Status and Outlook for CO_2 Capture Systems

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Carbon Capture, Utilization and Storage: Status, Issues, Needs
Resources for the Future
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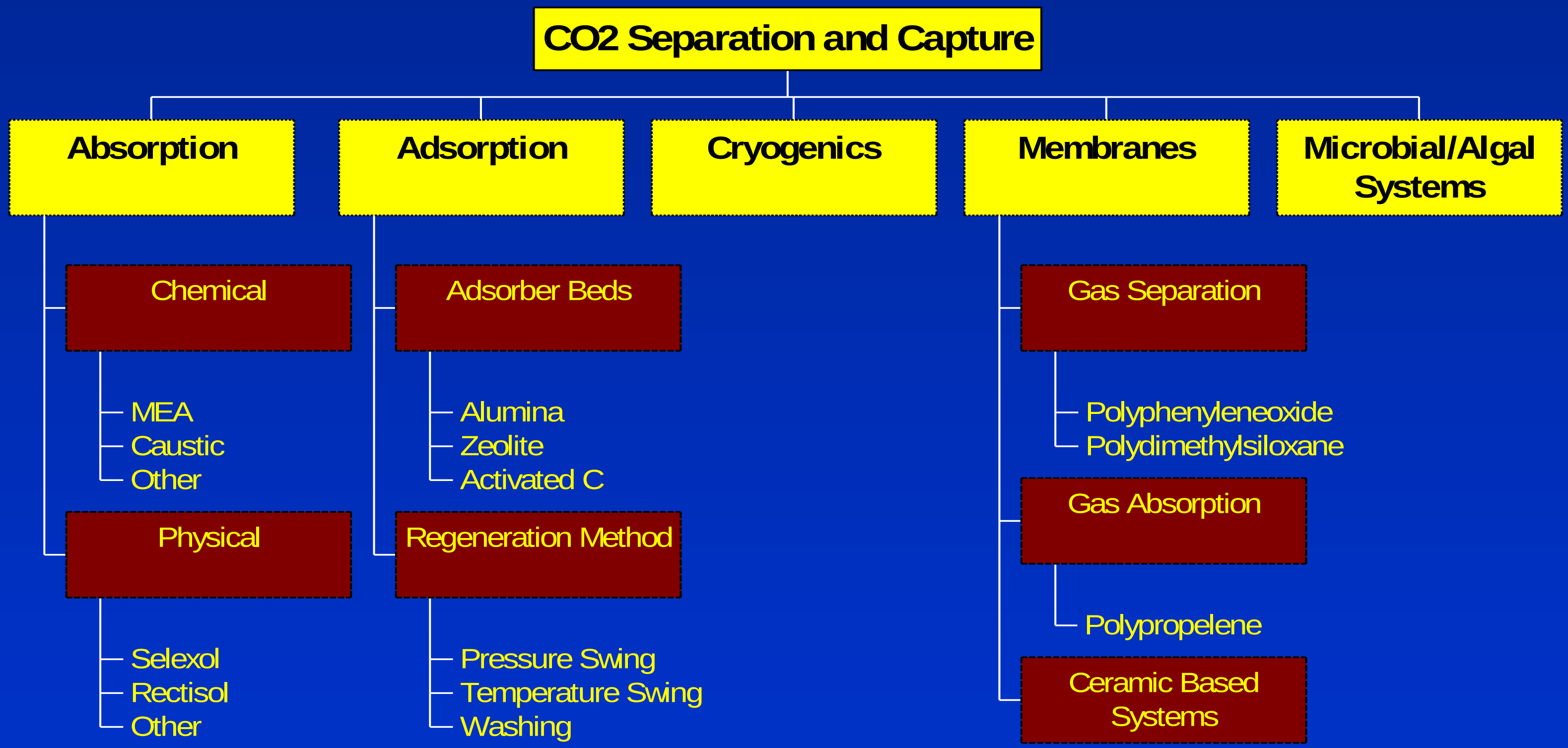
Outline of Talk

- Current status of CO_2 capture technology
- Potential for advanced lower-cost systems
- What's needed to achieve capture goals

Current status

Many Ways to Capture CO_2



Choice of technology depends strongly on application

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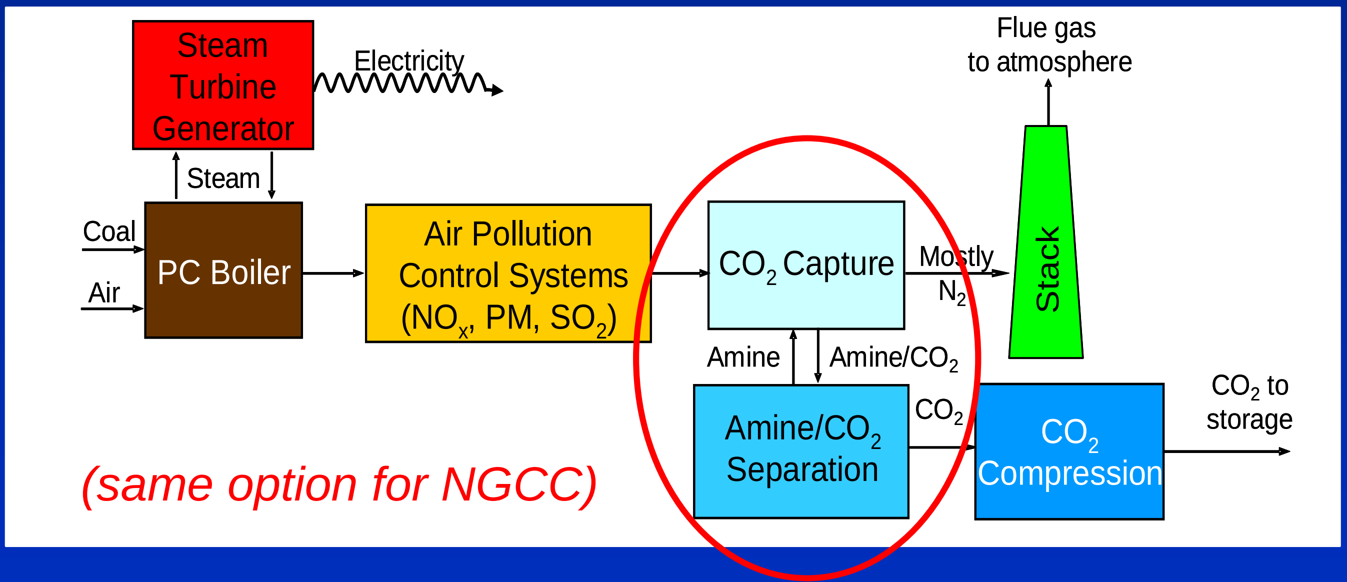
Amine-Based CO_2 Capture at a Natural Gas Processing Plant

