U.S. Department of Energy
Office of Fossil Energy

Regis K. Conrad

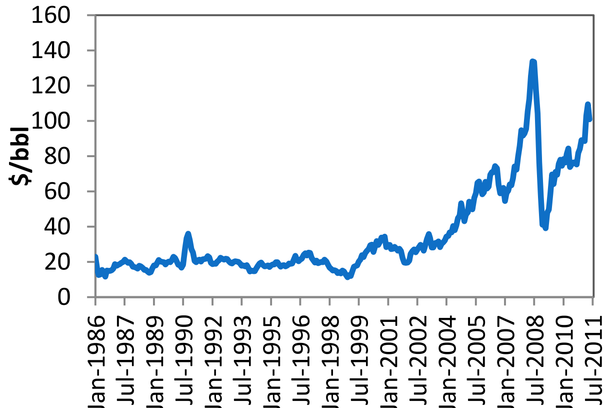
Director, Division of Cross-cutting Research

6 June 2012

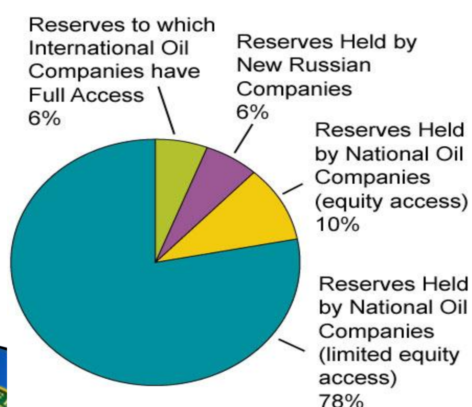
U.S. Energy Challenges

Energy Security

Monthly Spot Price OK WTI

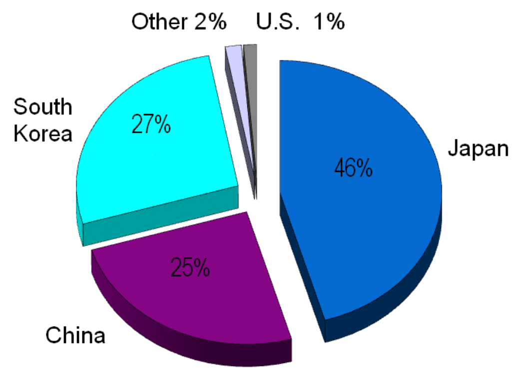


Share of Reserves Held by NOC/IOC

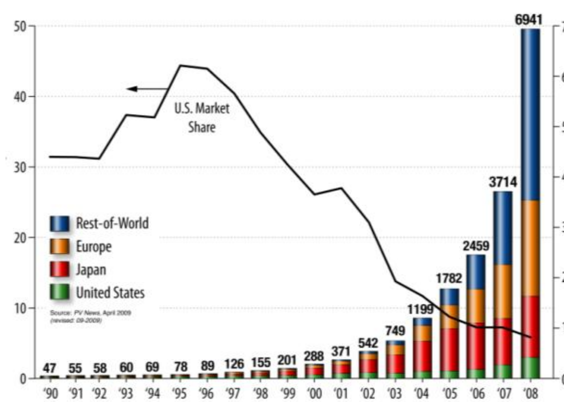


Competitiveness

Global Lithium-ion Battery Manufacturing (2009)

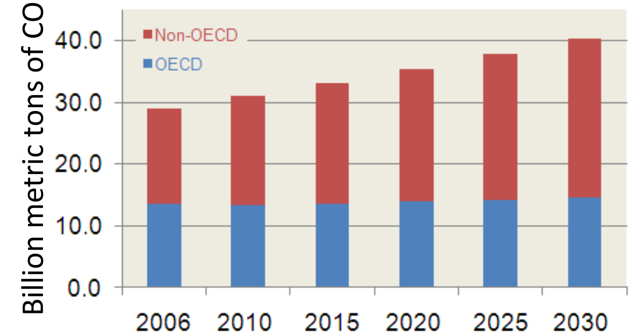


Worldwide Shipments of Solar Photovoltaics (MW)

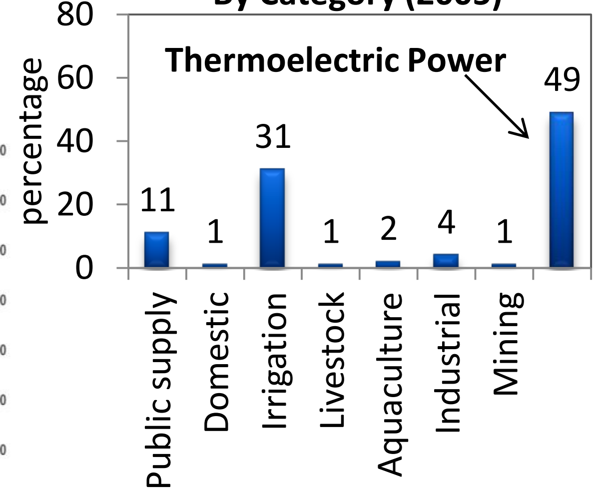


Environmental Impacts

CO_2 Emissions in OECD vs non-OECD Countries



Water Withdrawals in % By Category (2005)



Fossil Energy: Helping Achieve DOE's Mission

Transform Our Energy Systems

- Cost-competitive carbon capture, utilization, and storage technology
- Advanced modeling and simulation to reduce upfront cost, risk of CCUS
- Materials for USC Power Plants
- Integration of Sensors and Controls
- Increased efficiency for cleaner use of coal.
- Advanced Plant Optimization through Sensors and Controls
- Safe and sustainable development of unconventional oil and gas resources
- International partnerships for clean energy deployment

Science & Engineering Enterprise

- Under graduate, graduate and post-graduate research and internship support

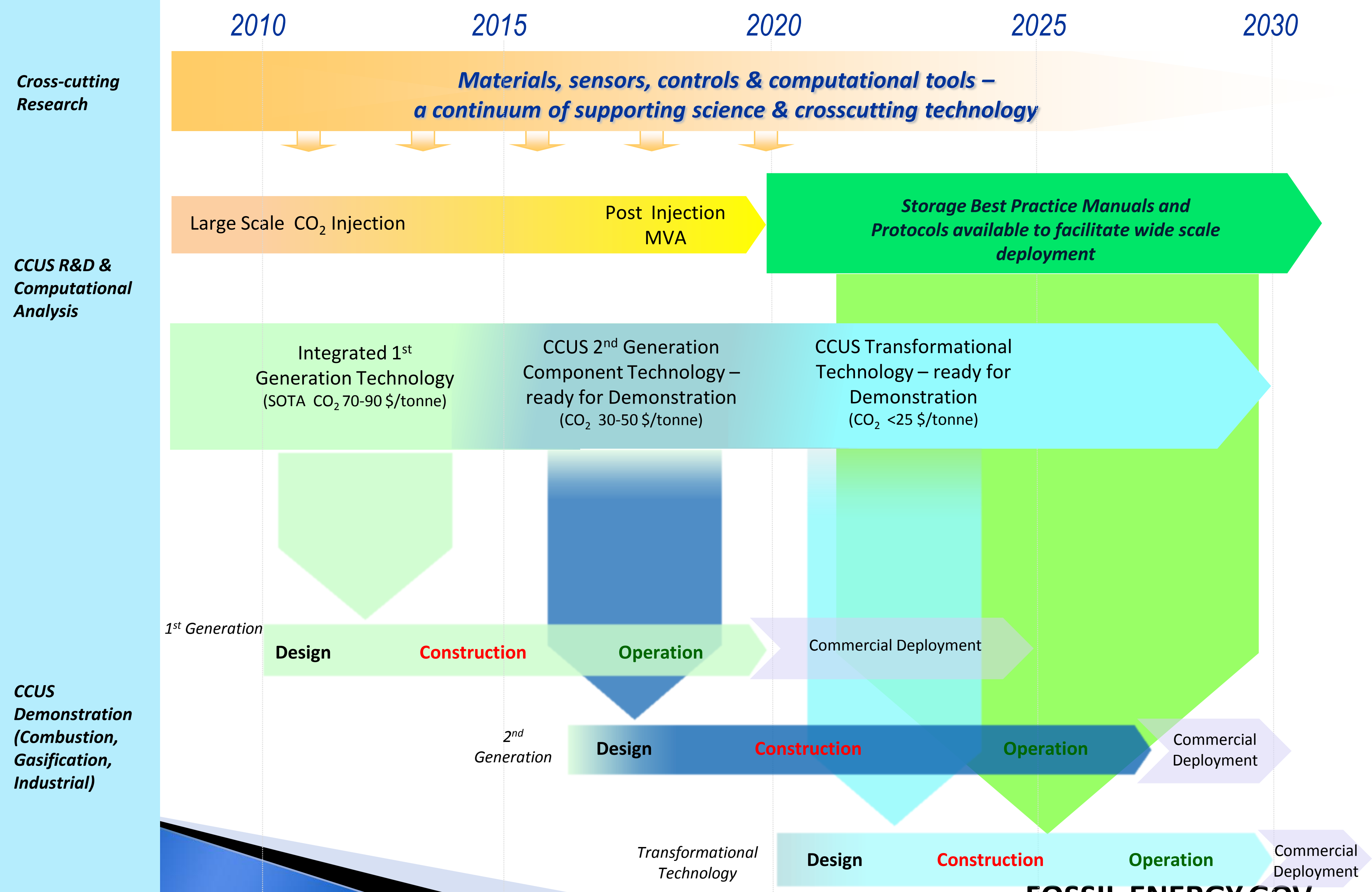
Secure Our Nation

- Technology innovation allowing fossil fuels to continue to be part of a diversified, low-carbon energy portfolio
- Strategic Petroleum Reserve and Northeast Home Heating Oil Reserve at full readiness

