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Power Generation with Reduced CO_2 Emissions via the Sorption Enhanced Water Gas Shift Process

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CO_2 Capture Program (CCP)

Joint project comprising leading energy companies

- BP
- Chevron Texaco
- ENI
- NorskHydro
- PanCanadian
- Shell
- Statoil
- Suncor

With co-funding from the US DOE, European Union, and Klimatek

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CO_2 Capture Program (CCP)

Scenario

1. **Large Combined Cycle Power Projects**
   - **"Norcap" 350 MW CCGT on Norwegian Cost**
   - **EOR Disposal in Gullfaks Field**

2. **Small Distributed Direct Drive Turbines**
   - **Alaskan Compressor Drives**
   - **EOR Disposal locally**

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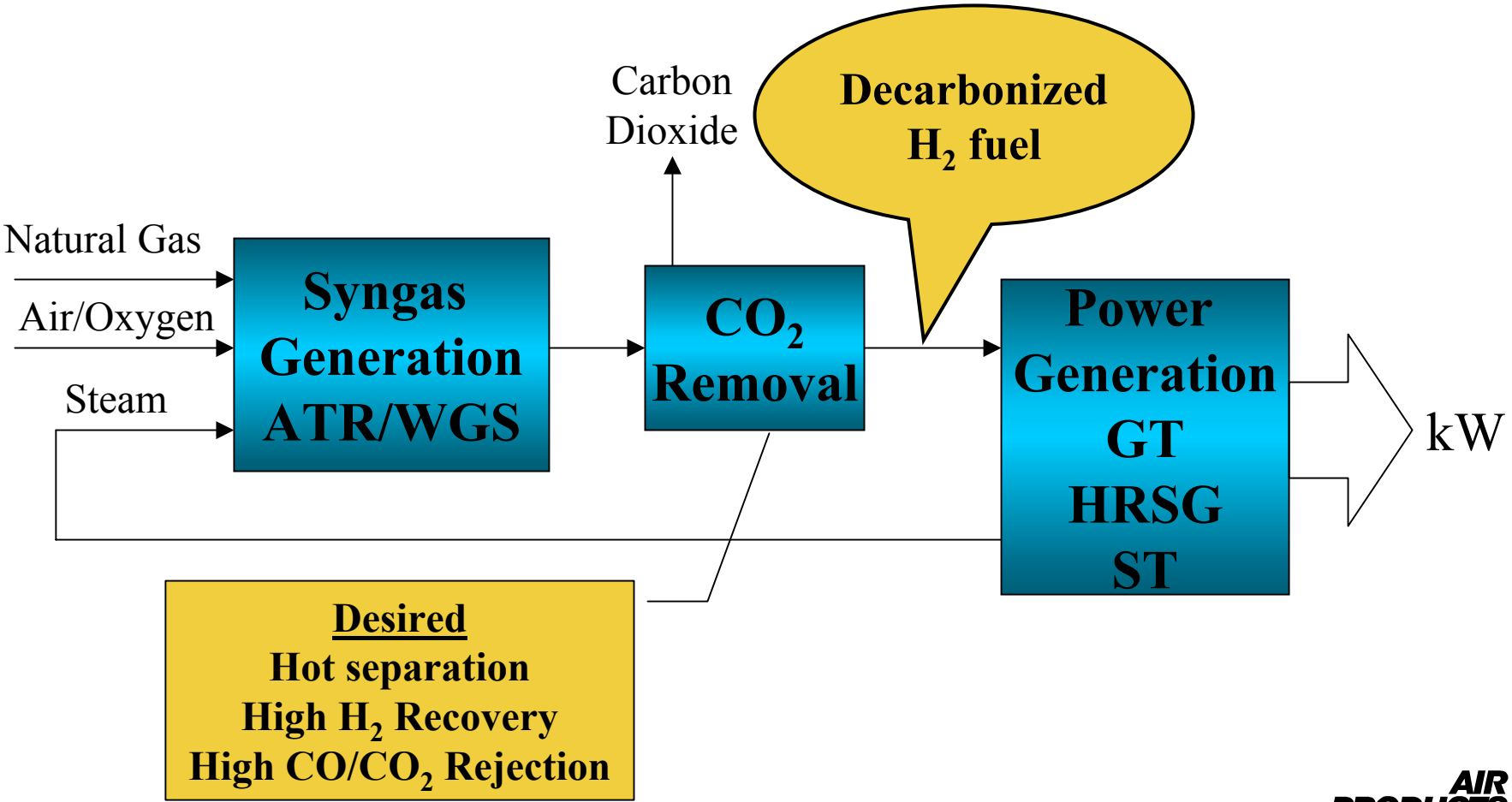
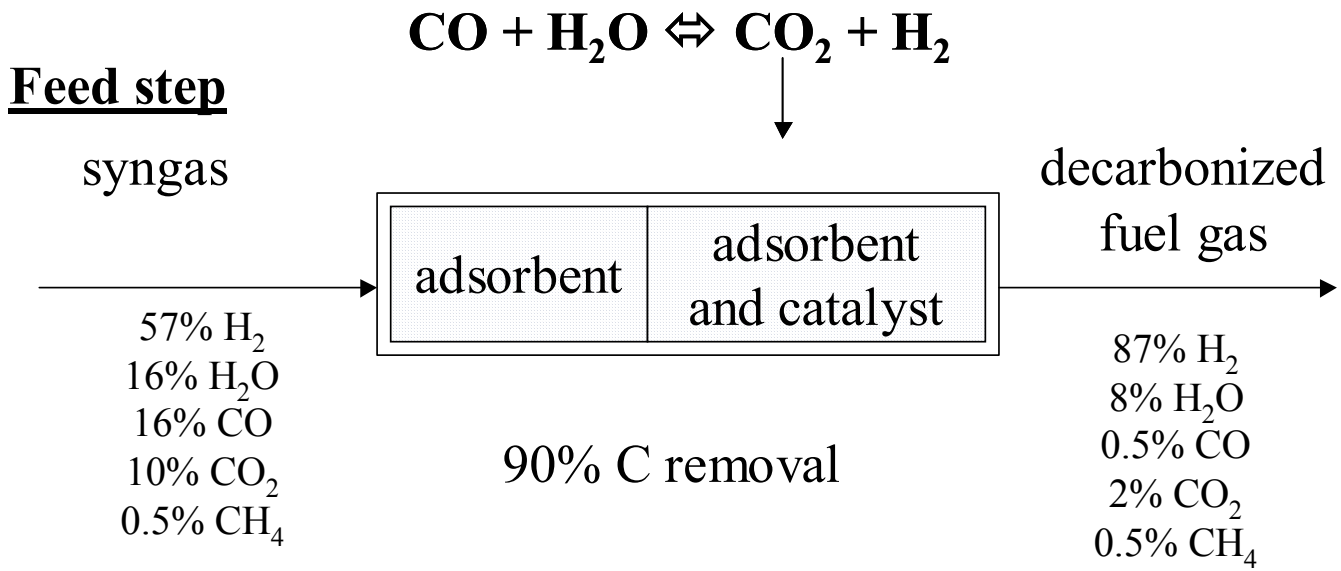
CO_2 Removal from Power Generation Processes