Source: IEAGHG, 2008

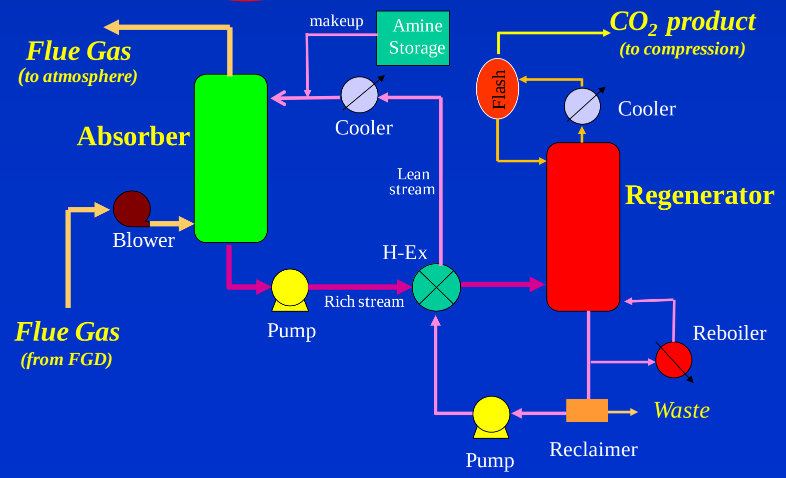
BP Gas Processing Plant, In Salah, Algeria

Power Plant Option 1: Post-Combustion CO_2 Capture



Details of amine-based CO_2 capture system

(capture efficiency typically ~90%)



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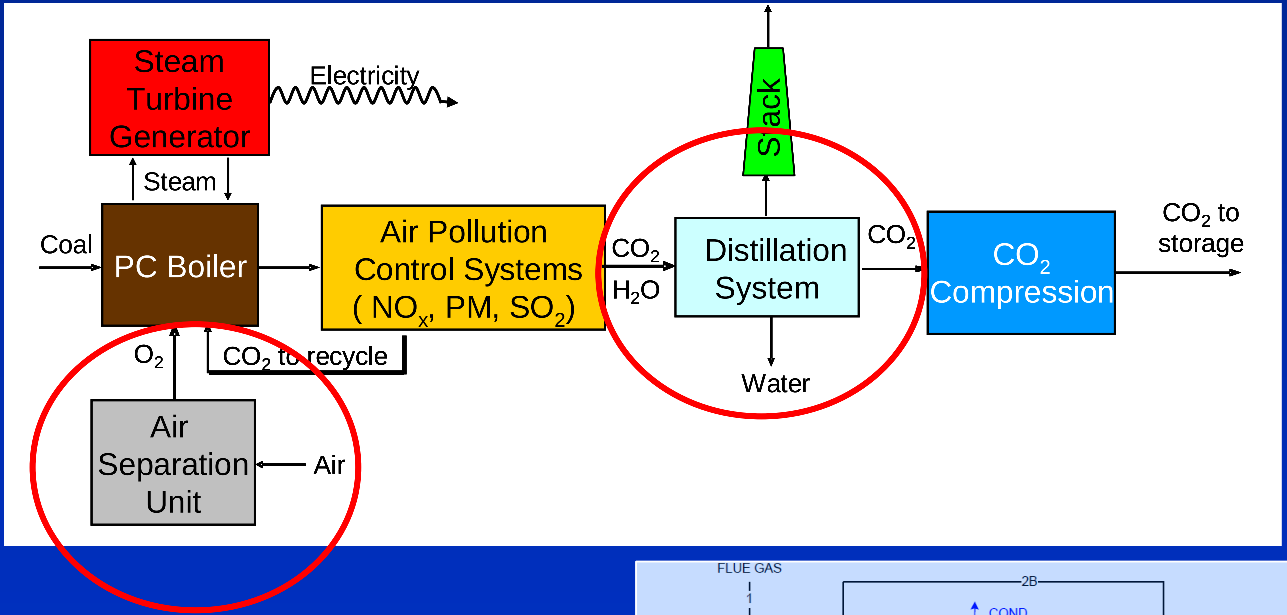
Post-Combustion Capture at the Boundary Dam Power Plant

Source: SaskPower, 2014

Post-Combustion Capture at the Petra Nova Power Plant

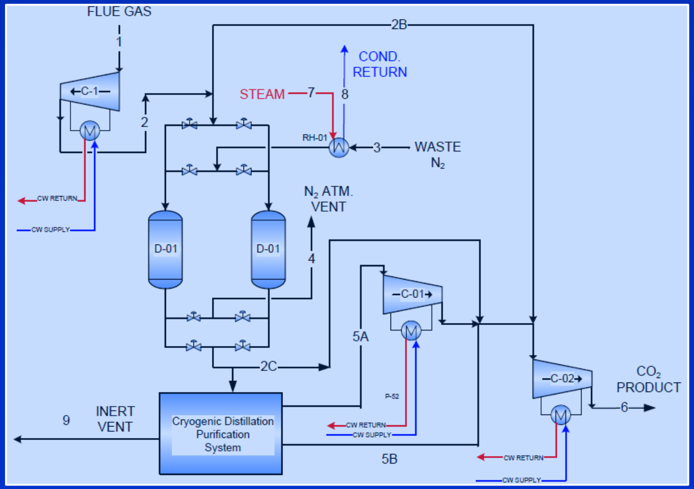
Source: NRG, 2017

Power Plant Option 2: Oxy-Combustion CO_2 Capture



Details of CO_2 purification system

(recovery efficiency typically ~90%)

