U.S. Department of Energy
Office of Fossil Energy

26th Annual Conference on Fossil Energy Materials

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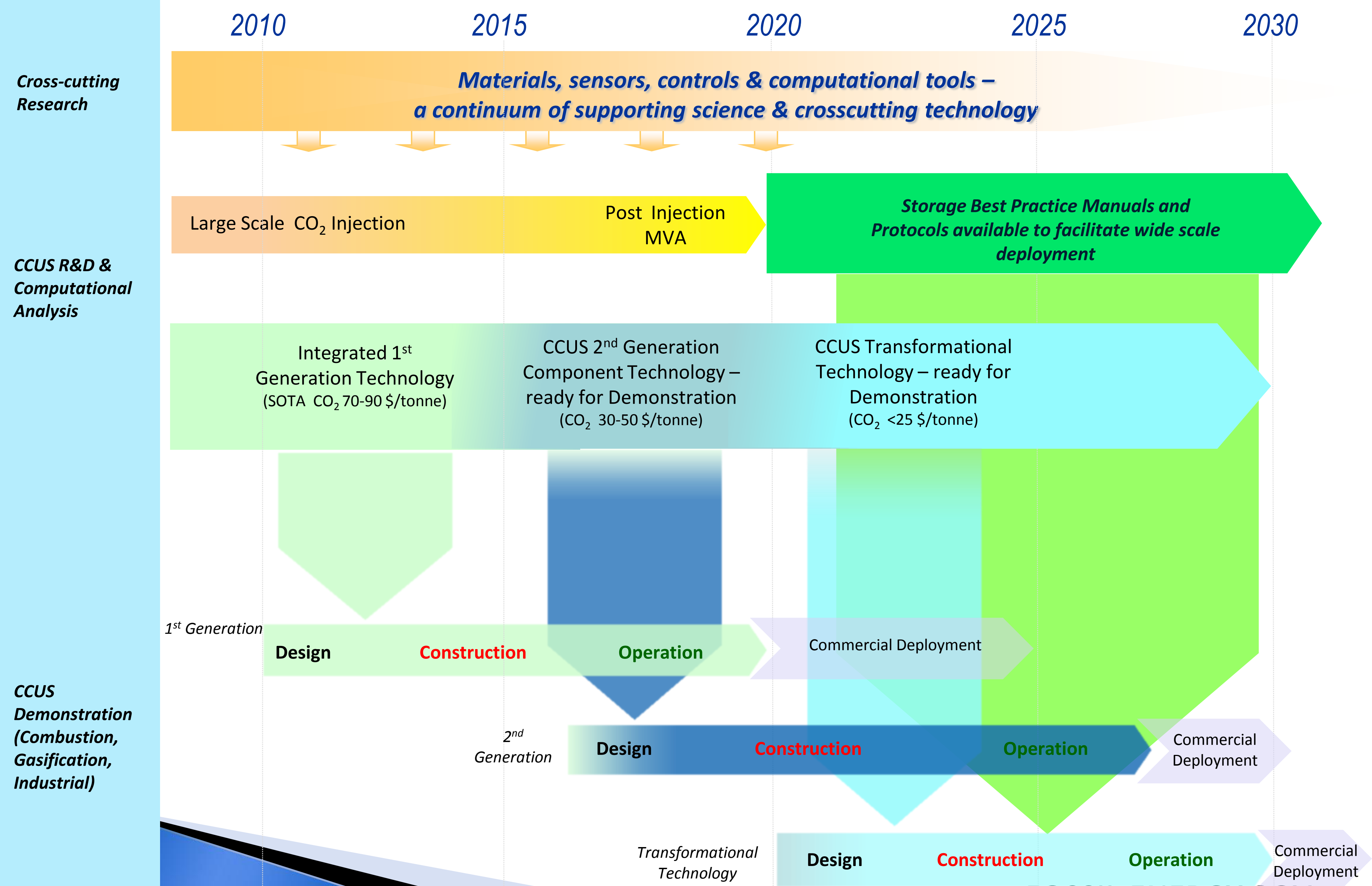
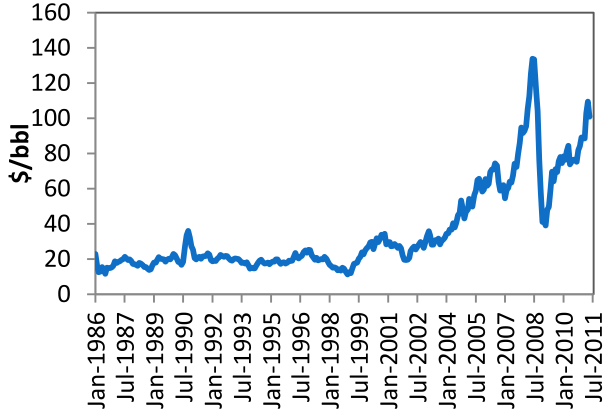
Integrated Coal Program Technology Roadmap



