October, 2006

Chilled Ammonia Technology for CO_2 Capture

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CO_2 Mitigation Options – for Coal Based Power

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✓Increase **efficiency**

Maximize MWs per lb of carbon processed

✓Fuel switch with **biomass**

Partial replacement of fossil fuels = proportional reduction in CO_2

✓Then, and only then ….**Capture** remaining CO_2 for EOR/Sequestration

= Logical path to lowest cost of carbon reduction

CO_2 Capture Approaches

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- **Post Capture**
  - **Adsorption**
  - **Absorption**
  - **Hydrate based**
  - **Cryogenics / Refrigeration based**
- **Oxy-fuel Firing**
  - **External oxygen supply**
  - **Integrated membrane-based**
  - **Oxygen carriers (chemical looping)**
- **Decarbonization**
  - **Reforming (fuel decarbonization)**
  - **Carbonate reactions (combustion decarbonization)**

Innovative options continue to emerge and develop

Low Carbon Combustion
Alternate Paths to CO2 Capture

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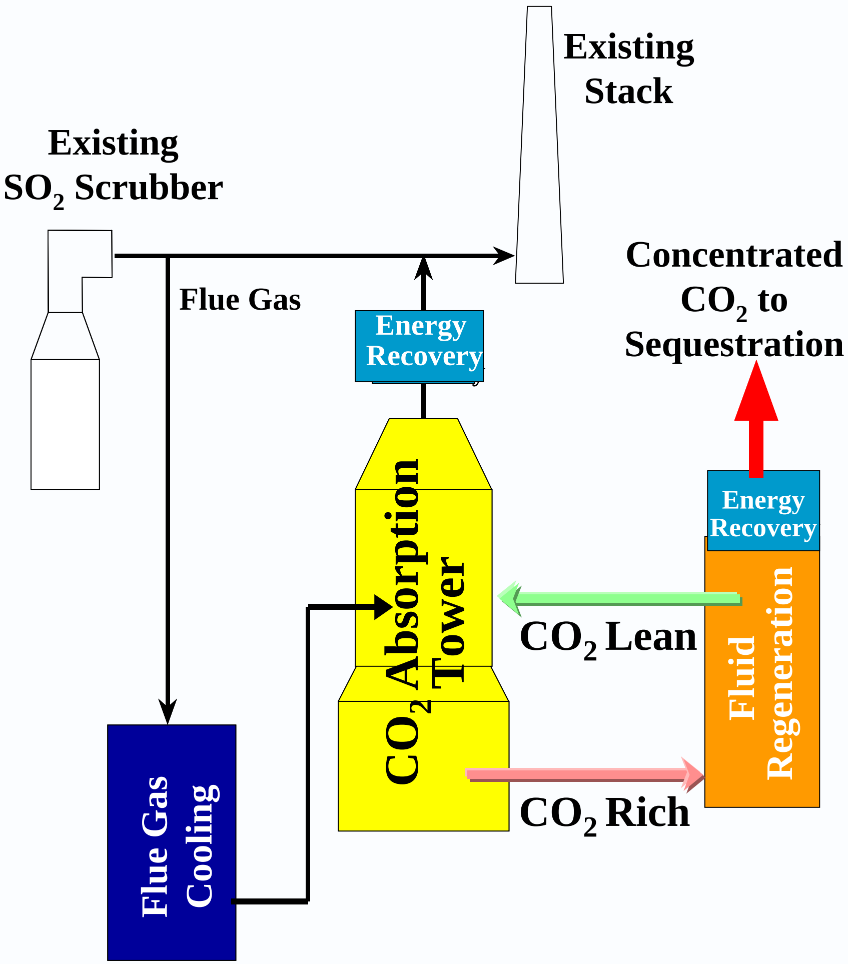
Technology	Status
CO_2 Scrubbing options – ammonia based	Demonstration in 2006. Advantage of lower costs than Amines. Applicable for retrofit & new applications
Advanced Amine Scrubbing	Further Improvements in Solvents, Thermal Integration, and Application of Membranes Technologies Focused on Reducing Cost and Power Usage – Multiple suppliers driving innovations
CO_2 Frosting	Uses Refrigeration Principle to Capture CO_2 from Flue Gas. Process Being Developed by Ecole de Mines de Paris, France, with ALSTOM Support
CO_2 Wheel	Use Regenerative Air-Heater-Like Device with Solid Absorbent Material to Capture ~ 60% CO_2 from Flue Gas. Being Developed by Toshiba, with Support from ALSTOM
CO_2 Adsorption with Solids	Being Developed by the University of Oslo & SINTEF Materials & Chemistry (Oslo, Norway), in Cooperation with ALSTOM

