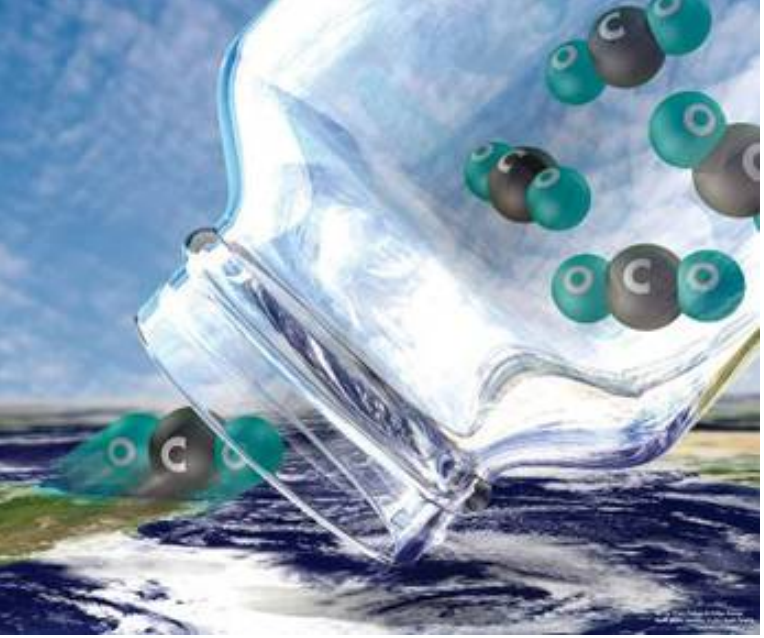

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CO_2 Capture and Storage

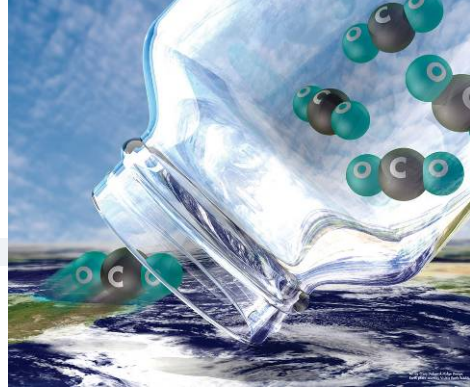
2008 EPRI Global Climate Change Research Seminar

May 21-22 Washington DC

Stuart Dalton

Director, Environment/Generation

Preparing for Carbon Constraints



Variation of Plants
Variation Geology

CO_2 Capture Cost and Energy

- Plant Efficiency
- Capture Technology
- Capture Pilots
- Capture Demonstrations

Confirmed Long Term Sequestration Technolgy

- Test Multiple Geologies
- Well Integrity
- Monitoring

Address Societal Concerns

- Liability
- Health
- Public Acceptance

Multiple Challenges Requiring Concurrent Resolution.

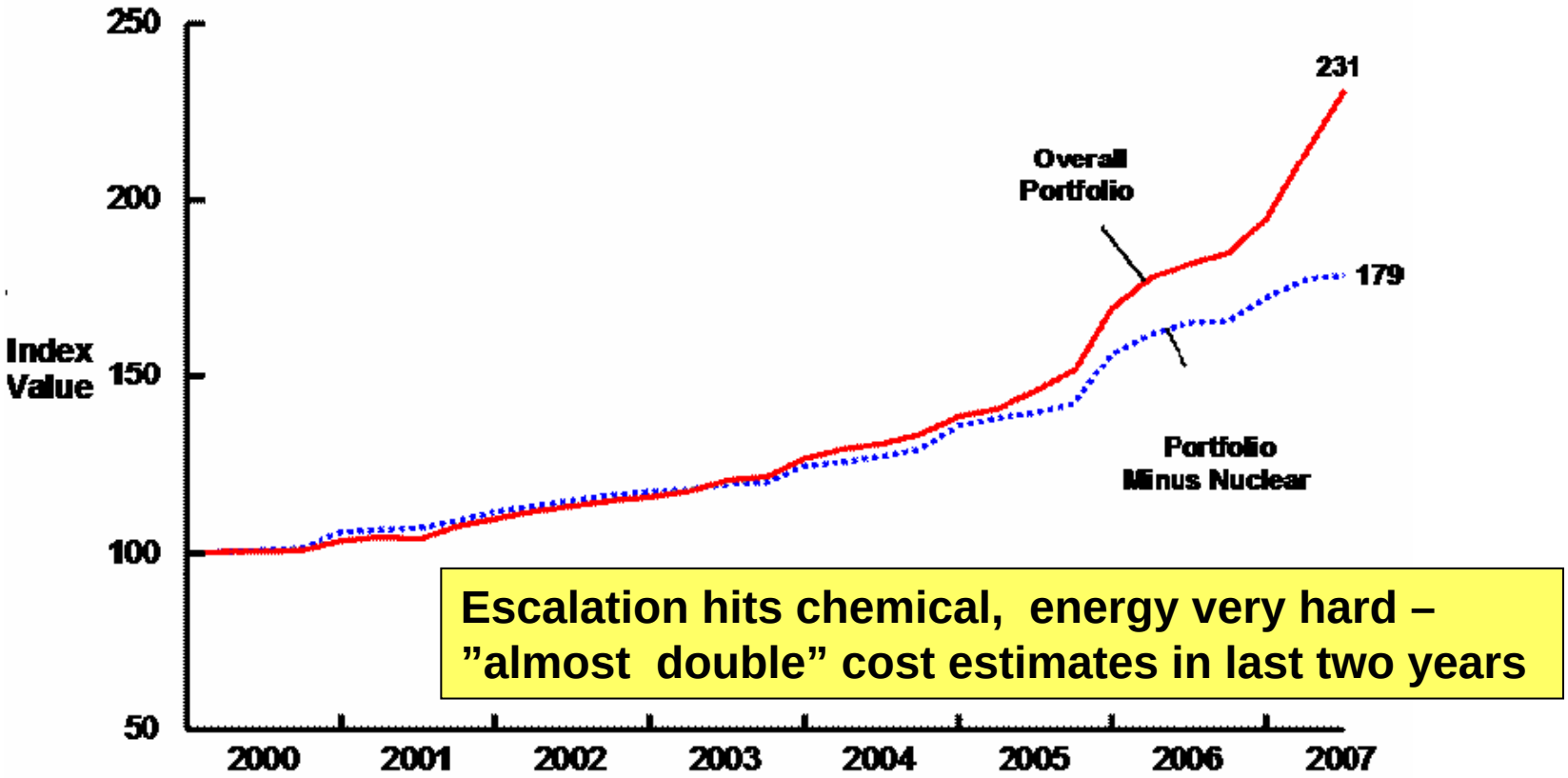
Background On Cost

- EPRI has redone capital cost and O&M estimates for Integrated Gasification Combined Cycle with Capture of CO_2 (IGCC/CCS) and Pulverized Fuel with CCS (PC/CCS)
- Huge escalation in past few years – world competition
- Options are needed
- New Federal , Private RD&D should reduce costs and improve efficiency
- Accelerated EPRI / industry funding for projects both supporting DOE projects and separate RD&D.

IHS/CERA Power Capital Costs Index

"North American Power Construction Costs Rise 27% in 12 Months"

"Continuing Cost Pressures Likely to Bring Delays and Postponements"