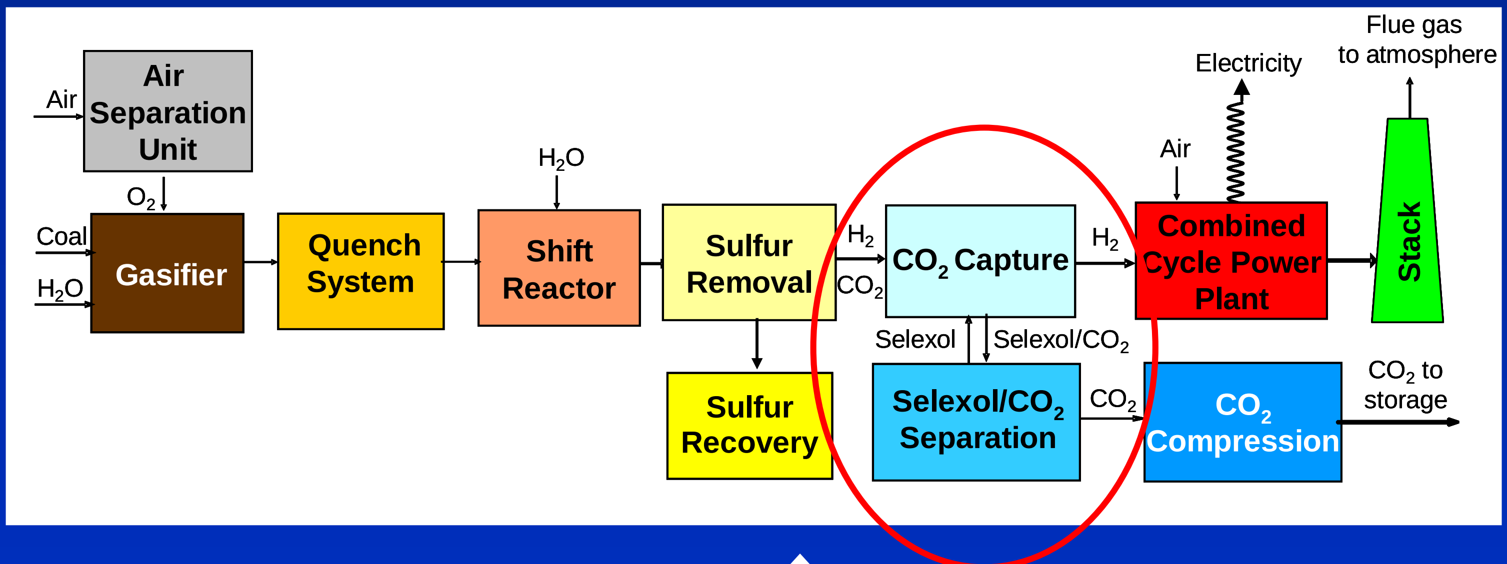


Oxy-Combustion CO_2 Capture from a Coal-Fired Boiler

30 MW_t Pilot Plant (~10 MW_e) at
Vattenfall Schwarze Pumpe Station
(Germany)

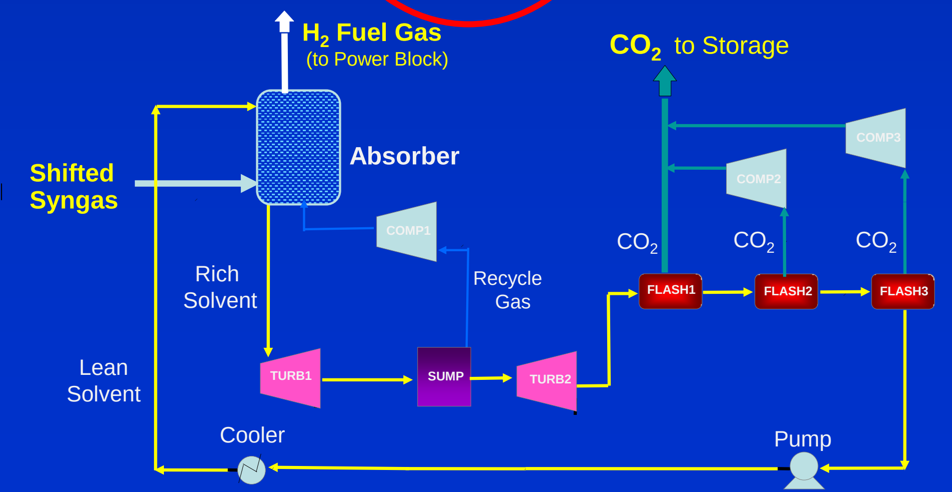
Source: Vattenfall, 2008

Power Plant Option 3: Pre-Combustion CO_2 Capture



Details of Selexol-based CO_2 capture system

(capture efficiency typically ~90%)



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Pre-Combustion CO_2 Capture at the Kemper IGCC Power Plant

Source: Southern Co., 2017

Industrial Process Applications

(Source: Chevron-Texaco)

