ACT Presentation

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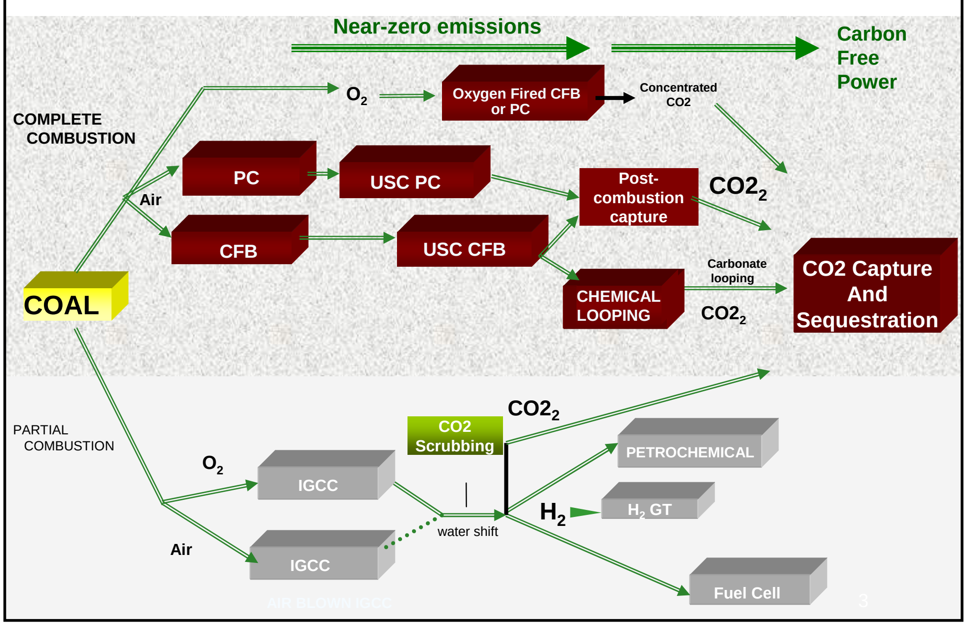
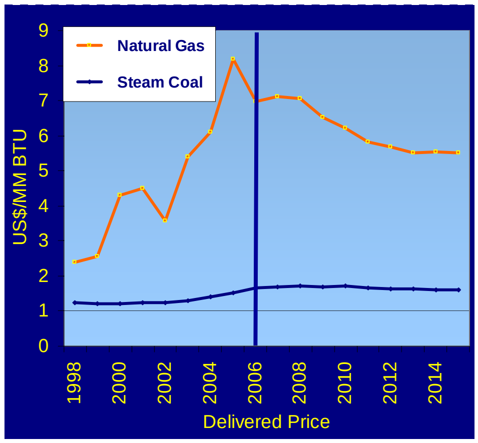
One Vision for New Coal Power
Portfolio of Clean Technologies



Drivers for New Coal Build North America



Source: U.S. EIA

- ❑ Base Energy needs versus Peaking Capacity
  - Base load demand expected to increase at roughly GDP
- ❑ Economics
  - Fuel Cost
  - End User price shocks driving demand for low cost energy
- ❑ Coal availability and prevalence
  - 200+ Years of Reserves in North America
- ❑ Advent of OTC (over the counter) markets for coal and emissions
- ❑ Environmental regulations drive new clean plants
- ❑ Fuel diversity

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New Coal Capacity Faces Challenges

- ❑ Economics
  - Utilization of all low cost domestic coals …and opportunity fuels
  - Competitive costs
- ❑ Operations
  - Highest reliability and commercial availability
  - Operating parameters to meet demands of grid
- ❑ **Environmental**
  - Near zero emissions …
  - and a carbon strategy