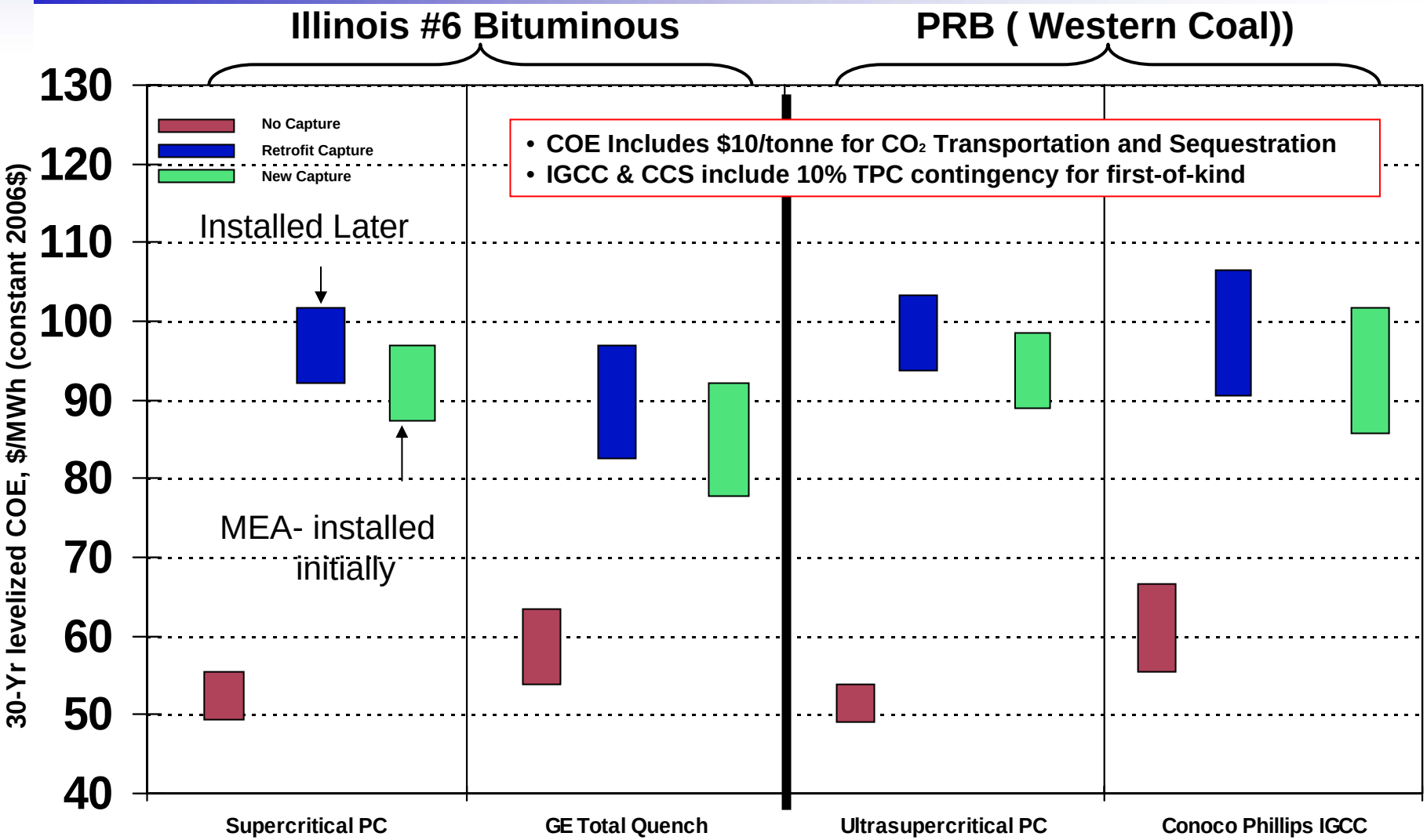
Escalation hits chemical, energy very hard – "almost double" cost estimates in last two years

Source: IHS/CERA Press Release 2/14/08

Capital Cost Estimates in Press Announcements and Submissions to PUCs in 2007–08—All costs are higher, more than would be predicted from indices (e.g., CEPCI)

Owner	Name/Location	Net MW	Technology/ Coal	Estimate Date	Reported Capital $ Million	Reported Capital $/kW	Notes/Status
AEP/ Swepco	Hempstead, AK	600	SCPC/PRB	Dec. 2006	1680	2800	CPCN issued
Southern Co.	Kemper County, MS	560	Air IGCC/ Lignite	Dec. 2006	1800	3000	FEED in progress
Duke	Cliffside, NC	800	SCPC/ Bit	May 2007	2400	3000	Permitted
Duke	Edwardsport, IN	630	IGCC/ Bit	May 2008	2350 In Service	3730	Permitted
AEP	Mountaineer, WV	630	IGCC/Bit	June 2007	2230	3545	Permit in Review
Tampa Electric	Polk County, FL	630	IGCC/Bit	July 2007	1613 (all $?) 2013 Serv	2554/ 3185	Shelved; now NGCC
Sunflower	Holcomb, KS	2 x 700	SCPC/PRB	Sept. 2007	3600	2572	Permit denied
Am. Muni. Power	Meigs County, OH	1000	SCPC/Bit & PRB	Jan. 2008	2900/3300	2900/3300	
Tenaska	Sweetwater County, TX	600	SCPC + CCS/PRB	Feb. 2008	3000	5000	

With Current Technology CO_2 Capture Costly No Clear Winners in Current Designs



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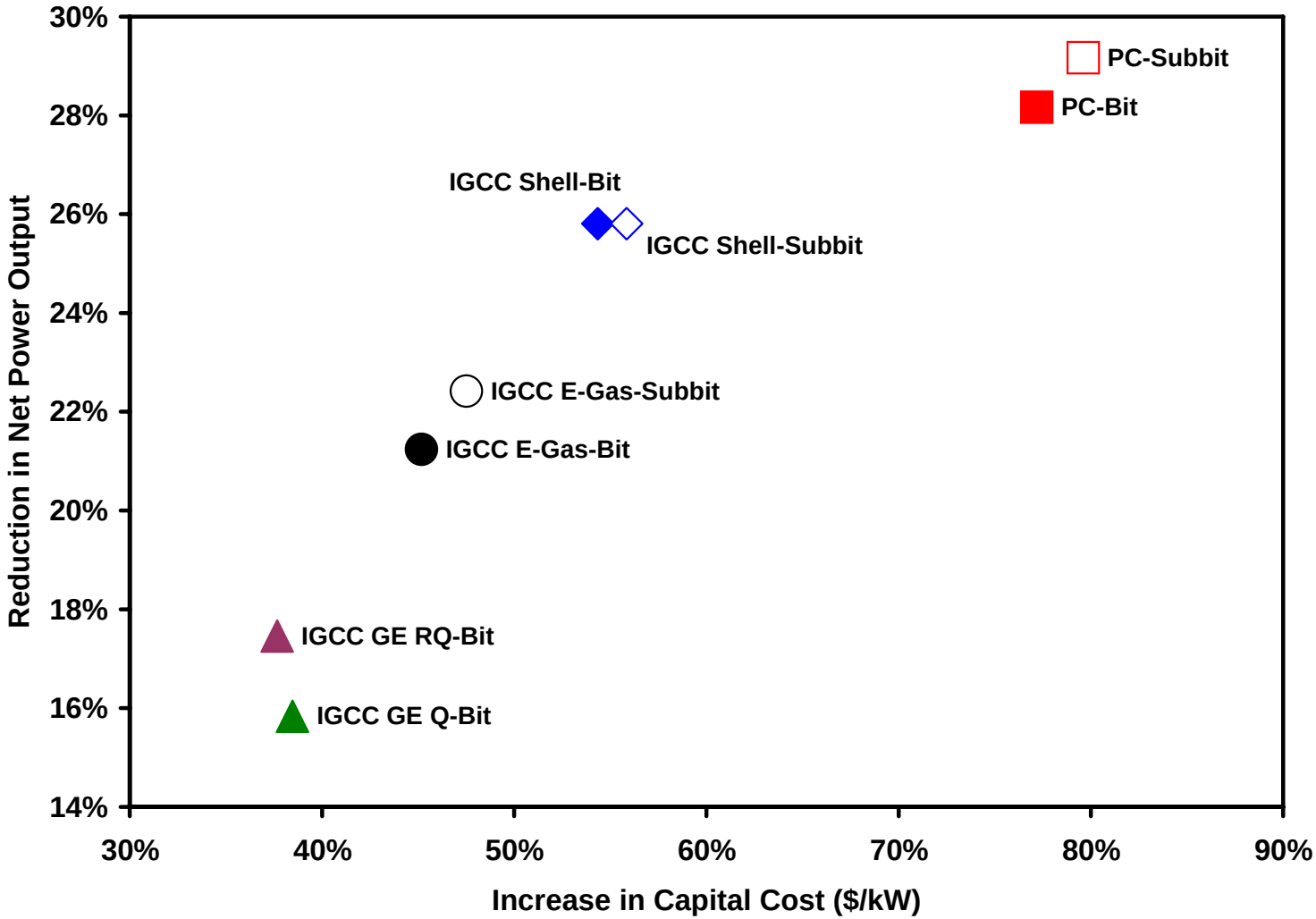
CO_2 Capture Can Be Done Today, But….

