U.S. Department of Energy
Office of Fossil Energy

Central Plant Technologies and Carbon Capture Utilization and Storage (CCUS)
What's the Future

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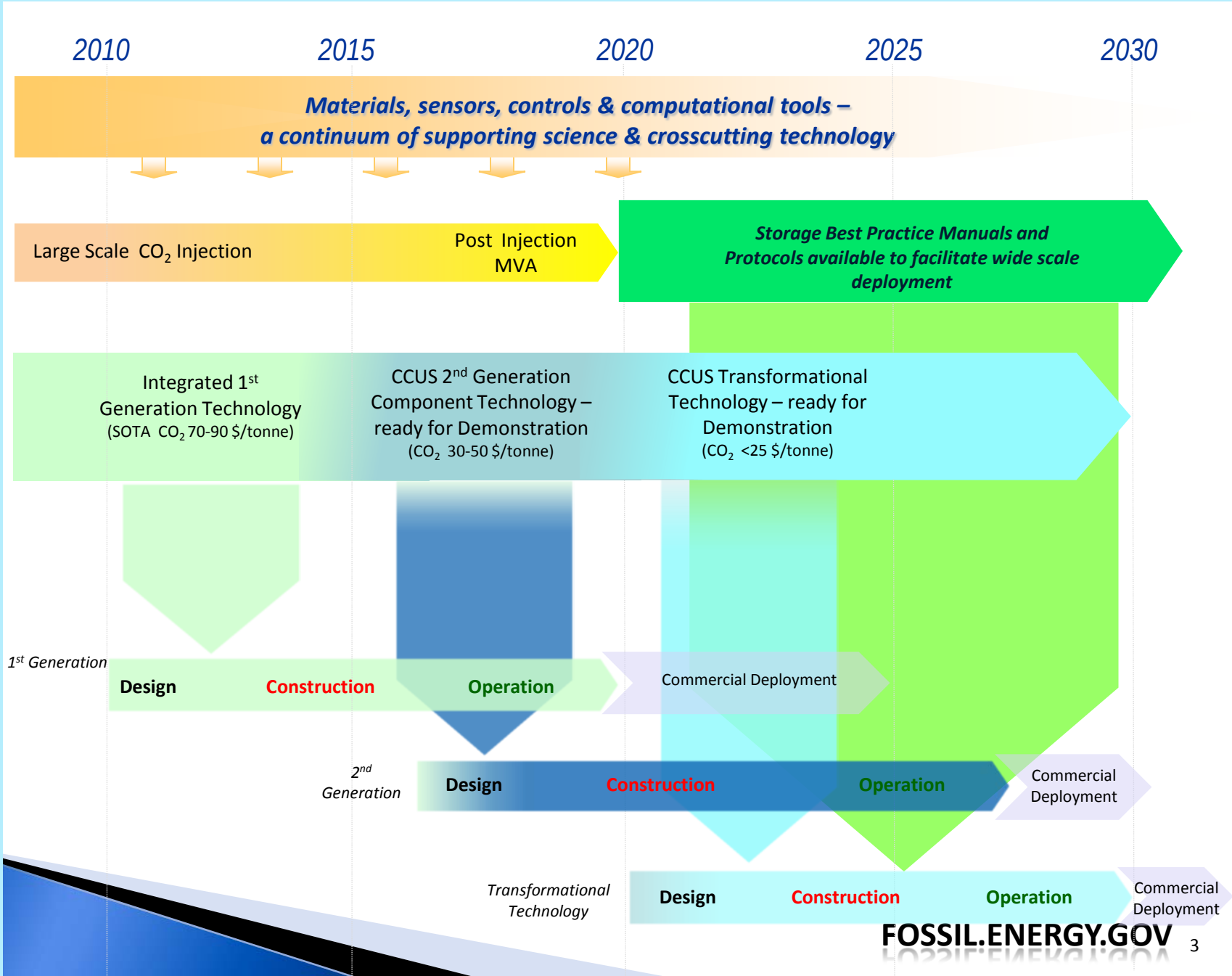
Meeting the President's Energy Goals

"This country needs an all-out, all-of-the-above strategy that develops every available source of American energy. A strategy that's cleaner, cheaper, and full of new jobs."

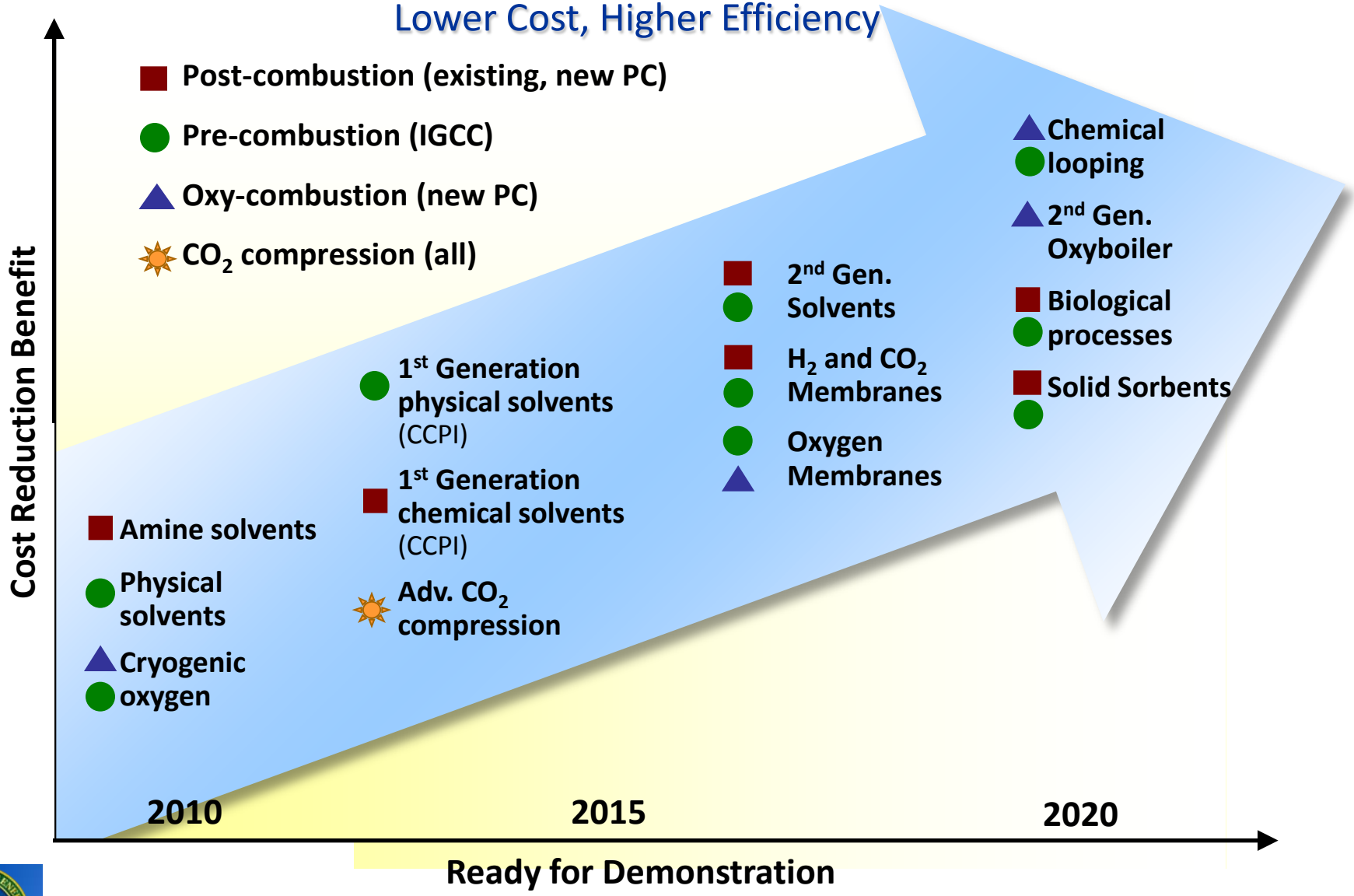
President Barack Obama
State of the Union Address
January 24, 2012

