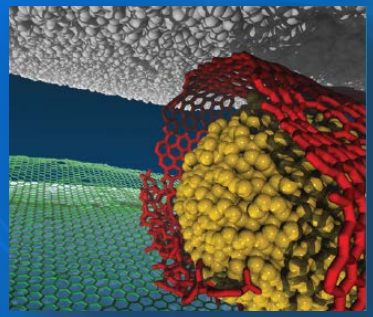


QTR





QUADRENNIAL TECHNOLOGY REVIEW

AN ASSESSMENT OF ENERGY TECHNOLOGIES AND RESEARCH OPPORTUNITIES

Lynn Orr, Under Secretary for Science & Energy
U.S. Department of Energy
Biological & Environmental Research Advisory Committ
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The Energy Challenge

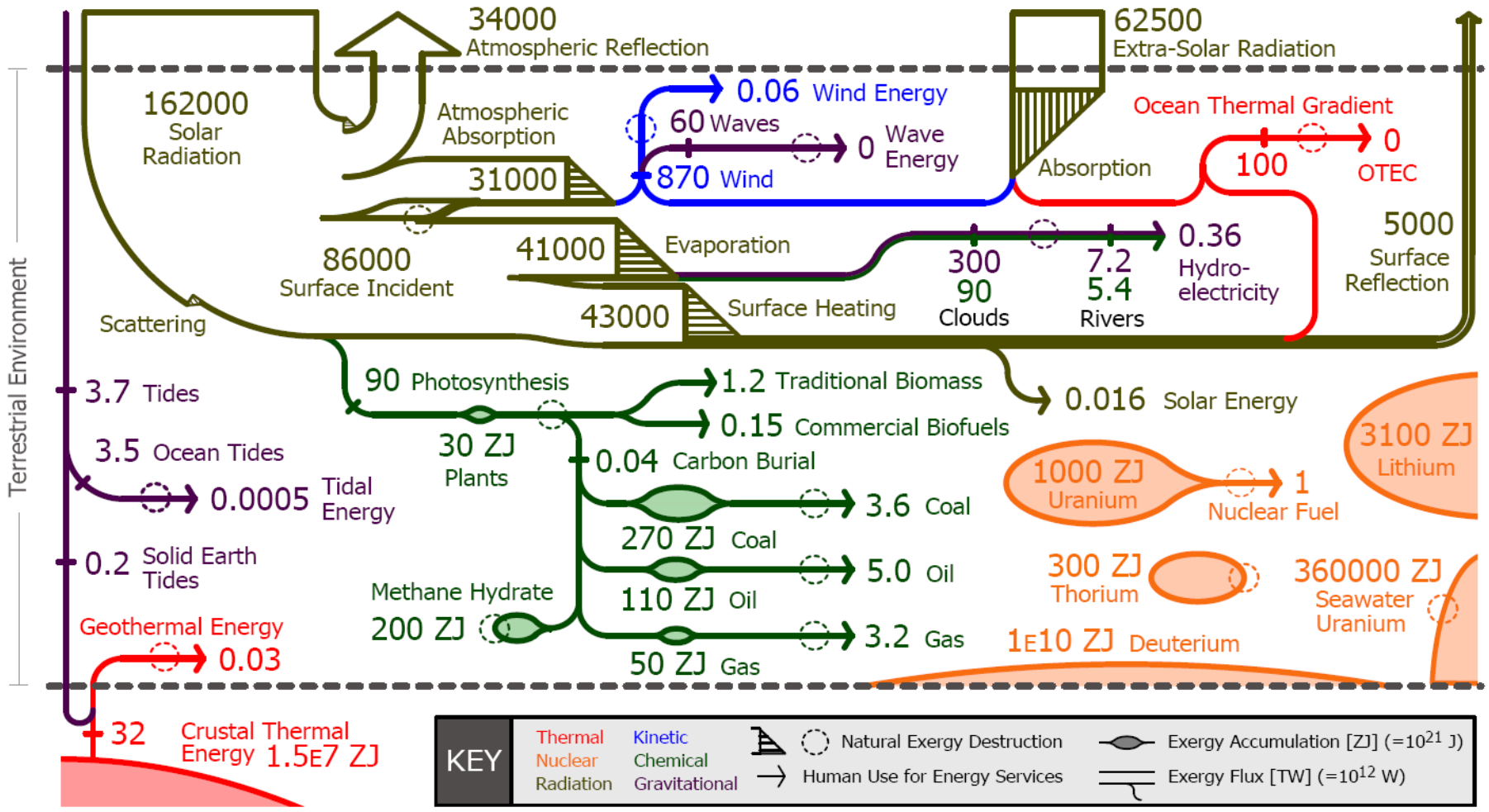
Goals for Energy Systems

1. Economic security – cost efficient energy systems
2. Energy security – energy systems that have multiple supply options and are robust and resilient
3. Environmental security – much lower emissions of greenhouse gases and other pollutants

Opportunity

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

What resources can we use?
Exergy flow of planet Earth (TW)



Exergy is energy that can be converted to another useful form: electricity, mechanical work, or heat.

