Quadrennial Technology Review-2015

Chapter 6:
Advancing Clean Electric Power Technologies

Public Webinar

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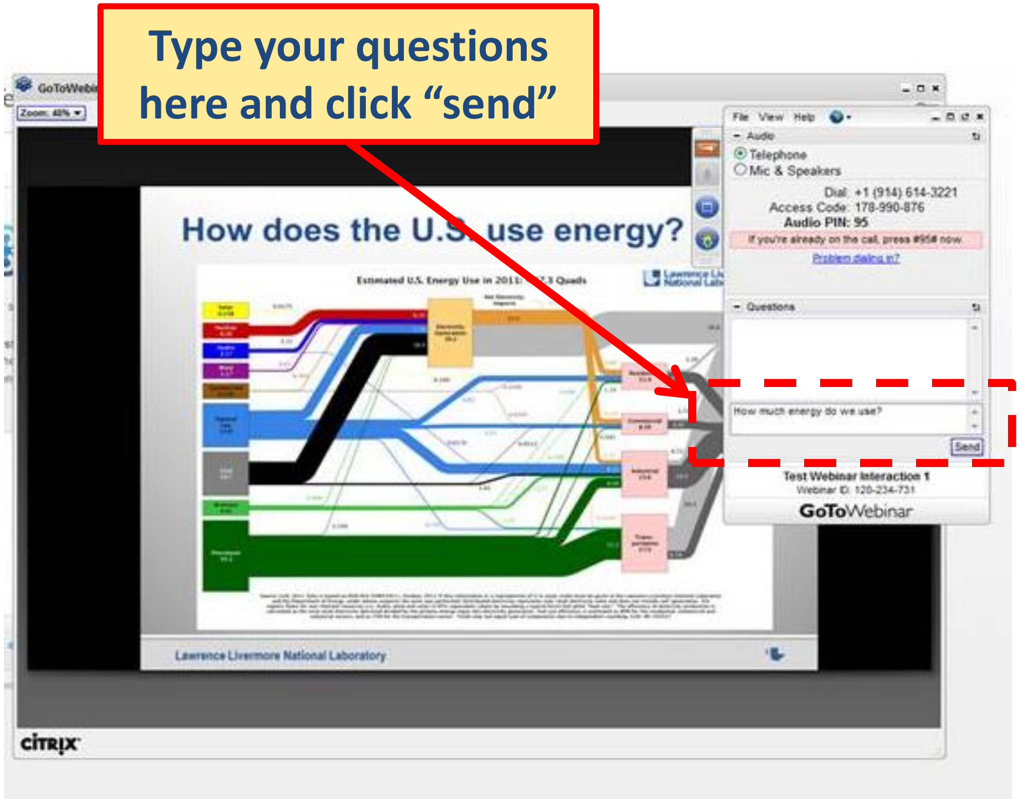
2014-10-14

Webinar Logistics

- Due to the large number of expected participants, the audio and video portions of this webinar will be a “one way” broadcast. Only the organizers and QTR authors will be allowed to speak.

- Submit clarifying questions using the GoToWebinar control panel. Moderators will respond to as many questions as time allows. Substantial input regarding chapter content should be submitted by email to: DOE-QTR2015@hq.doe.gov



Webinar Schedule (all times EST)

Begin	End	Chapter	Topic
10:00 AM	10:30 AM	N/A	QTR and Webinar Overview
10:30 AM	12:00 PM	4	Fuels
12:00 PM	1:00 PM	5	Electric Grid
1:00 PM	2:30 PM	6	Power Generation
2:30 PM	3:30 PM	7	Buildings
3:30 PM	4:30 PM	8	Manufacturing
4:30 PM	5:30 PM	9	Transportation

Administration priorities

- President Obama set forth the Administration's Climate Action Plan in June 2013 with three key thrusts:
  - Cutting carbon emissions in the United States
  - Preparing the United States for the impacts of climate change
  - Leading international efforts to address global climate change
- Research, development, demonstration and deployment of innovative energy technologies will be critical to achieving these objectives.
- The QTR 2015 will facilitate DOE's contribution to the President's Climate Action Plan by examining an "all of the above" range of energy technologies to inform future planning.

Quadrennial Reviews Underway

- Quadrennial Energy Review: Called for by the President to analyze government-wide energy policy, particularly focused on energy infrastructure.

- Quadrennial Technology Review: Secretary Moniz requested the second volume be published in parallel with the QER to provide analysis of the most promising research, development, demonstration, and deployment (RD3) opportunities across energy technologies in working towards a clean energy economy.

The resulting analysis and recommendations of the QTR 2015 will inform the national energy enterprise and will guide the Department of Energy's programs and capabilities, budgetary priorities, industry interactions, and national laboratory activities.

Expanded Scope of QTR 2015

- The QTR will evaluate major changes since the first volume of the QTR was published in 2011 and provide forward leaning analysis to inform DOE's strategic planning and decision making.

- In doing so, the QTR 2015 will provide three levels of analyses:
  - Systems Analyses – Uses systems frameworks to evaluate the power, buildings, industry, and transportation sectors, enabling a set of options going forward.
  - Technology Assessments – Examines in detail, the technical potential and enabling science of key technologies out to 2030.
  - Road Maps – Uses these analyses and assessments to extend R&D Roadmaps and frame the R&D path forward.

- The QTR is a comprehensive assessment of science and energy technology RD3 opportunities to address our nation's energy-linked economic, environmental, and security challenges.

QTR 2015 Chapter Outline

Introduction

1. Energy Challenges
2. What has changed since QTR 2011
3. Energy Systems and Strategies

Assessments

4. Advancing Systems and Technologies to Produce Cleaner Fuels
5. Enabling Modernization of Electric Power Systems
6. Advancing Clean Electric Power Technologies
7. Increasing Efficiency of Buildings Systems and Technologies
8. Increasing Efficiency and Effectiveness of Industry and Manufacturing
9. Advancing Clean Transportation and Vehicle Systems and Technologies
10. Enabling Capabilities for Science and Energy

Integrated Analysis

11. U.S. Competitiveness
12. Integrated Analysis
13. Accelerating Science and Energy RDD&D
14. Action Agenda and Conclusions; Web-Appendices
    Web Appendices

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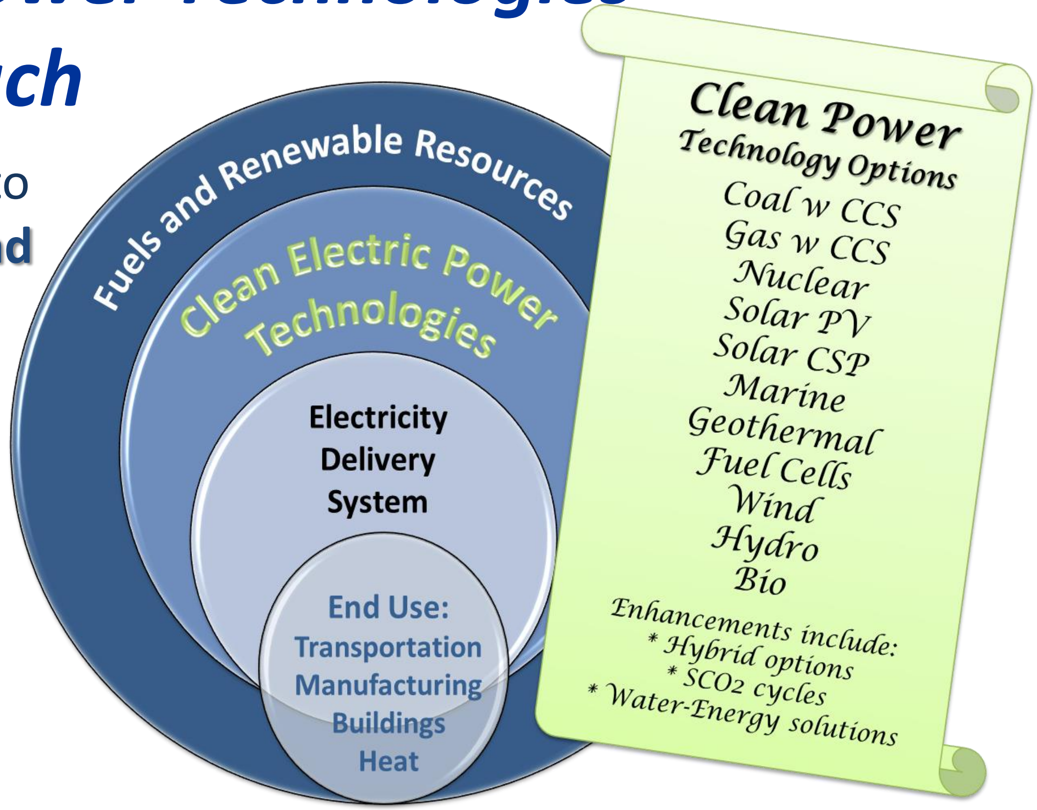
Chapter 6 Advancing Clean Electric Power Technologies

Clean Electric Power Technologies Systems Approach

Advanced technologies are critical to maintaining **reliable, affordable, and clean power** solutions while addressing global environmental goals (i.e. IEA 2DS).



Clean Power Research Focus:

- Increased efficiency
- Greater flexibility
- Lower emissions
- Decreased cost

Regional portfolios can be tailored to meet local needs, state directions, and requirements.

