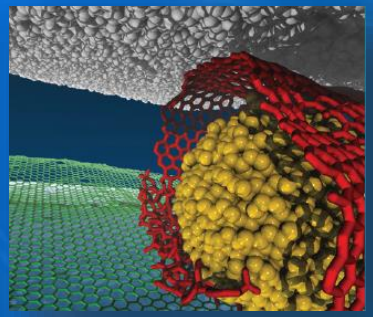
# QTR

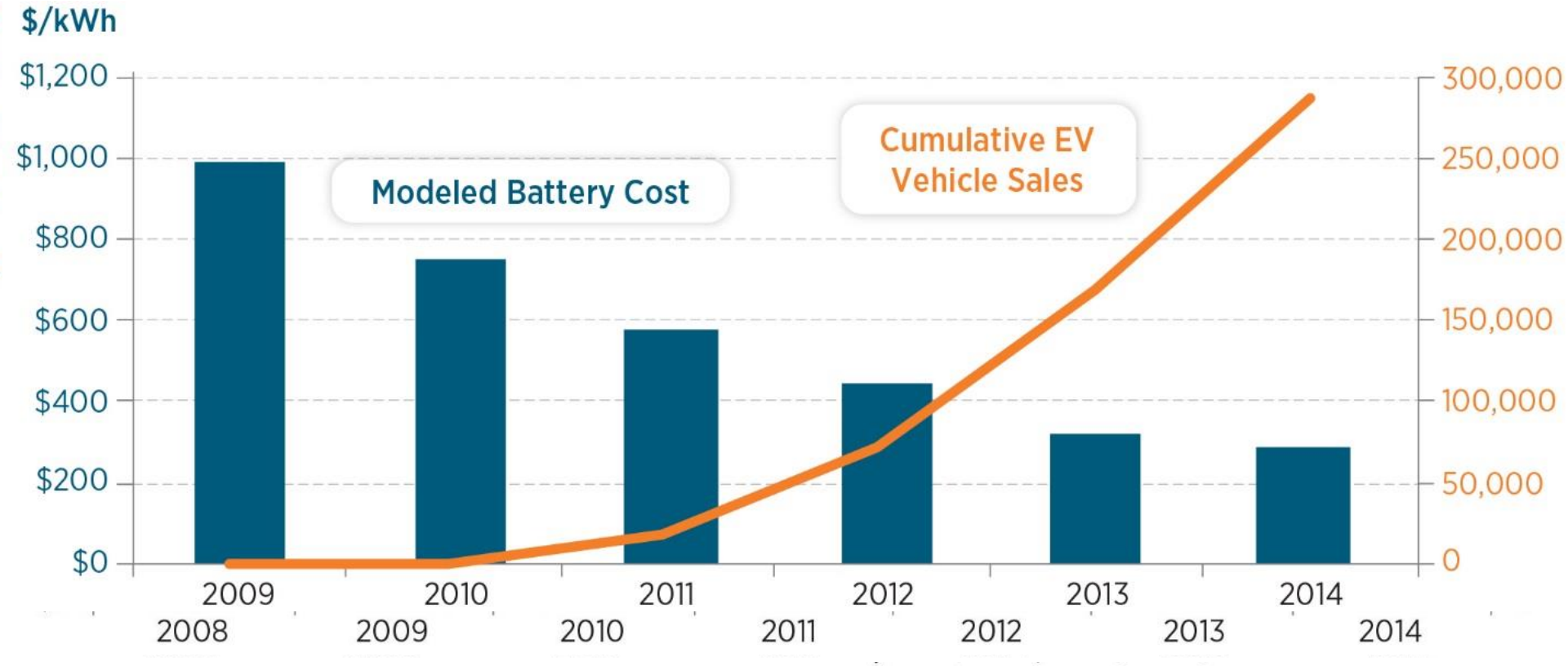


# QUADRENNIAL TECHNOLOGY REVIEW

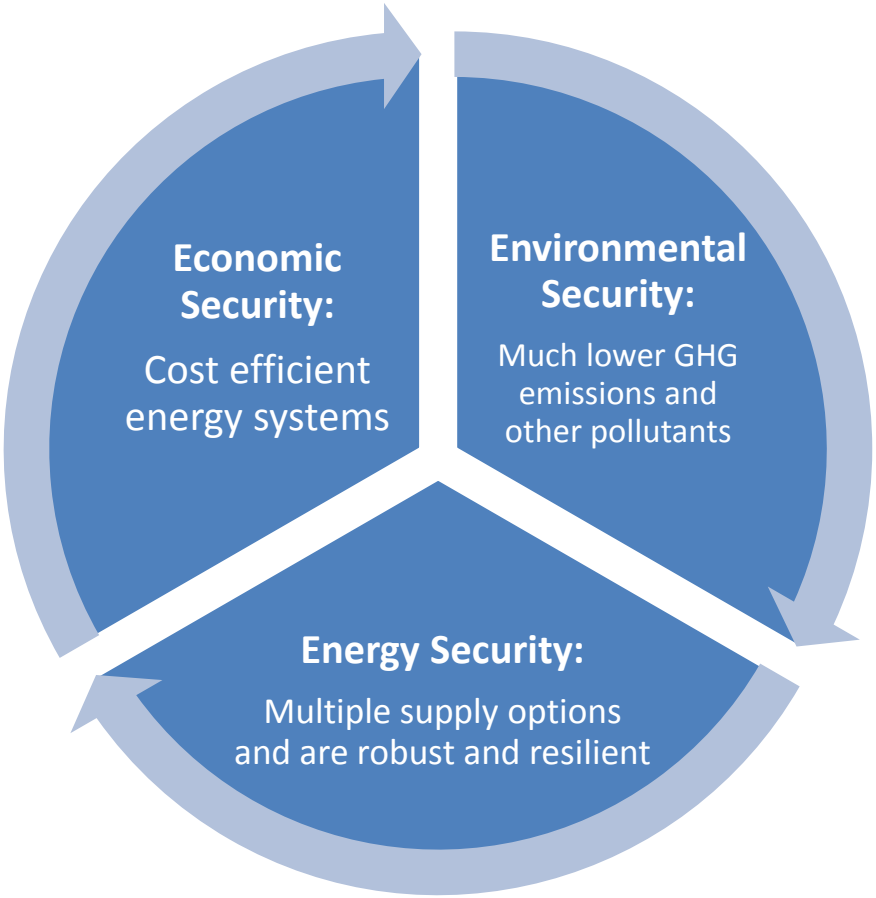
## AN ASSESSMENT OF ENERGY TECHNOLOGIES AND RESEARCH OPPORTUNITIES

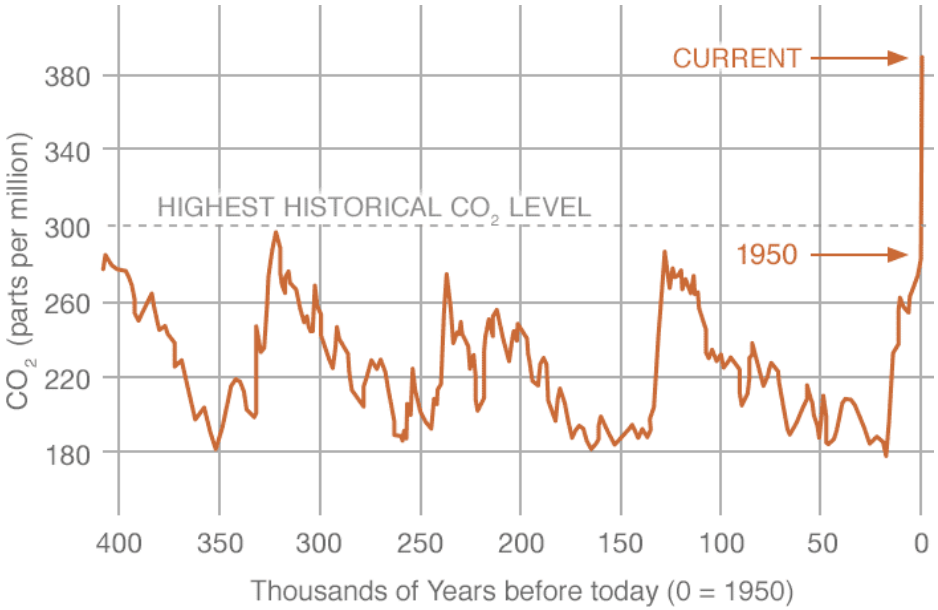
**Dr. Lynn Orr, Under Secretary for Science & Energy**
U.S. Department of Energy
Presentation to ASCAC
April 4, 2016