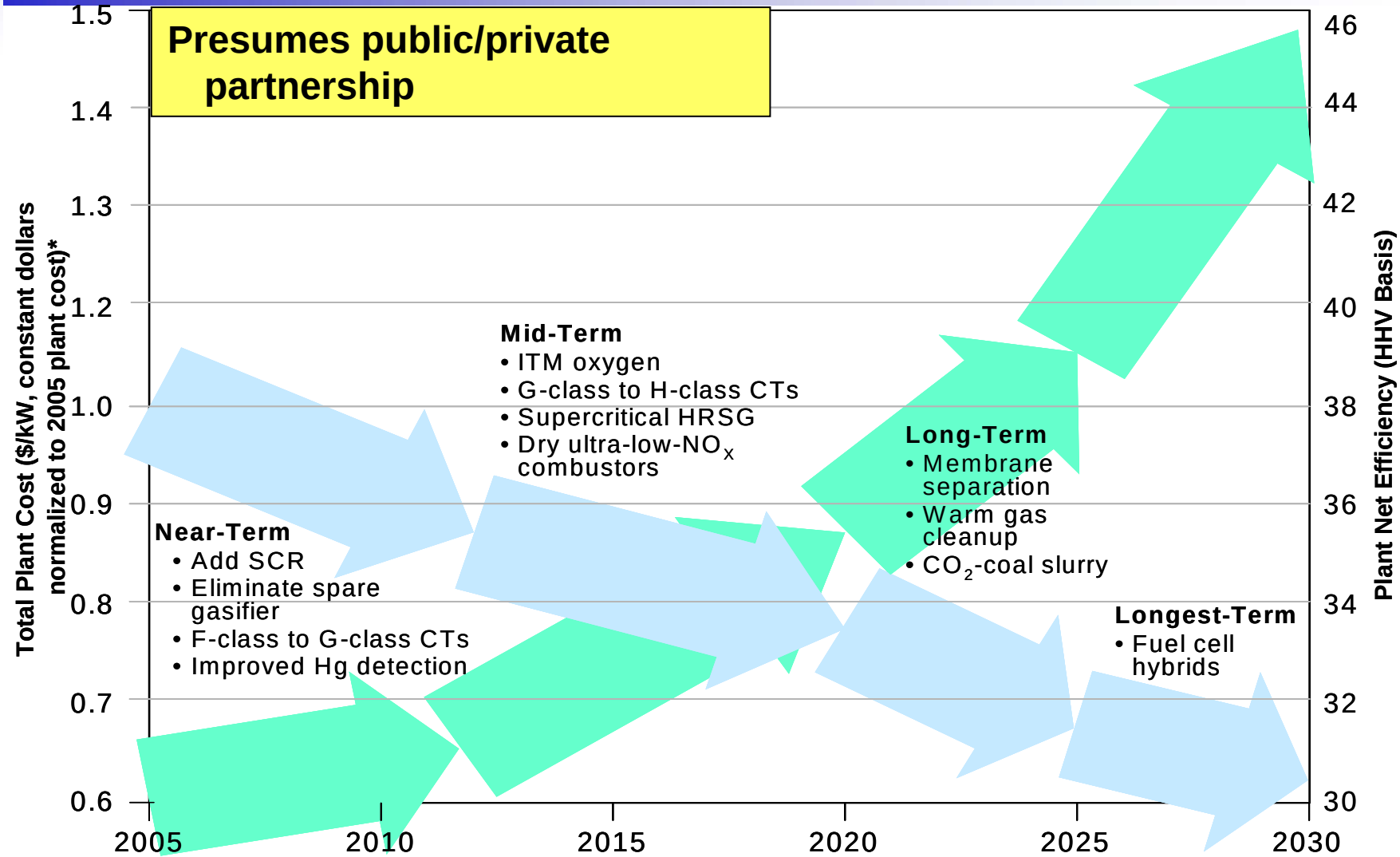
- As last slides shows It would increase the cost of electric power from coal significantly and there are no clear winners for all coals
- EPRI's current estimates
  - Cost of power from a pulverized coal plant with post-combustion capture would be 60-80% higher
  - Cost of power from an IGCC with pre-combustion capture would be 40-50% higher (but IGCCs start out with a higher cost, so won't necessarily be cheapest option with CCS)
  - Cost of oxy-combustion more difficult to estimate with certainty at this stage of development but overall cost of power probably similar to PC + post combustion capture
- Luckily, EPRI also estimates that with a concerted RD&D effort, the cost impact of CCS should decrease dramatically

Cost & Performance Penalties for CO_2 Capture

(based on retrofit of existing PC or IGCC plant – today's technolgy)



EPRI Estimates of the Benefits and Timing of RD&D in Gasification of Coal



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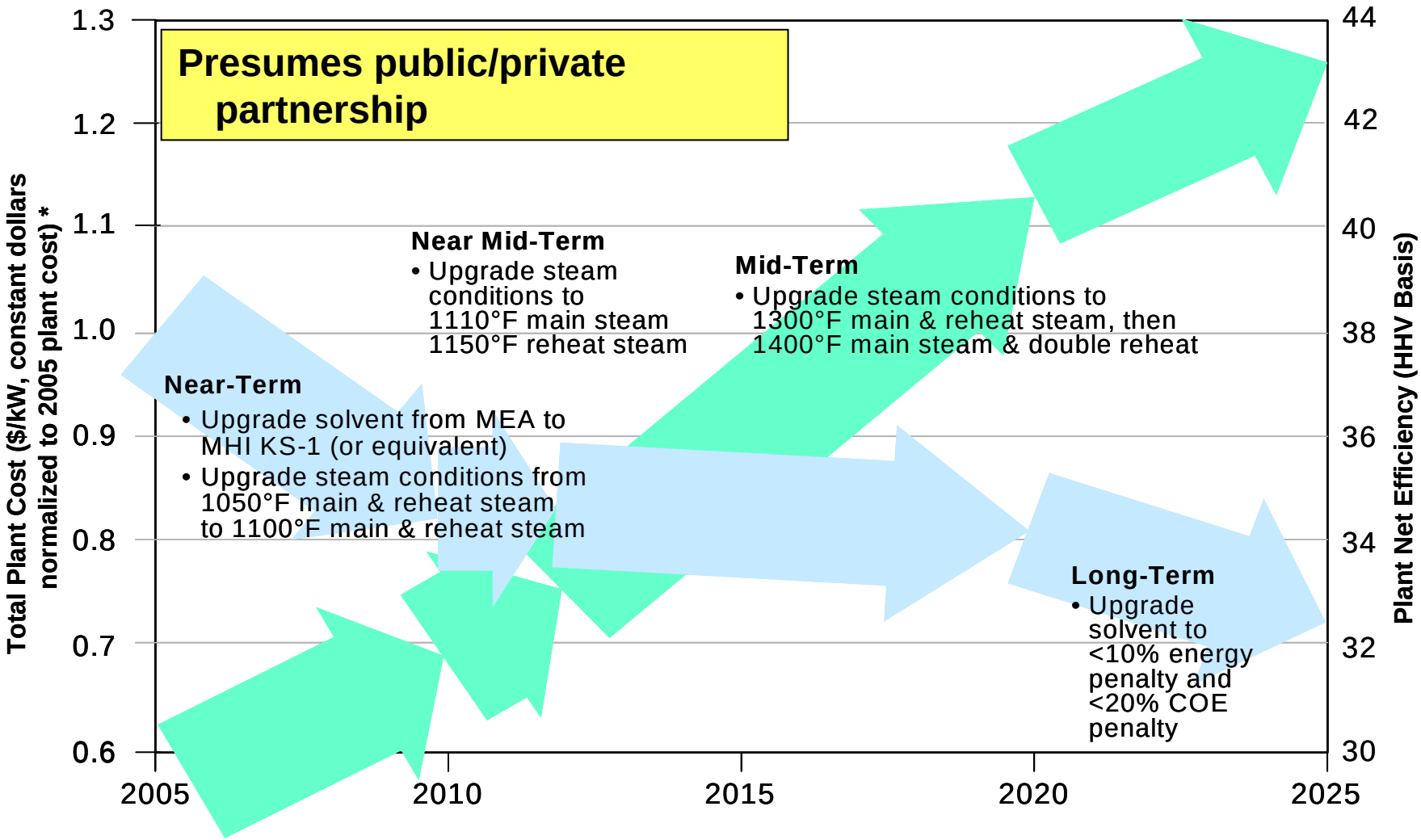
EPRI Estimates of the Benefits and Timing of RD&D in Combustion