Current Global Exergy Usage Rate
~ 15 TW (0.5 ZJ per year)

Systems Analyses and Technology Assessments

- Maturity (and time period)
- Materiality (impacts)
- Market potential
- Public benefits
- Public role

Sectors/Systems Analyses	Technology Assessments
Clean Fuels	5
Grid Modernization	6
Clean Electric Power	19
Buildings	10*
Industry & Manufacturing	14
Clean Transportation & Vehicles	5

* Roadmaps

- Cyber & Physical Security
- Designs, Architectures, Concepts
- Electric Energy Storage
- Flexible & Distributed Resources
- Measurement, Comm., Control
- T&D Components

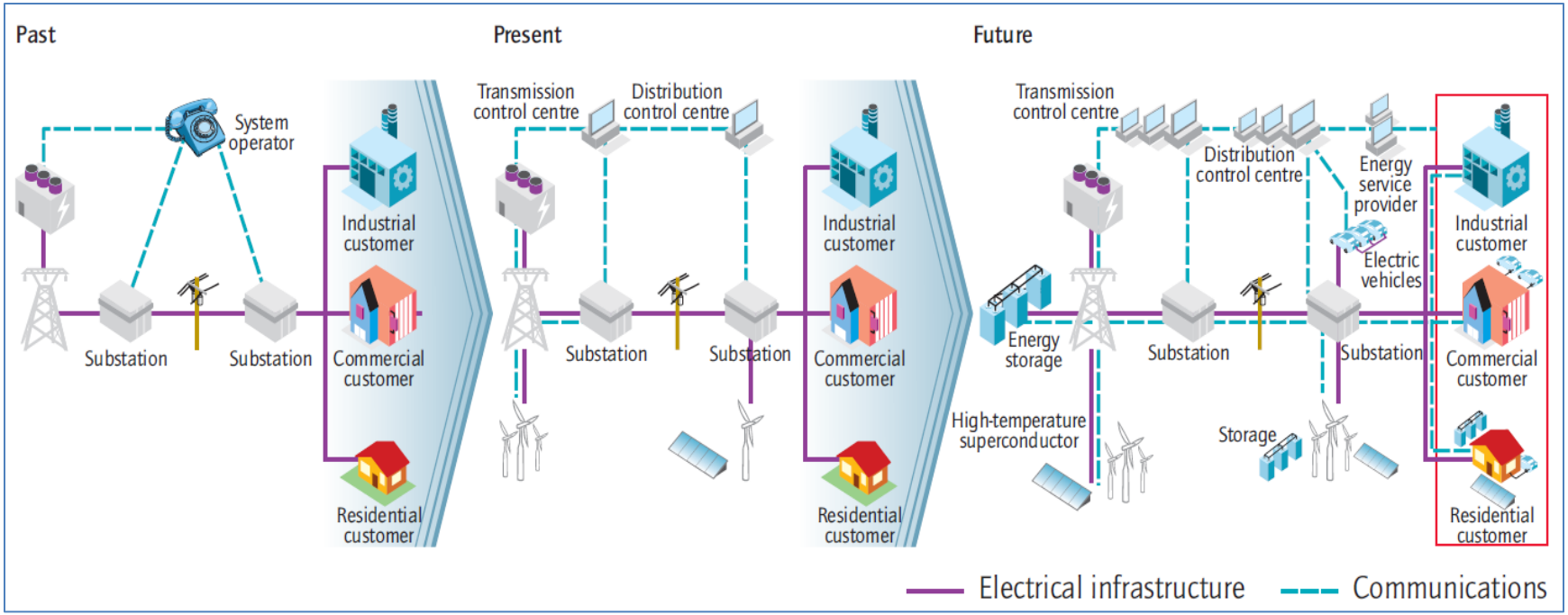
- Advanced Plant Technologies
- Biopower
- CO_2 Capture & Storage Value-Added Options
- CO_2 Capture for Natural Gas & Industrial Applications
- CO_2 Capture
- CO_2 Storage
- Crosscutting Technologies in CCS
- Fast-Spectrum Reactors
- Geothermal Power
- High Temp. Reactor
- Hybrid Nuclear-Renewable
- Hydropower
- Light Water Reactors
- Marine Hydrokinetic Power
- Nuclear Fuel Cycles
- Solar Power
- Stationary Fuel Cells
- Supercritical CO_2 Brayton Cycle
- Wind Power

- Additiv
- Combined Heat and Power
- Composite Materials & Manufact
- Critical Materials
- Materials Flow Through Industry
- Process Heating
- Process Intensification
- Roll-to-roll Processing
- Smart Manufacturing
- ……