Photo courtesy of the White House, Pete Souza

Integrated Coal Program Technology Roadmap



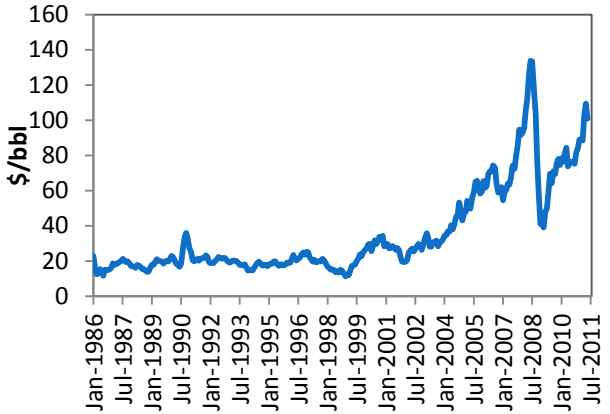
Advanced 2nd Generation CCS and Transformational Capture Technologies



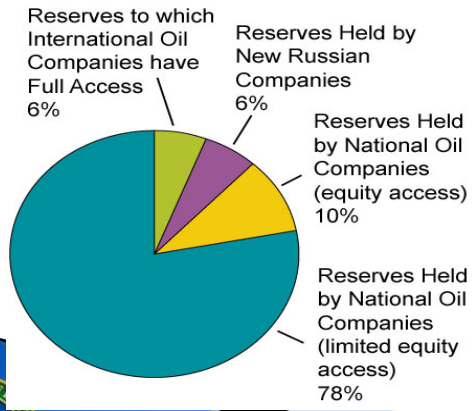
U.S. Energy Challenges

Energy Security

Monthly Spot Price OK WTI

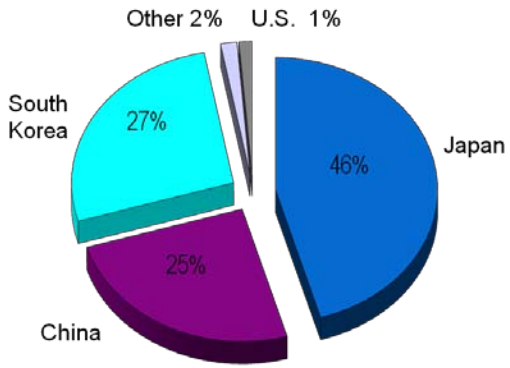


Share of Reserves Held by NOC/IOC

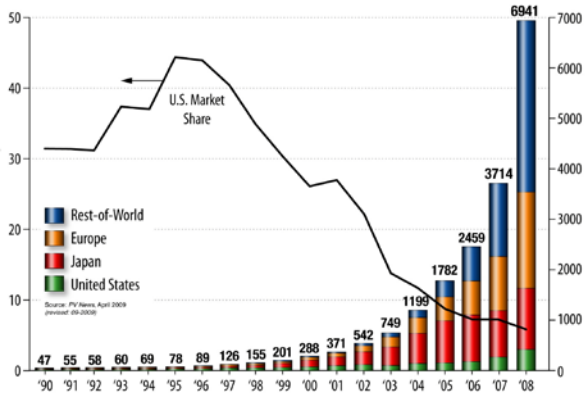


Competitiveness

Global Lithium-ion Battery Manufacturing (2009)

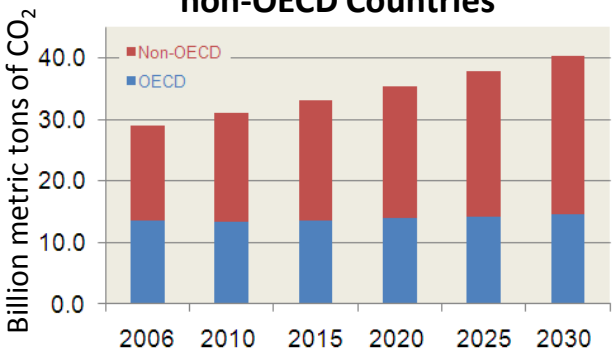


Worldwide Shipments of Solar Photovoltaics (MW)

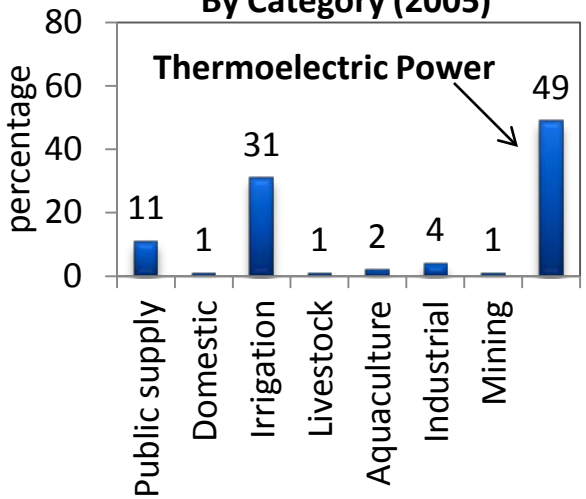


Environmental Impacts

CO_2 Emissions in OECD vs. non-OECD Countries

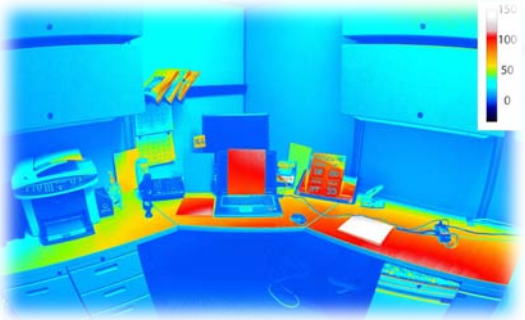


Water Withdrawals in % By Category (2005)



