Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Session 3D: Advanced Capture

CO_2 Capture by Formation of Hydrates: Economical Analysis and New Promoter Process

R. Currier (fill-in speaker)
Los Alamos National Laboratory

G. Deppe, A. Lee, S.S. Tam
Nexant, Inc.

D.F. Spencer
SIMTECHE

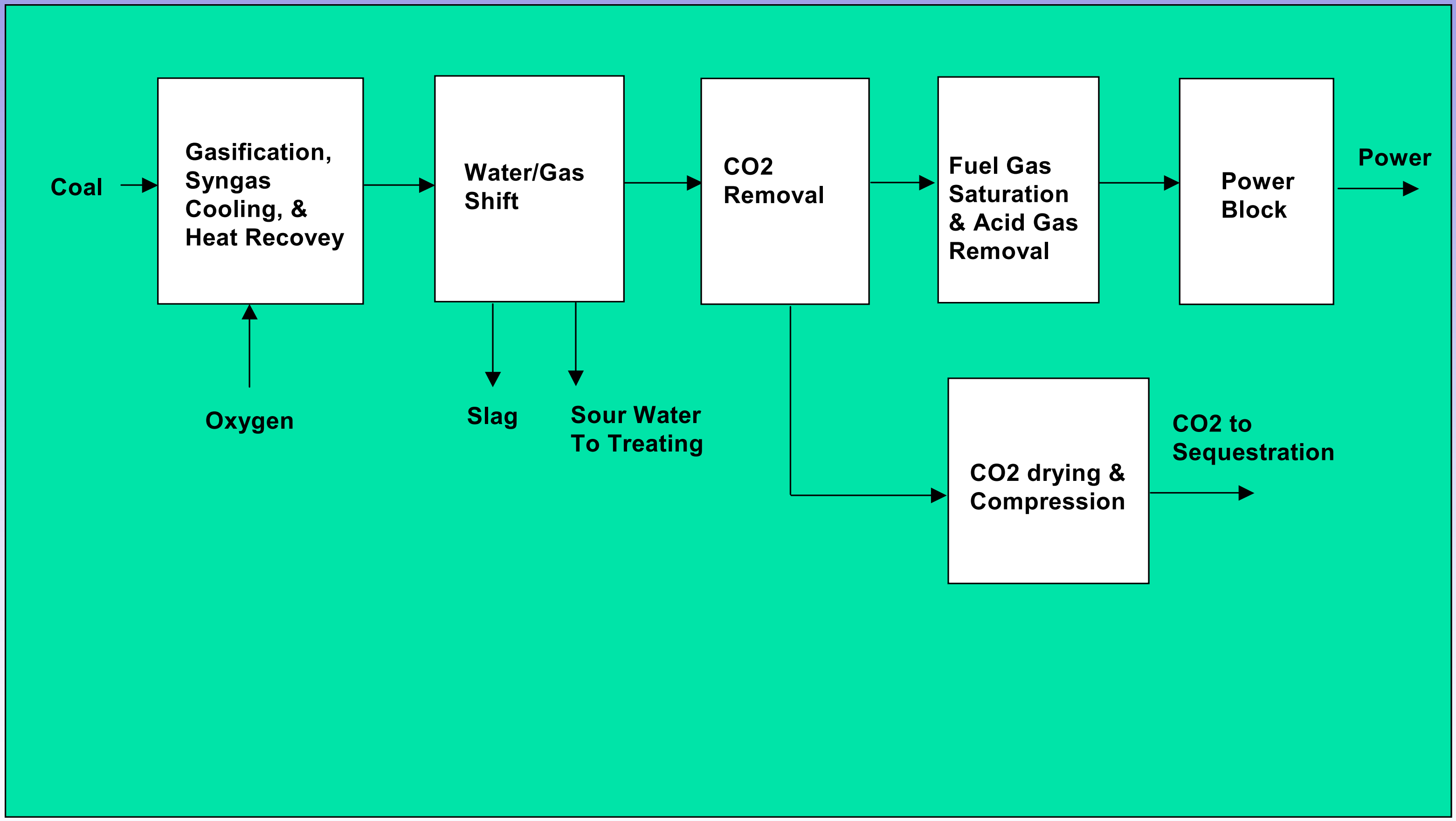
Supported by DOE-FE/NETL: José D. Figueroa, Project Manager

May 8-11, 2006 • Hilton Alexandria Mark Center • Alexandria, Virginia

Presentation Outline

- Process Features
- Performance and Economics
- Research and Development Status
- Path Forward