Petcoke Gasification to Produce H_2

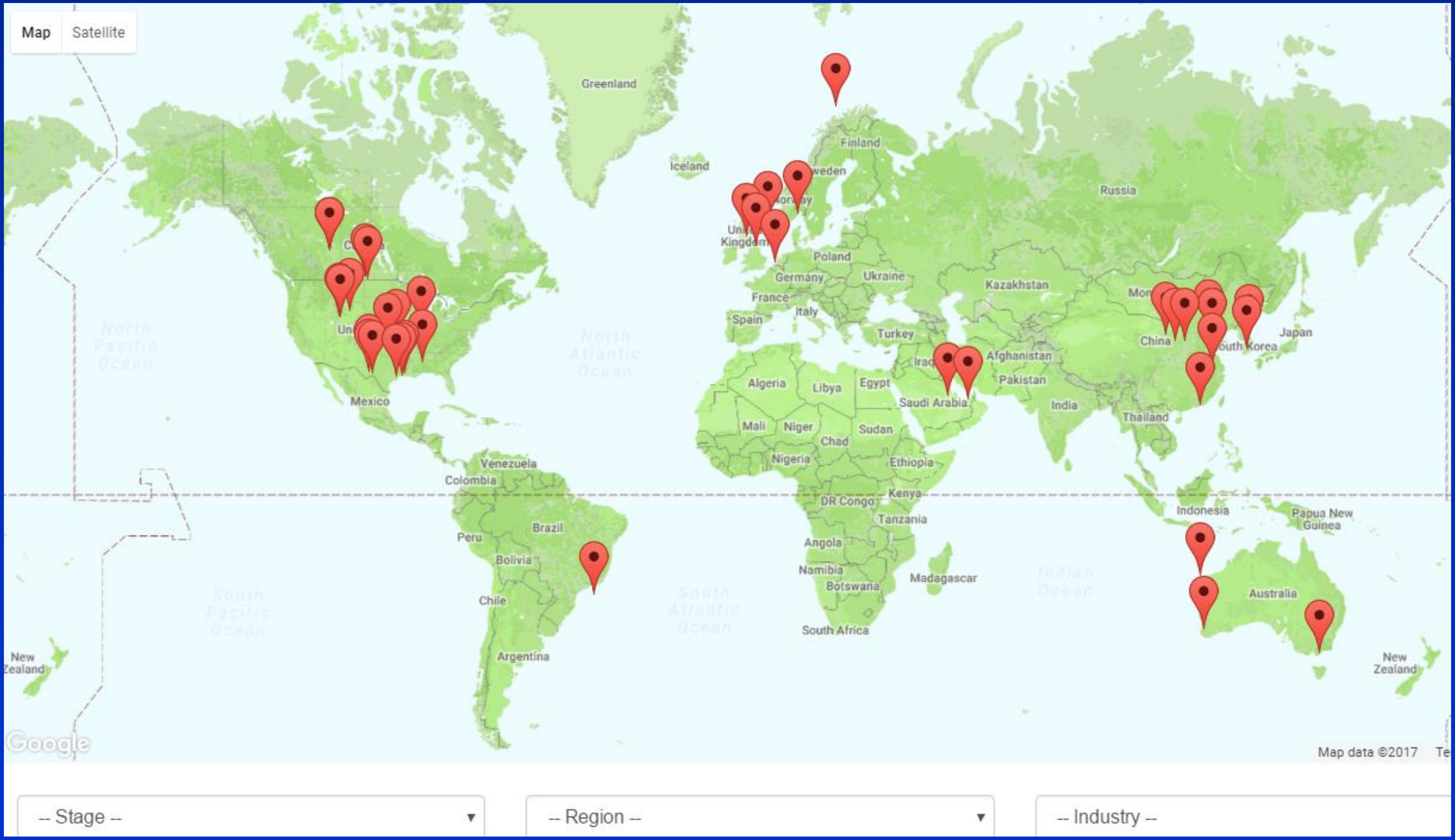
(Coffeyville, Kansas, USA)

(Source: Dakota Gasification)

Coal Gasification to Produce SNG

(Beulah, North Dakota, USA)

Current CCS Projects



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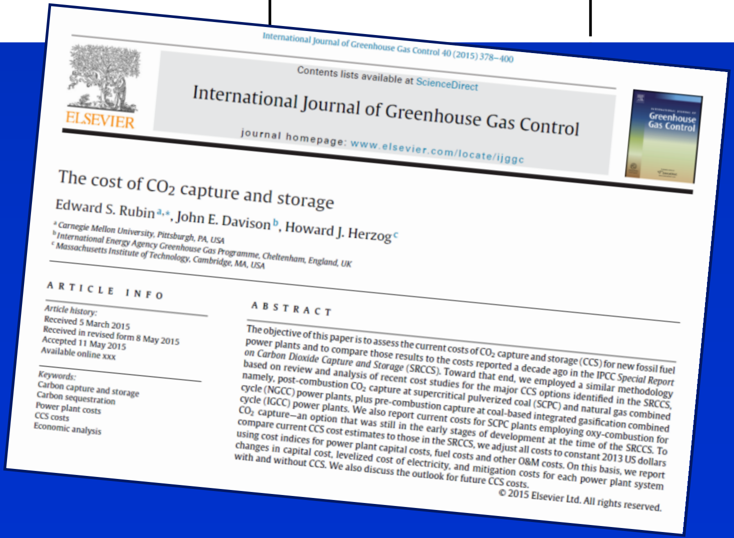
Source: GCCSI, 2017

CCS Cost Estimates for New Power Plants Using Current Technology

Incremental cost of CCS relative to same plant type w/o CCS (based on 90% capture with geological storage)	Supercritical Pulverized Coal Plant, post-comb. (SCPC)	Supercritical Pulverized Coal Plant, oxy-comb. (SCPC)	Integrated Gasification Combined Cycle Plant (IGCC)	Natural Gas Combined Cycle Plant, post-comb. (NGCC)
Increase in levelized electricity generation cost (2013$/MWh)	**~ 30–70**	**~ 35–75**	**~ 25–50**	**~ 20–50**

- ***Capture accounts for most (~80%) of total CCS cost***
  (Details in IJGGC paper, 2015)
- ***EOR credits can reduce CCS cost significantly***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The cost of CO_2 capture and storage