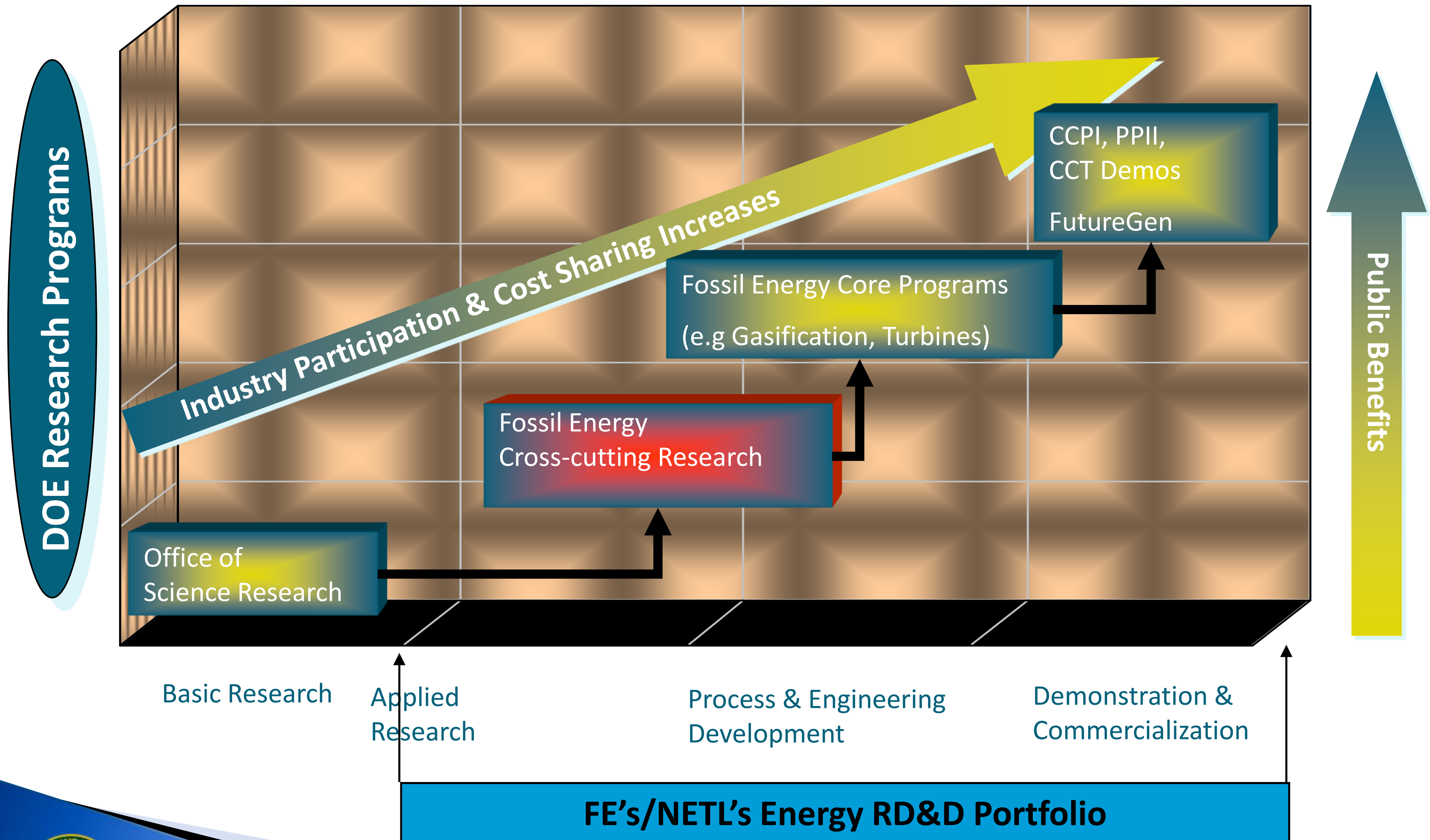
Management & Operational Excellence

- FE-wide business review assessment for mission success

Integrated Coal Program Technology Roadmap



Fossil Energy Program Outline

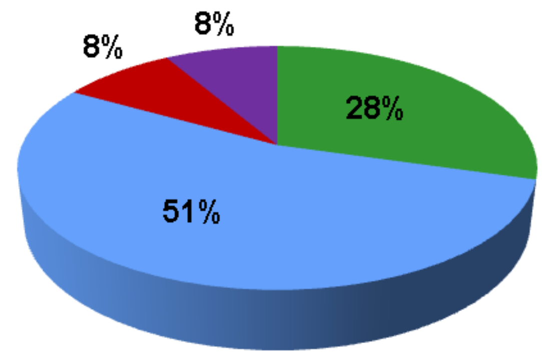


Crosscutting Research Program

Key Activity / Component	FY11 Actual Budget	FY12 Budget	FY13 President Budget
Plant Optimization Technologies	8,000	13,663	7,000
Computational System Dynamics	12,758	11,800	7,800
Computational Energy Science	12,235	13,371	9,400
System Analysis Product Integration	0	4,000	0
University Training & Research	2,395	3,000	2,400
Historically Black Colleges & Universities	848	1,000	850
Crosscutting Research TOTAL	**36,236**	**46,834**	**27,450**
Advanced Materials (ACS)	**9,082**	**5,000**	**0**

Dollars $K

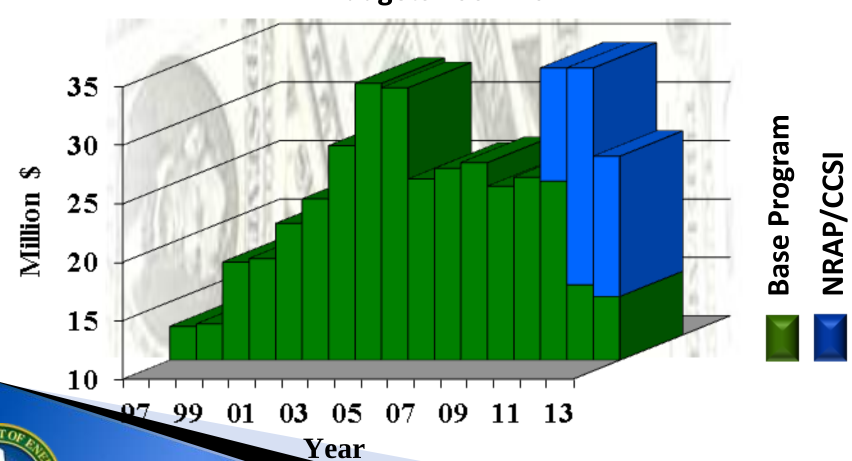
FY12 Budget Distribution among Crosscutting Research Program Elements



NETL Managed = $46,834

- Plant Optimization Technologies ($13,663)
- Coal Utilization Sciences ($25,171)
- System Analysis Product Integration ($4000)
- Historically Black Colleges and Universities, University Training and Research ($4,000)

Crosscutting Research Program Budgets 1997-2012

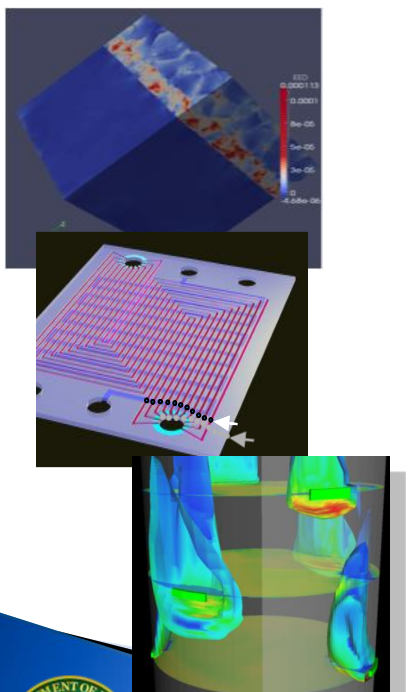


Crosscutting Research Program

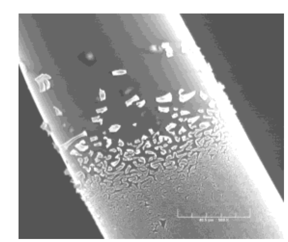
- Crosscutting science, tools, and technology development program
- Has a 15-25 year horizon for technology that supports breakthrough concepts, addresses gaps, and has commercial application
- Innovation through fundamental and applied developments that benefit Coal-based Fossil Energy Systems

