THE IMPORTANCE OF R&D IN ADVANCING ENERGY TECHNOLOGIES

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Congressional Briefing, June 30, 2017

Cover image: Aerial view of Tomakomai CCS Demonstration Project facilities located at Tomakomai City, Hokkaido, Japan. Image provided by JCCS.

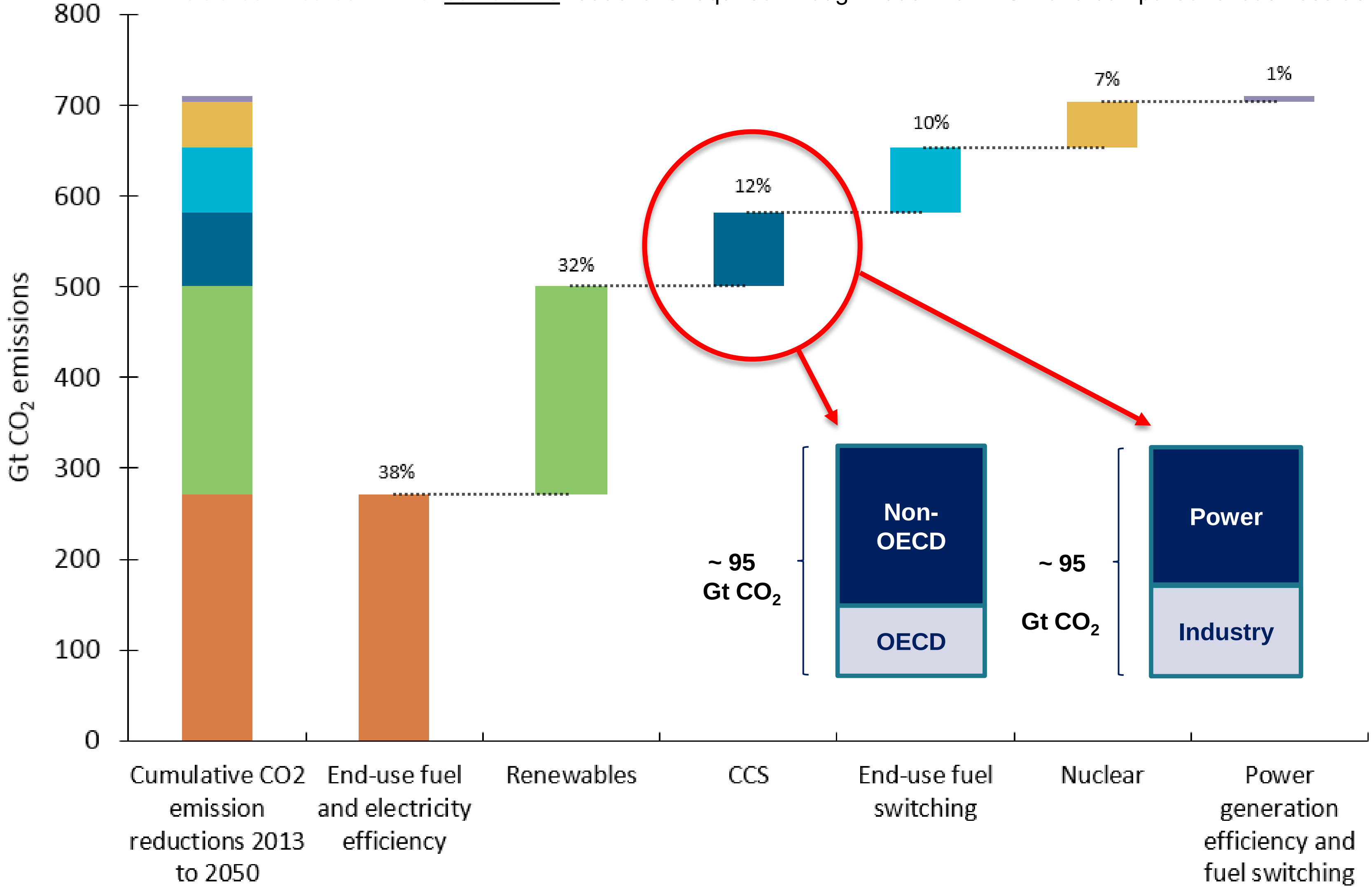
The Global CCS Institute

One mission: to accelerate CCS deployment on a global scale by increasing . . .

- ***Public understanding*** and acceptance of Carbon Capture
- ***Policy support*** for Carbon Capture, and
- ***Commercial opportunities*** for Carbon Capture