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



Historical

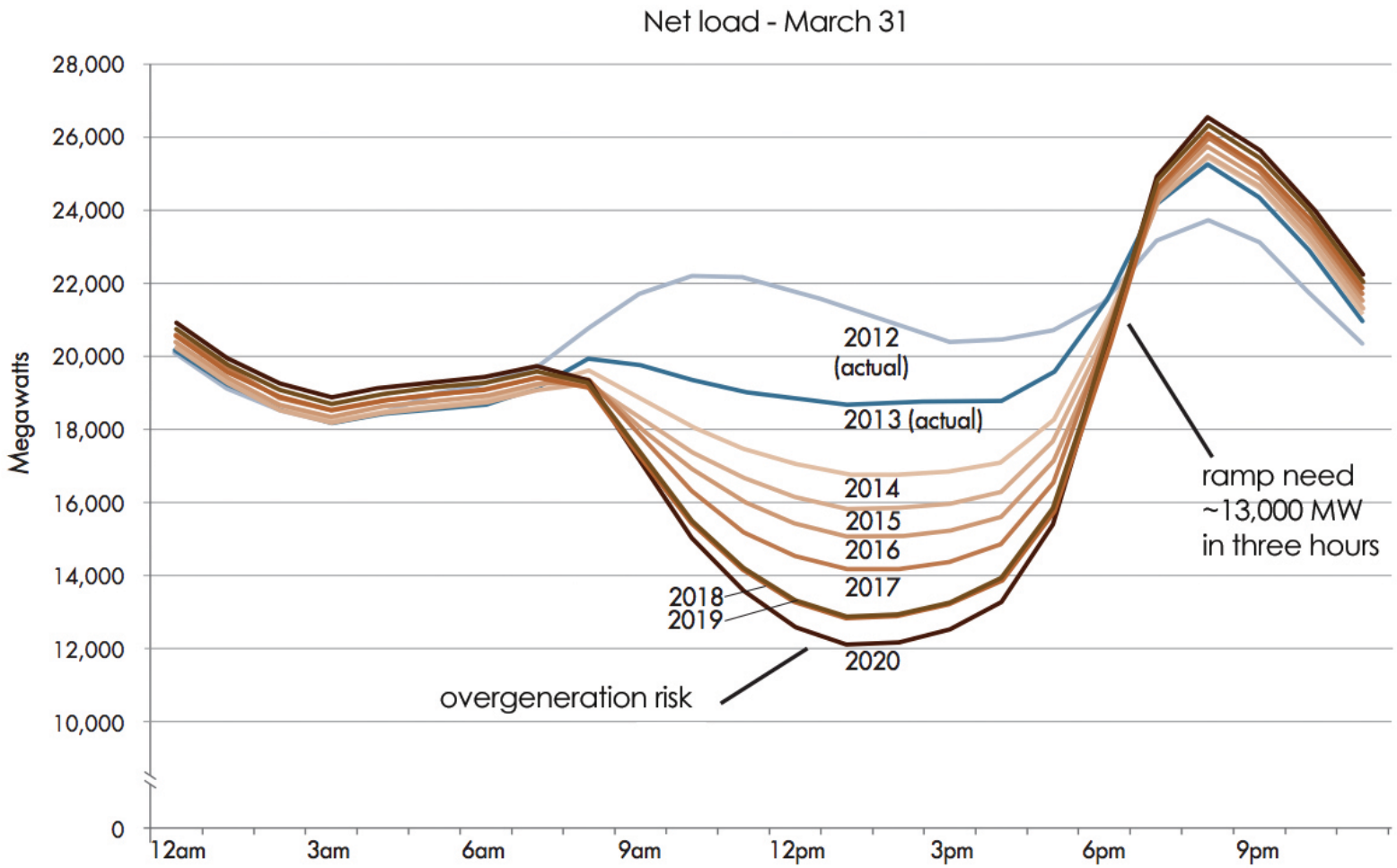
- *Operator-Based Grid Management*
- *Centralized Control*
- *Off-Line Analysis / Limit Setting*