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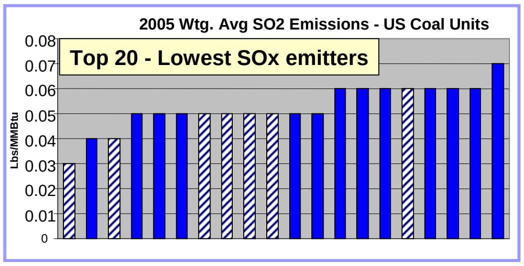
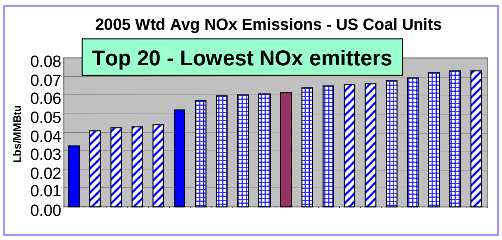
Operating Coal Combustion – Best in Class Emissions



PC and CFB Clean Coal technologies have demonstrated the lowest emissions :

- Exceed Requirements
- Cost Effectively
- Reliably



Bit. PC
SubBit. PC
CFB
IGCC (operating)

Source: Energy Velocity database (EPA CEMS 2005 data)

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Ultra Clean Coal Combustion Emissions Control Capability

- Today's state-of-the-art
  - NOx ≥95% reduction with optimized firing systems and SCR
  - SO_2 ≥99% capture with Wet FGD and DBA
  - Particulates 99.99% capture
  - Hg 80- 95% capture (coal dependent)
- Next steps
  - Continued improvements
  - Integrated Multi-pollutant systems to reduce costs
  - High Hg capture on all coals (without reliance on ACI)
  - Introduction of CO_2 capture

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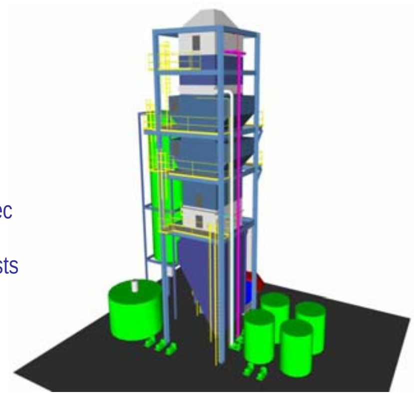
Multi-pollutant APC Systems

- Integrated APC systems based around commercially proven and reliable technologies
- Use readily available reagents
- Produces reusable byproduct(s)
  - No impact on fly ash
- Superior cost/performance ratio:
  - Extremely compact design
    - Reduces capital costs for equipment, erec and BOP
  - Fewer moving parts reduces maintenance costs
  - Superior environmental performance
    - Reduced permitting schedule/cost
    - Avoided cost for SO_2 credits
- Targeted emissions levels:
  - SO_2: 0.02 lb/MMBTU (> 99.5%)
  - Hg: 1.0 lb/TBTU (> 90%)
  - PM: 0.01 lb/MMBTU (99.99%)
  - NO_x: 0.05 lb/MMBTU w/SCR
    - "Polishing" (Level TBD) w/o SCR



Controls SO_x, $PM_{10}/PM_{2.5}$ Mercury & NOx

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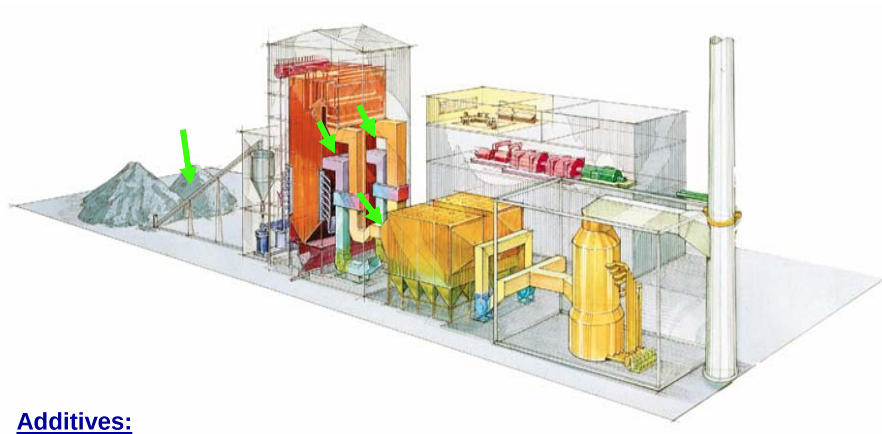
When Additional Control is Needed - Mercury Capture Technologies