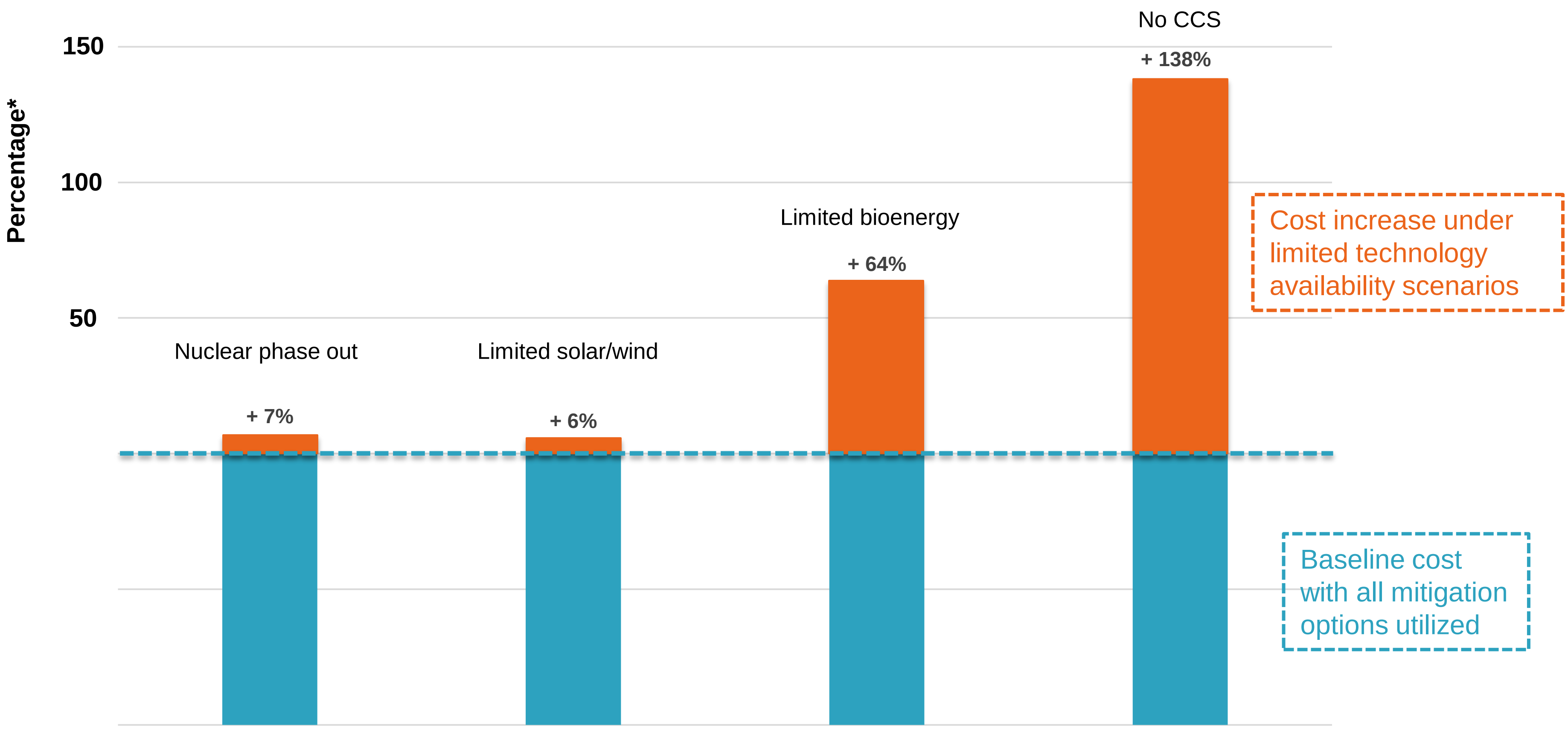
CCS is critical in a portfolio of low-carbon technologies

CCS contributes 12% of cumulative reductions required through 2050 in a 2DS world compared to ‘business as usual’



Source: *IEA, Energy Technology Perspectives (2016)*

Mitigation costs more than double in scenarios with limited availability of CCS

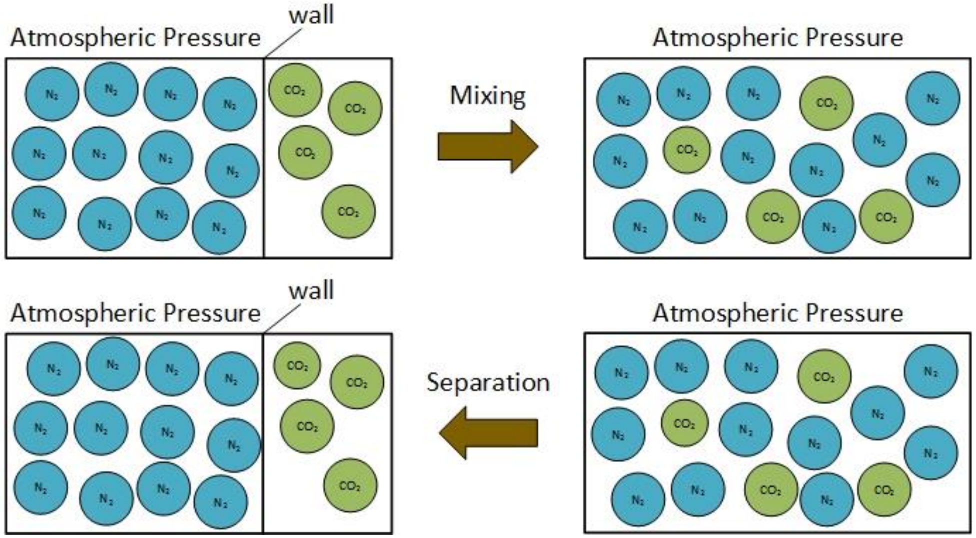


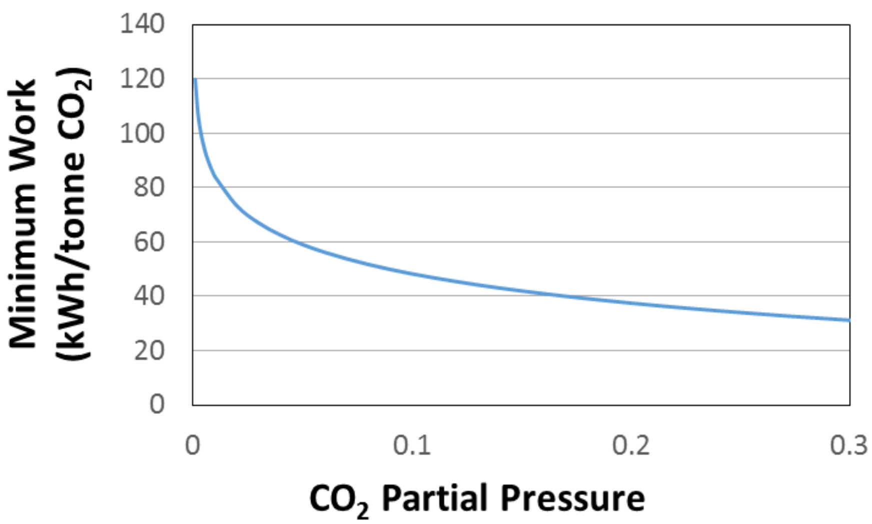
*Percentage increase in total discounted mitigation costs (2015-2100) relative to default technology assumptions – median estimate

Source: *IPCC Fifth Assessment Synthesis Report, Summary for Policymakers, November 2014.*