Emerging

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

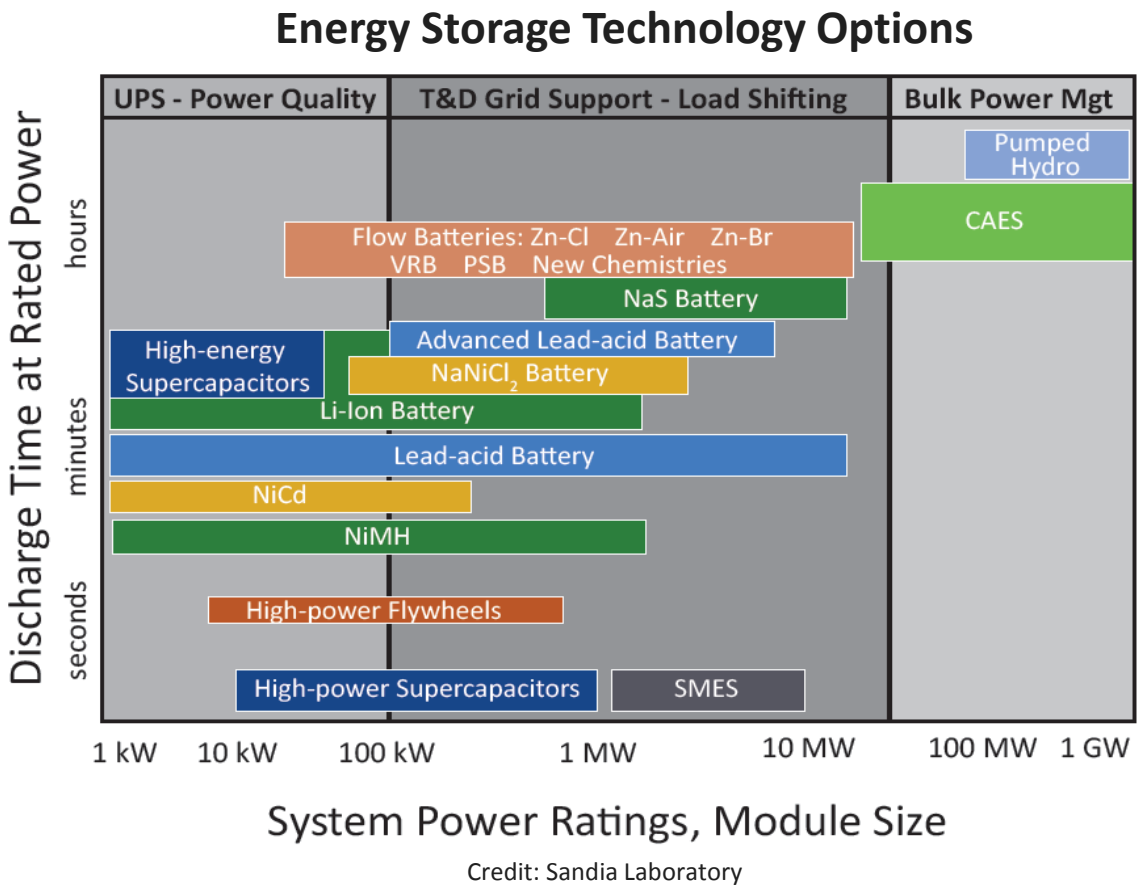
Graphic Source: International Energy Agency

Integration of Intermittent Renewables



Energy Storage

- Role in electric power and transportation
- Options depend on scale of application
- R&D options to reduce costs at all scales
- Integration of storage with infrastructure



Credit: Sandia Laboratory

Clean Electric Power

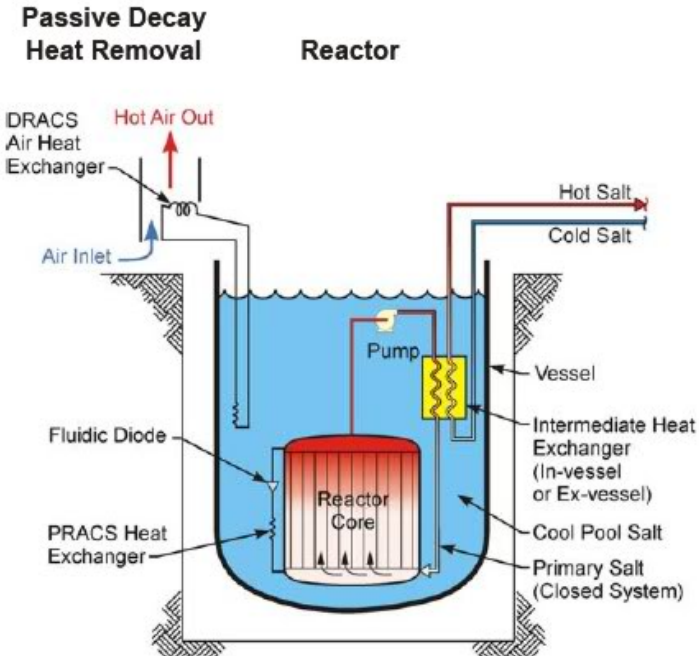
Carbon Capture and Storage

- Capture with solvents demonstrated at scale
- 2nd generation demos (1 MW) testing adv solvents, sorbents, membranes
- Goal: reduce energy penalties and costs of components, materials, chemistries, separations, integrated plant designs
- Research: phase change separations, electrochemical capture
- Storage in a variety of subsurface geologic settings
- Demonstrate for post-combustion retrofits, natural gas generation

