CURC-EPRI Roadmap and the Industry Perspective on Clean Coal RD & D

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Companies in red indicate 2012 Steering Committee Members

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What is CURC's Purpose?

To advocate for support of research, development, demonstration and widespread deployment of technologies that will ensure the continued long-term use of U.S. coal supplies in a cost-effective and environmentally acceptable manner.

To develop and provide peer-reviewed information to policy-makers and regulators that clearly and simply explains coal-related technology status, capability, timing and needs.

To coordinate with other industry organizations (ACCCE, EEI, EPRI, NRECA, UMWA) and interest groups, including labor and NGO's, regarding technology capabilities and impacts on technology development resulting from policy choices.

Coal Utilization Research Council (CURC) www.coal.org

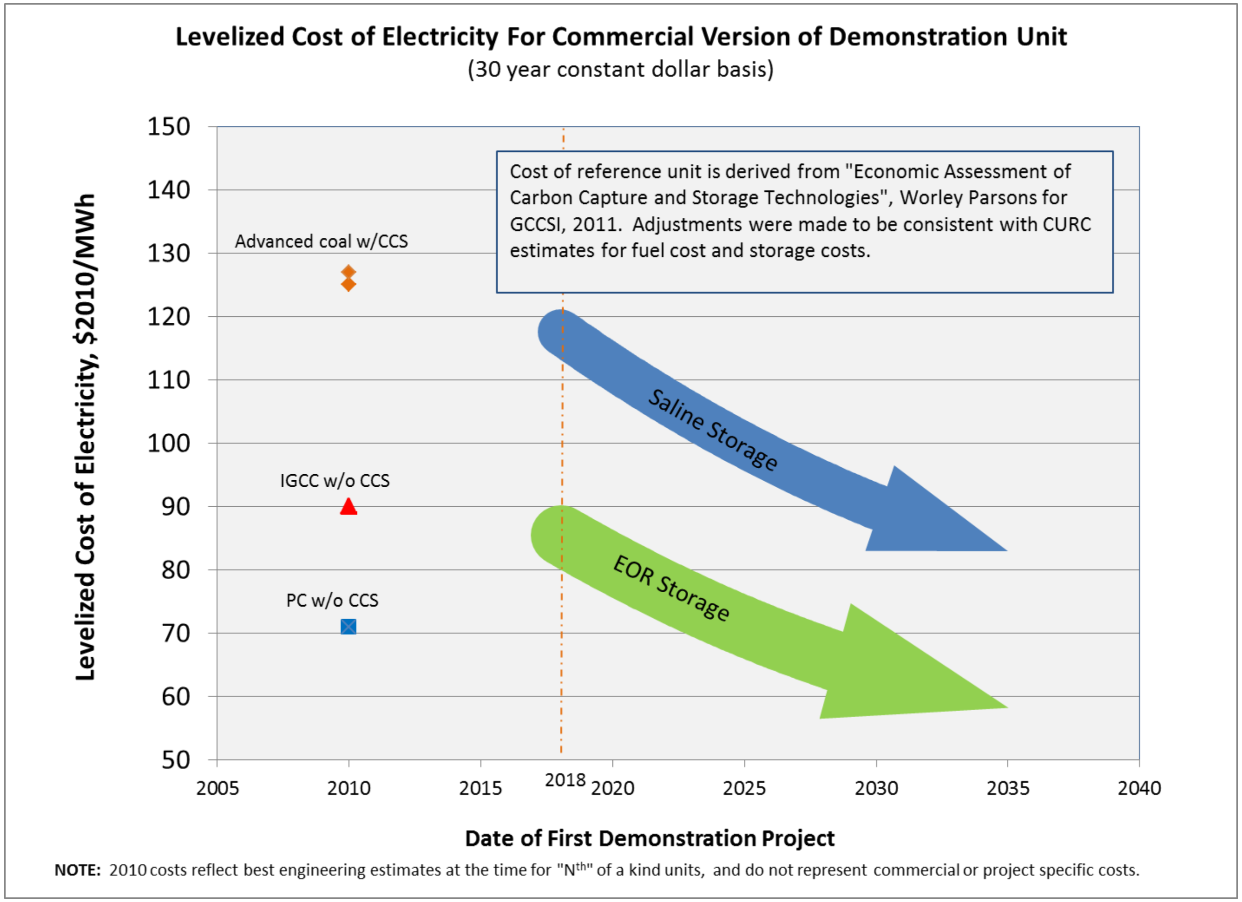
THE CURC-EPRI COAL TECHNOLOGY ROADMAP

Prepared by the Coal Utilization Research Council and the Electric Power Research Institute

June 2012

The Roadmap is a plan – ***to be undertaken in partnership with the federal government*** – to improve the environmental performance of coal while continuing to deliver low-cost electricity, energy and other valuable coal-derived products to America, and defines a set of specific technology solutions in order to meet those goals.