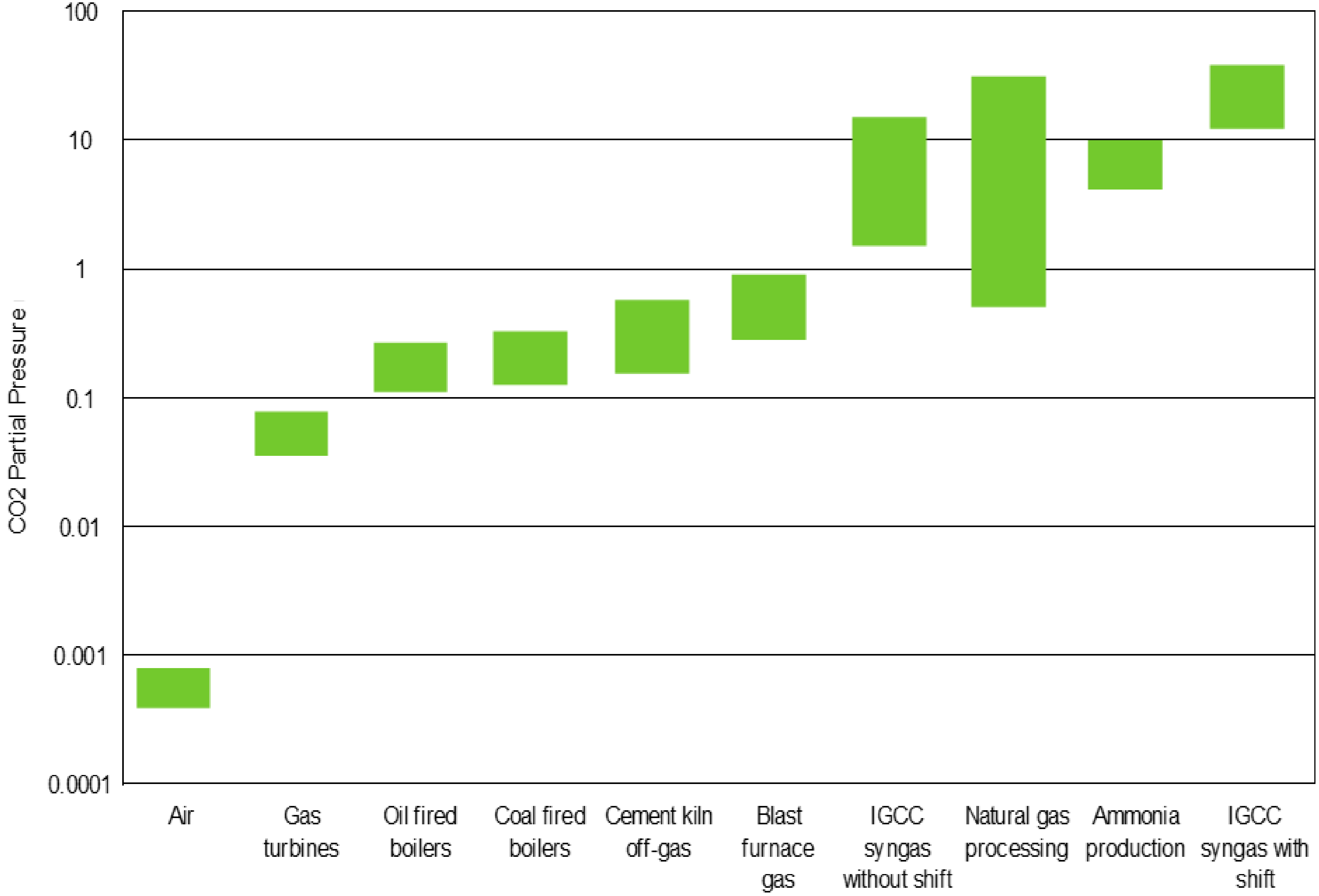
Definition of CO_2 Capture

Separation of the CO_2 from a gas stream produced in a power station or an industrial process to obtain pure CO_2 for geological storage or further use