Bridge the gap between fundamental & applied technology

Reflective of Program & Industry needs and drives new technology



- **Advanced Materials**
  - Ultrasupercritical Boilers & Turbines
  - High-strength, oxidation & corrosion resistant metallic & intermetallic alloys
  - High Performance Materials
- **Sensors and Controls**
  - High Temperature Material & Sensor Designs
  - Sensors Networks and Advanced Control
- **Modeling and Simulations**
  - High fidelity models of potential advanced power systems
  - Advanced power systems using mathematical computational simulations
  - Carbon Capture Simulation Initiative
  - National Risk Assessment Partnership
- **University Training and Research (UTR)**
  - Historically Black Colleges & Universities (HBCU)
  - University Coal Research
- **Mercury and Water Control**



Point of Reference

- **The power generation industry is at a critical juncture**
  - Demand, resources, workforce, reliability, regulation, grid integrity, transmission, etc.
- **Competing demands for reliable, low-cost energy and climate change mitigation appear incongruent**
- **Uncertainty of regulatory outcomes and rising costs impact industry's willingness to commit capital investment, endangering near-term production capacity**
- **The power industry must foster new processes that address conflicting energy objectives simultaneously**
- **FE's mission is to increase efficiency and mitigate CO_2 emissions in current plants and to develop novel carbon capture ready power generation processes for the future**

Motivation for Developing New Sensors and Control Technology

- Low cost, high benefit technology
- Existing technology is inadequate
- Boosts efficiency of existing facilities and significantly contributes to high reliability
- Supports all other power generation technologies and related infrastructures
- Makes operation of future ultra clean energy plants possible
- Enables new paradigms in plant and asset management beyond traditional process control

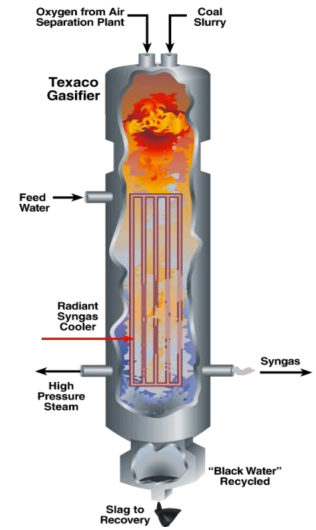
Harsh Environments

Solid Oxide Fuel Cells

- Utilizes Hydrogen from gaseous fuels and Oxygen from air
- 650 – 1000 °C temperature
- Atmospheric pressure

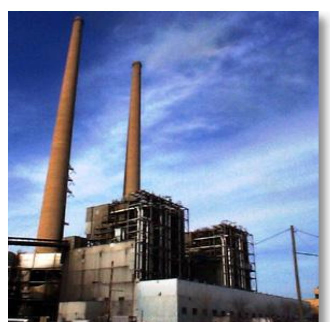
Advanced Combustion Turbines

- Gaseous Fuel (Natural Gas to High Hydrogen Fuels)
- Up to 1300 °C combustion temperatures
- Pressure ratios of 30:1



UltraSupercritical Boilers

- Development of ferritic, austenitic, and nickel-based alloy materials for USC boiler conditions
- Up to 760 C temperature
- Up to 5000 PSI pressure

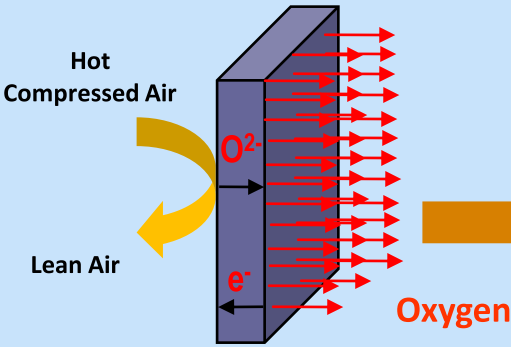


Gasifiers

- Up to 1600 C, and 1000 PSI (slagging gasifiers)
- Erosive, corrosive, highly reducing environment
- Physical shifting of refractory brick, vibration, shifting "hot zones"

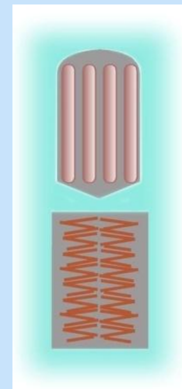
Key Gasification R&D Areas

Oxygen Membrane



Reduces Capital Cost by 25% and 5.0% reduction in COE

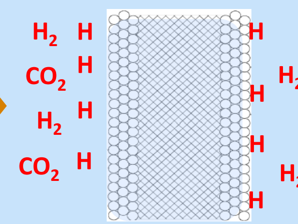
Fuel Gas



Warm Gas Cleaning

- Efficiency increases by 2.9 %pt
- COE decreases by 12.0%

H_2/CO_2 Membrane



H_2 Rich Stream

CO_2

Low-rank Coal*
Alternative Feedstocks*

- Energy security
- Carbon footprint reduction

Water-Gas Shift*

Process improvement and intensification

Improve RAM*

- Refractory durability
- Feed system reliability
- Heat removal/integration
- **Temperature measurement & control**
- Dynamic simulator
- CFD gasifier modeling
- Slag model development

* Advanced Gasification

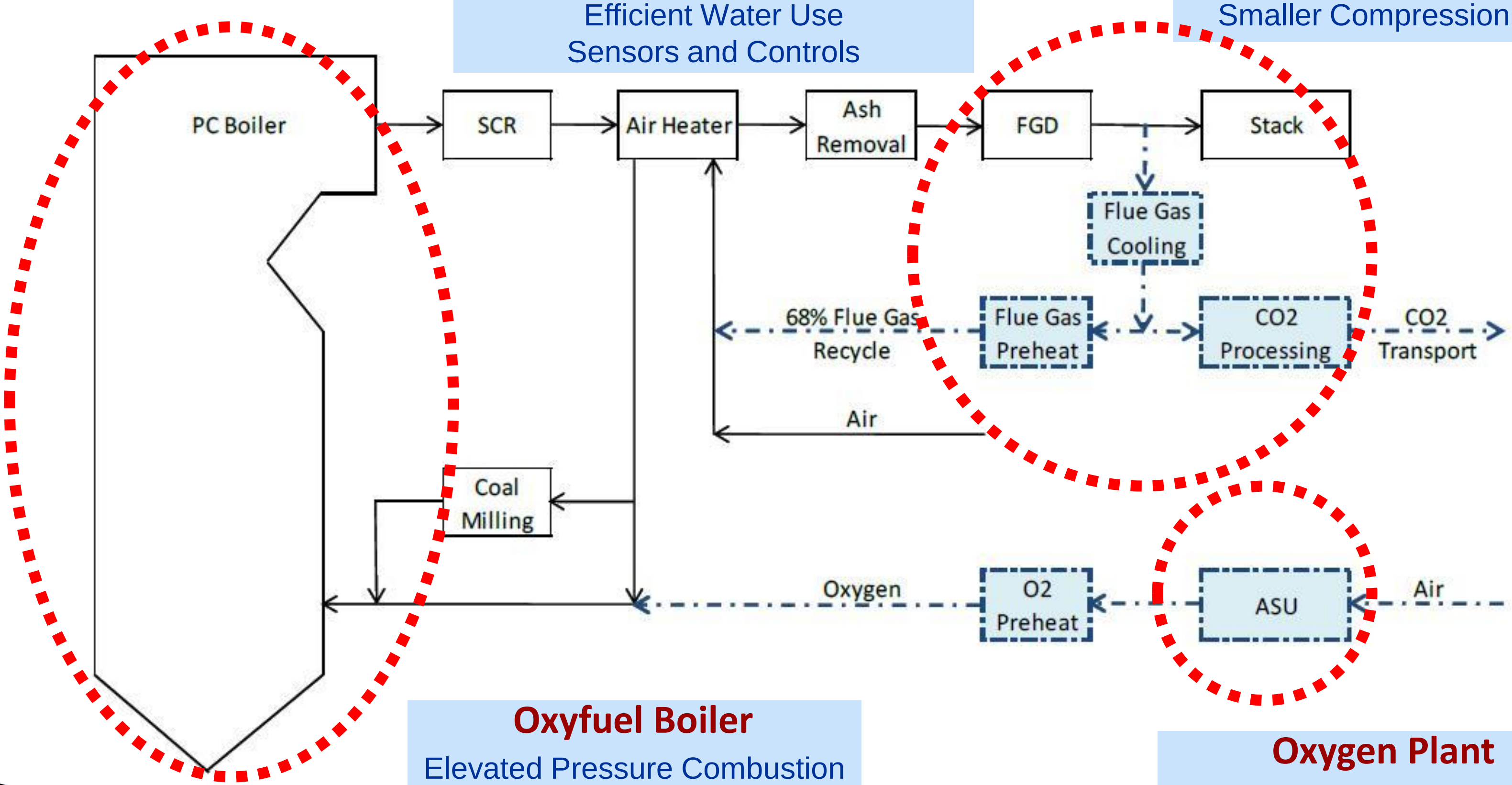
Combustion System
Oxycombustion with CCS