# Changes in the Energy Landscape



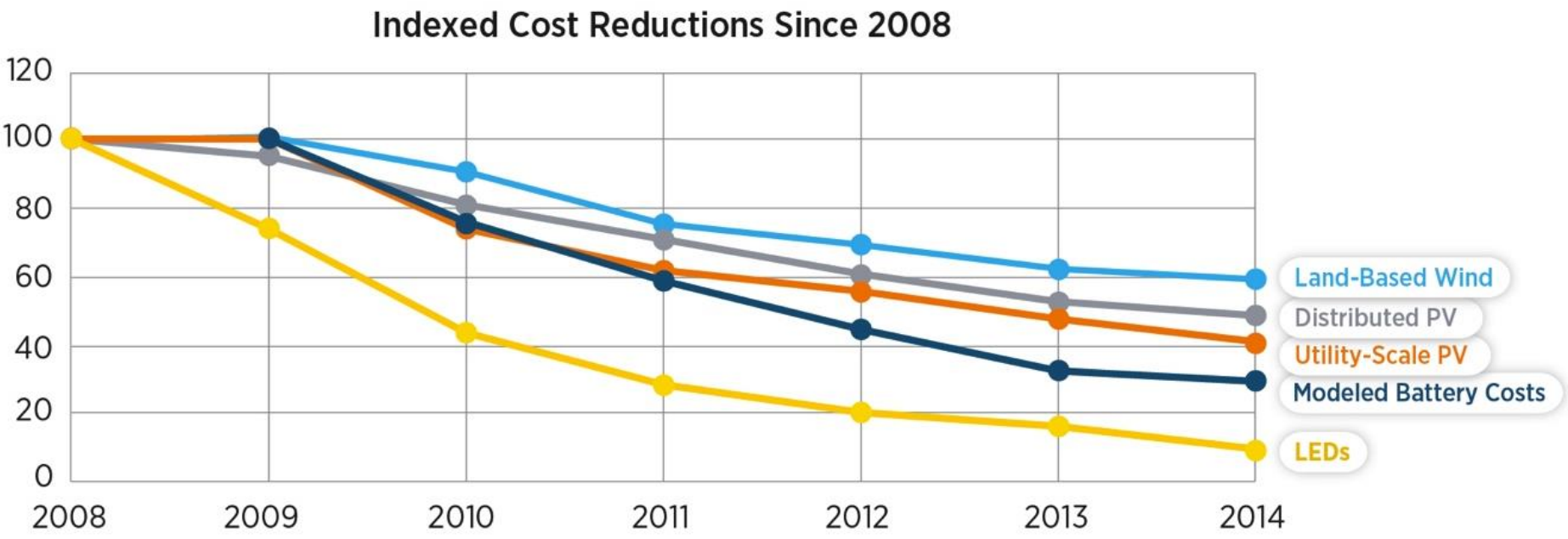
# The Energy Challenge



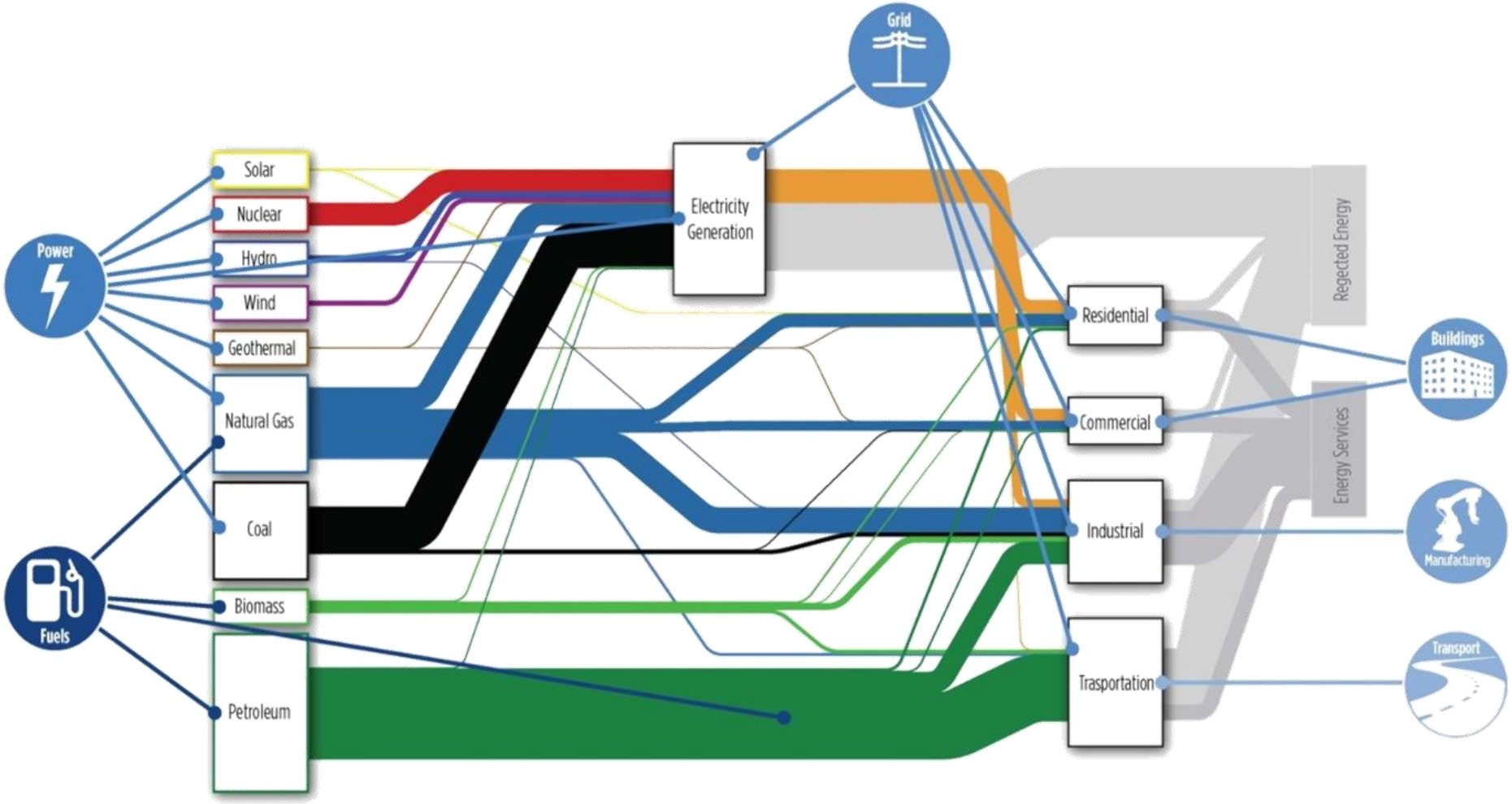

**Opportunity: Create and manage linked, complex systems that deal with all three challenges**

# Learning Curves for Selected Technologies



# The U.S Energy