CARBON UTILIZATION RESEARCH COUNCIL
ADVANCING FOSSIL ENERGY SOLUTIONS

OVERCOMING BARRIERS TO ADVANCE FOSSIL ENERGY TECHNOLOGIES

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2018 NETL CO_2 Capture Technology Project Review Meeting

Pittsburgh, PA

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Companies in orange indicate Steering Committee Members

*CURC Leadership Council

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Forces Impacting Power Sector Technology Innovation in the U.S.

Modified from Duke Energy

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The 2018 CURC-EPRI Advanced Fossil Energy Technology Roadmap

- Represents a plan for delivering cost-competitive, low to zero-carbon emission fossil-fueled power plant technologies between 2025-2035.
- Identifies industry RD&D priorities and the public-private sector investments needed to bring technologies to the commercial marketplace.
- Informs policymakers on technology direction and annual budget needs to achieve Roadmap goals.
- Analyzes and communicates the potential benefits of U.S. fossil energy innovation.

2018 Roadmap Cost and Performance Goals

- Performance targets for technologies in 2025 and 2035 to enable candidate replacement options for aging fleet.
- Cost Targets:
  - **New Coal Unit with 90% Carbon Capture**:
    - **2030** – 20% reduction in COE compared to a new unit with CCS built in 2015
    - **2040** – 40% reduction in COE compared to a new unit with CCS built in 2015
  - **New Natural Gas Unit with 90% Carbon Capture**:
    - **2030** – 15% reduction in COE compared to a new unit with CCS built in 2015
    - **2040** – 30% reduction in COE compared to a new unit with CCS built in 2015
  - 90% CO_2 capture represents typical DOE convention of modeling CCS costs and performance (is only intended to be a target).
- Majority of technologies support both coal and natural gas applications.

2018 Roadmap RD&D Pathways to Achieve Cost and Performance Targets

- Identifies RD&D for existing coal and natural gas fleet.
- Defines RD&D priorities for new fossil energy systems that include CCUS.
- Forecasts accelerated RD&D needs to facilitate breakthroughs on new transformational technologies that:
  - Yield highly efficient electricity generation while facilitating CO_2 emissions reductions at a lower energy penalty and cost.
  - Represent a “step-change” improvement in cost, flexibility of operations, efficiency and performance relative to current technologies.
- Emphasizes carbon capture RD&D focused on reducing the costs associated with carbon capture.
- Includes RD&D for evaluating carbon storage potential and CO_2 utilization pathways.

2018 Roadmap RD&D Pathways to Achieve Cost and Performance Targets

New Plants

- AUSC systems with CCUS
- Transformational Energy Conversion Systems*
  - Pressurized Oxygen Combustion
  - Chemical Looping (CLC)
  - Supercritical CO_2 cycles (sCO_2)
  - Gasification
  - Hydrogen Generator
- Natural Gas systems

