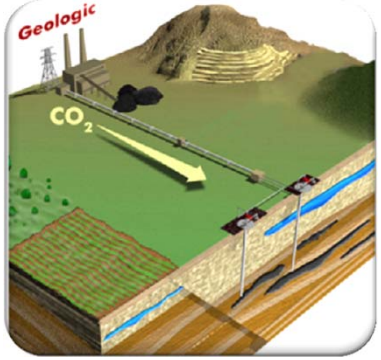


Rising to the Challenge of Climate Change: The Role of Innovation

Dr. Darren Mollot

Director, Office of Clean Energy System
Office of Fossil Energy

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We live in a time of energy abundance
Once in a generation opportunity to build

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

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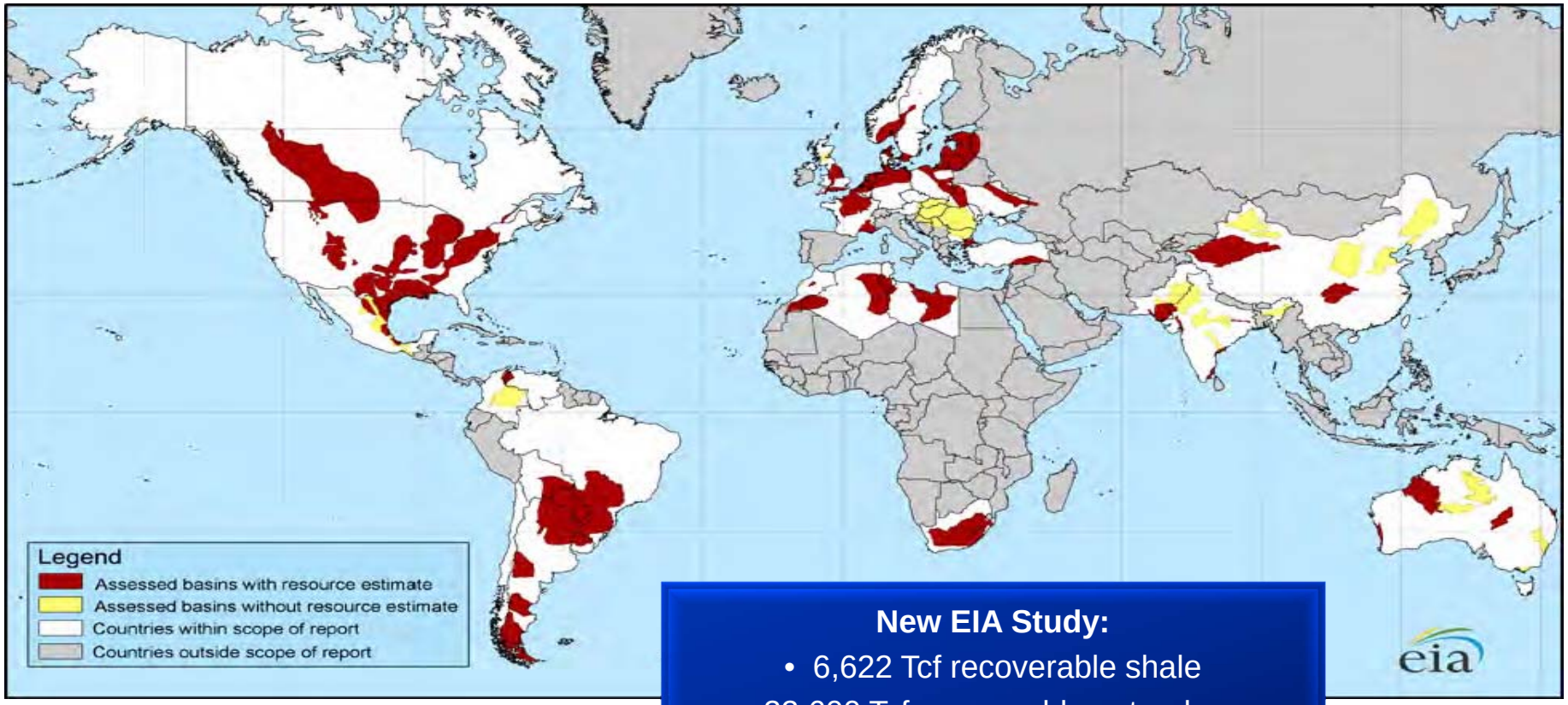
A Global Resource – Could Transform the World



New EIA Study:

- 6,622 Tcf recoverable shale
- 22,600 Tcf recoverable natural gas

Global shale adds 40%!

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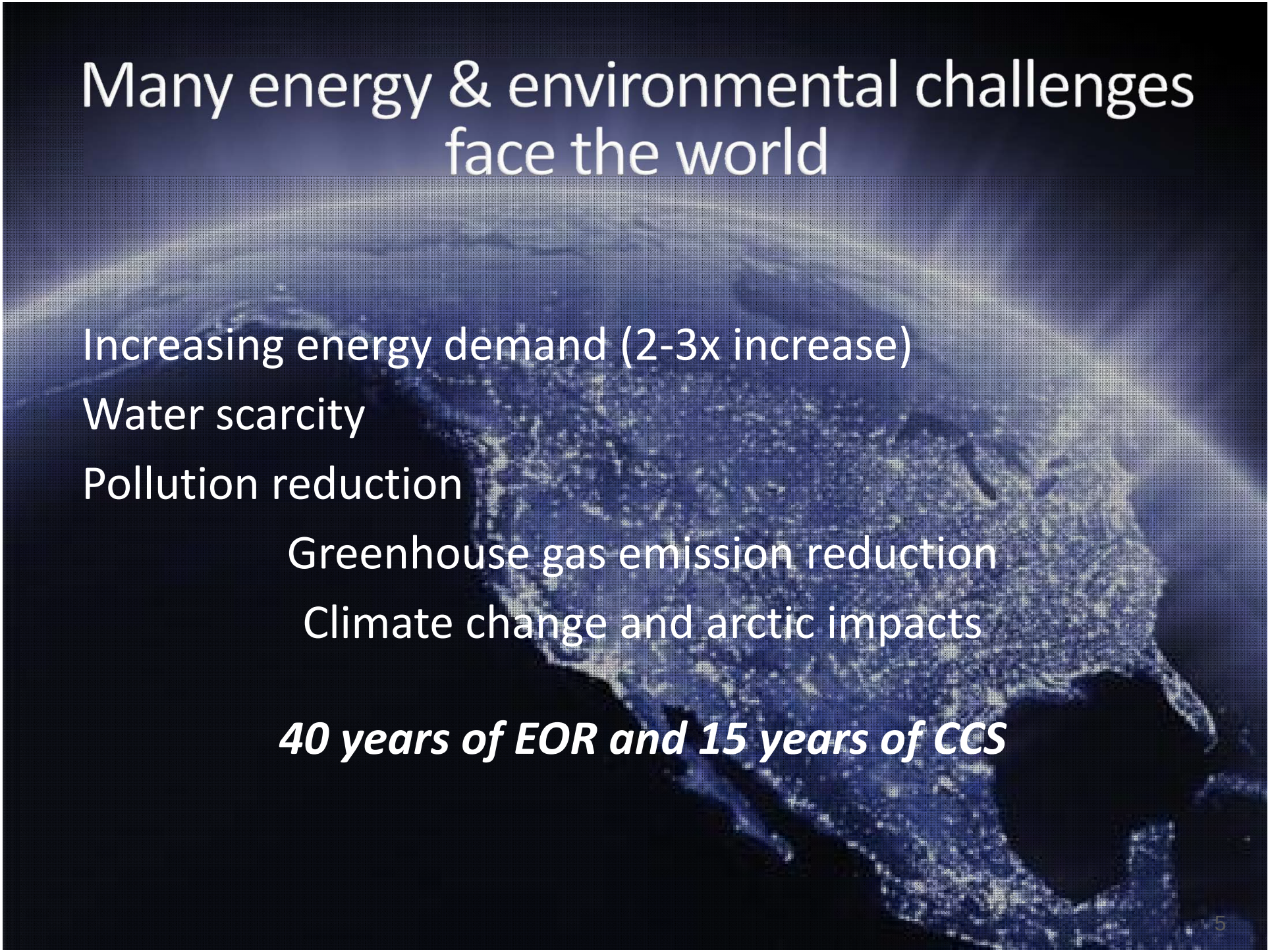
Many energy & environmental challenges face the world



Increasing energy demand (2-3x increase)