The Roadmap Delivers Improvements in Power Costs and Increases our Nation's EOR Potential

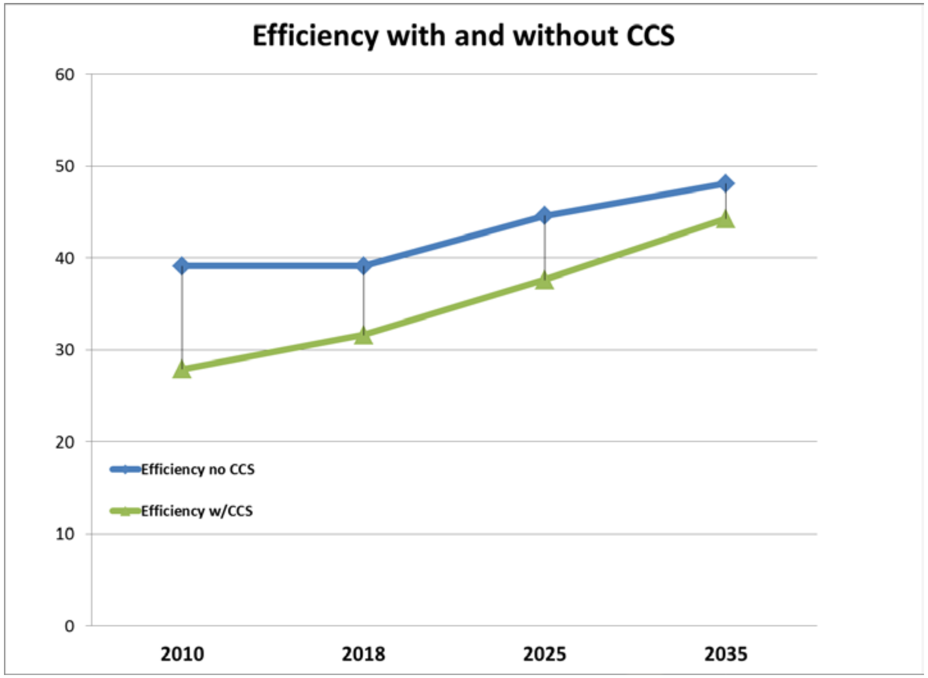


Successful implementation of the Roadmap will:

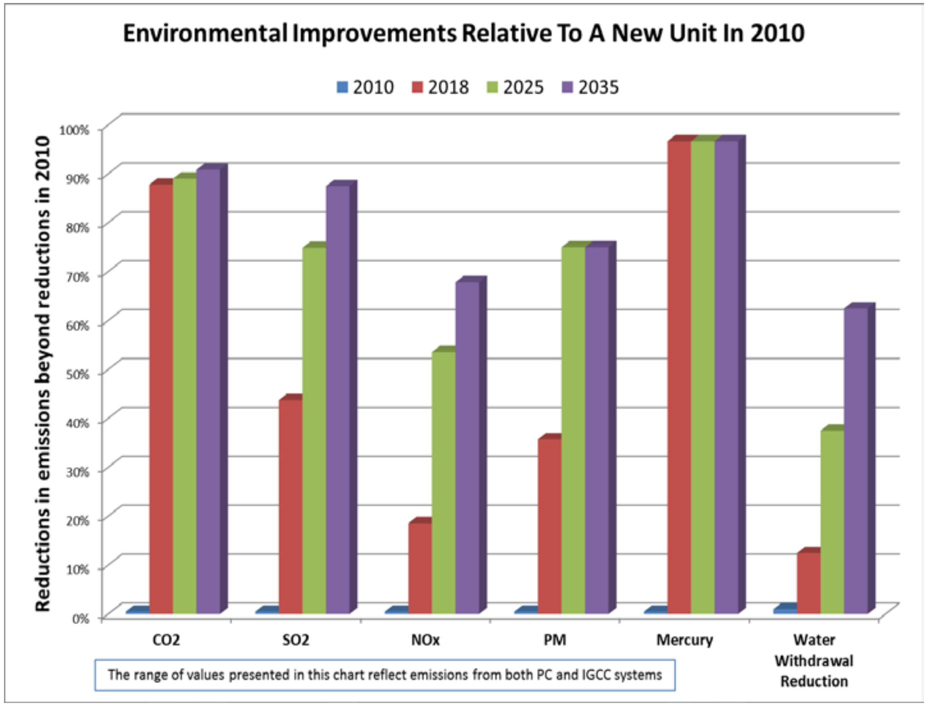
- Deliver cost competitive electricity to consumers, manufacturers and industry
- Retain and create jobs
- Improve U.S. global economic leadership
- Improve our nation's economic and energy security by displacing imports of foreign oil using CO_2 for domestic EOR production

The Roadmap Delivers Improvements in Environmental Performance

Independent of a climate driver, less CO_2 is emitted as a result of increased power generation efficiency, and less coal is used for the same unit of power output