**New process technologies that facilitate improved and lower cost CO_2 capture*

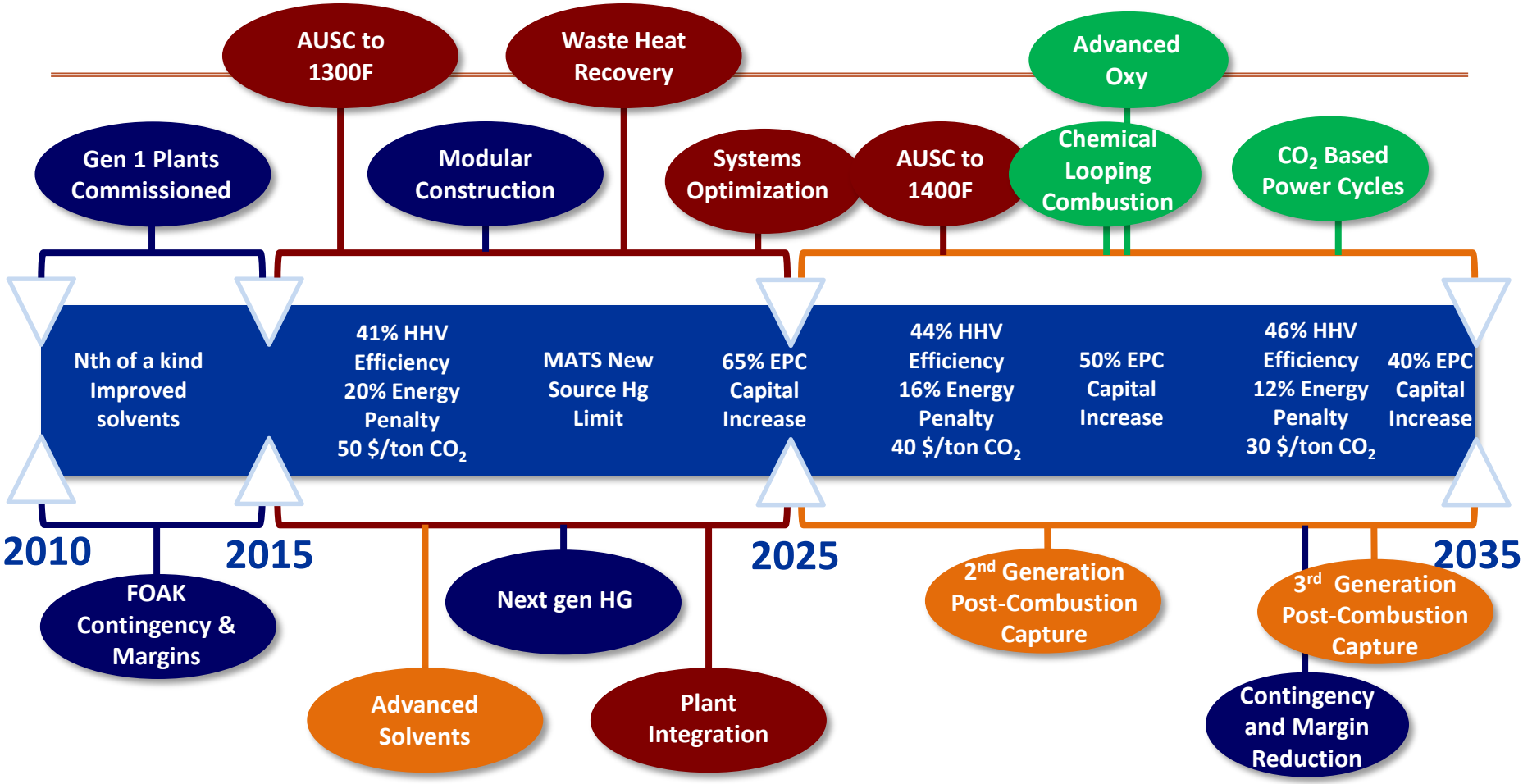
Existing Plants

Cross-Cutting Programs

- A-USC Materials
- Carbon Capture
- Carbon Storage
- Turbines
- Fuel Cells
- Sensors & Controls
- Breakthrough
- Water management

