NREL
NATIONAL RENEWABLE ENERGY LABORATORY

A Sustainable Energy Future: Research and Technology Needs

National Academy of Sciences
Japan-U.S. Workshop on Sustainable Energy Futures

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A Profound Transformation is Required

Today's Energy System

- Dependent on non-domestic sources
- Subject to price volatility
- Increasingly vulnerable energy delivery systems
- 2/3 of source energy is wasted
- Significant carbon emissions
- Role of electricity increasing

TRANSFORMATION

Sustainable Energy System

- Carbon neutral
- Efficient
- Diverse supply options
- Sustainable use of natural resources
- Creates economic development
- Accessible, affordable and secure

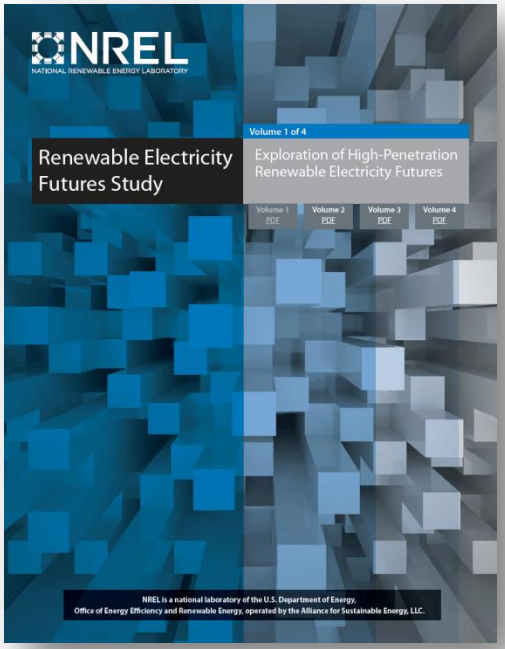
Global Status: 2011

Increasing Capacity and Expanding Investment

- 1360 GW of Renewable Power Capacity
  - 238 gigawatts of wind capacity
  - 70 gigawatts of solar
- ~28 billion gallons of biofuels produced
- Clean energy investment grew to $260B in 2011

Source: REN21

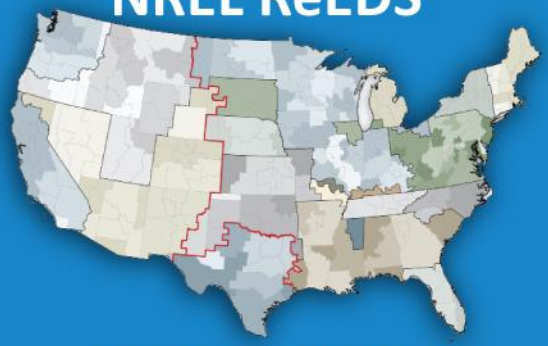
Renewable Electricity Futures Study



Leading Experts

Renewable Technology
Grid Integration
Power System Operation
End-Use Electricity

NREL ReEDS



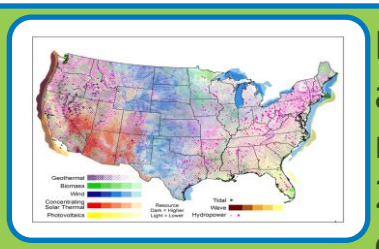
Capacity Expansion
(2010 – 2050)

NREL Solar DS
Rooftop Solar PV
(2010 – 2050)

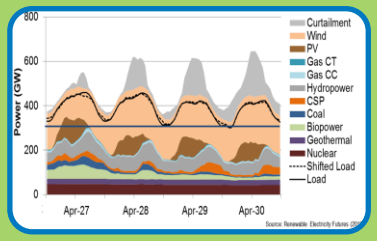
ABB Inc. GridView
Hourly Operation
in 2050

Unprecedented geographic and time resolution for the contiguous United States

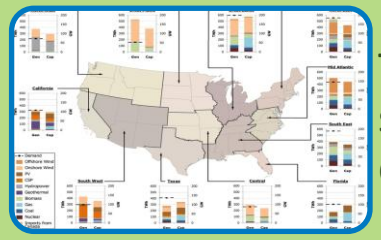
RE Futures Study Key Findings



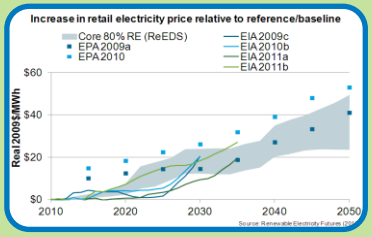
Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country.