- **Pre-combustion Decarbonization**



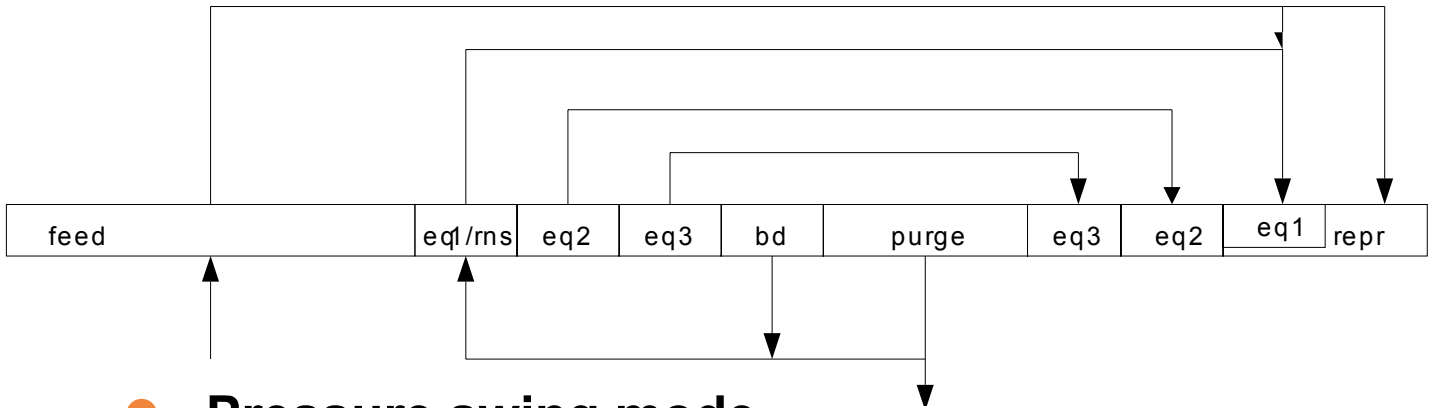
Sorption Enhanced Water Gas Shift Process (SEWGS)



