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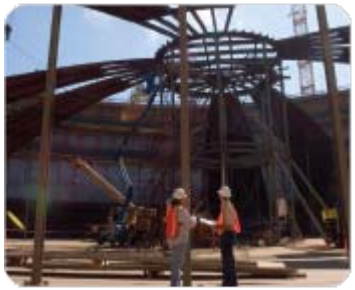



Technology and Cost Considerations in CO_2 Sequestration

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Senior Consultant

September 21, 2007

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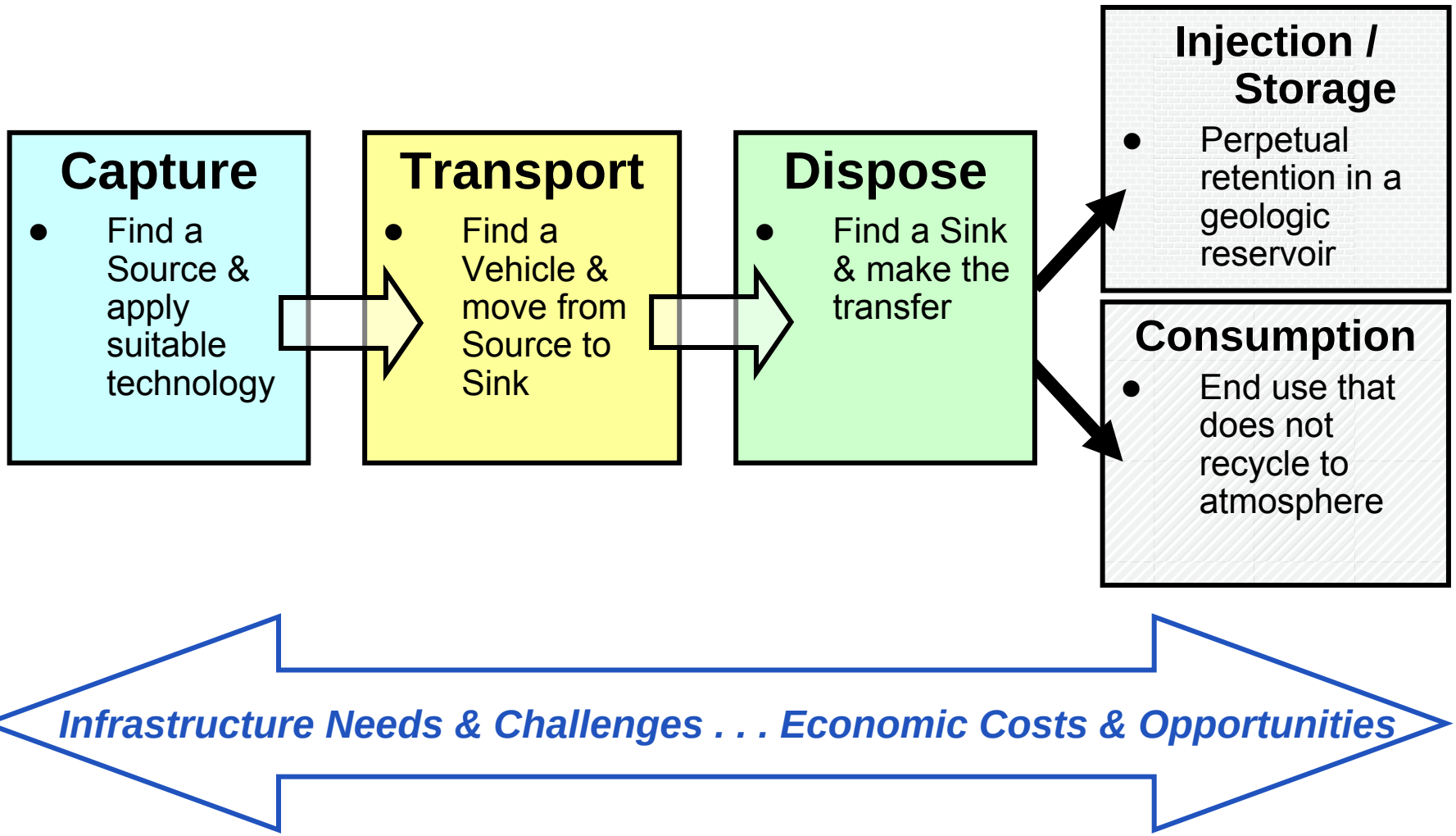
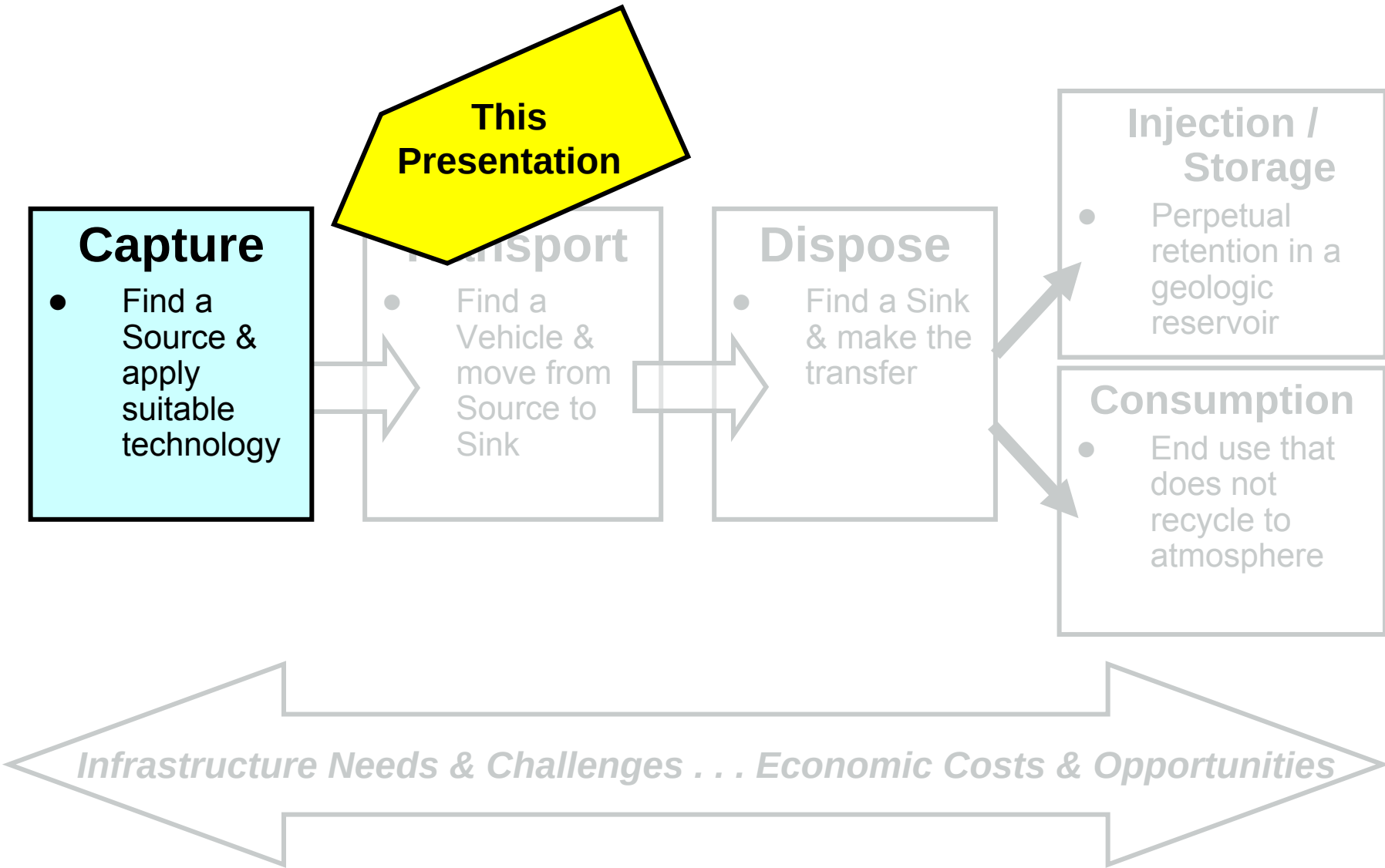
  - Alex Silver
  - Tom Guenther