Additives:

- **Halogen(s)**
- **Powdered Activated Carbon**
- **Halogenated Powdered Activated Carbon**

= Potential additive injection points

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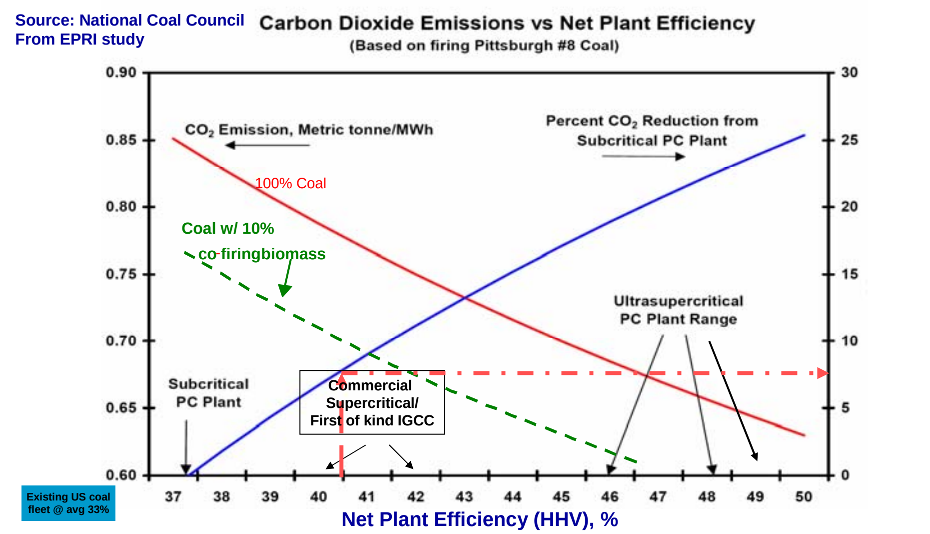
Efficiency –
Critical to emissions strategy



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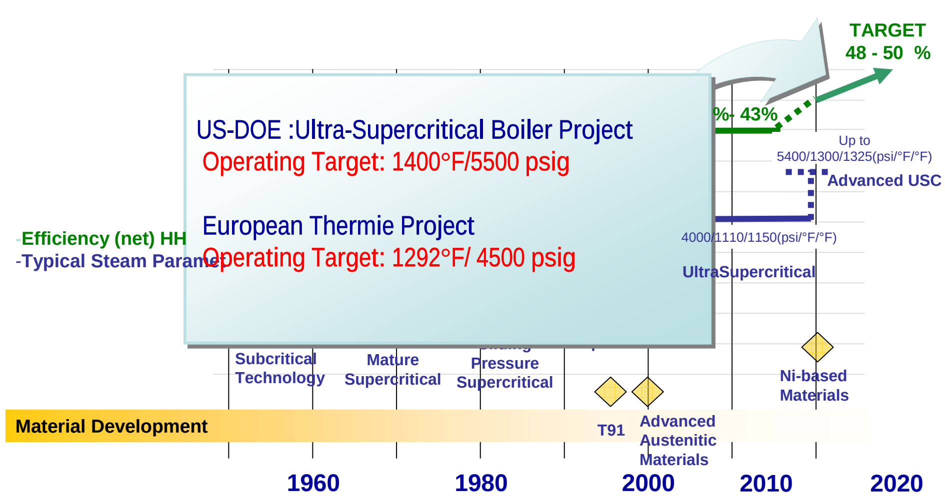
Progression of Plant Efficiency via Advanced Steam Conditions and Plant Designs