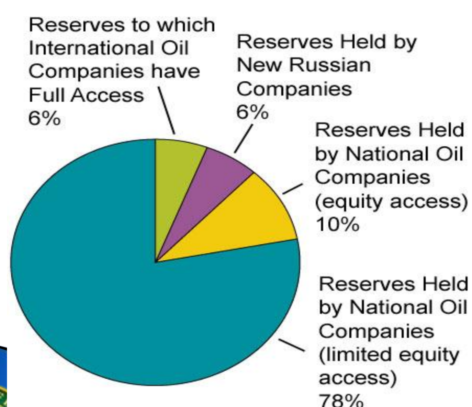
U.S. Energy Challenges

Energy Security

Monthly Spot Price OK WTI

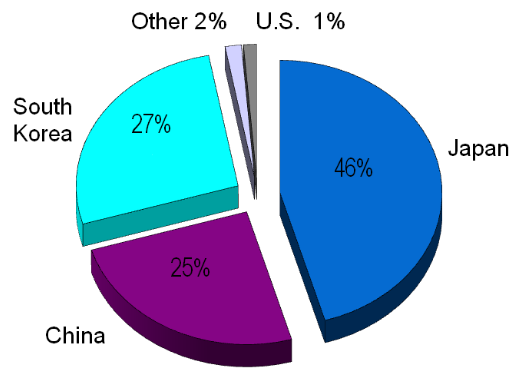


Share of Reserves Held by NOC/IOC

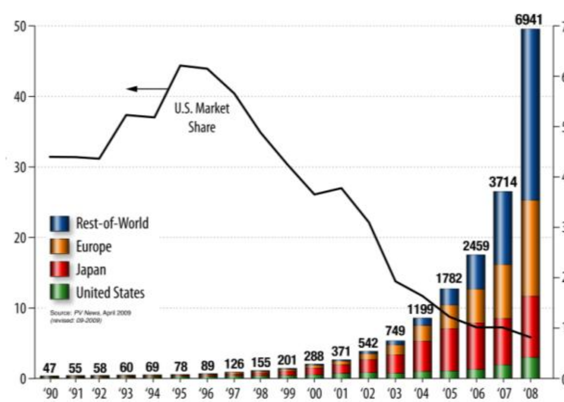


Competitiveness

Global Lithium-ion Battery Manufacturing (2009)

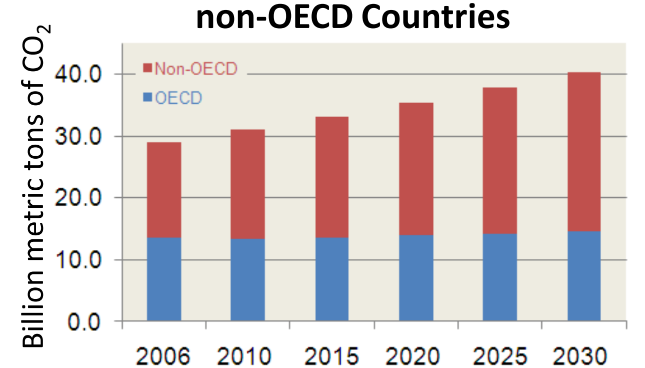


Worldwide Shipments of Solar Photovoltaics (MW)

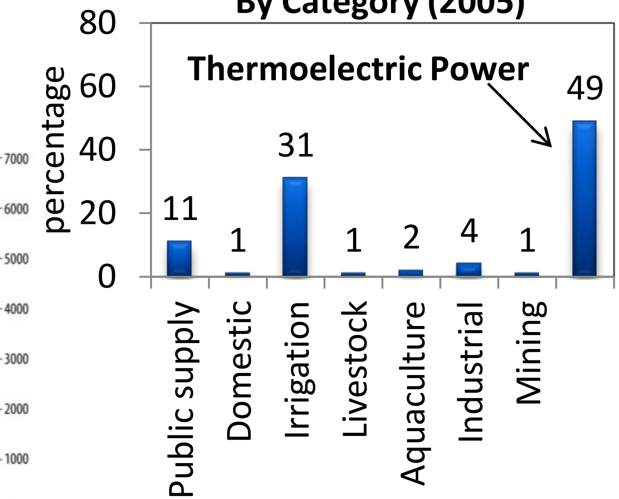


Environmental Impacts

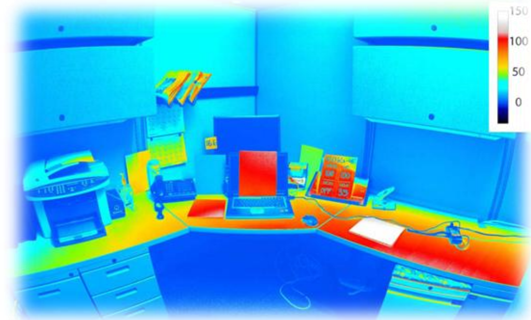
CO_2 Emissions in OECD vs non-OECD Countries



Water Withdrawals in % By Category (2005)



Technology Headroom for DOE



<u>Building and Industrial Efficiency</u>

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

<u>Grid Modernization</u>

- Communication and data
- Management and control
- Energy storage

<u>Clean (Low-Carbon) Power</u>

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

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
- Increased efficiency for cleaner use of coal.
- 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

Times Have Changed

Then	Now
2009	**2012**

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.