Increased electric system flexibility, needed to enable electricity supply-demand balance with high levels of renewable generation, can come from a portfolio of supply- and demand-side options, including flexible conventional generation, grid storage, new transmission, more responsive loads, and changes in power system operations.

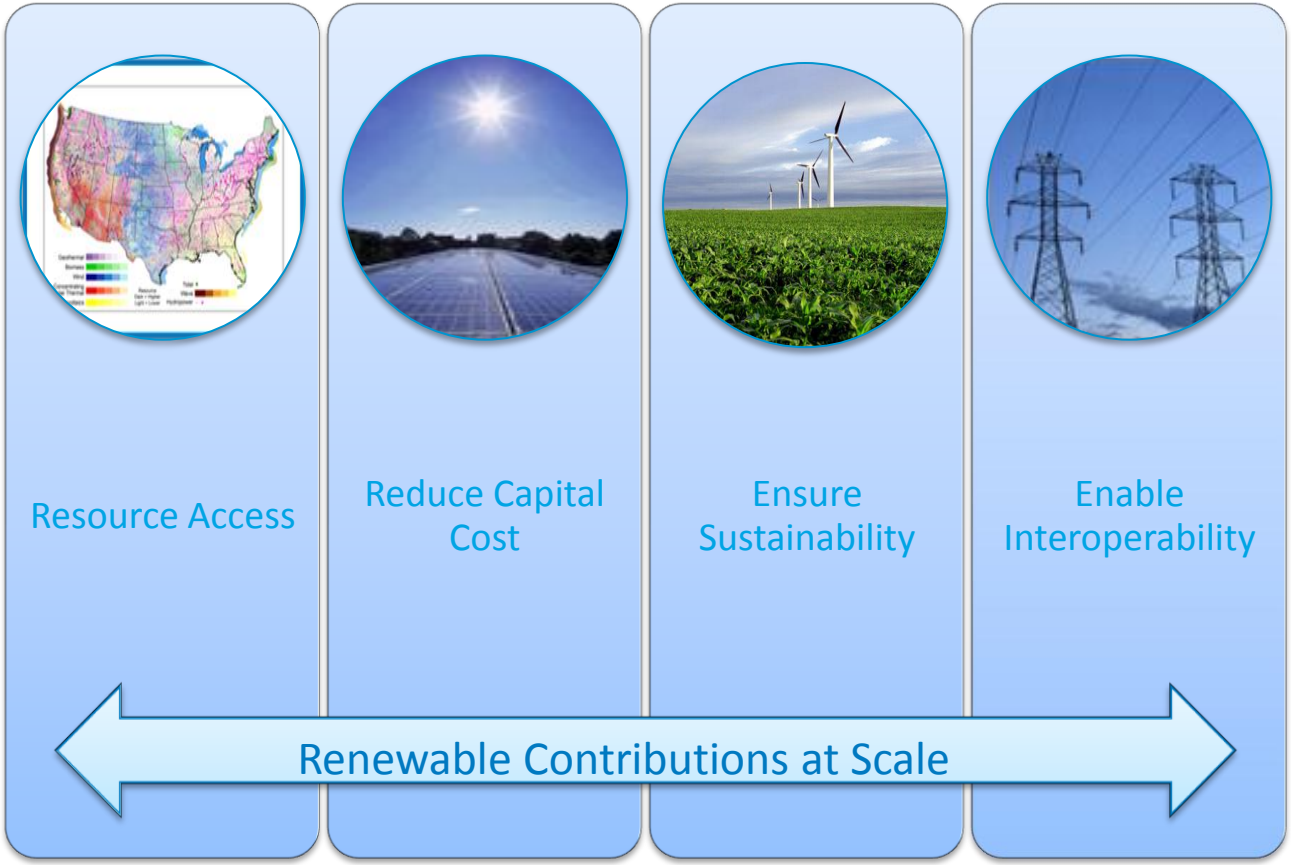


The abundance and diversity of U.S. renewable energy resources can support multiple combinations of renewable technologies that result in deep reductions in electric sector greenhouse gas emissions and water use



The direct incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost.