Technology programs in blue are cross-cutting for coal and natural gas

Transformational Technologies Roadmap



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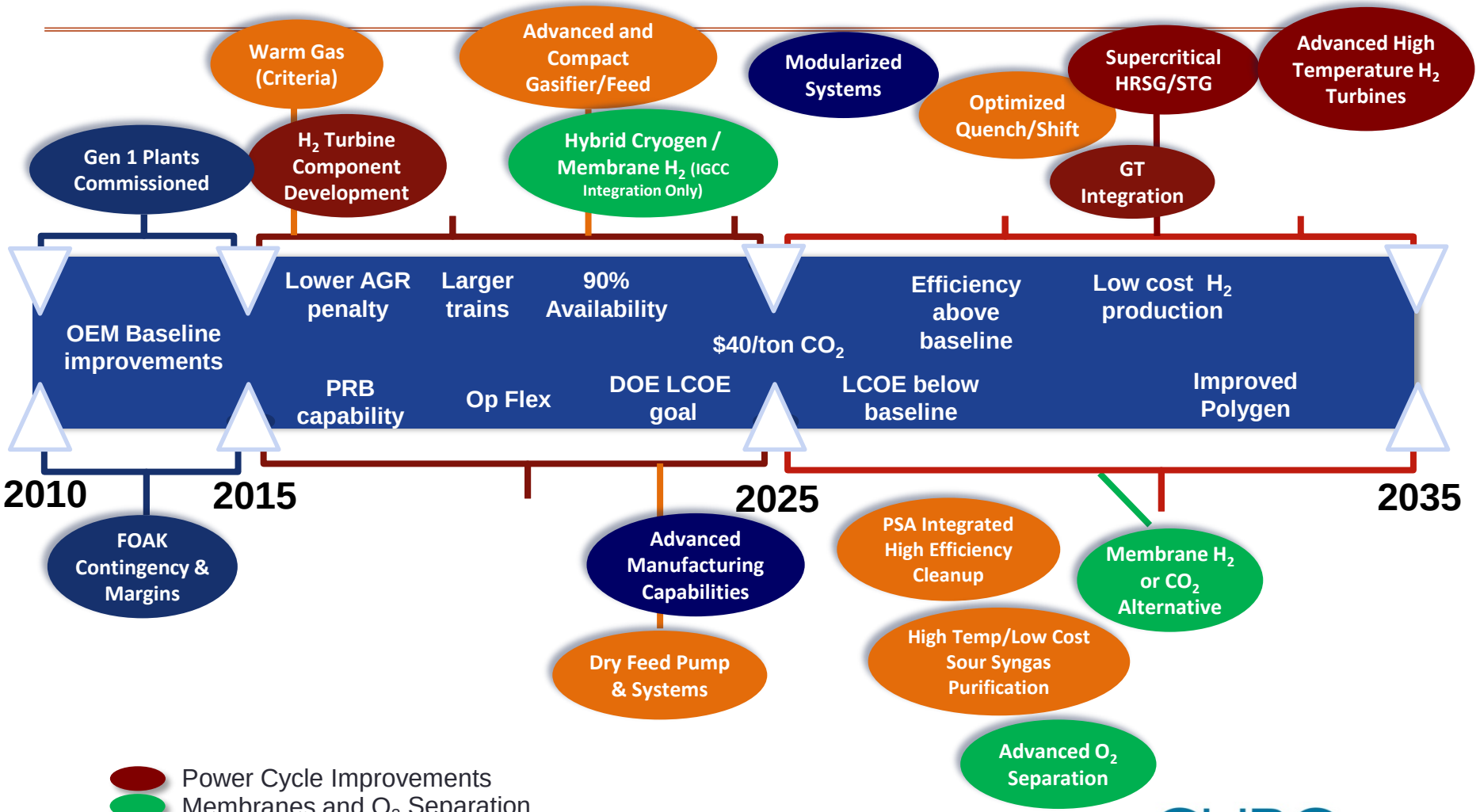
Gasification Roadmap



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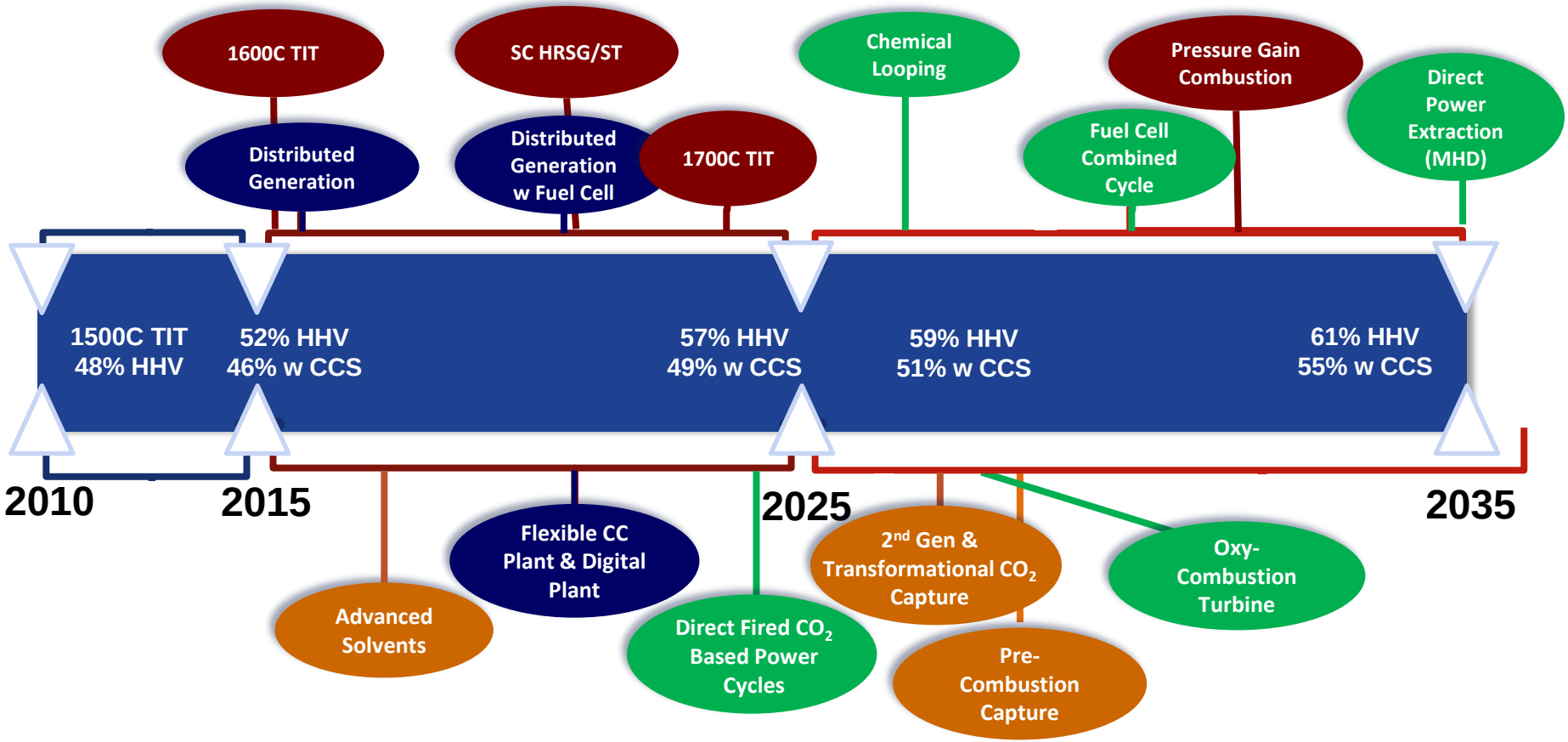
Natural Gas Roadmap