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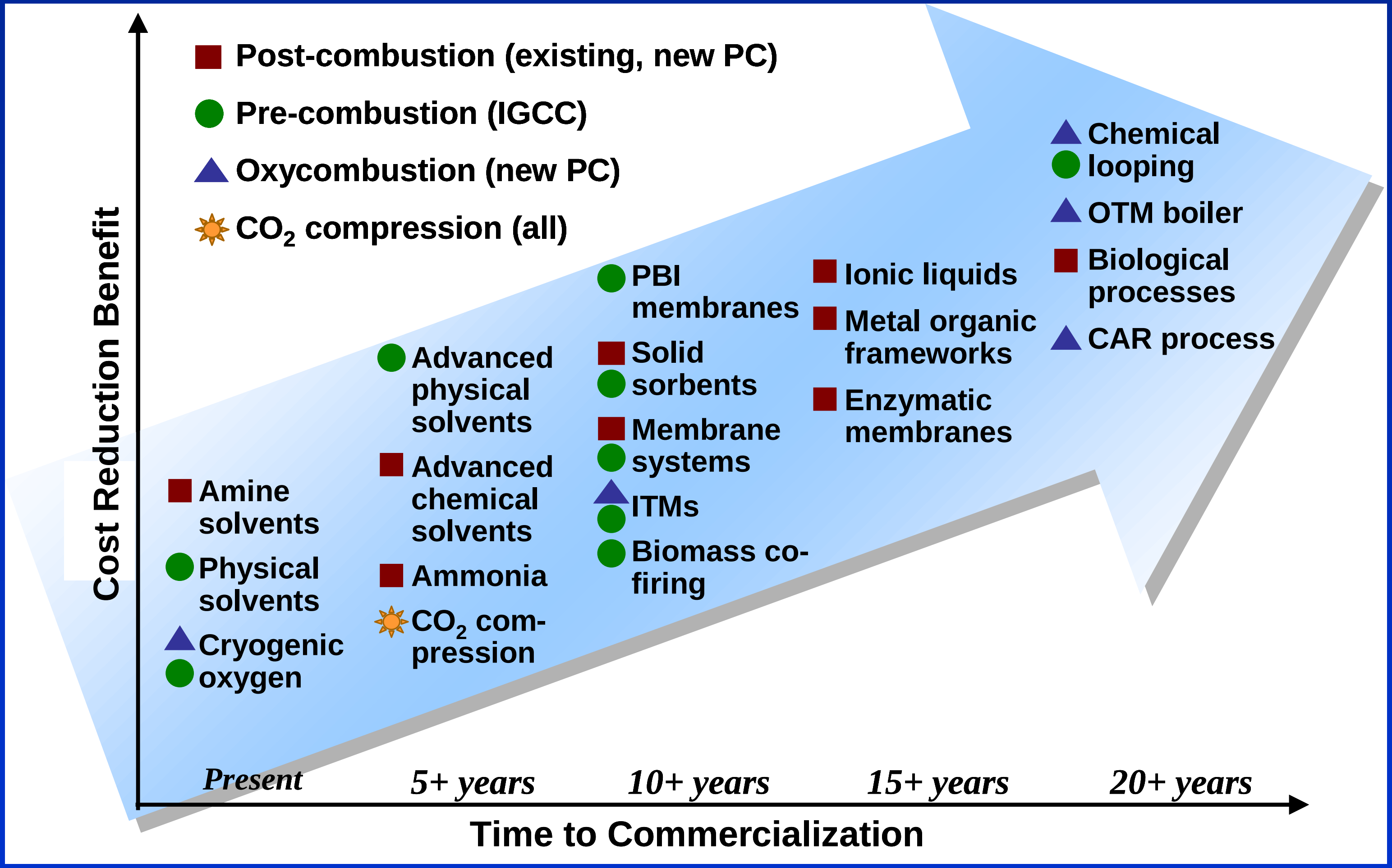
ABSTRACT
The objective of this paper is to assess the current costs of CO_2 capture and storage (CCS) for new fossil fuel power plants and to compare those results to the costs reported a decade ago in the IPCC *Special Report on Carbon Dioxide Capture and Storage* (SRCCS). Toward that end, we employed a similar methodology based on review and analysis of recent cost studies for the major CCS options identified in the SRCCS, namely, post-combustion CO_2 capture at supercritical pulverized coal (SCPC) and natural gas combined cycle (NGCC) power plants, plus pre-combustion capture at coal-based integrated gasification combined cycle (IGCC) power plants. We also report current costs for SCPC plants employing oxy-combustion for CO_2 capture—an option that was still in the early stages of development at the time of the SRCCS. To compare current CCS cost estimates to those in the SRCCS, we adjust all costs to constant 2013 US dollars using cost indices for power plant capital costs, fuel costs and other O&M costs. On this basis, we report changes in capital cost, levelized cost of electricity, and mitigation costs for each power plant system with and without CCS. We also discuss the outlook for future CCS costs.

Potential for advanced lower-cost capture systems

R&D Programs Seek to Develop Lower-Cost Capture Systems



Source: USDOE, 2010

Two Principal Goals of Advanced Capture Technology

- Improvements in performance
  - Lower energy penalty
  - Higher capture efficiency
  - Increased reliability
  - Reduced life cycle impacts
- Reductions in cost
  - Capital cost
  - Cost of electricity
  - Cost of CO_2 avoided
  - Cost of CO_2 captured

Most Goals Focus on Reducing Cost

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Recent R&D goals of the U.S. Department of Energy

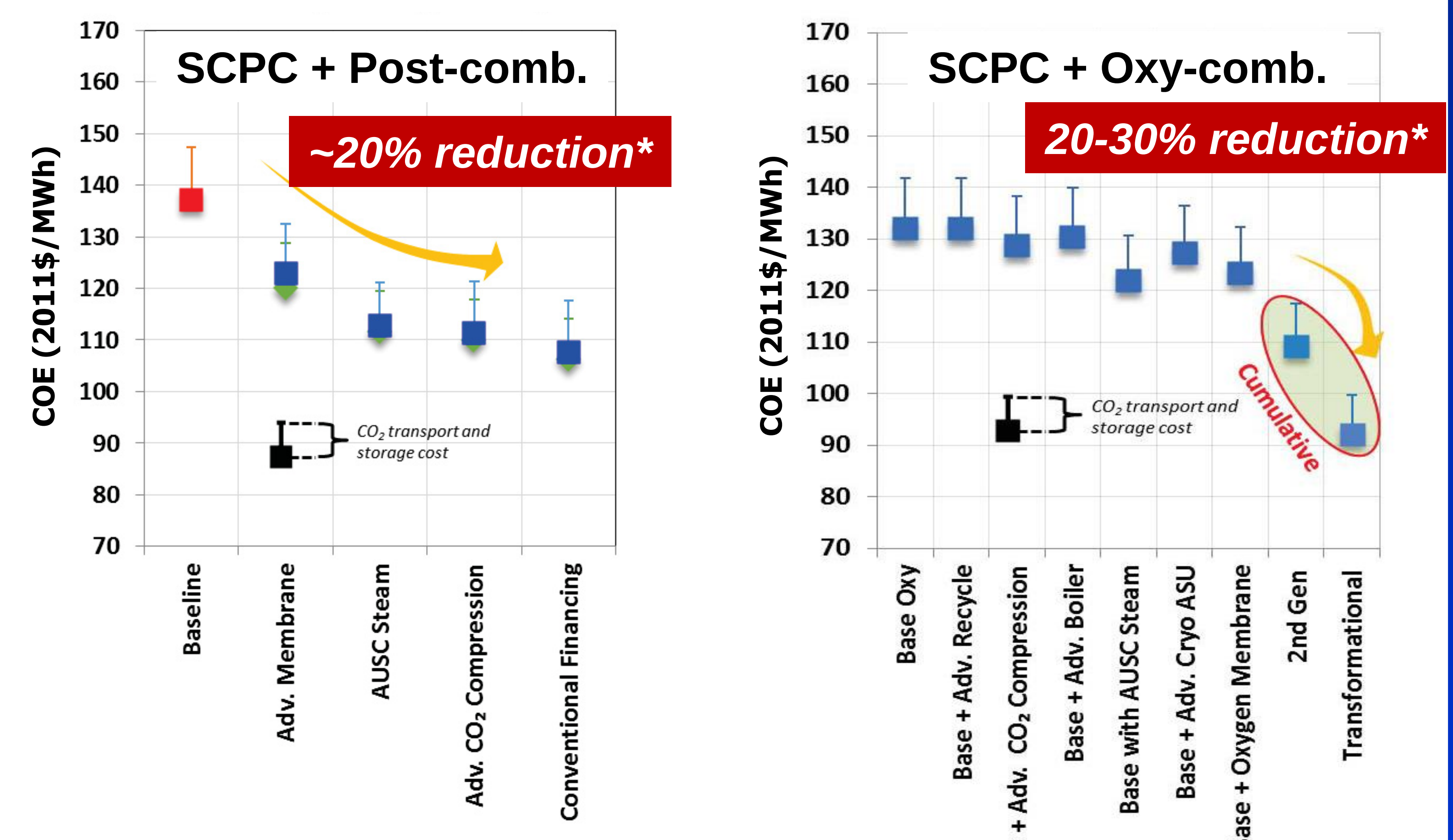
Table 3-1. **Market-Based R&D Goals for Advanced Coal Power Systems**