Beyond the QTR scope:

- Regulatory and policy discussions and recommendations in the QER
- Public acceptance and education are key, but not the focus here
- Global Policy is both critical to collaborative approaches and influenced by technical advances, but only technical issues discussed here

Progress, Goals and Priorities

	2010 GW Capacity	2014 GW Capacity	2010 TWh Generation	2014 TWh Generation
CCS				
Coal	316.8	336	1,847,290	1,500,000
Gas	409.7	486	999,010	970,000
Nuclear	101.2	108	806,968	700,000
Fuel Cell	0.3	?	1	?
Biopower	11.4	14.7	56,089	51,300
Geothermal	2.4	3.8	15,219	15,000
Wind	39.1	61.1	94,652	170,000
Solar	0.9	13	1,212	17,000
Hydropower	78.8	78.5	260,203	230,000
Marine HK	-	-	-	-

Table 1: Electric power capacity and production 2010 and 2014

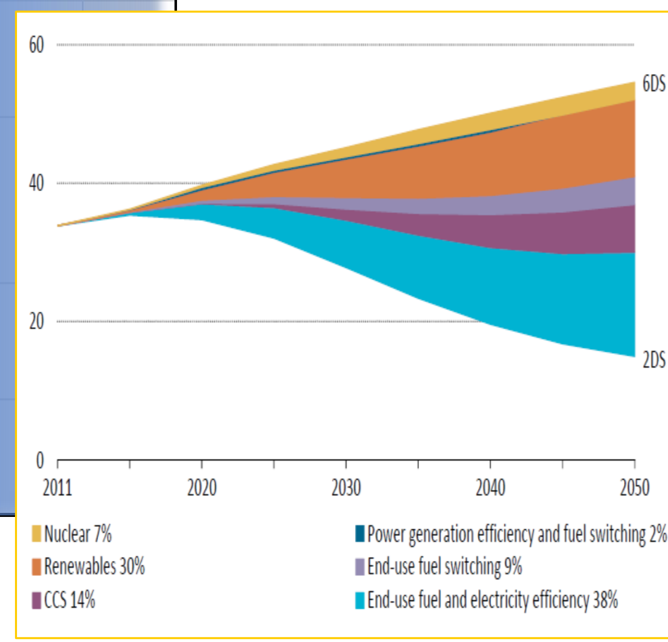
** EIA Electric Power Annual Reports 2011 and in process (2013 reported)*

Balancing Drivers

		Power supply planning based on siting characteristics				Flexibility needs				Additional criteria		
		Criteria pollutants	Available fuels	Available transmission	Available water	Minimum loads	Frequency response	Ramp rates	Security	Waste Releases	GHG footprint	water impacts
System Requirements	Reliability											
	Resiliency											
	Safety											
	Minimal Environmental Footprint											
	Flexibility											
	Affordability											

Challenges: Balancing tradeoffs

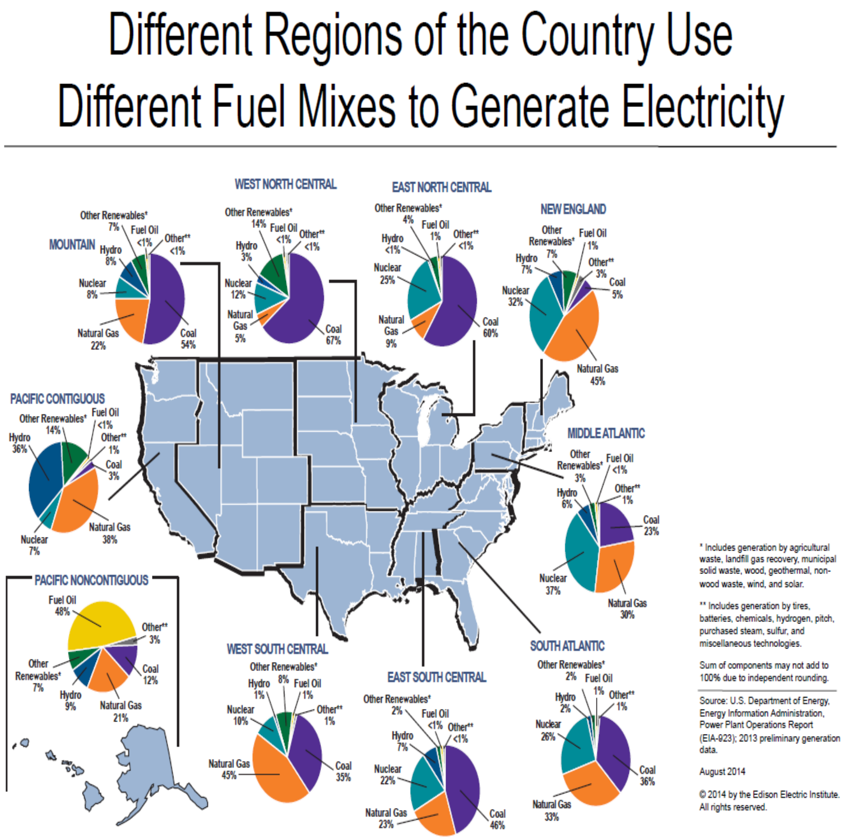
- Cost vs environment
- Accessibility vs security
- Base load vs variable sources
- Social need vs acceptance



Technology Options

		Power supply planning based on siting characteristics				Grid Requirements		Additional criteria			
		Traditional pollutants	*Available fuels*	*Available transmission*	*Available water*	*Dispatch-ability*	*Ramp rates*	*Security*	*Waste*	*GHG footprint*	*water impacts*
FUEL	*Coal w CCS*	1	1	1	3	1	2	2	3	2	4
	Natural Gas w CCS	1	1	2	2	1	2	3	2	2	3
	Nuclear	1	1	1	3	1	3	3	4	1	4
	Biopower	1	2	2	3	2	2	2	2	2	4
	Hydro	1	3	1	4	1	1	2	1	1	3
	Geothermal	1	3	3	2	2	3	2	1	1	2
	Solar	1	2	2	2	4	3	3	2	1	1
	Wind	1	2	4	1	4	3	3	1	1	1
	MHK	1	4	4	4	2	3	3	1	1	1
	Fuel Cells	2	1	1	2	2	1	2	3	1	3

Qualitative assessment of technology attributes with respect to selection criteria



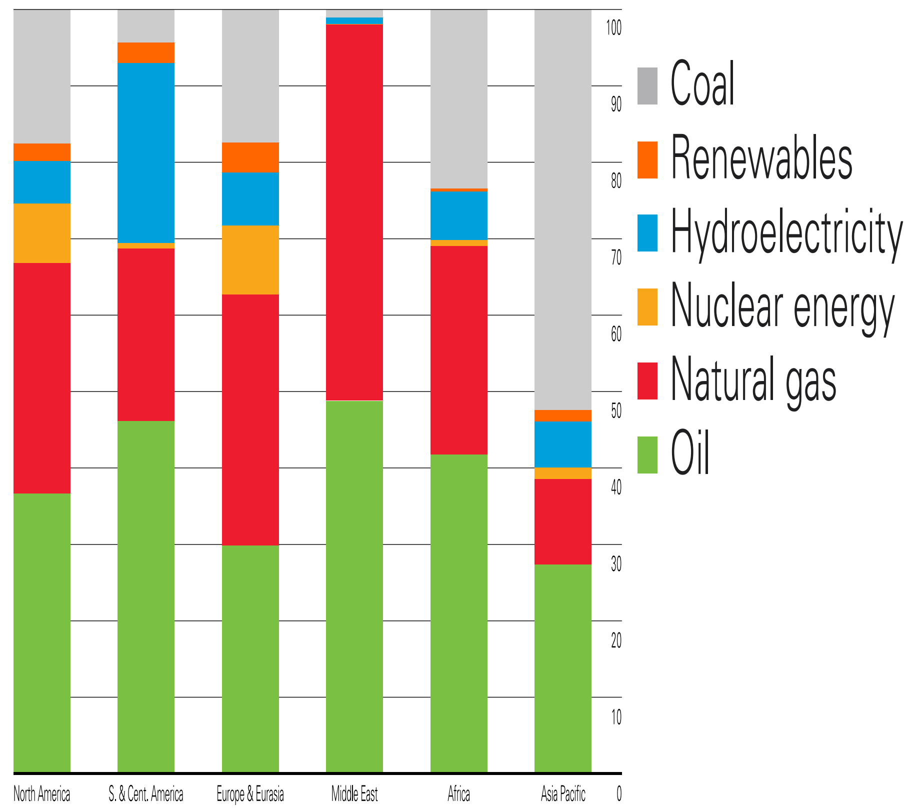


Figure 4 Domestic and global regional fuel consumption.

© EEI 2014 - Edison Electric Institute, data from EIA

© BP 2014 - BP Statistical Review of World Energy 2014

Electric Power System Challenges

Electric power generation technologies are maturing to a new level of integration and interdependencies that require a system approach and a global view. Broad questions include:

- How will industry develop to meet growing electrification and carbon reduction goals?
- How do domestic choices on clean energy technologies interface with global energy choices?
- How much and how quickly can technologies be scaled up?
- Pacing of technology readiness for deployment, i.e. supply constraints?
- How much variable renewable generation (utility scale and distributed generation) can the grid support with agile baseload units, and at what cost?
- How does public acceptance affect the technology portfolio? Can technology development help to reduce deployment risks such as regulatory uncertainty and siting limitations?

Technology Assessments

1. Carbon Capture Technologies
2. Carbon Storage Technologies
3. CCS for Natural Gas and Industrial Plants
4. Advanced Plant Technologies
5. Cross-cutting Technologies in CCS
6. Light Water Reactors
7. High-Temperature Reactors
8. Fast-Spectrum Reactors
9. Hybrid Energy Systems
10. Nuclear Fuel Cycle
11. Biopower
12. Stationary Fuel Cells
13. Geothermal Power
14. Solar Power
15. Hydropower
16. Marine and Hydrokinetic Power
17. Wind Power

These assessments, separate from the main report, will contain the data and analysis that supports the technology discussion in the chapter. They will be available on the web.