<u>Goal by 2020: + 35% LCOE</u>

LCOE: Levelized Cost of Electricity

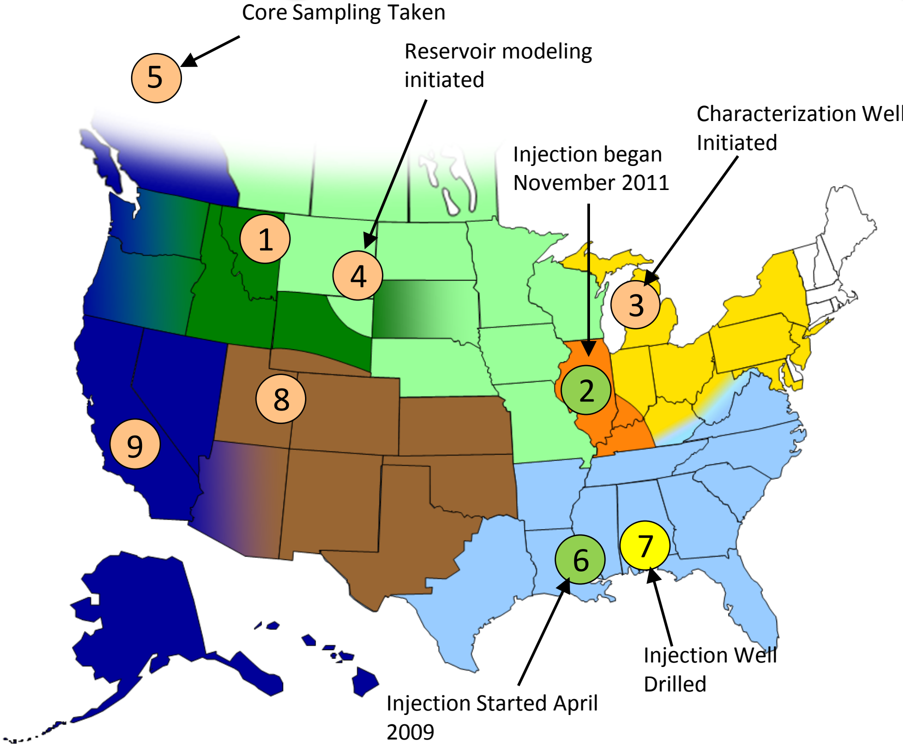
Now — 2012

- 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 = $100/barrel; global competition stronger.
- CCUS has been successfully developed in FE demos.

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

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

Addressing Storage Challenges: Regional Carbon Sequestration Partnerships



Injection Ongoing

2012 Injection Scheduled

Injection Scheduled 2012-2015

Note: Some locations presented on map may differ from final injection location

- Large-scale injection wells
- Establishing monitoring and verification protocols.
- Addressing regulatory, environmental, and outreach issues.
- Establishing Best Practices
- Assessing risks
- Validating sequestration technology and infrastructure.
- Engaging regional, state, and local governments

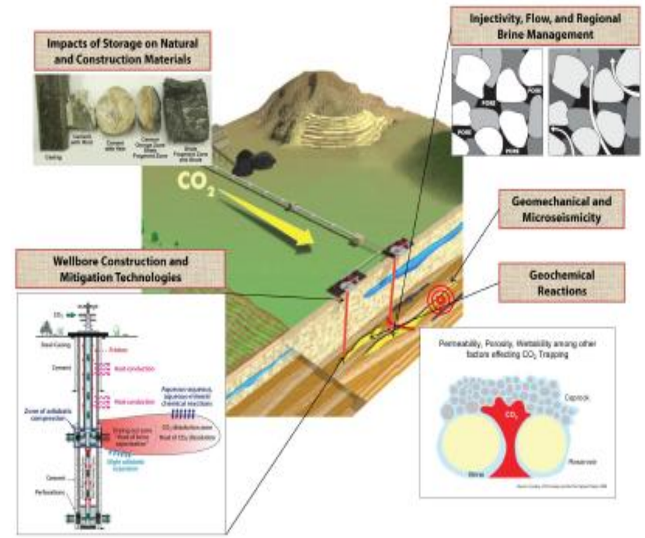
Carbon Storage Program – Core R&D

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

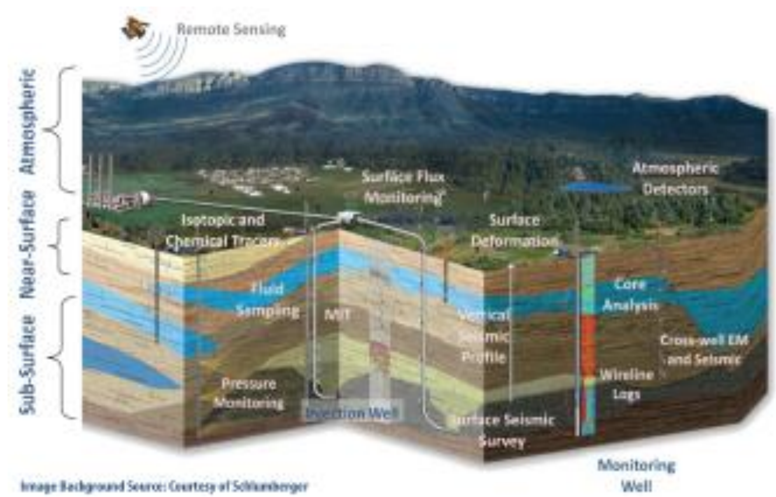
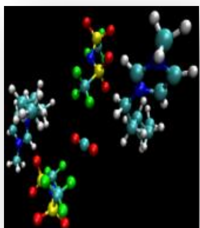


Image Background Source: Courtesy of Schlumberger

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

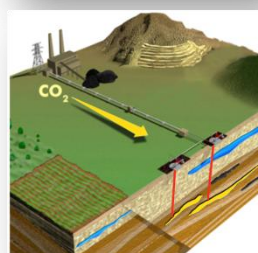
Science-Based Computational Tools for Accelerating CCS Technology Development & Deployment

