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Carbon Capture and Storage: From Research to Reality

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McIlvaine Hot Topic Hour

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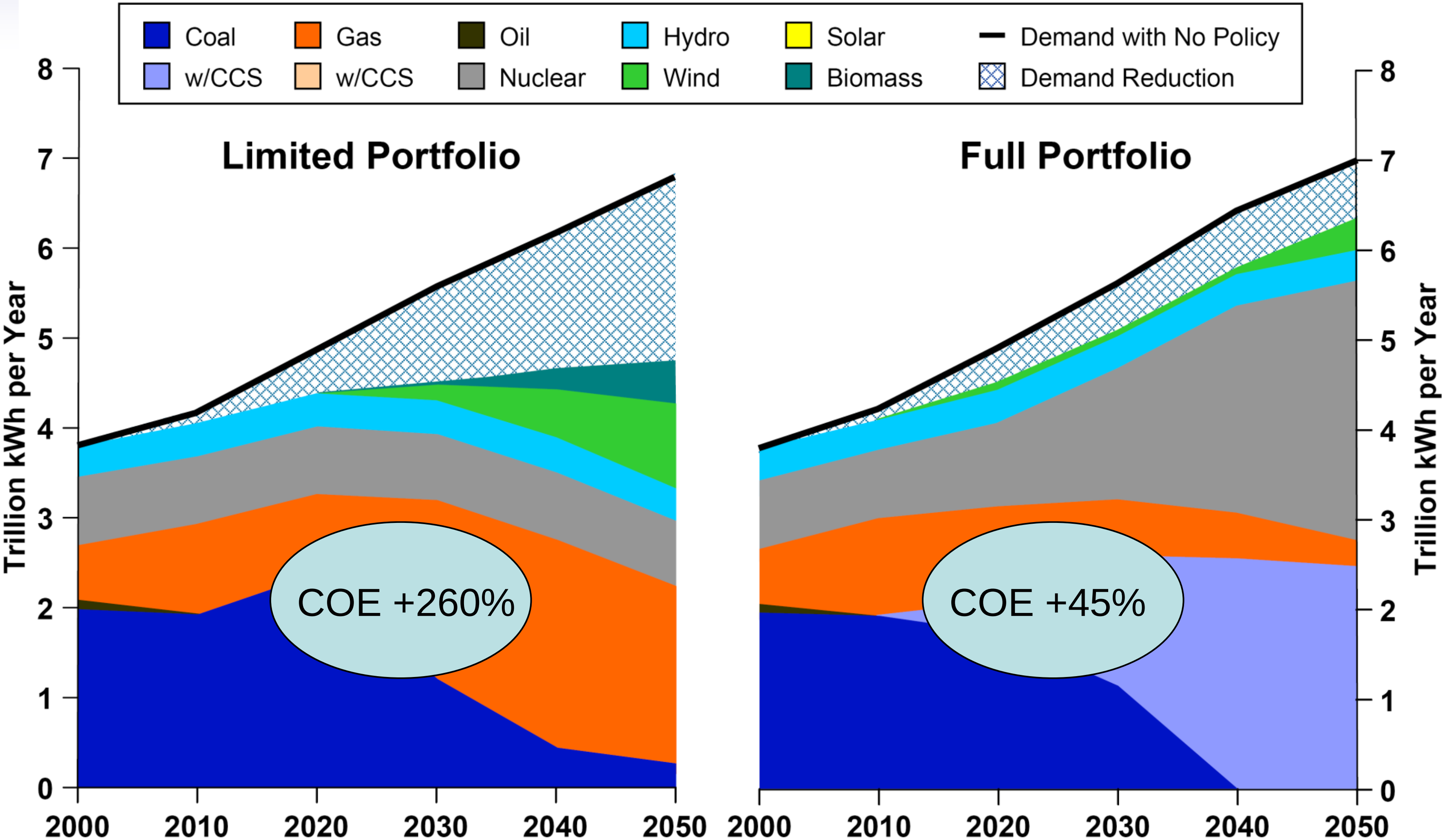
The Challenge: Reducing CO_2 Emissions While Sustaining Economic Well Being

- Various strategies identified to lower CO_2 emissions from the power generation sector
  - Coal not favored by objectors
- EPRI analysis shows that coal with CO_2 capture and storage (CCS) is essential to keeping electricity affordable.
- CCS technology not yet commercially available for power plant application and must evolve quickly to meet the challenge
  - Post-combustion CO_2 capture practiced at small scale (≈20 MW equiv.) producing high-value products for food and chemical industries
  - Need scale up and more efficient designs for power industry application to reduce cost and energy penalties.