CO2 Capture Innovations
Chilled Ammonia System

- Ammonia reacts with CO_2 and water and forms ammonia carbonate or bicarbonate
  - Absorption at low temperature prevents ammonia release
  - $2NH_3 + CO_2 + H_2O \rightleftarrows (NH_4)2CO_3$
  - $NH_3 + CO_2 + H2O \rightleftarrows NH_4HCO_3$
  - $(NH_4)2CO_3 + CO_2 + H_2O \rightleftarrows 2NH_4HCO_3$
- Moderately raising the temperature reverses the above reactions – producing CO_2
  - Regeneration at high pressure and low concentrations of ammonia prevent gaseous ammonia release



Ammonia Process Innovations

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- Cooling the flue gas to 0-10ºC (32-50 °F)
  - Condensing H_2O and eliminating residual contamination
  - Reducing flue gas volume and increasing CO_2 concentration
- Operating the absorber at 0-10ºC for high CO_2 capture efficiency with low NH_3 emission
- Regeneration at >120ºC (250 °F) and >20 (300 psi) bar to generate high pressure CO_2 stream with low moisture and low ammonia concentration

Advantages of Ammonia

- High efficiency capture of CO_2
- Low heat of reaction
- High capacity for CO_2 per unit of solution
- Easy and low temperature regeneration
- Low cost reagent
- No degradation during absorption-regeneration
- Tolerance to oxygen and contaminations in gas

Basic Comparison with MEA

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	MEA	NH3
Molecular weight	61	17
Practical CO2 loading, Kg/Kg solution	0.05	0.1-0.2
Heat of reaction, Kcal/gmole	20-22	6-8
Absorption temperature, C	40-70	0-10
Regeneration temperature, C	110-130 (230-266F)	110-130
Regeneration pressure, bara	1-1.5 (14.5-22psi)	20-40 (300-600 psi)
H2O/CO2 in regenerator gas outlet (mole ratio)	1-1.5	0.01-0.05
Makeup requirements, kg/ton CO2	2	0.2
Makeup cost, $/ton	1000-1500	200-300

Basic Comparison with MEA

	Supercritical PC Without CO_2 Removal	SCPC With MEA CO_2 Removal Parsons Study	SCPC With NH_3 CO_2 Removal Current Study
Coal Feed rate, lb/hr	333,542	333,542	333,542
Coal heating value, Btu/lb (HHV)	11,666	11,666	11,666
Boiler heat input, MMBtu	3,891	3,891	3,891
LP Steam extraction, lb/hr for reboiler	0	1,215,641	179,500
Steam Turbine Power, kWe	498,319	408,089	484,995
Generator loss, kWe	(7,211)	(5,835)	(7,018)
Gross plant, kWe	491,108	402,254	471,301
Plant Auxiliary Load (IDF, FGD, BFW pumps, Water pumps, Cooling Towers, CO2 unit, Chillers, CO2 compressor, BOP), kWe	(29,050)	(72,730)	(53,950)
Net Power Output	462,058	329,524	421,717
Net efficiency, % HHV	40.5	28.9	37.0
Avoided Cost, $/ton CO2	Base	51.1	19.7