Reduced emissions of traditional air pollutants, reduced water use and consumption, and reduced CO_2 emissions

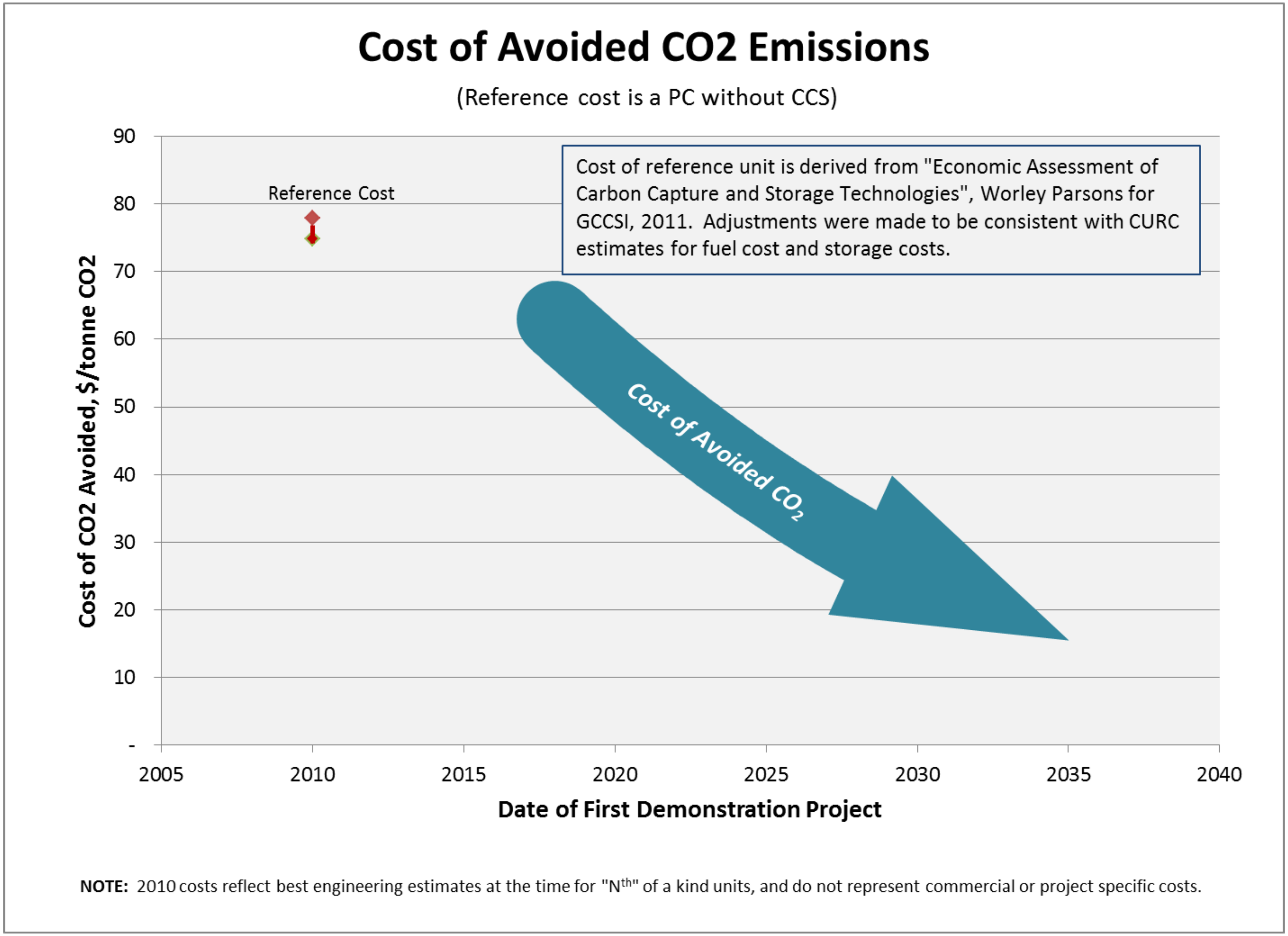


<u>2010 "State of the Art" Baseline Data</u>

Reductions reflect a range of values for both PC and IGCC technology changes after 2010, but the reductions in 2010 are very significant:

- **CO_2:** 0% (no carbon controls in use)
- **NOx and SO_2:** 90 - 99% reduction
- **PM:** 99.6% reduction
- **Mercury:** 90% reduction
- **Water Withdrawal Reduction** (as a result of cooling towers)**:** 98%