System—Linkages

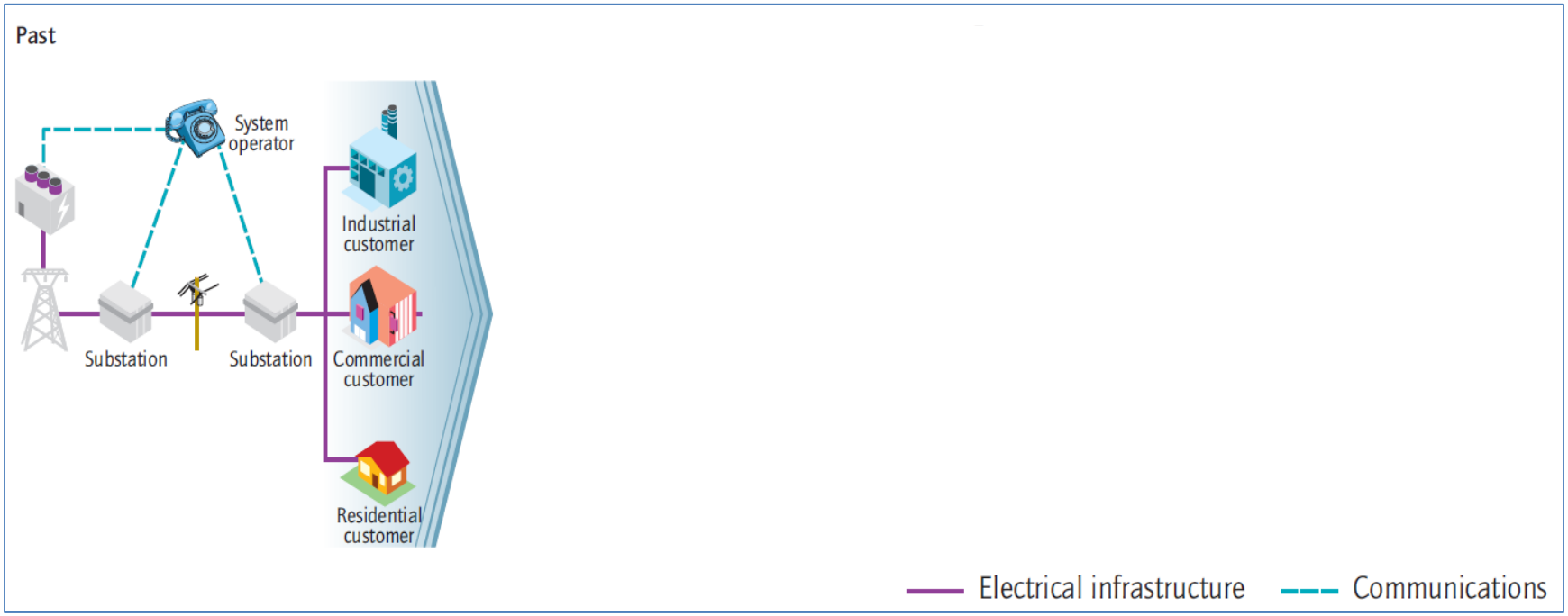
**Estimated U.S. Energy Use in 2014: ~98.3 Quads**



# The Grid

# The Future Grid Differs Radically from the Present

Characterized by More Flexibility and Agility: Prevent local disturbances from spreading, and recover more quickly from storm disruptions