Fossil Fuel with Carbon Capture and Storage

Carbon Capture and Storage Technology

Major Technology Challenges:

- Advancing to commercial-scale demonstration
- Establishing the basis for financial support through confidence in the technology (demonstration and deployment)
- Lowering costs

Current Status:

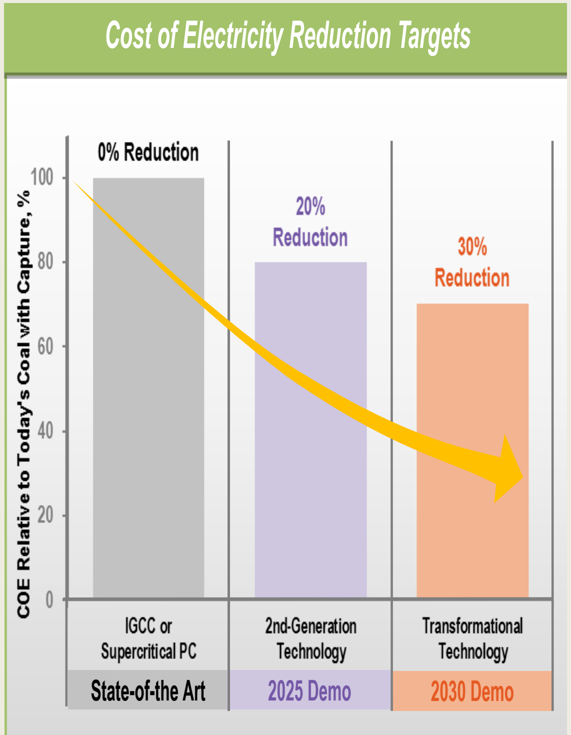
- 50% increase in large-scale CCS projects since 2011 – over 20 global projects in operation or construction and beginning to provide operational data and confidence
- Promising 2nd generation technologies continue to develop
- EPA draft regulations require CCS for new coal plants in the US

Factors driving change in the technologies:

- ARRA funds for CCS demos in the US: >$3B, 8 large-scale demos
- Continued increase in coal use worldwide
- Climate projections show the need for CCS on all fossil fueled plants (industrial, NGCC)

Where the technology R&D needs to go:

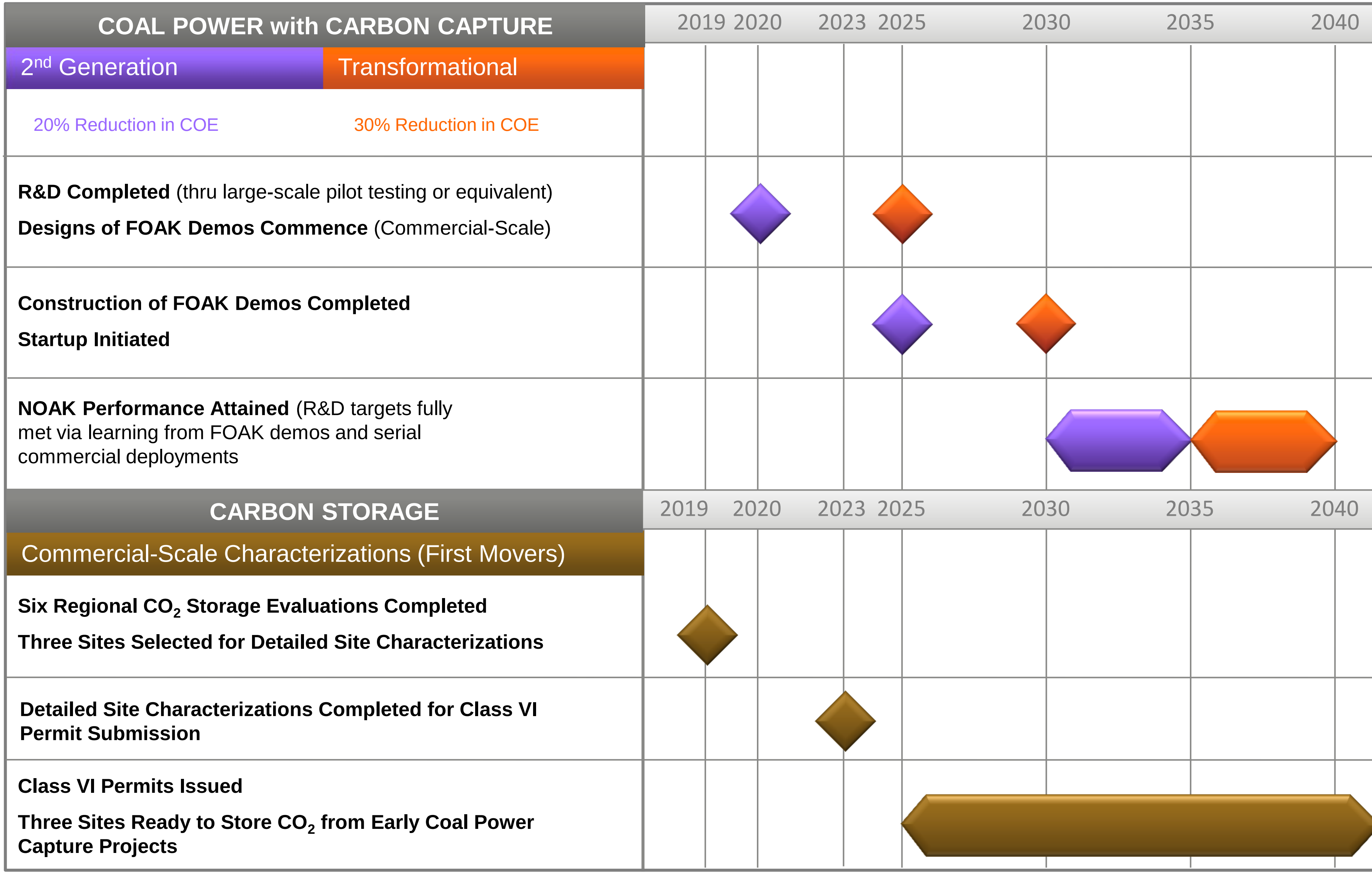
- 2nd generation pilot demonstrations
- Retrofit demonstration and deployment
- Application to Natural Gas and Industrial plants
- International Partnerships



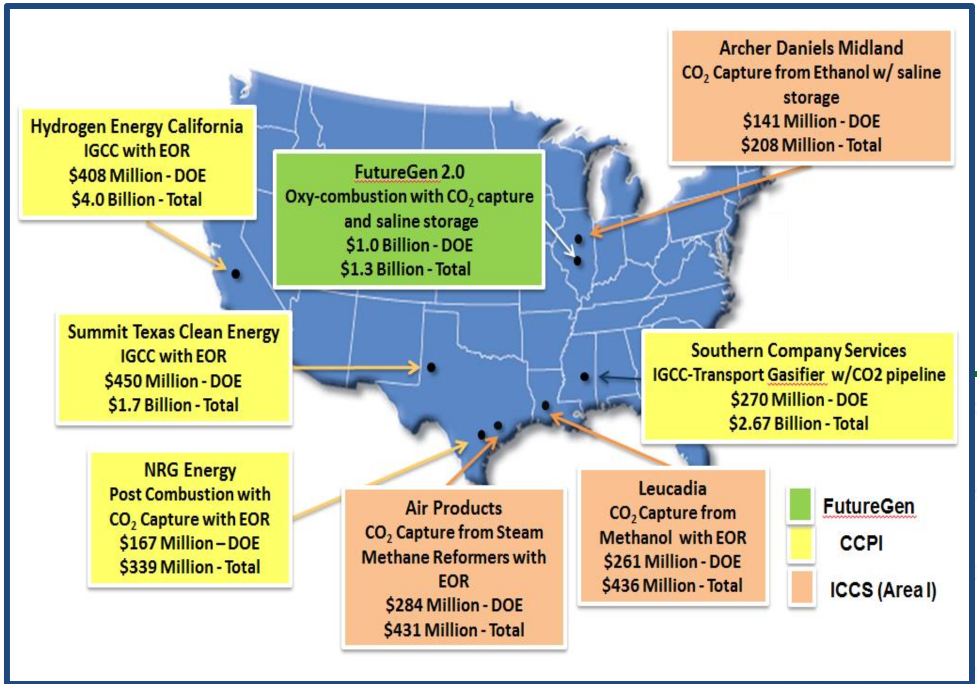
Goals shown are for greenfield plants. Costs are nth-of-a-kind and include compression to 2215 psia but exclude CO_2 transport and storage costs.

Driving down the Cost of Coal Power with CCS

CCS Technology Timeline

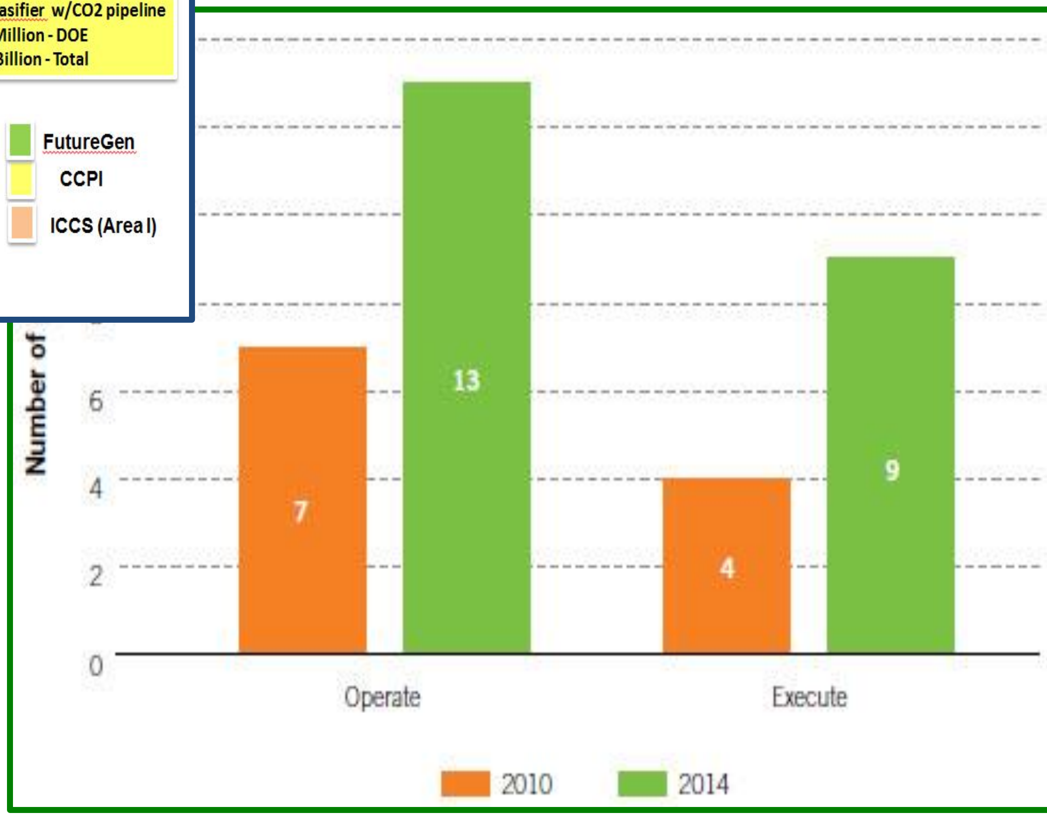


Large-Scale Integrated Demonstration and Deployment



Domestic Large-Scale Integrated Projects*

International Large-Scale Integrated Projects



*TO BE UPDATED prior to final publication

CO2 Capture Technology

Major Challenges:
- Separation of CO_2 typically uses solvents, sorbents, and membranes
- Reduce capital costs and energy requirements
- Scale technologies to demonstration

What we have Learned:
- First generation technologies being demonstrated
- Next generation plants needed to achieve cost goals
- Hybridizing capture processes and/or combining them with balance of plant equipment already required show promise

Current RD3:
- Testing 5 advanced solvent systems at the 1MWe scale and 9 bench scale projects at the <0.1MWe scale.
- 60 independent projects of technology readiness levels ranging from conceptual engineering and materials design to 25 MW-electrical (MWe) equivalent pilot testing.