Water scarcity

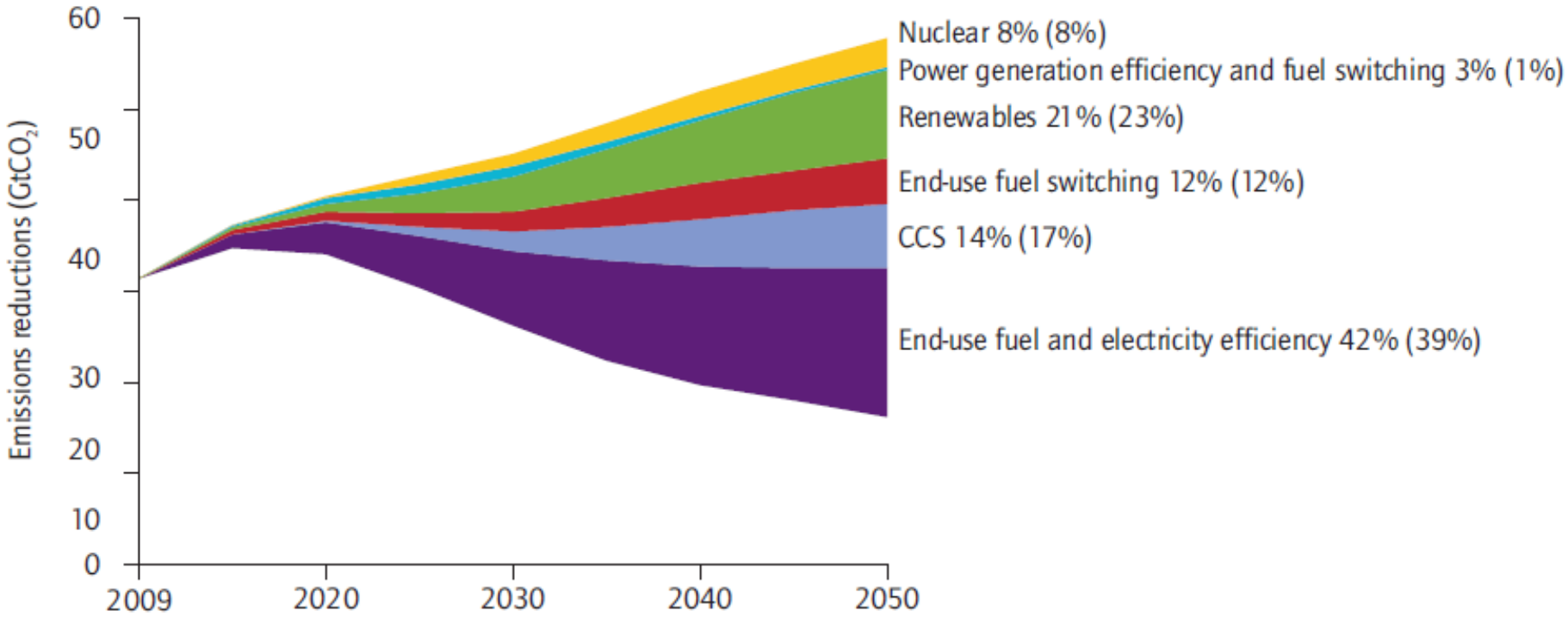
Pollution reduction

Greenhouse gas emission reduction

Climate change and arctic impacts

40 years of EOR and 15 years of CCS

IEA CCS Roadmap 2013: Key Technologies for Reducing Global CO_2 Emissions



Most 2050 climate budgets require CCS from NatGas power

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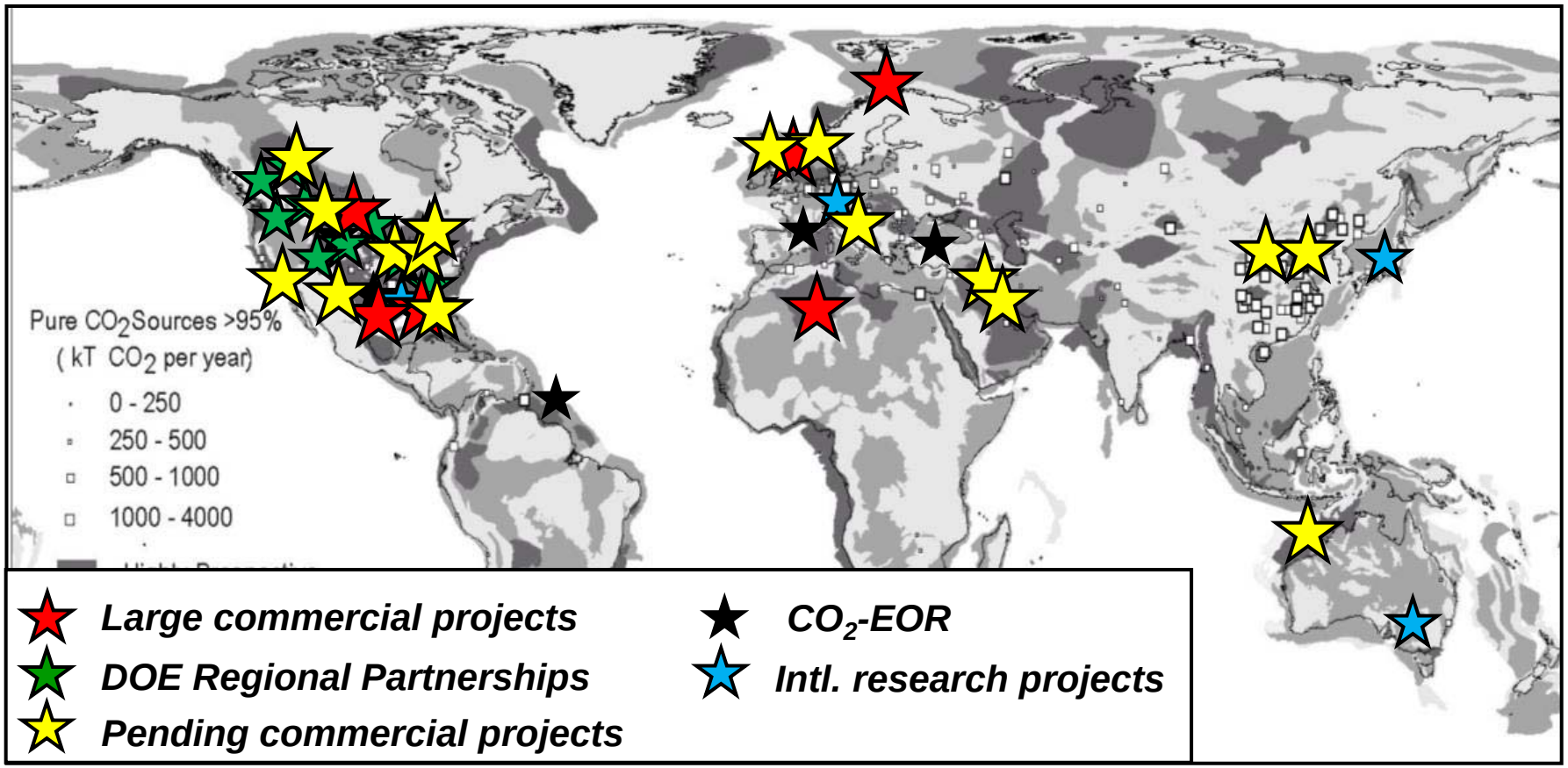
Source: IEA Roadmap 2013.
Note: Numbers in brackets are shares in 2050. For example, 14% is the share of CCS in cumulative emission reductions through 2050, and 17% is the share of CCS in emission reductions in 2050, compared with the 6DS.

The US and international community have deployed over a dozen large CCS projects



Key unit of innovation – global engines of discovery

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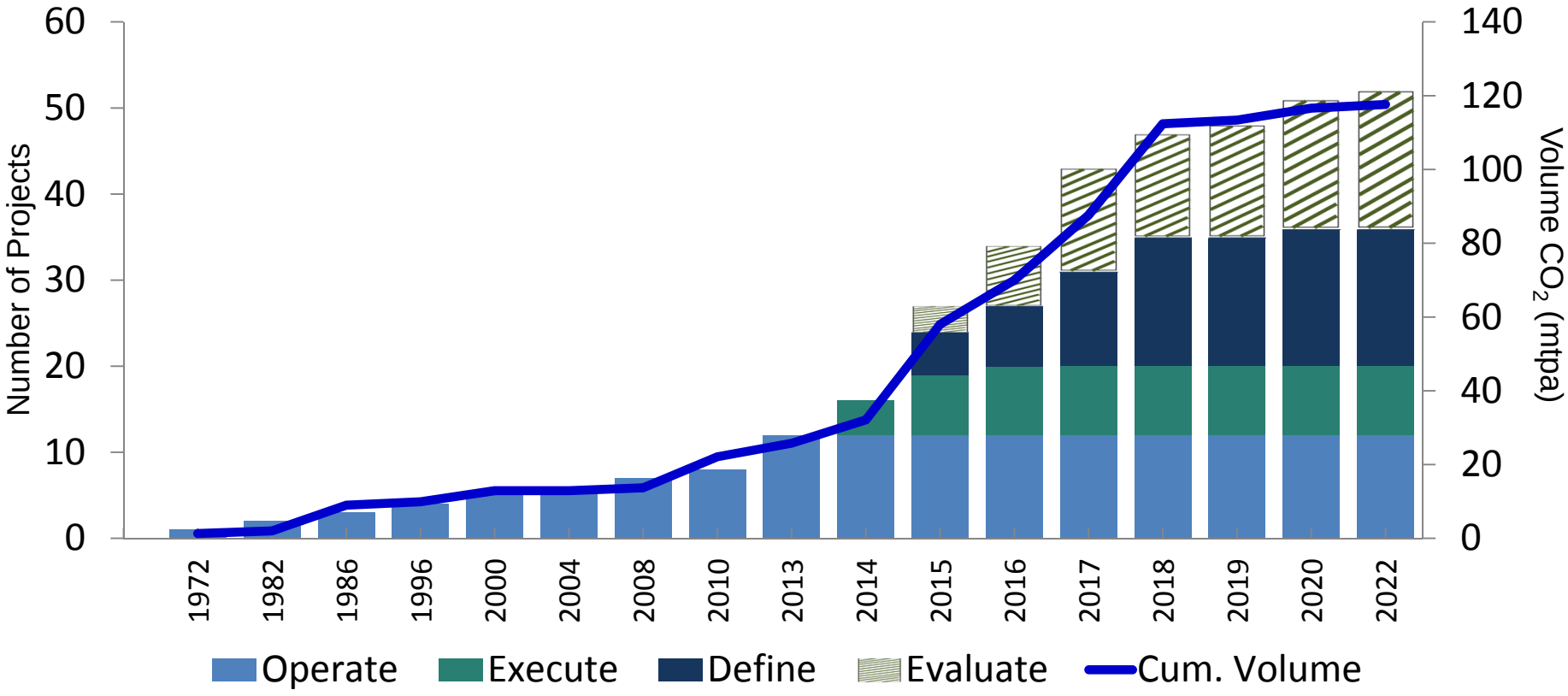
Large Scale Integrated Projects World Wide



Data from Global CCS Institute

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DOE Office of Fossil Energy Clean Coal Program

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DOE/FE's Clean Coal and CCS Mission

Success of the demos

- Serial # 1 in operation 2013-2018
- A deep and rich set of public learning

R&D – Making CCS technology widely adopted

- Intrinsic Capture of CO2 e.g. Advanced combustion
- Dramatic reductions in size, reliability, and cost
- Ensure storage is safe and permanent

New mode: delivering solutions

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Integrated Fossil Energy Solutions

Advanced Combustion

5 MWE Oxycombustion Pilot

- ❑ Pressurized
- ❑ O_2 membrane
- ❑ Chemical looping
- ❑ USC Materials

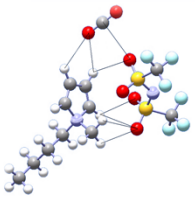
Advanced Energy Systems

- ❑ Gasification
- ❑ Turbines
- ❑ Supercritical CO_2
- ❑ Direct Power Extraction

Advanced Turbines

Efficiencies > 45%
↓ Capital Cost by 50%
$10 - $40/tonne CO_2 Captured
Near-zero GHGs
Near-zero criteria pollutants
Near-zero water usage

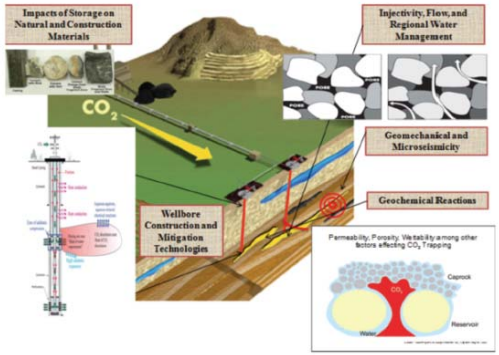
Advanced CO_2 Capture and Compression



- ❑ Solvents
- ❑ Sorbents
- ❑ Membranes
- ❑ Hybrid
- ❑ Process Intensification
- ❑ Cryogenic Capture