Block Flow Diagram (IGCC)



Process Features

- **Selective Removal of CO_2 and H_2S From Shifted Synthesis Gas**
  - **Initially – 1000 psig**
  - **Future – Lower Pressure Systems**

- **High Pressure Regeneration of CO_2/H_2S Product Gas**
  - **75% Recovered at 600+ psig**

- **Integration of Process Heat With Regeneration**

Process Features

- **Process Performance Improves With Feedstock Sulfur Content**
- **Promoter Compounds Identified that Increase Separation**
- **No Solvent Regeneration Requirement**

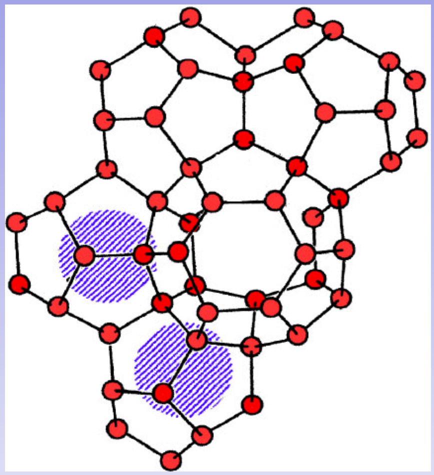
CO_2 Hydrate Separation

- **Limited by Minimum CO_2 Hydrate Formation Pressure (MHFP)**
  - Modification of CO_2 Hydrate Phase Diagram
  - CO_2 Hydrate Promoters
    - Lower Formation Pressure and/or Increase Formation Temperature

- **Initial Promoter**
  - Low Concentrations of H_2S, Occurring in Shifted Syngas
    - 1-2% Could Significantly Reduce CO_2 MHFP
    - 40 Mole % CO_2, 1% H_2S, Gives an "Effective" H_2S Concentration of 2.5% H_2S – Based on Phase Equilibrium Experiments

CO_2 Hydrate Separation

- **Additional CO_2 Hydrate Promoters**
  - Organic Liquids e.g. cyclic ethers
  - Organic Salts e.g. Alkylonium Compounds
    - Highly Soluble in Water



- **Could Decrease CO_2 MHFP Below 50 psia**
  - Increase Separation from 60-70% (1000 psia; Shifted SynGas), to Over 90%, if Desired
  - Two-Stage CO_2 Hydrate Separation Process may be required

Process Performance and Economics

ENGINEERING ANALYSIS BASIS

- **On-Stream Factor: 80%**
  Coal Cost: $ 29/short ton (Illinois #6)
  Steel Prices: Updated (2005)
  Electric Drives Assumed for All Rotating Equipment
  Capital Cost: 15%/year
  Labor Cost Estimates Consistent w/EPRI Studies

- **Major Equipment Costs Estimated from ASPEN "Icarus"**

- **Installation Factor: 2.5 average**
  (1.7 large compressors; 3.4 vessels, pumps, exchangers)

- **Contingencies: 20% Process; 40% Hydrate Reactors**

SIMTECHE

(once-thru, no promoter additives)

- 68% CO_2 Capture (assumes H_2S in gas stream)
- One Hydrate Formation Reactor Stage
- Ammonia Refrigeration at 22 deg F
- CO_2 Recovery Flashes
  - High Pressure – 625 psia
  - Low Pressure – 285 psia
- CO_2 Drying and Compression to 2200 psig

SIMTECHE
(w/promoter additive)

- 90% CO_2 Removal
- Two Separate Hydrate Formation, CO_2 Flash and Chilled Water Recycle Stages
- Ammonia Refrigeration at 22 deg F
- CO_2 Recovery Flashes
  - High Pressure – 625 psia (both Stages)
  - Low Pressure – 285 psia (1st Stage)
  - Low Pressure – 108 psia (Promoter Stage)
- CO_2 Drying and Compression to 2200 psig

INITIAL ANALYSIS: 3 CASES

Carbon Control Cost	No Capture	Selexol UOP Projections	SIMTECHE	
			Base Case (once-thru)	Hydrate Promoter
CO_2 Separation Ratio	0%	90%	68%	90%
Total Installed Cost ($MM)	581	750	737	768
Net Plant Power (MWe)	424	391	412	398
Gross Capture Cost ($/ton CO_2)	-	19.5	18	18
Shift Cost ($/ton CO_2 captured)	-	6	8	6
Capture Cost ($/ton captured)	-	13	10	12
Net Cost ($/ton CO_2 avoided)	-	23	25	24