Southern Company Kemper Project, IGCC + CC + EOR
Credit: Mississippi Power

Nuclear Power

- 19% of current electric power generation, 60% of non-GHG power, baseload with 89% capacity factor
- Reactor R&D options:
  - Small modular reactors (passive safety, lower cost?)
  - High temperature, gas cooled reactors (more efficient power generation, process heat?)
  - Fast spectrum reactors (reduced waste)
- More R&D opportunities in advanced fuels, high performance materials for rad environments
- Challenges: waste storage, siting, licensing and construction costs

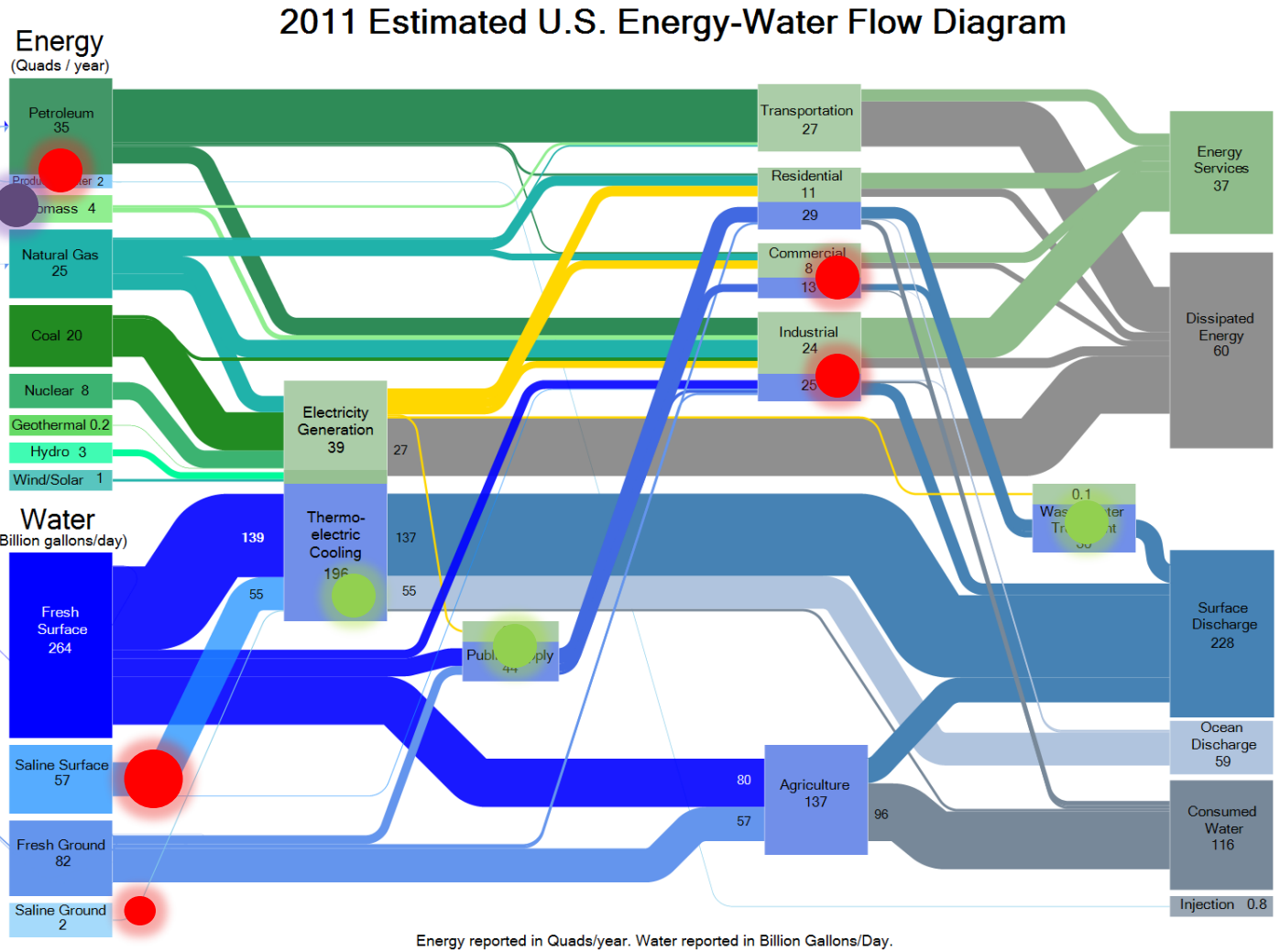


Challenges in the Energy-Water System

Improved Water Efficiency in Bioenergy Systems

Treatment, Management, and Beneficial Use of Nontraditional Waters

Water-Efficient Cooling



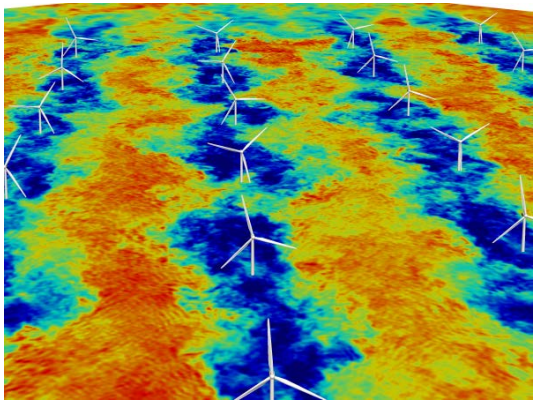
Optimized Water and Energy in Commercial and Industrial Systems