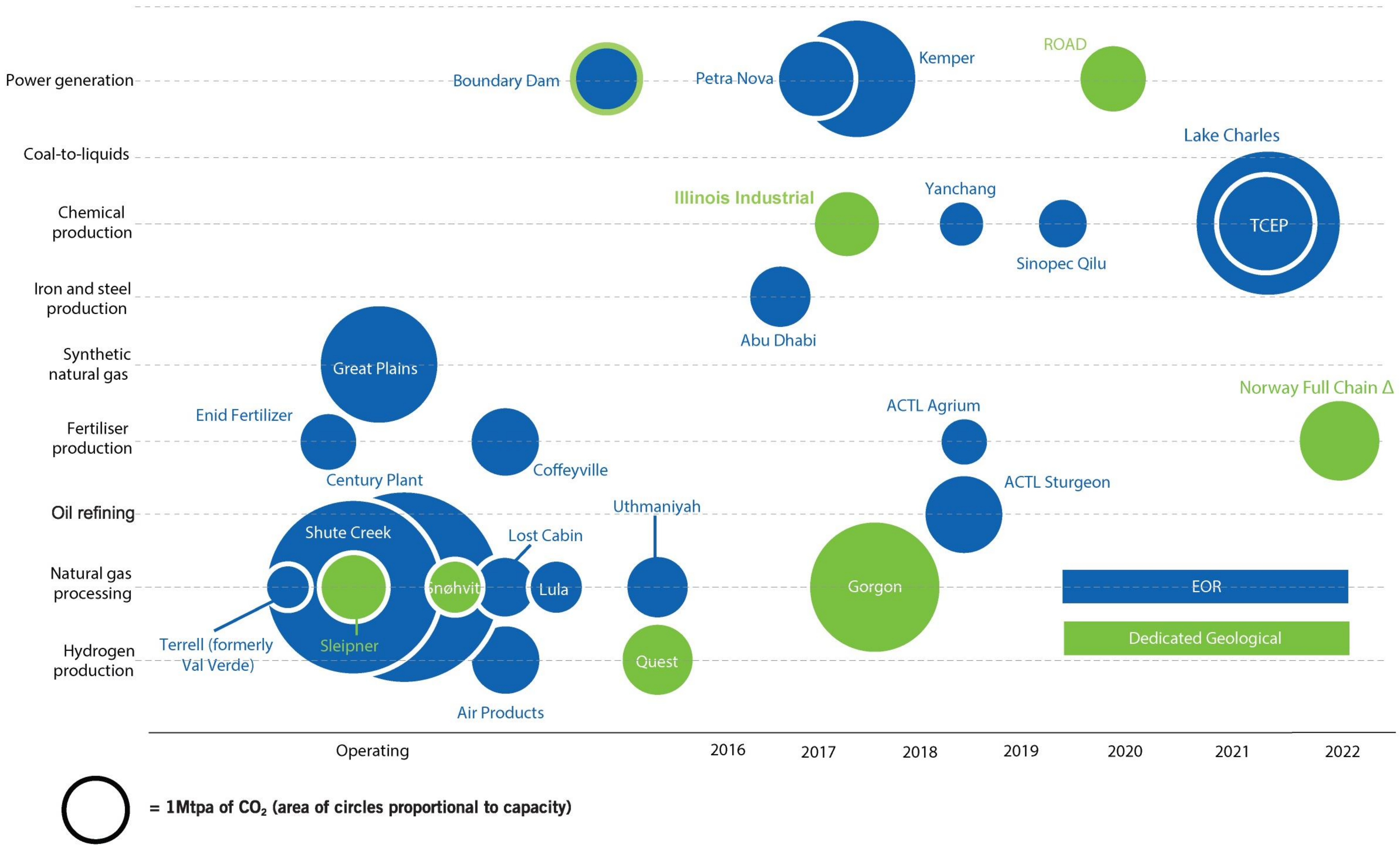




CO_2 Concentrations: Select Sources



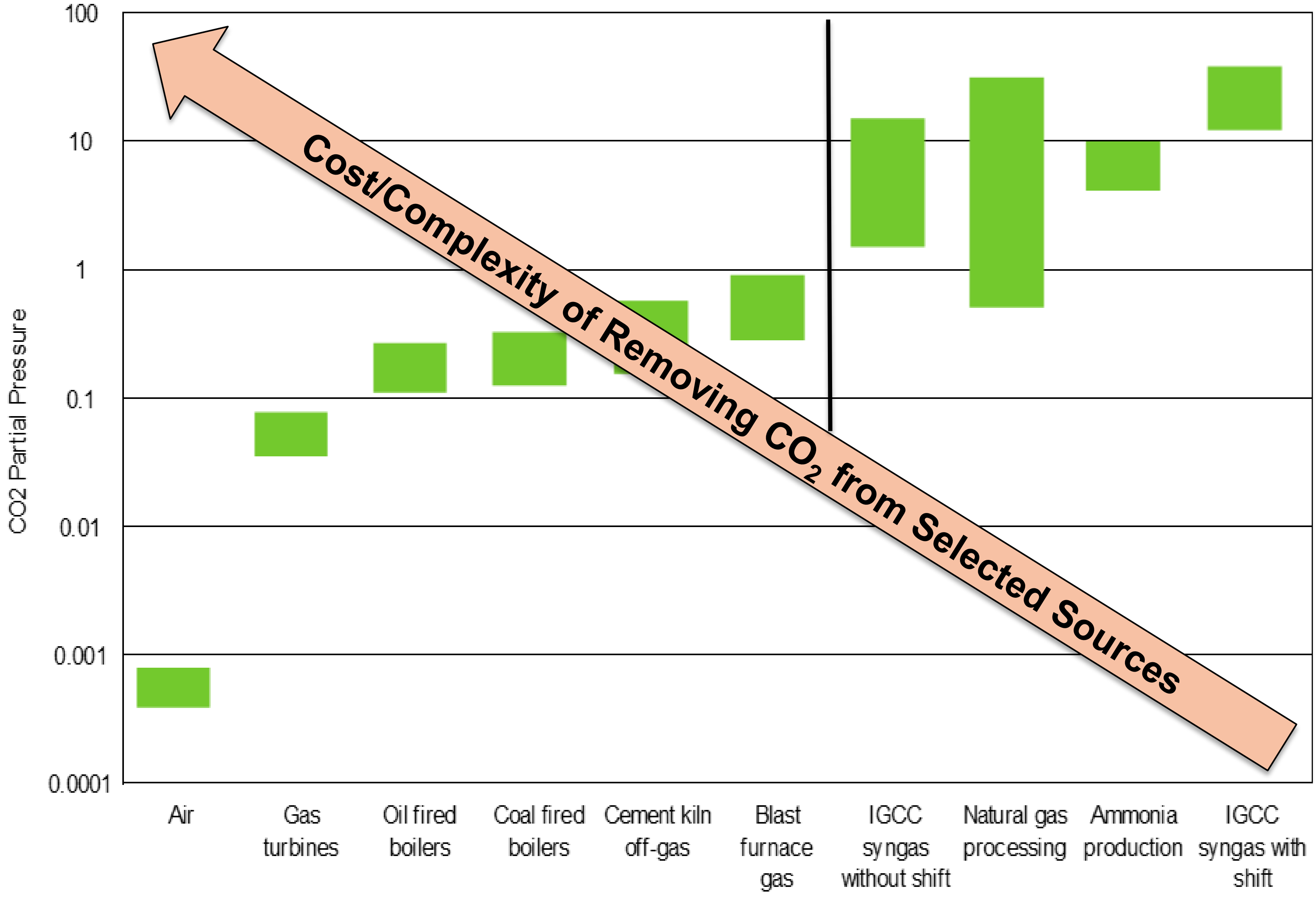
Actual and expected operation dates up to 2022 for large-scale CCS projects by industry and storage type*



*** Includes projects in the Operate, Execute and Define stages**

Δ Feasibility studies assessed the possibility of CO_2 capture and storage from ammonia production, from cement production and from waste-to-energy sources

Cost/Complexity Increase at Lower CO_2 Concentrations

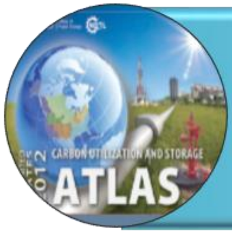


DOE Fossil Energy Program

Major Demonstrations
First Generation fossil energy technology systems built to validate first-of-a-kind fully integrated projects at full scale for the power and industrial sectors

Advanced Energy Systems
Technologies that greatly improve plant efficiencies, reduce CO_2 capture costs, increase plant availability, and maintain the highest environmental standards