Performance: New Promoter Cases

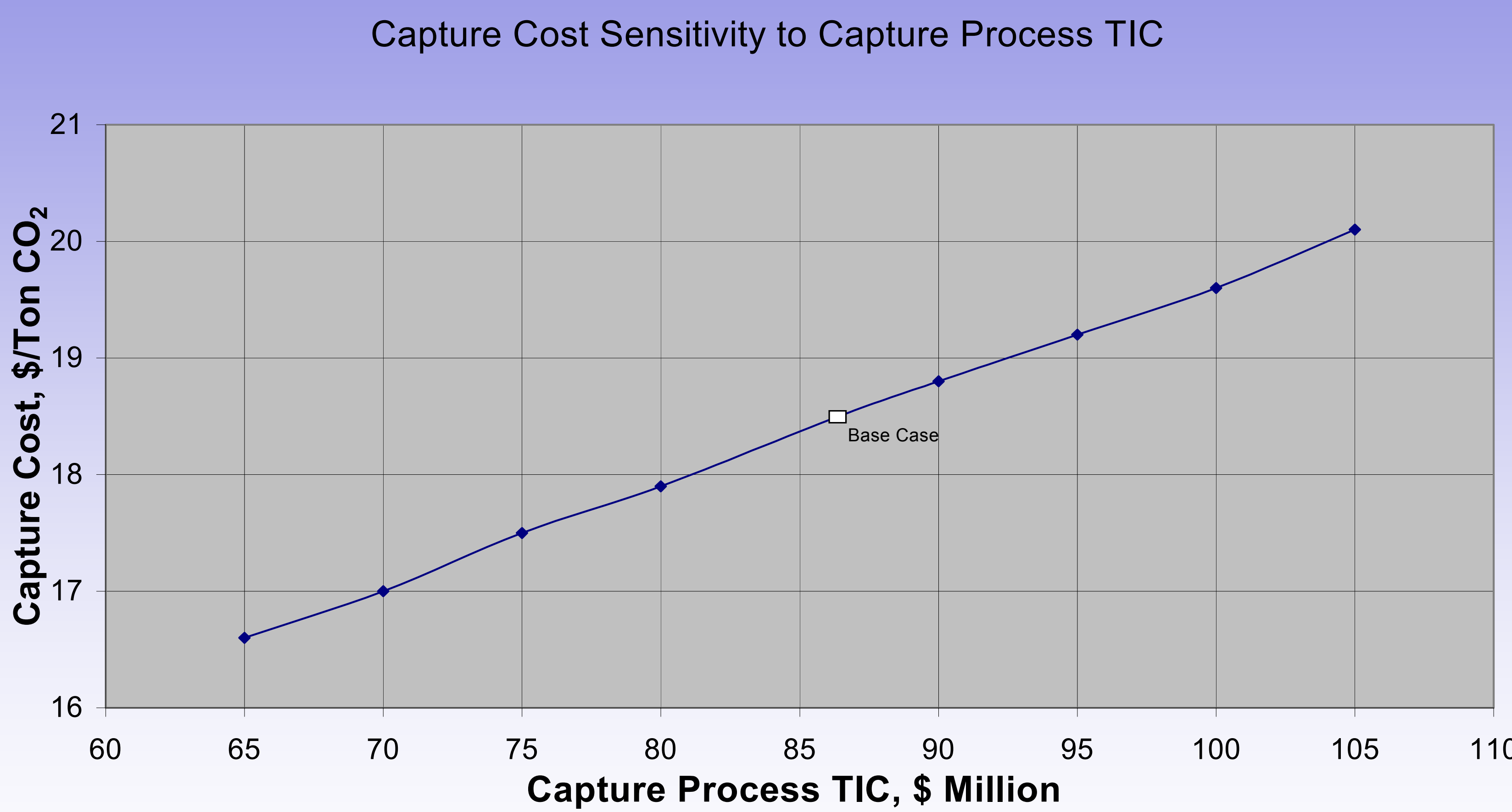
	Simteche Base-Case	Low-Temp Organic Promoter	High-Temp Organic Promoter
Process Conditions	1 C, sI 68% removal	1-10 C, sII 90% removal	30 C, salt 90% removal
Gross Power Output, (Mwe)	497	497	497
Net Power Output, (MWe)	412	400	425
Net Efficiency, % (HHV)	38.0	36.7	38.9
Total Installed Cost ($MM)	58.1	86.4	56.8