CO_2 Storage

- ❑ Carbon Utilization (EOR)
- ❑ Infrastructure (RCSPs
- ❑ Geological Storage
- ❑ Monitoring, Verificatio and Accounting



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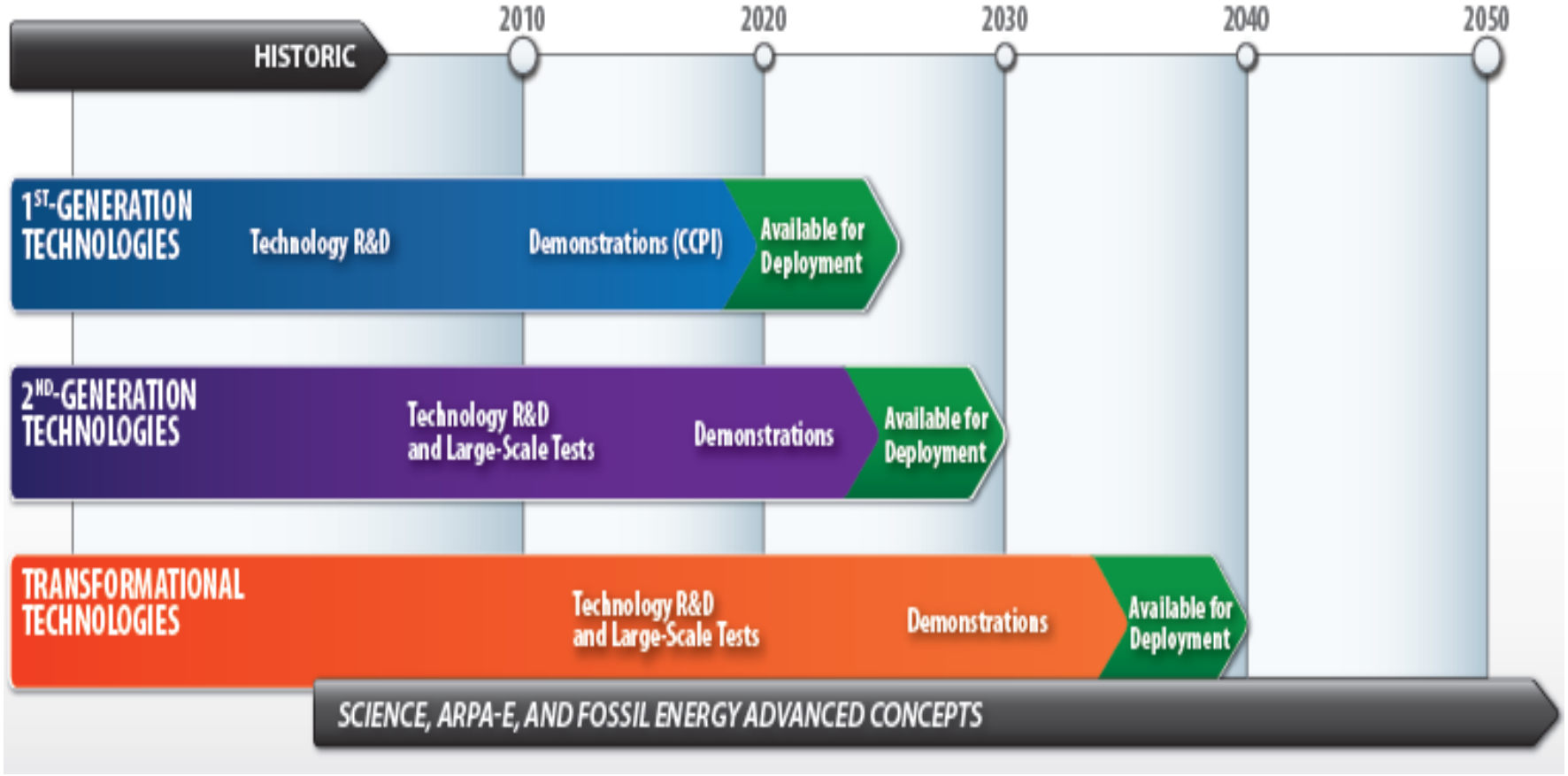
A technology pipeline for affordable CCS



We need more 2nd generation pilots!

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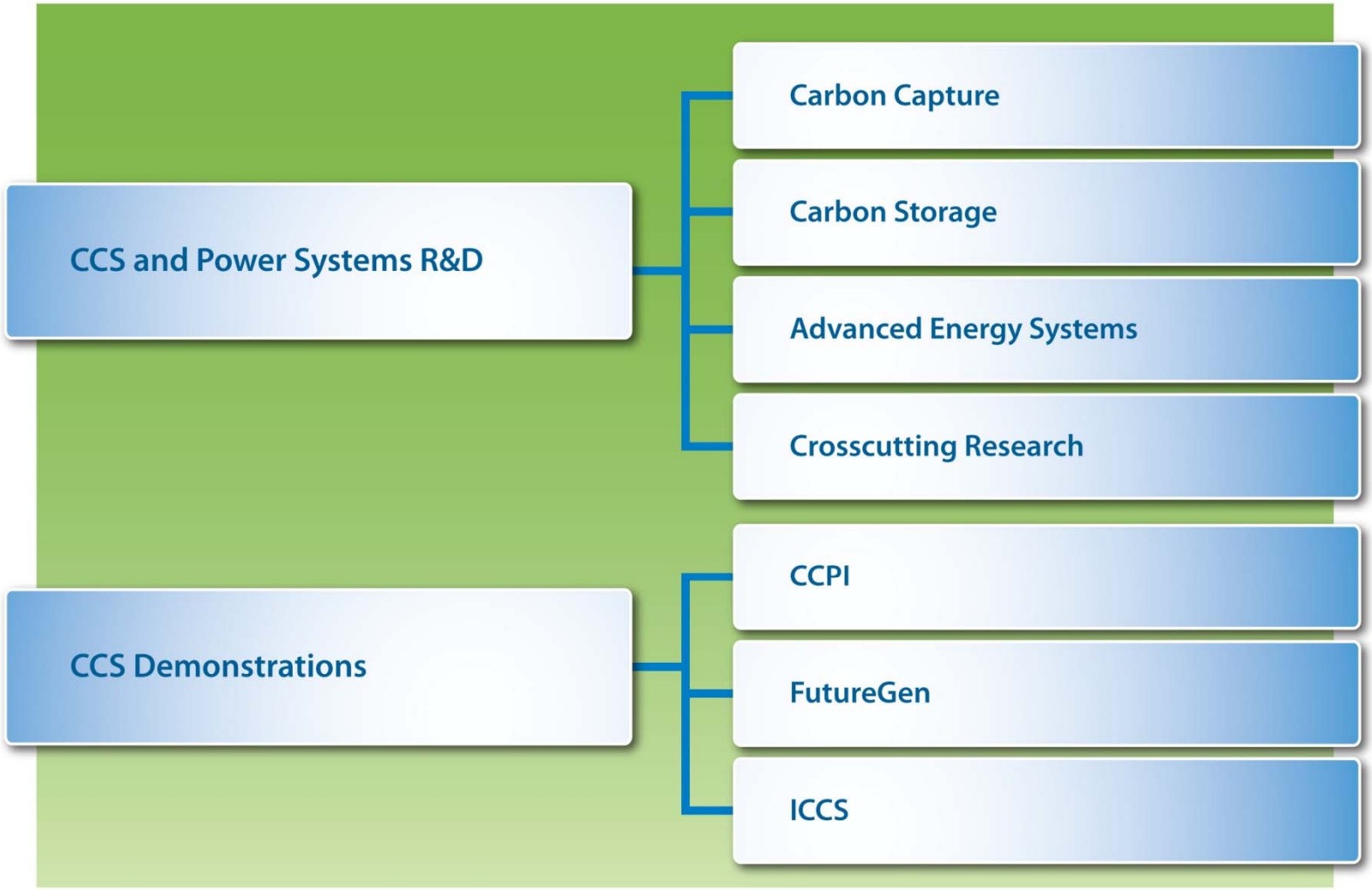
CLEAN COAL RESEARCH PROGRAM



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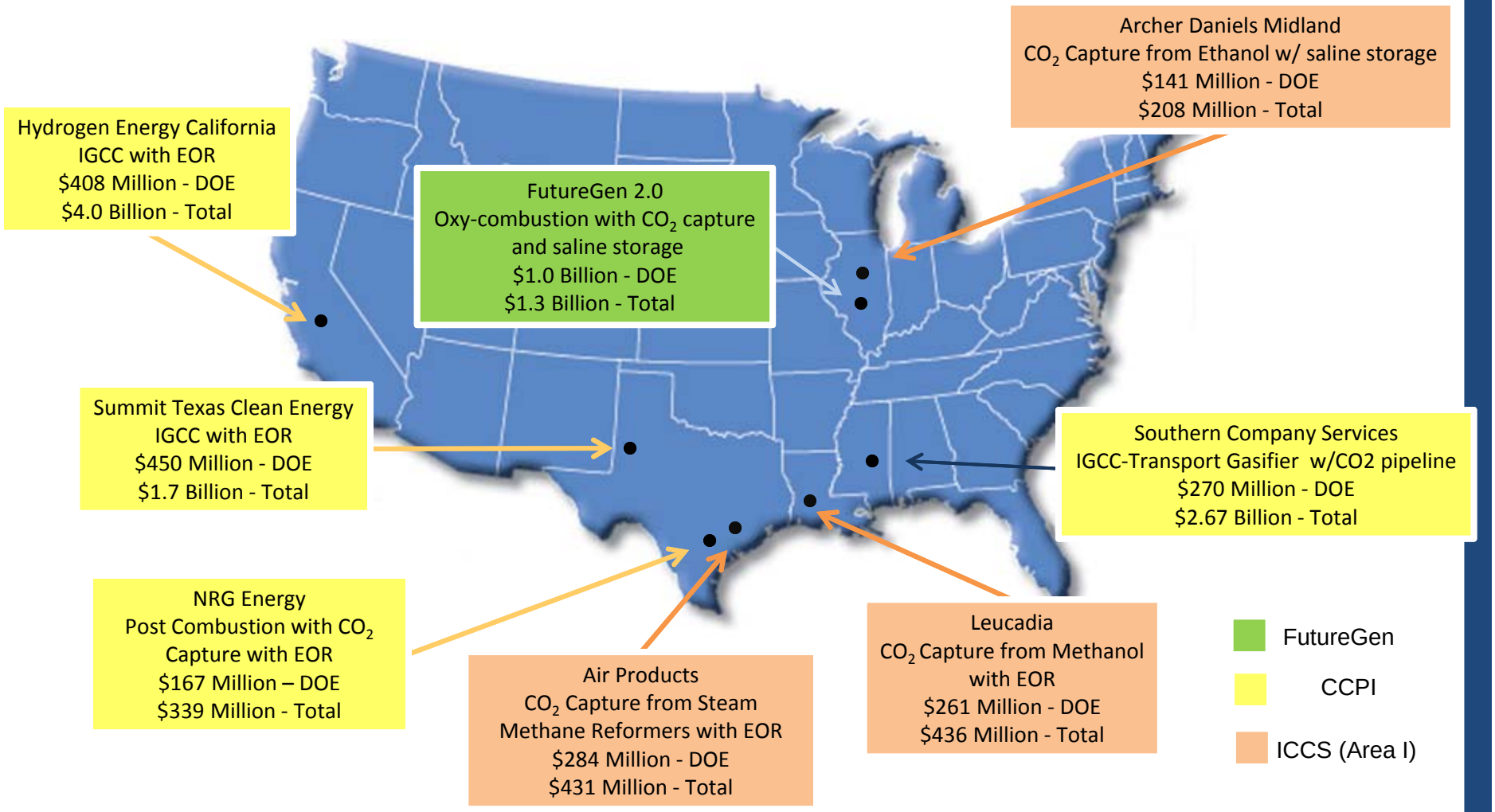
DOE CCUS Demonstration Projects

Focus – Large-scale commercial demonstration of CCUS integrated with coal power generation and industrial sources.