EPRI Merge Analysis: Effect on Levelized COE



Effect of Adding CCS to 500 MW PC Plant

Percent changes in three parameters relative to PC plant without CCS

	2000 (1)	2008 (2)	2020 (3)
Capital cost	72	42	19
Cost of electricity	65	44	11
Power output	-28	-19	-8

(1) DOE–EPRI study for SC PC using post-combustion capture with MEA

(2) EPRI update of study using post-combustion capture with KS-1

(3) Projection based on improvements to post-combustion solvents, thermal integration, and generating efficiency

Research to Reduce Cost of CO_2 Capture from Coal Combustion Power Plants

- Improvements to post-combustion capture technology.
- Development of oxy-combustion technology.
- Increased power generation efficiency.
- Improved thermal integration of CCS plant with power plant.
- Demonstration of technologies to accelerate their commercialization.

"Established" perspectives often redundant once CO_2 capture included.

Post-Combustion Capture Improvements: Examples

- Extensive activity to develop new solvents
  - Ammonia-based: Powerspan and Alstom
  - Improved amines: MHI, Cansolv, PurEnergy, Dow, Toshiba, and others
  - Amino acid salts: BASF and Siemens
  - Anhydrase enzyme to promote CO_2 absorption in water or aqueous solvents: CO_2 Solutions, Carbozyme, and CSIRO
  - Separating carbonate salt to lower water to be heated in stripper:
    - Precipitate formed by TNO Coral and Alstom's chilled ammonia processes
    - Three H Technologies form a separate phase from non-aqueous solvent
- Solid adsorbents: RTI, ADA, and Toshiba
- Algae production for production of biofuels
- Cement by reaction with seawater: CCS Materials, Calera
- Membrane separation from flue gas: MTR, RITE, and Tetramer

Post-Combustion Capture Demonstration

Several pilot plant studies in progress

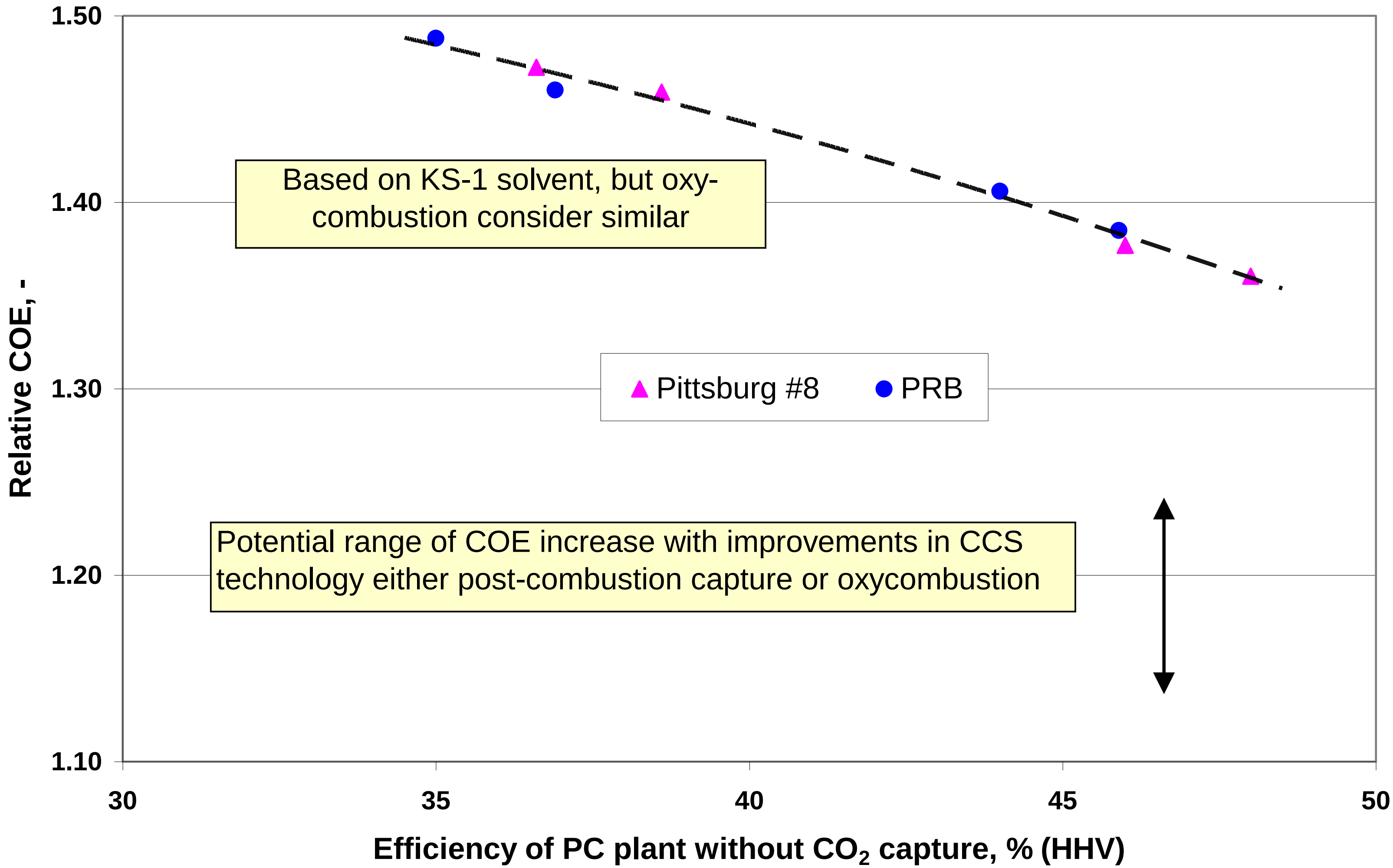
- E.ON Energie will test the technology of four suppliers at power plants in Germany in 9,000 to 12,000 ACFM range (≈10 MW)
  - Cansolv, Fluor Econamine FG+, and MHI, and Siemens (2009 to 2011)
- Alstom testing chilled ammonia (≈1.7 MW) at a We Energies' site
- MHI testing KS-1 (≈0.5 MW) in Nagasaki Japan
- RWE npower plans a 1-MW pilot plant at Aberthaw station in South Wales, to be operational in 2010