Capture Cost Comparison

	Simteche Base-Case	Low-Temp Organic Promoter	High-Temp Organic Promoter
Process Conditions	1 C, sI 68% removal	1-10 C, sII 90% removal	30 C, salt 90% removal
Increased Cost of Electricity, cents per kWhr (%)	1.2 (24%)	1.6 (32%)	1.0 (21%)
Capture Cost, \$/Ton CO_2(Including Shift)	18	18	12.5
Cost of Shift, \$/Ton CO_2	8	6	5.8
Net Capture Cost, \$/Ton CO_2	10	12	6.7

Capture Cost Sensitivity

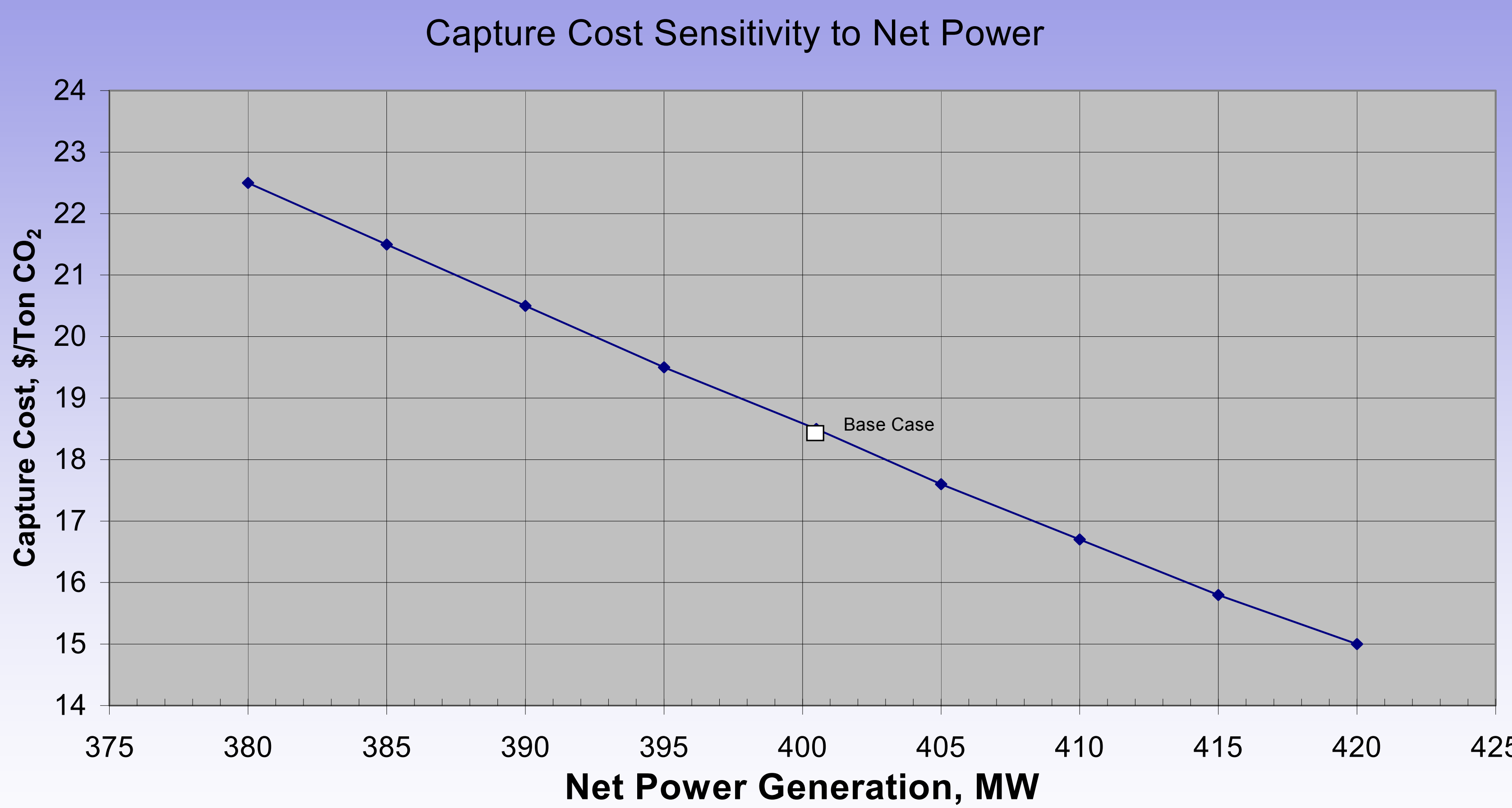
(Low Temp Promoter Case)