The CO_2 Sequestration Value Chain



The CO_2 Sequestration Value Chain



Technology and Cost Considerations in CO_2 Capture

- Carbon-emitting electric power plants in the conterminous USA
  - CO_2 emission as a function of fuel and type of power plant
  - Plant locations
- Capture of CO_2 from power plants
  - Technologies
  - Costs

CO_2 Capture from Electric Power Plants

- Proven technologies exist for capturing CO_2 from carbon-fueled power plants
- Several unproven technologies show promise
- No USA electric-power plants currently capture any significant percentage of CO_2 generated
- Costs to capture CO_2 are high for all processes

CO_2 Emission from Combustion of Fuel

- Carbon dioxide (CO_2) is a by-product of all combustion processes involving carbon fuels (C*):

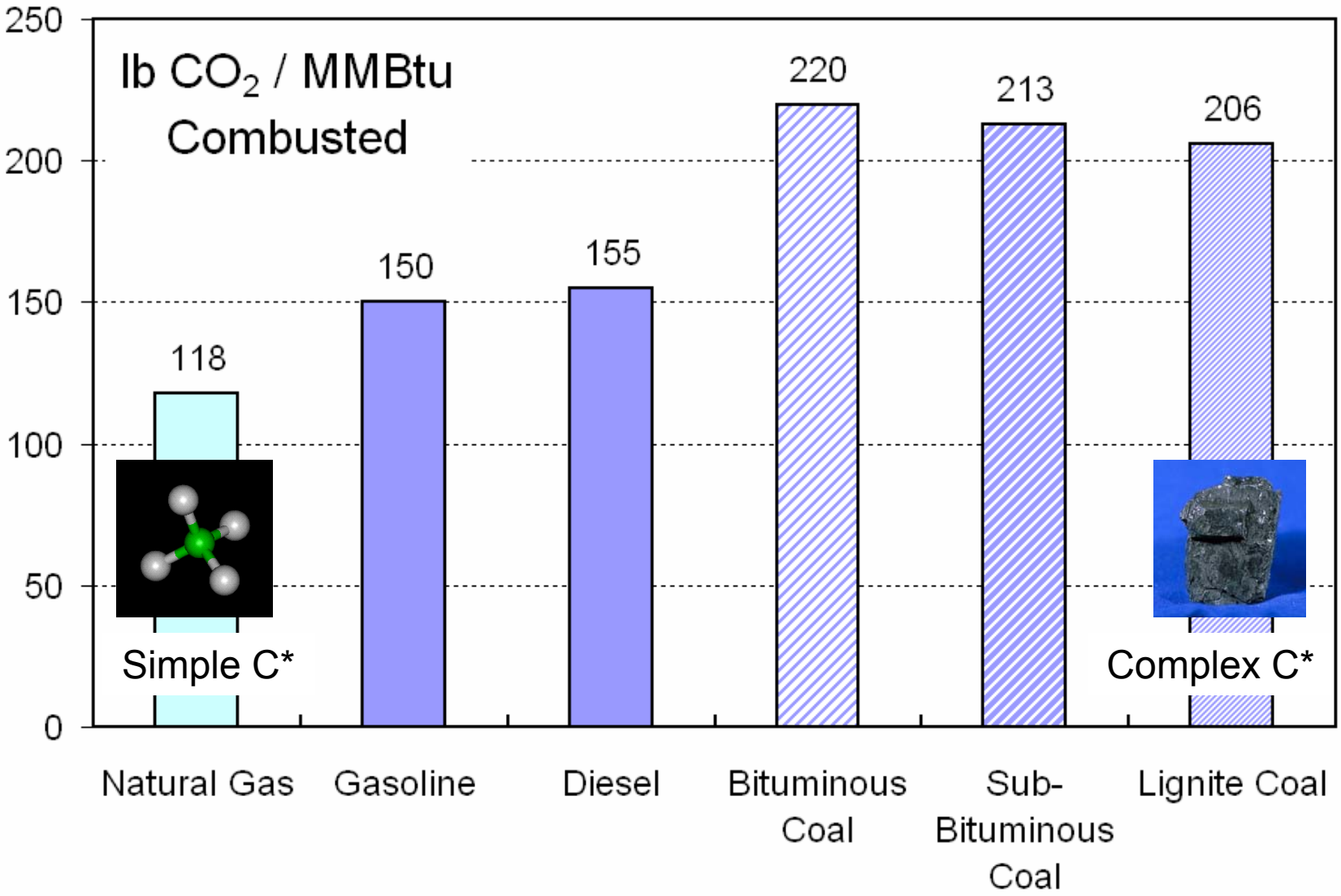
$$x\ \mathbf{C^*} \quad + \quad y\ \mathbf{O_2} \quad \rightarrow \quad z\ \mathbf{CO_2}$$

fuel — air or process gas — effluent gas

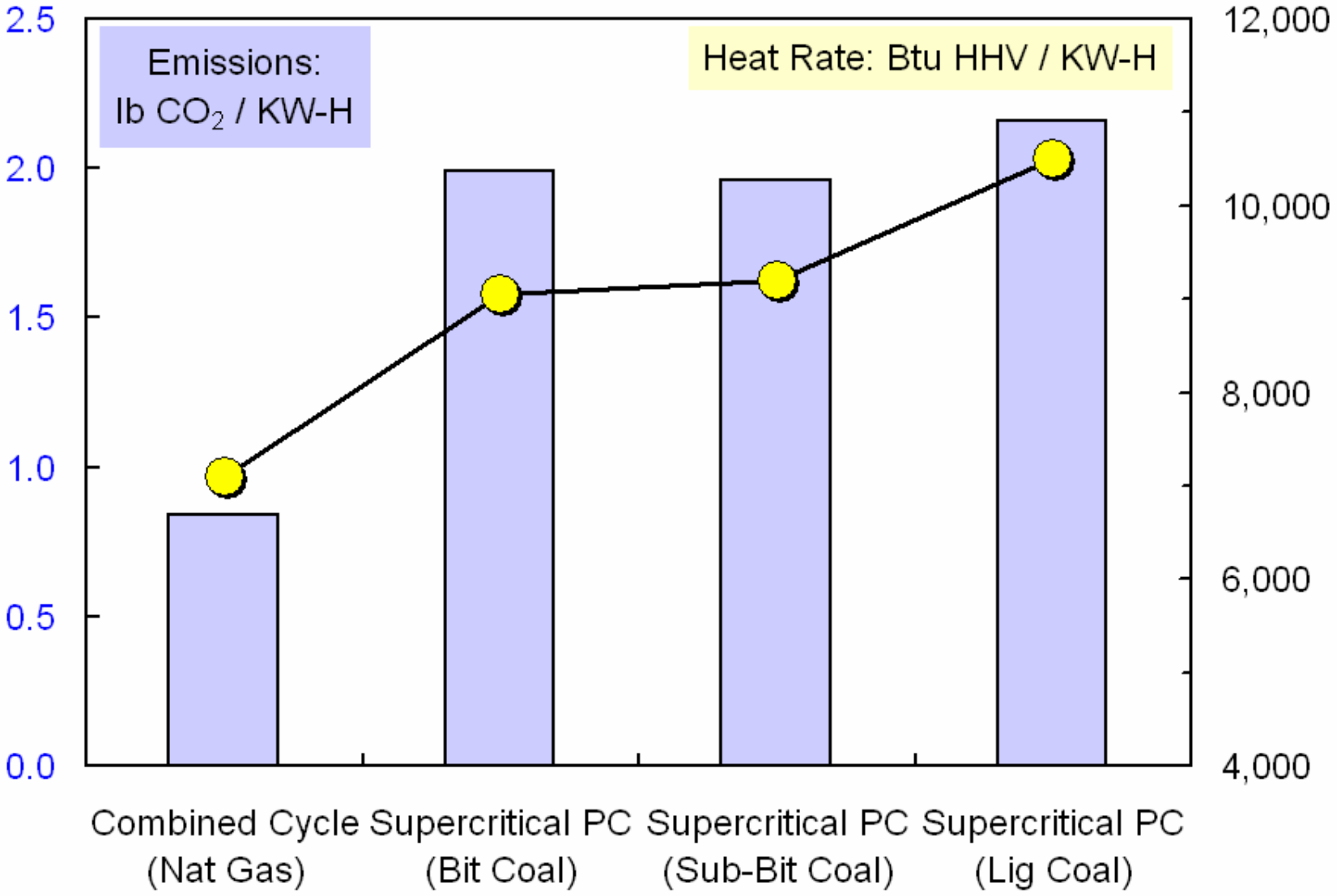
* Usually a complex mixture of natural chemical compounds