- Efficiency Improvements
- Advanced Power Cycles
- Advanced Processes
- Other Improvements

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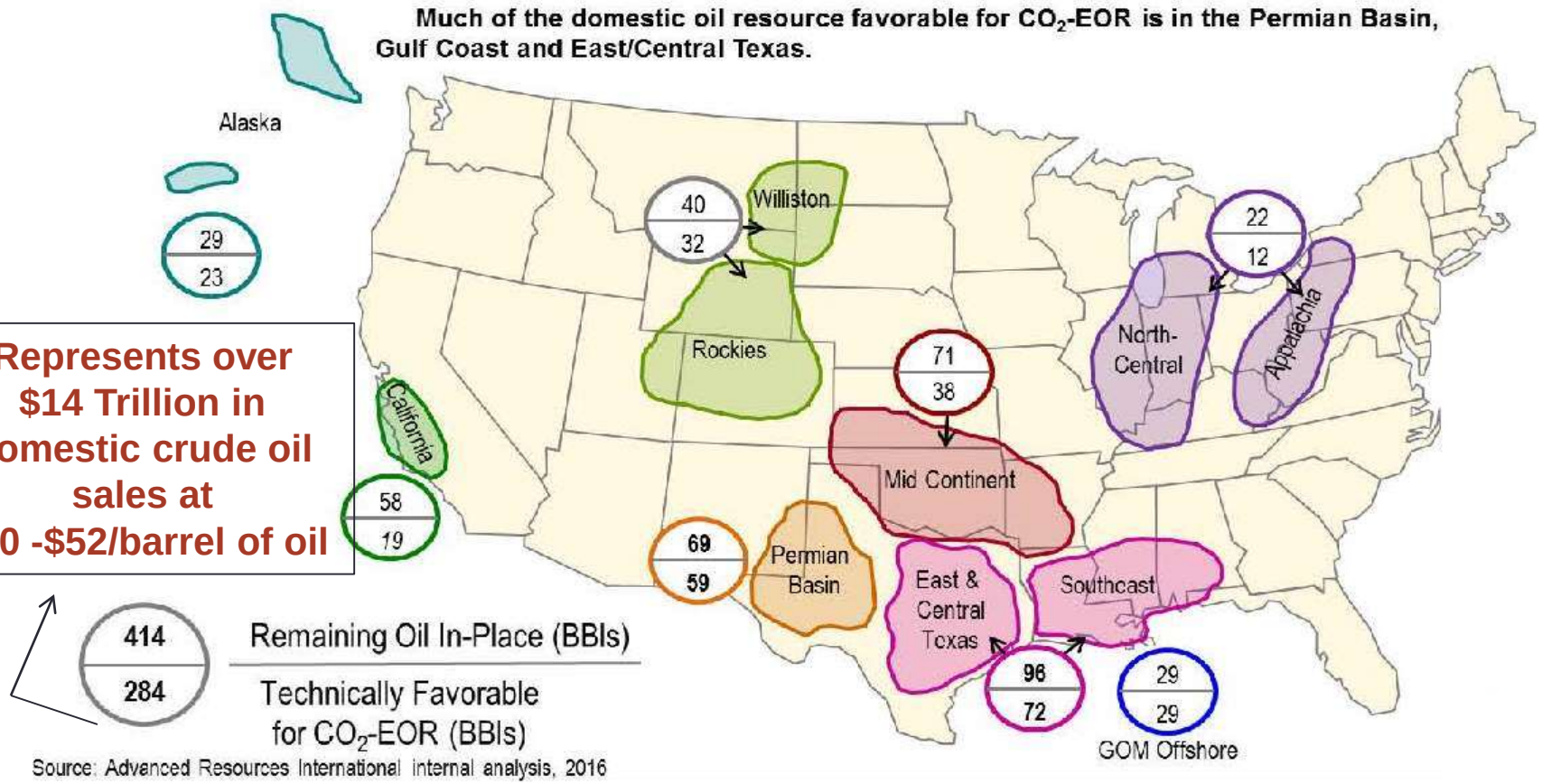
CURC-ClearPath Foundation Companion Macroeconomic Benefits Study