*Graphic Source: International Energy Agency*

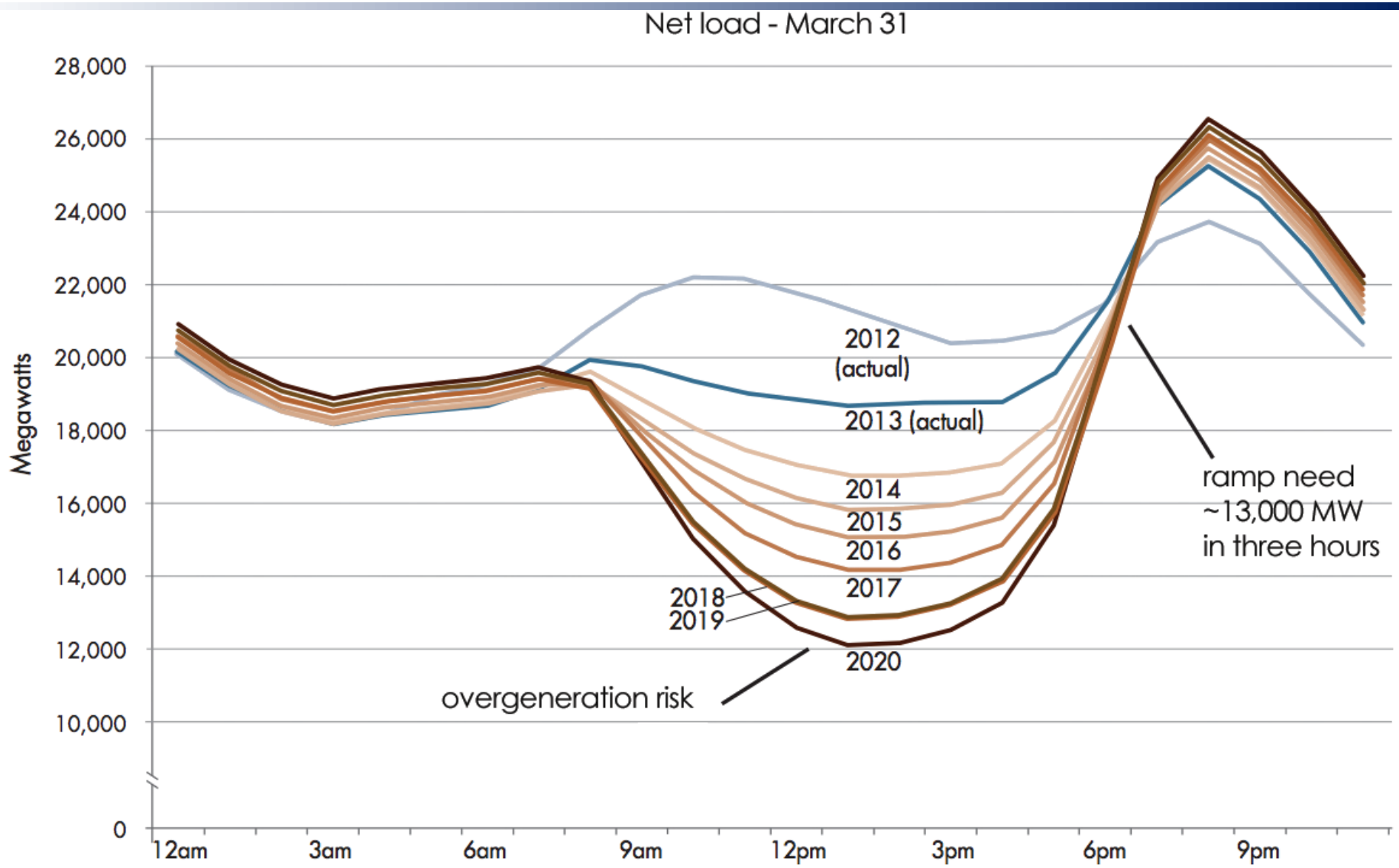
**Historical**

- *Operator-Based Grid Management*
- *Centralized Control*
- *Off-Line Analysis / Limit Setting*

**Emerging**

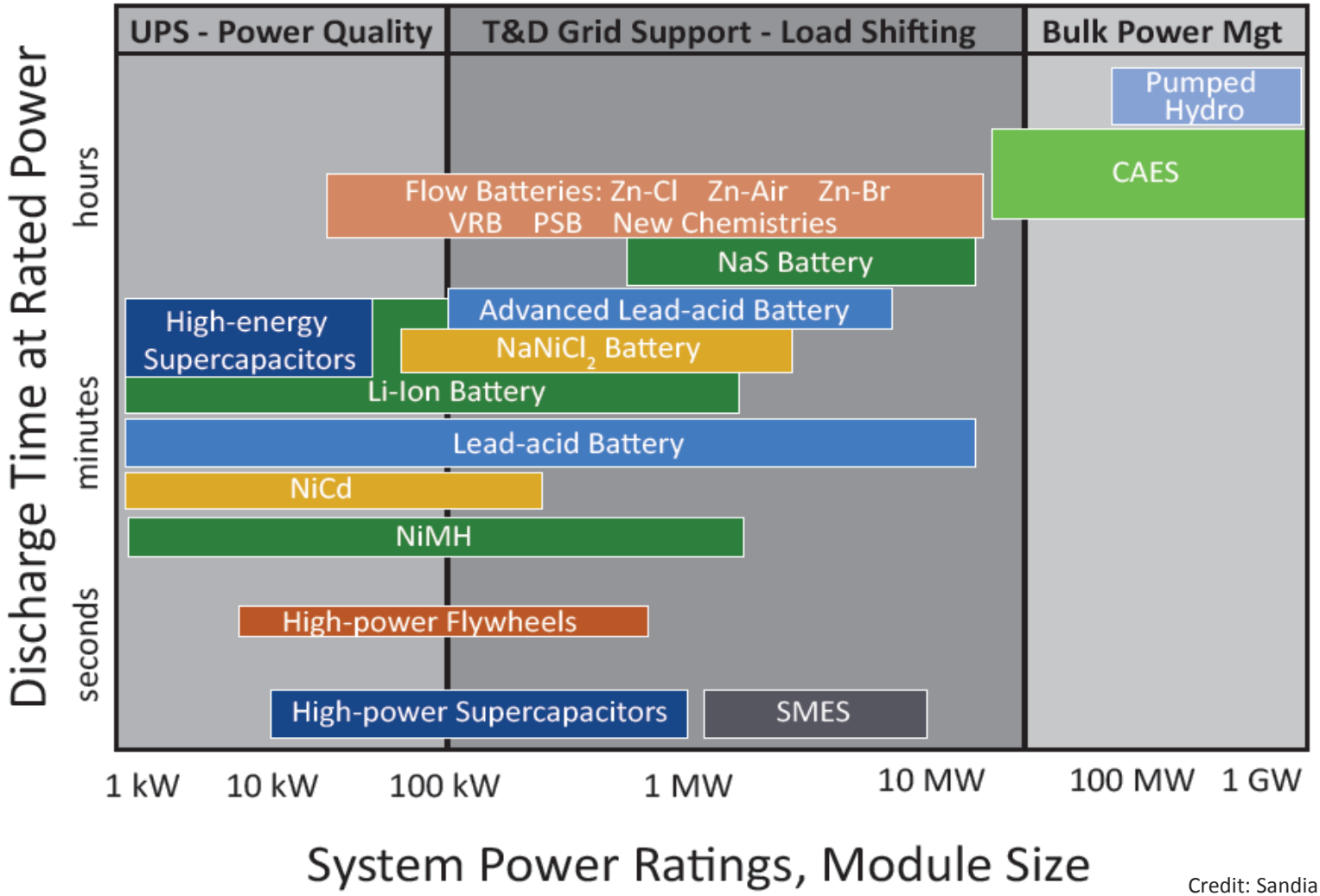
- *Flexible and Resilient Systems*
- *Sensors and Data Acquisition*
- *Algorithms and Computer Infrastructure*
- *Multi-Level Coordination / Precise Control*
- *Faster-than-Real-Time Analysis*