Renewable Energy Research



Solar Electricity: *State of the Technology*




Photovoltaics (PV)

- Market: Residential; Commercial, Utility
- Geographically diverse
- kWs to MWs to GWs
- U.S. Capacity: 4.0 GW
- U.S. Forecast: 22+ GWs in pipeline
- Costs. $3 to $7/W: *LCOE 7 to 16¢/kWr
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery

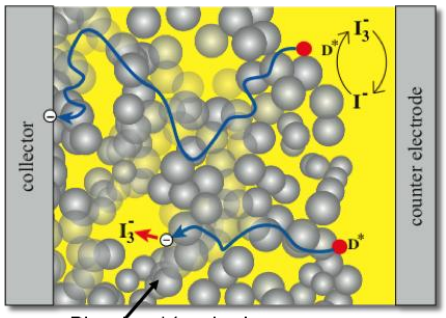
Solar Thermal Electric (CSP)

- Market: Commercial; Utility
- Geographically confined to “sun bowls”
- MWs to GWs
- U.S Capacity: 0.5 GW
- U.S. Forecast: ~6 GWs in pipeline
- Costs. $4 to $8/W: *LCOE 12 to 20 ¢/kWr
- Technologies: Conversion; parabolic troughs, central receivers, dish. Storage; thermal, up to 15 hours.

*With federal incentives; e.g. the FTC.

Updated: April 2012
Source: GTM/SEIA : U.S. Solar Market Insight Q4 2011 & 2011 Year-in-Review

Solar Energy



SunShot U.S. Department of Energy

Major RD&D Directions

Photovoltaics

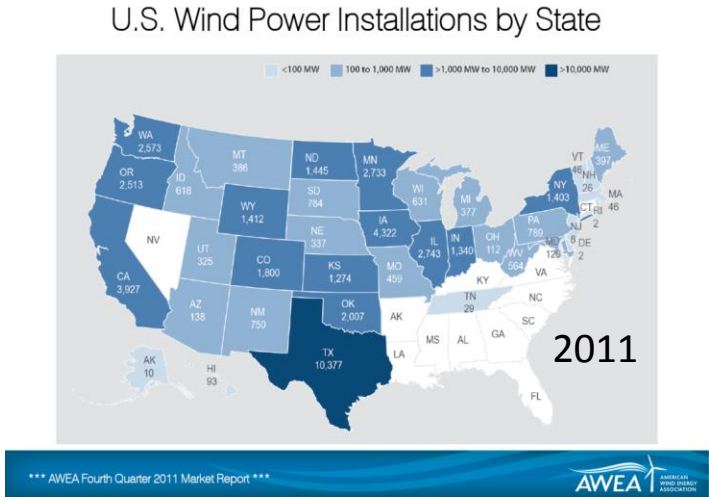
- PV Materials, Processes and Device Designs
  - Thin Films
  - Next-Generation PV
- Manufacturing Technology
- Power Electronics
- Balance of System

Concentrated Solar Power

- Thermal energy storage
- Optical materials and coatings
- Manufacturing
- System Engineering /Balance of Plant