Technology Headroom for DOE

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

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

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

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

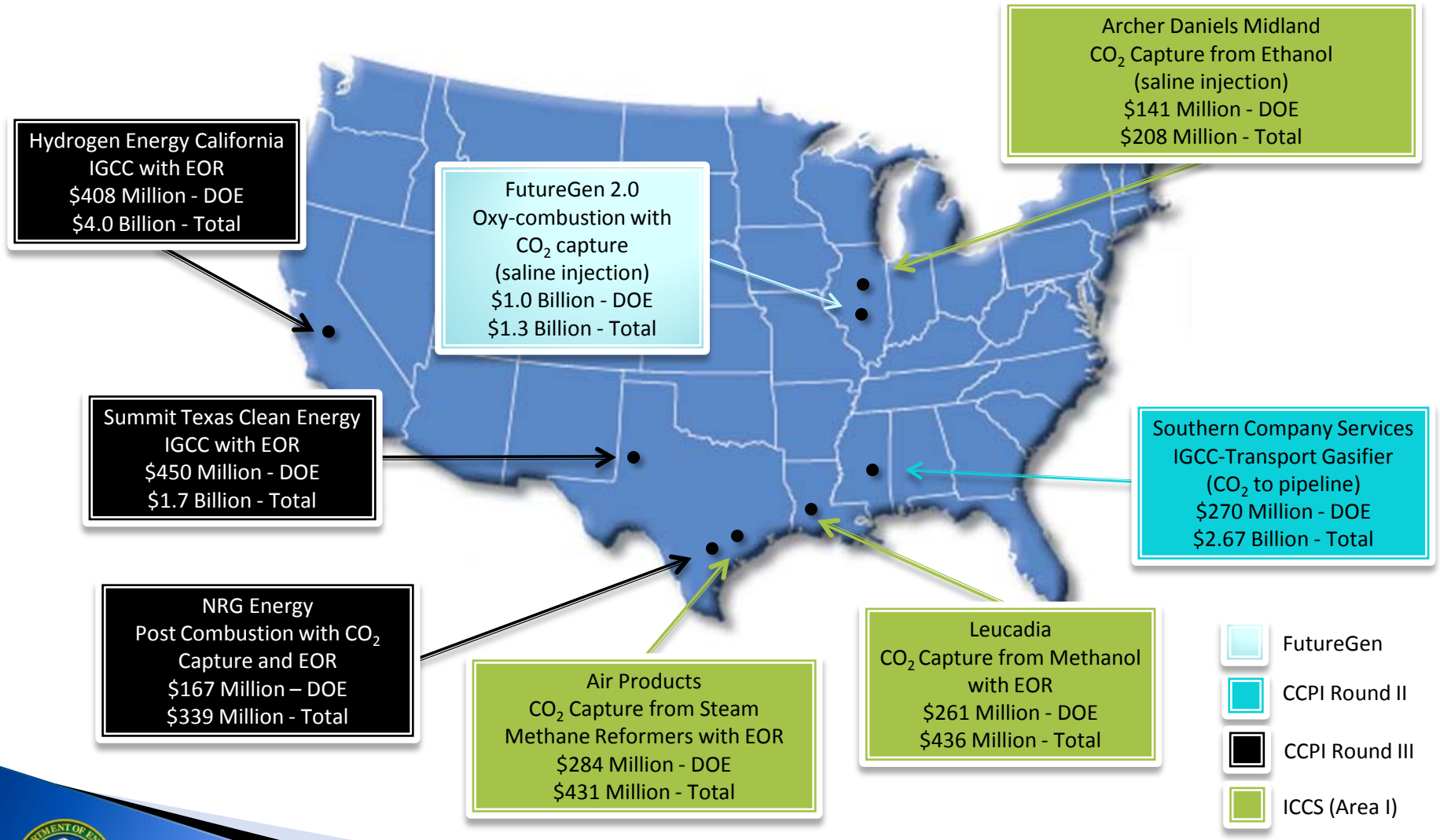
Carbon Capture Cost can support a long-term business case to invest.

Clean Coal - Major U.S. Demonstrations

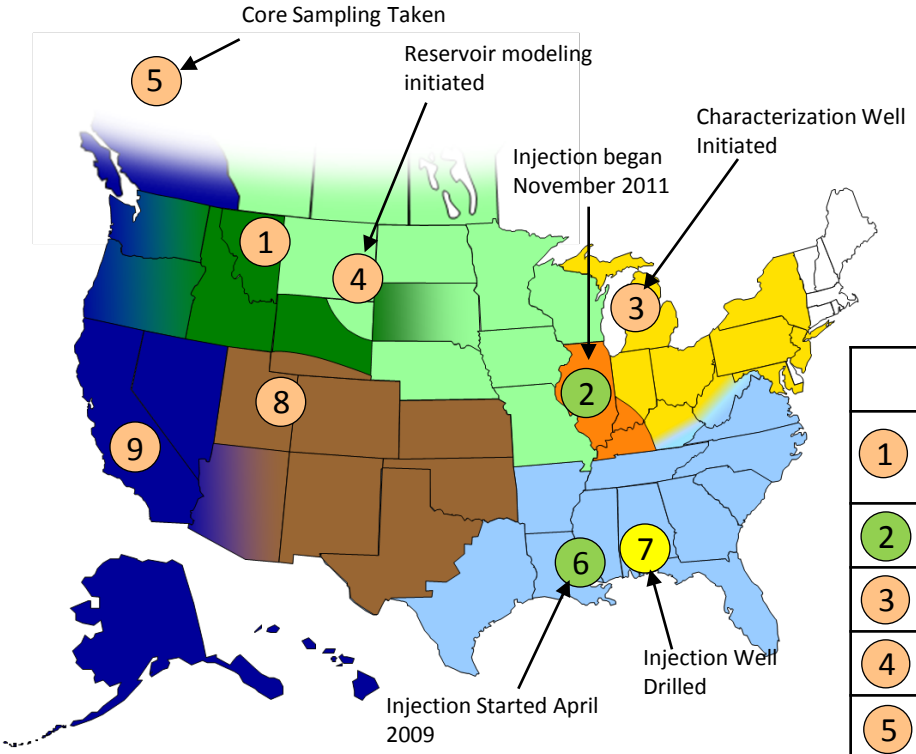
- Large-Scale Geologic CO_2 Storage
- CO_2 Capture from Industrial Facilities
- Post-Combustion Capture with Enhanced Oil Recovery
- IGCC with Enhanced Oil Recovery
- Oxy-combustion
- Monitoring, Verification, and Accounting (MVA)
- IGCC with CO_2 Capture (to pipeline)