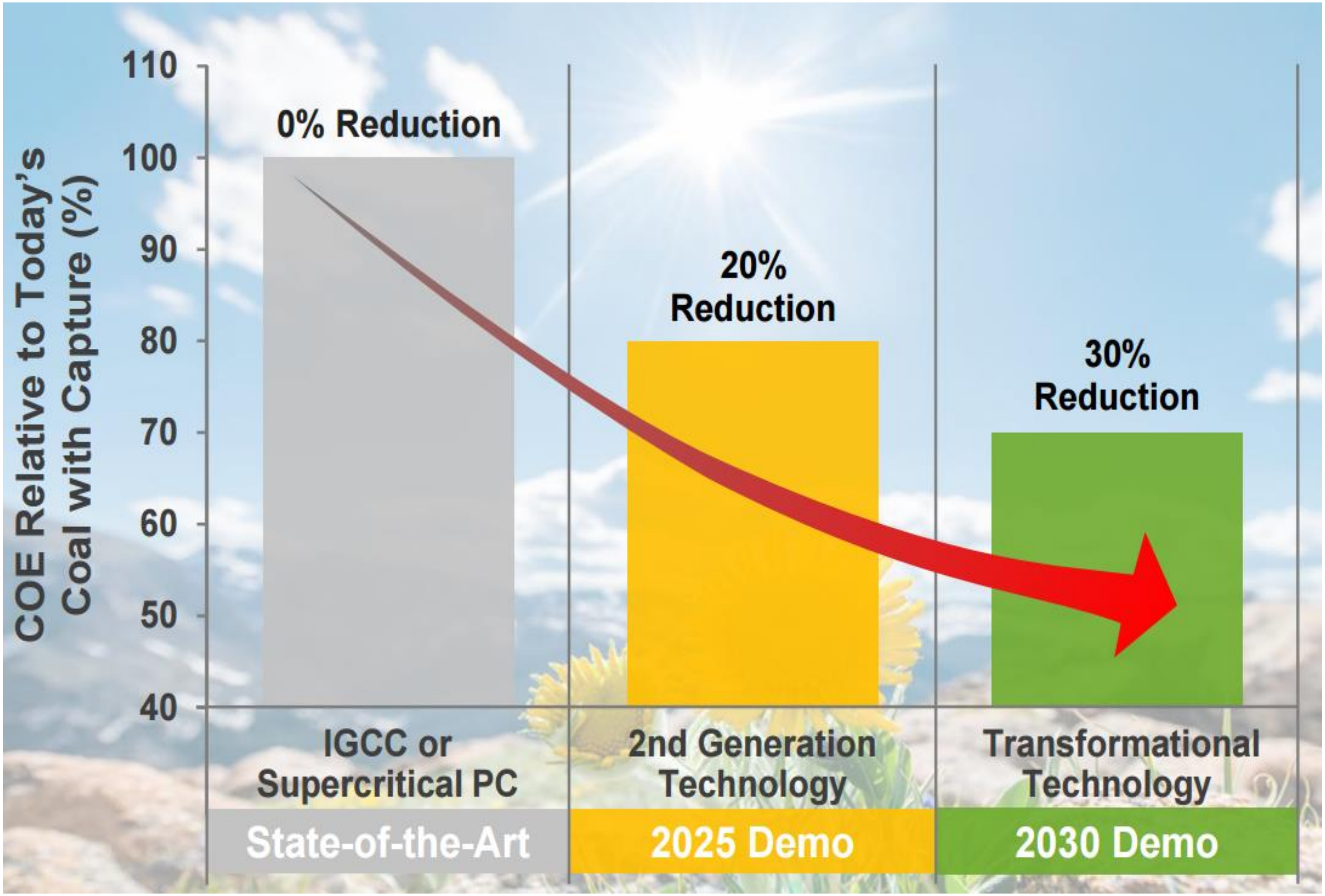
Carbon Capture
R&D and scale-up technologies for capturing CO_2 from new and existing industrial and power-producing plants



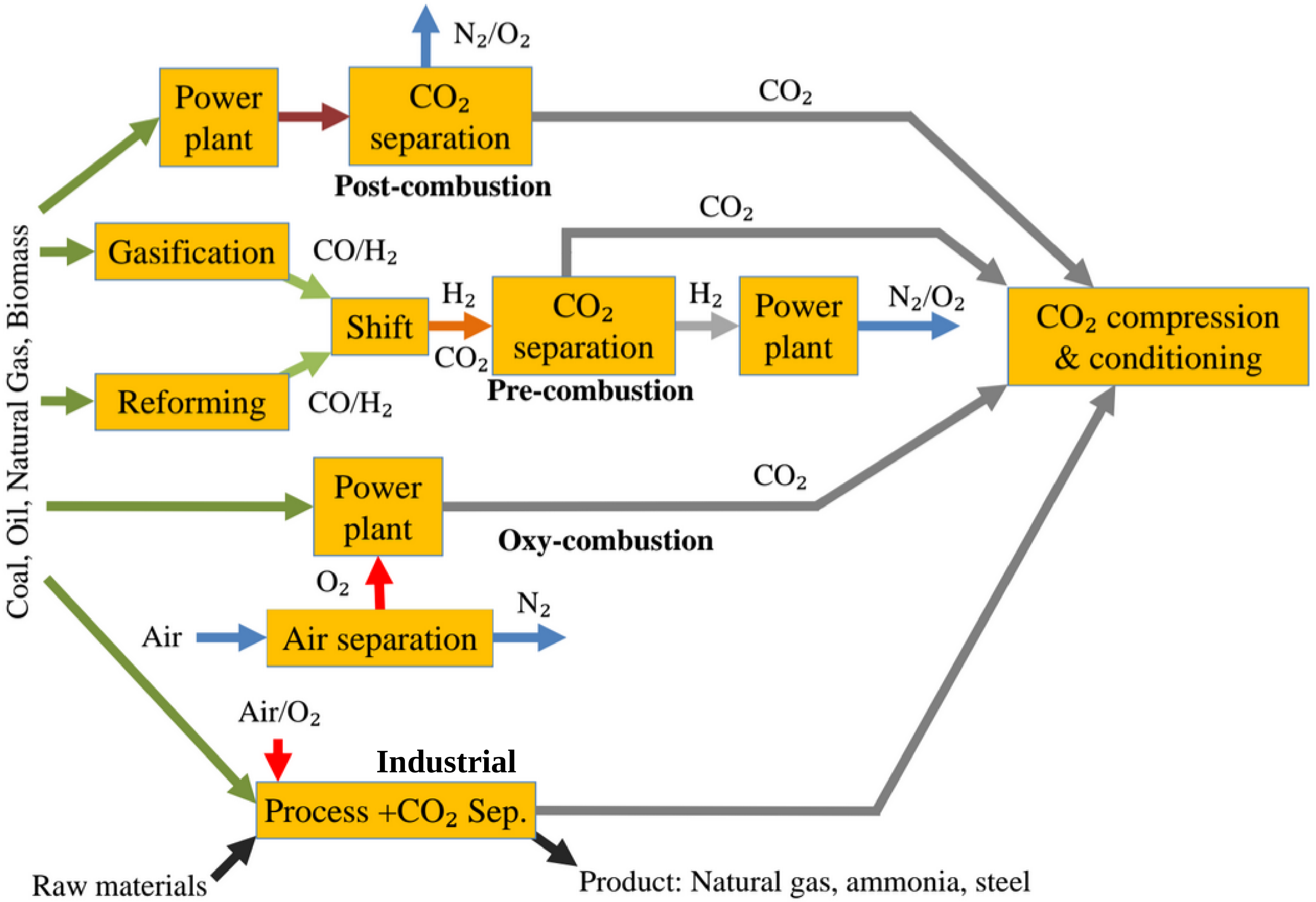
Carbon Storage
Safe, cost- effective, and permanent geologic storage of CO_2 in depleted oil and gas fields and other formations