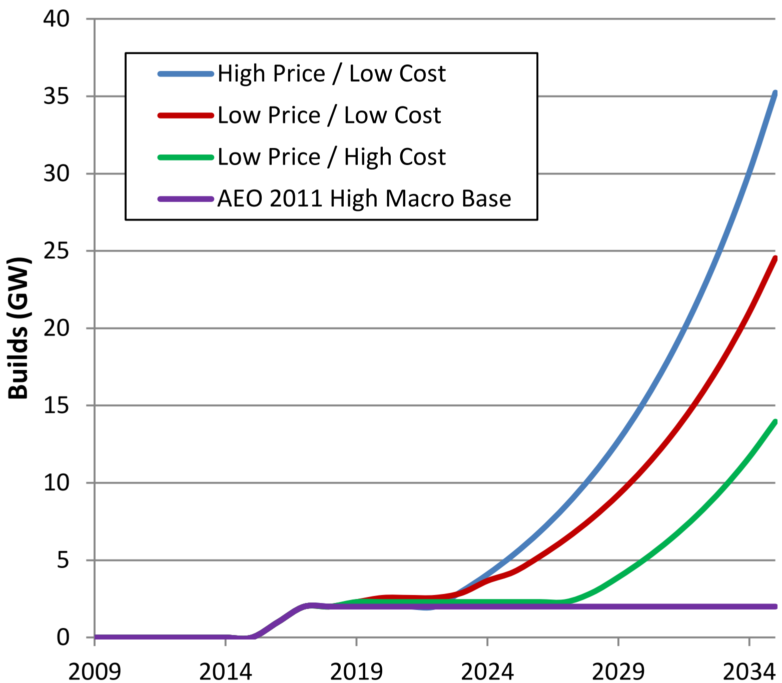
The Roadmap Delivers Improvement in CO_2 Reduction Costs



NETL Analysis of CURC-EPRI Roadmap

Summary of NEMs Roadmap Simulation:

NEMs shows market penetration of new coal units with CCS-EOR:



- Analysis ran NEMS AEO-2011 Hi-growth scenario
- Applied CURC-EPRI Roadmap performance targets + 5 years
- CO_2 valued at ~ \$40/t or \$60/t for EOR in TX or CA, less transport cost of \$13/t or \$20/t (CA, TX = \$4/t).
- **Results: 5-15 GW new coal projected in 2030; 15-35 GW in 2035.**
- Most builds in SE (VA to MS), TX, MI.
- Did not analyze CCS retrofits or polygeneration.

Source: DOE National Energy Technology Laboratory, June 12, 2012

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CURC-EPRI Roadmap

Technical Analysis

Roadmap Structure and Assumptions

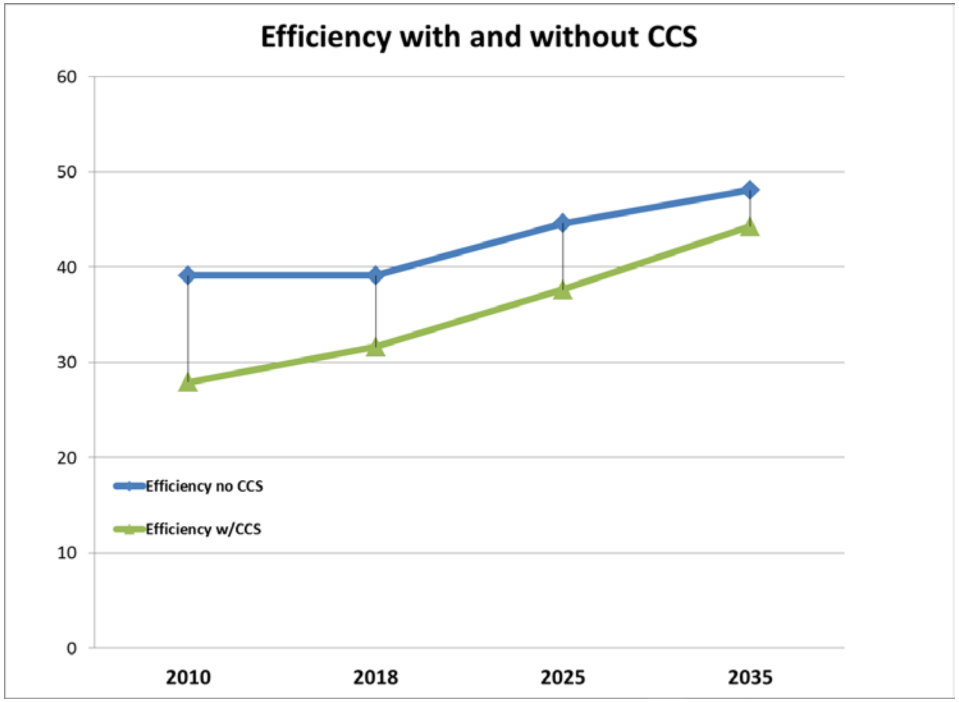
- Three technology areas examined:
  - Gasification
  - Combustion
  - Technologies that cross cut both platforms, including CO_2 storage, air separation, compression, water use, coal drying
- 2010 base case, sets targets for 2018, 2025 and 2035:
  - Criteria pollutants, CO_2 and efficiency
  - LCOE and capital costs assumes 90% capture except for base case
  - Dates assume a first commercial demonstration unit in operation
- Analysis focuses on electricity, while recognizing benefits of other products derived from coal