Advanced Technology for Carbon Capture, Utilization and Storage

Clean Coal - Major U.S. Demonstrations



Regional Carbon Sequestration Partnerships
Phase III: Development



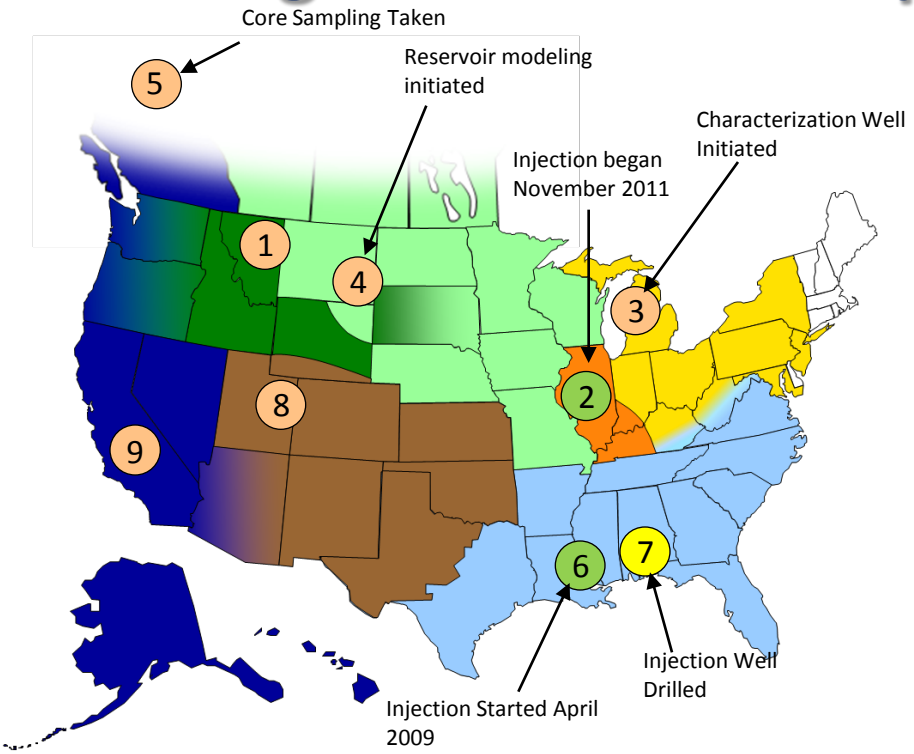
- ✓ Large-volume tests
- ✓ One injection commenced April 2009; another in November 2011
- ✓ Remaining injections scheduled 2012-2015

	Partnership	Target Injection Volume (tonnes)
1	Big Sky	1,000,000
2	MGSC	1,000,000
3	MRCSP	1,000,000
4	PCOR	1,500,000
5		1,000,000
6	SECARB	2,402,000
7		300,000
8	SWP	1,000,000
9	WESTCARB	TBD

- Injection Ongoing
- 2012 Injection Scheduled
- Injection Scheduled 2012-2015

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

Addressing Storage Challenges: Regional Carbon Sequestration Partnerships



- Injection Ongoing
- 2012 Injection Scheduled
- Injection Scheduled 2012-2015

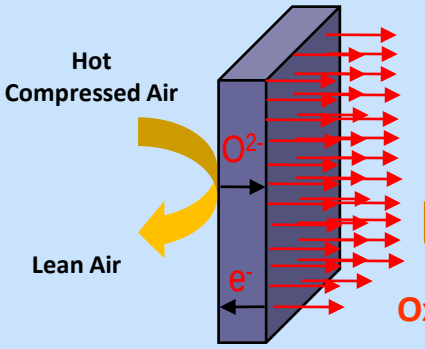
Note: Some locations presented on map may differ from final injection location

- 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 Capture Utilization and Storage R&D program

Key Gasification R&D Areas

Oxygen Membrane

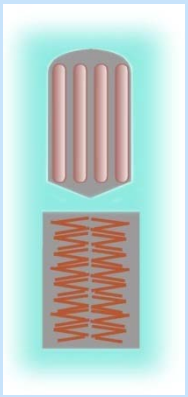


Oxygen

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

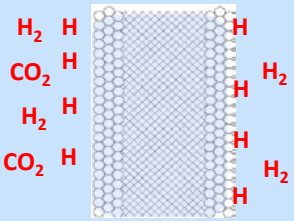
Warm Gas Cleaning

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



Fuel Gas

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

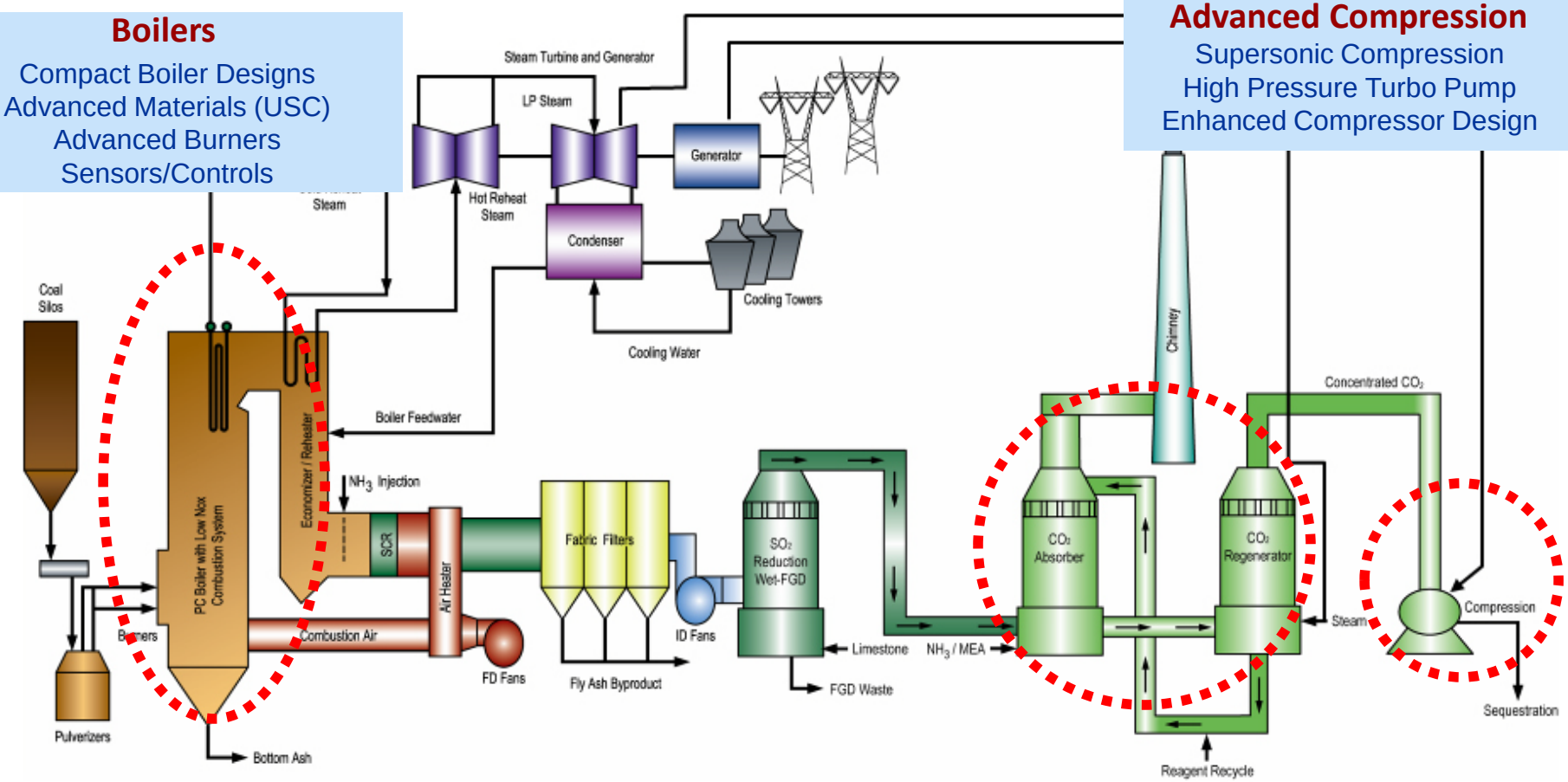
Combustion System
Pulverized Coal with CCS