- **Water gas shift catalyst + high temperature CO_2 adsorbent**
- **Removes CO_2 from hot syngas (400-500C), drives CO towards extinction**
- **Multiple beds undergo cyclic process steps (reaction/adsorption and regeneration)**

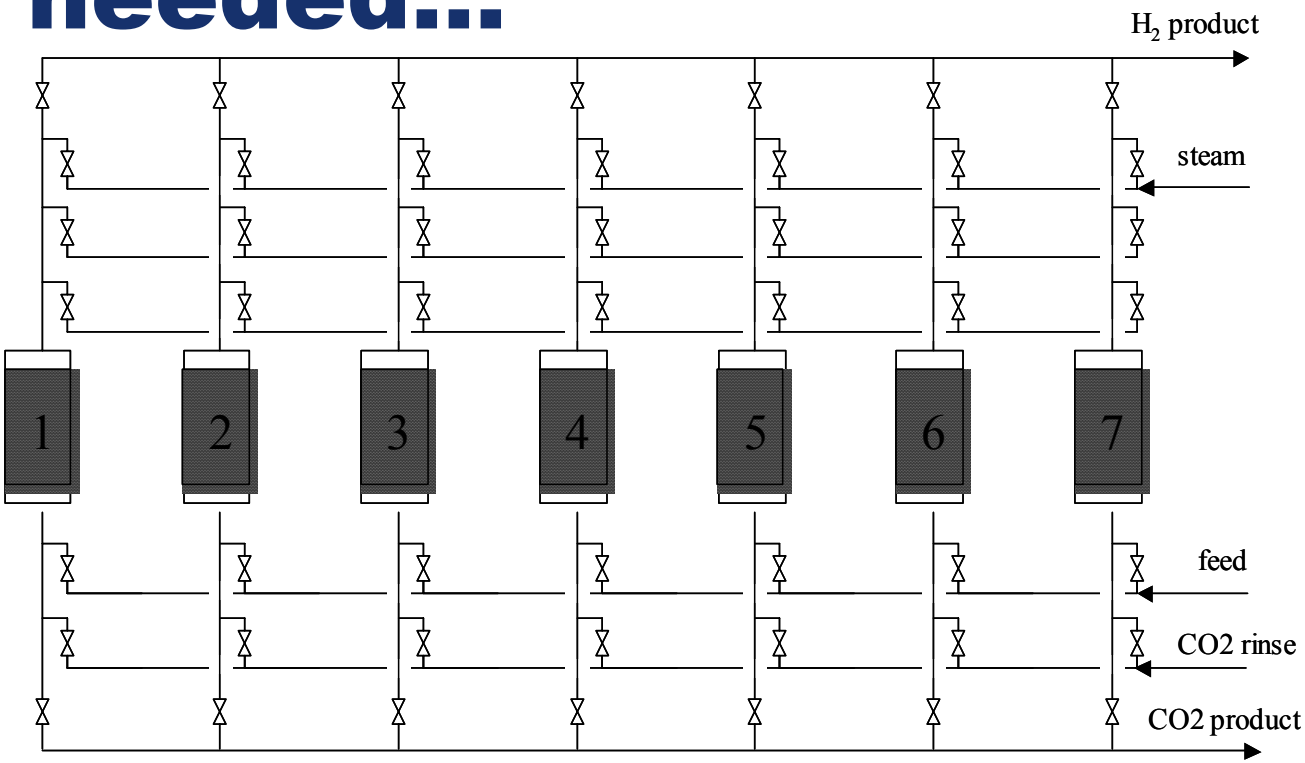
SEWGS Process Cycle

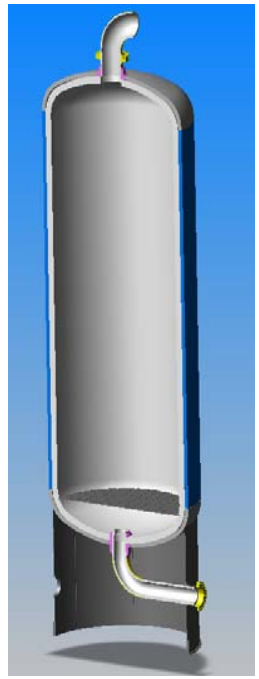
feed				eq1/rns	eq2	eq3	bd	purge		eq3	eq2	eq1	repr
eq1	repr	feed				eq1/rns	eq2	eq3	bd	purge		eq3	eq2
eq3	eq2	eq1	repr	feed				eq1/rns	eq2	eq3	bd	purge	
purge		eq3	eq2	eq1	repr	feed				eq1/rns	eq2	eq3	bd
eq3	bd	purge		eq3	eq2	eq1	repr	feed				eq1/rns	eq2
eq1/rns	eq2	eq3	bd	purge		eq3	eq2	eq1	repr	feed			
		eq1/rns	eq2	eq3	bd	purge		eq3	eq2	eq1	repr	feed	