Cross Cutting Research
Materials, sensors, and advanced computer systems for future power plants and energy systems

Cost reduction targets



CO_2 Capture routes



R&D areas

Pre-Combustion

- Solvents
- Sorbents
- Membranes
- Hybrid processes
- Water-gas shift reactor

Post-Combustion

- Solvents
- Sorbents
- Membranes
- Hybrid processes

Advanced Combustion

- Atmospheric oxy-combustion
- Pressurized oxy-combustion
- Oxygen transport membrane
- Chemical looping

Advanced Compression

- Intra-stage cooling
- Cryogenic pumping
- Supersonic shock wave compression

Deployment Barriers for CO_2 Capture in Low-Concentration Gas Streams

Energy Penalty

- 20% to 30% less power output

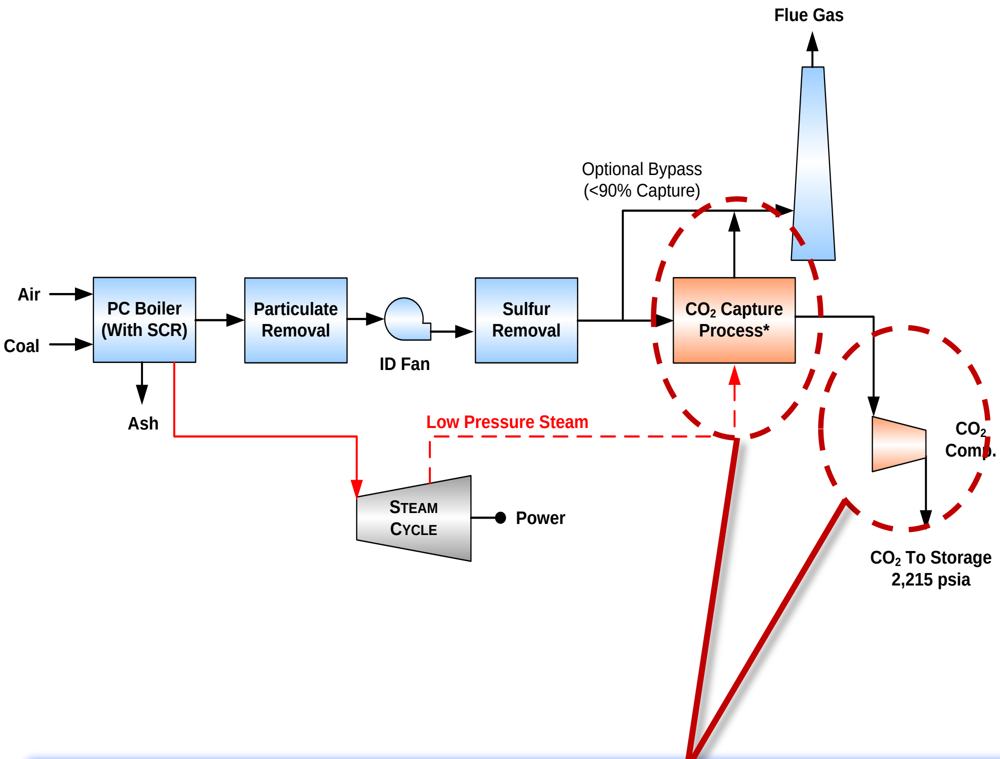
Cost

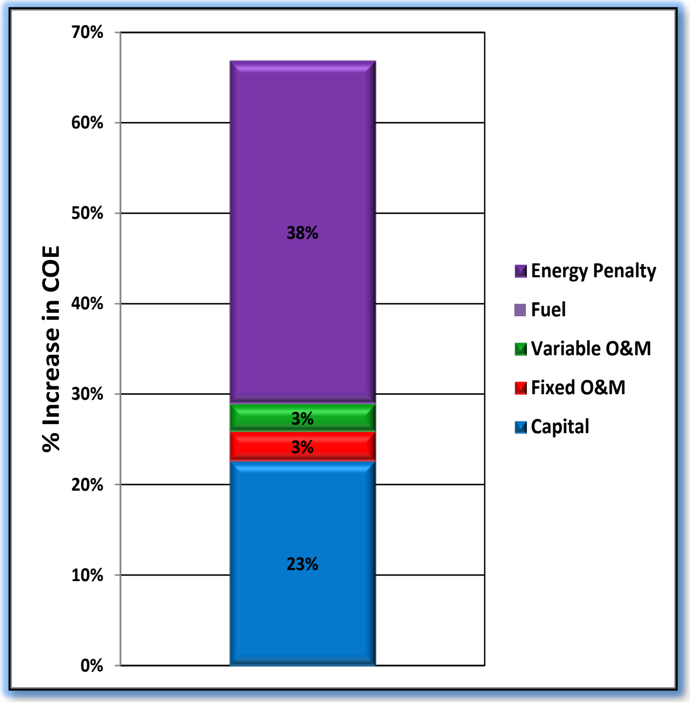
- Increase Cost of Electricity
- Adds Substantial Capital Cost