- But the proportion of CO_2 produced per unit of C* combusted, z / x, varies with the chemical identity of C*
- Selection of fuel (C*) historically has been driven by availability and cost

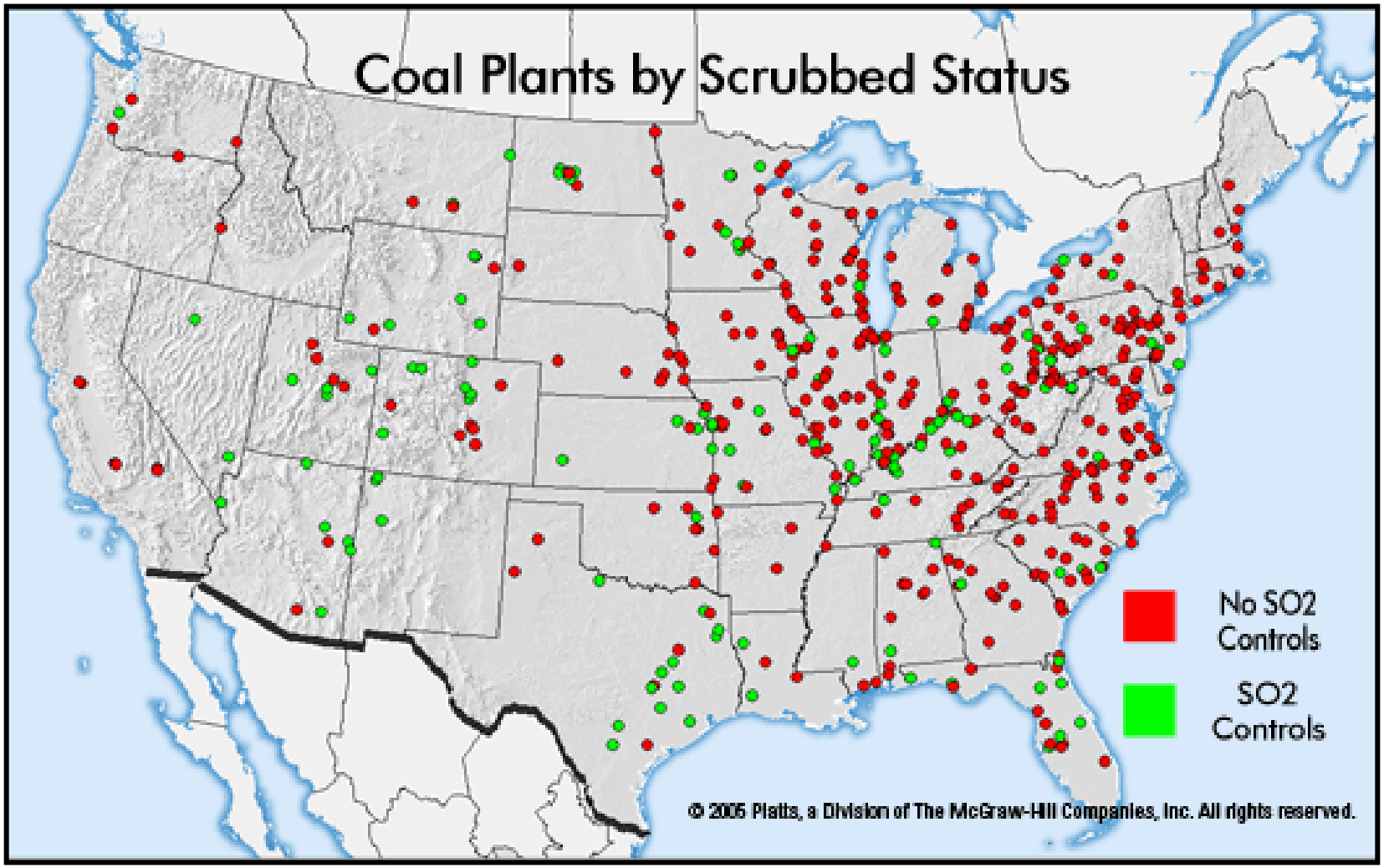
CO_2 Emission as a Function of Fuel Type (C*)