We Energies Pleasant Prairie
Host Site Location for 5MW Pilot

Proposed Pilot Location

Host Site Location

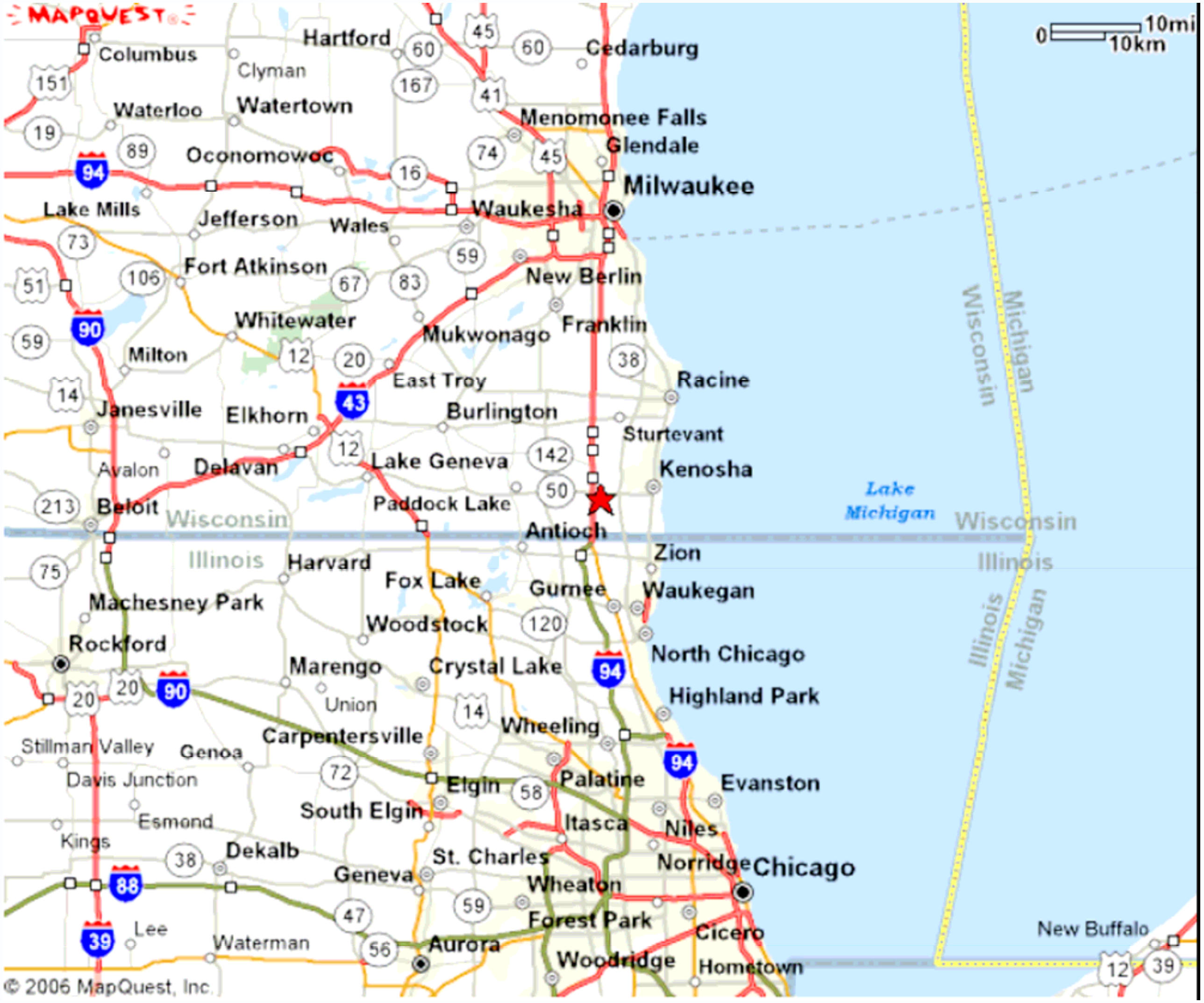
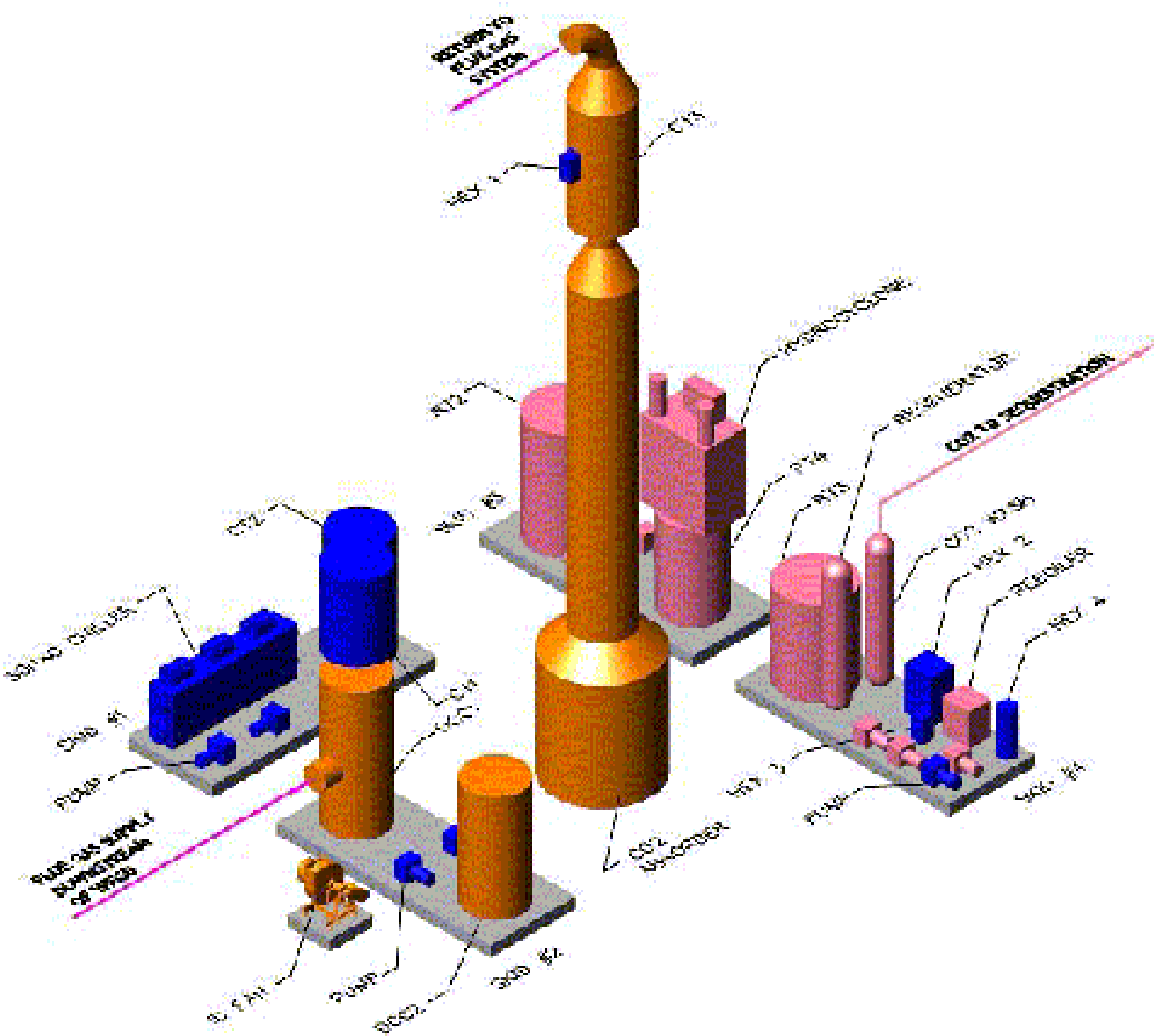