	Goals (for nth-of-a-kind plants)		Performance Combinations that Meet Goals	
R&D Portfolio Pathway	*Cost of Captured CO_2, $/tonne*[1]	*COE Reduction*[2]	*Efficiency (HHV)*	*Capital/O&M Reduction*[3]
2nd-Geneneration R&D Goals for Commercial Deployment of Coal Power in 2025[4]				
In 2025, EOR revenues will be required for 2nd-Generation coal power to compete with natural gas combined cycle and nuclear in absence of a regulation-based cost for carbon emissions.				
Greenfield Advanced Ultra-Supercritical PC with CCS	40	20%	37%	13%
Greenfield Oxy-Combustion PC with CCS	40	20%	35%	18%
Greenfield Advanced IGCC with CCS	≤40	≥20%	40%	18%
Retrofit of Existing PC with CCS	45	n/a		
Transformational R&D Goals for Commercial Deployment of Coal Power in 2035[4]				
Beyond 2035, Transformational R&D and a regulation-based cost for carbon emissions will enable coal power to compete with natural gas combined cycle and nuclear without EOR revenues.				
New Plant with CCS—Higher Efficiency Path	<10[5]	40%	56%	0%
New Plant with CCS—Lower Cost Path	<10[5]	40%	43%	27%
Retrofit of Existing PC with CCS	30	≥40%	n/a	

The specific form and magnitude of goals may change over time.

Source: USDOE/NETL, 2012

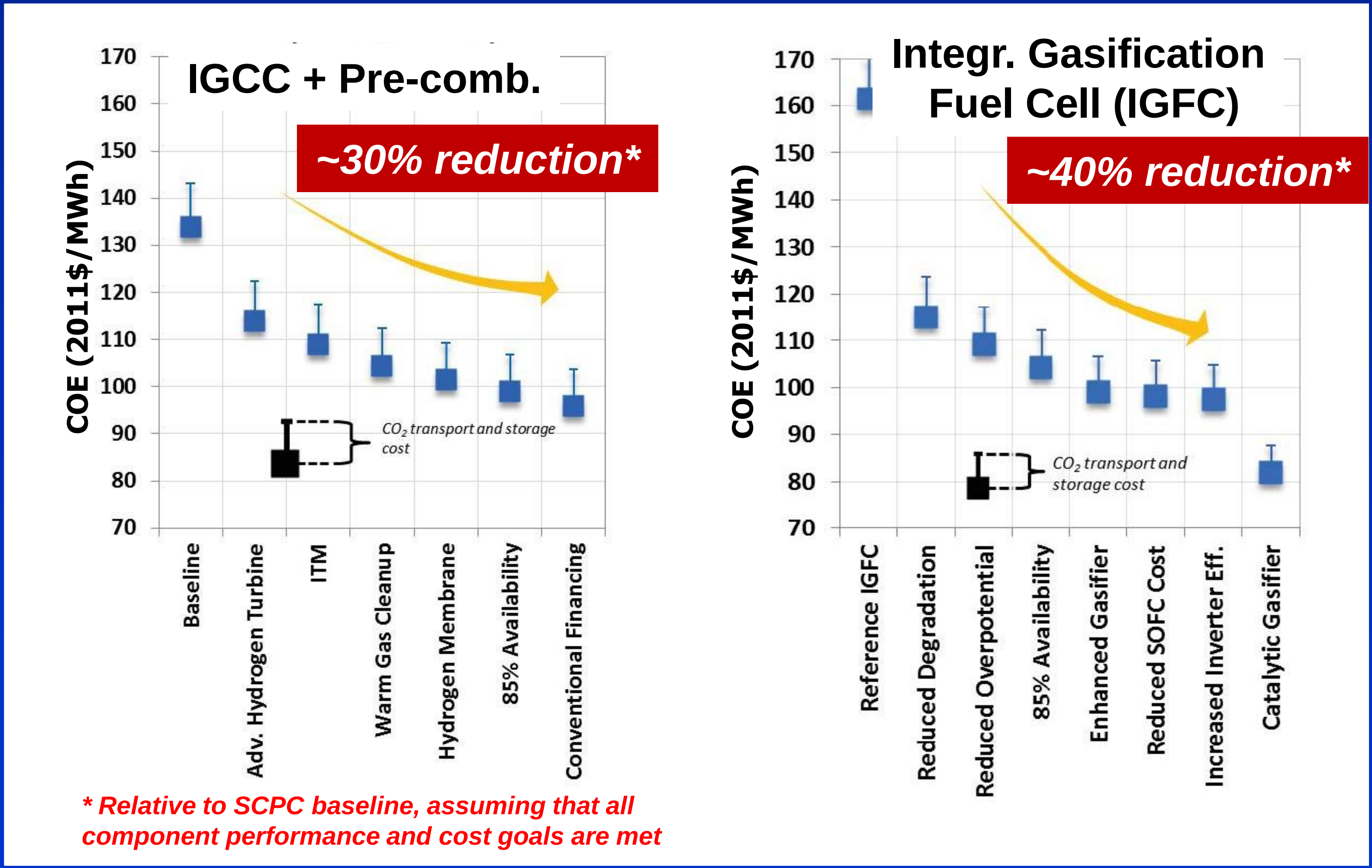
Projected cost reductions from "bottom-up" analyses of advanced plant designs *(1)*