- Collaboration between the private sector and the federal government can produce affordable technologies to mitigate CO_2 emissions from coal and natural gas-fueled power plants.
- Early deployment of these technologies will primarily be driven by the use of CO_2 to enhance oil production from partially depleted domestic oil reservoirs.
- The study evaluates the potential economic benefits of RD&D to reduce the cost of Carbon Capture, Utilization, and Storage (CCUS) through market-driven deployment of CCUS.
- Study commissioned by CURC and ClearPath Foundation, with support from the International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers & Helpers; the International Brotherhood of Electrical Workers; and the United Mine Workers of America.
- Modeling done by NERA Economic Consulting and Advanced Resources International with analysis by Doug Carter.

Economic Potential of CO_2-EOR in the US

Regional Distribution of CO_2-EOR Potential



Represents over $14 Trillion in domestic crude oil sales at $50 -$52/barrel of oil

Price of Oil: Bloomberg Energy

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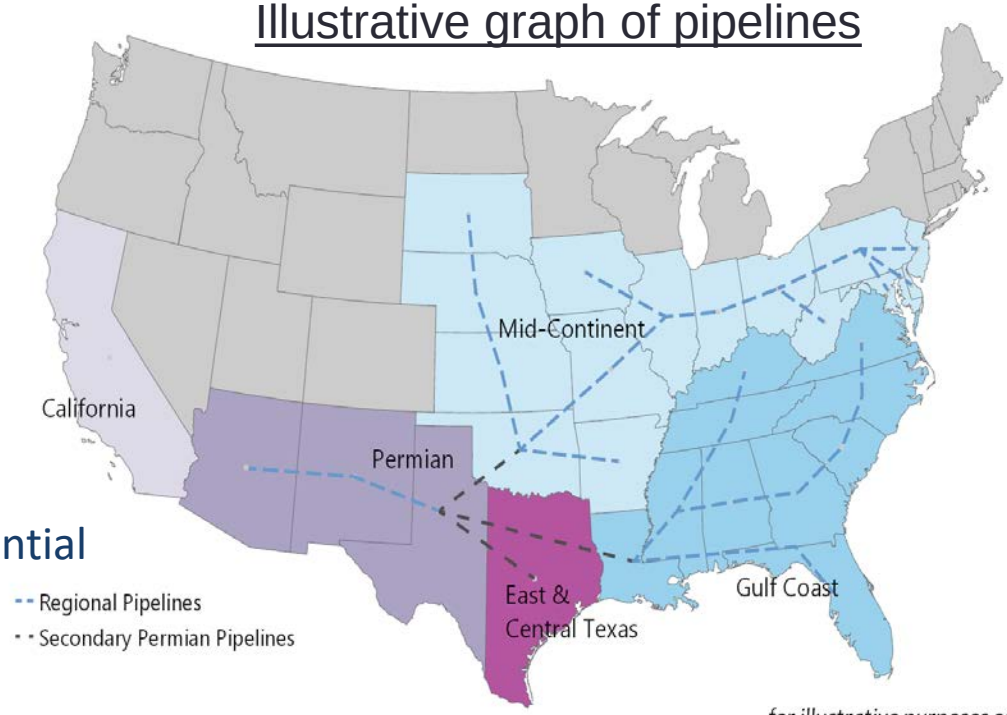
Key Study Assumptions

