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CO_2 Capture and Storage for Coal-Based Power Generation

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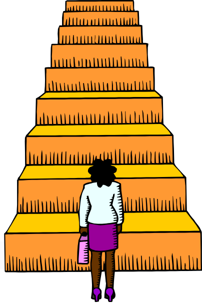
The Challenge for Coal-Based Generation



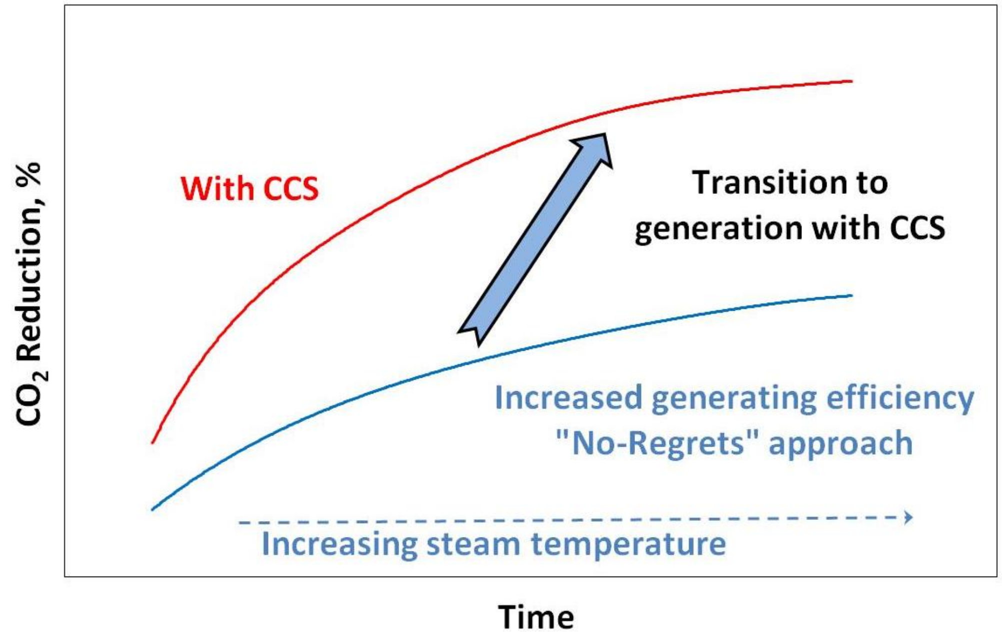
60% of world's CO_2 emissions do NOT come from coal

- Coal-based power has met many previous challenges and environmental controls can reduce SO_X, NO_X, mercury and particulate matter down to very low levels at acceptable cost
  - These technologies evolved over more than 40 years.
- Reducing CO_2 poses an extreme challenge: CO_2 released from low-sulfur bituminous coal is ~120 times more than SO_2
  - Development to be in less than 40 years: no more than 10 to 15 years.
- The EPRI-MERGE analysis identifies the economically optimum technology portfolio to lower U.S. CO_2 emissions to ~ 1905 level
  - In 2050 coal <u>without</u> CCS: cost of electricity 210% higher than in 2007
  - In 2050 coal with CCS: cost of electricity 80% higher than in 2007 assuming CCS widely deployed starting ~ 2025
  - Similar values determined by International Energy Agency.
- Eventually gas-fired units will require CCS: it's a fossil fuel too!

330 GW of coal capacity in USA: replacing 1 GW/month takes 28 years

Re-Inventing and Demonstrating Coal-Fired Power Plant Technology

- Dual development approach
  - More cost-effective CO_2 capture and storage (CCS) technologies
  - Raise steam towards 1400 F to increase generating efficiency and reduce CO_2/MWh: less CO_2 to capture, transport, and store.



- EPRI analysis indicates that US will not require significant amounts of new coal-fired generation until ~2025
  - The interim period allows for technologies to be demonstrated and be commercially available by that time.