- **Pressure swing mode**
- **Feed/CO_2 Rinse/Pressure Equalization/Blowdown/Purge/Repressurization/…**
- **Purged with low pressure steam**

Multiple Sorber/Reactors are needed…



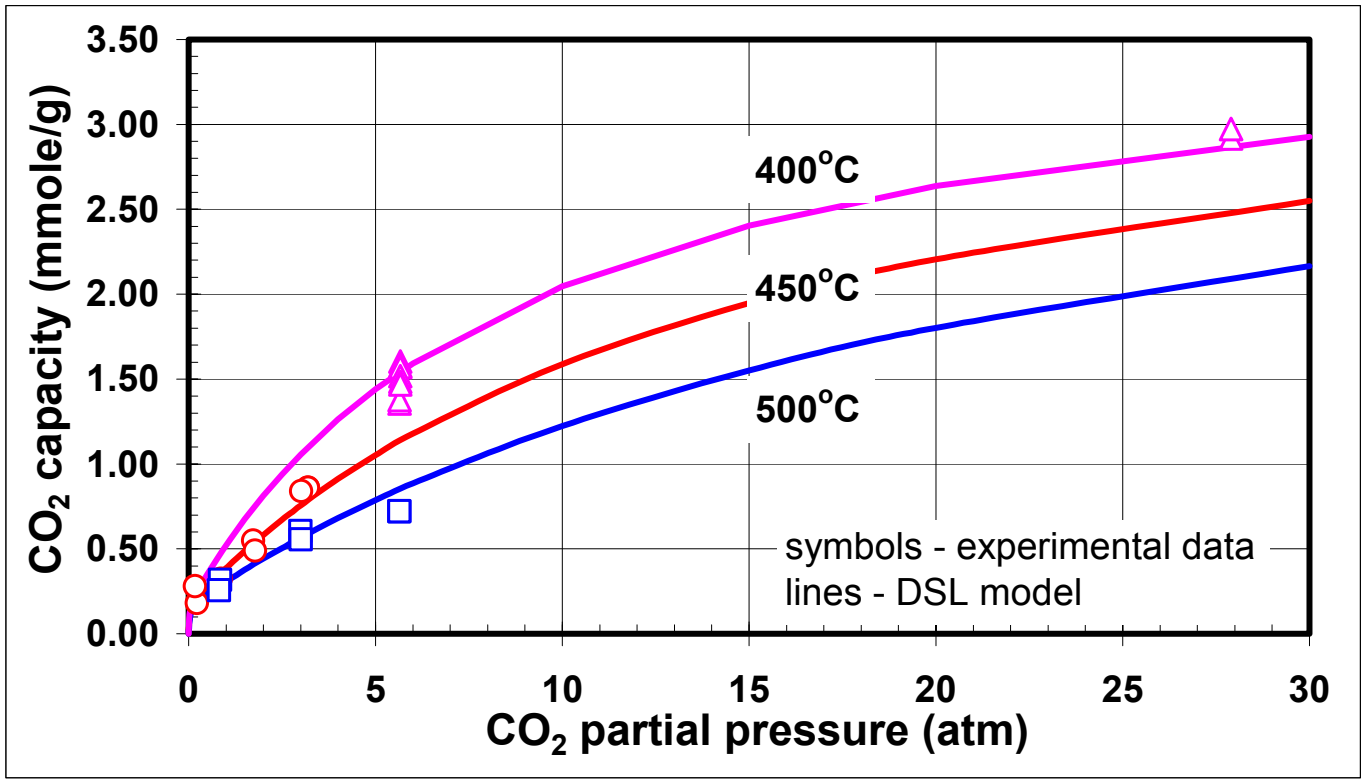


- 7 beds/train
- 7 switch valves / bed
- Surge tank needed for CO_2 product

CO_2 Adsorbent is key….