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

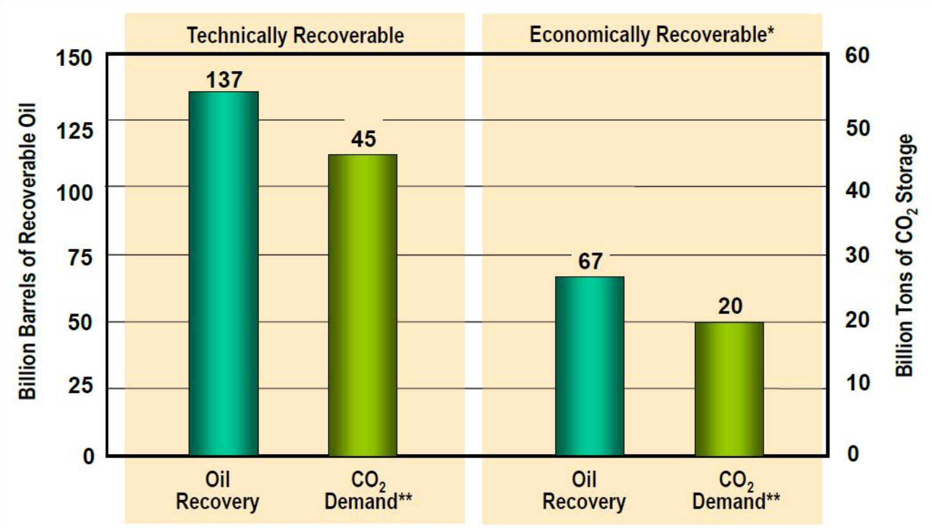
NETL | Berkeley Lab | Los Alamos National Laboratory | Lawrence Livermore National Laboratory | Pacific Northwest National Laboratory

CO_2-Enhanced Oil Recovery

- The "Un-Mined Gold" Story for Energy and Jobs
- Benefits[1] of CO_2-EOR:
  - $10 trillion in economic activity over 30 years;
  - 2.5 million jobs
  - 30 – 40 percent reduction in imported oil

[1] *Source: U.S. Carbon Sequestration Council*

Domestic Oil Supplies and CO_2 Demand (Storage) Volumes from "Next Generation" CO_2-EOR Technology**



*At an oil price of $85/B, a CO_2 market price of $40/mt and a 20% ROR, before tax.
**Includes 2,300 million metric tons of CO_2 provided from natural sources and 2.6 billion barrels already produced or being developed with miscible CO_2-EOR.
Source: Advanced Resources Int'l (2011).

Materials Performance in CO_2 and CO_2-Steam Environments

- **Evaluate oxidation/corrosion performance of metallic structural alloys in pure CO_2 and in CO_2-steam environments over a wide temperature range**

- **Establish the kinetics of scaling and internal penetration, if any, and develop correlations for long term performance**

- **Identify viable alloys for structural and gas turbine applications Evaluate the influence of exposure environment on the mechanical properties (especially creep, fatigue, and creep-fatigue) of the candidate alloys**

Breakthrough Concepts Direction

- **Computational Materials Design with Experimental Verification**

  Combine computational materials development with experimental verification to engineer new high performance materials

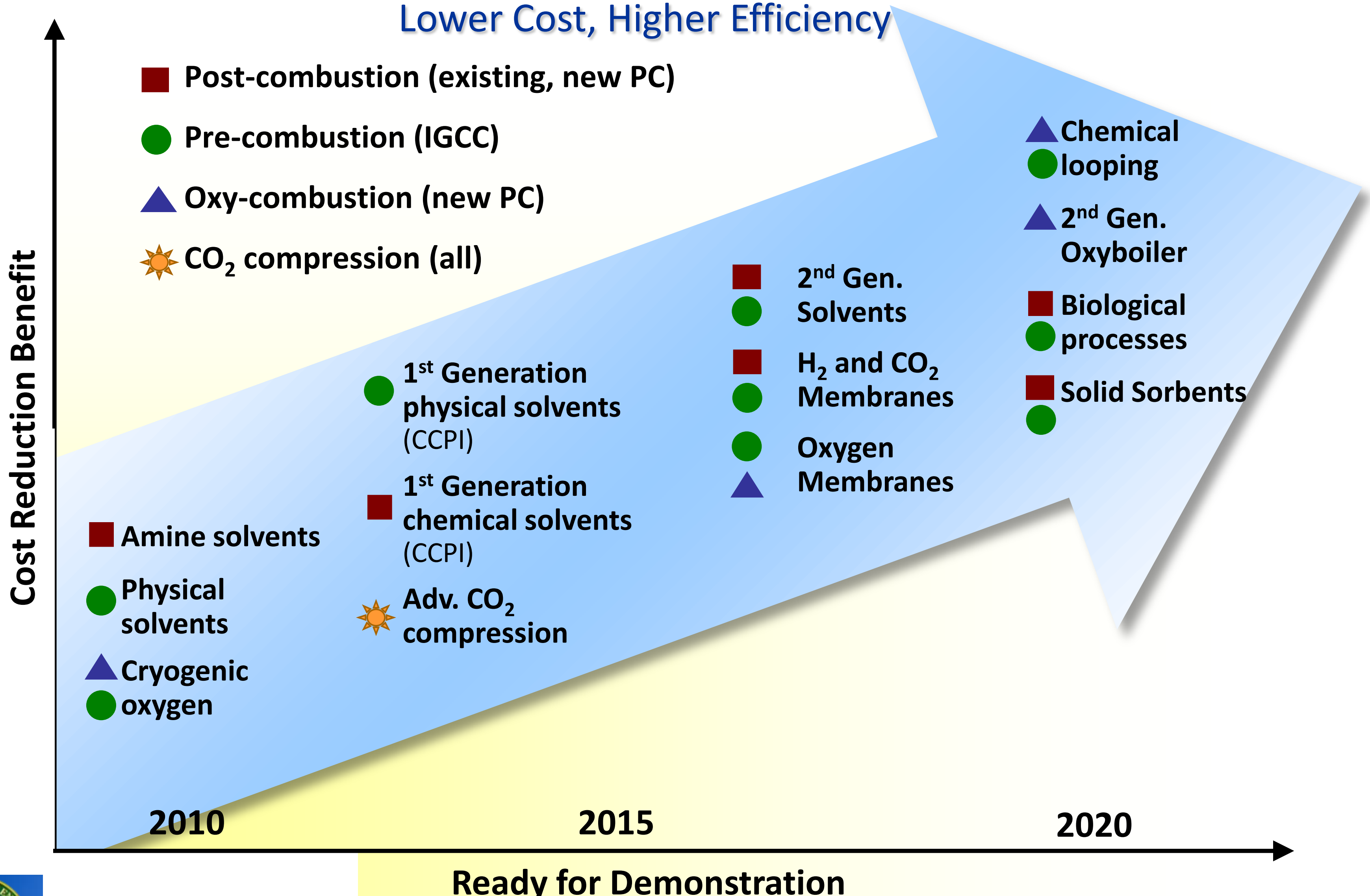
Parting Thoughts

- 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.