Scale-up

- 550 MWe power plant produces 13,000 TPD

Energy Penalty – Low-Concentration Gas Streams



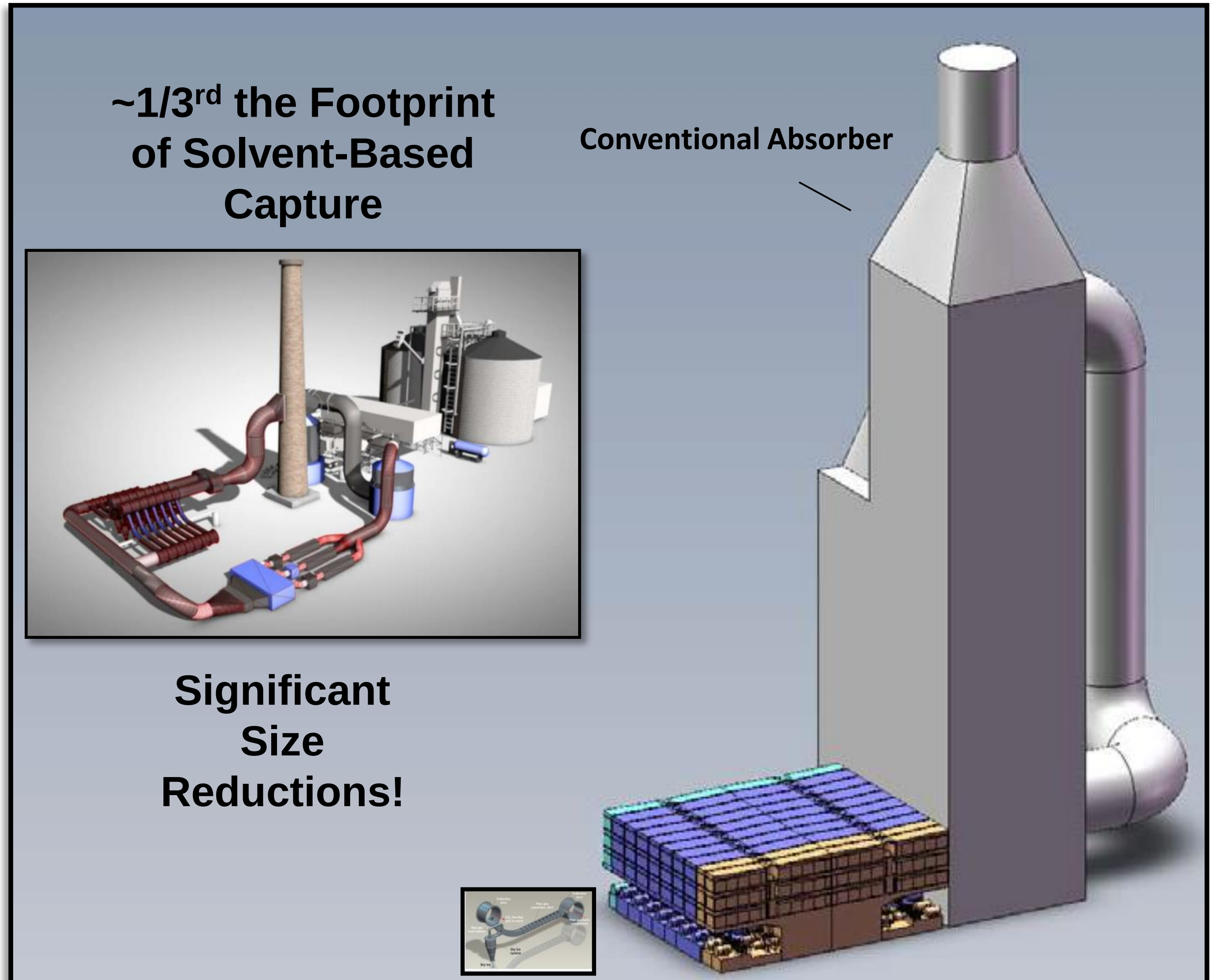


Two-step separation process requiring 5 energy inputs:

Energy = Q (sensible) + Q (reaction) + Q (stripping) + W (Process) + W (Compression)

ALL must be reduced in order to significantly reduce Capture COE impact!

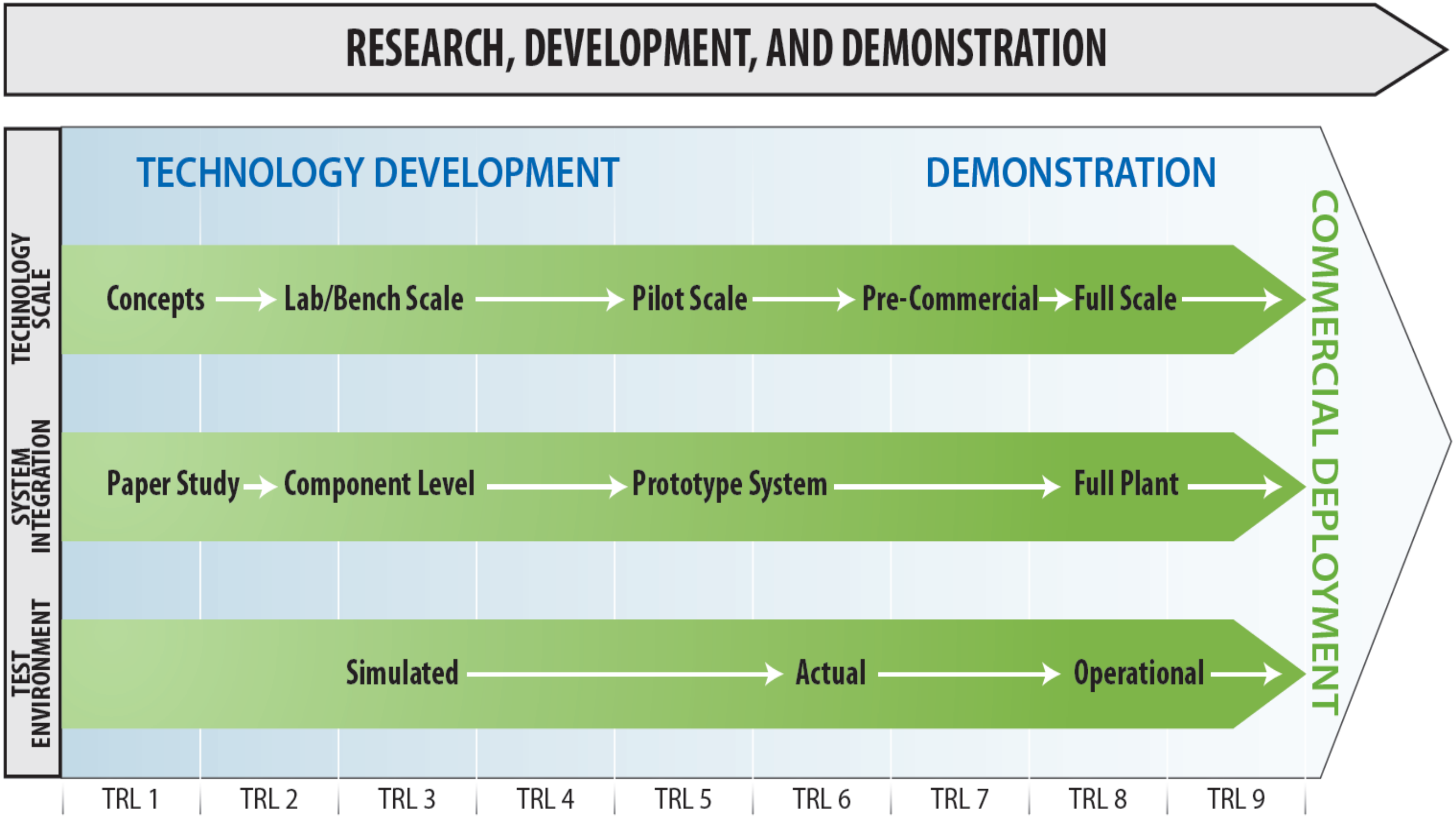
Reactor Size Reduction – Lowers Capital Cost