K_2CO_3 Promoted Hydrotalcite

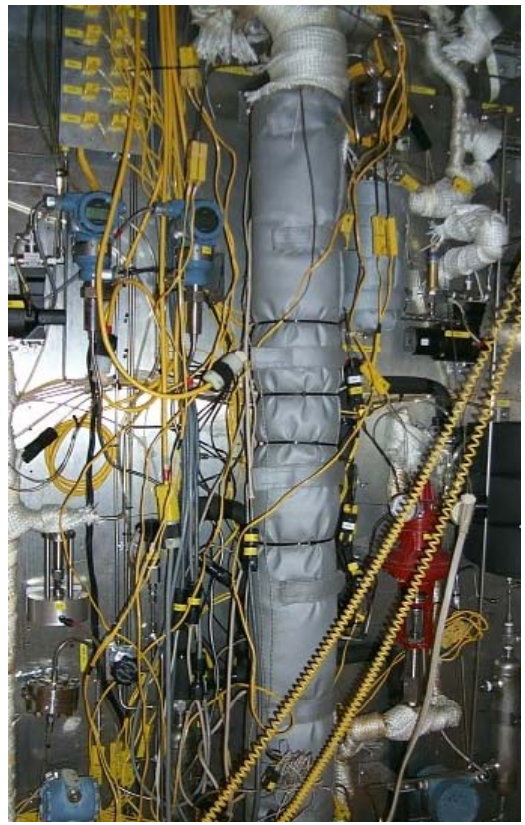
$$Mg_6Al_2(OH)_{16}[CO_3]*4H_2O$$



Process Test Unit

Demonstrate concept and generate process design information

- 450 psig / 500C
- Single steps (breakthrough or regeneration) or cyclic operation
- Feed $CO_2/N_2/H_2O$, $CO/CO_2/H_2/H_2O$
- Purge N_2/H_2O
- Automated operation



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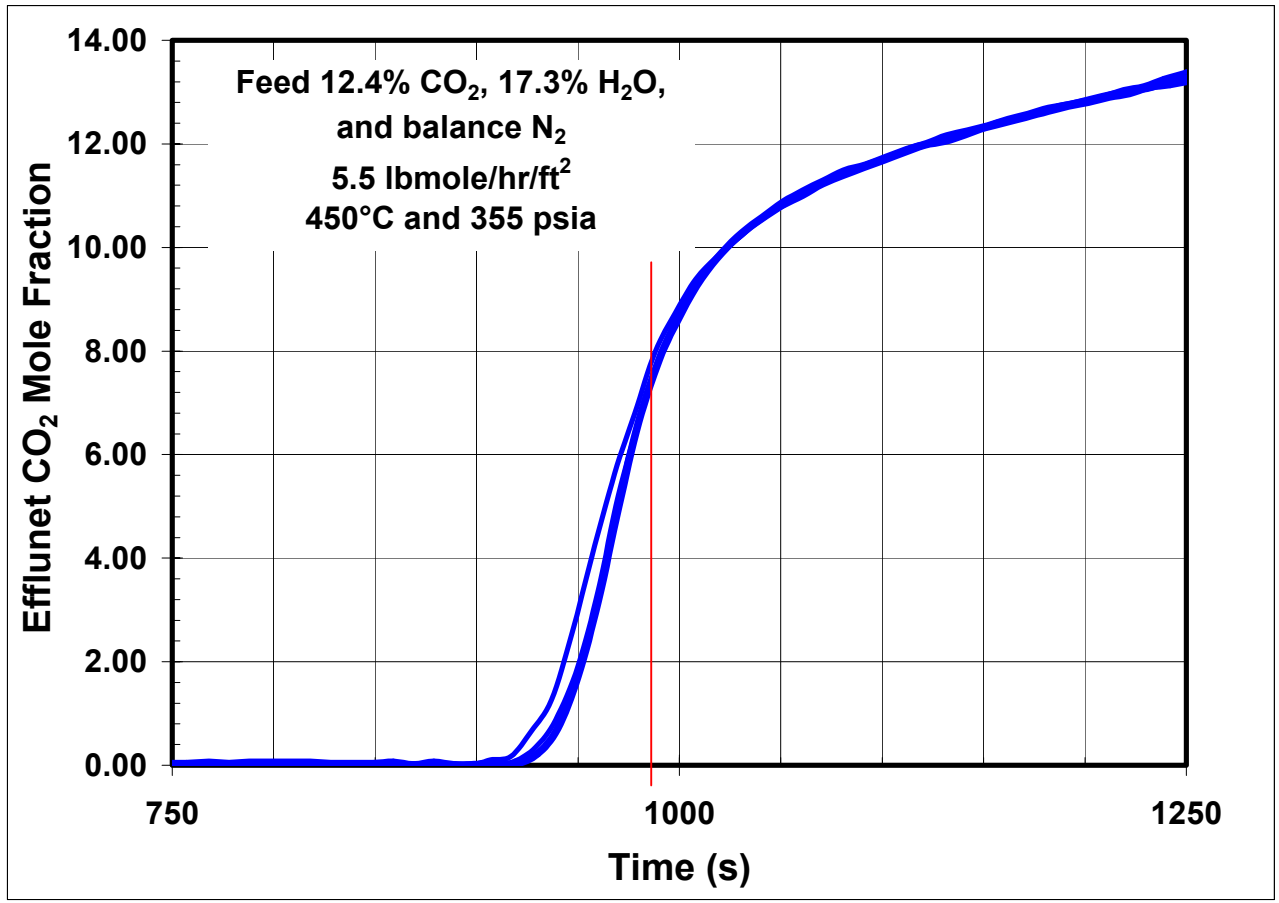
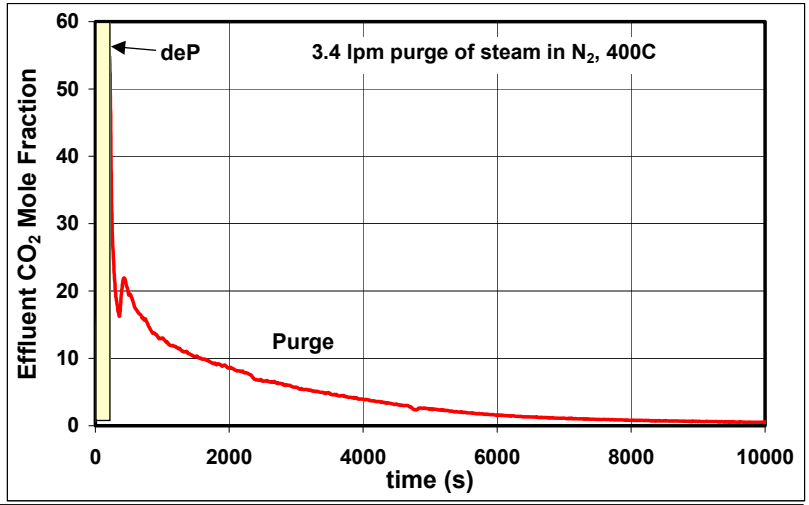
$CO_2/N_2/H_2O$ Breakthrough Experiments