# Integration of Intermittent Renewables



# Energy Storage

## Energy Storage Technology Options




Credit: Sandia Laboratory

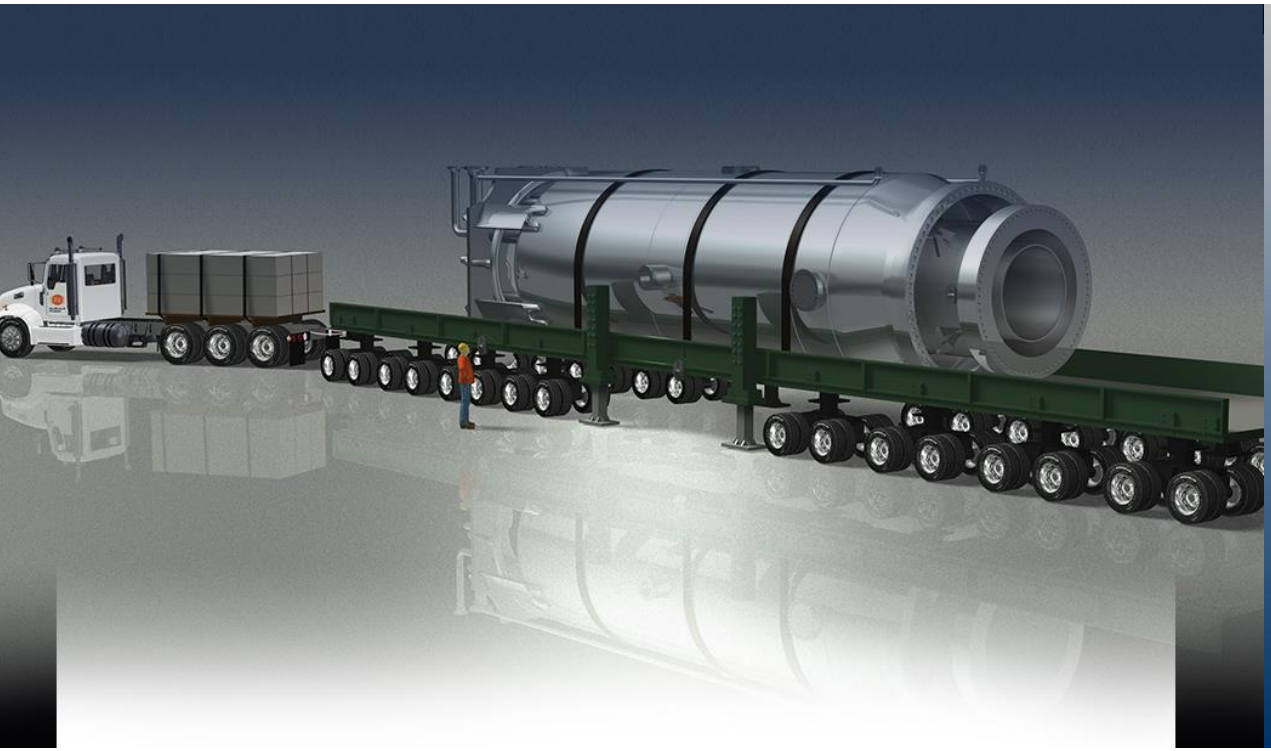
# Clean Electric Power

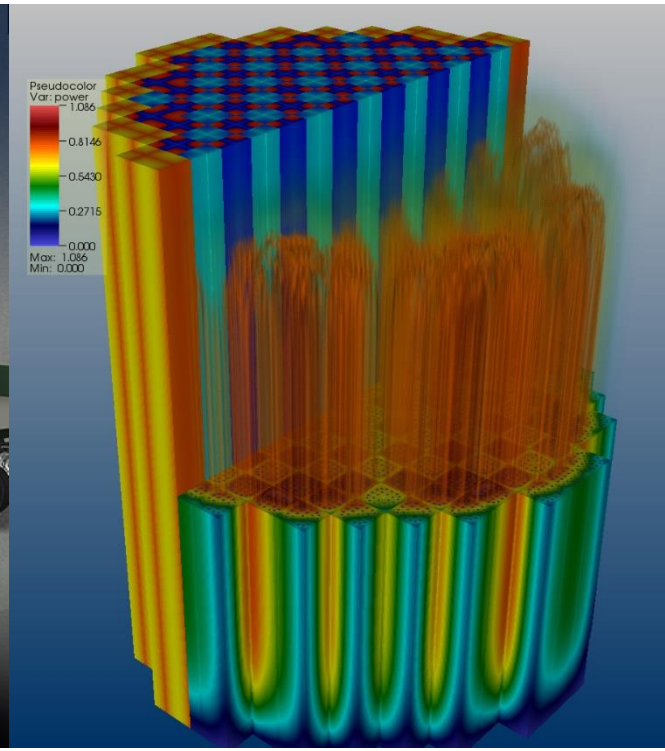
# Carbon Capture and Storage

Southern Company Kemper Project
Credit: Mississippi Power

# Optimizing $CO_2$ Compression on Titan

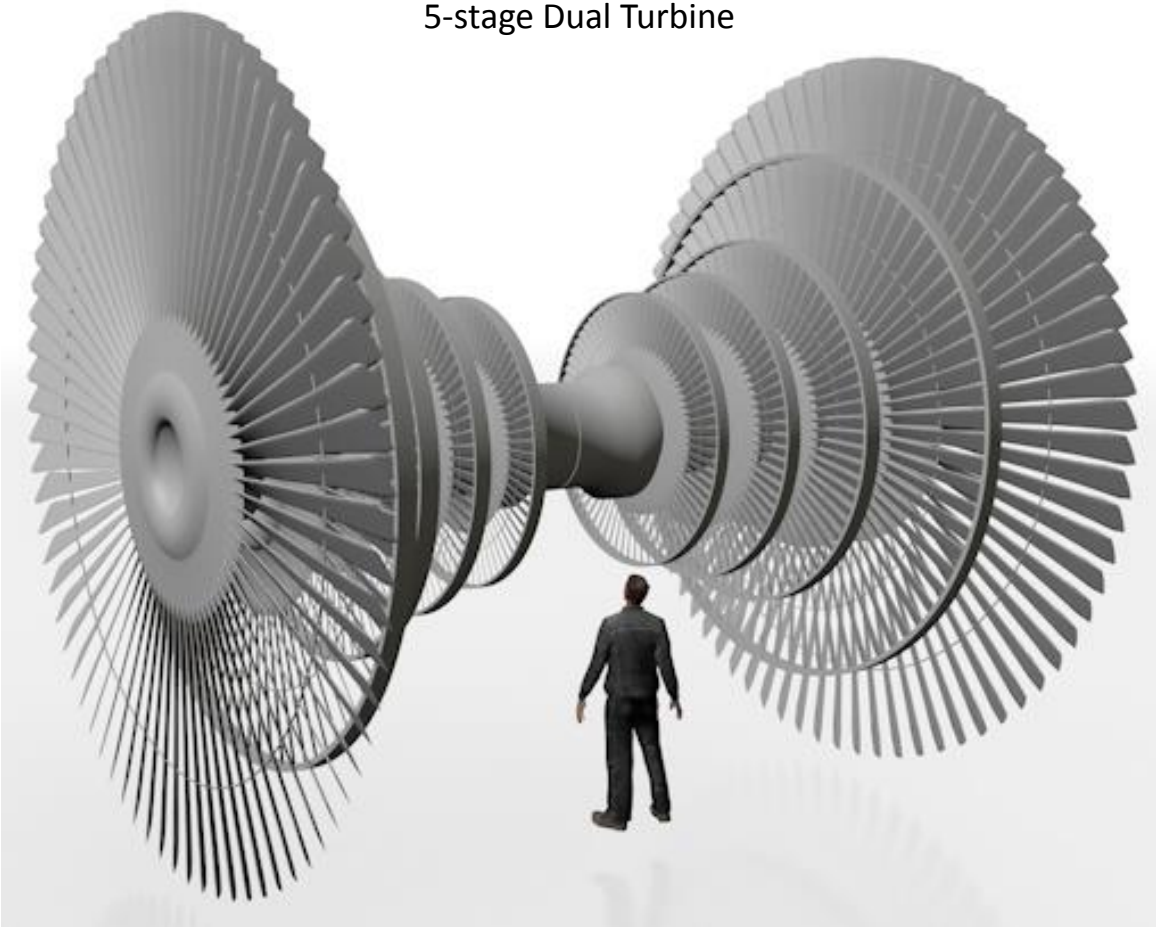
# Nuclear Power





# Supercritical $CO_2$ – Brayton Cycle

5-stage Dual Turbine

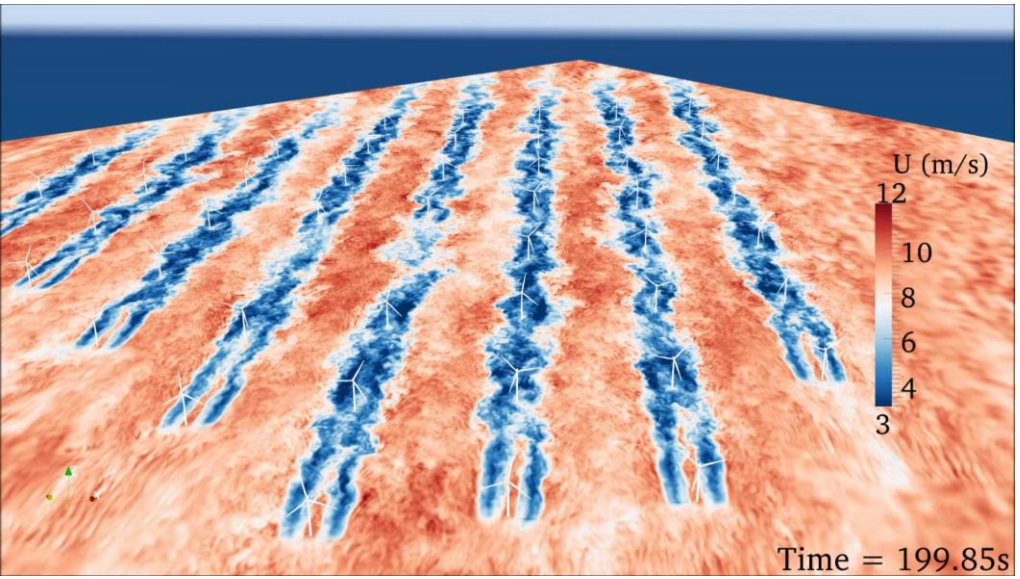


**20 meter Steam Turbine (300 MWe)**
(Rankine Cycle: ~33% efficient)

3-stage Single Turbine

**1 meter $sCO_2$ (300 MWe)**
(Brayton Cycle: > 40% efficient )

# Wind Power

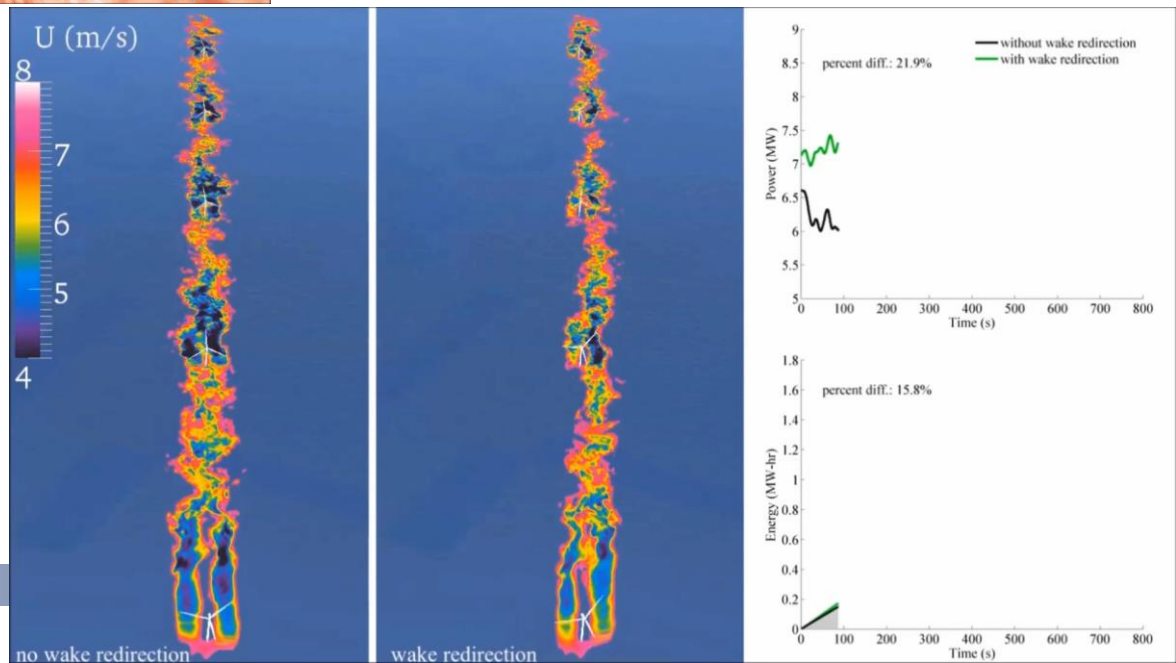



**Lillgrund Offshore Wind Plant**

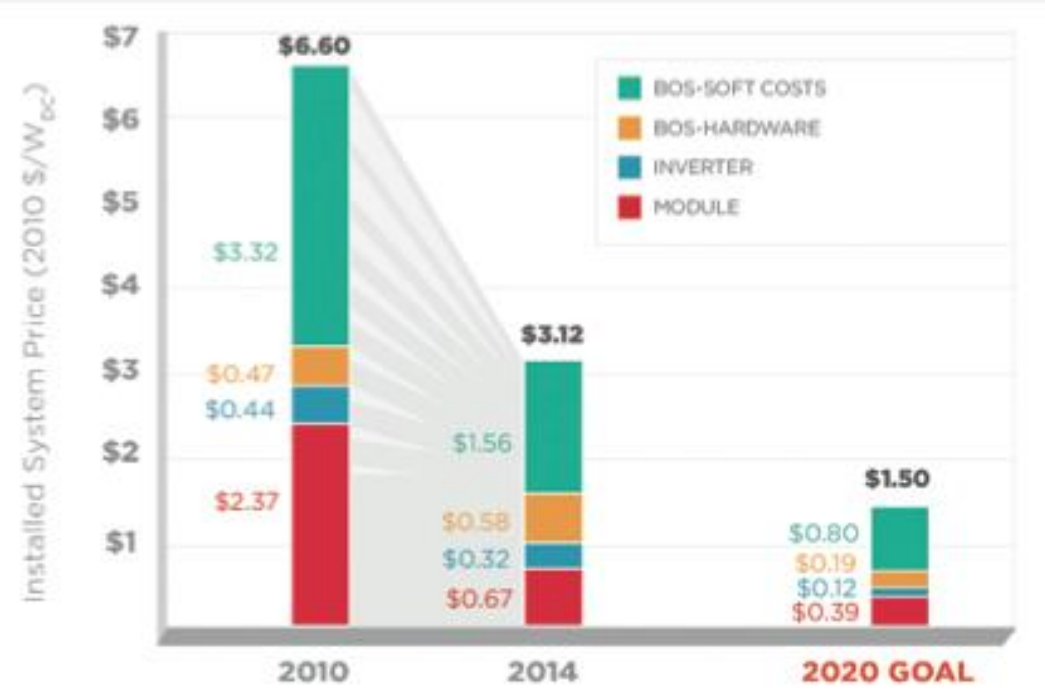
- 48 turbines