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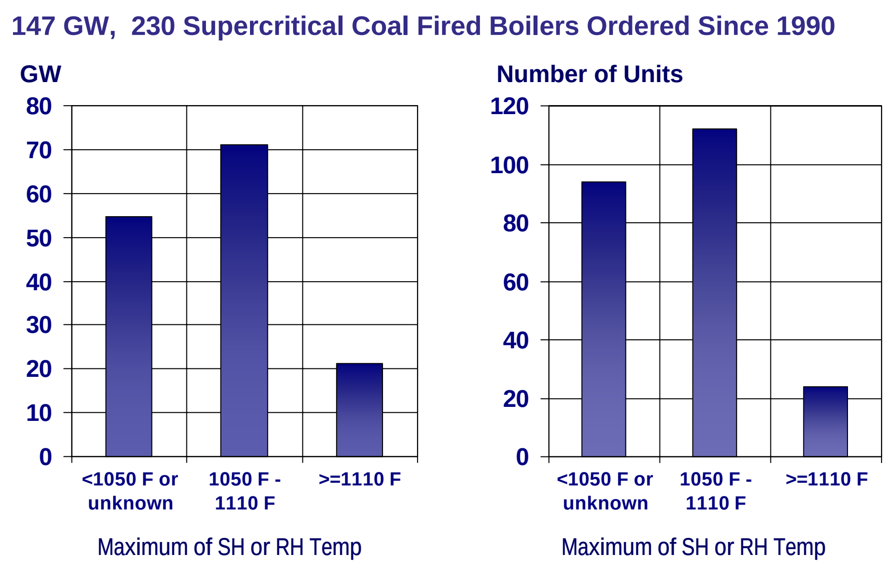
Clear Trend to Advanced Supercritical Cycles



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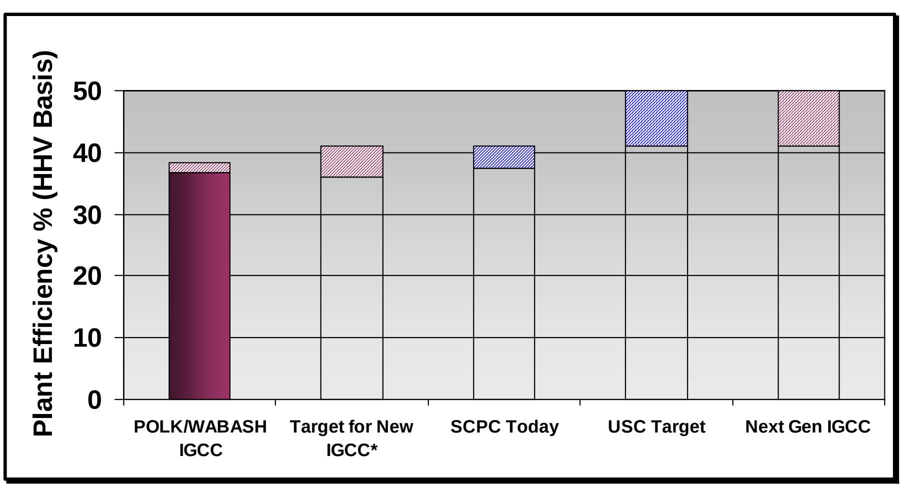
Meeting the Goals for Coal Based Power - Efficiency