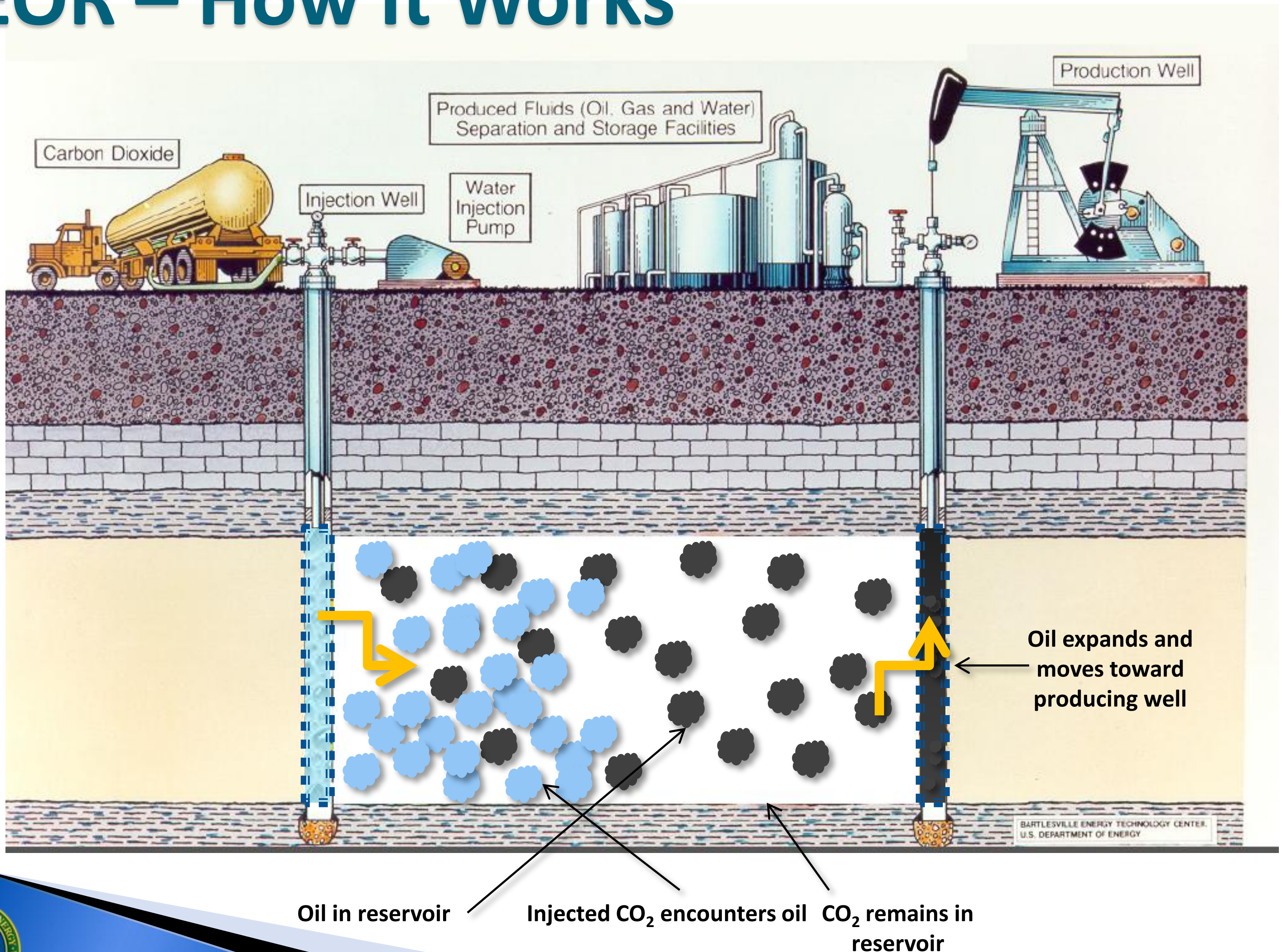
Questions

Advanced 2nd Generation CCS and Transformational Capture Technologies

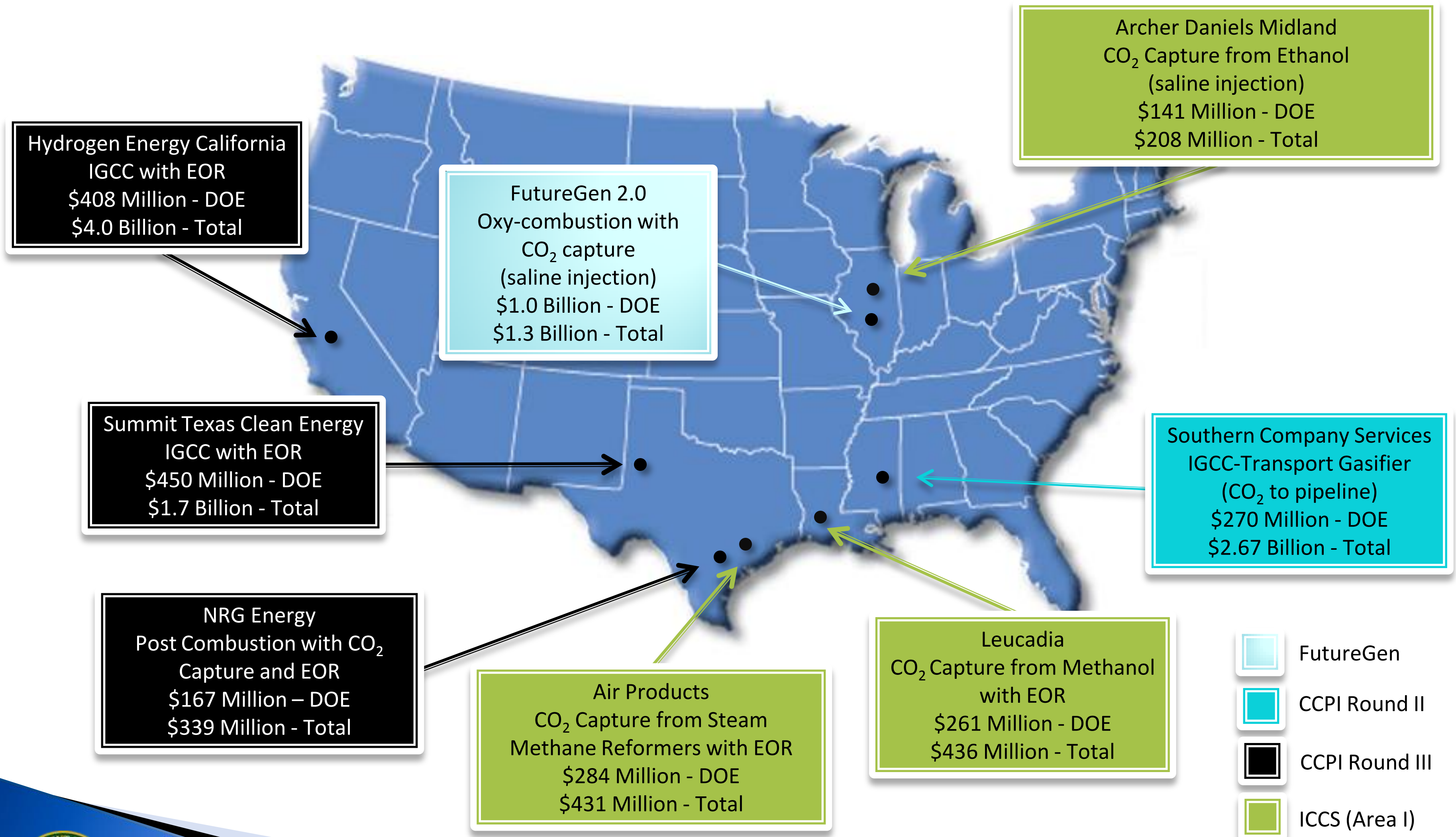
Lower Cost, Higher Efficiency