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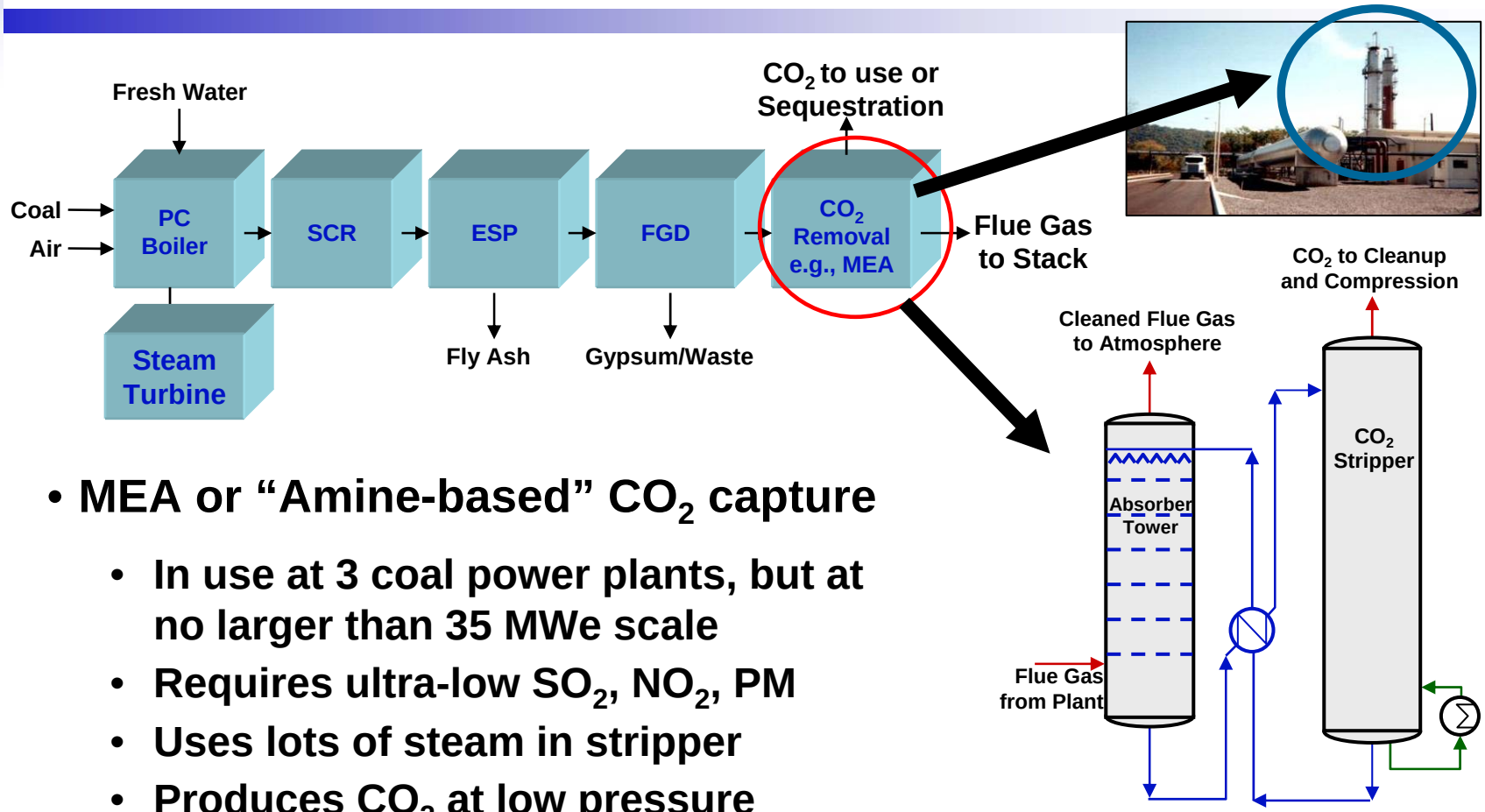
Pulverized Coal With CO_2 Capture – Commercial Technology Status



- MEA or "Amine-based" CO_2 capture
  - In use at 3 coal power plants, but at no larger than 35 MWe scale
  - Requires ultra-low SO_2, NO_2, PM
  - Uses lots of steam in stripper
  - Produces CO_2 at low pressure

$/ton Cost of Capture Is High – Need More Economical Processes

1.7 MWe CO_2 Capture R&D Pilot Plant

Pleasant Prairie Power Plant, Pleasant Prairie, Wis.

Dedicated February 2008

Pilot Project Team Members

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- Partial project funding with support of >35 collaborative funders
- Pilot testing
- Performance/economic evaluation

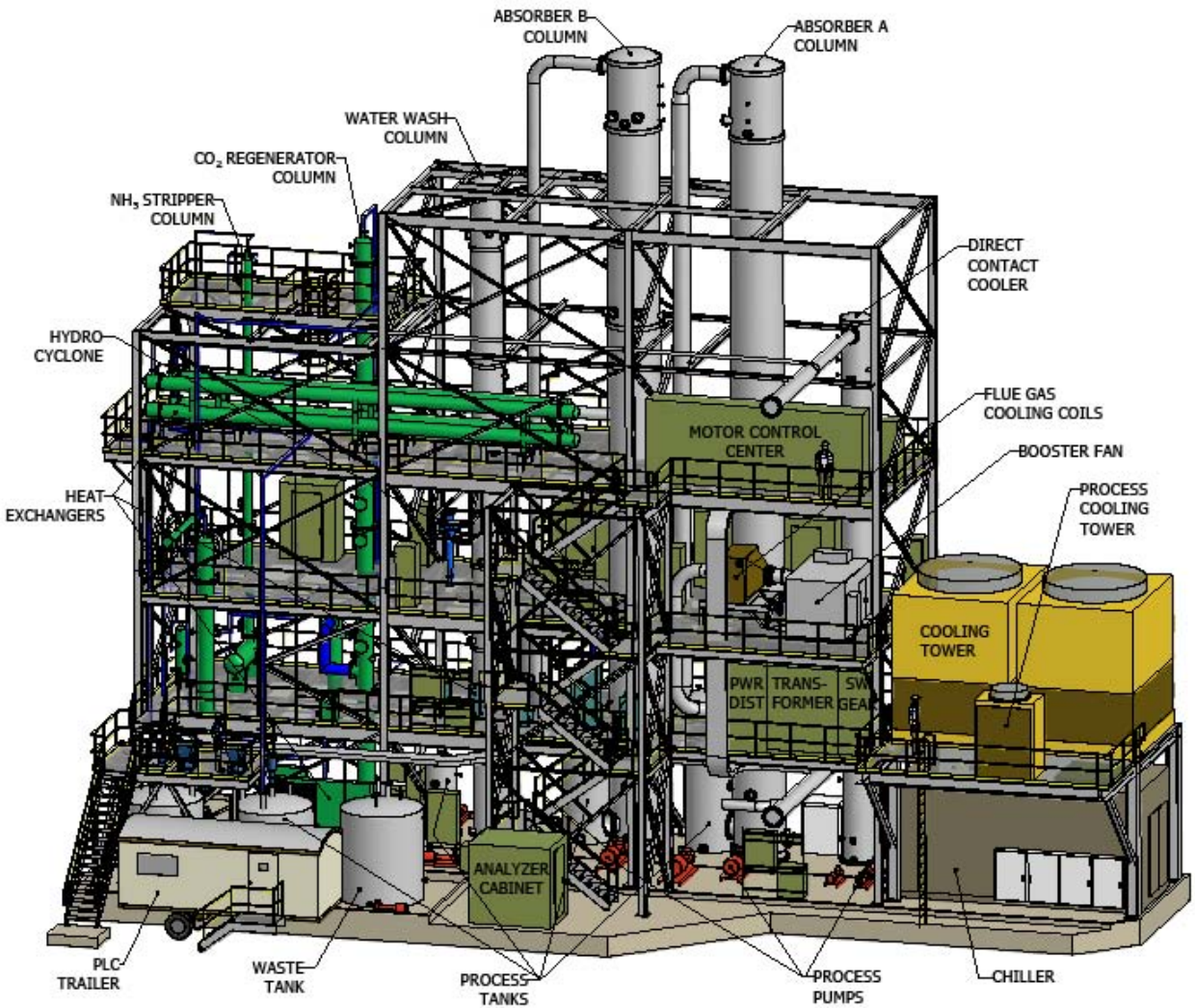
ALSTOM

- Partial project funding
- Pilot plant owner
- Responsible for:
  - Design
  - Construction
  - Operation
  - Maintenance
  - Demolition