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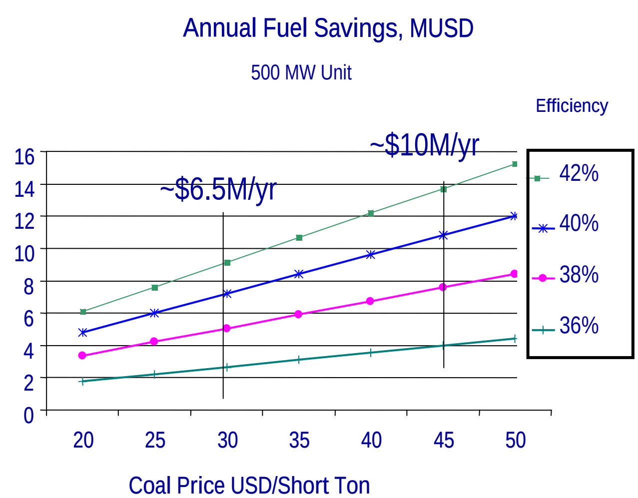
Increased Value for Efficiency



Compared to 34% subcritical efficiency, 11,000 BTU/lb coal, 80% capacity factor

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CO_2 Mitigation Options – for Coal Based Power

- ✓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

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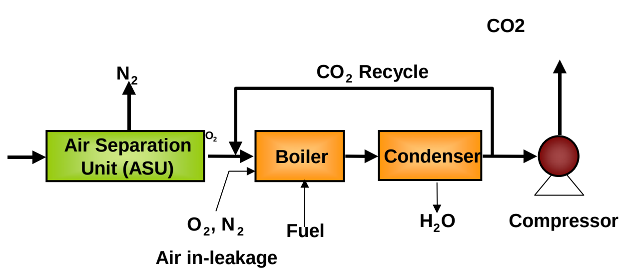
CO2 Capture – Post Combustion

Technology	Status
CO_2 Scrubbing options – ammonia based	Demonstration in 2006. Advantage of lower costs than Amines. Applicable for retrofit & new applications
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
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

Technology Validation & Demonstration

Oxygen Firing to produce concentrated CO_2 stream



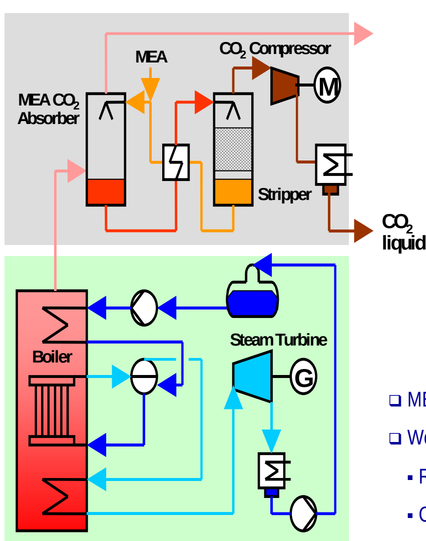
3 MWt pilot CFB

- Oxygen Firing – Direct concentration of CO_2 to >90% for reduced capture costs

30 MWth Oxy-fired PC Pilot Plant – Vattenfall

Development Steps	Scale-up Factor	Objective	Com	Partners
Laboratory Tests 10 / 55 kWth		Fundamentals of oxyfuel combustion	2004 2005	Universities (Stuttgart, Chalmers, Dresden) Vattenfall, ALSTOM..
Test Plant 500 kWth	1:50	Fundamentals of oxyfuel combustion with flue gas recirculation	2005	CEBra, BTU Cottbus, Vattenfall, ALSTOM
Pilot Plant 30 MWth	1:60	Test of the oxyfuel process chain	2008	Vattenfall..., ALSTOM, others
Demo Plant 600 MWth	1:20	Realisation with CO2 sequestration,	2015	
Commercial Plant approx. 1000 MWel	approx. 4-5		2020	

Amine-Based Absorption - CO2 Capture



SHADY POINT, OKLAHOMA, USA
An AES CFB power plant with
MEA CO2 separation

- MEA has demonstrated performance on coal based flue gas
- Work required to address:
  - Regeneration power
  - Compression ratio
  - Cost of solvent

Advancements
Absorption Stripping CO2 Capture

Amine scrubbing continues to develop

- Ionic Liquids “designer solvents”

- “Piperazine” - alternative solvent

- Process integration and improvement has driven cost down from 70 to 40-50 \$/ton CO_2 further progress expected