- Demonstration plants being planned ≈ 250 MW
  - Alstom Dow amine-based plant in Poland, chilled ammonia plant at AEP's Northeastern plant in Oklahoma
  - Vattenfall plants near Cottbus, Germany and in southeast Denmark
- E.ON UK preparing for 300-MW slip stream from new 800-MW SC PC unit at Kingsnorth near London

Oxy-Combustion Improvements

- Oxy-combustion technology being developed by boiler vendors in conjunction with oxygen suppliers
  - Alstom (Linde), B&W (Air Liquide), Doosan Babcock (Air Products), Foster Wheeler (Praxair), IHI (Air Liquide)
- 30 MWt pilot plants built,
  - B&W completed one-year test program November 2008 in Ohio
  - Vattenfall commenced testing August 2008 in Germany
- Power plants being planned
  - Vattenfall (250-MW PC), CS Energy (40-MW PC), and Jamestown (NY) (40-MW CFB)
- Optimize ASU design and investigate oxygen production alternatives such as ion transfer membrane (Air Products) and temperature-swing absorption (Linde)

When CO_2 Capture Included Higher PC Efficiency Lowers COE



Capture only. No allowance for transportation and storage

Higher Temperature Steam Conditions

- Raising steam temperatures to raise efficiency
  - Reduces CO_2/MWh
  - Less CO_2 to capture, compress, transport and store lowers cost of CCS
- Ferritic steels can accommodate up to 1160 F but beyond that high nickel alloys must be used
- AD700 program proving boiler and turbine materials for 1290 F steam conditions at 50 Hz
  - 450-MW USC PC plant planned for Germany by E.ON Energie
  - In US need to lower temperature to 1260 F for 60 Hz operation
- US DOE program proving boiler and turbine materials for 1400 F steam conditions
  - Research promising but now need to fund long-term demonstration for certification of materials