Advanced Process Integration

Reduce CO_2 Recycle
High Temperature Materials
Efficient Water Use
Sensors and Controls

CO_2 Purification

2 Stage Purification
Removes SO_x, NO_x, O_2, inerts
Smaller Compression Plant



Oxyfuel Boiler

Elevated Pressure Combustion

Oxygen Plant

Reduce Cost and Load

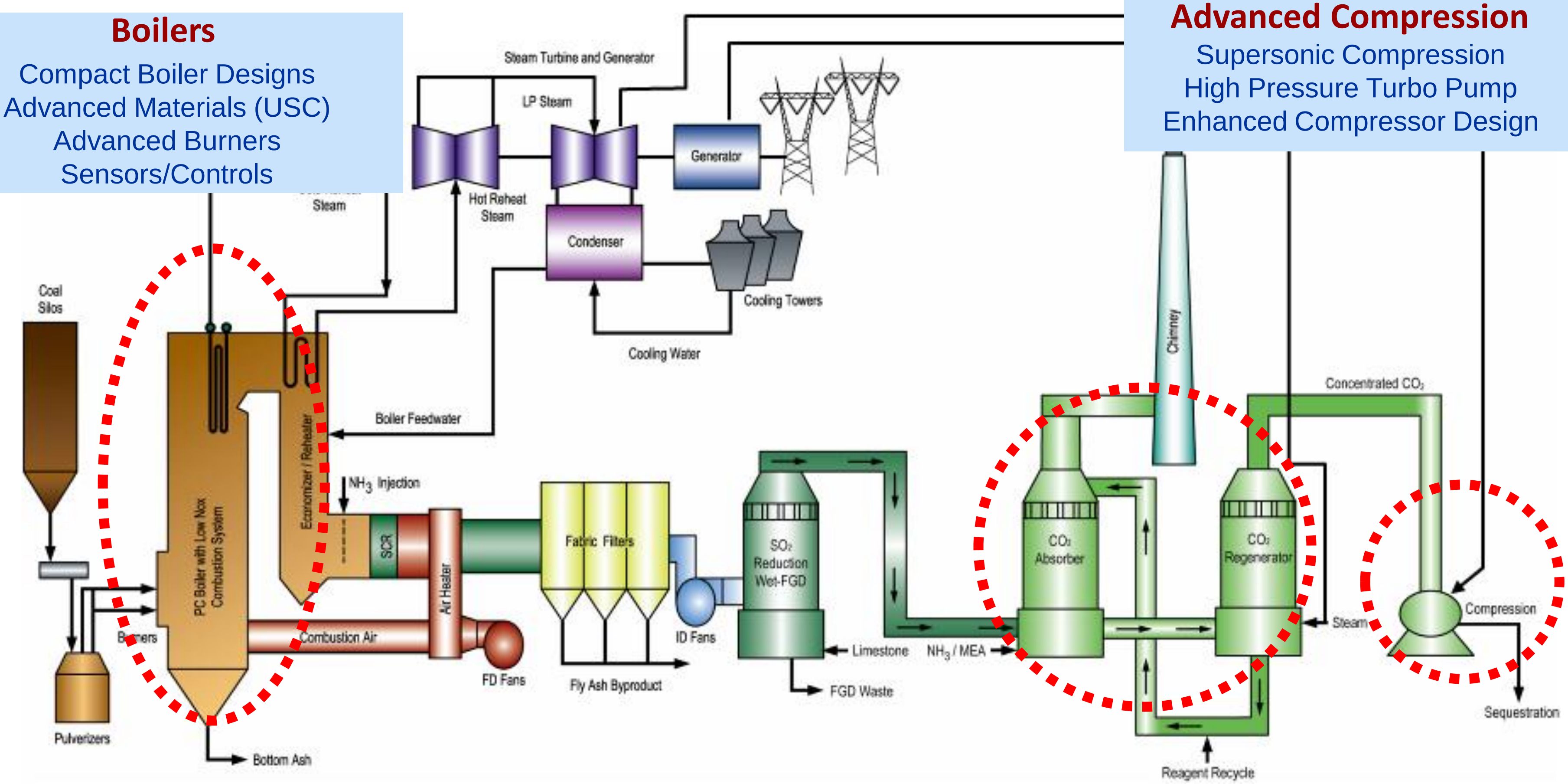
Combustion System
Pulverized Coal with CCS

Boilers

Compact Boiler Designs
Advanced Materials (USC)
Advanced Burners
Sensors/Controls

Advanced Compression

Supersonic Compression
High Pressure Turbo Pump
Enhanced Compressor Design



Post Combustion Capture

Multi-pollutant capture
Advanced Sorbents
Advanced Membranes

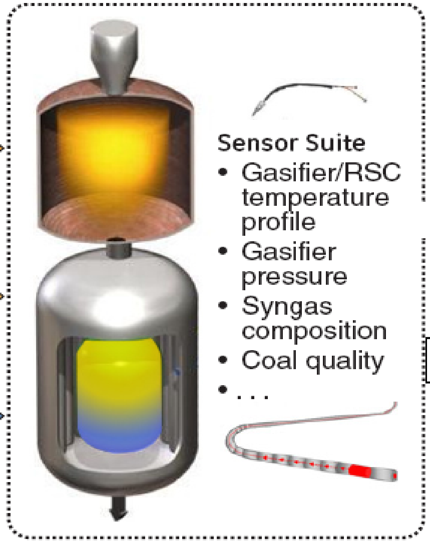
Integrated Sensing & Controls for Coal Gasification

Model-Based Sensing & Control – 2007-2010 ($3MM)

Variations
- Coal quality
- Slurry composition
- Syngas demand (load)

Constraints
- T,P limits
- Slag viscosity
- Stress limits
- Operation limits from ASU, PowerGen

Control Actuation
- Slurry, O_2, recycle moderator
- Syngas flowrate
- RSC water, steam flow



- **Very limited online sensing available due to harsh environment**
- **Limited online information on key performance variables**

Complement online sensors with model-based estimation

Advanced Sensing System

- Harsh-environment sensing

+

- Model-based virtual sensing

Advanced Control System (MPC)

- Model-based online multivariable constrained dynamic optimization

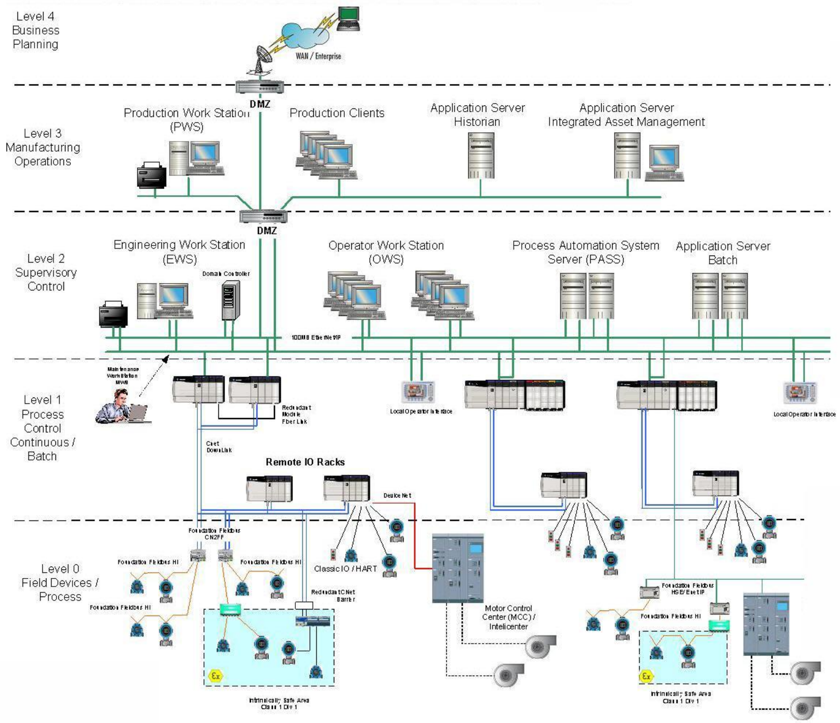
Supervisory level model-based optimization through coordination of multiple inputs

- Focus on Gasification section
- Online monitoring of key performance and operability parameters
- Robust, reliable, optimized & flexible plant operation

- Faster Startup - 20% less pre-heating time
- Faster load transient – 20% faster turndown
- Optimized steady state performance – online optimization for efficiency and carbon conversion
- Optimized performance for coal & coal-petcoke blends