- System Integration

Wind energy: *State of the Technology*



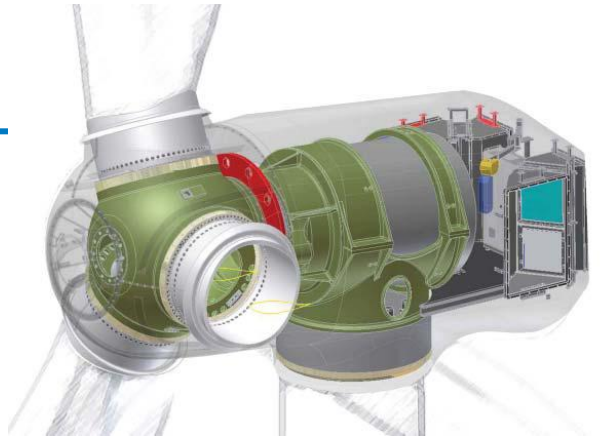
- Costs: 7-10 cents/kWh LCOE*
- Installed wind project cost = $2,155/kW
- 1.5-3.0 MW commercial turbines are typical
- 10 MW prototype machines in development
- Direct drive generators more common
- Variable speed and grid-friendly operation
- Technologies targeting offshore wind markets

- U.S. installed capacity = 46.9 GW (12/2011)
- 38 of 50 states have utility-scale wind with 14 states > 1,000 MW installed
- Over 8.3 GW currently under construction
- U.S. wind capacity represents more than 20% of the world's installed wind power
- U.S. wind percentage of electricity is over 2.3%
- Over 400 manufacturing facilities across the U.S. make components for wind turbines

Updated: April 2012

* Estimate for utility-scale wind, class 4 wind sites, no subsidies

Wind Technology Innovation



Turbine Component Research

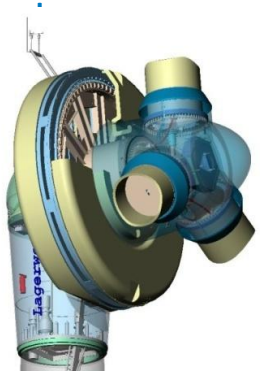
- Active controls/Power Electronics
- Gearbox reliability
- Advanced drivetrain power conversion systems
- Modular large components/Flexible, ultra-large rotors and systems
- Off shore technology

Siting and Forecasting Research

- Aeroelasticity research to understanding complex terrain a wake effects
- Wind forecasting and integration with utility operations
- Turbine – wildlife interactions