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Performance Summary of Four PC Designs

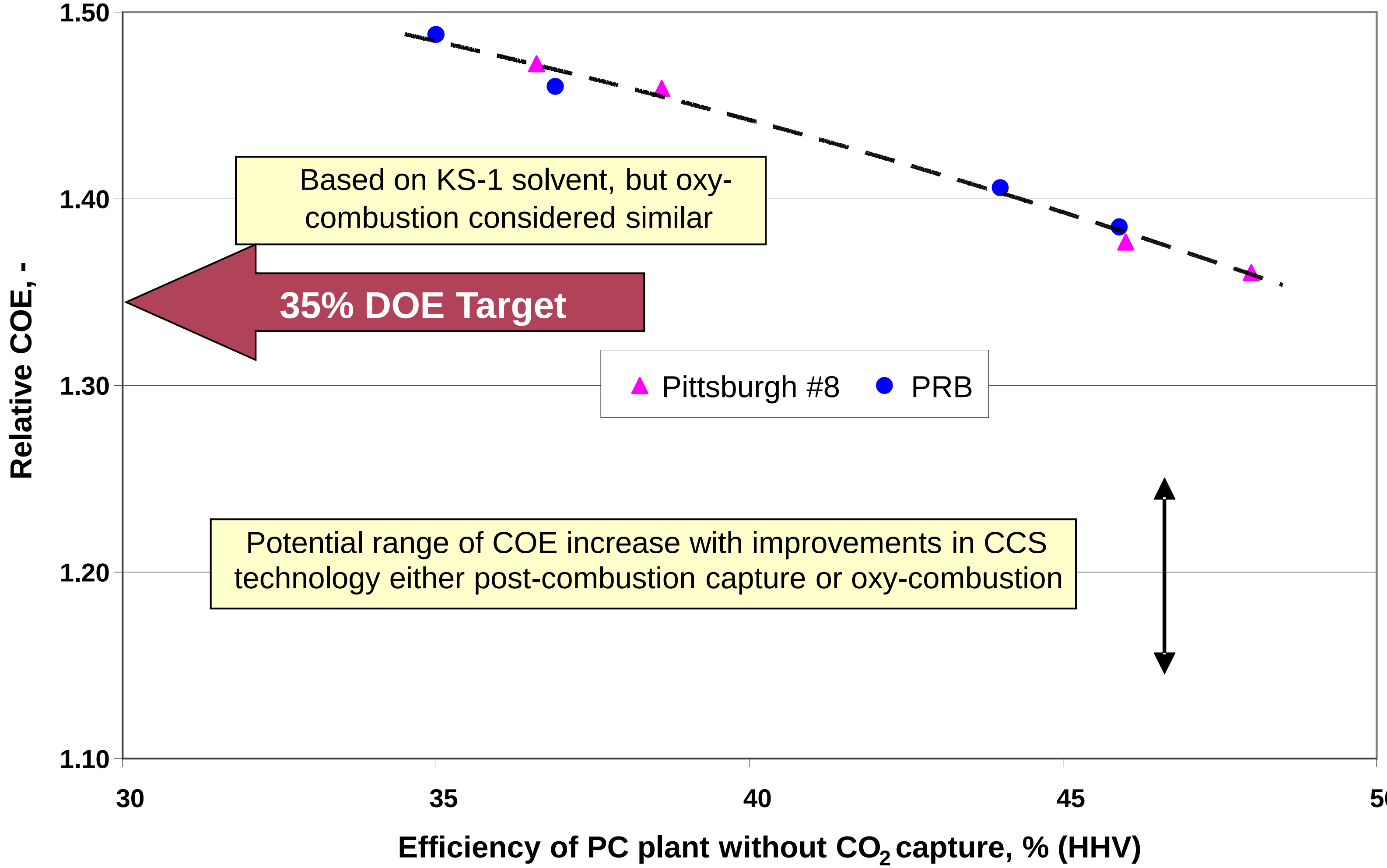
CO_2 emissions per MWh from 1300°F A-USC unit are 16.2% lower than emissions from subcritical unit

	Subcritical	Supercritical	1100 USC	1300 A-USC
Main stream, °F/psia	1005/2600	1080/3800	1120/4000	1290/5100
Net efficiency, % HHV	36.5	38.5	39.2	43.4
Net heat rate, Btu/kWh HHV	9370	8880	8720	7880
Coal flow lb/hr (PRB coal))	840,600	797,000	782,700	707,000
Flue gas, ACFM	2,107,000	2,016,000	1,982,000	1,7901,000
Make-up water, gpm	4,260	3,750	3,650	3,300
NO_X & SO_2, lb/MWh	0.280	0.266	0.261	0.236
CO_2, lb/MWh from plant	1980	1880	1840	1660
CO_2, lb/MWh from mining and transportation (*)	146	139	136	123