Combustion Roadmap: General Technology Assumptions

	Technology Progression	Performance / Specifications
2010	• Ultrasupercritical (Turk equivalent) • Closed cycle cooling (conventional cooling towers) • Water treatment and discharge • Activated carbon injection • No CCS	i. Steam temperature: 1,150ºF ii. Cycle efficiency: 39% iii. No CCS iv. Net efficiency: 39% HHV v. Capital cost: $2,300/kW (add $2,600 for current CCS)
2018	• Ultrasupercritical or oxycombustion • Closed cycle cooling (conventional cooling towers) • Water treatment and discharge • Advanced mercury sorbents • Advanced amine-based CCS	i. Steam temperature: 1,150ºF ii. Cycle efficiency: 39% HHV iii. CCS: 90% CO_2 capture, 20% energy penalty iv. Net efficiency: 32% HHV v. Capital cost: $4,200/kW ($2,300 base + $1,900 CCS)
2025	• Advanced ultrasupercritical or advanced oxycombustion • Hybrid cooling (air and cooling towers) • Zero liquid discharge • Advanced mercury sorbents • Elevated pressure solvent-based CCS	i. Steam temperature: 1,300ºF ii. Cycle efficiency: 45% HHV iii. CCS: 90% CO_2 capture, 16% energy penalty iv. Net efficiency: 38% HHV v. Capital cost: $4,000/kW ($2,400 base + $1,600 CCS)
2035	• Advanced ultrasupercritical or advanced oxy combustion or chemical looping combustion or CO_2-based power cycles • Dry cooling • Zero liquid discharge • Advanced mercury sorbents • CCS operating at full-sequestration pressures	i. Steam temperature: 1,400ºF ii. Cycle efficiency: 48% HHV iii. CCS: 90% CO_2 capture, 8% energy penalty iv. Net efficiency: 44% HHV v. Capital cost: $3,300/kW ($2,400 base + $900 CCS)

Combustion Technologies Deliver

Improved Efficiency



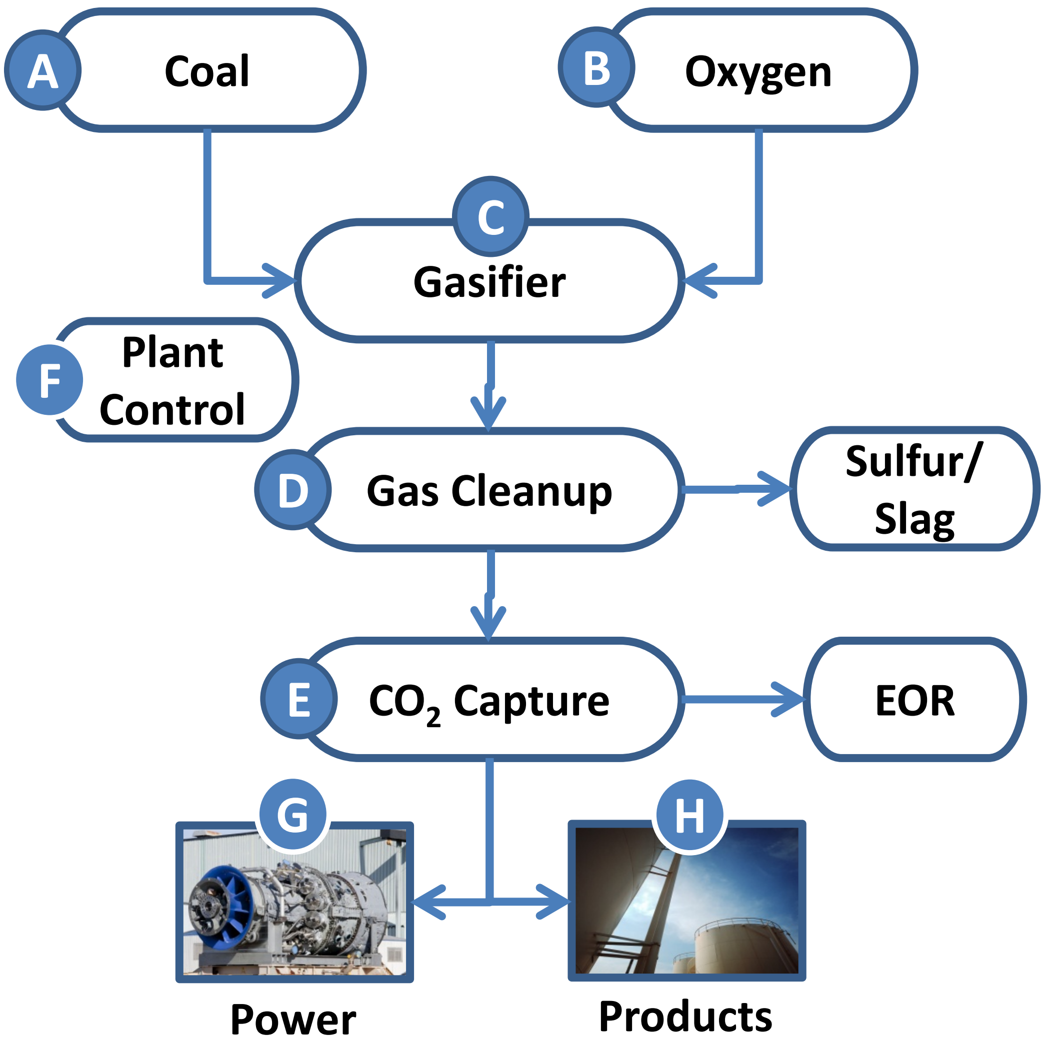
New and Improved Generation and Retrofit Technologies:

- Retrofit capabilities for both criteria pollution control and reduced emissions of CO_2
- New platforms for highly efficient advanced generation systems
- Reduced water consumption and withdrawals for both retrofit and new systems

Gasification Roadmap: General Technology Assumptions

	Technology Progression	Performance / Specifications
2010	• Conventional GE IGCC (Duke Edwardsport equivalent) • Slurry coal feed • Cool gas cleanup • Cryogenic oxygen production • No shift CO_2 removal ("entitlement CO_2")	i. Net efficiency: 37% HHV ii. No shift CCS: 15% CO_2 capture iii. Cost CO_2 avoided[1]: $89 iv. Capital cost: $4,100/kW
2018	• Natual gas equivalent CO_2 IGCC (GHG NSPS) • Dry coal feed • Warm gas cleanup • Alternatives to cryogenic oxygen production • Single-stage shift CO_2 removal (natural gas equivalent)	i. Net efficiency: 33% HHV ii. CCS: ~60% CO_2 capture, 780 #-CO2/MWh iii. Cost CO_2 avoided[1]: $66 iv. Capital cost: $3,600/kW
2025	• Advanced IGCC with 90% CO_2 capture • High temp, low cost sour syngas cleanup • Hybrid cryogenic / membrane oxygen production • High hydrogen gas turbines • Multi-stage shift and temperature-swing CO_2 sorbents	i. Net efficiency: 37% HHV ii. CCS: 90% CO_2 capture, 195 #-CO2/MWh iii. Cost CO_2 avoided[1]: $50 iv. Capital cost: $3,200/kW
2035	• Advanced IGCC w/fuel cells or oxyfiring, 90% CO_2 capture • Advanced gasification and coal feed systems • Ion transport membrane oxygen with gas turbine integration • Oxygen combustion turbine • Advanced membrane CO_2 separation • Game Changers: chemical looping, fuel cell toping cycles, flue gas water recovery, ultra-high unit flux O_2 membranes	i. Net efficiency: 43% HHV ii. CCS: 90% CO_2 capture, 185 #-CO2/MWh iii. Cost CO_2 avoided[1]: $39 iv. Capital cost: $2,900/kW

IGCC/Gasification Technologies



Primary program

A
- Dry feed
- In-situ beneficiation

B
- Membrane O_2
- Cryo-alternative O_2

C
- 24K refractory
- Advanced gasifiers
- Optimized construction
- Partial water quench