Where the technology R&D needs to go:
- Scaling of technologies to 10MWe+ by 2020 for integrated 2nd generation target
- Use of Advanced Manufacturing
- Accommodating high viscosity solvents
- Hybridizing system with other approaches
- Attrition resistant sorbents
- Facilitated transport mechanisms to increase selectivity at high permeability

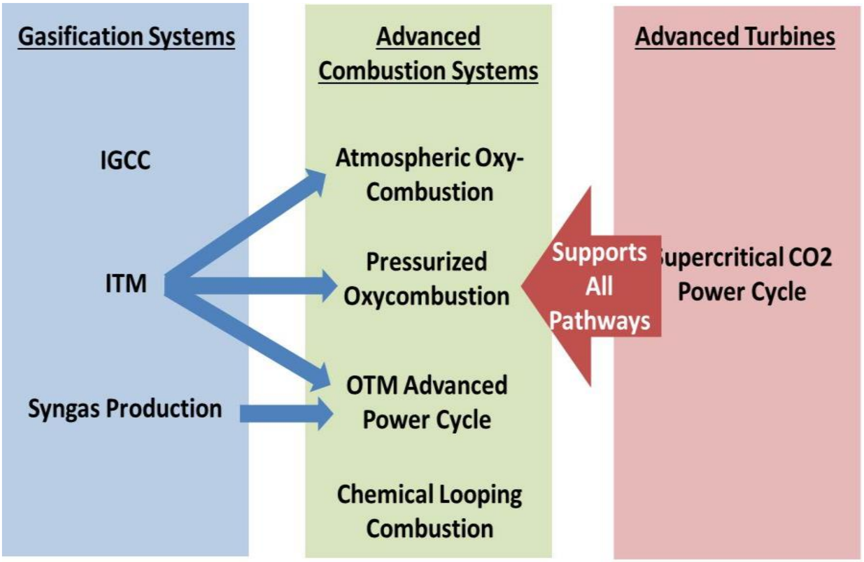
Plant Cost and Efficiency Technology

Major Challenges:

- improving fuel conversion efficiencies
- increasing plant availability
- reducing water consumption
- achieving ultra-low emissions of traditional pollutants

What we have Learned:

- Advanced Combustion Options at 1 MWe pilot-scale
  – data for scaling up to large pilots , such as:
    - equipment sizing parameters;
    - gas and solids flow rates;
    - heat transfer rates and reactivities



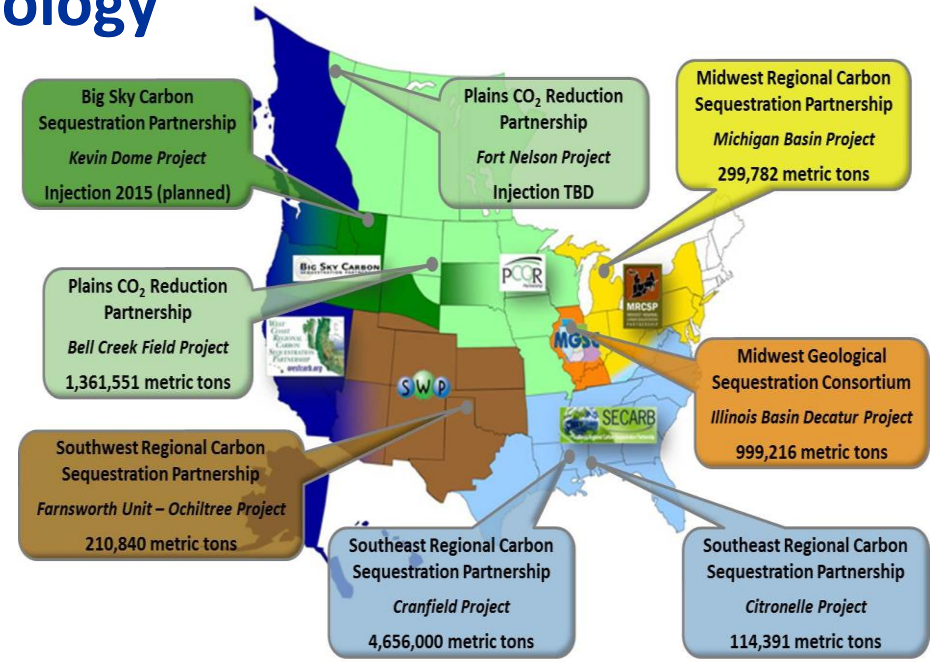
Current RD3:

- Advanced Combustion Systems
- Gasification Systems
- Advanced Turbines
- Solid Oxide Fuel Cells

Where the technology R&D needs to go:

- Demonstration
- Integration technologies - Sensors & Controls R&D , Materials Research , Simulation-Based Engineering R&D, Water Management Research

Carbon Storage Technology



Major Challenges:

- Storage Types (Onshore and Offshore)
- Subsurface Containment
- Risk Minimization

What we have Learned:

- >7,000,000 metric tons CO2 stored
- Regional storage strategies
- RSCSP: > 400 organizations, 43 states and 4 Canadian provinces.

Current RD3:

- Large-scale field validation testing of storage and monitoring technologies
- Understanding trapping mechanisms, plume tracking and stabilization, pressure management, well integrity, and identification and mitigation of release pathways
- Risk assessment through modeling and simulation of geomechanical processes

Where the technology R&D needs to go:

- Field tested processes, procedures and tools
- Advanced tools and modeling capabilities
- Assessment of offshore storage resources
- Subsurface engineering

Emerging Opportunities

Large-scale demonstrations

CCS Retrofits

Three-quarters of coal fired capacity in non-OECD countries is less than 20 years old, coal generation predicted to grow at 2.3%.

CCS on Natural Gas and Industrial Plants

Coal-based R&D effectively advanced the field of carbon capture for all fossil fuel applications such that technologies transfer to natural gas and industrial plants.

International Partnerships

CO_2 Capture Test Centers - sharing knowledge and expertise

Integrated Demonstrations - China and U.S. have agreed to deploy large-scale, integrated CO_2-EOR and CO_2 storage

Saline Storage - sustained, million tonne/year CO_2 saline injection projects in the US and elsewhere

Nuclear Power Technology

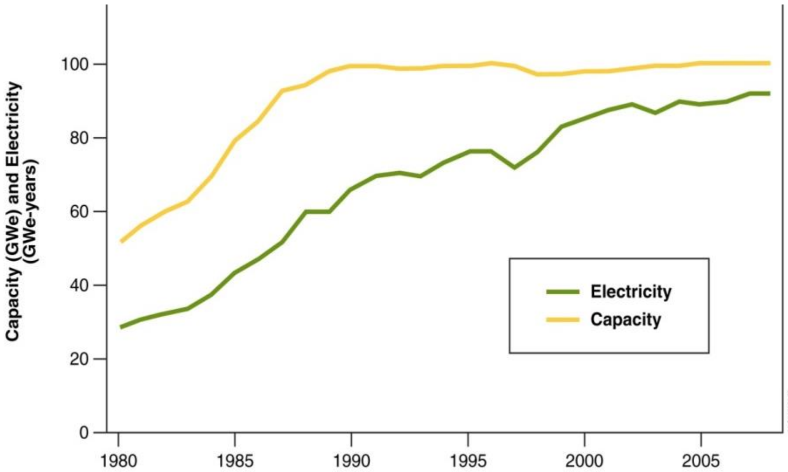
Nuclear Power Technology

- **Current Status**
  - 19% of US electricity; 60% of non-emitting generation
  - Five US reactors permanently closed in last three years; five reactors being built in Southeast
  - 439 reactors deployed globally; 69 under construction

	2009	2013
Reactors	104	100
Capacity (GW)	101.0	99.1
Generation (TWh)	799	789
Cap. Factor	90.3%	90.9%

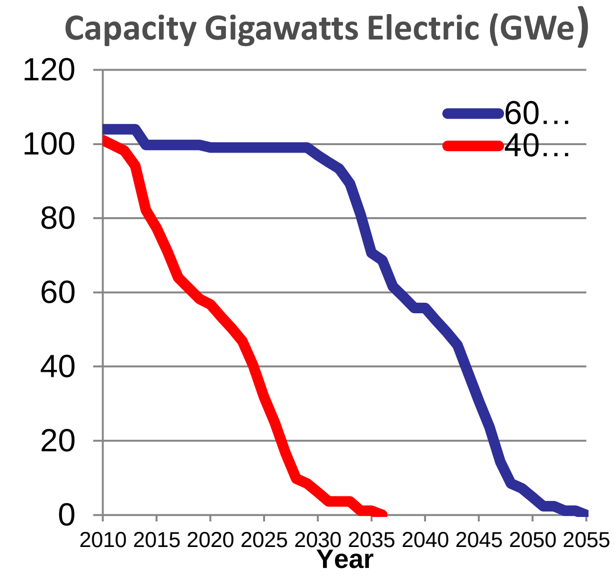
- **Nuclear to Meet Climate Challenge**
  - IEA World Energy Outlook projects nuclear capacity would need to more than double in 2DS scenario
  - Including replacing retiring units, implies new builds of over 30GW per year

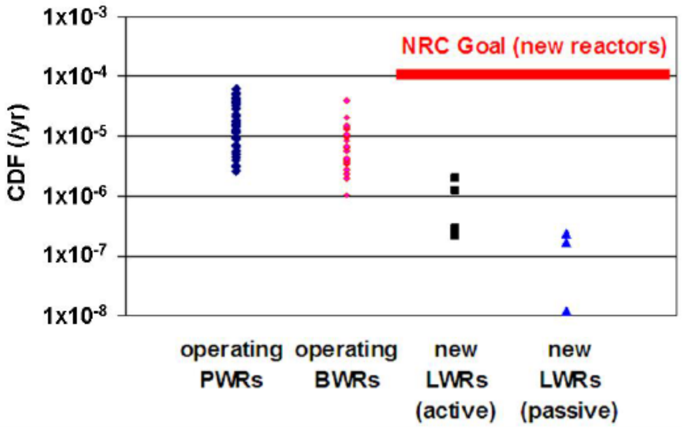
- **Nuclear Challenges for R&D to Address**
  - Continually improving safety
  - Reducing costs
  - Waste management
  - Nonproliferation