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

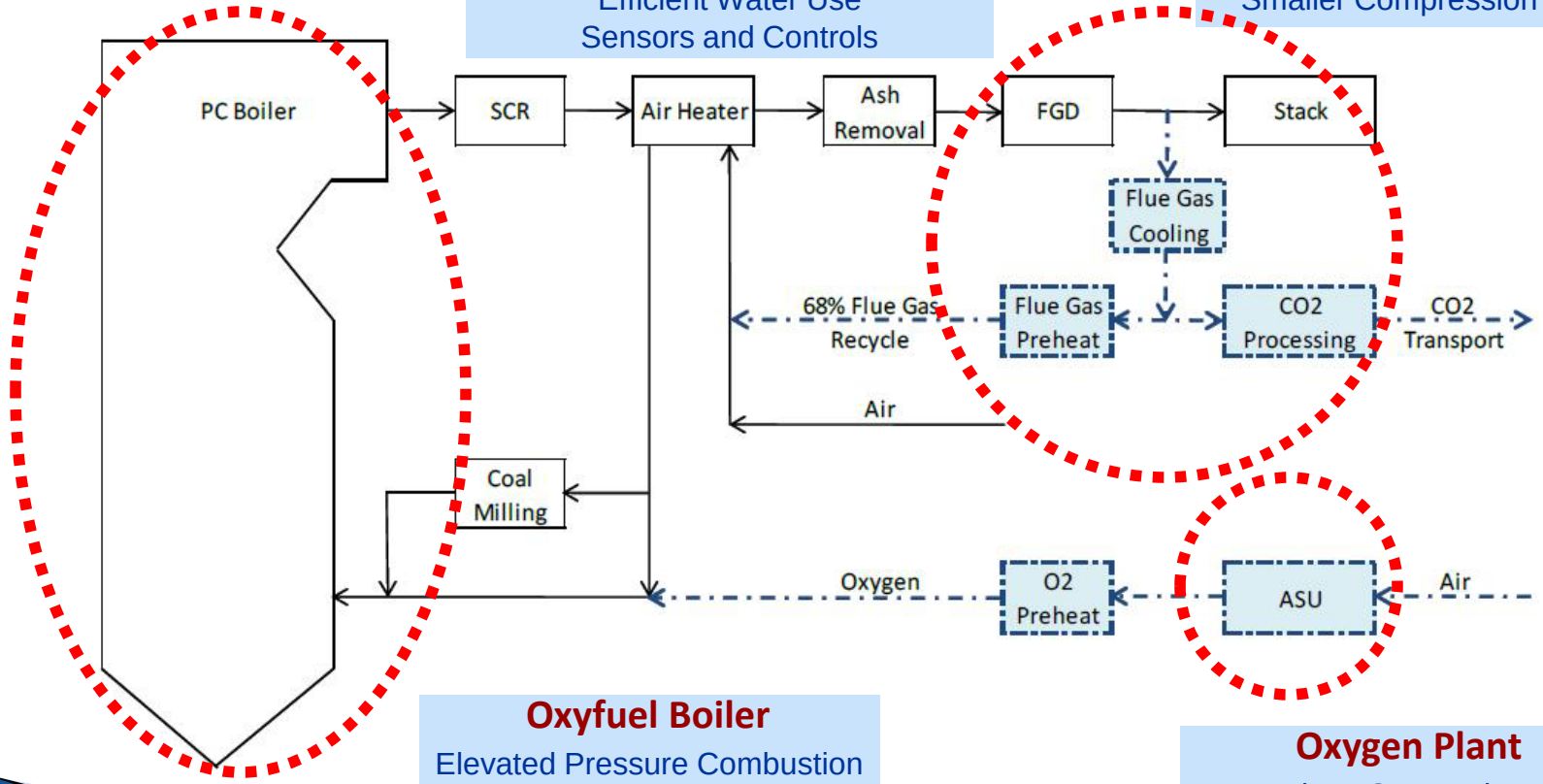
Combustion System
Oxycombustion with CCS