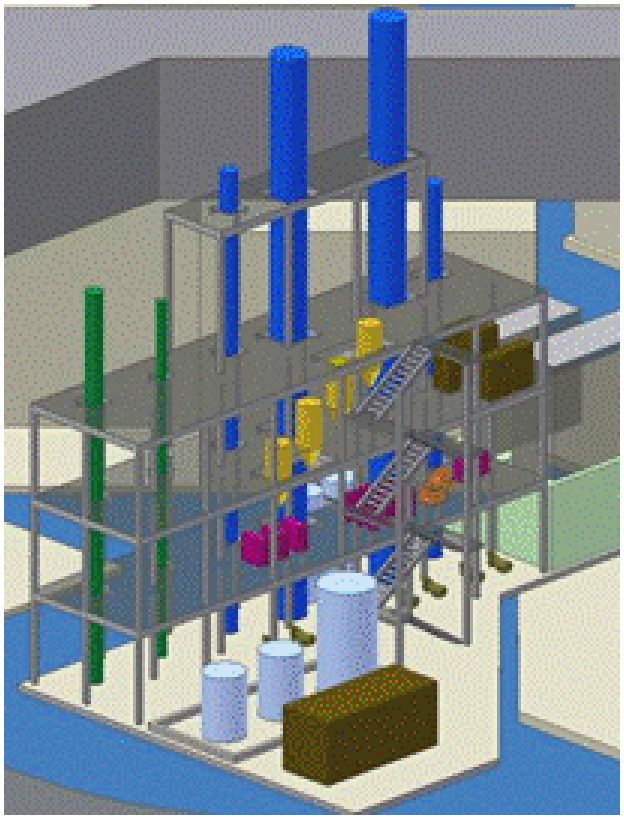
we energies

- Partial project funding
- Host Site
- Plant interface, permitting, utilities

Chilled Ammonia Pilot Plant



Post-combustion CO_2 Capture with Storage – Expected Major Contributor to CO_2 Reduction



Two capture processes

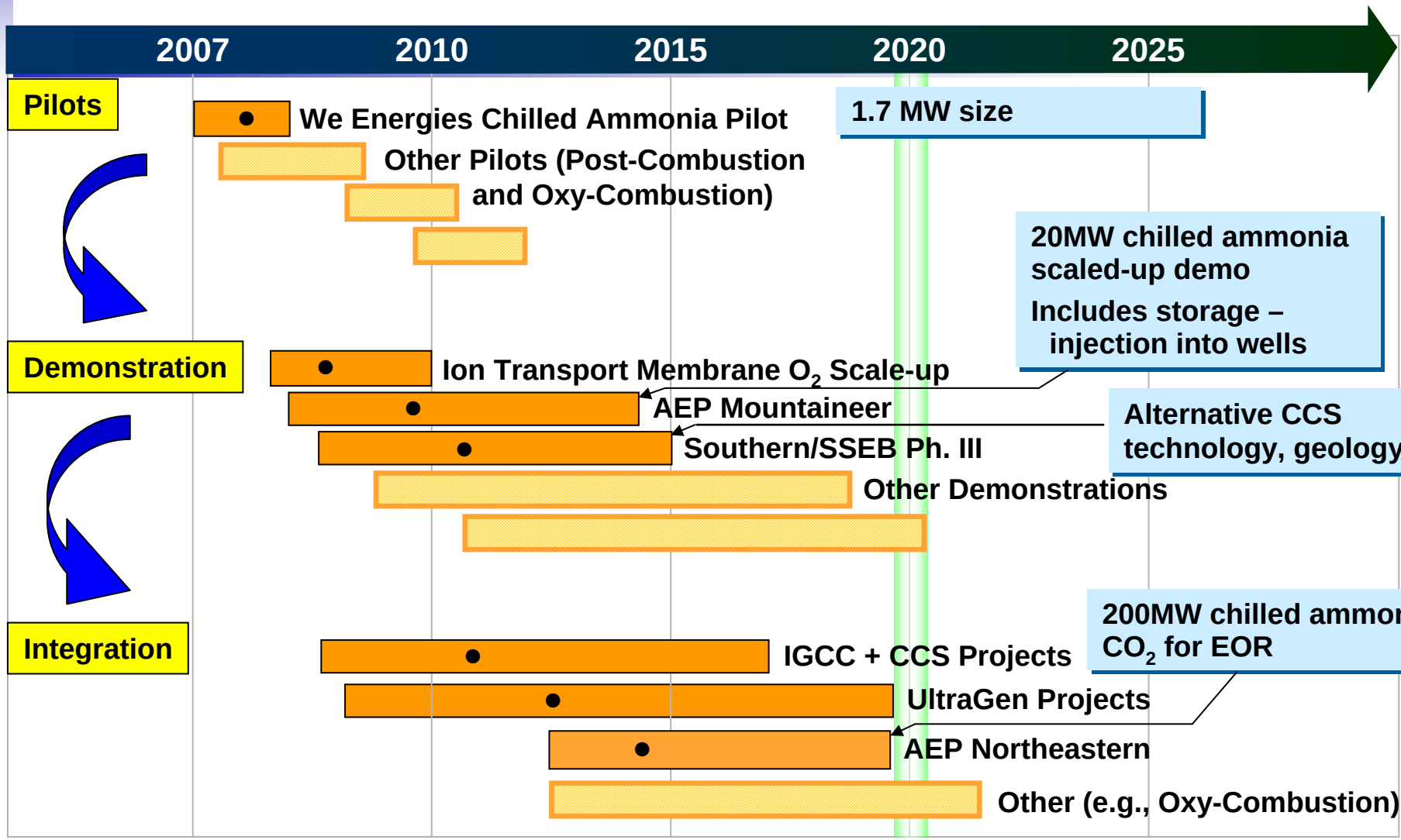
- (1) Chilled ammonia (2010-2014)
  - AEP Mountaineer
- (2) Different capture process (2011-2015)
  - DOE SECARB (SSEB)
  - Southern Co. plant (early FGD)

Value

- Reduce risk of facing CO_2 limits with:
  - Only 60-80% ΔCOE technology
  - Storage not accepted
- Have time to learn in low-risk environment
- Demonstrate permitting for injection, MMV

- **Technologies ready (or nearly ready) for scale-up**
- **Early storage tests on anthropogenic CO_2**

We Energies Pilot Is Only 1st Step



Goals – Affordable, Energy Efficient, Accepted

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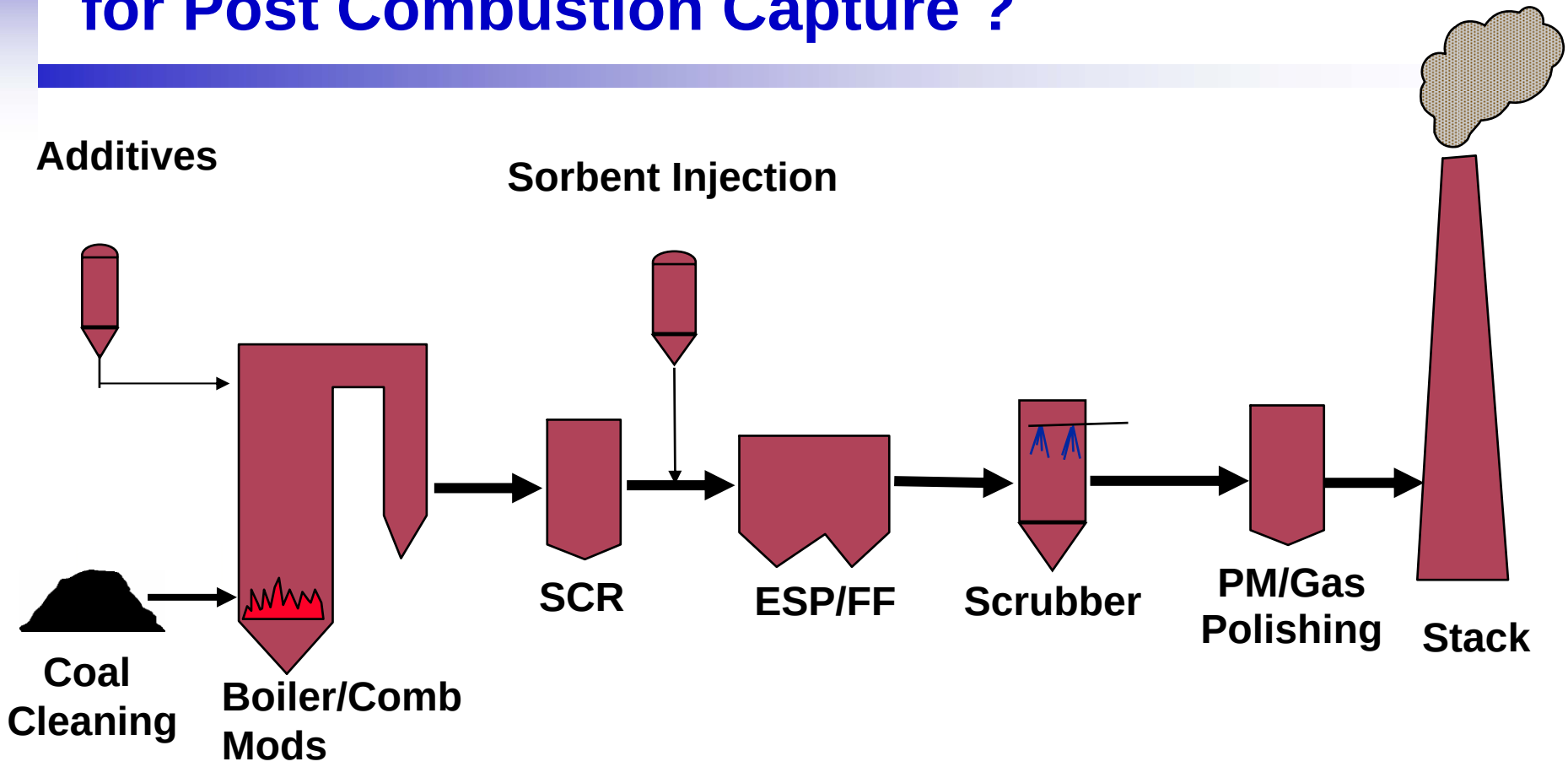
Near Zero Emissions (NZE) Concept – Needed for Post Combustion Capture ?