Light Water Reactor Technology

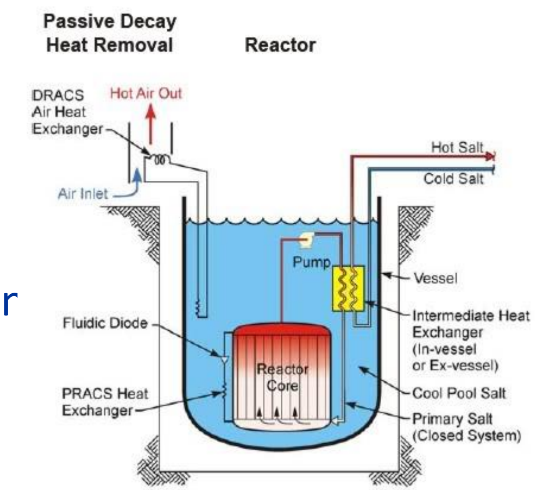
- **Major Challenges:**
  - Aging reactor fleet
  - Large new plants very capital intensive
  - Limited operational flexibility
- **Current Status:**
  - Dominant design approach – low-enriched uranium fuel with water moderator/coolant
  - 71 reactors licensed to operate 60 years in US
  - State-of-the-art Gen 3+ incorporate passive safety systems
- **Factors driving change in the technologies:**
  - Capacity uprates and license renewals
  - Drive towards small modular reactors (SMRs) with reduced cost and greater use of passive safety – significant investment by DOE and private sector
  - Post-Fukushima safety considerations
- **Where the technology R&D needs to go:**
  - Characterizing reactor material aging
  - Drive down costs of new construction
  - Advance manufacturing technologies
  - Analysis tools to characterize safety margins





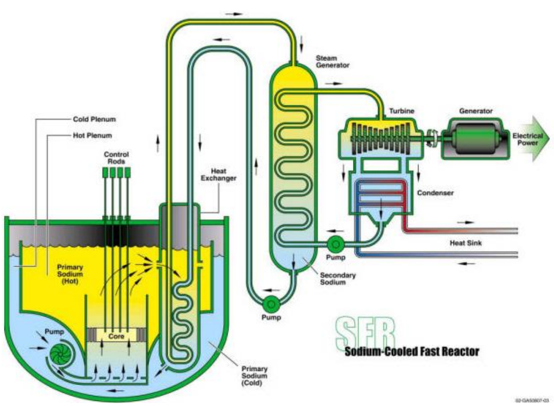
Advanced Reactor Technologies

- **Major Challenges:**
  - Increase operating temperatures (HTR)
  - Enable expanded fuel cycle options (Fast Reactors)
  - Improved structural materials
  - Approval for new fuel forms



- **Current Status:**
  - Prototypes and demonstrations built, operated, retired in U.S.; broader experience globally
  - HTR – focus on gas-cooled designs
  - Fast reactors – focus on sodium coolant and metal fuel

- **Factors driving change in the technologies:**
  - HTR – Interest in salt coolants with greater energy density that can reduce size of reactors
  - Fast reactors – Emphasis on waste minimization rather than fissile material production



- **Where the technology R&D needs to go:**
  - Drive down costs
  - Advanced materials/fuels for high-temperature, high-burnup
  - Modeling and simulation with validation experiments to demonstrate performance

Fuel Cycle Technologies

Major Challenges:

- Long time horizon for permanent disposal
- Need for extended storage of spent fuel
- Developing fuels that cope with severe conditions
- Ensuring uranium availability

Current Status:

- Administration strategy for consolidated interim storage of used fuel and development of geologic repository
- International interest in closed fuel cycle
- U.S. R&D investigating once-through and recycle systems

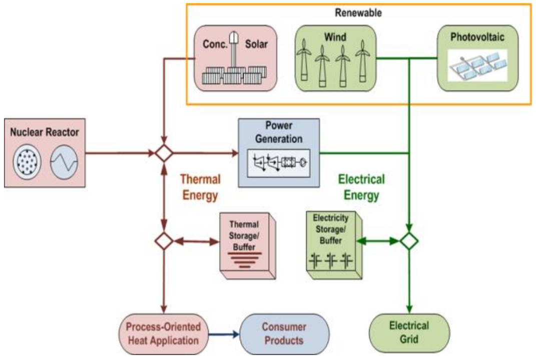
Factors driving change in the technologies:

- Higher burnup fuels for longer irradiation cycles
- Uncertainty of repository geology
- Emphasis on transuranic destruction not plutonium utilization; non-proliferation
- Fukushima event focused attention on improved fuel cladding

Where the technology R&D needs to go:

- Improved understanding of material degradation of high-burnup fuels
- Assessing alternate repository geologies and long-term interaction effects with waste forms
- Research and testing of actinide-bearing fuels
- Alternate sources of uranium

Hybrid Nuclear-Renewable Energy Systems



Major Challenges:

- Nuclear and intermittent renewable technologies avoid GHG emissions but do not offer the flexibility deal with fluctuating demand
- Continued need to reduce emissions from non-power sectors

Current Status:

- Combine nuclear and renewable technologies to form a system that can switch between power production and process heat applications in response to demand
- Concept development stage

Factors driving change in the technologies:

- Operational pressures on baseload plants in markets with sizable renewable deployment
- Limited ability to curtail output

Where the technology R&D needs to go:

- Dynamic modeling of system to assess feasibility and economics
- Demonstration of subsystem interfaces including instrumentation and control

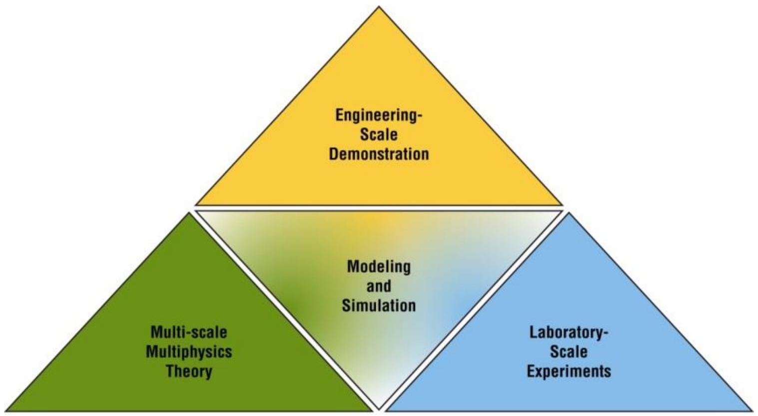
Nuclear R&D

Nuclear Testing and Demonstration

- Experimental nuclear facilities are expensive and not well-suited to private investment
- DOE has capabilities including hot cells and test reactors
- Difficult to deploy demonstrations in US
- International cooperation for access to limited capabilities – fast-spectrum testing
- Need for US to explore future testing needs

Modeling and Simulation

- Challenges in developing experimental and demonstration capabilities create opportunity to use high performance computing
- Must be combined with validation and verification to be useful
- Tools also must be useful to industry - CASL



CASL
A DOE Energy Innovation Hub

Biopower Technology

Biopower with CCUS

Major Challenges:

- R&D is needed to improve the state of biomass gasification and integration with carbon capture (BGCC) and utilization/sequestration (CCUS)
- The technical pathway to providing cost-competitive biopower gasification /combined cycle coupled to CCUS needs to be validated
- R&D on processing biomass feedstock (and refuse-derived sources) to achieve higher density, high heating value, better suitability for transport, and feedstock consistency and reliability needs to be applied to biomass gasifier injection

Current Status:

- Co-firing in conventional plants is now practiced in U.S. and Europe. DOE has supported co-firing combustion trails in the U.S.
- DOE has completed technical/economic assessments for co-firing and co-gasification applications in the U.S.
- World-wide demonstration of coal gasification and biomass gasification technology and gas cleanup is going forward
- CCUS demonstration at utility scales has begun and is planned to expand
- Currently BGCC coupled to CCUS has not been demonstrated

Factors driving change in the technologies:

- Utility-scale BGCC with CCUS will jointly improve power production efficiency and may offer a cost-competitive GHG reduction alternative
- BGCC is a dispatchable renewable power option with some flexibility to support grid

Where the technology R&D needs to go:

- Advancements for biopower gasification and CCUS are similar for coal
- Leverage commercial, and DOE-sponsored, coal-fired power gasification and gas cleanup technology development
- Leverage biofuels feedstock logistics R&D
- Leverage and complete DOE-sponsored biomass gasifier dry feedstock injection R&D

Stationary Fuel Cell Technology

Fuel Cells

- **Major Challenges:** High reliability and high electrical efficiency offset by current high capital costs, requiring the following:
  - Increase efficiency and durability
  - Reduce manufacturing cost
  - Reduce cost of biogas cleanup subsystem to reduce total CO_2 emissions

- **Current Status:**
  - Prototypes and demonstrations built, operated, retired in U.S.; early commercial units deployed by private sector and government agencies, including DOD. U.S. is a net exporter of fuel cells.

- **Factors driving change in the technologies:**
  - Increasing need for integration with electric grid
  - Expansion in CHP applications to support buildings
  - Synergy with distributed generation for plug-in vehicles

- **Where the technology R&D needs to go:**
  - Drive down costs
  - Focus on gas cleanup for increased fuel flexibility, advanced materials, hydrogen production, and manufacturing technology
  - Modeling and simulation with technology validation to demonstrate performance

- **Programmatic risk**
  - Lack of incentives aimed at commercial and institutional buildings to reduce carbon footprint

Fuel *Cells* Goals and Timelines

2020

- Natural Gas FCs competitive with conventional CHP (reciprocating engines)
- Target multi-family, commercial & institutional buildings

2025

- Capital cost of biogas cleanup subsystem reduced from $1,900/kW (current) to less than $600/kW, enabling penetration in regions with higher electricity prices

2030

- Costs of fuel cells, electrolyzers and hydrogen storage are low enough to enable significant grid integration support

<u>RD&D GOALS</u>

LCOE < 10 cents/kWh for natural gas FC systems by 2020; < 8 cents/kWh by 2027

LCOE < 10.5 cents/kWh for biogas FC systems by 2020; < 8.5 cents/kWh by 2027

Geothermal Power Technology

Geothermal Energy

- **Major Challenges:**
  - Cracking the code for subsurface engineering necessary for Enhanced Geothermal Systems (EGS)
  - High cost of drilling creates high up-front cost when risk is still high leading to financing challenges.