*** Relative to SCPC baseline, assuming that all component performance and cost goals are met**

Source: Gerdes et al, NETL, 2014

Projected cost reductions from “bottom-up” analyses of advanced plant designs *(2)*



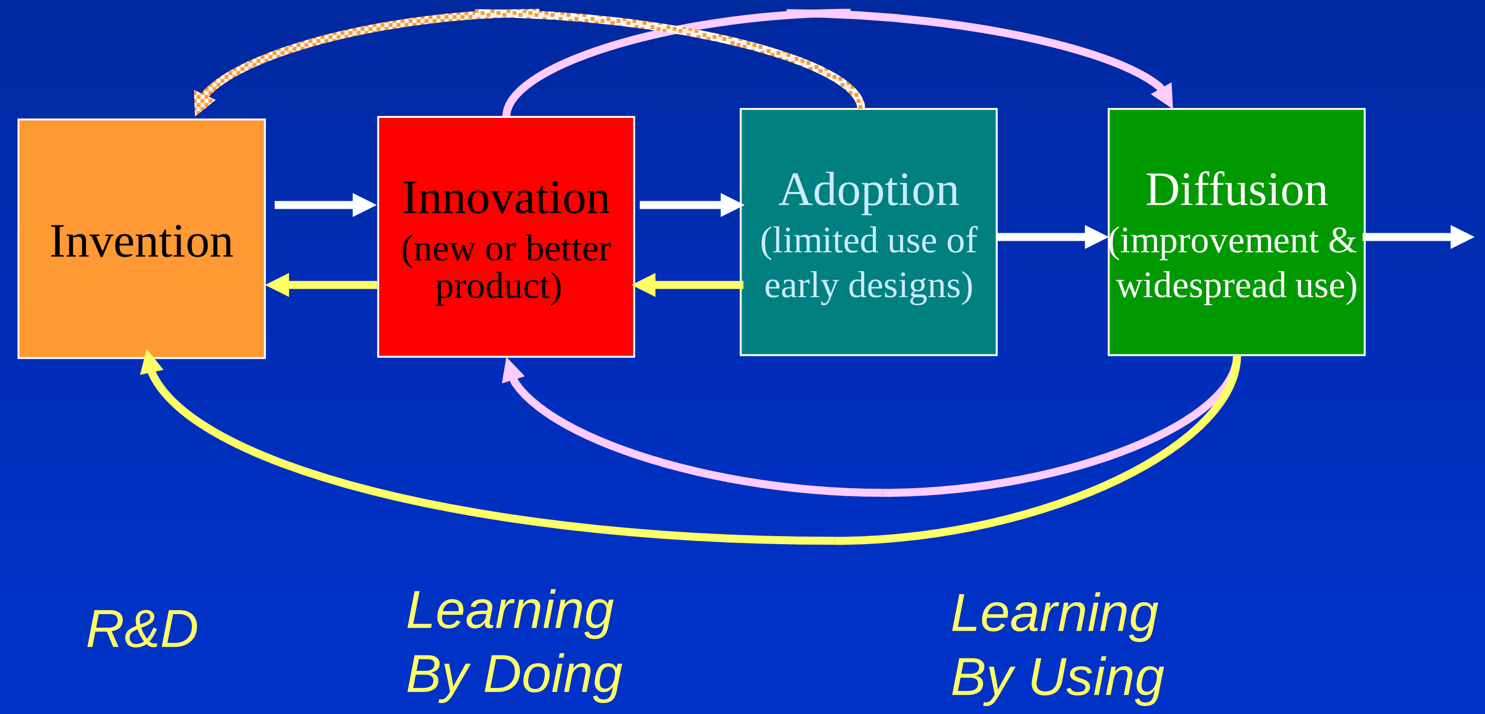
Source: Gerdes et al, NETL, 2014

What we do *not* learn from bottom-up cost studies

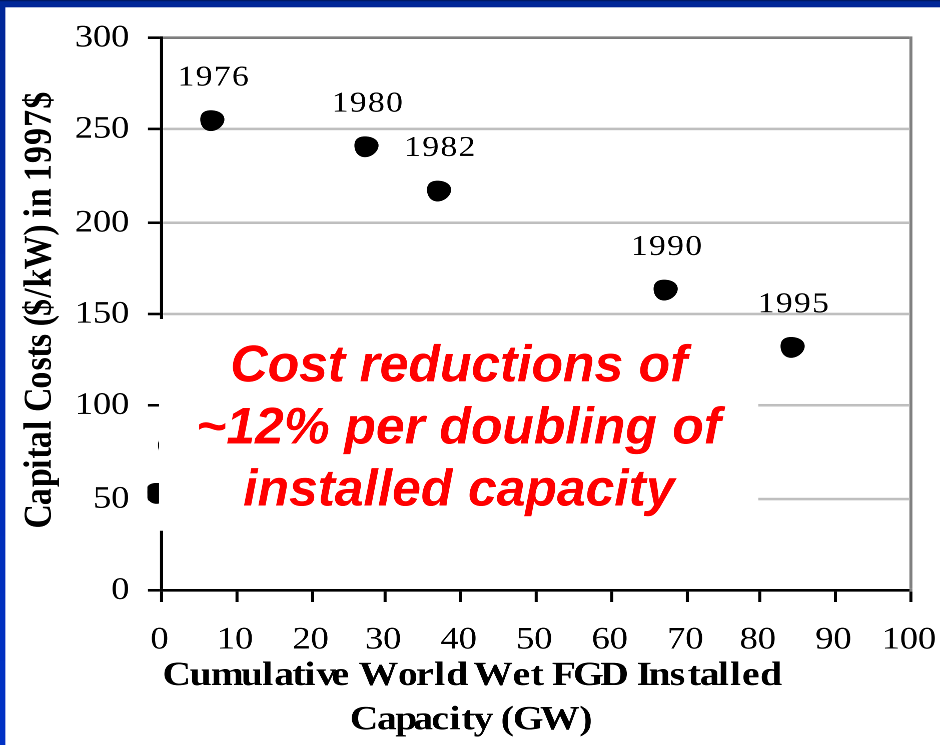
- Likelihood of achieving performance and/or cost goals for technologies that are still at early stages of development
- Time or experience needed to achieve cost reductions of different magnitude

What it takes to achieve CCS cost reductions

A Model of Technological Change



"Learning Curves" reflect the notion that experience is critical to reducing costs



Source: Rubin, et al., 2007

Data fitted to learning (experience) curves of the form: $C_i = a\,x_i^{-b}$

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Review article

A review of learning rates for electricity supply technologies

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H I G H L I G H T S

- We review models explaining the cost of 11 electricity supply technologies.
- The most prevalent model is a log-linear equation characterized by a learning rate.
- Reported learning rates for each technology vary considerably across studies.
- More detailed models are limited by data requirements and verification.
- Policy-relevant influences of learning curve uncertainties require systematic study.