- Breakthrough time defines adsorption capacity
- Mass transfer zone characterizes mass transfer rates

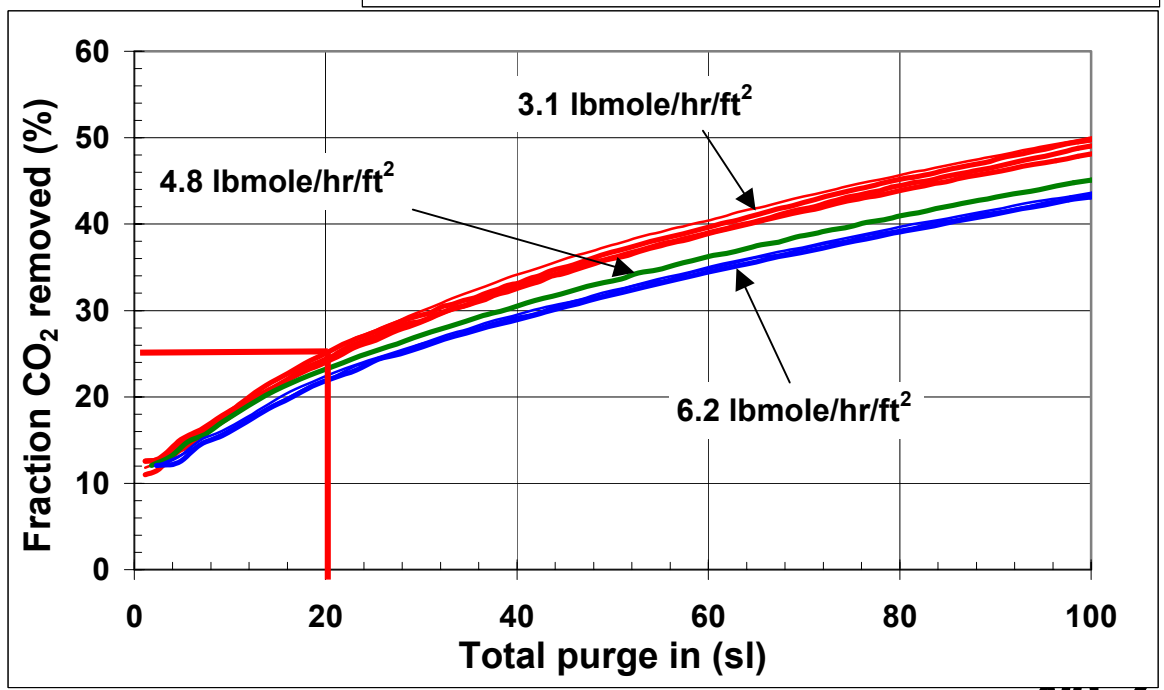


$CO_2/N_2/H_2O$ Regeneration Experiments

Efficient regeneration is <u>critical</u>



- Depressurization and steam/N_2 purge
- CO_2 effluent composition and flow yield plots of fraction of CO_2 removed