A 10% change in installation factor gives a $1/ton change in avoided cost

Capture Cost Sensitivity

(Low Temp Promoter Case)



A 5% increase in net power gives a 20% reduction in avoided cost

Path Forward – Engineering Analysis

- Replace Ammonia Vapor Compression Refrigeration with Ammonia Absorption
- 90 % CO_2 Capture with One Stage vs. Two Stage Hydrate Reactors
- Supercritical CO_2 Recovery (pump slurry to supercritical flash reactor)
- Higher Pressure Hydrate Formation Reactors
- Recycle Loop of Hydrate Slurry to Provide Better Control of Reactor Heat Removal
- Alternate Reaction Heat Removal/Supply Scheme:
  - Replacement of Ammonia Refrigeration with Cooling Water/Steam Systems

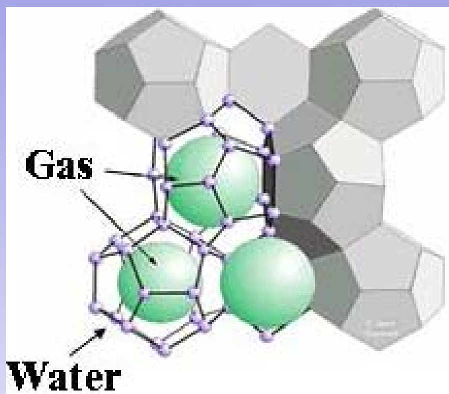
Conclusions

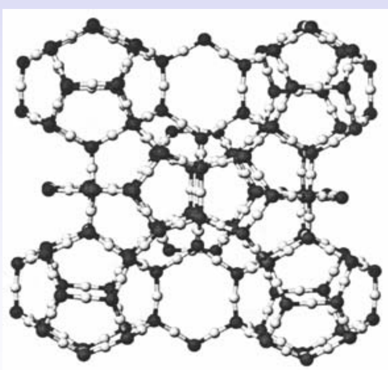
- **SIMTECHE 68% and 90% CO_2 Capture:**
  - **Net Capture Costs of $10-13 per Ton CO_2**
  - **Advanced Promoters May Reduce Avoided Costs by $3-11 per ton of CO_2**
  - **Approaching DOE FutureGen Goals for CO_2 Capture**
  - **Initial Comparative Studies Indicate Process is *at Least* Competitive with Existing Alternatives (i.e. UOP's projections for Selexol)**
  - **Refinements Underway (engineering, new promoter development)**

CO_2 Capture by Formation of Hydrates: Economical Analysis and New Promoter Process