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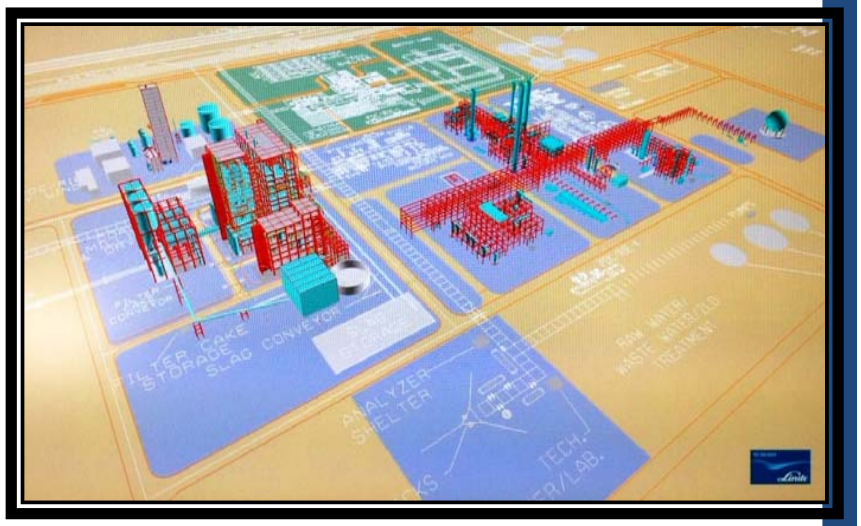
Major Demonstration Projects

Recipient	Project	Location	DOE Funding	Status	Storage Type	CO_2 Seq. (Metric Tons Per Year)	Storage Start
Air Products	Steam Methane Reformer Hydrogen Production	Port Arthur, TX	$284M	Operations	EOR	~925,000	2013
Southern Company Services (Kemper)	Integrated Gasification Combined Cycle (IGCC)	Kemper County, MS	$270M	Under Construction	EOR	~3,000,000	2014
Archer Daniels Midland	Ethanol Fermentation CO_2	Decatur, IL	$141M	Under Construction	Saline	~900,000	2014
NRG Energy (Petra Nova) WA Parish	Retrofit Pulverized Coal plant	Thompson, TX	$167M	Financing	EOR	1,400,000	2016
Summit Texas Clean Energy Project	Integrated Gasification Combined Cycle Polygeneration	Penwell, TX	$450M	Financing	EOR	2,200,000	2017
Leucadia Energy, LLC	Methanol from Petcoke Gasification	Lake Charles, LA	$261M	Front End Engineering & Design	EOR	~4,500,000	2017
FutureGen 2.0	Oxycombustion Pulverized Coal Boiler Retrofit	Meredosia, IL / Morgan County, IL	$1B	Front End Engineering & Design	Saline	1,000,000	2017 (est.)
Hydrogen Energy California (HECA)	Integrated Gasification Combined Cycle Polygeneration	Kern County, CA	$408M	Front End Engineering & Design	EOR	2,570,000	2019 (est.)

Summit Texas Clean Energy, LLC CCPI-3

Advanced IGCC-Polygen

- **Penwell, Ector County, TX (greenfield)**
- **600 MW (syngas); 400 MW (power plant); 200 MW (net) to grid, 0.84 MMtonnes/yr urea**
  - SFG-500 gasifiers (2 x 50%)
  - High H_2 SGCC6-5000F combined cycle (1 x 1)
- **Fuel: PRB sub bituminous coal**
- **90% CO_2 capture – ~2,630,000 tonnes CO_2/year**
  - 2.0 MM tonnes EOR; 0.63 MM to Urea production
  - 2-stage Water Gas Shift, Linde Rectisol ® AGR
- **EOR: Permian Basin oil fields**
- **Total DOE Project: $1.727 B; DOE Share: $450 MM (26%)**
- **Total Plant Cost ~$3.85 B**



Key Dates

- Project Awarded: Jan 2010
- Air Permit; Dec 2010
- NEPA Record of Decision: Sep 2011
- Financial Close: Jun 2014
- Construction: Jul 2014
- Operation: Sep 2018

Status

- Urea contract: Jan 2011; CO_2 contracts: Nov 2011
- PPA: Dec 2011; expired & being renegotiated
- Chexim signed for debt financing MOU: Sep 2012
- Sinopec signed EPC agreement: Aug 2013; now just EP
- STCE seeking separate construction contract

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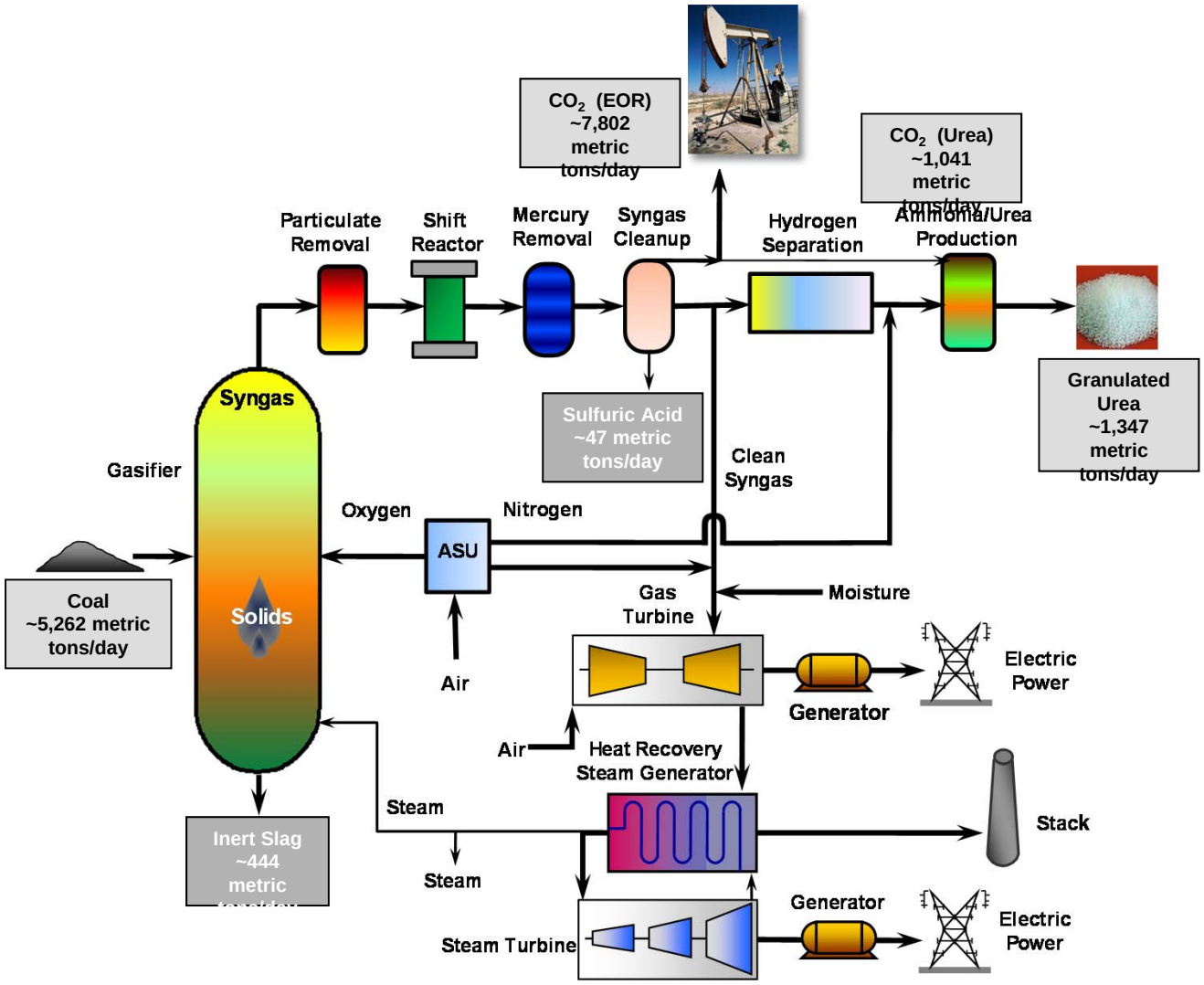
Summit – Texas Clean Energy Project