CO_2 Emission Variations with Type of Power Plant

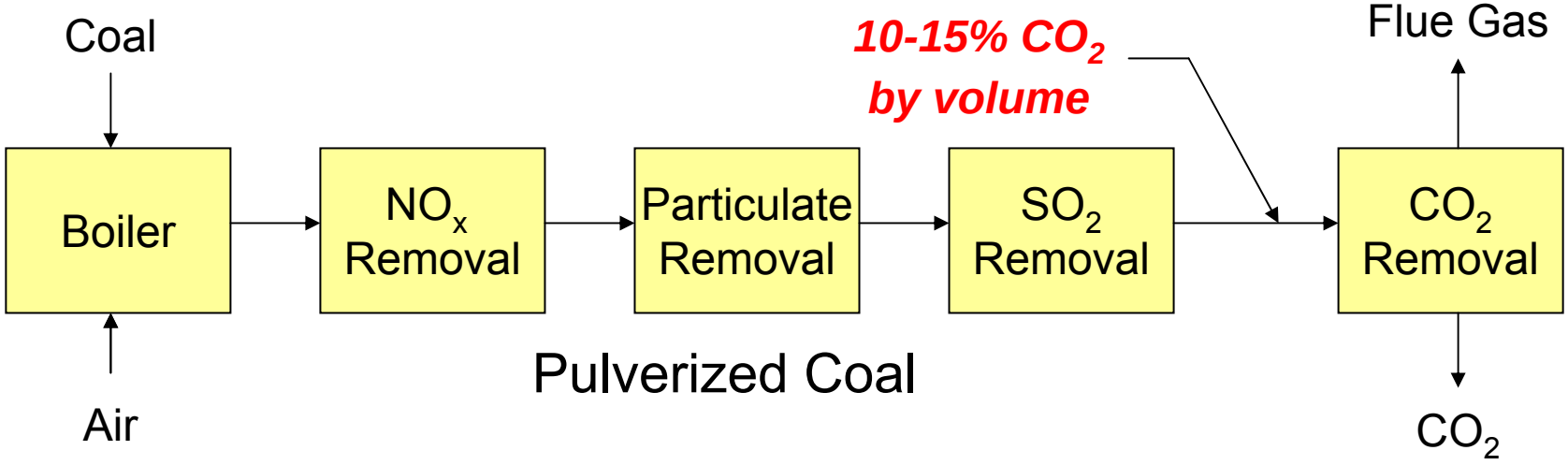


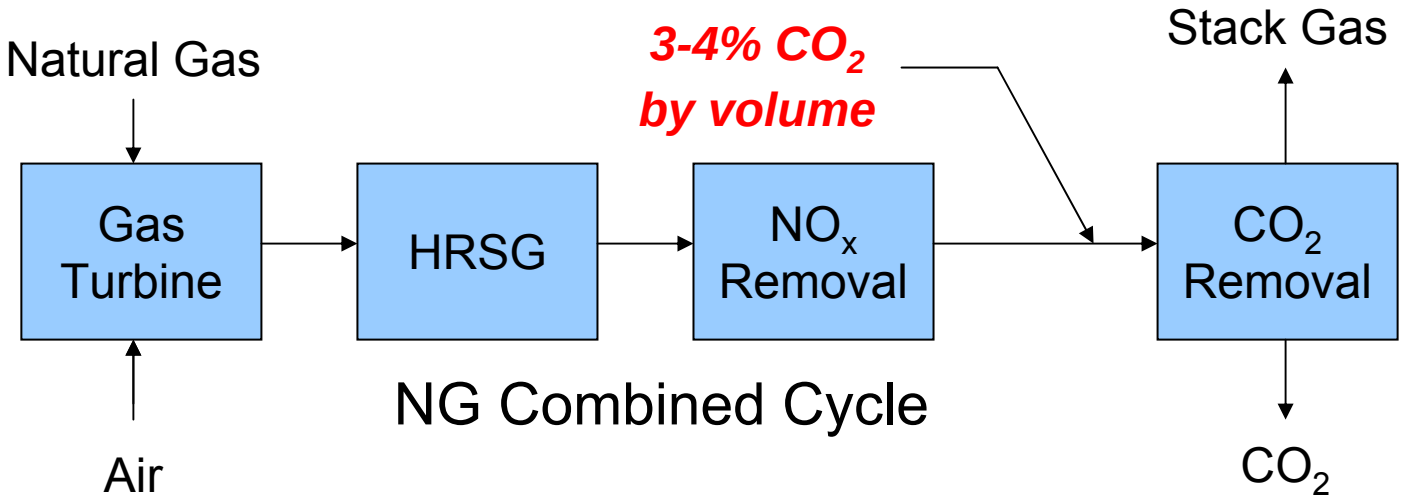
Coal-Fired Electric Power Plants in the Conterminous USA