A R T I C L E I N F O

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A B S T R A C T

A variety of mathematical models have been proposed to characterize and quantify the dependency of electricity supply technology costs on various drivers of technological change. The most prevalent model form, called a learning curve, or experience curve, is a log-linear equation relating the unit cost of a technology to its cumulative installed capacity or electricity generated. This one-factor model is also the most common method used to represent endogenous technical change in large-scale energy-economic models that inform energy planning and policy analysis. A characteristic parameter is the "learning rate," defined as the fractional reduction in cost for each doubling of cumulative production or capacity. In this paper, a literature review of the learning rates reported for 11 power generation technologies employing an array of fossil fuels, nuclear, and renewable energy sources is presented. The review also includes multi-factor models proposed for some energy technologies, especially two-factor models relating cost to cumulative expenditures for research and development (R&D) as well as the cumulative installed capacity or electricity production of a technology. For all technologies studied, we found substantial variability (as much as an order of magnitude) in reported learning rates across different studies. Such variability is not readily explained by systematic differences in the time intervals, geographic regions, choice of independent variable, or other parameters of each study. This uncertainty in learning rates, together with other limitations of current learning curve formulations, suggests the need for much more careful and systematic examination of the influence of how different factors and assumptions affect policy-relevant outcomes related to the future choice and cost of electricity supply and other energy technologies.

Experience for FGD may serve as a model for CCS

Key Barriers to CCS Deployment

- Policy
- Policy
- Policy

Without a policy requirement or strong economic incentive to reduce CO_2 emissions significantly there is no reason to deploy CCS widely

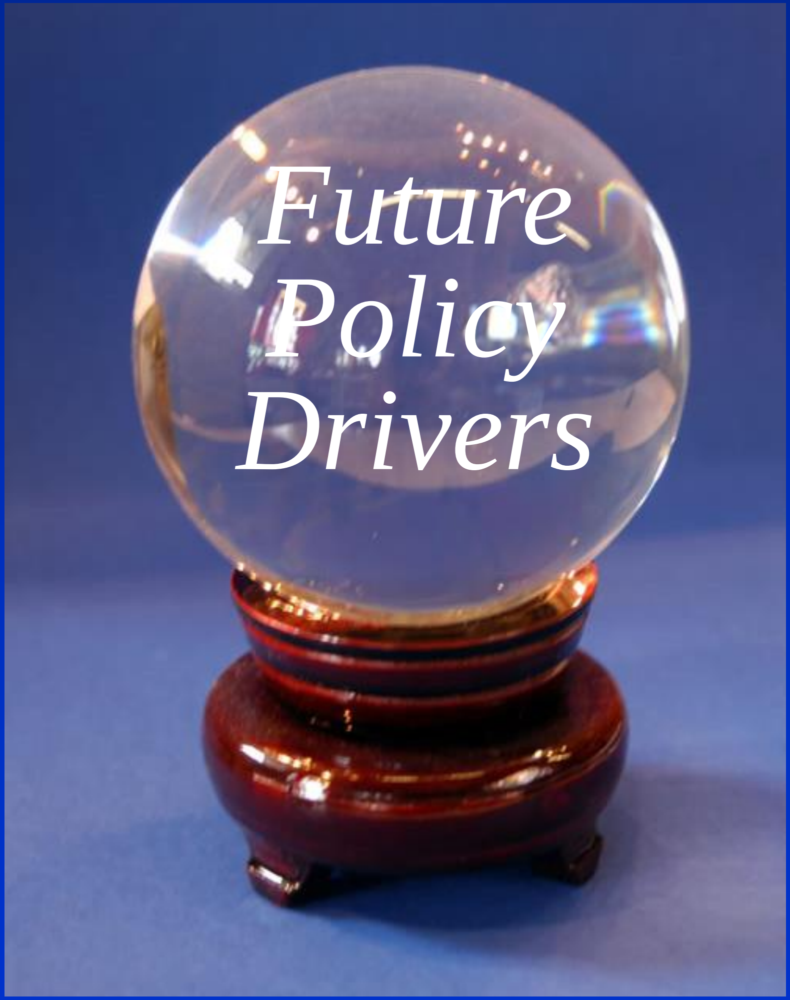
Policy options that can foster CCS and technology innovation

"Technology Policy" Options			Regulatory Policy Options
Direct Gov't Funding of Knowledge Generation	**Direct or Indirect Support for Commercialization and Production**	**Knowledge Diffusion and Learning**	**Economy-wide, Sector-wide, or Technology- Specific Regs and Standards**
• R&D contracts with private firms (fully funded or cost-shared) • Intramural R&D in government laboratories • R&D contracts with consortia or collaborations	• R&D tax credits • Patents • Production subsidies or tax credit for firms bringing new technologies to market • Tax credits, rebates, or payments for purchasers/users of new technologies • Gov't procurement of new or advanced technologies • Demonstration projects • Loan guarantees • Monetary prizes	• Education and training • Codification and diffusion of technical knowledge (e.g., via interpretation and validation of R&D results; screening; support for databases) • Technical standards • Technology/Industry extension program • Publicity, persuasion and consumer information	• Emissions tax • Cap-and-trade program • Performance standards (for emission rates, efficiency, or other measures of performance) • Fuels tax • Portfolio standards

Source: NRC, 2010

What is the Outlook for Lower-Cost CCS Technology?

- Sustained R&D is essential to achieve lower costs; but …
- Learning from experience with full-scale projects is especially critical
- Strong policy drivers that <u>create</u> <u>markets</u> for CCS are needed to spur innovations that significantly reduce the cost of capture
- **WATCH THIS SPACE FOR UPDATES ON PROGRESS**



Thank You

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