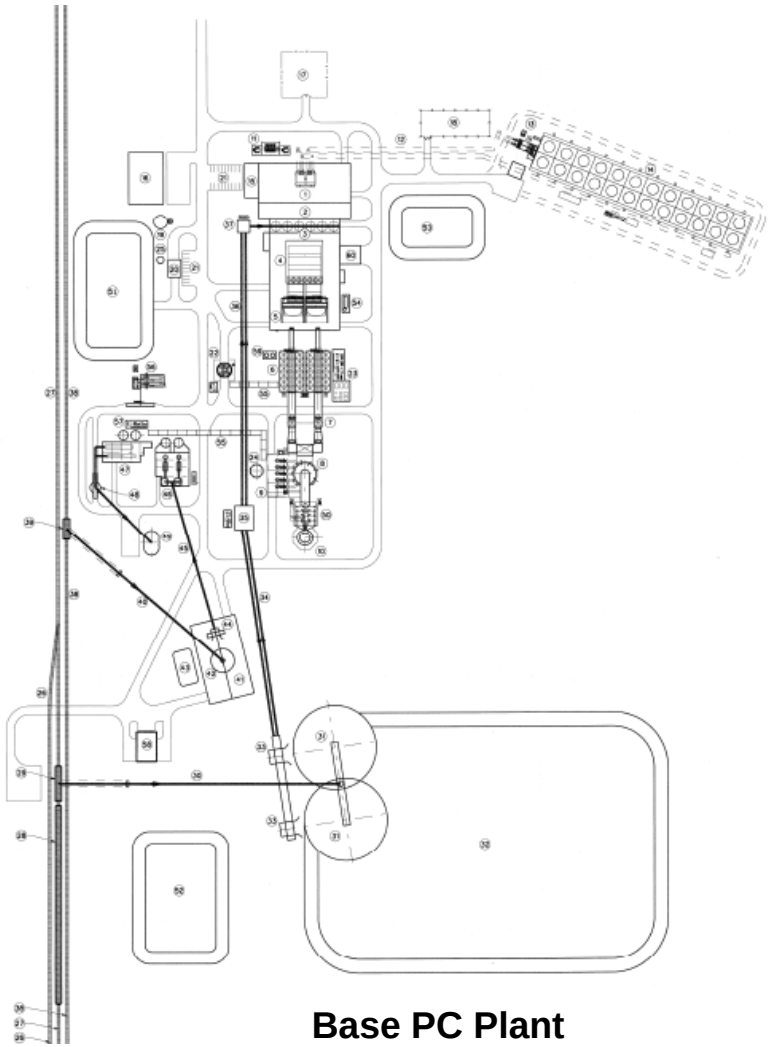


Mg/Nm3	NOx	PM	SO_2	SO_3	Hg
Current	86	14	184	-	-
NZE	12	1	7	< 1ppm	<0.1µg/Nm³

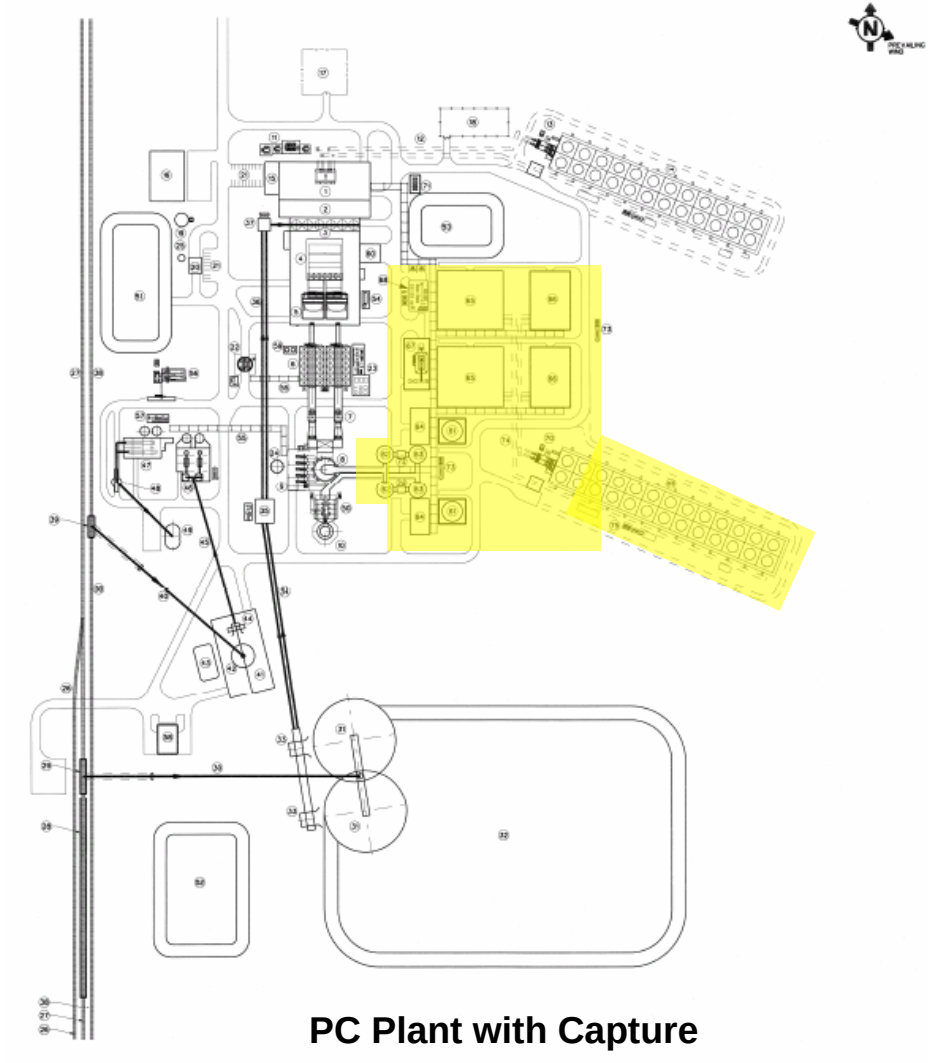
Retrofit Required…What Plant Modifications are Required?