(*) Values based on life-cycle assessment model prepared by Carnegie Mellon University

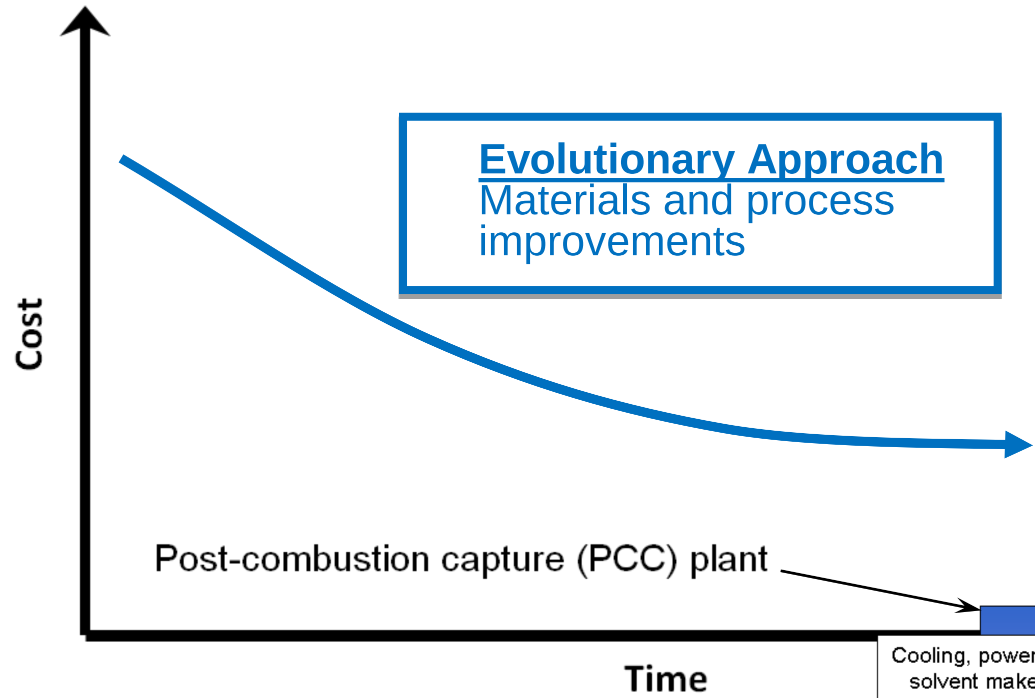
Long-range option: using CO_2 as the working fluid can raise 1300 A-USC efficiency to 46.4 percent, lowering CO_2 emissions/MWh by 27.1%

When CO_2 Capture Included, Higher Generating Efficiency Lowers Levelized Cost-of-Electricity