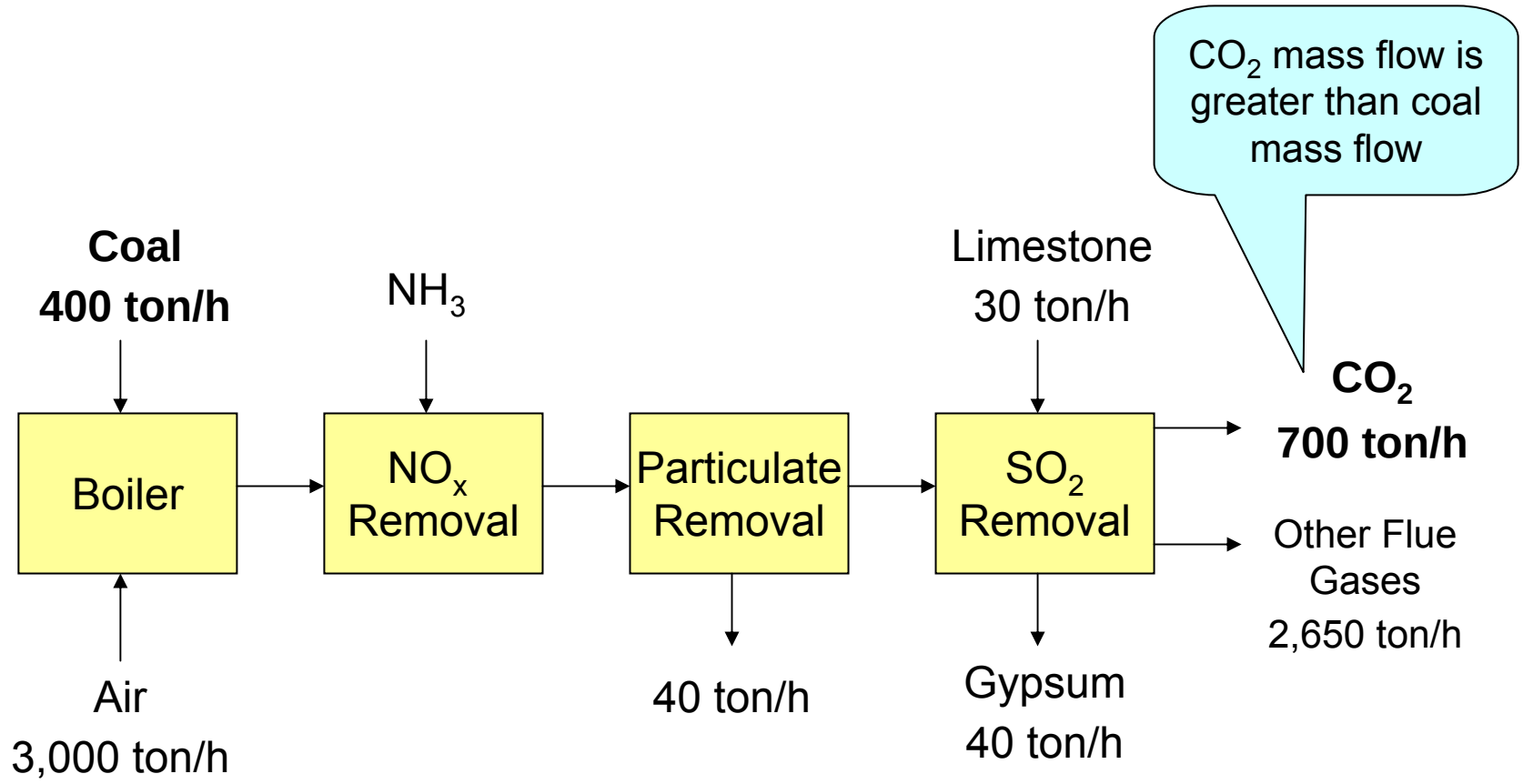
Source: Platts (The McGraw-Hill Co.)