Evolutionary vs Revolutionary

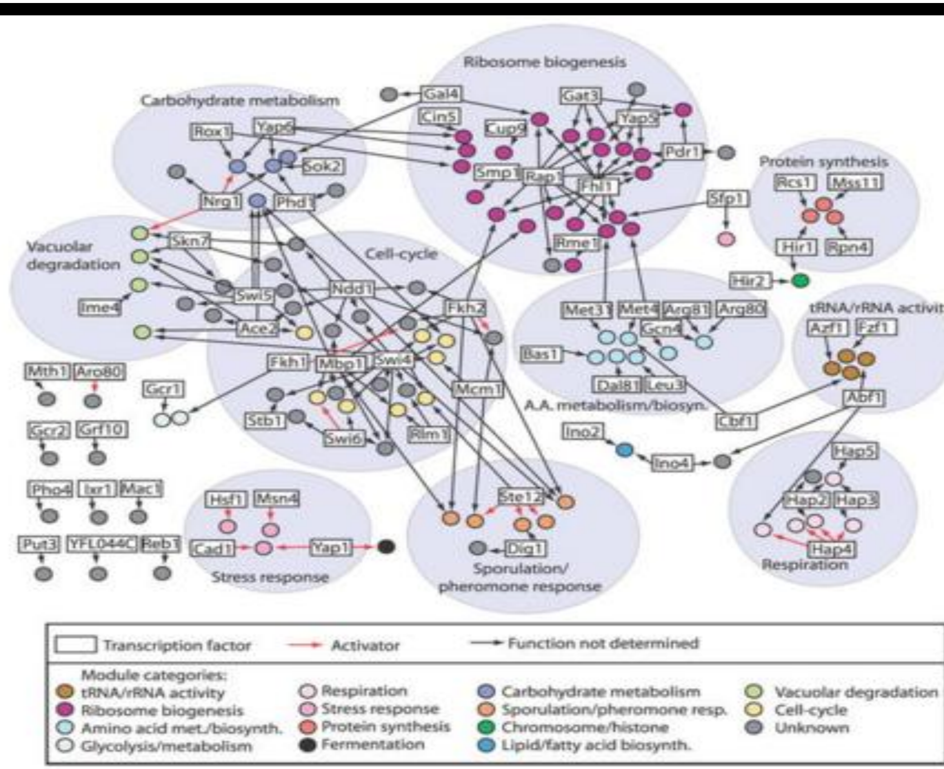
Challenging conventional architectures to support advancements in computational intelligence



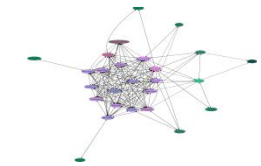
Traditional Control Architecture
For Distributed Control Systems (DCS)

- Linear and based on minimization of error and set points

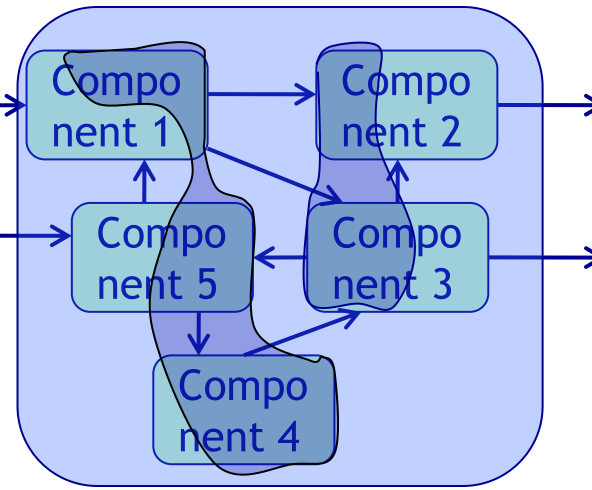
New approaches mimic biological systems, utilize distributed intelligence, and designed to handle complexity

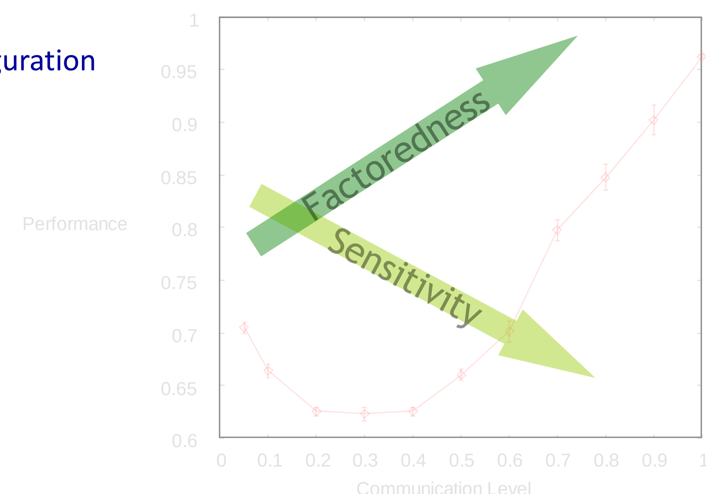


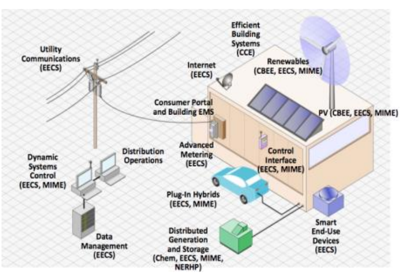
Distributed Sensor Coordination for Advanced Energy Systems

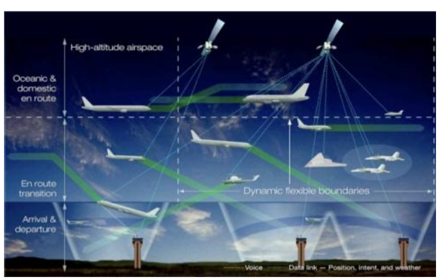


- Motivation:
  - Advanced energy systems are becoming more interconnected
  - Computation pushed down to sensors
    - *How do we control and coordinate such systems?*
- Objectives:
  - Derive criteria for assessing sensor effectiveness and system impact
  - Demonstrate effectiveness and reconfigurability of sensors to changes in system
- Concept:
  - Focus on *what* to control, *what* to optimize (not *how* to control):
    - Get better objective functions for each subsystem
    - Get better system decomposition
- Benefits:
  - To Advanced Energy Systems: Response to sudden changes / System reconfiguration
  - To the Department of Energy: Smart power grid / Safe energy systems
  - To the US public: Smart House / Smart airports









Drivers for Advanced Sensing Technology

- **Advanced Power Generation has harsh conditions through out a plant that need to be monitored with new instrumentation and sensor technology**

- **Target development of critical on line measurements**
  - Sensor materials and designs are aimed at up to 1600°C for temperature measurement and near 500°C for micro gas sensors

- **Reduce Total Cost of Ownership of plants / systems by developing and supporting control algorithms and condition monitoring technologies**
  - Focus on improving the reliability, availability and maintainability of existing and future power systems
  - Enable coordinated control for advanced power plants including carbon capture

Areas of Research in Sensors and Controls

Stakeholder Input

Industrial On Line Measurement Needs

Sensors Materials

For High Temperatures & Harsh Environments

Sensor Designs

Sensor Packaging

Prototyping and Testing

Sensor Placement and Networking

Integration with Process Control and Monitoring

Novel Control Architectures
Distributed Intelligence
Heterogeneous Dense Sensor Networks
Self Organization

Sensor Research and Development Areas

Optical Sensors
- Spectroscopic / Non contact
- Fiber based

Optical Access, Interference management

Single Point, Distributed and Multiplexed Sensors, Coatings for sensing, protection, and attachment

Micro Sensors
- Single point
- Array based

Active sensing layers and protection materials, Algorithms for Gas Identification and Quantification, Packaging of sensors, lead wire and connector improvements

Other
- Embedded sensors
- Imaging

Active films, direct write sensors, Metamaterials, Capacitance Imaging, Algorithms for image reconstruction

Enabling Technologies
- Wireless
- Energy Harvesting

Passive Wireless, Active Wireless communication, Thermoelectric and vibration energy harvesting approaches, Sensor Networking

Conclusions

- **Challenges require innovation at all levels**
  - Creation of low cost reliable, zero emission power and multi product large scale plants utilizing domestic resources will require advanced control for operation and achievement of performance goals

- **Materials, design, and approach are key**
  - For sensing technology to overcome barriers associated with harsh environments (temperature, pressure, conditions, packaging, high temp connections)

- **Value in reduction to practice**
  - Development of individual S&C technologies, including enabling technologies, are required but value is derived from integrating, adapting, networking, packaging for systems and plant level operation and control

Times Have Changed

Then

2009

- Strong likelihood of cap-and-trade legislation.
- EOR applications seen as niche opportunity to offset some cost;
- Oil $50 - $60/barrel;
- CCS storage focus with CO_2 tax support.