- For the PC plant to accommodate CO_2 capture from an MEA process, the following modifications to the plant are required:
  - Ability to extract significant quantities of LP steam
  - Ability to extract IP steam intermittently for MEA reclaiming
  - Ability to receive significant quantities of hot condensate return
  - Ability to supply large increase in cooling water load to meet PC demands
  - Ability to handle increase in electrical distribution capacity to meet large PCC power demands
  - Ability to reroute flue gas ducting to handle the flue gas to, and from, the PCC

Plot Plan for USC PC Power Plant with Post-Combustion CO_2 Capture



Base PC Plant



PC Plant with Capture

Design Considerations for CO_2 Capture Report

- Version 1 published in December 2007
- Outlines key aspects that could be considered in new-build coal plant design to ease future transition to CO_2 capture mode
- Version 1 currently covers
  - Post-combustion capture
  - IGCC
- Expand to include:
  - Steam turbine modifications
  - Oxy-fuel
  - Chilled ammonia
  - Process X?
- Input derived from existing (IEA), ongoing (Nexant, FWI), and future studies
- Incorporated into Advanced PC Design Guideline and UDBS for IGCC

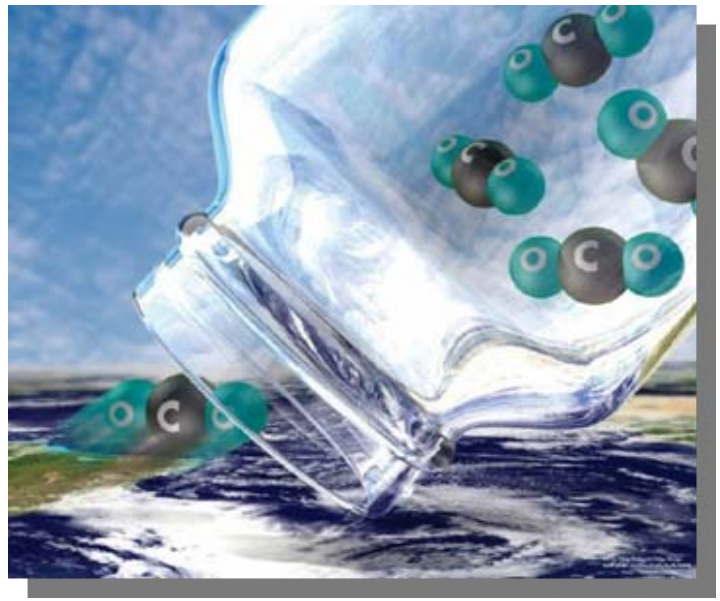
Showcase: Accelerate CO_2 Capture Development

The Problem:

- No commercially available post-combustion capture systems available
- Near-commercial options costly; $$$ and BTUs

The Response:

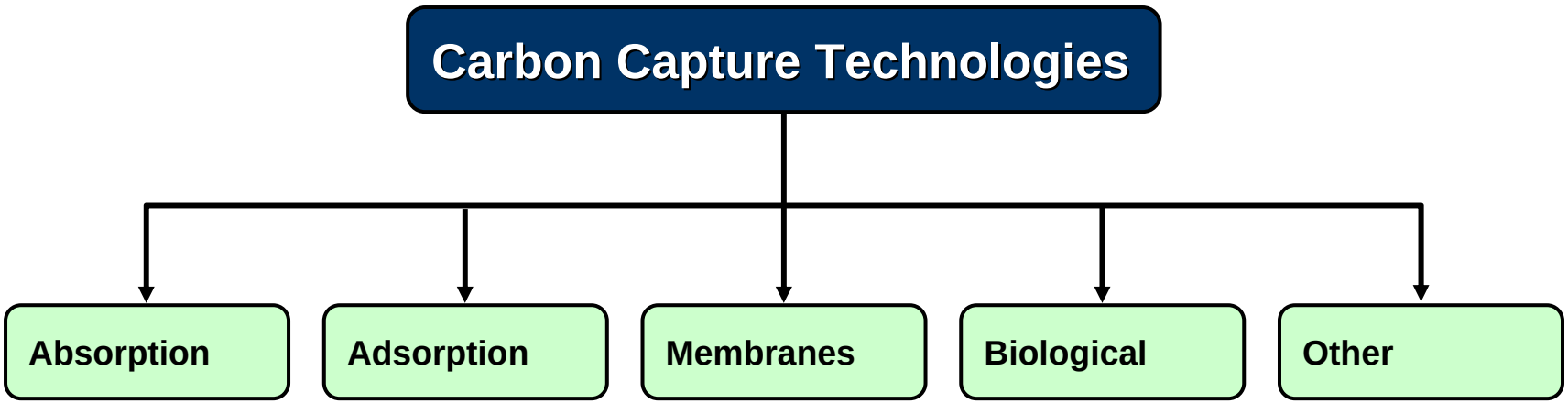
- Aggressively seek and propel dramatic improvements
- TI Showcase Project: *identify the most promising emerging post-combustion carbon capture technologies and assist in their development to accelerate their time to market*.



Read more about CO_2 Capture and Storage in the Spring 2007 issue of the EPRI Journal

EPRI Found Many Process Being Developed for Post-Combustion CO_2 Capture

Report #1012796 (30 processes, 20 more since report [2/07])



- **Absorption**
  - Amines (many)
  - Ammonia
  - Carbonates
  - Hydroxide
  - Limestone
- **Adsorption**
  - Carbonaceous Sorbents
  - Metal Organics
  - Zeolites
- **Membranes**
  - Fibers
  - Microporous
- **Biological**
  - Microalgae
  - Cyanobacteria
- **Other**
  - Cold Separation
  - Hybrid Capture

Few Approach Goal of ≤ 10% Energy Penalty, ≤ 20% COE Increase

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Technologies in Database

Absorption, Liquid
- MHI, KS-1
- CAP, Chilled Ammonia
- CANSOLV
- "7/2" MEA & PZ*
- CASTOR
- IFP, Dual Phase*
- Econamine FG+
- ECO2
- Ionic Liquids, Notre Dame
- Sargas
- SkyMine
- AWL*
- WowClean*
- Ionic Liquids, U. S. Carolina
- MEA:MDEA
- RITE -- COCS Solvent
- GRT*
- Immobilized Activator*
- Enzyme Catalysis*
- AEEA
- HTC PurEnergy*
- InnoSepra*
- CarbonTrap*
- TNO CASTOR2*
- JustCatch*

Absorption, Solid
- CO_2 Wheel
- RTI
- Hyperbranched Polyamine*
- Polyethyleneimine (PEI)*
- Amine on inert support*

Adsorption
- Metal Organic Frameworks
- Advanced Mesoporous Materials
- Heavy Reflux PSA*
- CO2CRC Adsorbent
- U. Akron

- **Biological Fixation**
- Carbon Capture Corp.*
- GreenFuel
- CO2 Solutions
- GSCleanTech*
- Conc. Solar Photoreactor
- Multiple New Algae Energy Systems*

* New since publication of 1012796

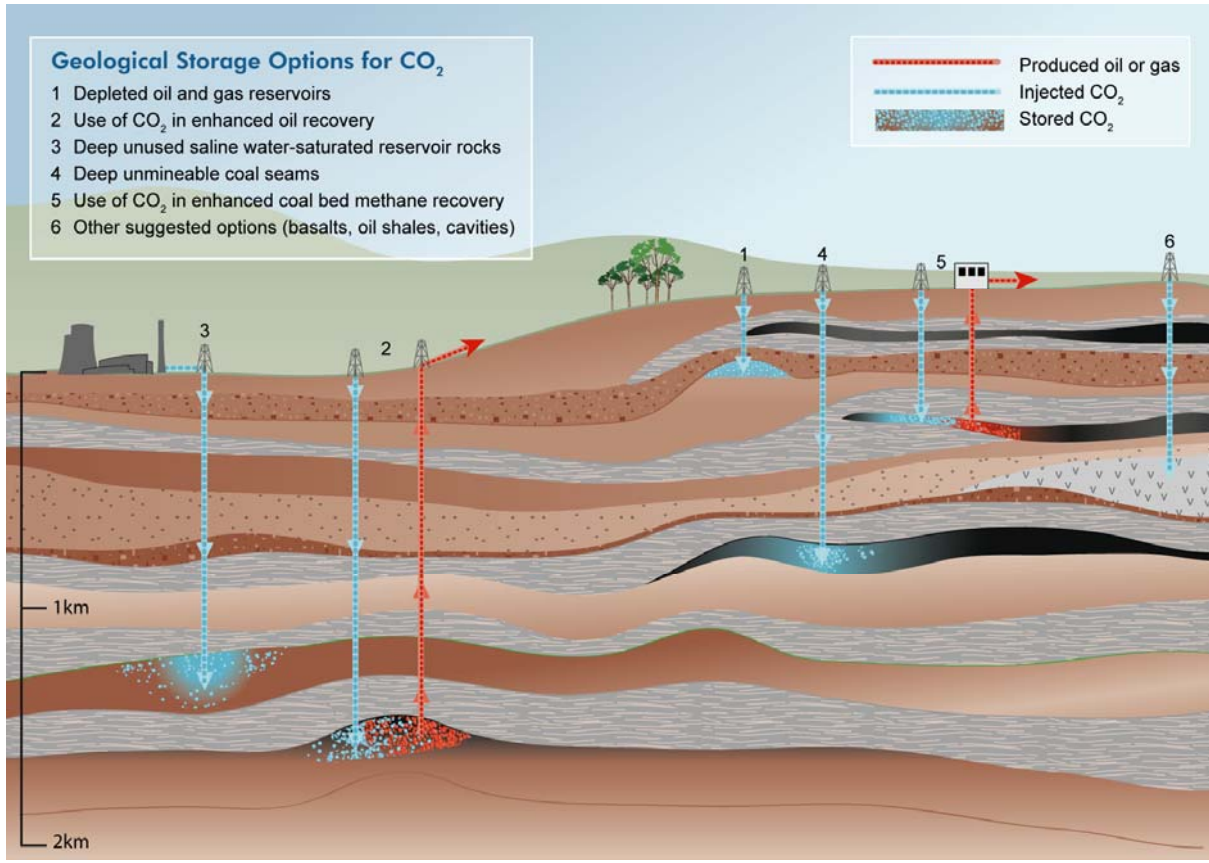
Membrane, Active
- MTR
- RITE, Cardo polyimide
- Tetramer Technologies*
- Poly(Ionic Liquid) Membrane

Membrane, Support
- Carbozyme
- Coral
- Kvaerner Membrane Contactor

Cryogenic
- CO2 Frosting
- Enecogen*

What Could We Do With CO_2?