CO_2 from Electric Power Plants: Coal vs. Natural Gas



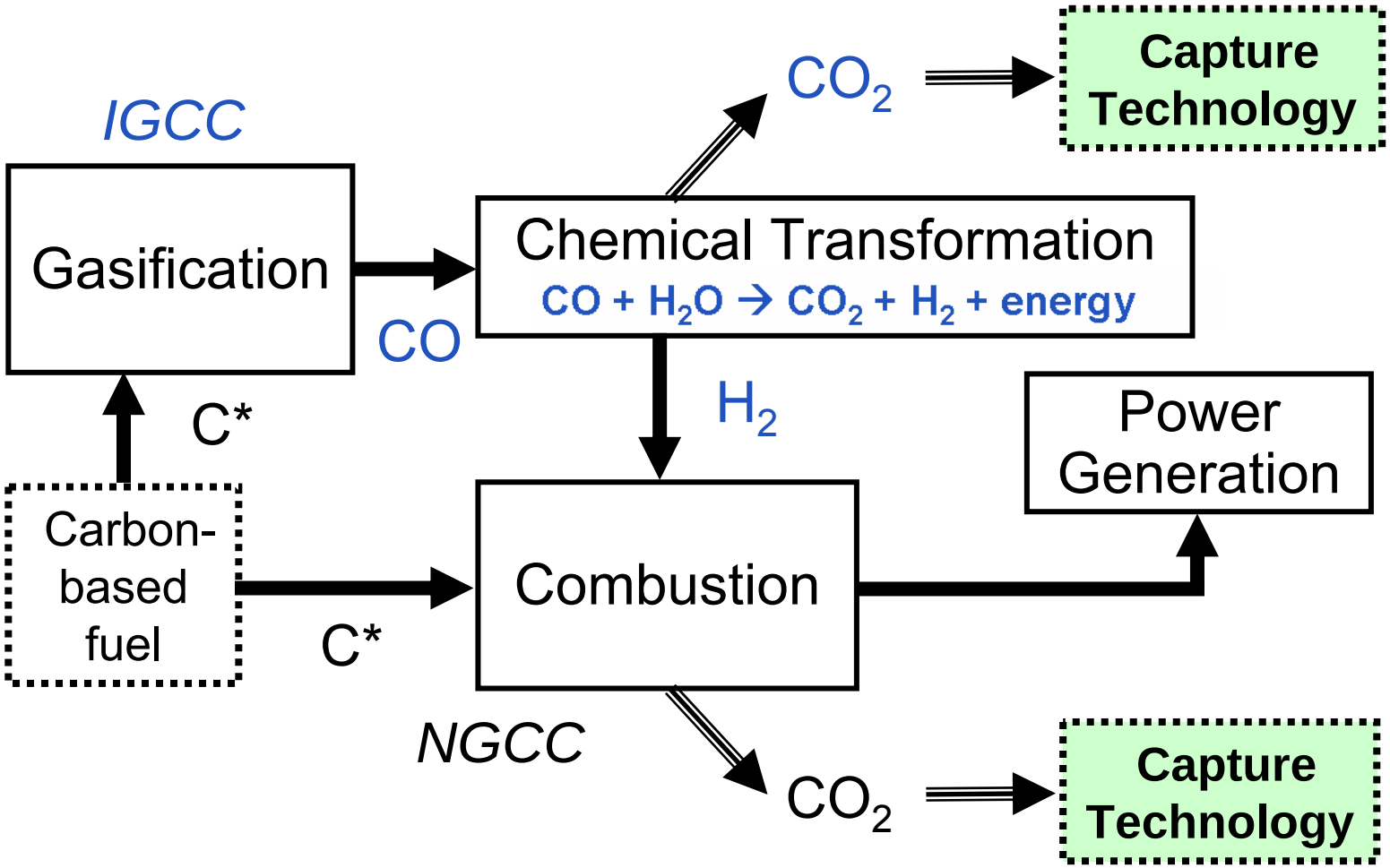


Coal-Fired Power Plant Mass Balance – 750 MW



Basis:
8,580 Btu/lb as-received coal
9,200 Btu/KW-H net heat rate

Pre- vs. Post-Combustion Removal of CO_2 at an Electric Power Plant



Technology Options for Capturing Gaseous CO_2 *

- **Solvent Absorbents**
  - Physical dissolving
  - Chemical reaction
    - Monoethanolamine (MEA)
    - Ammonia
- *Membranes*
- *Molecular Sieves*
- *Solid Adsorbents*
- *Cryogenic*

Source: MHI