- State of the art limited to simplified blade models & flat terrain

**Wake-Steering Example**

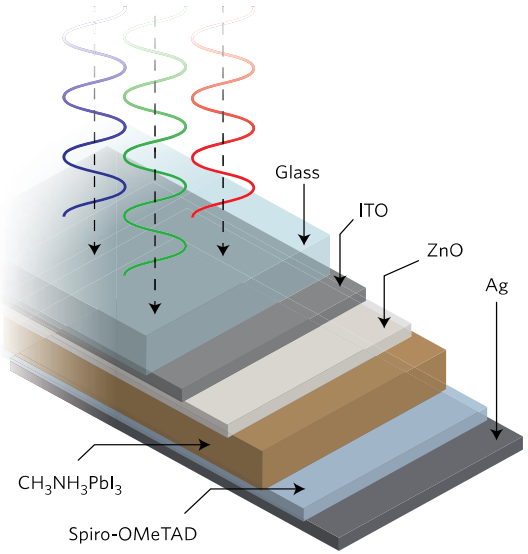
- Redirecting wake away from downwind turbines increases energy capture by 14%



# Solar Power




***Perovskite efficiencies have increased to > 20% in only 2 years***



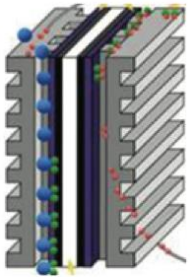

*from Liu and Kelly. Nat. Phot. 2013*

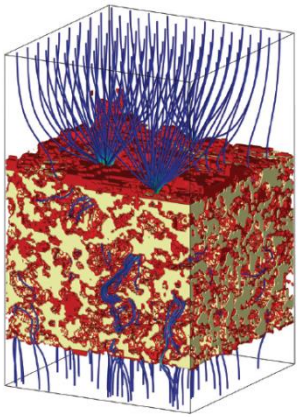
# Clean Transportation and Vehicle Systems

# Advancing Clean Transportation and Vehicle System Technologies

- Combustion efficiency
- Co-optimization of fuels and engines
- Lightweighting
- Plug-in electric vehicles (PEVs)
- Fuel cell electric vehicles (FCEVs)
- Other modes (e.g., air, rail, and marine)
- Connected and automated vehicles
- Transportation systems

**Figure 8.6** Complex In-cylinder Flow During Intake Stroke in Diesel Engine[23]





# Advanced Manufacturing

IMTS
2014

Oak Ridge National Laboratory

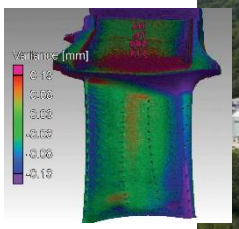
# Enabling Science

# Understanding and Controlling Matter at the Atomic Scale

***Unique, cutting-edge experimental tools for characterization, discovery, and synthesis of novel materials and energy systems.***

*X-ray light sources* provide a range of wavelengths capable of probing structures as small as atoms to whole cells and beyond.

- LCLS-II and APS-U will provide higher energy and brighter beams.
- Instrument development brings NSLS-II's world-leading beam brightness to more experiments.



*Neutron sources* are uniquely suited to non-destructive 3D structure determination of real systems.

- The SNS Second Target Station would enable new science in condensed matter, structural biology, and energy materials.