- Enhanced oil recovery is the only economic use for captured carbon dioxide
- Lowest cost power dispatches
- Status quo regulatory policy
- Capital charge adder to reflect potential financing challenges
- Cost of technology consistent with *CURC-EPRI Roadmap* for both coal & natural gas systems

Illustrative graph of pipelines



*for illustrative purposes only**

Regions with significant EOR potential were excluded from the study (Rocky Mountain Corridor, North Dakota, Ohio) because of the availability of lower cost natural or industrial sources of CO2 as well as relatively flat load growth or demand.

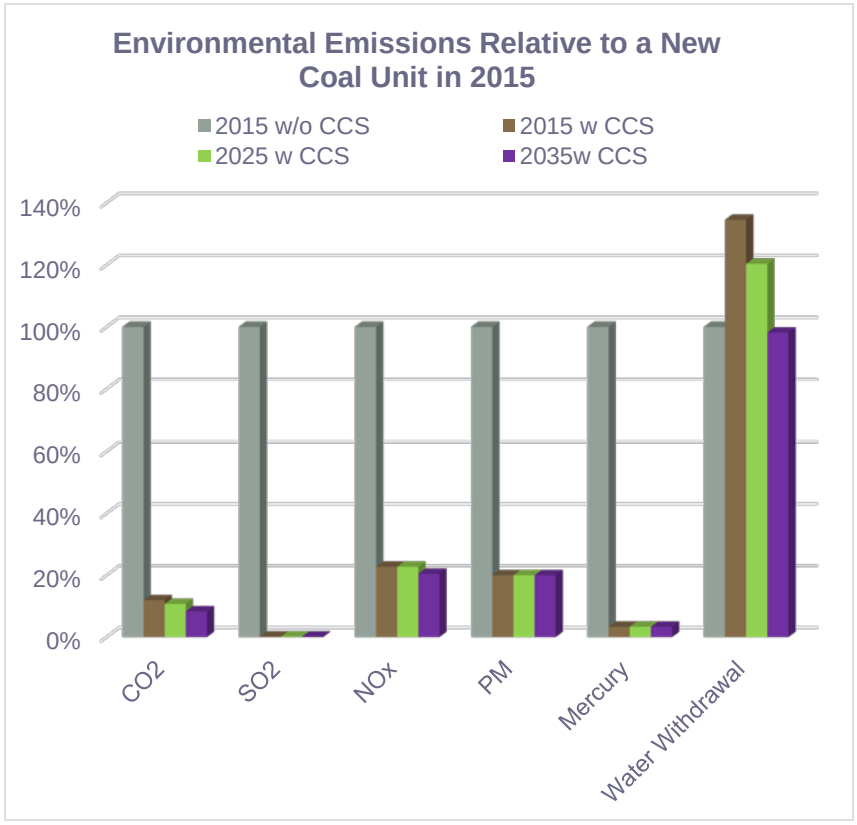
Study Results:
Benefits to the U.S. from CCUS RD&D