Goal by 2020: + 35% LCOE

- LCOE: Levelized Cost of Electricity

Now

2012

- Cap-and-trade legislation unlikely in the near term.
- No deadlines for utilities, no reason to invest in carbon capture and storage.
- Oil more expensive = $85/barrel; global competition stronger.
- CCUS has been successfully developed in FE demos.

Current Capture Cost: $70-90/Ton Goal by 2020: $40/Ton

Carbon Capture Cost can support a long-term business case to invest.

What Next

2013 ------

- Cap-and-trade legislation?
- Cost of Oil ?
- Impact of Gas ?
- Impact of MATS ?
- CCUS for EOR ?

Parting Thoughts

- Energy Security: Promote U.S. energy security by increasing domestic oil production and reducing imports.
- Jobs: Create millions of new high paying **jobs** in the energy and related sectors.
- Revenues: Provide **trillions of dollars** of new domestic revenues and economic activity.
- Trade: Improve the U.S. balance of trade by significant reductions in oil imports.
- CCS and Climate Change Impact: Help achieve a meaningful and significant reduction in U.S. CO_2 emissions through safe and permanent geologic storage for **EOR** operations.

Questions

FE-20
Clean Coal
Deputy Assistant Secretary
James F. Wood

FE-26
Office of Planning & Environmental Analysis
Jarad Daniels

FE-22
Office of Clean Energy Systems
Darren Mollot

FE- 221
Division of Advanced Energy Systems
Samuel Tam

Advanced Combustion
- Oxycombustion
- USC Boiler Materials

Gasification Systems
Hydrogen Turbines
Hydrogen from Coal
- CTL & CBTL

Solid Oxide Fuel Cells

FE-222
Division of Carbon Capture & Storage Demonstrations
Joseph Giove

FutureGen 2.0
Clean Coal Power Initiative (CCPI)
- *IGCC*
- *PC Retrofit*

Industrial Carbon Capture & Storage (ICCS) – Area 1 projects
- *Biofuel*
- *Hydrogen Production*
- *Chemical Plant*

FE- 223
Division of Carbon Capture & Storage Research
Mark Ackiewicz

Carbon Capture
- *Post Combustion Capture*
- *Pre-Combustion Capture*

Carbon Storage
- *Regional Carbon Seq. Partnerships*
- *Geologic Storage*
- *Monitoring, Verification, Accounting and Assessment*
- *Carbon Use and Reuse*
- *Focus Area for Carbon Sequestration Science*

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Division of Cross-cutting Research
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Plant Optimization Technologies
- *Sensors and Controls*
- *Cross-cutting Materials R&D*

Coal Utilization Science
- *Computational System Dynamics*
- *Computational Energy Science*

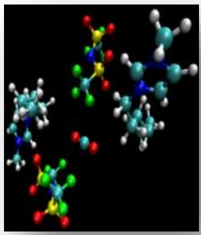
Energy Analyses
System Analysis/product Integration
University Training and Research
- *University Coal Research*
- *HBCUs, Education & Training*

SBIR Program
Budget, Metric

Carbon Capture Simulation Initiative (CCSI) and National Risk Assessment Partnership (NRAP)

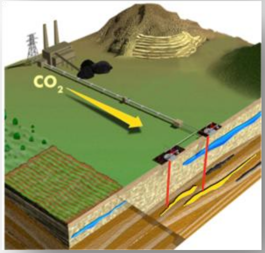
Science-Based Computational Tools for Accelerating CCS Technology Development & Deployment

First Principles



CFD

Process Simulation



NRAP

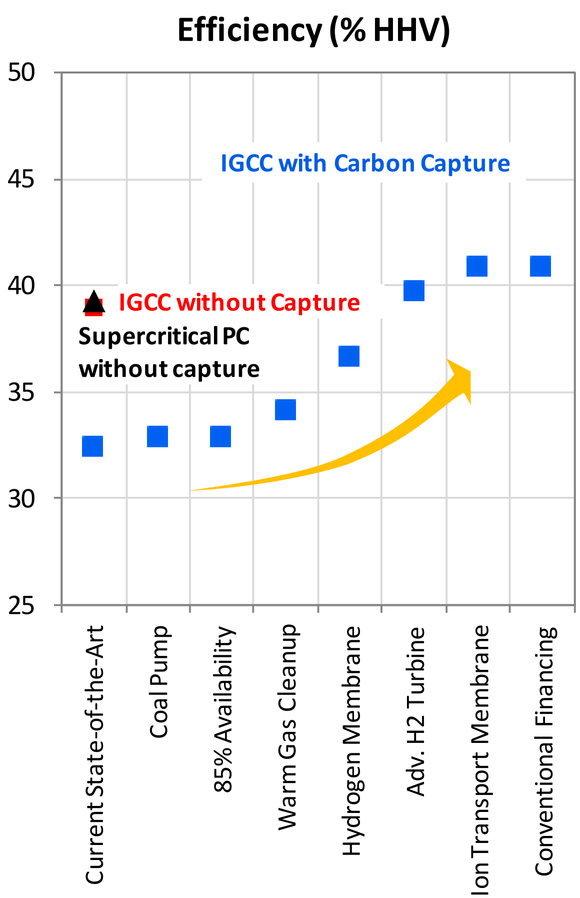
Commercial Plants

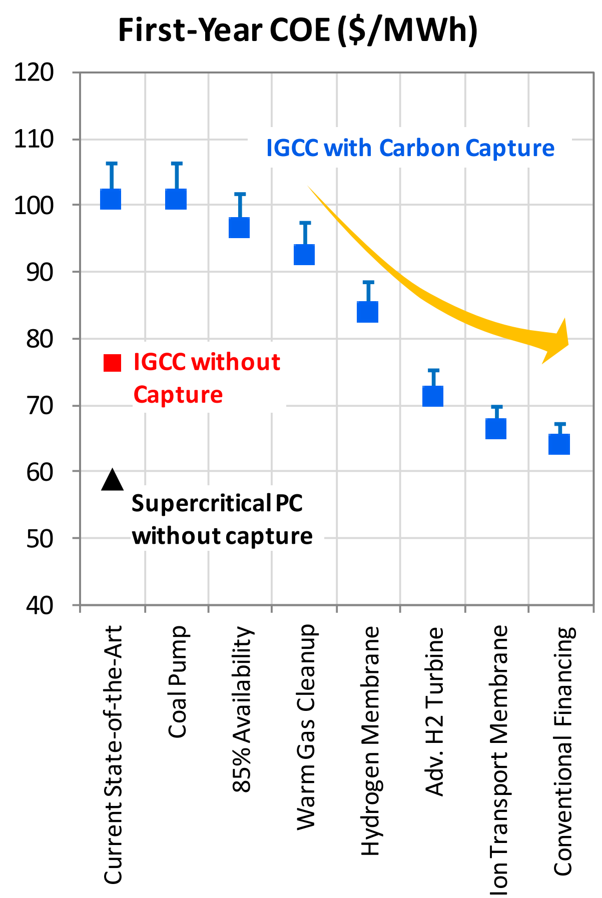
Identify promising concepts → **Develop optimal designs** → **Quantify technical risk in scale-up**

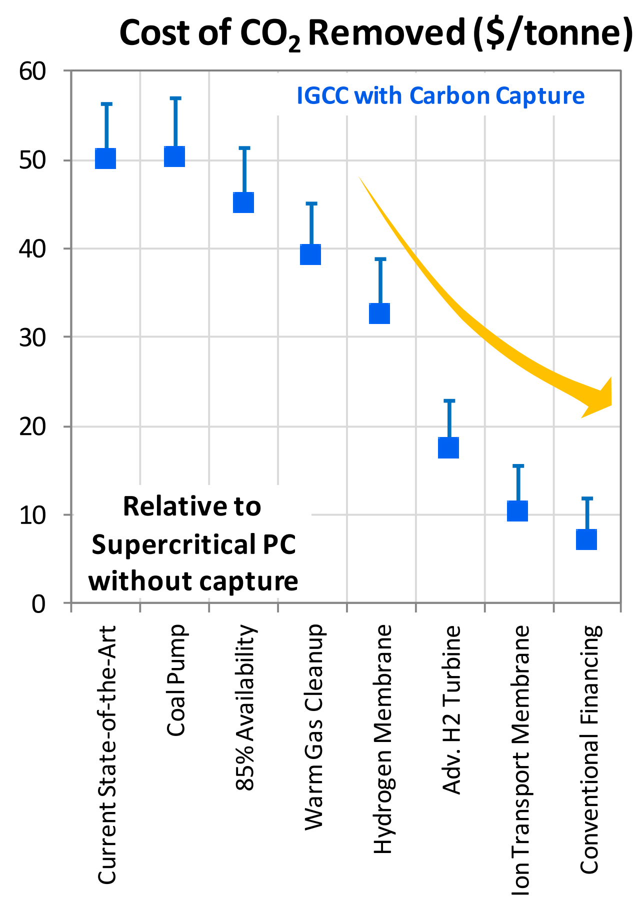
Accelerate learning during development & deployment