Illustration of the Pilot



Roles of Project Team Members

Task	Title	EPRI	ALSTOM	WE Energies
	CO2 PILOT - 5MW			
	Roles of Project Team Members			
Task	**Title**	**EPRI**	**ALSTOM**	**WE Energies**
1.	Pilot Plant Design and Construction			
1.01	Site Permitting		S	X
1.02	Define base design data,		X	
1.03	Mass balance calculation, P&ID		X	
1.04	Prel equipment sizing & GA		X	
1.1	Preliminary Design & Calculation, Phase I		X	
1.2	Detailed Design, Phase II		X	
1.3	Procurement		X	
1.4	Fabrication		X	
1.5	Process Safety review		S	X
1.6	Construction		X	
1.7	Commissioning & Start-up		X	S
2.	Operation & Maintenance			
2.1	Consumable Supply			X
2.2	Waste Disposal			X
2.3	Operation Labor		X	S
2.4	Maintenance Labor		S	X
3.	Testing			
3.1	Test Plan	X	S	S
3.2	Baseline Tests	X	S	S
3.3	Parametric Tests	X	S	S
3.4	Long-Term Tests	X	S	S
3.5	Data Analysis	X	S	S
4.	Performance and Economic Evaluation	X	S	S
5.	Management and Reporting			
5.1	Project Management, PM & PE	S	X	S
5.2	Reporting	S	X	S
5.3	Accounting/Invoicing	S	X	S
6.	Pilot Plant Decommissioning		X	
	X - Lead Party			
	S - Support			