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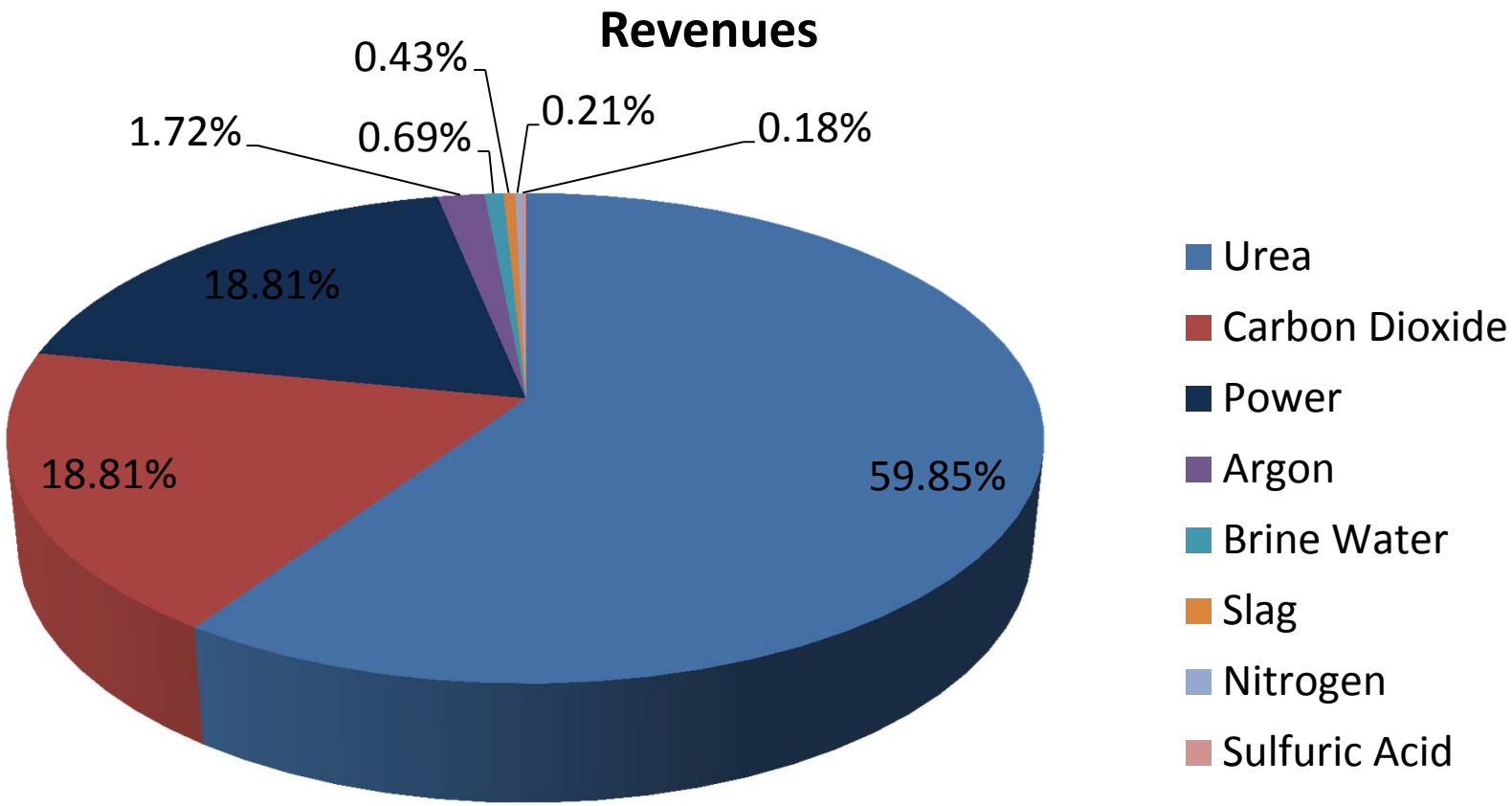
Summit Annual Revenues (30-yr avg)



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Petra Nova – NRG W.A. Parish CCPI-3

Advanced Post Combustion CO_2 Capture

- Thompsons, TX (near Houston)
- 240 MWe slipstream at NRG Energy's W.A. Parish power plant (originally 60 MWe)
- Fuel: PRB sub-bituminous coal
- 90% CO_2 capture (KM CDR Process®) 1,400,000 tonnes CO_2/year
- EOR: Hilcorp West Ranch oil field
- Total DOE Project: $472 MM
  DOE Share: $167 MM
- Total Project Cost: $1.1 B

Key Dates

- Project Awarded: May 2010
- Air Permit: Dec 2012
- NEPA Record of Decision: May 2013
- Financial Close: June 2014
- Construction: Mar 2014 (LNTP)
- Operation: Apr 2017

Status

- EOR Host Site acquired: Oct 2011
- 240 MWe FEED completed: Feb 21, 2012
- MHI initiated detailed design: Dec 2012
- NRG-Petra Nova signed engagement letter with a debt financing provider: Dec 2012
- Signed EPC contract, Issued LNTP: Mar 2014
- Finalizing debt financing arrangements

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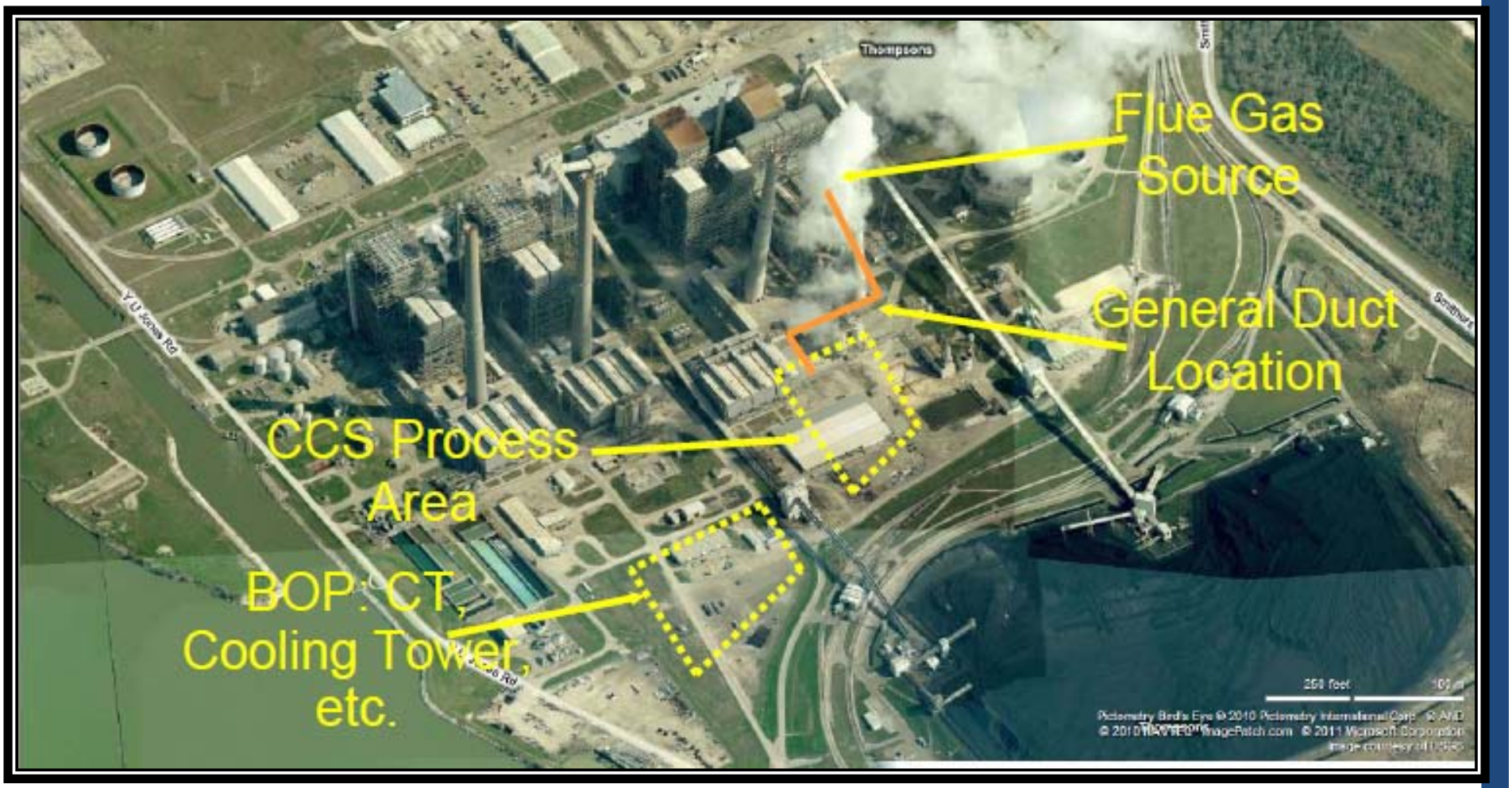
W.A. Parish Site Overview



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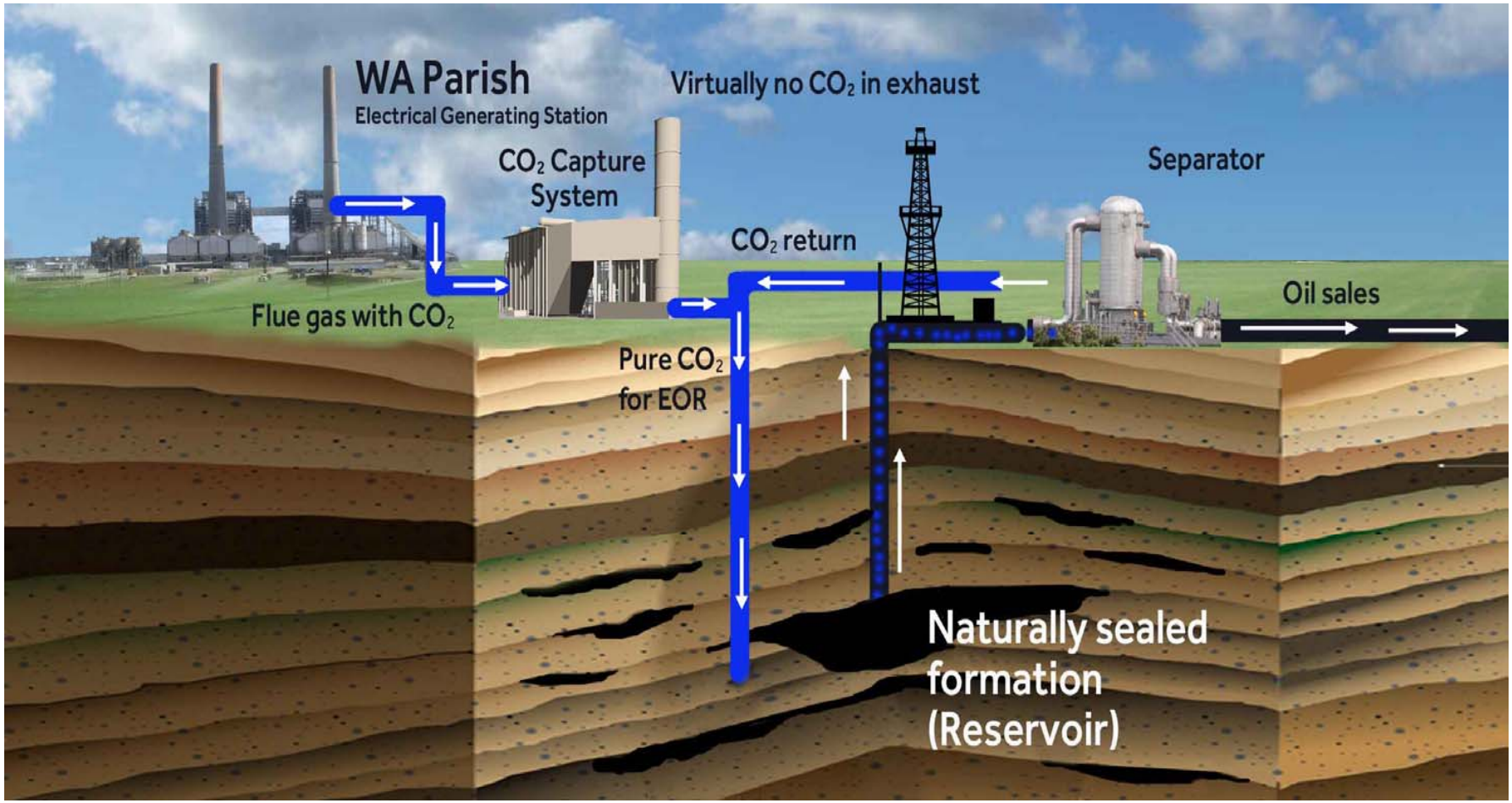
Advanced Post Combustion CO_2 Capture with Enhanced Oil Recovery