* **Pre-operational pilot testing**

Bench-level R&D phase

Functions Required to Accomplish CO_2 Capture

Function / Plant	PC	NGCC	IGCC
Amine	●	●	
Customized chemical solvent			●
Solvent refrigeration / compression			●
Steam for solvent stripping	●	●	
CO_2 compression	●	●	●

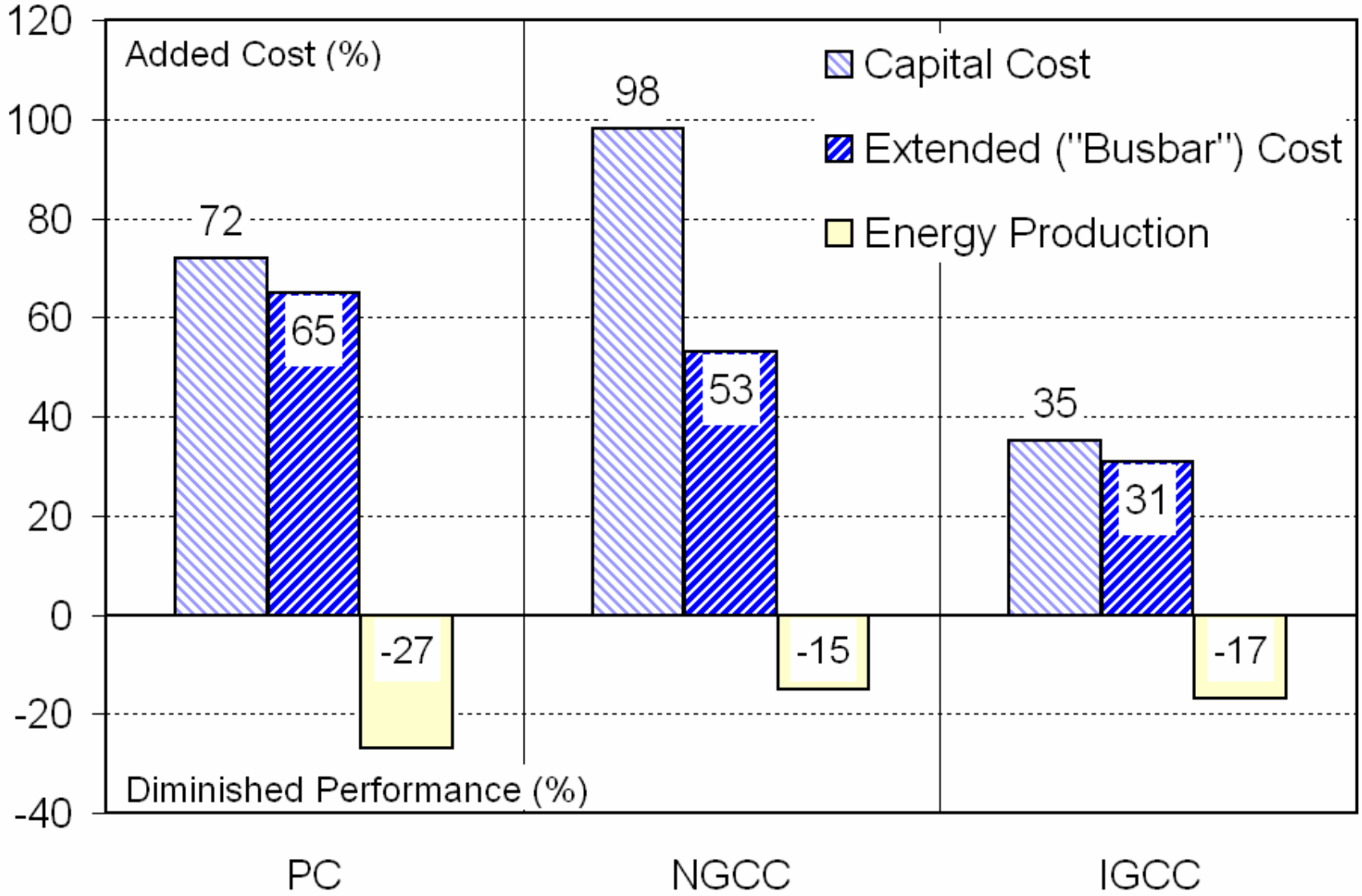
Fluid Comparison: CO_2 vs. CH_4

	CO_2	CH_4
Boiling (*Sublimation) Temperature	-109º F *	- 259º F
Critical Temperature	88º F	- 181º F
Critical Pressure	1,071 PSIA	731 PSIA
Liquid : Gas Reduction Ratio	418 : 1	615 : 1