EOR – How It Works



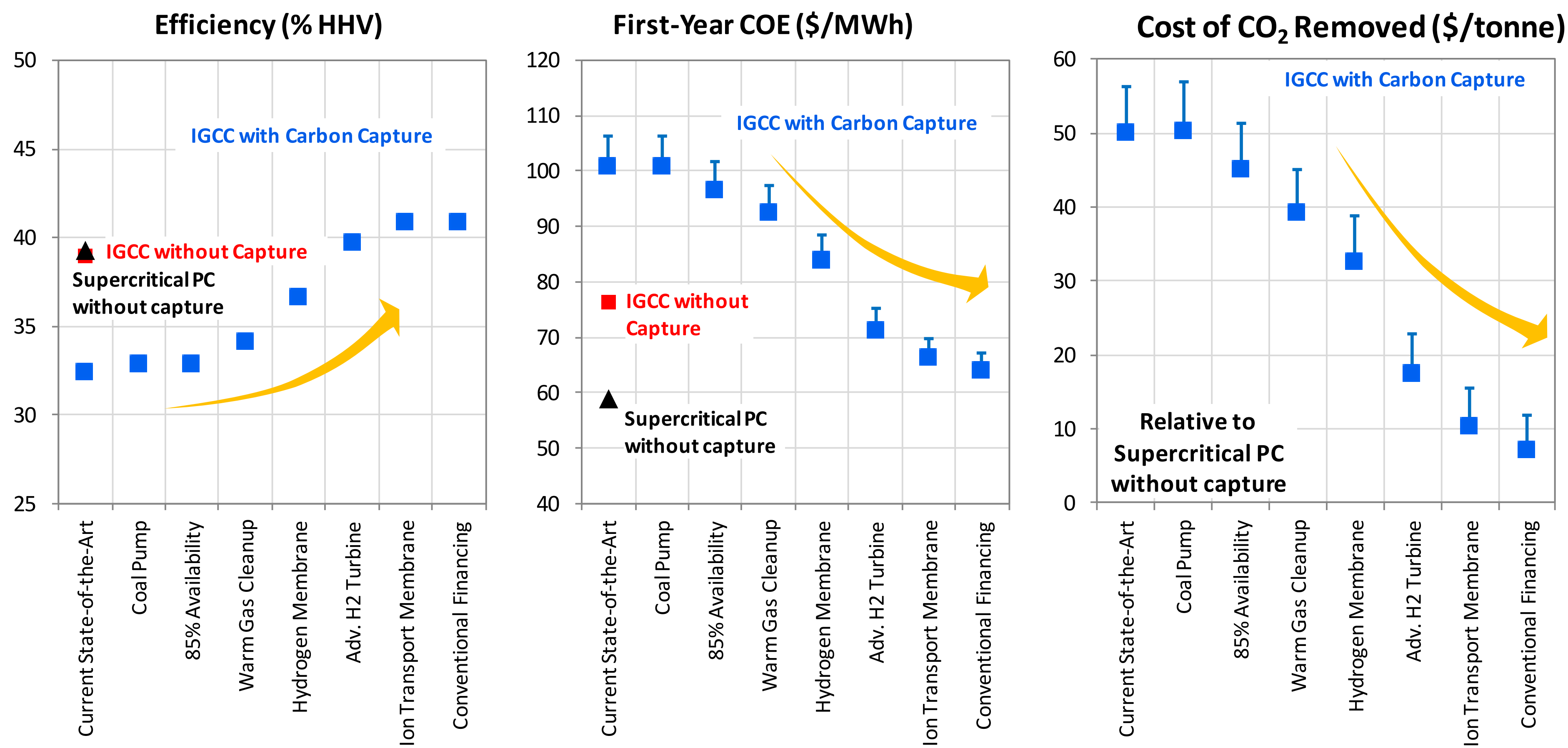
Clean Coal - Major U.S. Demonstrations

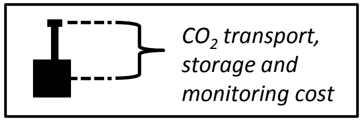


R&D program

Advanced IGCC Systems

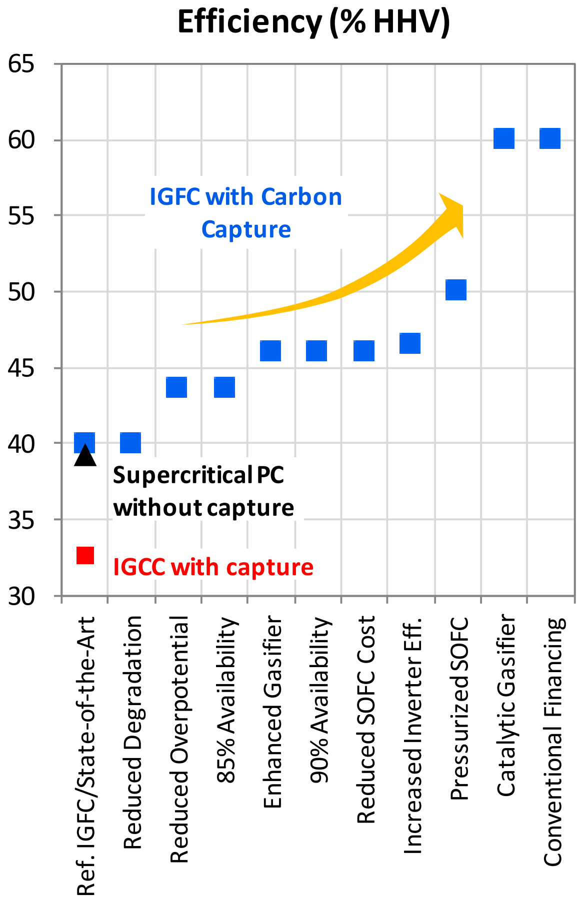