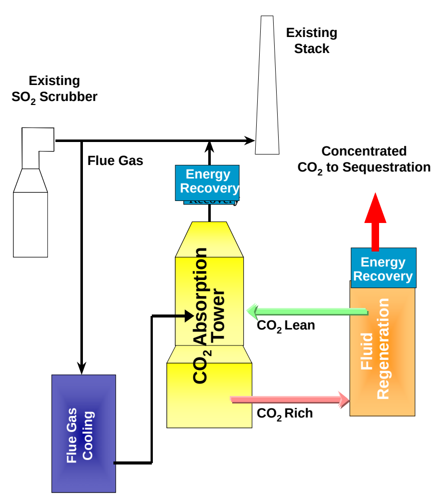
➢ With industry focus on improvements, advanced amines likely to be competitive solution for post combustion capture

CO2 Capture Innovations
Chilled Ammonia System

- Ammonia reacts with CO_2 and water and forms ammonia carbonate or bicarbonate

- Moderately raising the temperature reverses the above reactions – producing CO_2

- Regeneration at high pressure



Advantages of Chilled 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 flue gas

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Post Combustion CO2 Capture
Chilled Ammonia

	Without CO2 Removal	MEA-Fluor Dan. Proc.	NH3
Total power plant cost, M$	528	652	648
Net power output, MWe	462	329	421
Levelized cost of power, c/KWh	5.15	8.56	6.21
CO2 Emission, lb/kwh	1.71	0.24	0.19
Avoided Cost, $/ton CO2	Base	51.1	19.7

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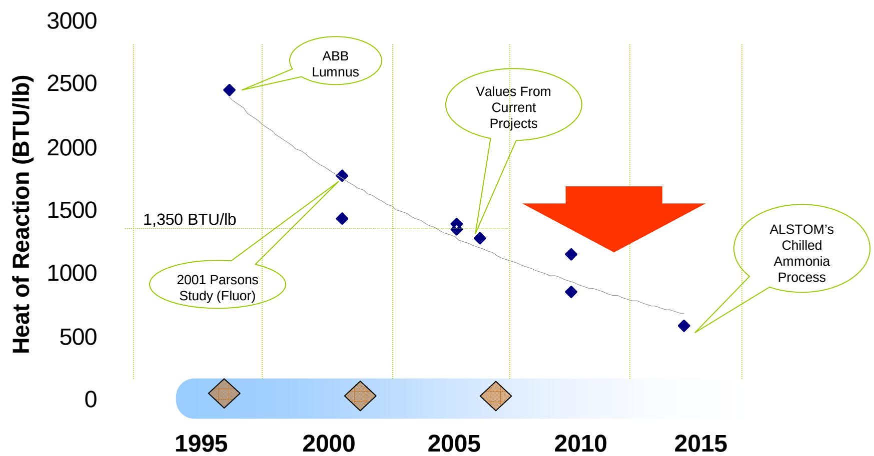
Going Down The Experience Curve for Post Combustion CO2 Capture



Significant Improvements Are Being Achieved

We Energies Pleasant Prairie Host Site Location for 5MW Pilot

we energies

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Carbon Free Power
Advanced Combustion

Innovative Combustion Options for 2010 and Beyond

- Oxygen Firing – Direct concentration of CO_2 to >90% for reduced capture costs
- Chemical Looping –Leapfrog technology with potential to achieve significantly lower costs than PC/CFB/IGCC