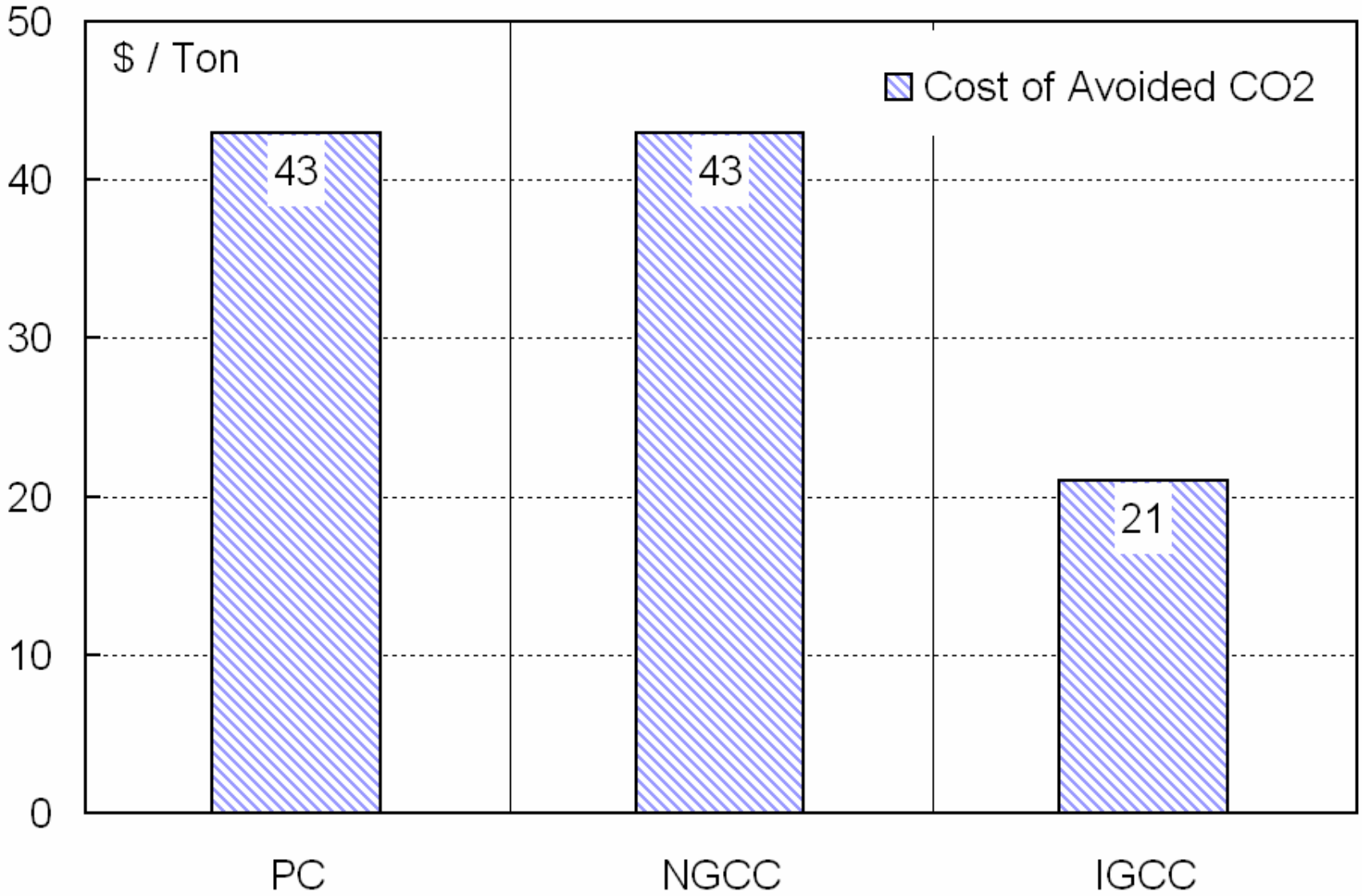
Costs for CO_2 Capture are Significant

- Additional equipment
  - CO_2 removal
  - CO_2 compression
  - CO_2 piping to sequestration site
- Energy penalty (12 – 40 percent depending on generation and capture technology)
- Solvent replacement (primarily amine processes)

Project Penalties for CO_2 Capture at Power Plants



Project Penalties for CO_2 Capture at Power Plants



Conclusions

- Coal-fired power plants are the obvious choices as "Sources" for CO_2 sequestration value chain
- Carbon-capture technologies vary between "laboratory benchtop" and "pilot plant" status
  - Several different options are being developed but none are yet deployed as "operational"
  - Chemical technologies (especially) will add complexities to power-plant design & operation
- Technology for CO_2 capture will add substantial costs to the entire power-plant enterprise
  - EPC costs might include "CO_2 adders" of 50-100%
  - Plant power-production efficiencies might fall by ~ 15-30%