Advanced manufacturing

- Strong, lightweight materials
- Automated processes



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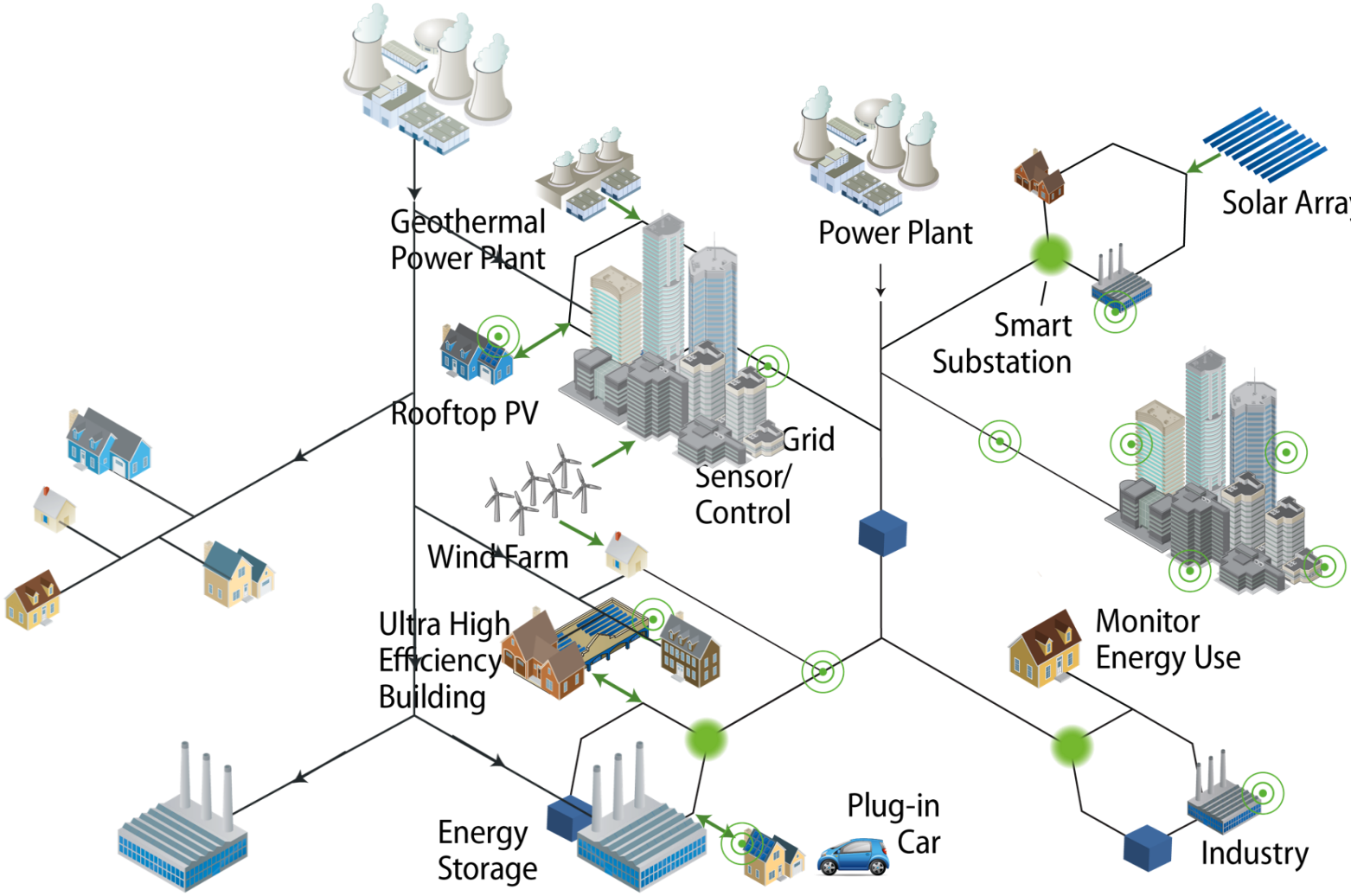
Systems Integration Research