Sustainable Utilities

Wind Provides Promising Potential

- **Wind has become a mainstream power source in the U.S.**
  - 4.4% of U. S. electricity in 2014
  - 70,000 jobs
- **Ability to Increase U. S. wind capacity faces technical, market and perception challenges**
  - Wind plant optimization (A2e)
  - Accessing best wind resources
  - Transmission capacity
  - Public awareness

Successfully addressing these challenges can lead to wind providing 35% of U.S. electricity by 2050

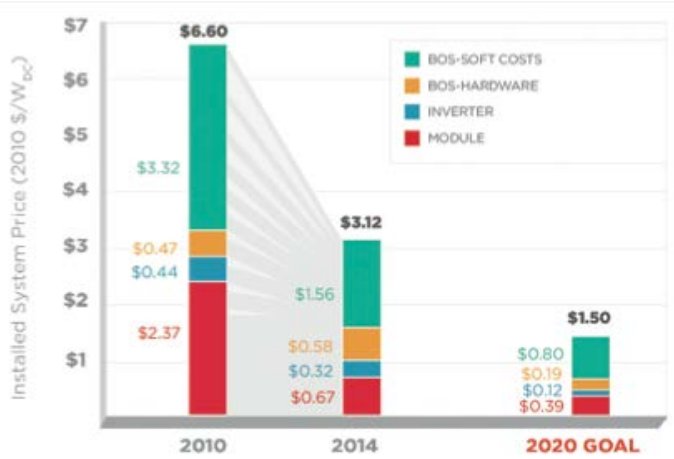


Wind Plant Optimization

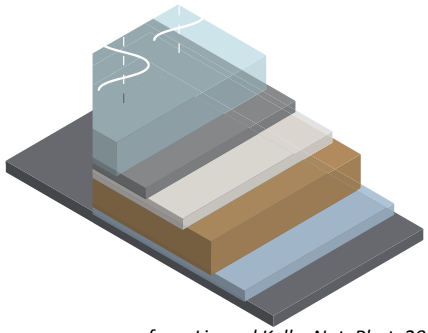
Offshore Wind Demonstration

Solar Offers Significant Potential

- **PV Installed costs**
  - Reduced over 50% in 4 years
  - Module costs significantly below $1/Watt
- **CSP offers storage capabilities**
- **Technology Challenges**
  - Reduce installed costs by addressing “soft costs”
  - Increase efficiencies and reliability with improved or new technology and manufacturing
  - High penetration requires advances in grid integration



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



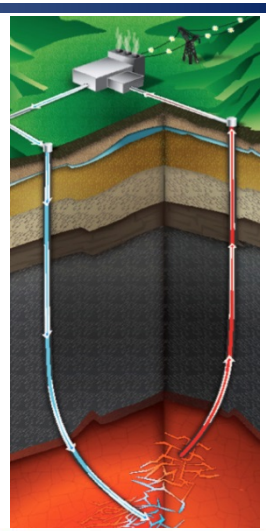
from Liu and Kelly. Nat. Phot. 2013

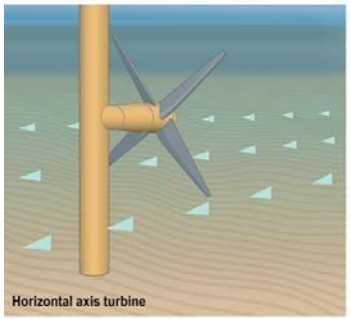
Overarching Strategies

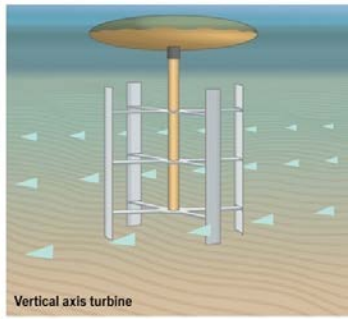
- “Soft cost” improvements
- Technology advances
- Systems approach