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

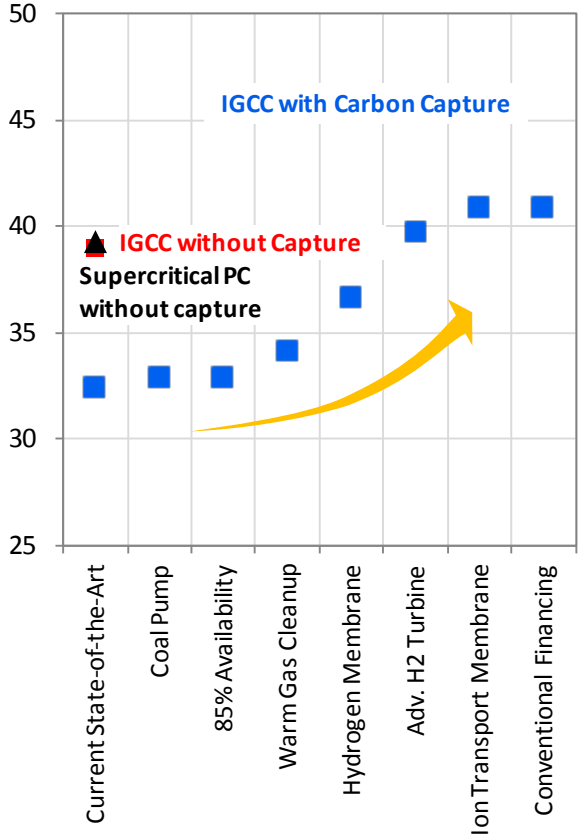
Oxygen Plant

Reduce Cost and Load

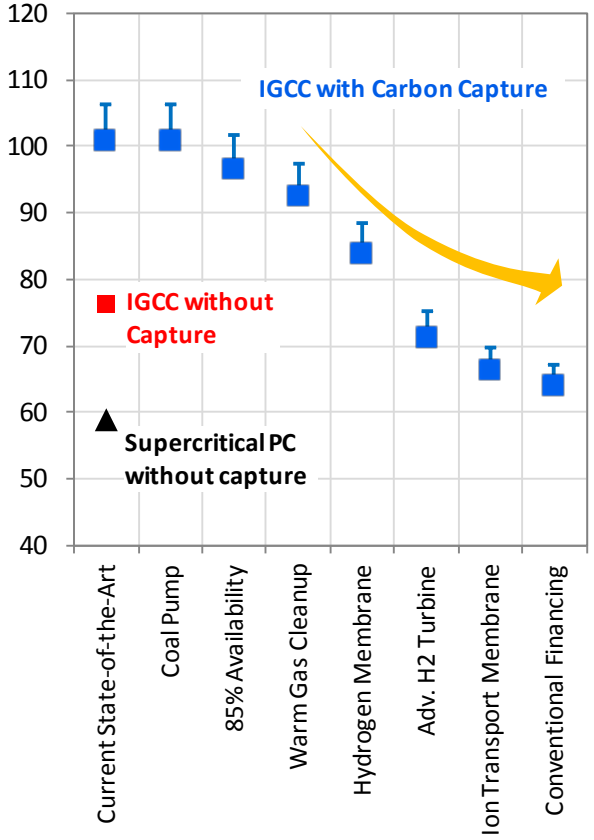
Advanced IGCC Systems

Driving Down the Cost

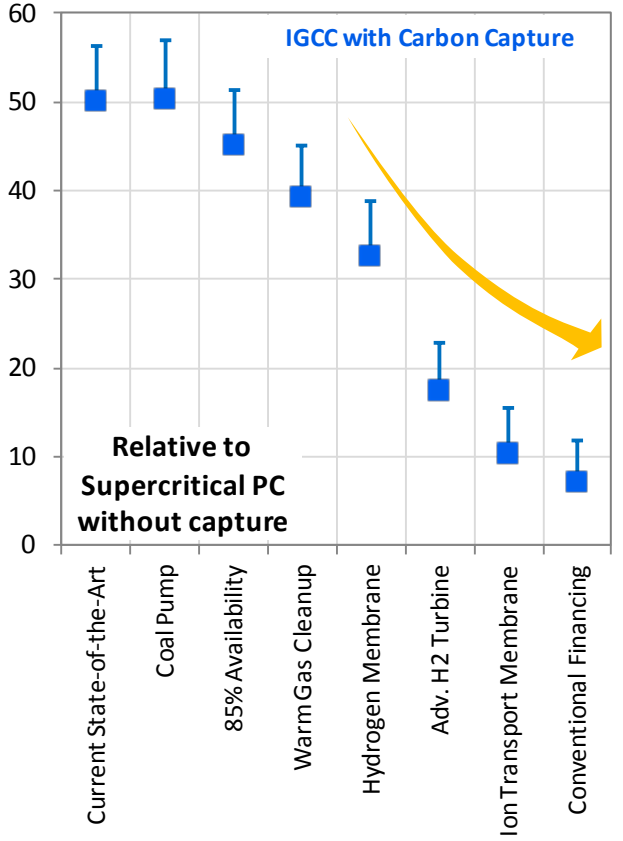
Efficiency (% HHV)

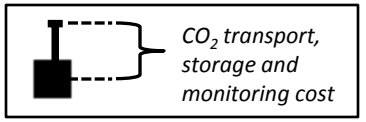


First-Year COE ($/MWh)



Cost of CO_2 Removed ($/tonne)





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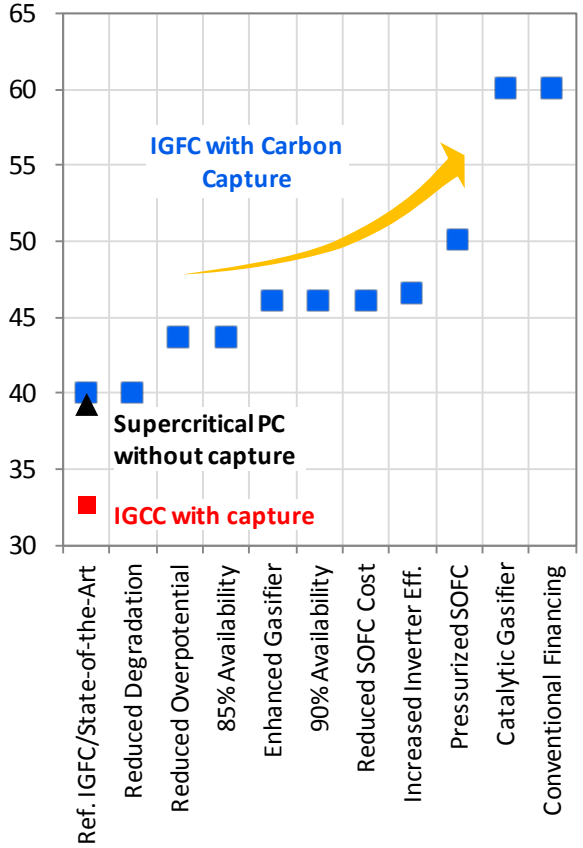
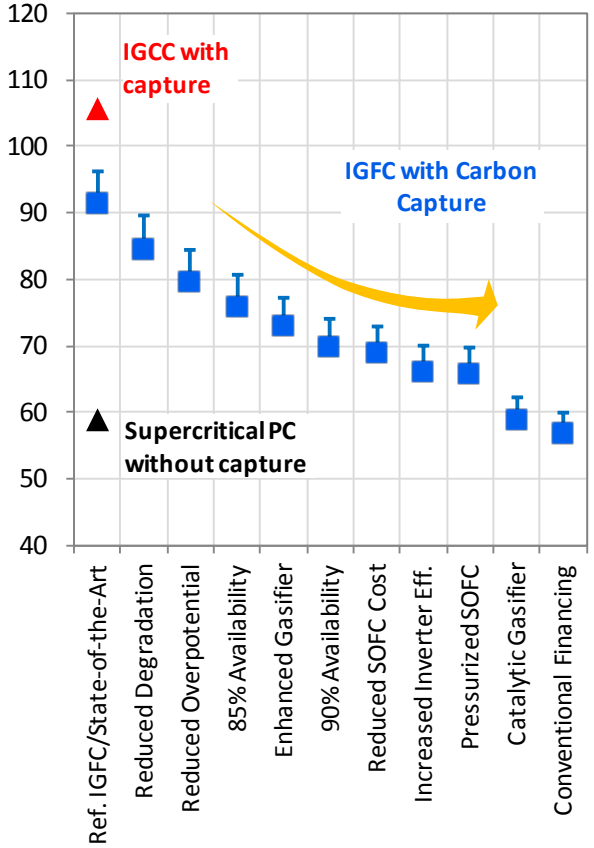
Advanced Gasification Fuel Cell Systems

Driving Down the Cost

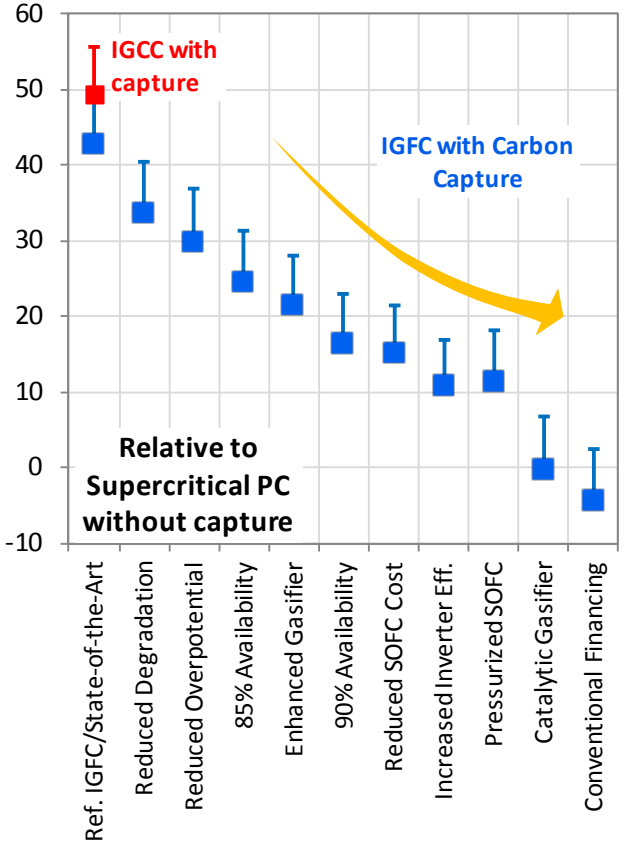
Efficiency (% HHV)