- **Saline reservoirs**
  - 100's yr capacity
  - Little experience
- **Economical, but lesser capacity options**
  - Depleted oil and gas reservoirs/enhanced oil recovery
  - Unmineable coal beds/enhanced coal-bed methane recovery
- **Deep ocean injection not acceptable today**
- **Mineralization highly uncertain**
- **No use for large amounts**



Courtesy of Peter Cook, CO2CRC

Storage in Saline Reservoirs Likely Choice

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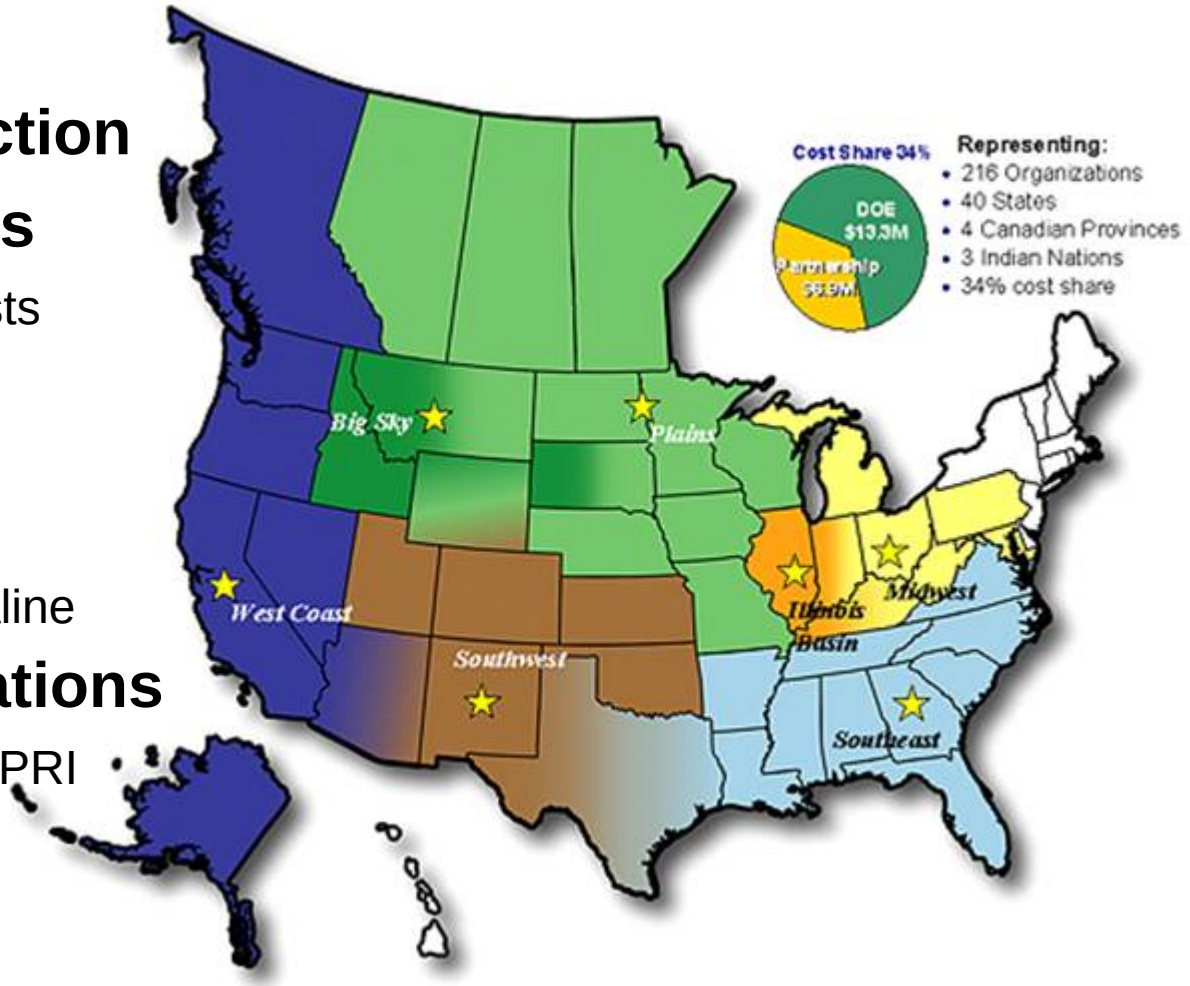
DOE Regional Carbon Sequestration Partnerships

- **Phase 1: Data collection**
- **Phase 2: Small pilots**
  - 22 Geologic Injection Tests
    - 8 EOR/Saline
    - 6 Saline reservoirs
    - 8 ECBM/EGR
  - EPRI involved in three saline
- **Phase 3: Demonstrations**
  - Several possibilities for EPRI involvement



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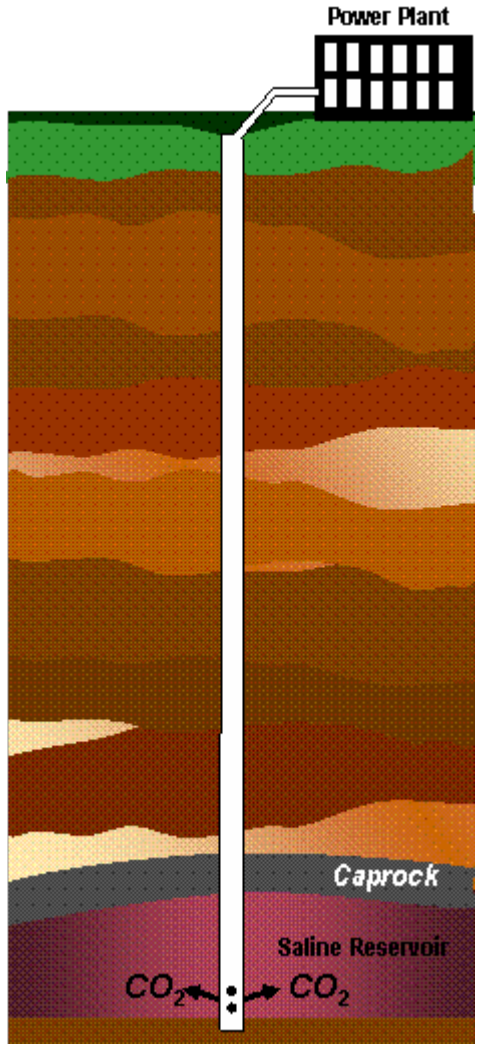
DOE Phase 3 Update

- **WESTCARB**
  - Original focus on BP Carson project, changed to Clean Energy Systems (CES)
  - 500k t/y for 4 years starting in 2010
- **SECARB**
  - Two part injection into same saline reservoir in two geologically separate locations
  - Cranfield: Purchased CO_2 @ 1Mt/y for 1.5 y
  - Anthropogenic test: Inject 100-250 kt/y from a CO_2 capture pilot located at a Southern Company site



RD&D Funding Needs for Advanced Coal Power Generation Technologies with CO_2 Capture

(Reference Sept 7,2007 Testimony S Dalton House Select Comm. on Energy Independence & Global Warming)

	2008–2012	2013–2017	2018–2022	2023–2027	2028–2032
Total Estimated RD&D Funding Needs *(Public + Private Sectors)*	$830M/yr	$800M/yr	$800M/yr	$620M/yr	$400M/yr
Advanced Combustion, CO_2 Capture	25%	25%	40%	80%	80%
Integrated Gasification Combined Cycle (IGCC), CO_2 Capture	50%	50%	40%		
CO_2 Storage	25%	25%	20%	20%	20%

Together...Shaping the Future of Electricity

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Image from *NASA Visible Earth*