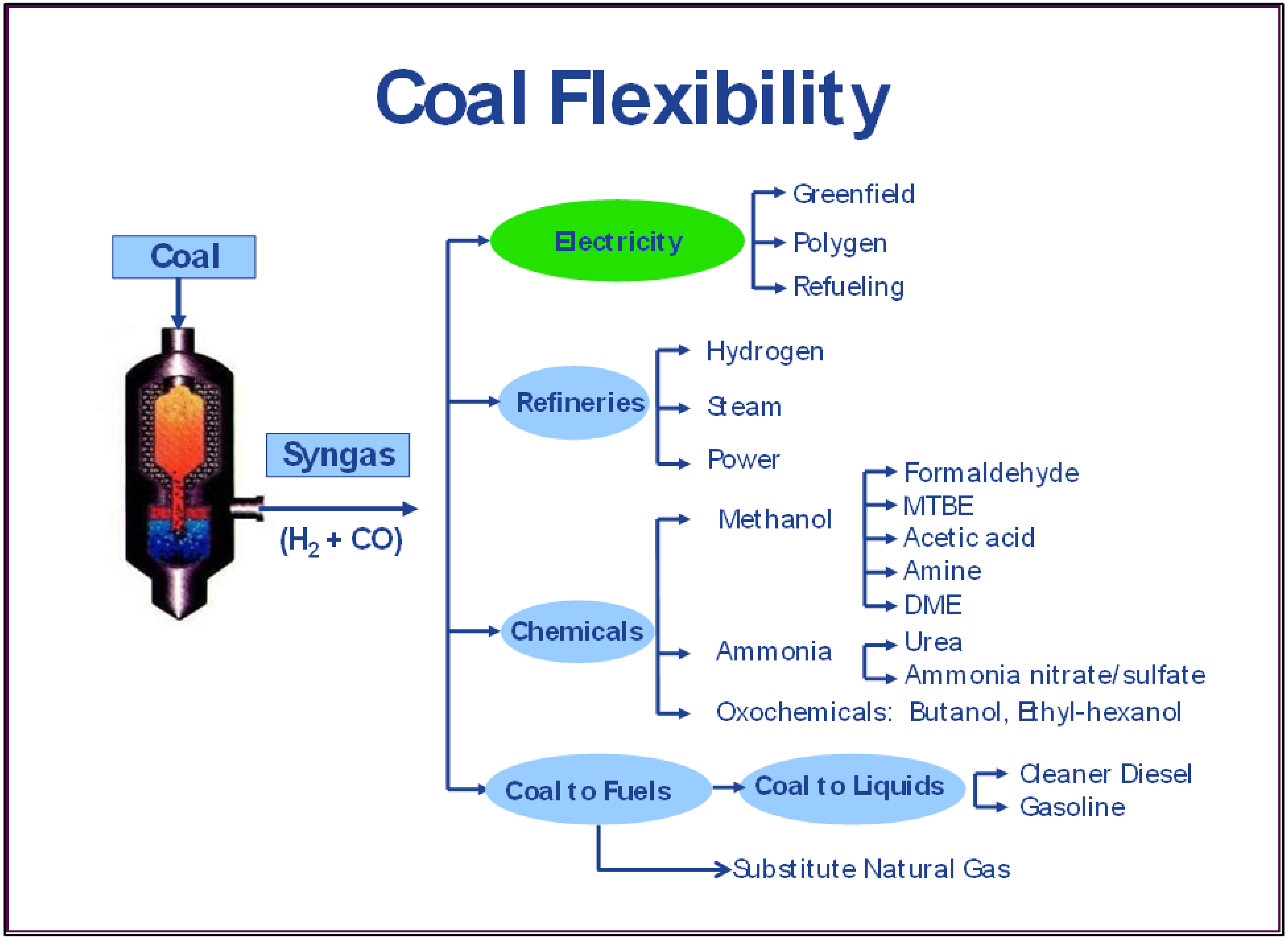
D
- 16K filters
- Grey water cleanup
- High T acid gas removal
- Warm gas cleanup

E
- New shift catalysts
- Temp swing/PSA sorbent
- Membrane H_2

F
- Advanced I&C
- Fast ramp/SUSD
- Health monitoring

G
- G/J/H turbines
- Non-foul HXs
- Advanced H_2 turbine
- Supercritical STG

Coal Produces Valuable Products: Potential Product Slate from Gasification



Cross-Cutting Roadmap

- Water Use RD&D
  - Water use and discharge, efficiency
- Coal Drying RD&D
  - Efficiency
- Air Separation RD&D
  - LCOE, capex, efficiency, availability
- CO_2 Compression, Utilization and Storage RD&D
  - CO_2 emissions, \$$CO_2$ avoided, LCOE, efficiency, capex, availability
- University Training, Breakthrough R&D
  - All

CO_2 Storage

- CO_2 storage projects integrate existing experience and technology from oil and gas sector. Greatest need is to build market and public confidence in CO_2 storage, largely through successful demo projects.
- CURC has a separate CCS-EOR Initiative underway, and strongly advocates for deployment incentives for CCS and CCUS, but this is outside the scope of the R&D technical needs of the roadmap.
- Even with CO_2-EOR, RD&D is needed for saline storage as a backup; it provides long term certainty of CO_2 storage capacity.
- The roadmap recommends a new site certification program to facilitate the commercial deployment of geologic storage. The program would characterize and qualify 5 regionally-diverse sites that can each accept 50 MM tons at 5 MM tons/yr.

What is Needed to Successfully Implement the Roadmap?

President's FY2012 Request: $291M
FY 2012 Omnibus: $369M ($390M in 2011)
President's FY2013 Request: $276M

Funding		2013-2018	2019-2025	2026-2035
R&D	Total ($M/year)	465	363	189
	Federal (80% share)	372	291	151
Demos	Total ($M/year)	$120M for pilot demos	6,100	3,500
	Federal (50% share)	Current planned demos	3,050	1,750
Total Number of Demos		~5 to 8 currently in planning stages	2-4	2-3

Note: These costs reflect the total expenditure needed for RD&D, including both Federal and private sector contributions. The R&D figures are expressed as an annual amount, averaged over the multi-year period, whereas the demonstration project costs are expressed as a total for that period.