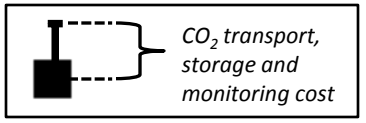


First-Year COE ($/MWh)



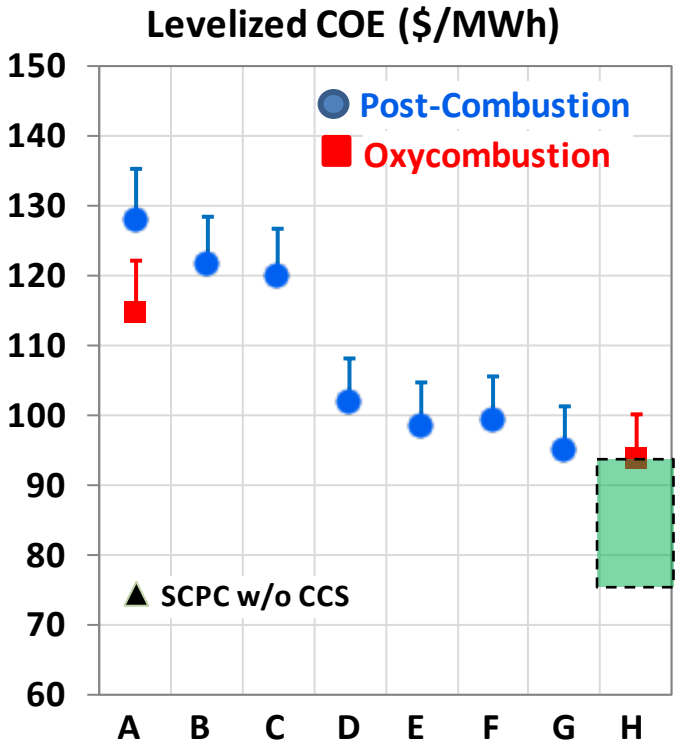
Cost of CO_2 Removed ($/tonne)

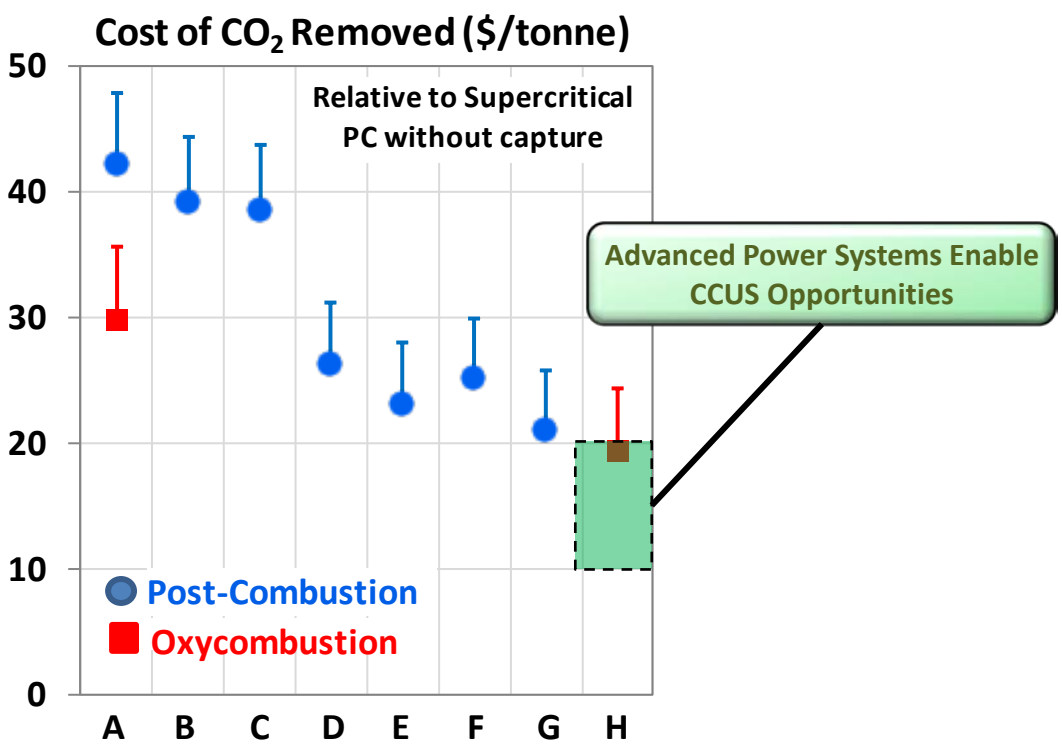




Low Cost Combustion Power Solutions

↓ 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

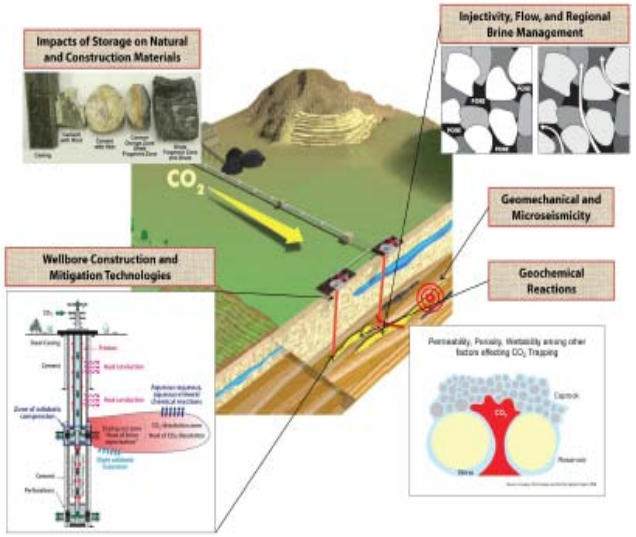
Carbon Storage Program – Core R&D

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

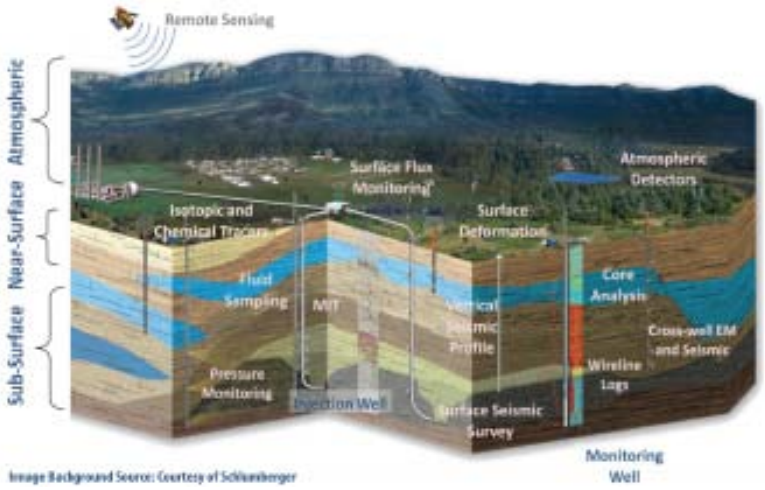


CO_2 Utilization

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

Simulation and Risk Assessment

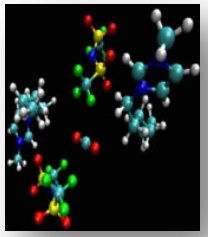
- Thermal and hydrologic fate and transport
- Geochemical simulations
- Geomechanical simulations
- Predicting biologic impacts on storage formations
- Risk assessment and quantification