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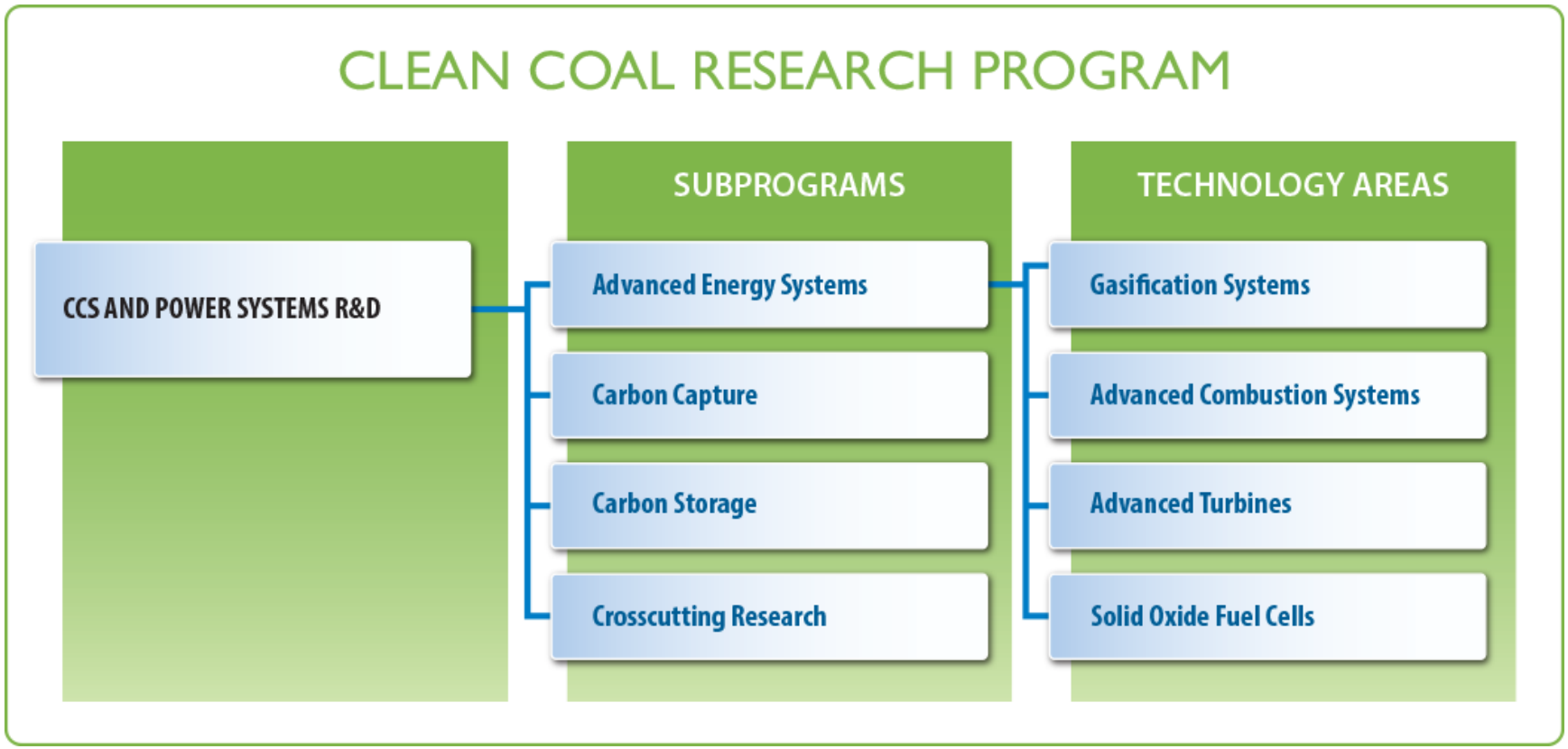
Clean Coal Research Program



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Integrated Fossil Energy Solutions

Advanced Combustion

5 MWE Oxycombustion Pilot

- ❑ Pressurized
- ❑ O_2 membrane
- ❑ Chemical looping
- ❑ USC Materials

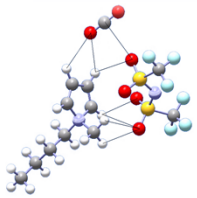
Advanced Energy Systems

- ❑ Gasification
- ❑ Turbines
- ❑ Supercritical CO_2
- ❑ Direct Power Extraction

Advanced Turbines

Efficiencies > 45%
↓ Capital Cost by 50%
$10 - $40/tonne CO_2 Captured
Near-zero GHGs
Near-zero criteria pollutants
Near-zero water usage

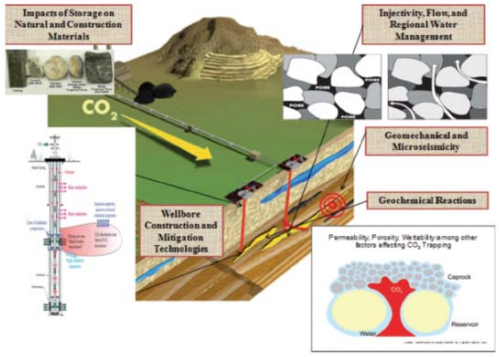
Advanced CO_2 Capture and Compression



- ❑ Solvents
- ❑ Sorbents
- ❑ Membranes
- ❑ Hybrid
- ❑ Process Intensification
- ❑ Cryogenic Capture

CO_2 Storage

- ❑ Carbon Utilization (EOR)
- ❑ Infrastructure (RCSPs
- ❑ Geological Storage
- ❑ Monitoring, Verificatio and Accounting



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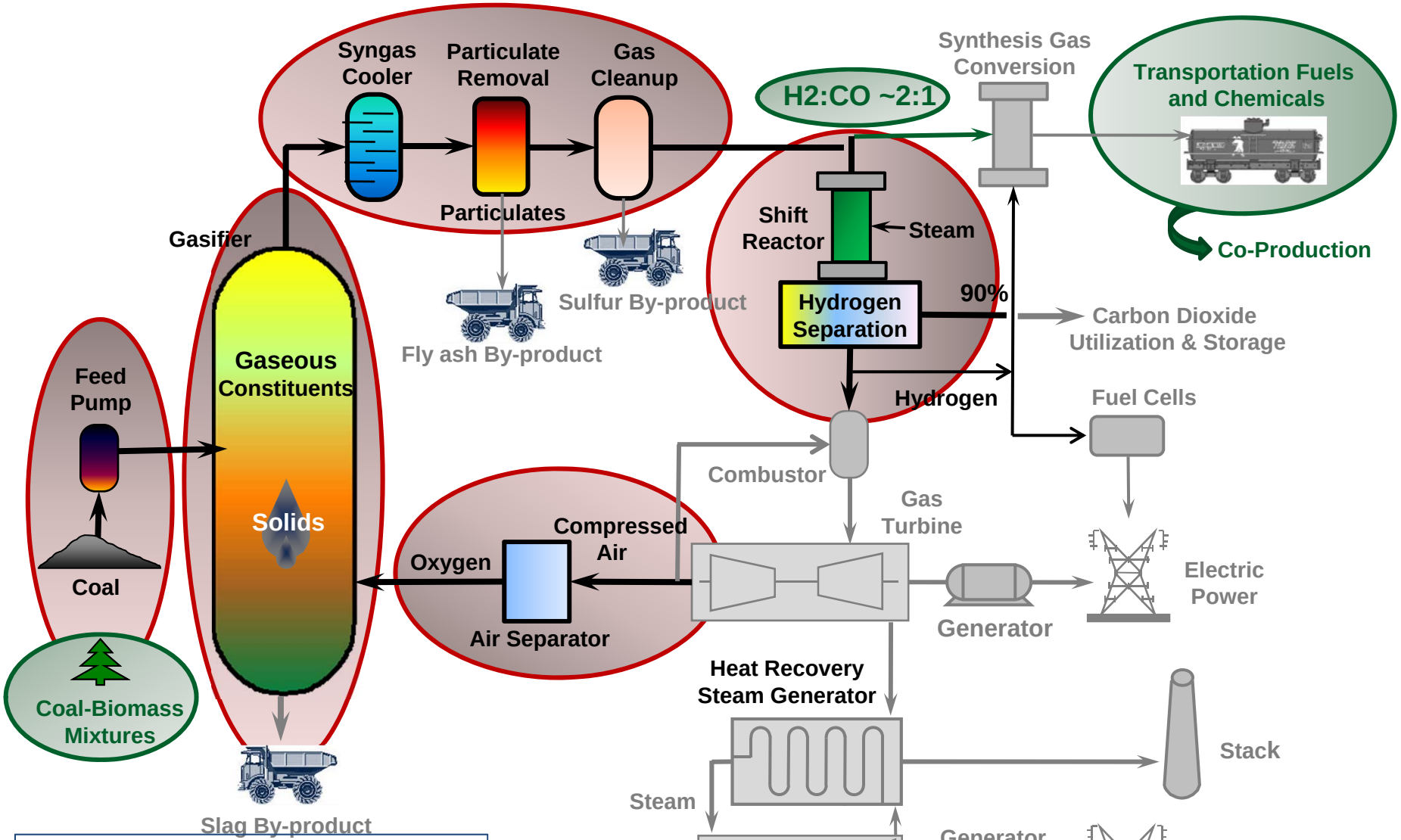
Gasification Systems