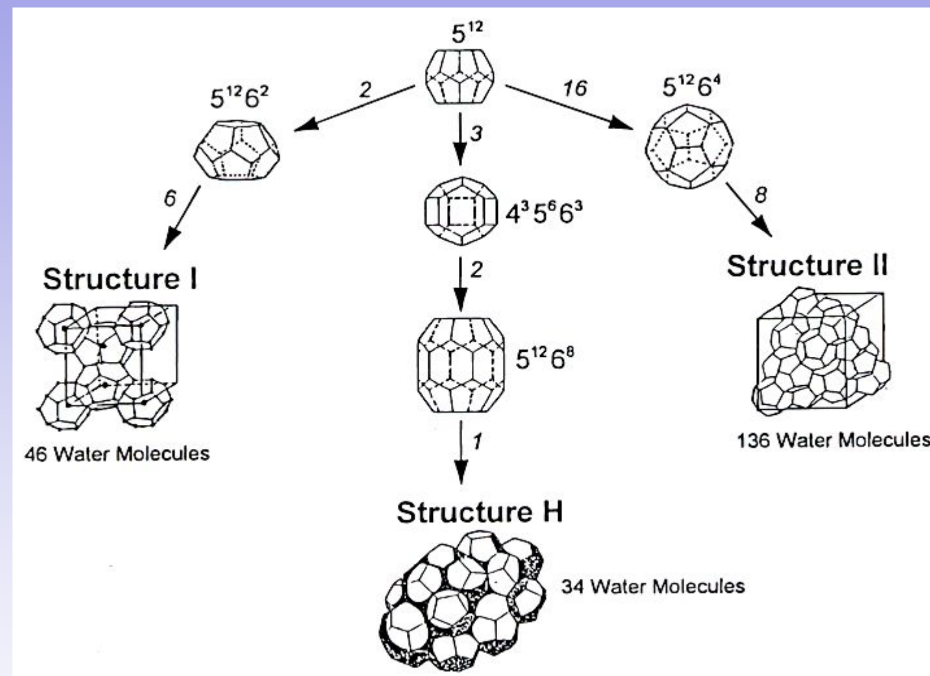
SUPPLEMENTAL

CO_2 Hydrate Separation





Source: V. Blackwell



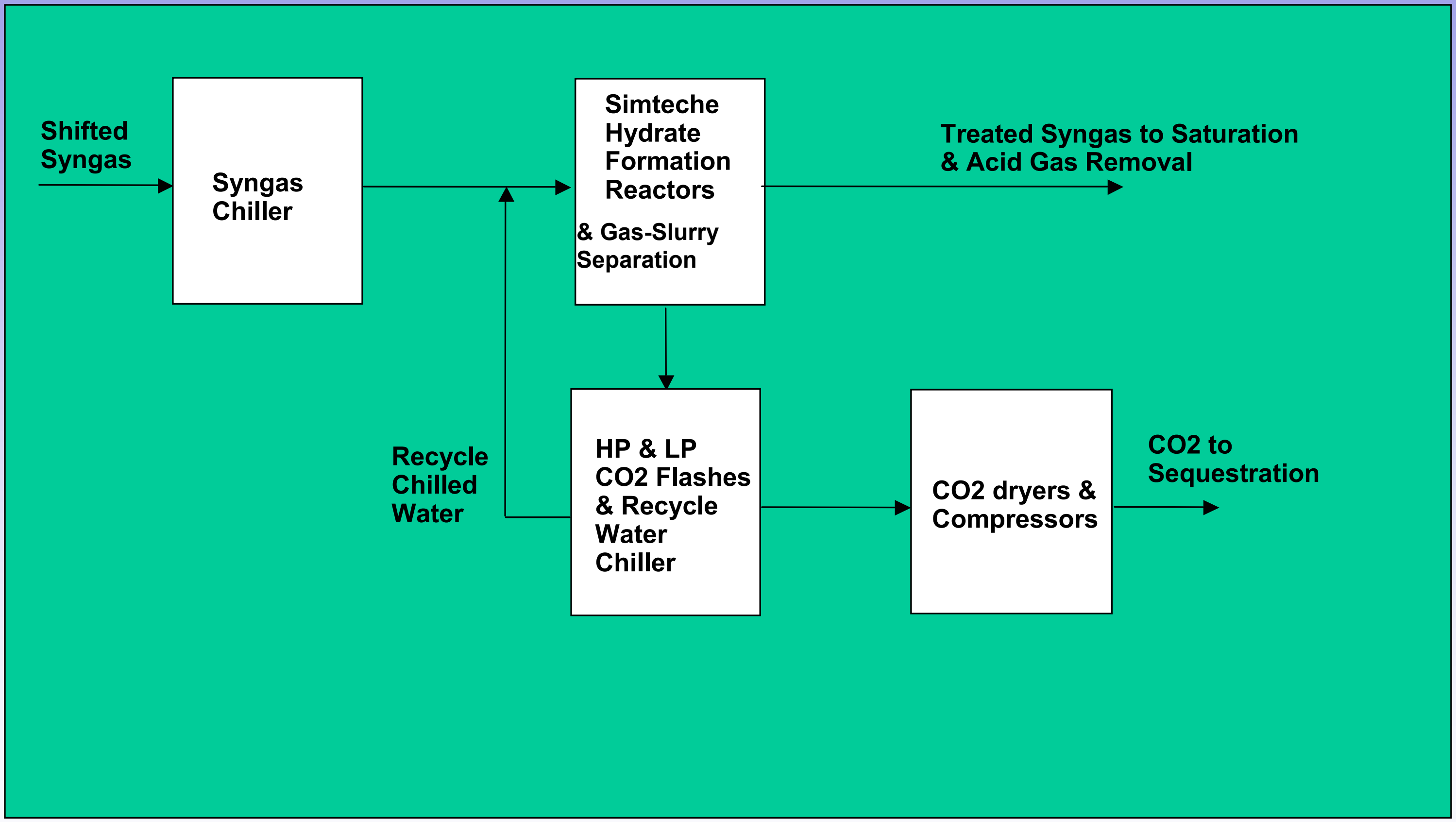
Source: E.D. Sloan

BASIS OF SEPARATION

H_2 Does Not Stabilize the Water Cages under Processing Conditions

Block Flow Diagram

(Once-Thru, 68% Removal)



SIMTECHE Promoter Case
Block Flow Diagram