*Nanoscale Science Research Centers* integrate theory, synthesis, fabrication, and characterization of novel nanomaterials

- New capabilities in *in operando* electron microscopy and accelerator-based nanoscience.
- Novel fabrication techniques in combinatorics and self-assembly.

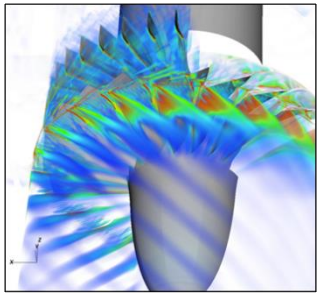
***On-going research, development, and upgrades for facilities opens new frontiers in materials characterization (real systems in real time).***

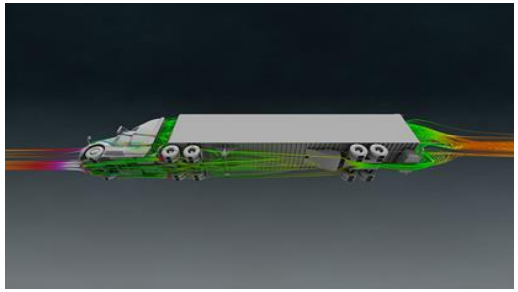
# Modeling and Simulation of Complex Phenomena

***Accelerating discovery through modeling and simulation of real systems.***

- DOE and SC supported supercomputers enable simulation of complex real-world phenomena, putting true "systems-by-design" in reach.
- The *Office of Advanced Scientific Computing Research* supports this push to modeling and simulation of real systems through parallel development of hardware, software, and skilled personnel.
  - *Leadership-class computers*
  - *Production-class computers*
  - *Energy Sciences Network*
- DOE computers - enabled through dedicated outreach from the laboratories - have an enormous impact across the engineering and manufacturing space.
- The development needs of *exascale* computing – hardware, software, and efficiency – are being supported through *co-design* centers.

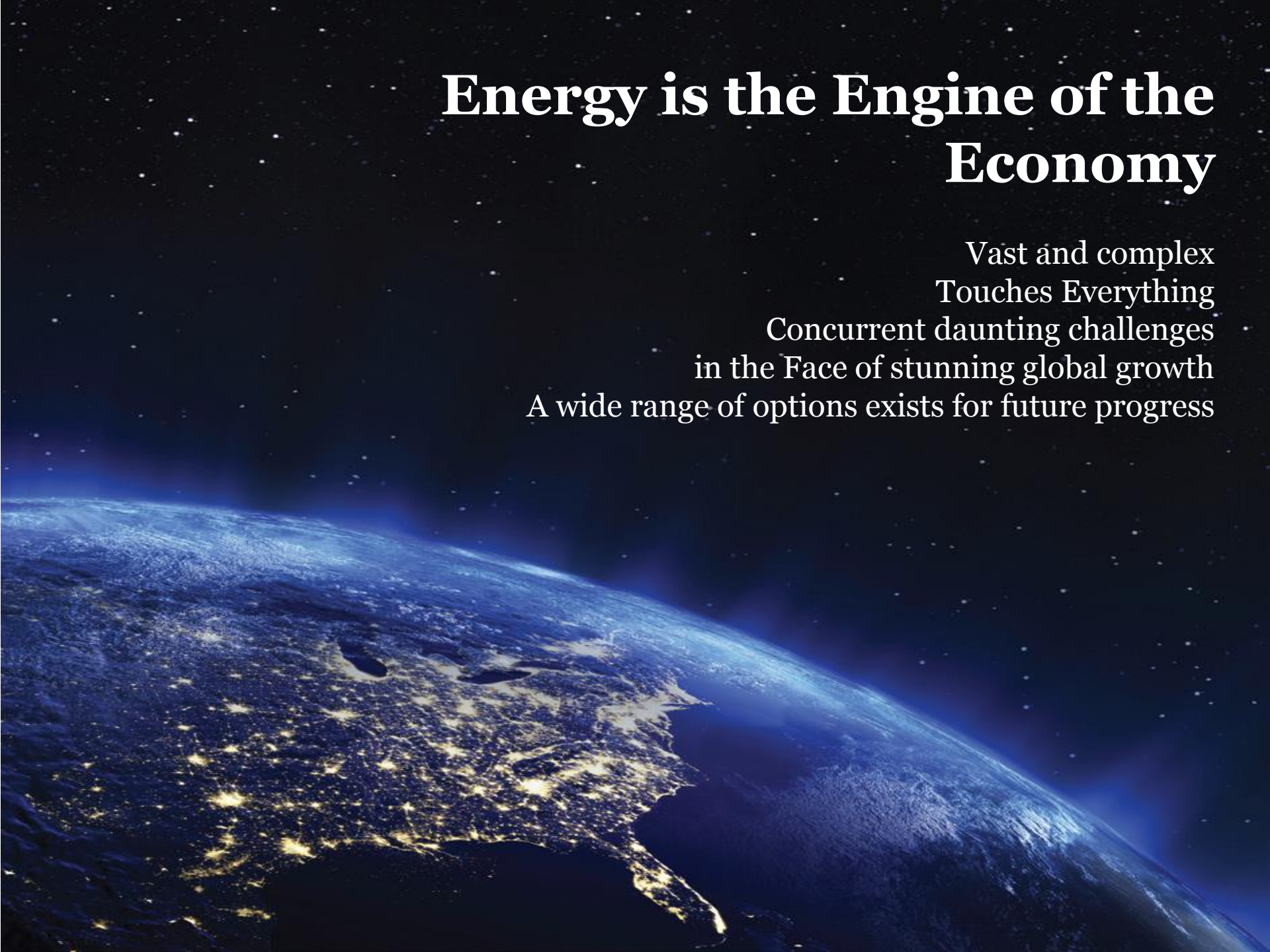
| Name | Performance (pflops/s) | Laboratory |
|---|---|---|
| Titan | 17.6 | Oak Ridge |
| Mira | 8.60 | Argonne |
| Cascade | 2.53 | Pacific Northwest |
| Edison | 1.65 | Lawrence Berkeley (NERSC) |
| Hopper | 1.05 | Lawrence Berkeley (NERSC) |
| Red Sky | 0.43 | Sandia/NREL |





# Conclusions

- Considerable progress has been made in energy technologies, but much more remains to be done
- There exists a very wide-ranging opportunity space, for individual technologies and for improved systems
- A portfolio approach is required:  fully stocked across primary energy resources, conversion technologies, systems, and time scales for application, with efficiency everywhere
- Enabling science and computing are essential to our energy future success

# Energy is the Engine of the Economy

Vast and complex
Touches Everything
Concurrent daunting challenges
in the Face of stunning global growth
A wide range of options exists for future progress