Technology Components

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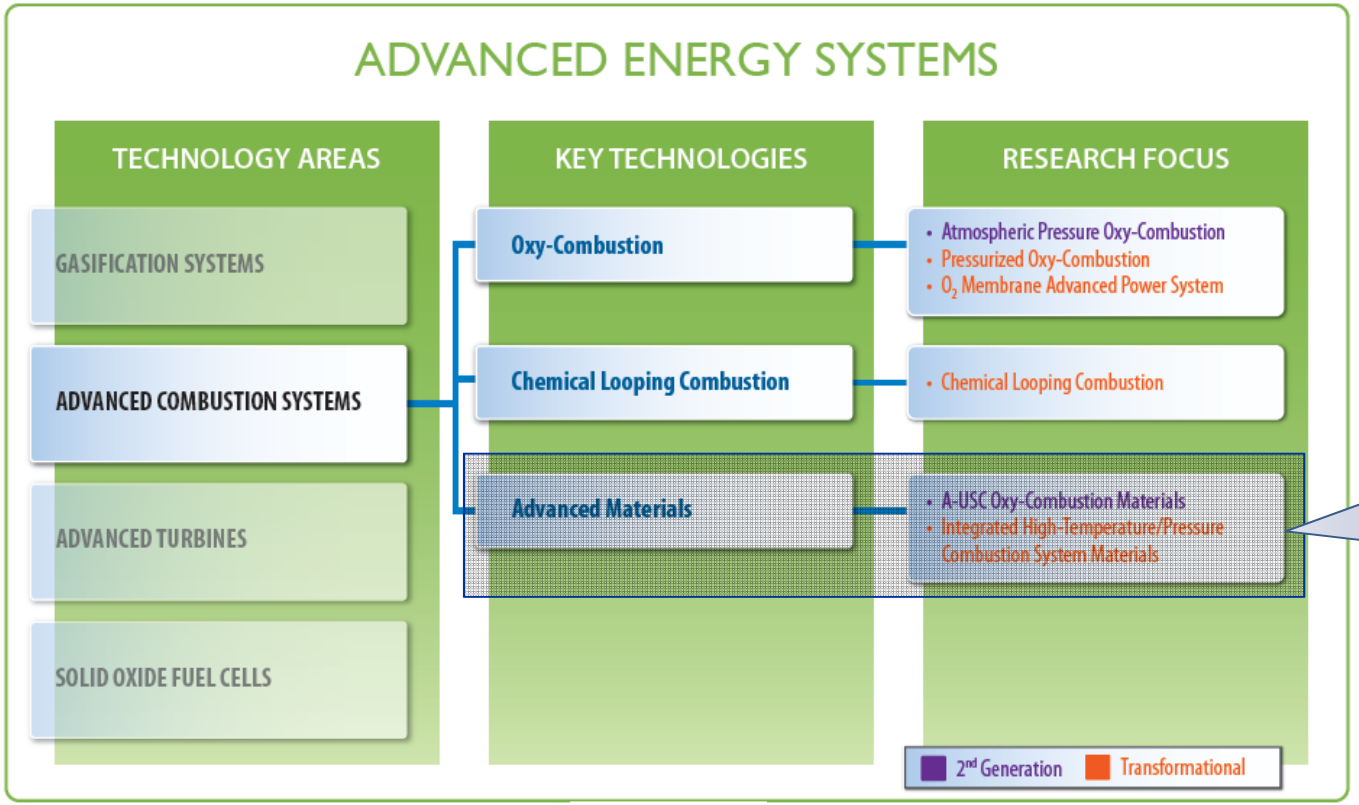
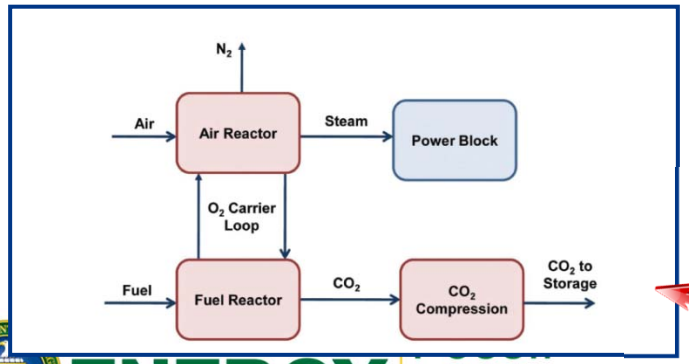
Advanced Combustion Systems Program

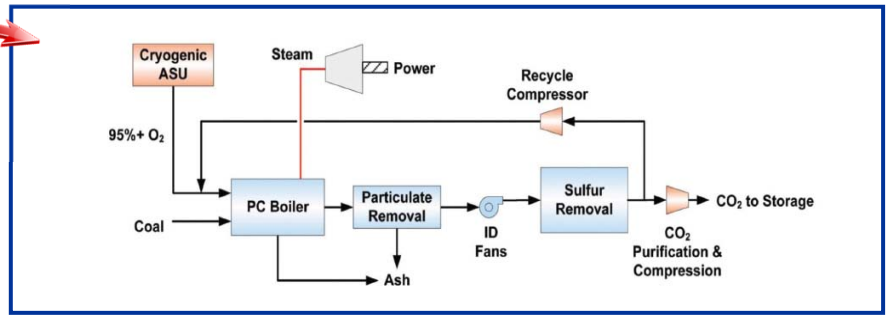


Coordinated with Crosscutting Research Technology Area

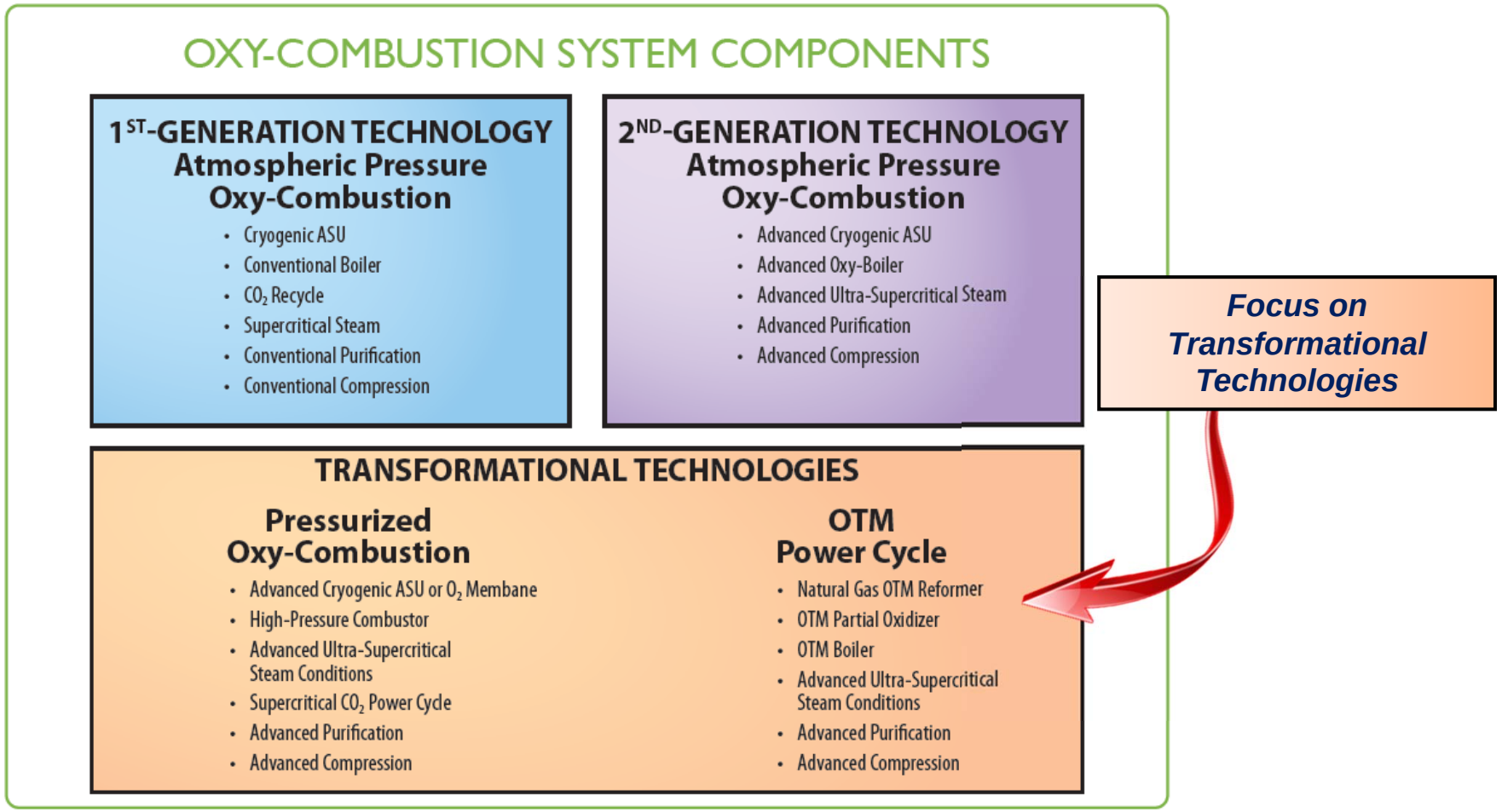


Oxy-Combustion

Chemical Looping



Advanced Combustion Systems Program



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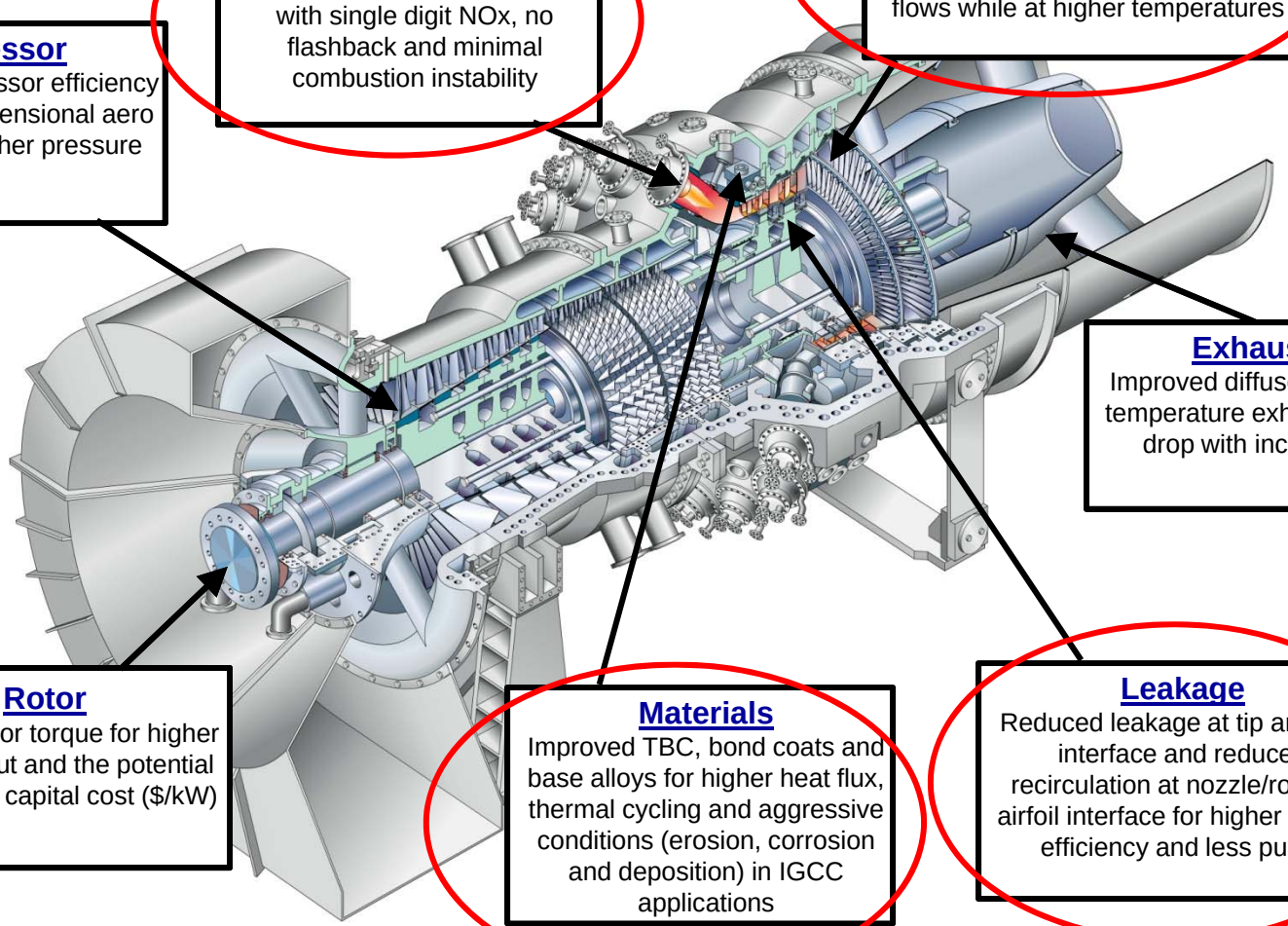
Targeted R&D Areas for H_2 Turbines