- **Current Status:**
  Demonstration projects have shown success
    - Reserve expansion (Geysers)
    - Electrons on the grid (Desert Peak)

  National focus on EGS is driving advances in technologies
    - Broad engagement from research and industrial communities

- **Factors driving change in the technologies:**
  - Need to reduce drilling costs and/or increase success rate of exploratory wells
  - Need to reduce risk in early stages of development

- **Where the technology R&D needs to go:**
  - Resource characterization
  - Purposeful control of subsurface fracturing and flow
  - Improved and lower $/MW subsurface access technologies
  - Additive value through mineral recovery and hybrid systems

- **Programmatic risk**
  - Limited geothermal resource potential without the large potential from Enhanced Geothermal Systems

Geothermal Analysis and Goals

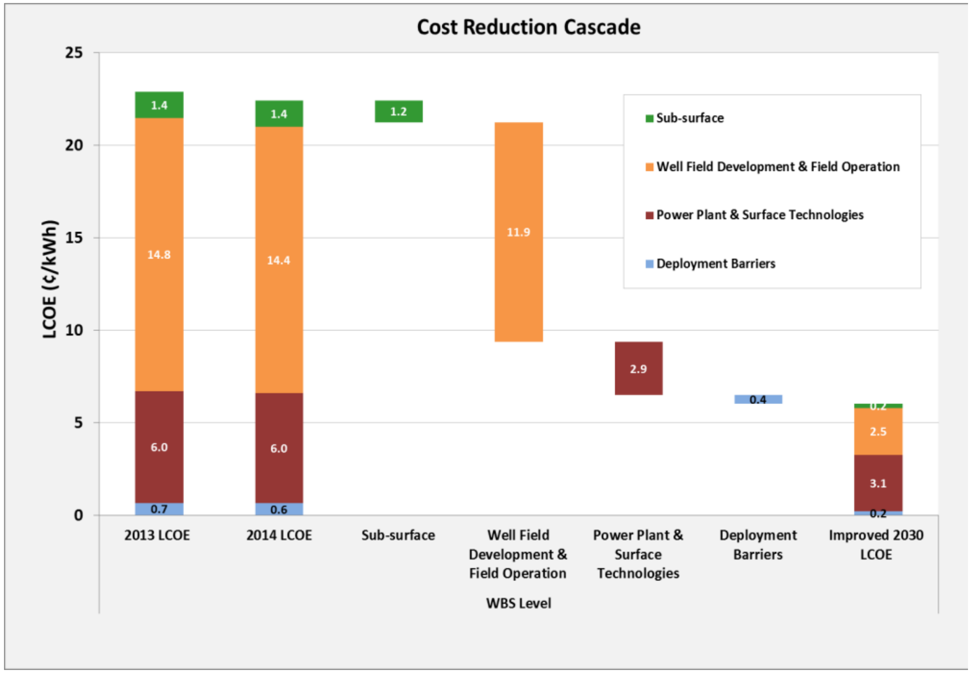
Greatest improvement potential is in well-field development and field operation.

- Driven by combination of
  - decline in drilling costs due to drilling cost reductions, and
  - decrease in number of wells required due to increase flow rate per well (better reservoir performance)

- Increase in drilling success rate, especially in confirmation phase, also has big impact

Decrease in power plant costs plays big role

Sub-surface cost reductions due to decrease in cost of stimulation



Waterfall chart is for EGS, was created from updated GETEM model. Model input derived from conversations with industry on current technology status and potential for improvement.

Solar Power Technology

Solar Power Technology

- **Major Challenges:**
  - PV: Further increases in efficiency as well as reliability and life-cycle sustainability in order to realize further reductions in the cost of PV electricity.
  - CSP: Higher temperature operation at higher efficiency, longer lifetime, and lower cost.
  - Systems Integration: Achieve high penetration at the distribution level and on the transmission grid in a safe, reliable and cost-effective manner.
  - Non-hardware Soft Cost: Develop innovative and scalable solutions in order to streamline processes and enable sustainable market conditions.
- **Current Status:**
  - Rapidly growing market: In 2013 solar energy reached more than 1% (13 GW) of the nation's electricity generation capacity. This was a vast increase from 2008, when solar generation was less that 0.1% of the nation's generation capacity.
  - Good and growing jobs: There are currently more than 142,000 solar workers in the U.S.
- **Factors driving change in the technologies:**
  - Significant investments in technology innovation, manufacturing scale-up, and market development have been driving cost down rapidly.
- **Where the technology R&D needs to go:**
  - PV: Innovation that will enable low cost manufacturing in the U.S.
  - CSP: Lower capital cost for large-scale deployment.
  - Systems Integration: Integration with storage solutions and energy management systems.
  - Non-hardware Soft Cost: Solutions to streamline processes and drive down costs of permitting, interconnection, finance, and customer acquisition.

Solar Power Goals and Timelines

Solar Power Strategic Focus Areas

- Photovoltaic Technology Development
- Concentrating Solar Power Technology Development
- Systems Integration
- Technology to Market
- Soft Costs of Solar Deployment

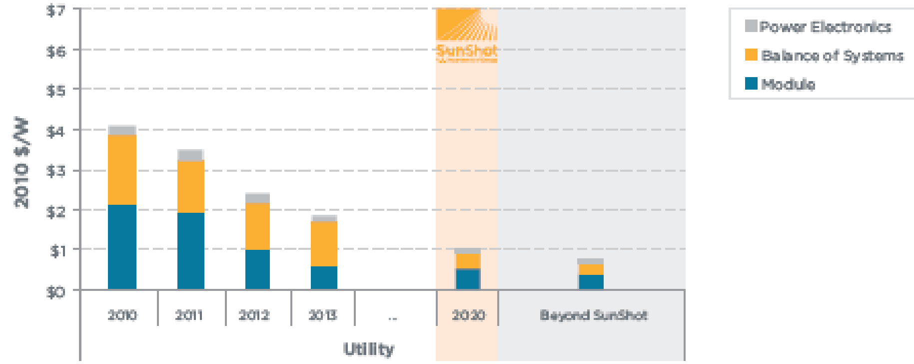


Figure 1. Evolution of the component costs of a PV system over time, also showing the SunShot targets and future reductions beyond SunShot. The PV subprogram work impacts the module and balance of systems costs.

Solar Power Opportunities

Solar has a vast resource base:

- PV panels on 0.6% of the nation's total land area could supply enough electricity to power the entire US.
- PV can also be integrated into the built environment on building rooftops and facades, parking lots, abandoned or degraded lands close to population centers, etc.
- CSP in seven southwest states could provide four times the current US annual electricity demand.

Targeted Outcomes:

- **Reduce the unsubsidized cost of solar power to $0.06/kWh at utility scale (PV and CSP), $0.08/kWh at commercial scale, and $0.09/kWh at residential scale, to make solar energy cost-competitive with conventional electricity generating technologies by 2020.**
- **This measure was set by targeting the solar technology installed system prices by 2020 to reach $1/watt (W) for utility-scale PV systems, $1.25/W for commercial rooftop PV, and $1.50/W for residential rooftop PV. For CSP the 2020 target is $3.60/$W_{AC}$ (including thermal energy storage).**
- **Based on analysis performed for the SunShot Vision Study it was determined that achieving these price targets would make PV and CSP systems competitive with wholesale and retail rates throughout the U.S. without any federal or state subsidies.**

Hydropower Technology

Hydropower Technology

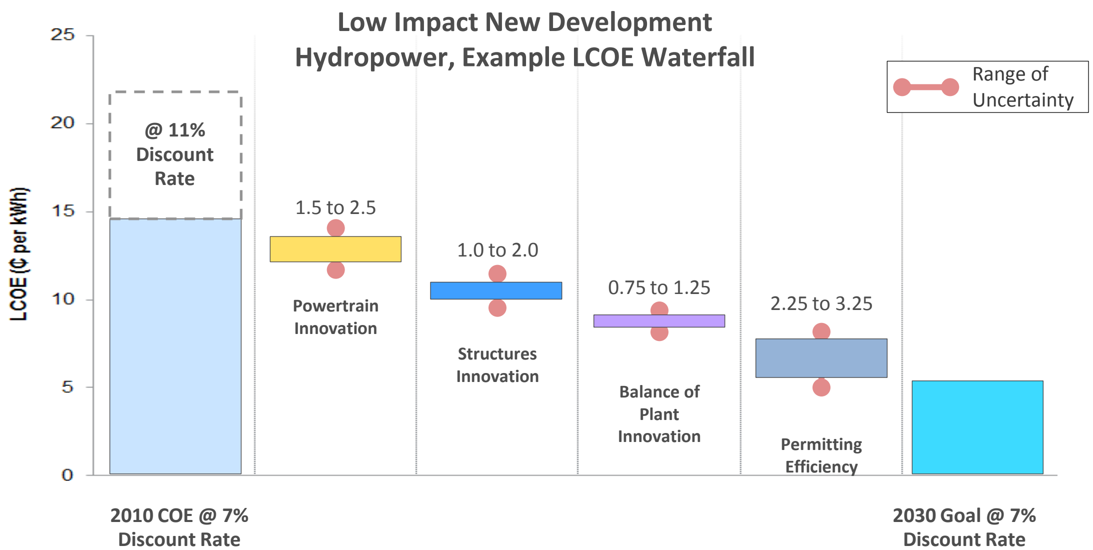
- **Major Challenges:**
  - Degradation of existing hydropower facilities
  - Reduction of civil and environmental impact mitigation footprint and costs
  - Downscaling pumped storage technologies for increased flexibility
- **Current Status:**
  - Mature technology in need of revitalization, 78 GW installed at 2013 year-end, 20 GW of pumped-storage. Hydropower provides approximately 50 percent of all U.S. renewable electricity generation and provided **7 percent** (213 terawatt hours in 2013) of annual total U.S. electricity consumption
- **Factors driving change in the technologies:**
  - Additional deployment accessing newly-identified resources requires improved environmental performance, reduced footprint, reduced cost, and improved market structures valuing ancillary and flexibility services
- **Where the technology R&D needs to go:**
  - Materials and turbine designs, modularization, technology-based footprint reduction for reduced environmental impact
  - Supporting Research needed in hydrologic, ecological, environmental, hydrodynamic, hydro-mechanical, operations, and power system data collection, monitoring, modeling, and analysis