Multiple Paths to CO2 Reduction Innovations for the Future

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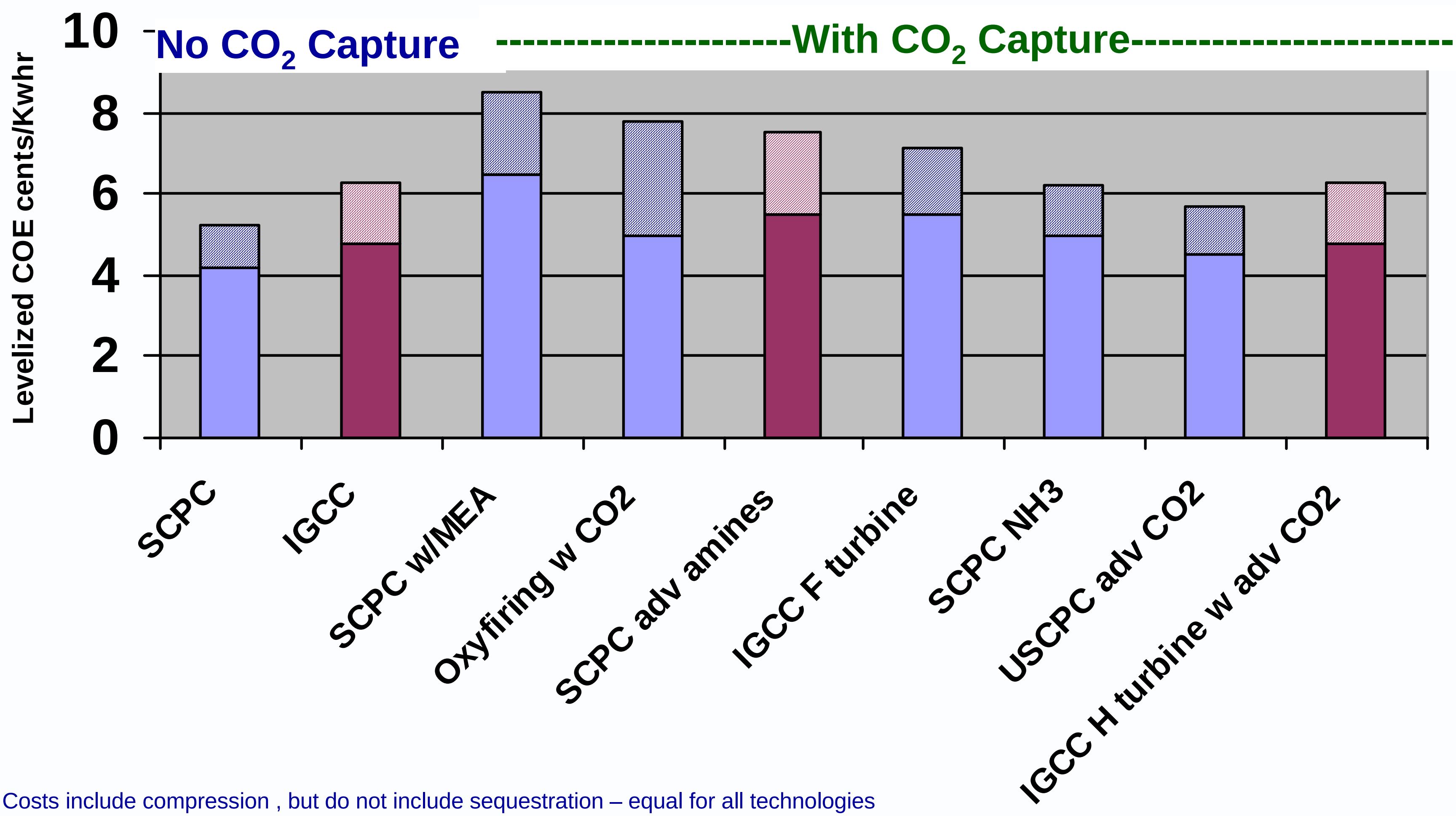
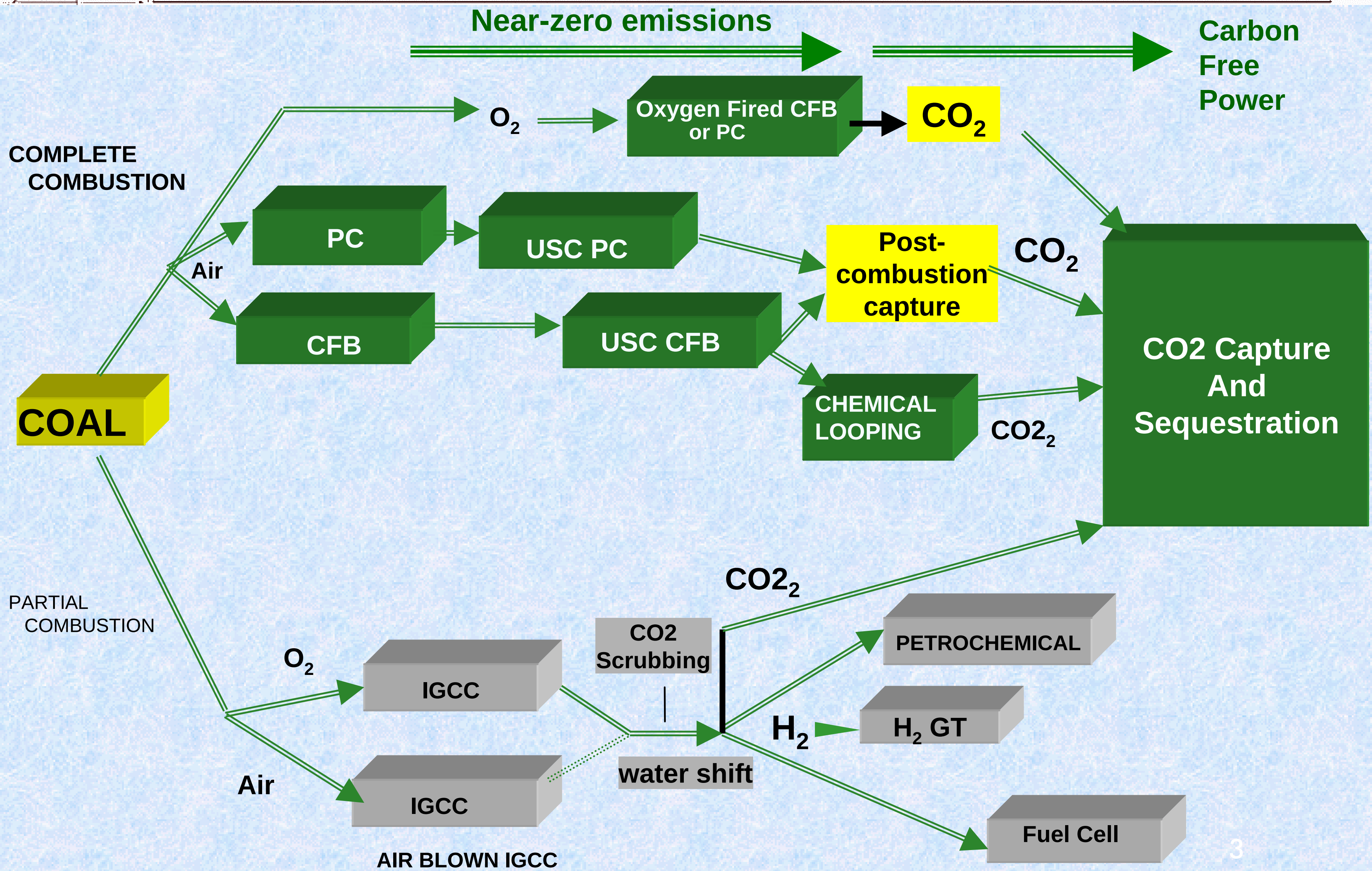
'Hatched' Range reflects cost variation from fuels and uncertainty



Note: Costs include compression , but do not include sequestration – equal for all technologies

Technology Choices Reduce Risk and Lower Costs

Our Vision for New Coal Power Portfolio of Clean Technologies



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