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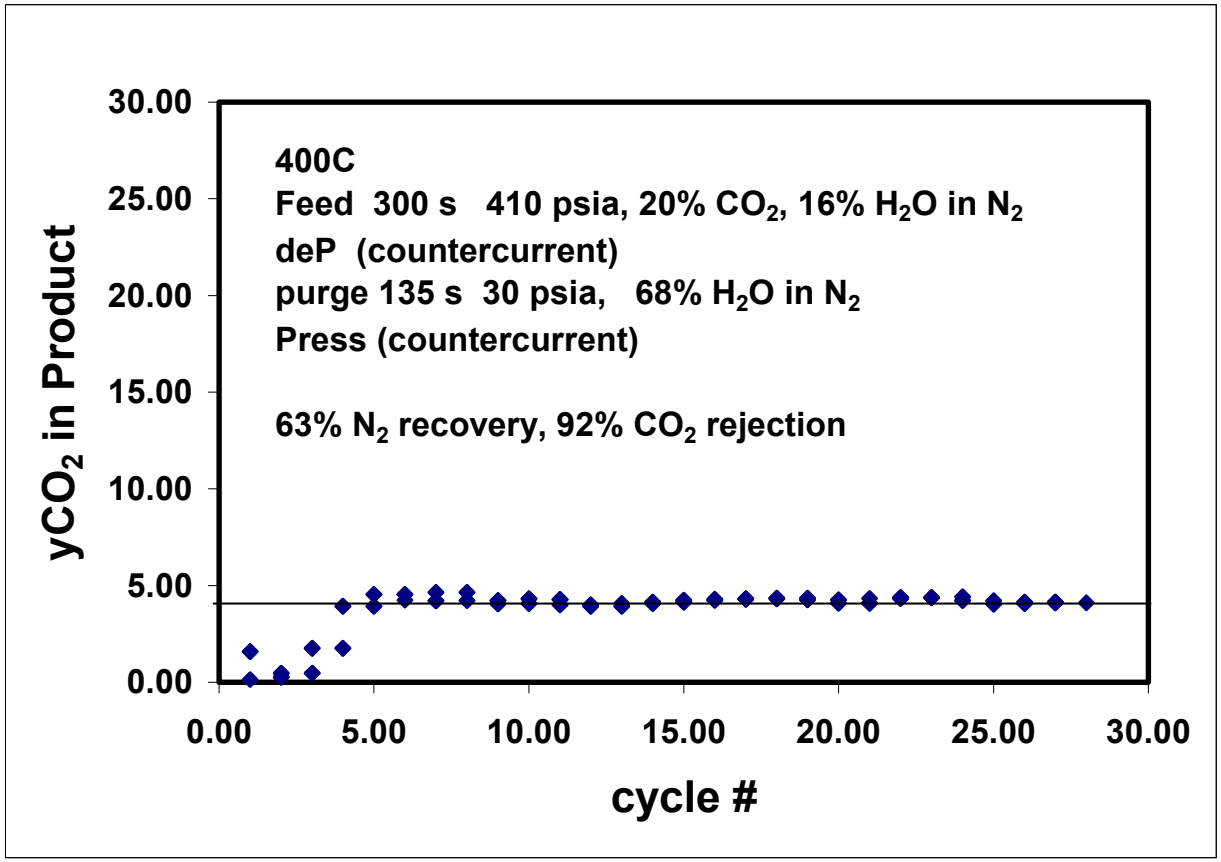
$CO_2/N_2/H_2O$ Cyclic Experiments

Cyclic steady state achieved – adsorbent can effectively remove CO_2 from feed gas at 400-500C