Hydropower Goals and Timelines

Hydropower Strategic Focus Areas

Each of these addresses the three hydropower techno-resource areas of Existing Water Infrastructure, Undeveloped Streams, and Pumped-Storage

- **Technology Development**
- **Sustainability**
- **Quantified Value**
- **Integrated Demonstration & Deployment**



Hydropower Opportunities

- Roughly 65 GW (340 TWh/year) of potential in the ***undeveloped streams*** resource class
- Roughly 12 GW (31 TWh/year) of hydropower resource potential can be added from development of ***existing non-powered dams***
- At least 5 GW (13 TWh/year) of additional capacity can be obtained by restoring and upgrading ***existing hydropower facilities***

Targeted Outcomes:

- **Reduce the cost of new hydropower to $0.12/kWh by 2020 to create a large and enduring economic benefit to the U.S. This includes up to 25 GW of additional hydropower capacity through improvements at existing facilities.**
- **By 2020, to have demonstrated the economic feasibility of modular pumped storage hydropower (m-PSH) at the municipal/industrial/commercial scale of 1-20 MW.**

**all costs at a 7% discount rate*

Marine and Hydrokinetic Power Technology

Marine and Hydrokinetic Power Technology

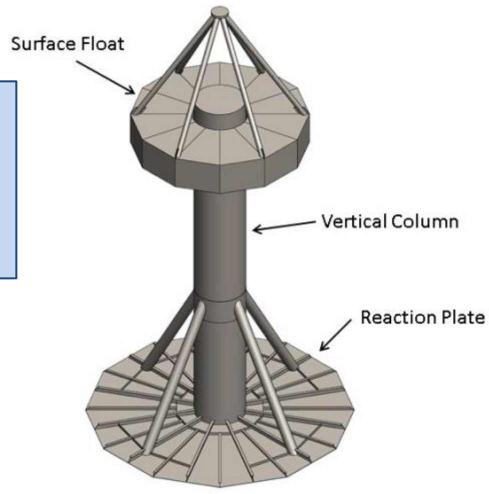
- **Major Challenges:**
  - Lack of a multi-berth, full-scale grid-connected open water test facility
  - Lack of scientific information and high monitoring costs can drive environmental and regulatory expenses to 30-50% of total early-stage MHK project cost
- **Current Status:**
  - Immature technology
  - Wide variety of designs and architectures
- **Factors driving change in the technologies:**
  - Need to improve and validate performance, demonstrate potential for reliability and survivability, and cost-reduction potential
- **Where the technology R&D needs to go:**
  - Next-generation component technology R&D designed specifically for the challenges of the marine environment. These technologies will drive the costs down for multiple energy conversion system solutions, including advanced controls to tune devices to extract the maximum energy from each sea state, compact high-torque low-speed generator technologies, and corrosion and biofouling resistant materials and coatings
  - Development of open source, fully validated MHK modeling and simulation codes
  - Collection of technology performance and cost data through device demonstrations

Marine and Hydrokinetic Power Goals and Timelines

Marine and Hydrokinetic (MHK) Power Strategic Focus Areas

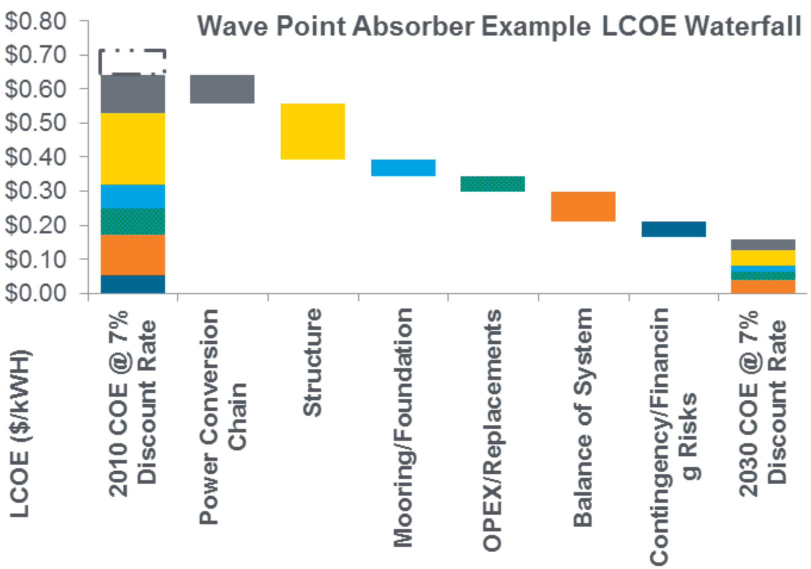
- Technology Advancement and Demonstration
- Testing Infrastructure and Instrumentation
- Resource Characterization
- Market Acceleration and Deployment

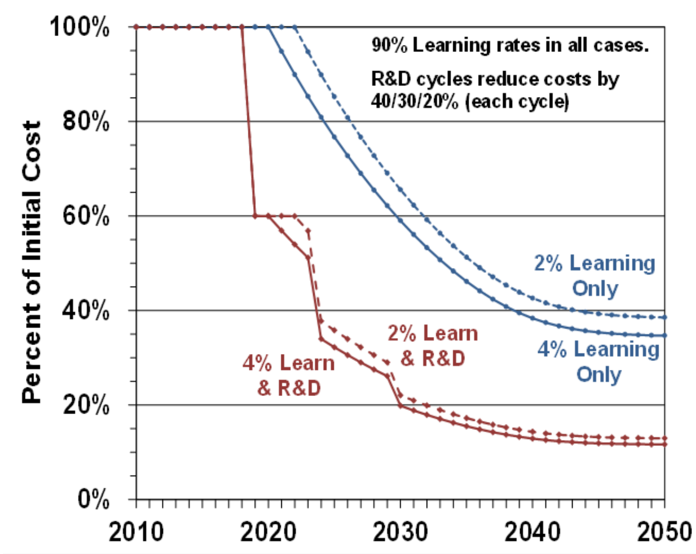
Targeted Outcome: Reduce MHK system cost to $0.35/kWh for wave; $0.21/kWh for tidal; and $0.19/ kWh for current by 2020. **all costs at a 7% discount rate*



MHK Opportunities

- The technically extractable potential U.S. MHK resource base includes 250 TWh/year of tidal energy, 1170 TWh/year of wave energy, and 283 TWh/year of combined ocean and river current energy located throughout diverse regions of the continental U.S., Hawaii, and Alaska.





Wind Power Technology

Wind Power Technology

Major Challenges:

- Lack of market valuation for carbon reduction leads to need for long-term policy stability
- Need for better understanding of fundamental atmospheric physics
- Lack of transmission capacity to high quality wind resource locations

Current Status:

- Commercial technology, 61 GW installed at 2013 year-end. Wind power provides approximately 35 percent of all U.S. renewable electricity generation and provided **4.3 percent** (168 terawatt hours in 2013) of annual total U.S. electricity consumption
- Wind power accounted for 42% of all 2012 U.S. power capacity additions, the highest of any resource
- Over 50,000 U.S. jobs in installation, manufacturing and operations

Factors driving change in the technologies:

- Must achieve unsubsidized competition with other power technologies in DOE's portfolio and reduce market barriers inhibiting deployment

Where the technology R&D needs to go:

- Access to high performance computing (HPC) capabilities and development of high-fidelity physics-based atmospheric and complex flow models to run on them is critical enabling research required to optimize wind power plant system output while lowering costs and increasing reliability
- Effective grid integration, including high resolution short term resource forecasting

Wind Power Goals and Timelines

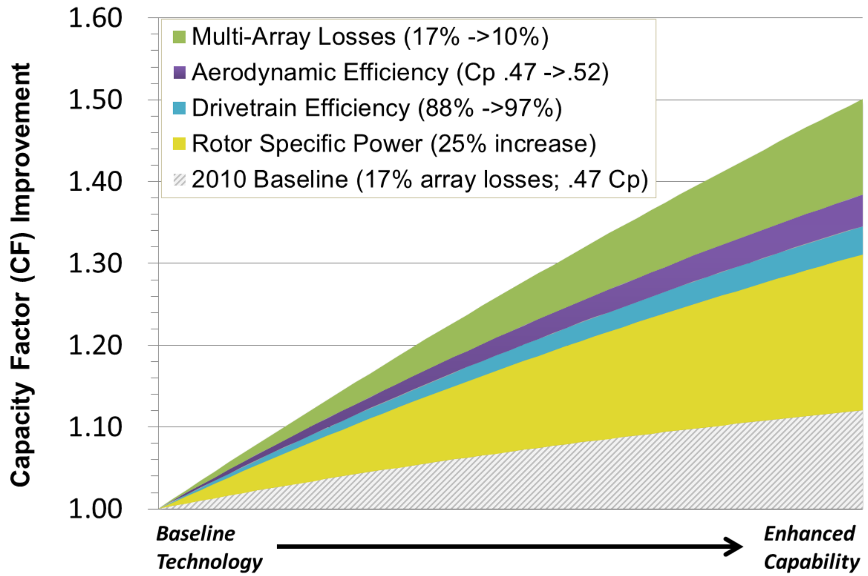
Wind Power Strategic Focus Areas

- Wind Plant Optimization
- Accelerating Technology Transfer
- Market Acceleration and Deployment
- Advanced Grid Integration

Wind Power Opportunities

Significant sustainable wind resource potential, greater than 10 times current total U.S. electricity consumption, supports high wind penetration scenarios

- Total Addressable U.S. Wind Energy Potential ≈ 140 Quads (90 Quad land-based, 50 Quad offshore)
- Total U.S. Energy Consumption ≈ 95 Quads
- Total U.S. Electrical Energy End Use ≈ 13 Quads
- Current U.S. Wind Contribution ≈ 0.57 Quads (2013)



Capacity factor has a direct correlation to Annual Energy Capture (AEP).