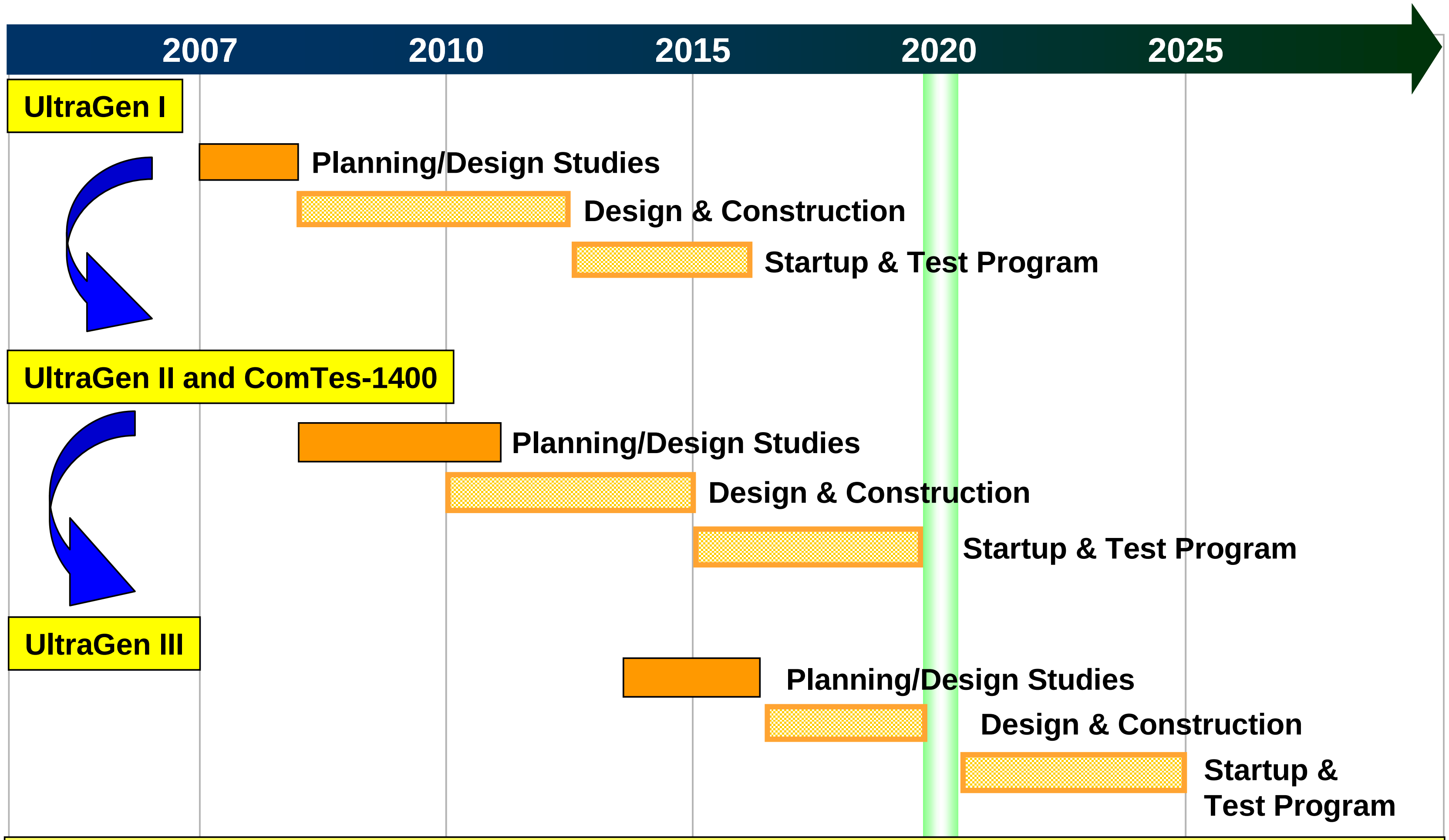
Improved Heat Integration

- Waste heat is valuable low-grade heat
  - Regenerate solvent lowering steam extraction & increasing net output
  - Dry low rank coals to decrease heat rate and lower CO_2/MWh
- Operate CO_2 compressors adiabatically to allow recovery of higher grade heat
  - Reduces steam extraction rate
  - Lowers heat rejected so lowers capital and operating costs for cooling
  - Optimize the system not the individual components
- Integrate ASU and cryogenic CO_2 purification stages

Demonstration of Improvements : The UltraGen Initiative

- Series of three commercial power projects and a test facility that progressively advance USC, NZE, and CCS technology
  - UltraGen I—800 MW net plant, main steam up to 1120°F
  - UltraGen II—600 MW net plant, main steam up to 1290°F
  - ComTes-1400 to test materials and components for UltraGen III
  - UltraGen III—600 MW net plant, main steam up to 1400°F
- The UltraGen projects are commercial units dispatched by their hosts (i.e., the host operates them for profitability) that incorporate technology demonstration elements
  - Host's incremental cost for new technology elements will be covered by tax credits and funds from industry-led consortium

UltraGen Initiative – USC PC with NZE and Integrated CCS



Need to Start UltraGen I Now to Achieve 2020 Performance Goal

Closing Comments

- There is no single approach to achieving cost-effective CCS
  - Oxy-combustion and post-combustion capture are evolving rapidly and efficiency and cost improvements are being identified
- Coal type, plant location, and power producer's business model are all shown to influence technology selection
  - Power producers need options allowing selection of the most appropriate technology for their specific circumstances.
- The economics of both technologies benefit from better heat integration and higher steam operating temperatures
- Demonstration projects are needed to prove commercial performance and accelerate development
  - This is the role of the UltraGen Initiative

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