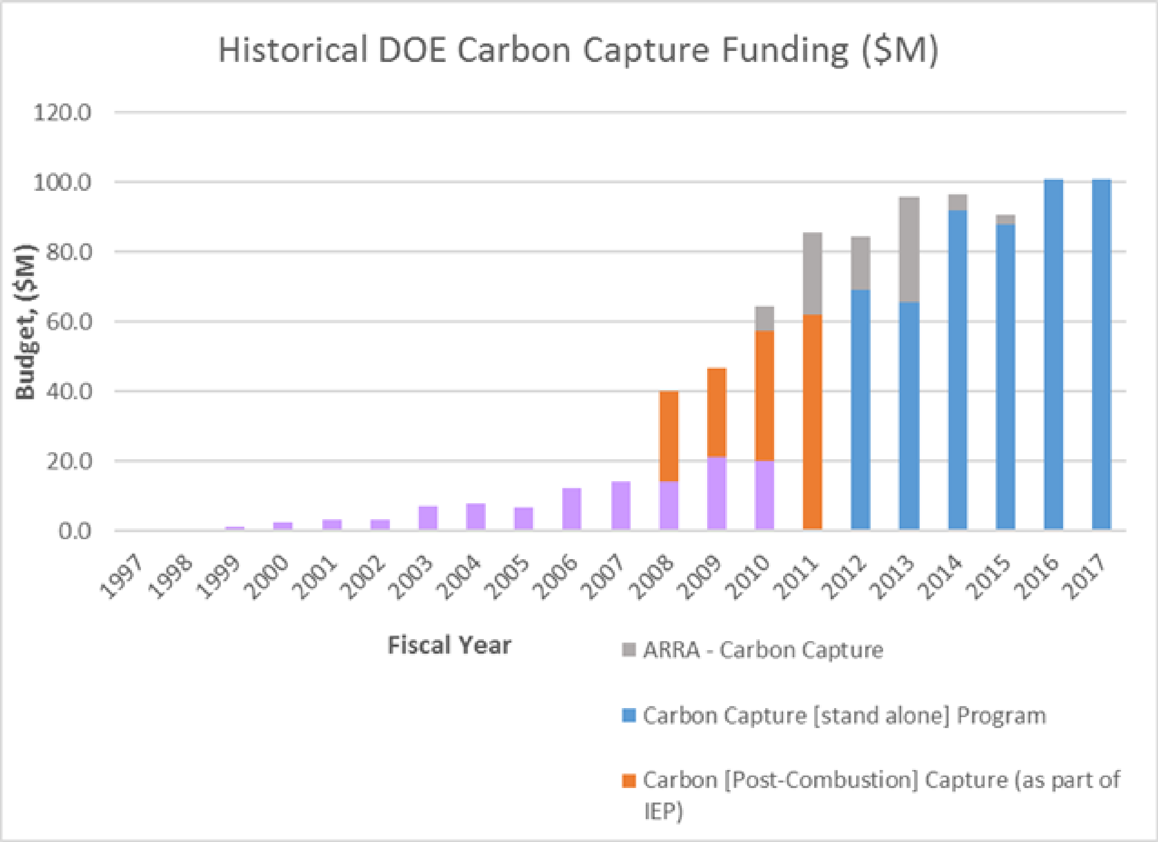
Tracking Progress of R&D

Technology Readiness Level (TRL)

- track the progress of technology development
- systematic measurement system that supports evaluation of the maturity of a particular technology



Progress of the Program to Date



Highlights

- Developed multiple 2nd gen solvents with reduced energy penalty
- Several process designs that reduce CapEx
- Membranes materials decreasing CapEx
- Graduated 6 technologies through TRL 6 – small pilot complete
- Testing 4 technologies at TRL 5 – small pilot in progress

Successful Past R&D Initiatives – Unconventional Extraction

Lab/bench through small pilot-scale development
TRL 2 - 5

1970s

- Early shale drilling/fracturing and three-dimensional microseismic imaging
  TRL 2 - 3
- **1976** – DOE patents early directional drilling technology
  TRL 3 - 4
- **1977** – DOE demonstrates massive hydraulic fracturing
  TRL 4 - 5

Scale-up and integration of technologies
TRL 5 - 6

1980s

- **1986** – First successful multi-fracture horizontal well drilled by joint DOE-private venture in West Virginia
  TRL 5 - 6

Demonstration-scale testing/commercialization
TRL 7 - 9

1990s

- **1991** – DOE/Gas Research Institute subsidize Mitchell Energy's first successful horizontal well in Texas Barnett Shale
  TRL 7
- **1998** –Mitchell Energy – commercial shale gas extraction
  TRL 9

"DOE started it, and other people took the ball and ran with it. You cannot diminish DOE's involvement."

- Dan Steward, former Mitchell Energy Vice President

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