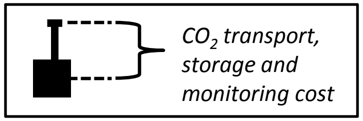
Advanced IGCC Systems

Driving Down the Cost





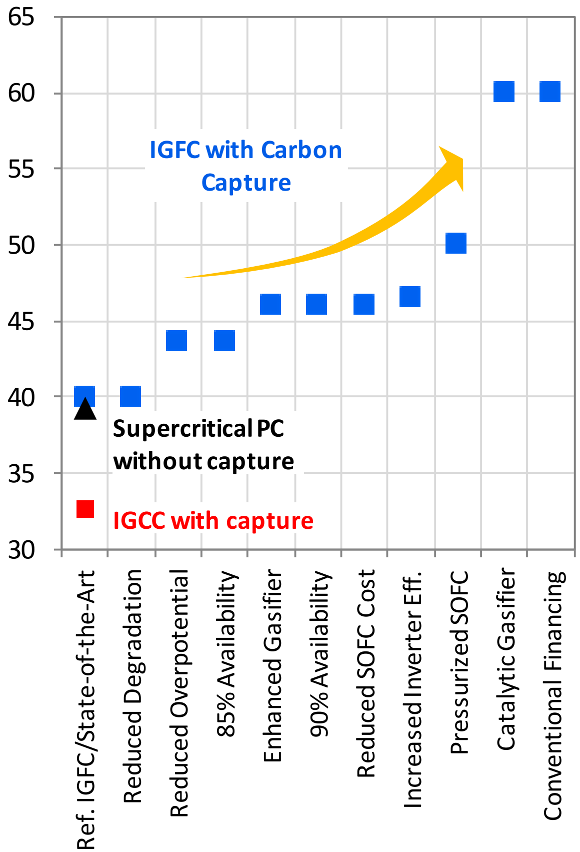




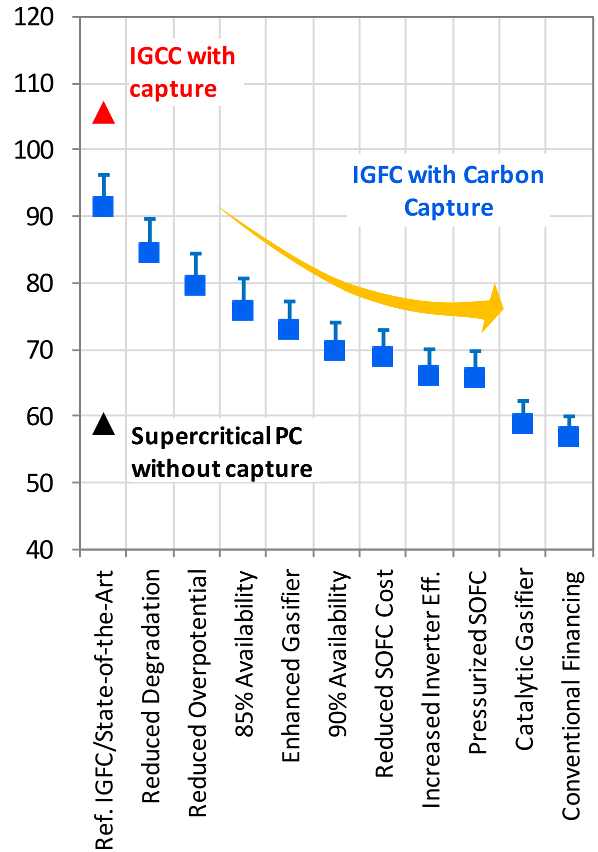
Advanced Gasification Fuel Cell Systems

Driving Down the Cost

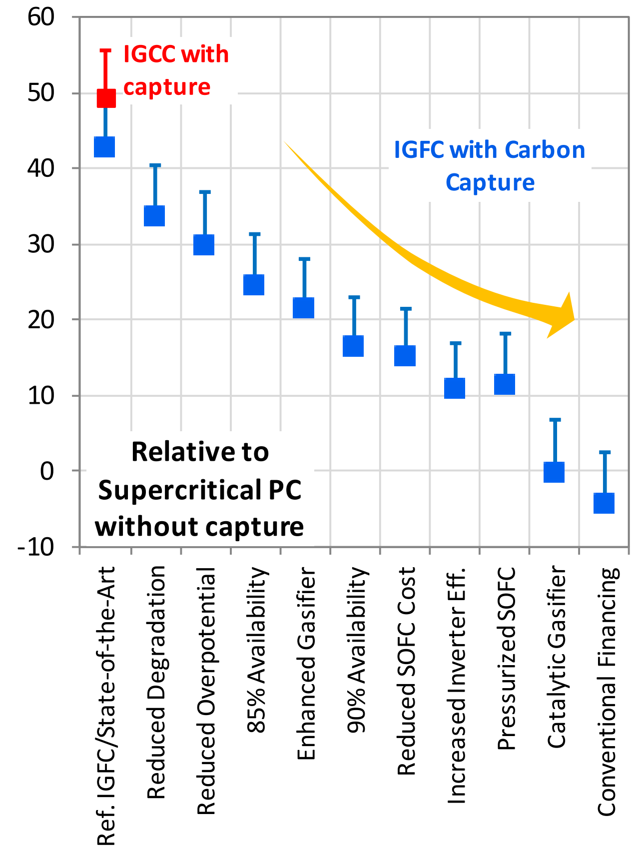
Efficiency (% HHV)

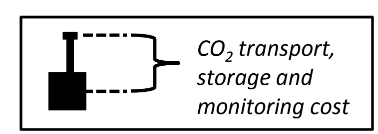


First-Year COE ($/MWh)



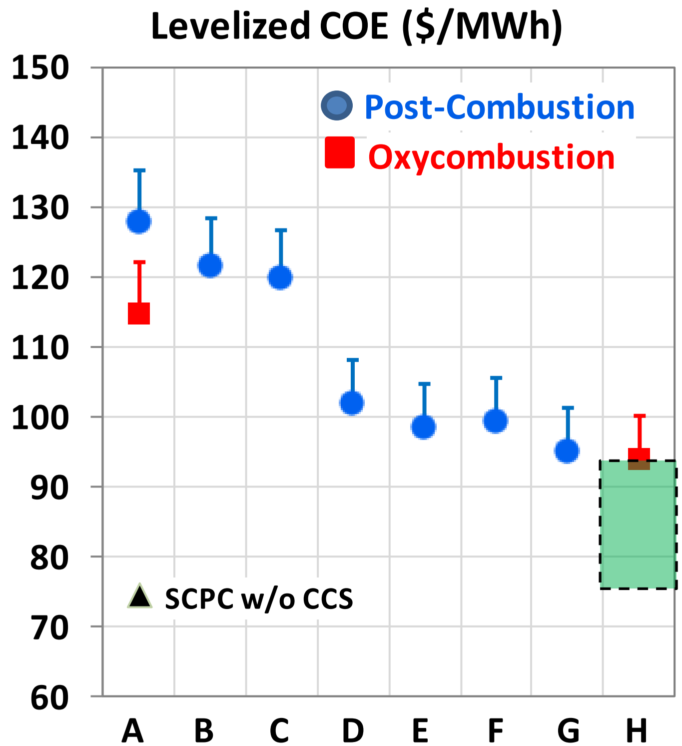
Cost of CO_2 Removed ($/tonne)