Targeted Outcomes:

- **Reduce the unsubsidized market LCOE for utility-scale land wind energy systems from a reference wind cost of $.080/kWh in 2010 to $.057/kWh by 2020 and $.042/kWh by 2030***
- **Reduce the unsubsidized market LCOE for offshore fixed-bottom wind energy systems from a reference of $.210/kWh in 2010 to $.167/kWh by 2020 and $.136/kWh by 2030***

**all costs at a 7% discount rate*

Systems solutions for increasing wind plant annual energy production (AEP)

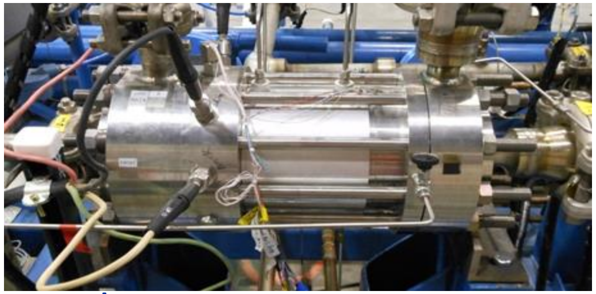
This graph compares relative technical opportunities for innovation to increase wind plant capacity factor—thereby increasing energy production—if unconstrained by cost and systems effects. As shown, greatest opportunities for significant improvements are increased rotor specific power and reduced array losses. Cost and system effects analysis will help identify the best economic opportunities for enhanced capability.

Cross-cutting Options

Cross-cut technologies
Public-Private roles
International Opportunities

Supercritical Carbon Dioxide (sCO_2) Technology

- **Major Challenges:**
  - Confirm viability of existing components and suitability of materials
  - Accommodating a wide range of operating parameters and applications
  - Integrating and scaling up existing technologies into a new application
- **Current Status:**
  - Functioning laboratory-scale sCO2 loops (250 KWe)
  - Dynamic modeling, compact heat exchangers and turbo machinery demonstration R&D is underway within
  - Currently no full scale applications
- **Factors driving change in the technologies:**
  - Need for greenhouse gas reduction
  - Desire to reduced water consumption



- **Where the technology R&D needs to go:**
  - Continue technology development activities to support the design, development, construction, and plans for testing of key components
  - Higher temperature and increased efficiency
  - Material qualification and availability
  - Further development of modeling and simulation codes
  - Reduce technical and financial risk through multiple demonstrations

Sub-Surface Technology

Major Challenges:

- Discovering, Characterizing, and Predicting
- Accessing - safe, cost-effective reservoir integrity
- Engineering - creating/constructing desired subsurface conditions
- Sustaining - maintaining subsurface conditions
- Monitoring

Current Status:

Integrated approach through the DOE SubTER team:

- identify and facilitate crosscutting subsurface R&D and policy priorities.
- discovering, characterizing, predicting and monitoring the subsurface;
- accessing wells and their integrity;
- engineering and permeability control;
- sustained production while sustaining the environment.

Where the technology R&D needs to go:

- permeability manipulation
- subsurface stress and induced seismicity
- Intelligent wellbore
- new subsurface signals

Water-Energy Nexus

Major Challenges:

- Thermoelectric power generation accounted for 45 percent, or 161,000 Mgal/d, of the water withdrawals in the United States in 2010
- Reduce freshwater needs
- Capital costs, larger physical footprints, and energy penalties

Current Status:

- Water withdrawals for thermoelectric-power declined 20 percent from 2005 to 2010, reflecting:
    1. a shift away from once-through cooling technologies toward lower water withdrawing technologies such as recirculating cooling and
    2. a change in the estimating method for water budget models for some power plants.

Where the technology R&D needs to go:

- Advanced Cooling – air-cooling, freshwater sources,
- Hybrid cooling,
- Water treatment technologies
- Utilization of waste heat

Electric Power System Challenges

Electric power generation technologies are maturing to a new level of integration and interdependencies that require a system approach and a global view. Broad questions include:

- How will industry develop to meet growing electrification and carbon reduction goals?
- How do domestic choices on clean energy technologies interface with global energy choices?
- How much and how quickly can technologies be scaled up?
- Pacing of technology readiness for deployment, i.e. supply constraints?
- How much variable renewable generation (utility scale and distributed generation) can the grid support with agile baseload units, and at what cost?
- How does public acceptance affect the technology portfolio? Can technology development help to reduce deployment risks such as regulatory uncertainty and siting limitations?

Technology Opportunities

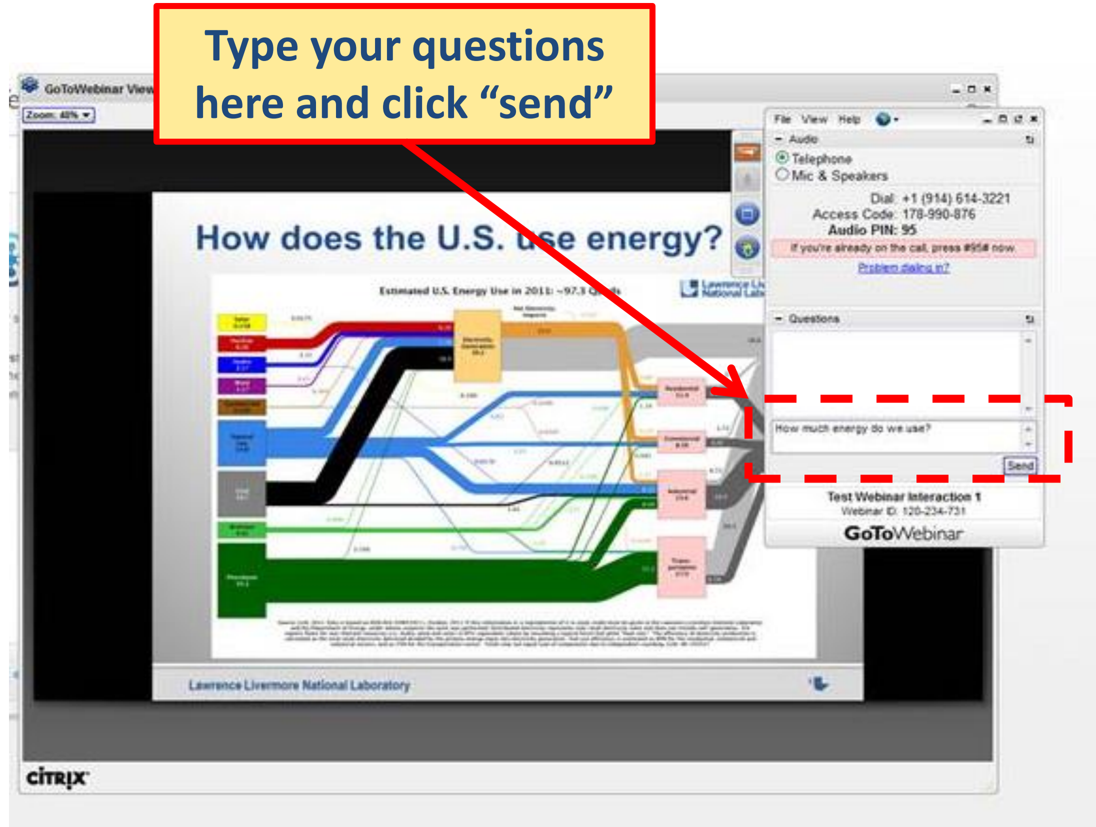
Technology	Where the technology R&D needs to go:
Carbon Capture and Storage	• 2nd generation pilot demonstrations • Retrofit plants w CCS • Application to Natural Gas and Industrial plants • International Partnerships
Nuclear Power	• Light water reactors: Characterize reactor material aging, Drive down costs of new construction, Analysis tools to characterize safety margins • High Temp and Fast Reactors: Advanced materials/fuels, modeling and simulation with validation experiments to demonstrate performance • Fuel Cycle Technology: Improved understanding of material degradation under extended storage of high-burnup fuels, Assessing alternate repository geologies and long-term interaction effects with waste forms, Research and testing of actinide-bearing fuels • Hybrid systems: Dynamic modeling and demonstration of subsystem interfaces
Solar (PV & CSP)	• Drive down costs • Focus on gas cleanup for increased fuel flexibility, advanced materials, hydrogen production, and manufacturing technology • Modeling and simulation with technology validation to demonstrate performance
Wind Power	• Access to high performance computing (HPC) capabilities and development of high-fidelity physics-based atmospheric and complex flow models to run on them • Effective grid integration, including high resolution short term resource forecasting
Hydropower	• Materials and turbine designs, modularization, technology-based footprint reduction • Supporting research needed in hydrologic, ecological, environmental, hydrodynamic, hydro-mechanical, operations, and power system data collection, monitoring, modeling, and analysis

Technology Opportunities

Technology	Where the technology R&D needs to go:
Marine Hydrokinetic Power	• Next-generation component technology R&D designed specifically for the challenges of the marine environment - including advanced controls to tune devices to optimize energy extraction, compact high-torque low-speed generator technologies, and corrosion and biofouling resistant materials and coatings • Development of open source, fully validated MHK modeling and simulation codes • Collection of technology performance and cost data through device demonstrations
Geothermal Energy	• Resource characterization • Purposeful control of subsurface fracturing and flow • Improved and lower $/Mw subsurface access technologies • Additive value through mineral recovery and hybrid systems
Fuel Cells	• Drive down costs • Focus on gas cleanup for increased fuel flexibility, advanced materials, hydrogen production, and manufacturing technology • Modeling and simulation with technology validation to demonstrate performance
Biopower	• Utility-scale BGCC with CCUS will jointly improve power production efficiency and may offer a cost-competitive GHG reduction alternative • BGCC is a dispatchable renewable power option • Use and integration of bio-gas processes
Supercritical CO2	• Dynamic modeling of system to assess feasibility and economics • Demonstration of subsystem interfaces including instrumentation and control
Water-Energy System	• Alternative cooling and heating fluids for fluid use in heat pipes and liquid metal coolants • Enhanced cooling systems coupled with non-traditional power generation cycles • Enhanced condensation and cooling in electricity power generating systems including hybrid or mechanical assist systems • Waste heat recovery technologies (e.g. solid state Thermo-electrics)

Public Input

- You are encouraged to submit questions using GoToWebinar’s “Questions” functionality. The moderators will respond, via audio broadcast, to as many appropriate questions as time allows.



- If you have questions or comments that cannot be addressed during the webinar, email them to DOE-QTR2015@hq.doe.gov