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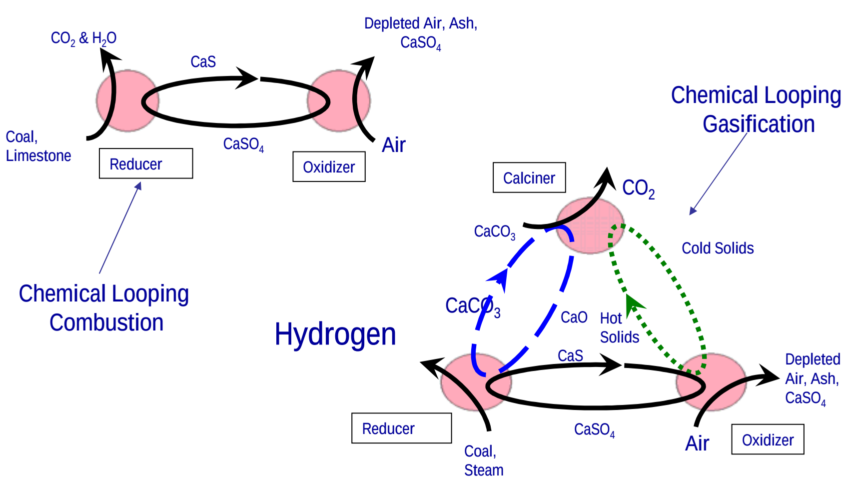
Future Technologies for CO_2 Capture
Chemical Looping



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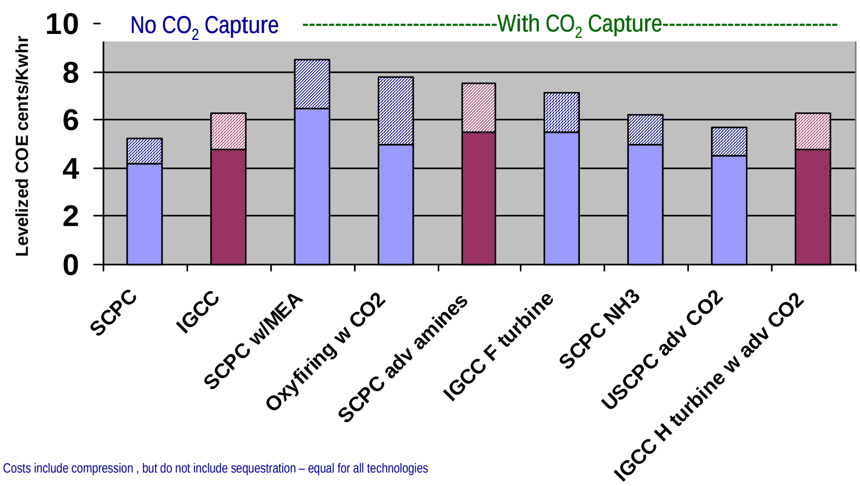
Multiple Paths to CO2 Reduction
Innovations for the Future

'Hatched' Range reflects cost variation from fuels and uncertainty

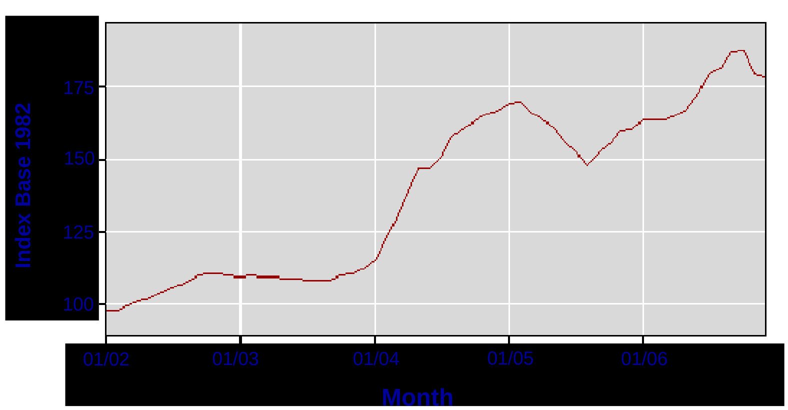
Technology Choices Reduce Risk and Lower Costs