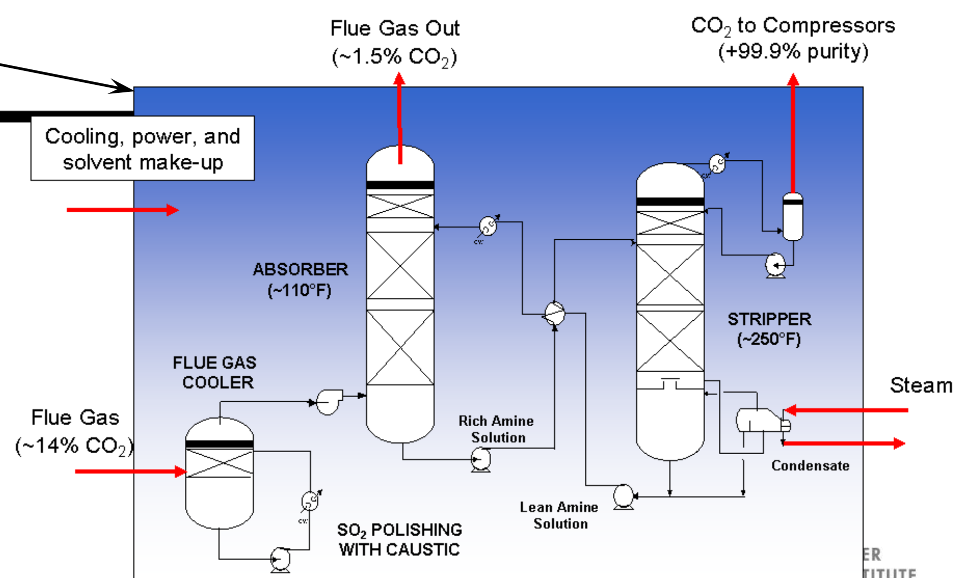


Capture only. No allowance for transportation and storage.

Dual Technical Approach for Cost Reduction: Evolution



- Various amine formulations
- Amino acid salts
- Ammonia
- Thermal integration
- Lower cost oxygen production



- AEP Mountaineer, 235-MW slip stream, Alstom's chilled ammonia
- NRG Parish, 60-MW slip stream, Fluor's Econamine
- Ameren Meredosia, 200-MW oxy-repowering project

Breakdown of Energy Losses from PCC Study for 750-MW 1100 F USC PC Plant

	MW	% of total loss
CO_2 compression	67	45
Turbine output reduction	55	37
PCC aux power (1)	17	11
Absorber cooling	10	7
TOTAL	149	100

(1) Fans, pumps, SO_2 polishing

- Compression to 2200 psia consumes most energy but most effort concentrates on lowering heat of regeneration to lower steam extraction and increase power generation.
- Most solvents can regenerate at pressure but increased CO_2 partial pressure requires higher regeneration temperature
  - Offsets reduction in compression duty: degrades amine solvents.

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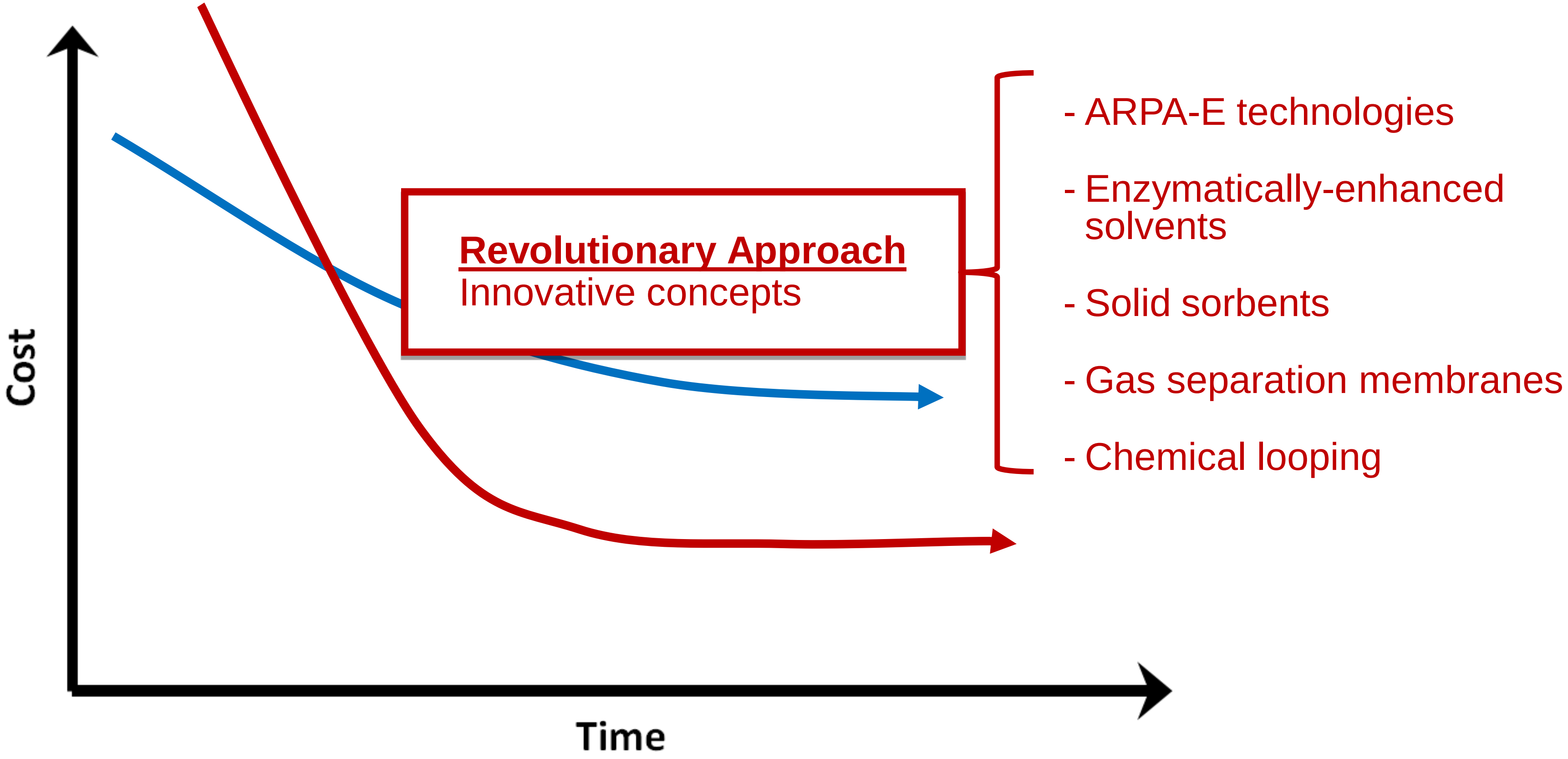
Dual Technical Approach for Cost Reduction: Revolution