Turbine
Improved aerodynamics, longer airfoils for a larger annulus / higher mass flow and improved internal cooling designs to minimize cooling flows while at higher temperatures

Combustor
Combustion of hydrogen fuels with single digit NOx, no flashback and minimal combustion instability

Compressor
Improved compressor efficiency through three dimensional aero dynamics for higher pressure ratio

Exhaust Diffuser
Improved diffuser designs for higher temperature exhaust, lower pressure drop with increased mass flow

Rotor
Increase rotor torque for higher power output and the potential for lowering capital cost ($/kW)

Materials
Improved TBC, bond coats and base alloys for higher heat flux, thermal cycling and aggressive conditions (erosion, corrosion and deposition) in IGCC applications

Leakage
Reduced leakage at tip and wall interface and reduced recirculation at nozzle/rotating airfoil interface for higher turbine efficiency and less purge

Photo courtesy of Siemens Energy

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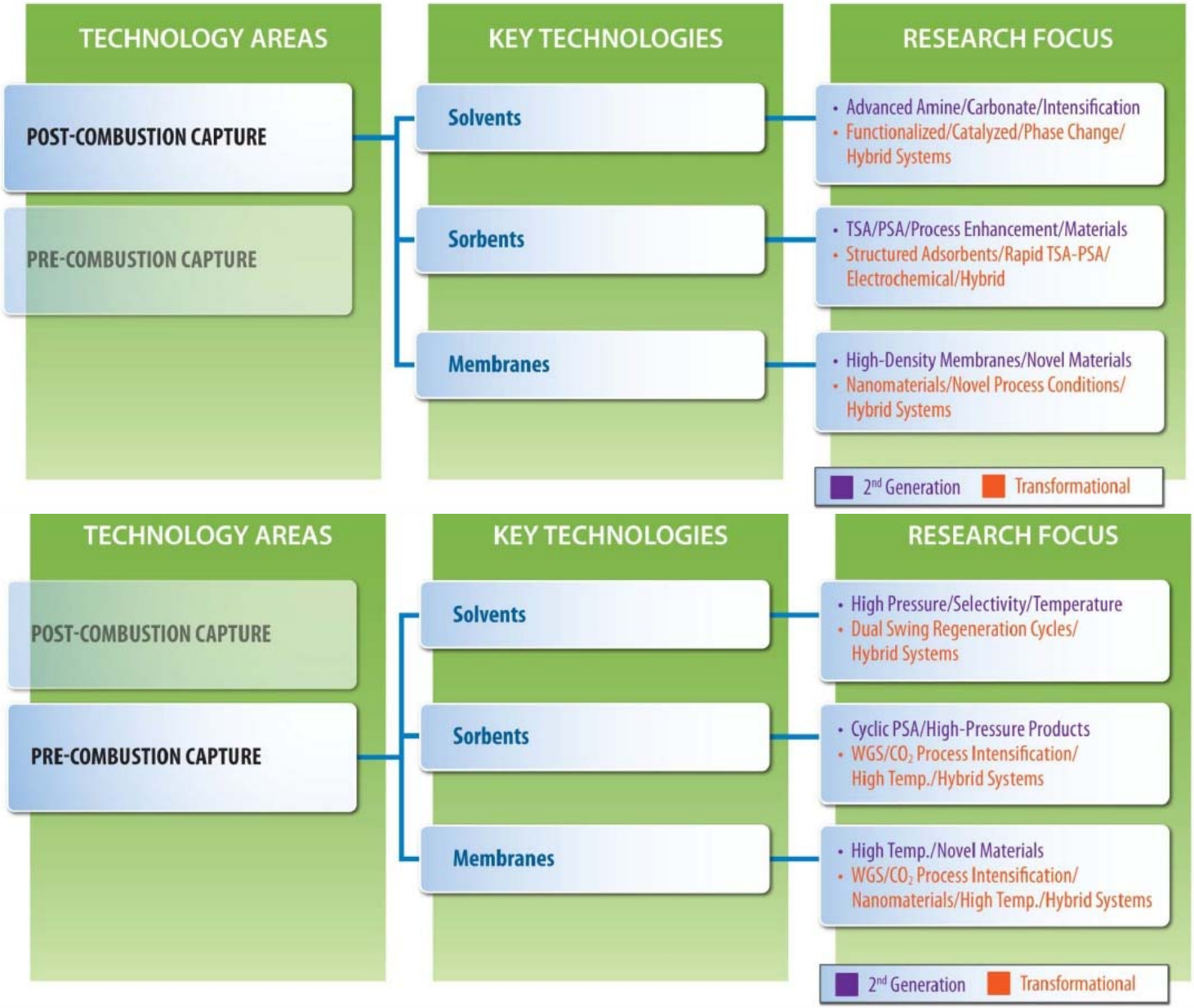
Carbon Capture Key Technologies



CO_2 Capture R&D: Need Advancements in Different Concepts and Several Areas for Success

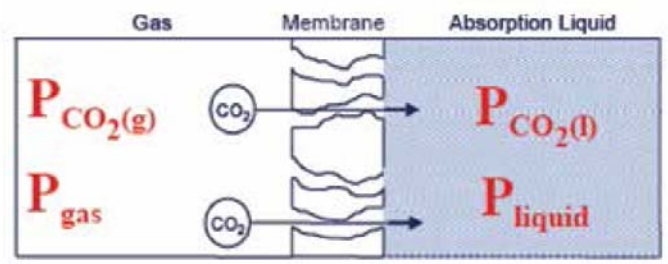
Technology Development Requires Coupling of Multiple Advancements

- **State of the art absorption process coupled with unconventional stripping and advanced solvent**
- **Pre-concentration of CO_2 to improve driving force for low-cost separation**
- **Coupling membrane and sorbent technologies to capitalize on advantages of each**
- **Use of advanced simulation to link engineered solvents or sorbents with unconventional processing techniques**

Advanced CO_2 Capture Technologies

Examples of novel materials for CO2 capture

- Nano Porous Membranes for solvent/gas contactor
  - *PEEK (polymer) membrane*
- Mixed Matrix Membranes
  - *Polymer and MOFs*
- Molecular basket sorbents
  - *Silica and immobilized PEI*



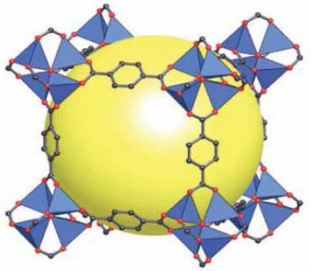
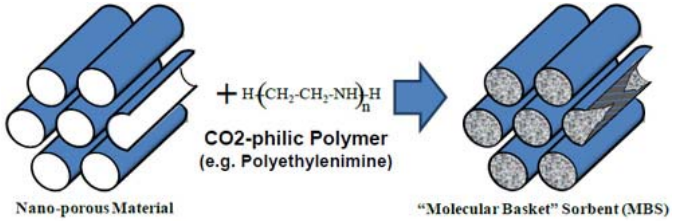
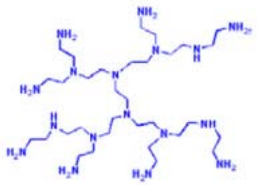
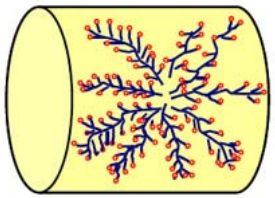


Figure 2: Model of MOF-5





Polyethylenimine (PEI)



Immobilize PEI into Nano-Pore

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Core R&D Research Areas

Key Technology Areas Research Pathways

Geologic Storage Technology Area

(Storage Technologies and Simulation and Risk Assessment)

- Wellbore construction and materials
- Mitigation technologies for wells and natural pathways
- Fluid flow, reservoir pressure, and water management
- Geochemical effects on formation, brine, and microbial communities
- Geomechanical impacts on reservoirs- seals and basin-scale coupled models; microseismic monitoring
- Risk Assessment databases and integration into operational design and monitoring

Monitoring, Verification, Accounting & Assessment (MVAA) Technology Area

- Atmospheric Monitoring and remote sensing technologies
- Near -Surface Monitoring of soils and vadose zone
- Subsurface Monitoring in and near injection zone

CO_2 Use/Reuse Technology Area

- Chemicals, plastics, minerals and cements (building products)
- Enhanced hydrocarbon recovery
- Other possible uses

Carbon Storage Program

Collaborating to Address Technical Issues

Focus Area for Carbon Sequestration Science

- National Carbon Sequestration Database (NATCARB)
- Energy Data Exchange
- Research on Storage Reservoirs, Seal Integrity, MVA technologies, Computational and Experimental Methods, CO_2 Utilization

Supporting Mechanisms

- Interagency and State Coordination
- ARRA Site Characterization and CCS Training Centers
- Systems and Benefits Analysis
- University and Research Laboratory Collaboration

Global Collaborations

- Leveraging Expertise with International CCS Projects
- IEAGHG R&D Program
- Carbon Sequestration Leadership Forum
- London Convention/London Protocol
- North American Carbon Atlas Partnership
- U.S.-China Clean Energy Research Center