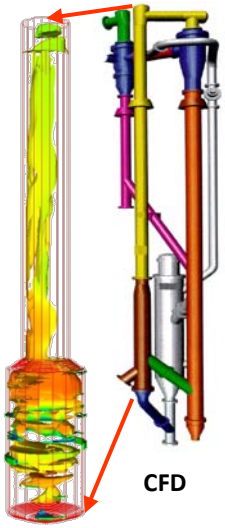


Carbon Capture Simulation Initiative (CCSI) and National Risk Assessment Partnership (NRAP)

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

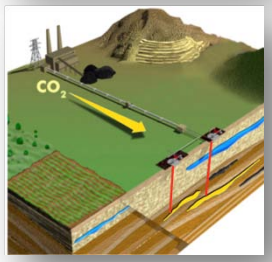
First Principles





CFD

Process Simulation



NRAP

Commercial Plants

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

Accelerate learning during development & deployment

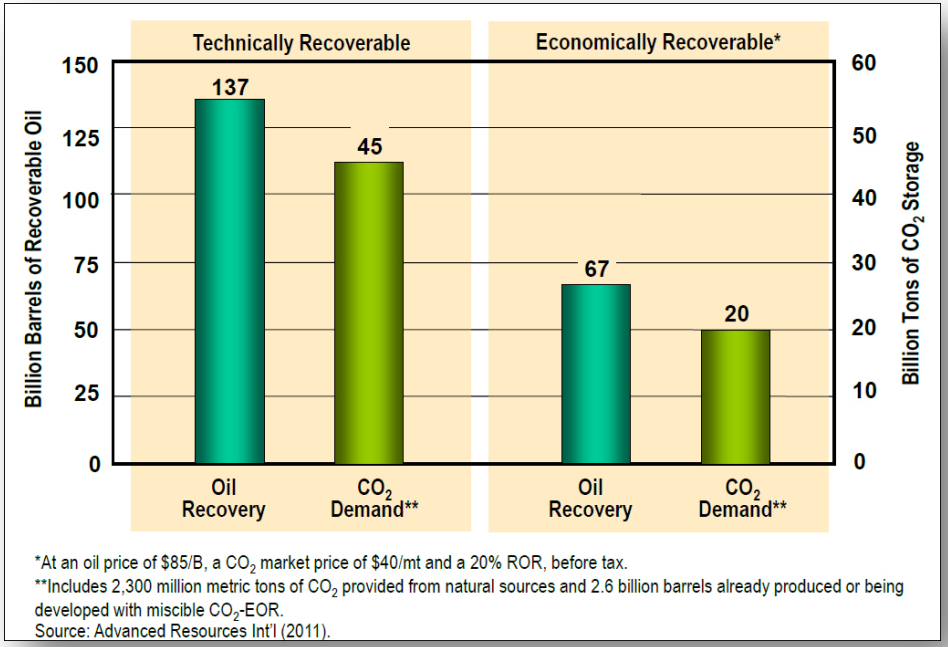
NETL · Berkeley Lab · Los Alamos National Laboratory (Est. 1943) · Lawrence Livermore National Laboratory (Science in the National Interest) · Pacific Northwest National Laboratory

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

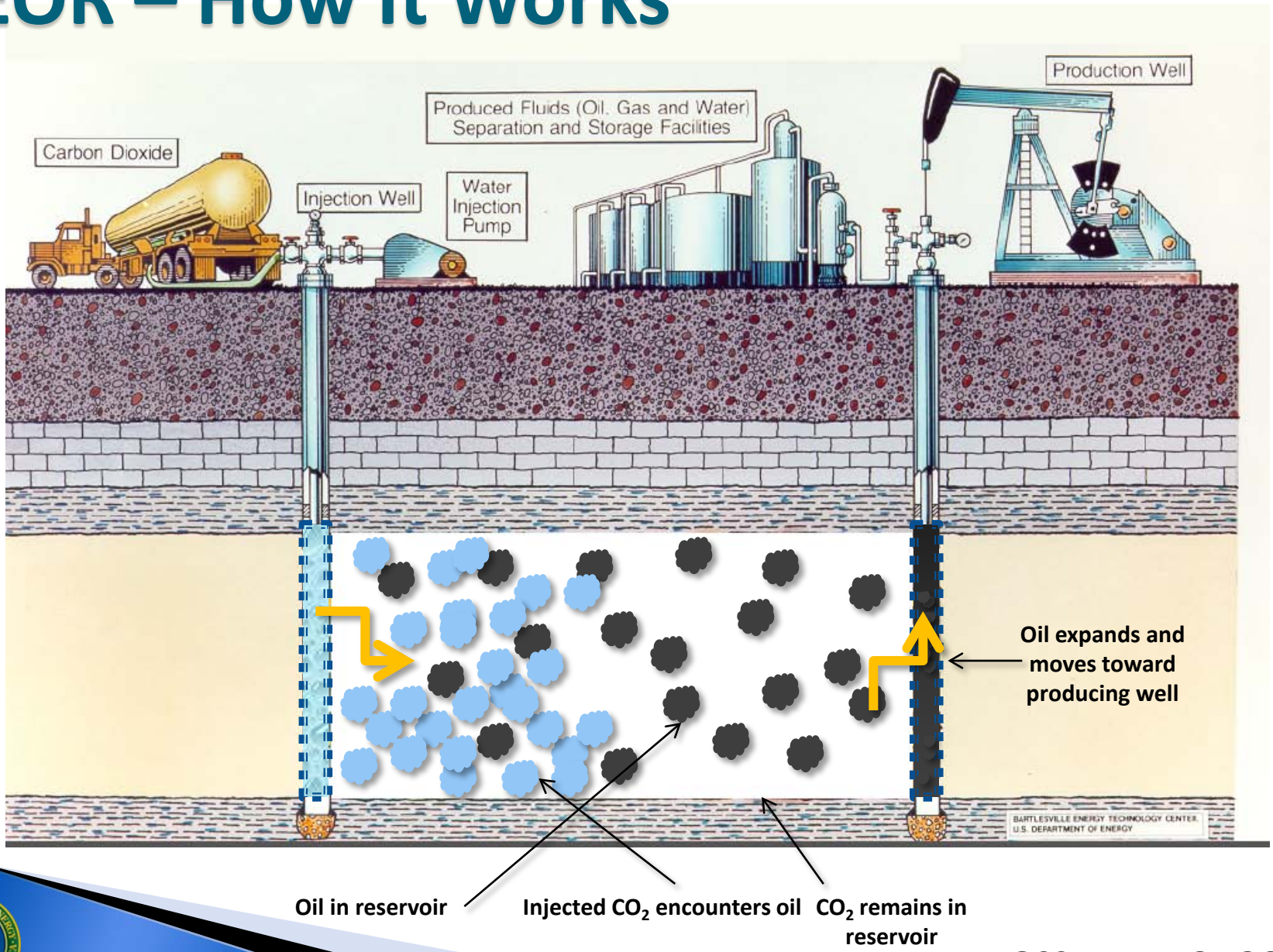
[1] *Source: U.S. Carbon Sequestration Council*

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).

EOR – How It Works



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.