Just How Important is RD&D?

Bill Gates at ARPA-E Summit in February 2012

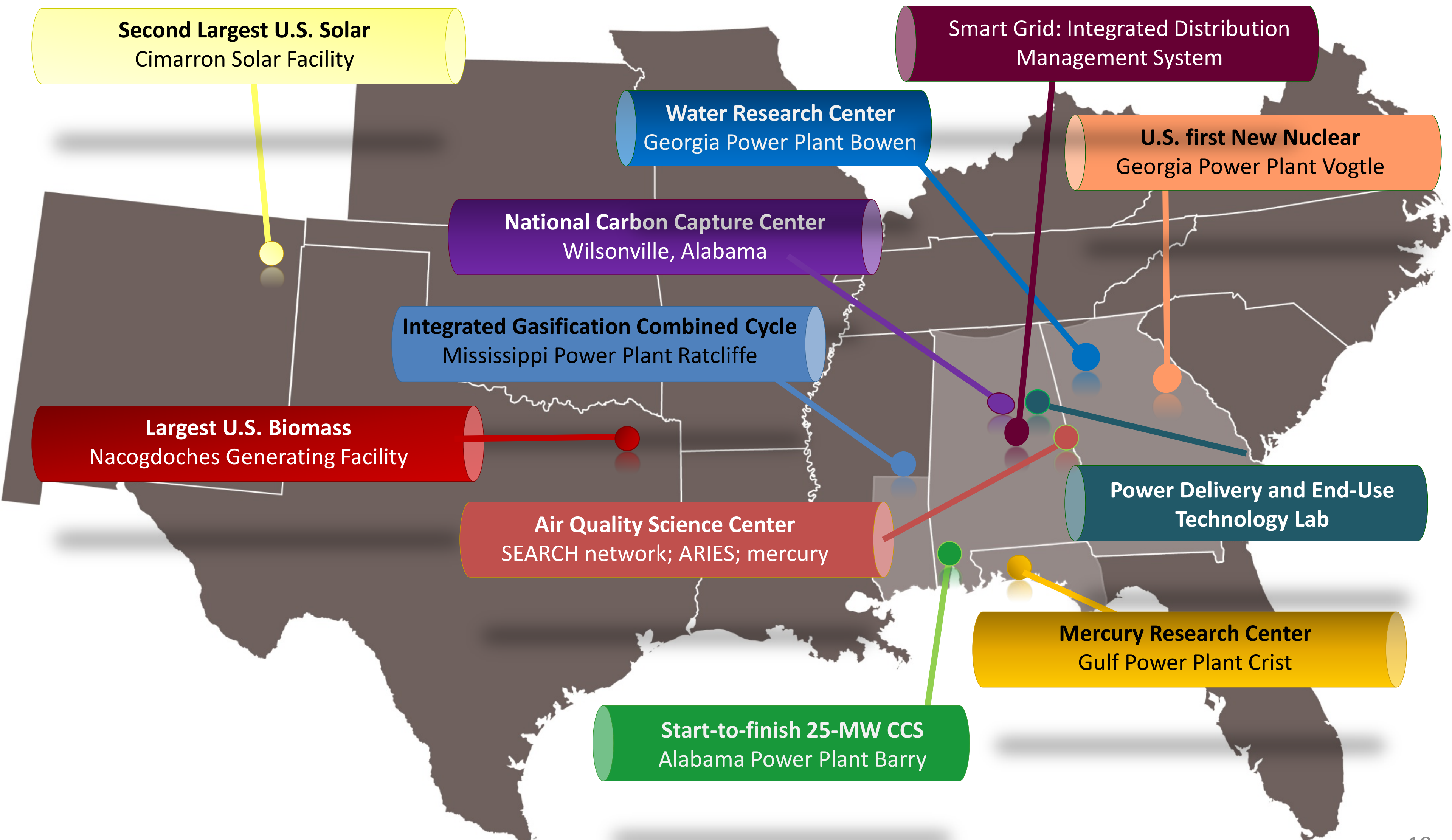
Bill Gates, who spoke on stage at the conference, remarked on the tremendous lack of funding in this space, pointing especially to the government. **"It's crazy how little we are funding this energy stuff."** He also said that giving a little bit of money and making it seem as if that's practically all that's needed is a disservice.

"People underestimate how far away we are. That's partly why we can end up underfunding the innovative work that needs to go on."

On CCS, Gates pointed out that **"Carbon dioxide doesn't have that many positive economic uses to justify taking [out] 7 billion tons a year in capture… I think it's really one of the more underinvested areas on a global basis."**

"The IT revolution is the exception that has warped people's minds in how quickly things work," Gates said. "It's very different than having a software company – or even a chip Factory – where your innovation cycles are two or three years, and your dependence on government policy is very low."

New Southern Company Projects with RD&D Foundations



Questions?

Thank you!

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