Transforming Our Electricity Infrastructure



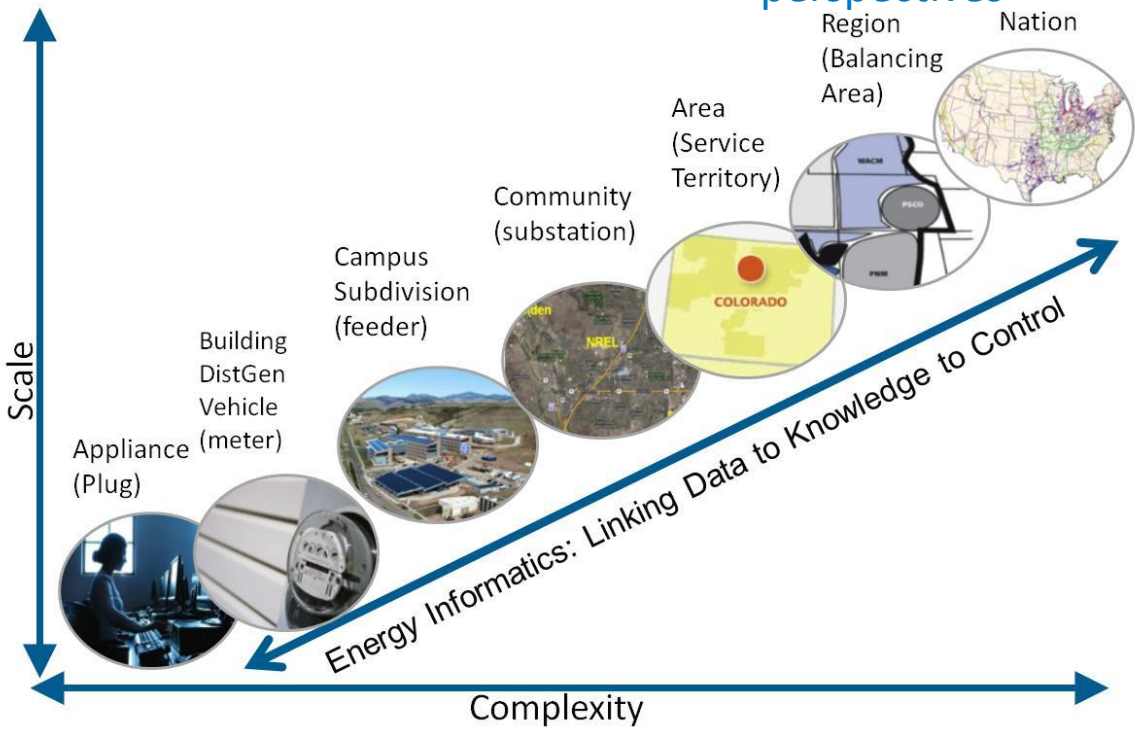
Transforming Systems

Key System Challenges

- Improve overall energy system efficiency
- Integrate and operate new technologies in existing infrastructure
- Engage consumers
- Tailor solutions to local parameters

Need to Understand

- System impacts of large-scale deployment
- Actual performance with subsystems and across interfaces
- Dynamic interactions across energy pathways
- Value across the system from various perspectives



Science-Based Approach to Systems

Energy Systems Integration Facility

- Designed to conduct systems experiments at deployment scale
- Links hardware and controls with system simulation environment
- Uses operating data to develop evidence based solutions – mining massive new data sets

System Research will

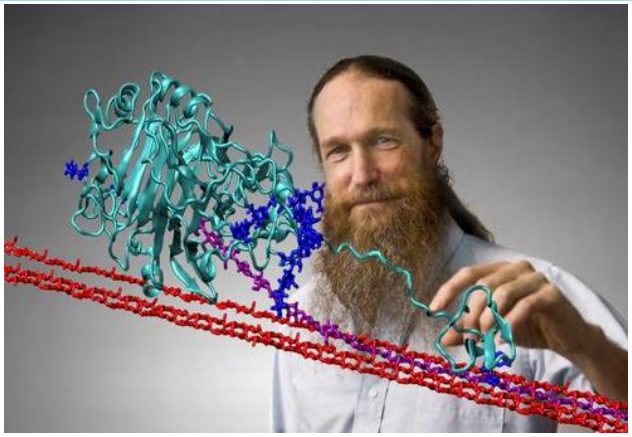
- Empirically drive refinements of energy system models and dynamic simulations
- Yield next-generation energy system design tools
- Lead to new control algorithms and interface technologies
- Allow simulating and assessing future energy scenarios

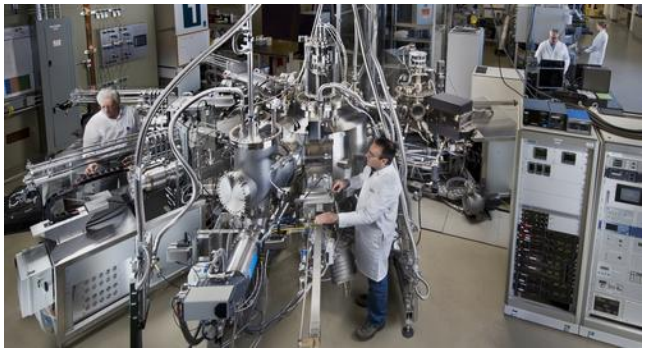
Forward Progress: Energy Systems Integration at All Scales

NREL is working with the Sacramento Municipal Utility District on visualizing impact of DG deployments.

Research Summary

- **Science Underpins Technology Advances**
  - High-performance computing
  - Materials science
  - Chemical and molecular science
  - Energy Bioscience
- **Technology RD&D Reduces Cost and Risk**
  - Reduce technology cost/improve performance
  - Address reliability and sustainability
  - Develop low-cost manufacturing
- **Systems Research Enables Integration and Interoperability**
  - Develop design tools that address dynamic factors
  - Achieve operational efficiencies and manage interfaces





Research to Advance Clean Energy Options is Essential to Achieve a Sustainable Energy Future