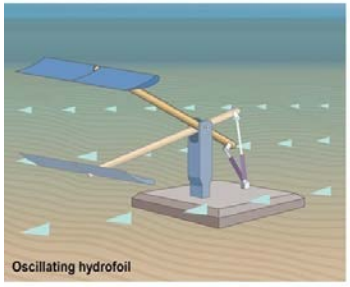
Other Renewables Support Diversified Energy Supplies

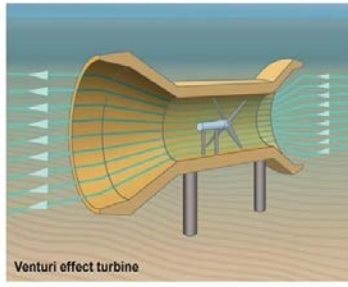
- **Enhanced Geothermal**
  - Could provide over 500 GW of base load renewable power
  - FORGE and SubTER initiatives advance subsurface S&T
- **Hydro and Pumped Hydro**
  - Used to balance grid as intermittent renewables increase
- **Marine and Hydro Kinetic (MHK)**
  - Harnesses energy from waves, tides, and river and ocean currents
  - Significant long-term potential - over half of U.S. population within 50 miles of coastlines











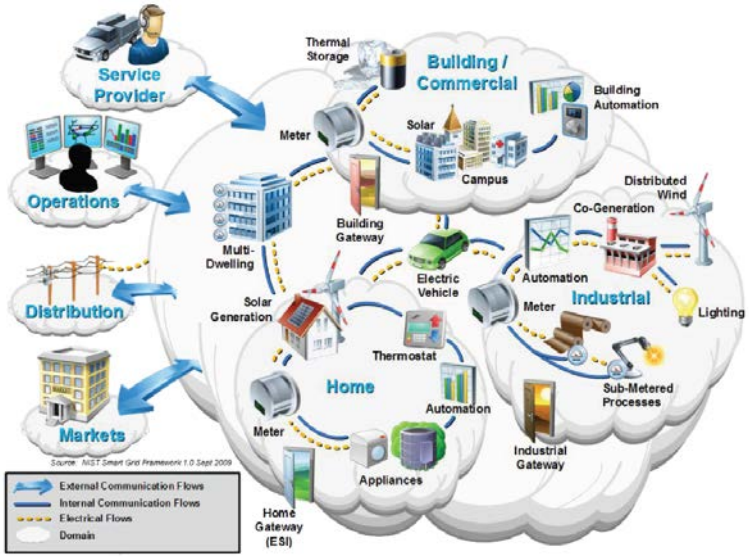
Efficiency of Building Systems and Technologies

Building Efficiency

- Buildings account for more than 75% of all electricity (40% of all energy) used in U.S.
- EE technology can reduce this by 20-35%, saving up to 13 Quads
- Efficiency is the first step; lessens the need for generation capacity
- Buildings will become assets on the grid, rather than just a load

Overarching strategies

- Reduce cost
- Improve performance
- Systems approach



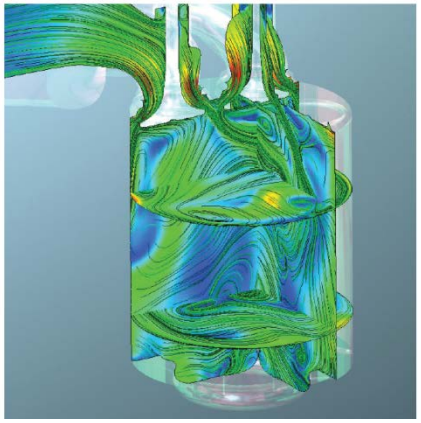
Major Research Opportunities

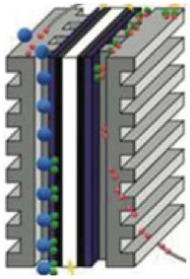
- Window innovations
- Lighting efficiency
- More efficient HVAC & refrigeration
- Highly efficient building designs
- Grid integration
- Sensors, controls, decision science

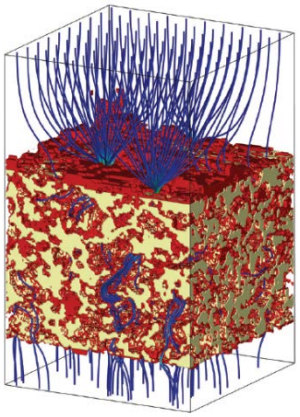
Clean Transportation and Vehicle Systems