Driving Down the Cost

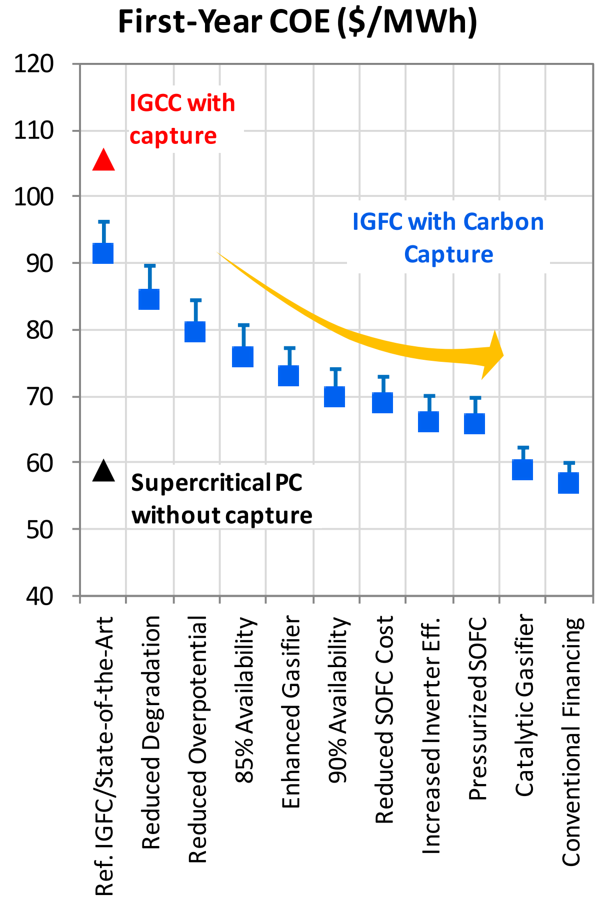


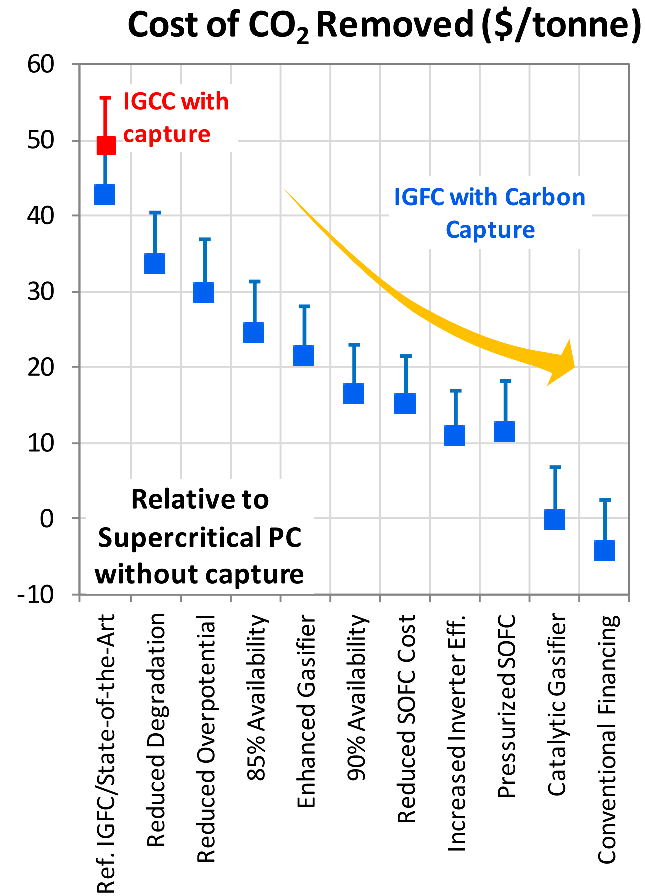


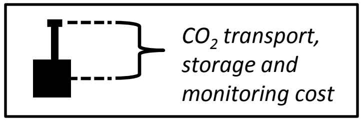
Advanced Gasification Fuel Cell Systems