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

Market Trends

Carbon Steel Price Trends



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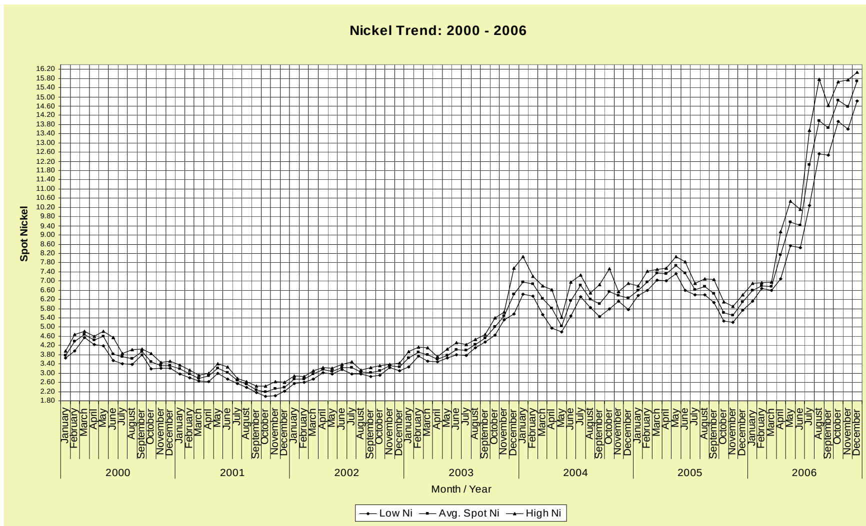

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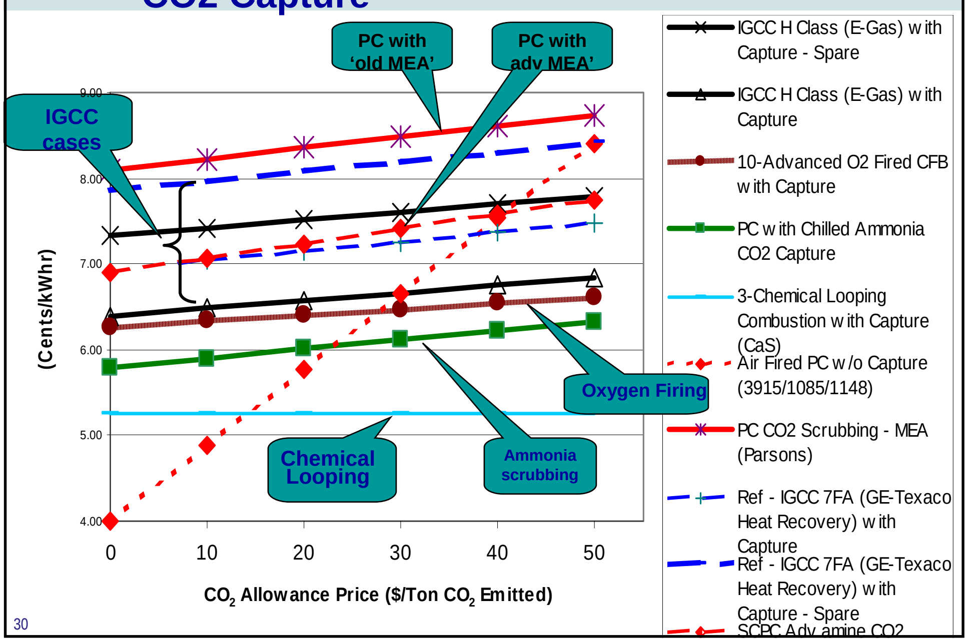
Technology Innovations
CO2 Capture



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CO_2 Capture

Innovative options continue to emerge and develop

- Post Combustion 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)

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Conclusions

- New coal fired power plants shall be designed for highest efficiency to minimize CO_2 and other emissions
- Lower cost, higher performance technologies for post combustion CO2 capture are actively being developed, and more are emerging
- There is no single technology answer to suit all fuels and all applications
- The industry is best served by a portfolio approach to drive development of competitive coal power with carbon capture technology

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