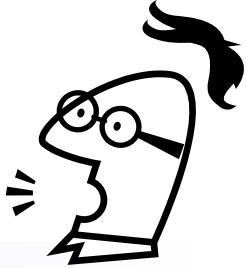
Some Novel Approaches Funded by Various DOE Programs

- Ionic liquids: a solid in liquid phase with multiple possible formulae
  - Amines dissolved in ionic liquid not water.
- Solvents that absorb CO_2 and form an immiscible liquid phase or a solid that is readily separated from mixture .
- Use of enzymes to accelerate kinetics for solvents with low CO_2 reaction rates but with low heats of reaction.
- Freezing CO_2 from flue gas
  - Pass flue gas through nozzle at supersonic speeds.
- Improved adsorbents and metal oxide frameworks that can be formulated with high specific surface: still need heat to release CO_2.
- Membranes to separate CO_2 from flue gas without need for regeneration energy: no reduction in compression energy.

www.netl.doe.gov **http://arpa-e.energy.gov/**

www.nationalcarboncapturecenter.com

Coal Plants Dispatch Ahead of NGCC Plants with or without CCS



	Capacity factor, %	LCOE, $/MWh		Dispatch cost, $/MWh	
			+ CO_2 adder (3)		+ CO_2 adder (3)
1290F A-USC PC (1)	85	55.1	75.9	17.2	41.0
2 x 7FB NGCC (1)	85	51.0	61.6	38.3	48.9
2 x 7FB NGCC	40 (2)	69.2	80.9	42.1	53.8
With 90% PCC					
1290F A-USC PC	85	86.5	89.3	21.5	24.4
2 x 7FB NGCC	85	68.5	69.8	46.7	47.9
2 x 7FB NGCC	40	97.6	99.0	51.2	52.5

(1) Coal $1.80 MBtu, gas $5.00/MBtu (2) Average CF in 2009 (3) $25/ton CO_2

- Lower dispatch cost for coal results in low capacity factors for NGCC
  - COE for NGCC at actual capacity factor higher than that of coal plant
  - This is part of why coal with CCS is essential in keeping electricity affordable.

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Concluding Remarks

- EPRI's MERGE analysis determines the mix of power generation technologies required for the USA to lower its CO_2 emissions to ~1905 levels by 2050.
- Coal-based generation with CCS can play a major role provided that the technology is commercially available in the next 10 to 15 years.
- The US-DOE is investing in the development of novel technologies and providing support to advance them to demonstration prior to their commercial operation.
- It is a worldwide challenge that will require international cooperation
  - We are all part of the solution.

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