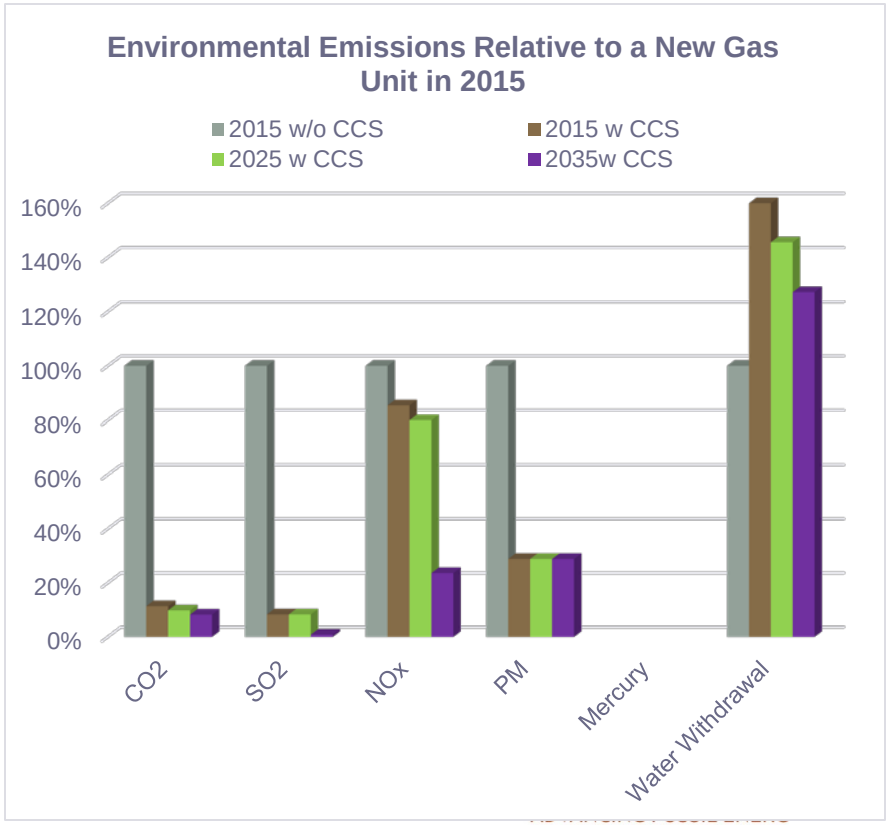
- If an RD&D program is implemented that achieves the Roadmap cost targets, market-driven deployment of **62 to 87 GW** of carbon capture power-sector projects under certain scenarios can be enabled by 2040.
- By 2040, the macroeconomic potential of undertaking the Roadmap are:

Scenarios	EOR-based Benefits		Electricity-based Benefits		Total Benefits	
	GDP ($B)	Jobs	GDP($B)	Jobs	**GDP($B)**	**Jobs**
1a & 1b	95	392,215	44	301,805	**140**	**694,020**
2a & 2b	97	407,410	38	260,214	**135**	**667,624**
3a & 3b	111	456,108	55	375,616	**166**	**831,724**
4a & 4b	47	191,422	30	207,017	**77**	**398,439**

Projected Environmental Benefits from Implementing the Roadmap

- Aggressive reduction of water use and criteria air emissions, including nitrogen oxides (NOx), sulfur dioxide (SO_2), mercury (Hg) and particulate matter (note that these reductions are from today's already reduced emissions levels)
- Reduction of CO_2 emissions





What is Needed to Implement Roadmap?

- Increased federal funding for R&D, piloting and commercially-demonstrating innovative technologies capable of competing in the commercial marketplace.

Current Federal Budget for Coal CCS & Power Systems	Average Annual Roadmap Budget
$430 million	$760 million

- Additional legislative efforts that will support Roadmap:
  - Already-enacted FUTURE Act, extending and expanding Section 45Q carbon sequestration tax credits
  - Legislation authorizing robust RD&D budgets targeting Roadmap goals
    - S. 2803, the Fossil Energy Utilization, Enhancement and Leadership (FUEL) Act of 2018
    - H.R. 5745, the Fossil Energy Research and Development Act
    - S. 1460, the Energy and Natural Resources Act
  - S. 2602, the USE IT Act, streamlining CO_2 pipeline infrastructure to help catalyze a CCUS industry
  - Investment Tax Credits for CCUS, including H.R. 5159

Roadmap Key Take-aways

- The CURC-EPRI Roadmap is a plan for delivering low- or zero-carbon emissions, fossil-fueled power plants and carbon capture technologies between 2025-2035 that can be cost-competitive with other sources of electricity under future market conditions.
- It is critical that a program for piloting and demonstrating emerging Roadmap technologies be implemented if they are to be successfully commercialized. Annual federal budgets must increase in the next several years to support the scale-up effort.
- The macro-economic benefits to the U.S. and the global environmental benefits far outweigh the federal investment recommended in the Roadmap.
- There is historical evidence of public-private partnerships developing new energy technologies that resulted in significant emissions reductions and are estimated to have resulted in a $50 billion economic benefit through 2005.

Thank you and Questions

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