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

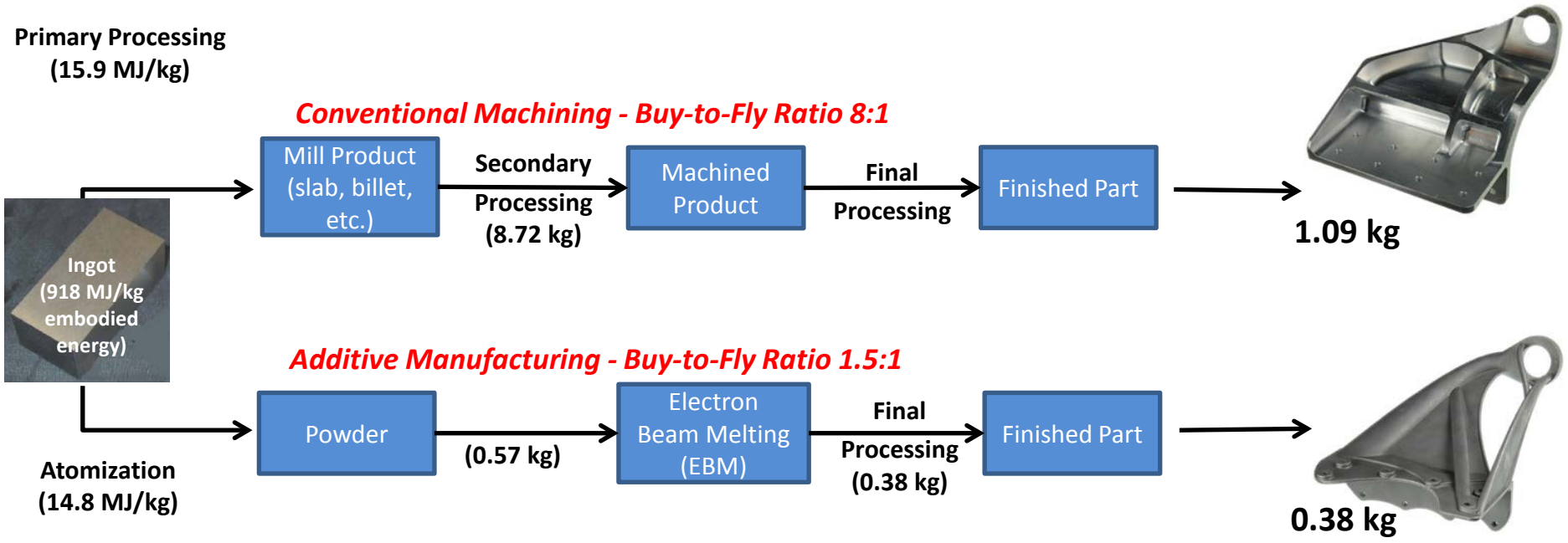






Advanced Manufacturing

Technology Assessment – Additive Manufacturing Example: Optimized Aircraft Bracket



Conventional bracket 1.09 kg

AM bracket 0.38 kg

Conventional bracket energy use 3 times AM bracket use

Source: MFI and LIGHTEnUP Analysis

Enabling Science

Understanding and Controlling Matter at the Atomic Scale

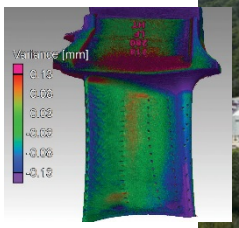
Unique, cutting-edge experimental tools for characterization, discovery, and synthesis of novel materials and energy systems.

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.

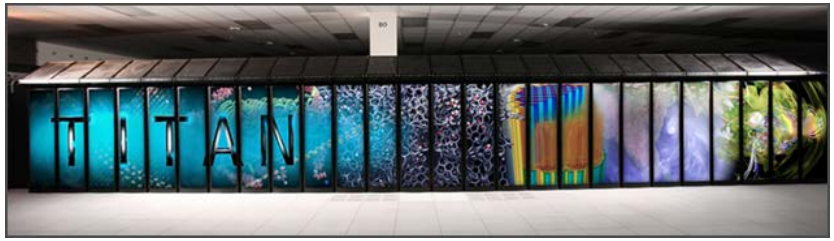
On-going research, development, and upgrades for facilities opens new frontiers in materials characterization (real systems in real time).

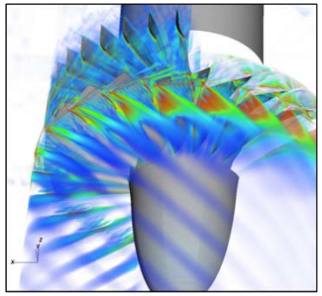
Modeling and Simulation of Complex Phenomena

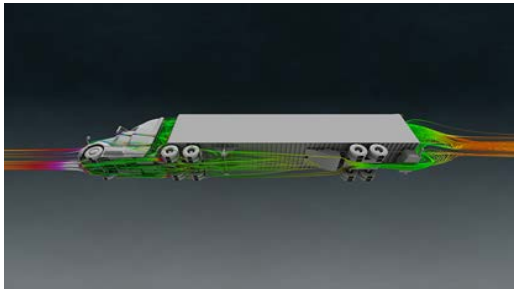
Accelerating discovery through modeling and simulation of real systems.

- 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 for future progress

www.energy.gov/QTR