Driving Down the Cost



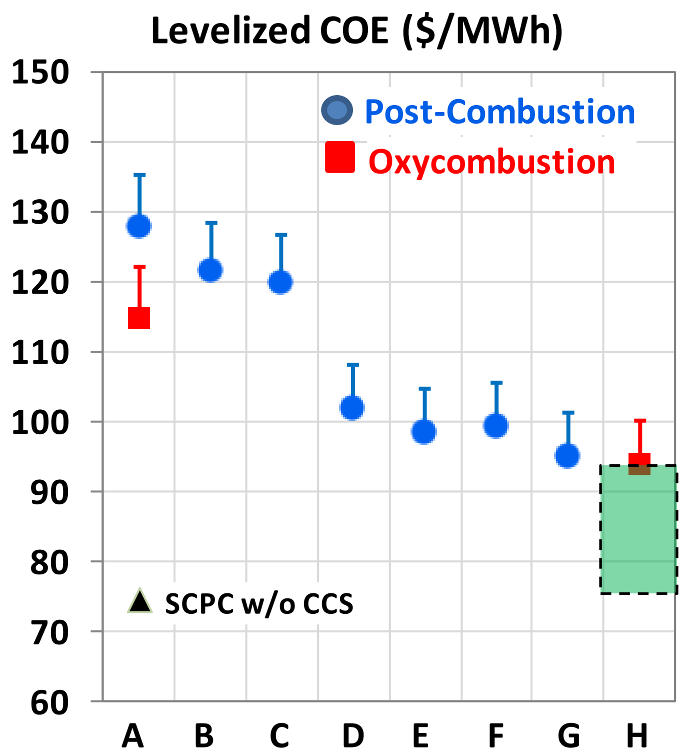


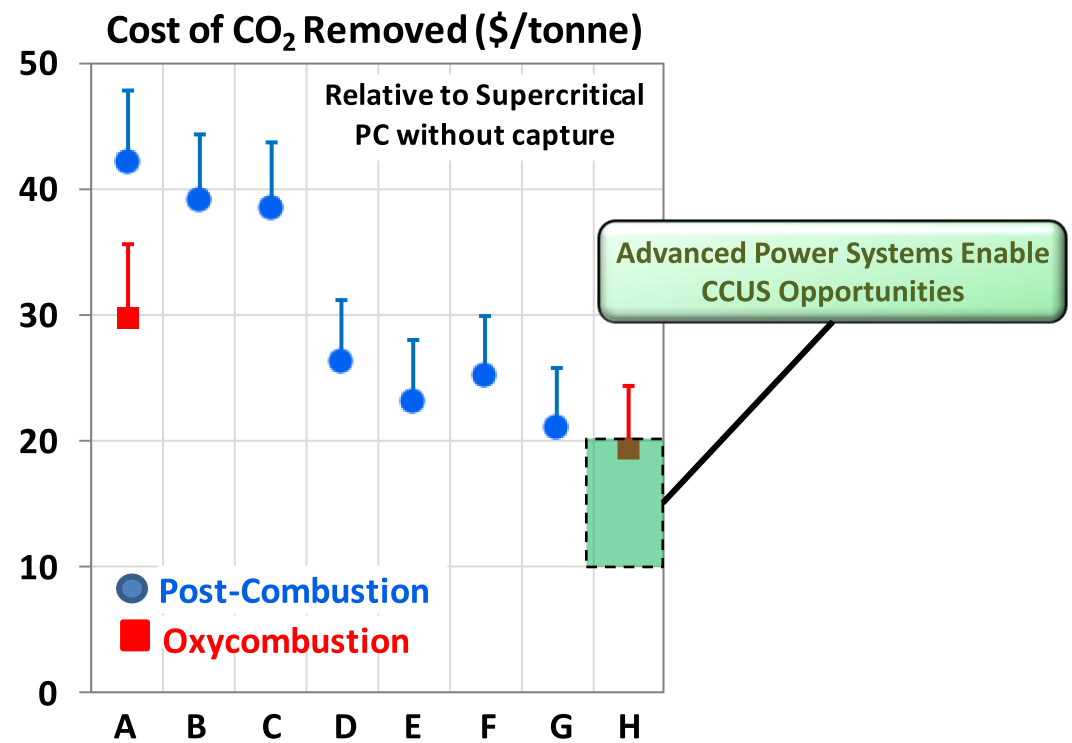




Low Cost Combustion Power Solutions

↓ *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