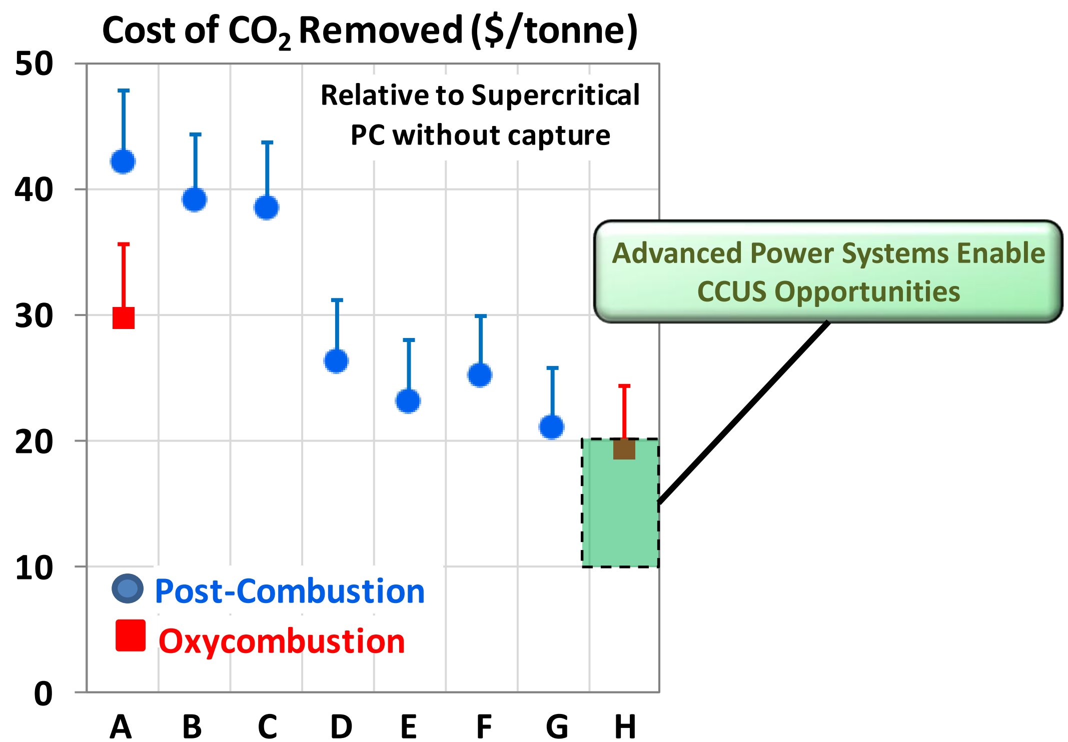




Low Cost Combustion Power Solutions

↓ Power Cost and ↑ CCUS Potential





A – Supercritical PC w/Current Amine Scrubbing

B – Ultrasupercritical PC w/Current Amine Scrubbing

C – USC PC w/Amine + Advanced Compression

D – USC PC w/Advanced CO_2 Sorbent + Adv. Comp.

E – USC PC + Adv. CO_2 Membrane + Adv. Comp.

F – Adv. USC PC + Adv. Sorbent + Adv. Compression

G – Adv. USC PC + Adv. Membrane + Adv. Comp.

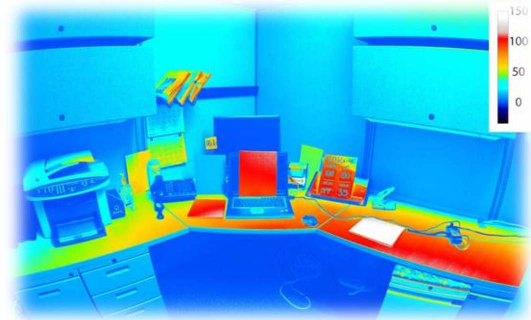
H – Advanced Oxycombustion Power Cycles

*USC = Ultra-supercritical PC (5,000 psig/1,200°F/1,200°F)

*Adv. USC PC = 5,000 psig/1,350°F/1,400°F

CO_2 transport, storage and monitoring cost

Technology Headroom for DOE



Building and Industrial Efficiency

- Data collection and usage
- Integrated systems analyses
- Next-gen processes and products

Grid Modernization

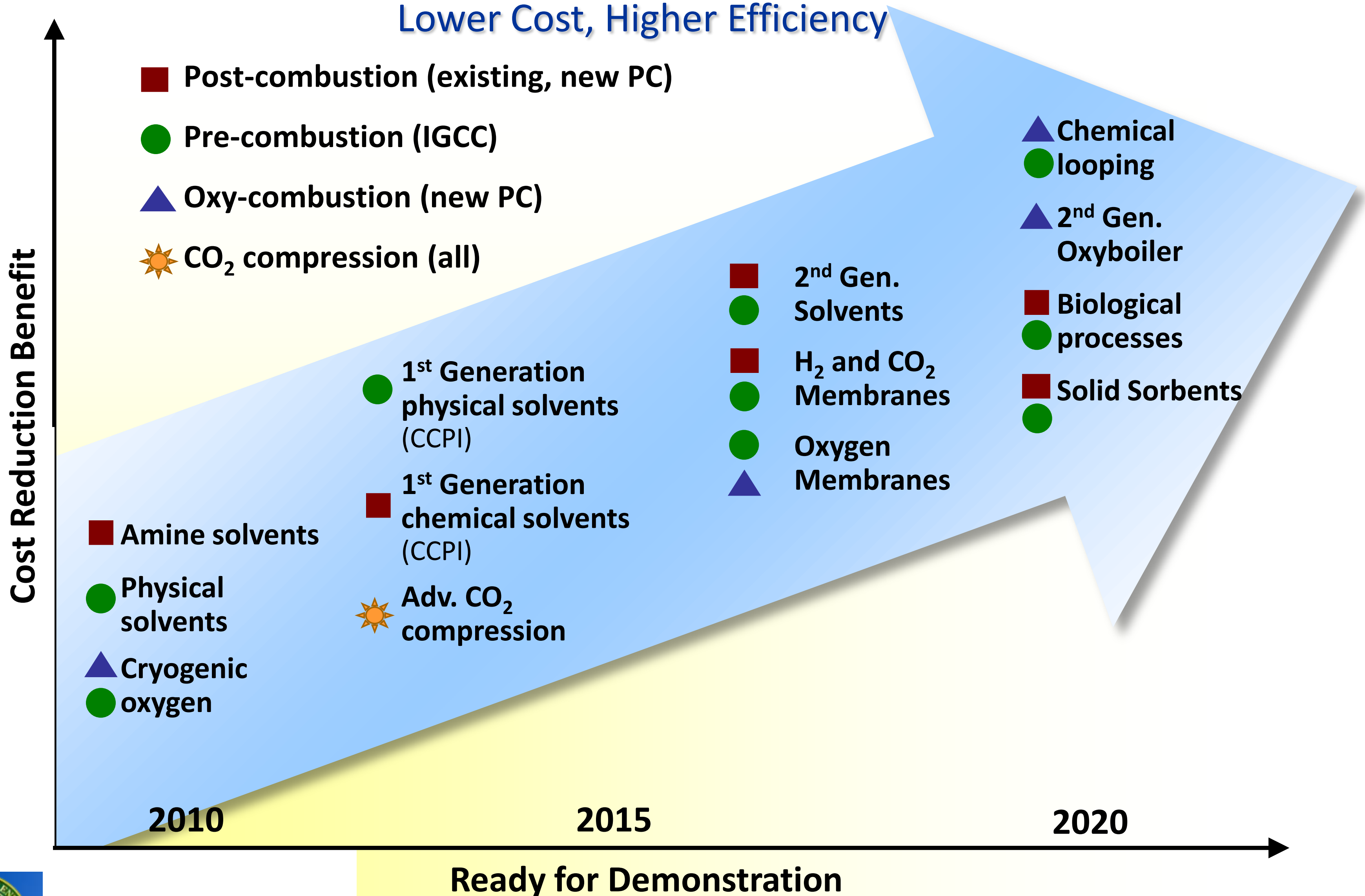
- Communication and data
- Management and control
- Energy storage

Clean (Low-Carbon) Power

- Drive down costs
- Improve Plant Efficiency
  - Advanced Materials
  - Sensors and Controls
- Coupling between energy and water use

Advanced 2nd Generation CCS and Transformational Capture Technologies

Lower Cost, Higher Efficiency



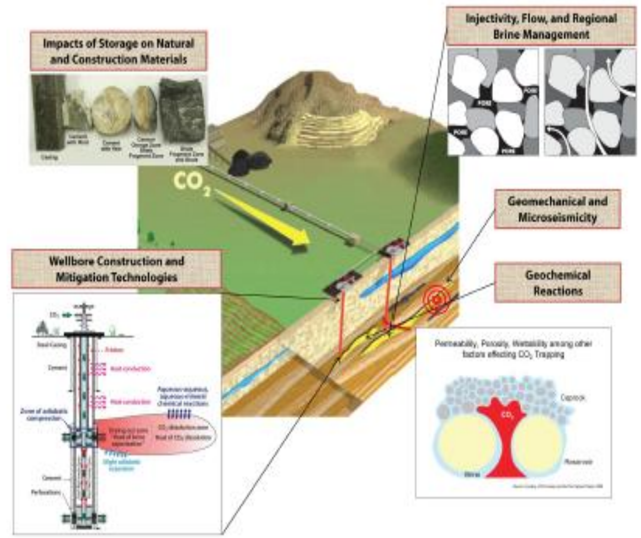
Carbon Storage Program – Core R&D

Monitoring, Verification, and Accounting

- Atmospheric and Remote Sensing Technologies
- Near surface monitoring of soils and vadose zone
- Subsurface monitoring in and near injection zone
- Intelligent monitoring systems for field management

Geologic Storage

- Wellbore construction and materials technologies
- Mitigation technologies for wells and natural pathways
- Managing fluid flow, reservoir pressure, and brines
- Geochemical effects of CO_2 injection
- Geomechanical effects on reservoirs and seals



CO_2 Utilization

- **<u>Enhanced Oil Recovery</u>**
- Conversion to commodities into chemicals and plastics
- Non-geologic storage in cement and minerals
- Beneficial use of produced waters

Simulation and Risk Assessment

- Thermal and hydrologic fate and transport
- Geochemical simulations
- Geomechanical simulations
- Predicting biologic impacts on storage formations
- Risk assessment and quantification