Effective CO_2 working capacity ~ 0.4 mmole/g

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SEWGS Reaction Experiments

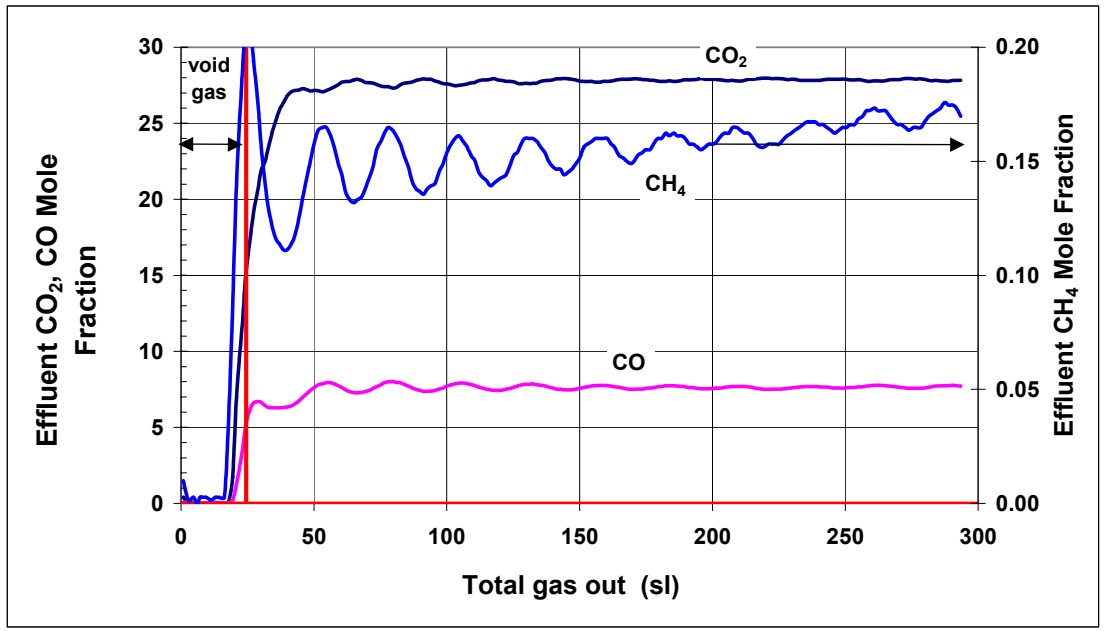
- **Catalyst/ceramic balls as baseline**

UCI C12-4-02, 6x6mm tablets, 5:1 ceramic balls:catalyst

9.3% CO, 17.4% CO_2, 57.5% H_2, 15.8% H_2O, 1720 1/hr, 400C, 400 psia

Expect 7.8% (dry) CO (equilibrium), observe 8.1%CO along with <0.2% methane

CO, CO_2 break through once void gas is pushed out – no CO_2 capacity or SER-effect for catalyst-only



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SEWGS Reaction Experiments

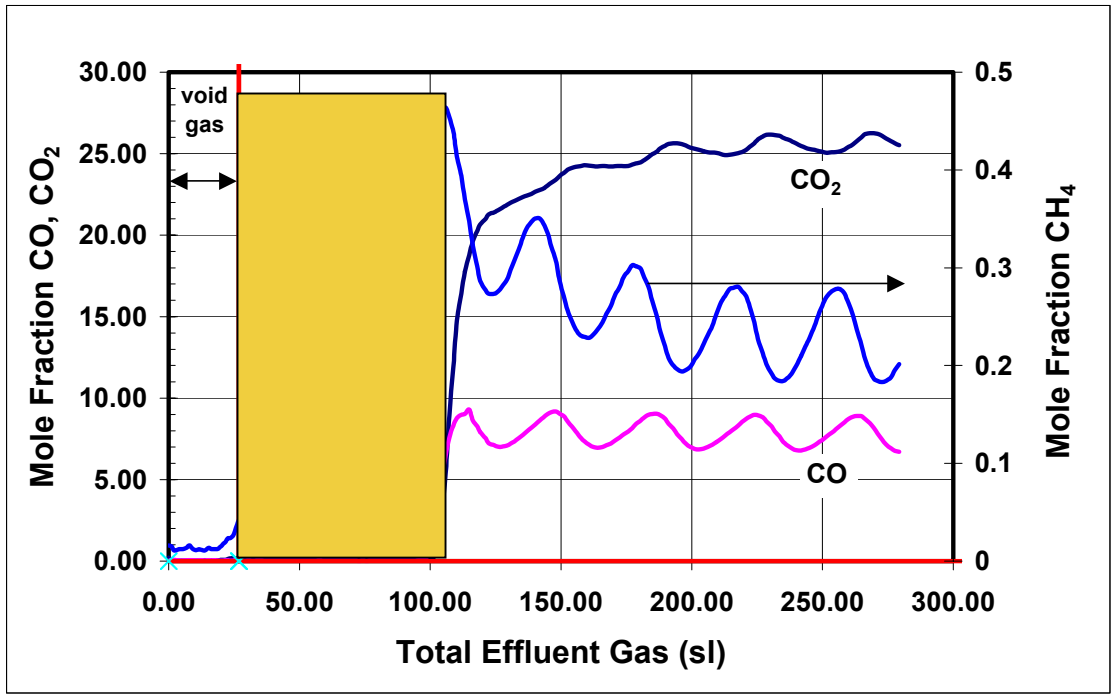
- **Catalyst/HTC adsorbent**

5:1 HTC:catalyst, same adsorbent sample used from previous runs

Same feed composition/rate as catalyst-only, 400C, 400 psia

CO, CO_2 retained by adsorbent, yielding ~90 sl of decarbonized H_2 product

Basic SER-concept demonstrated for WGS reaction



Power Generation Simulation

- ASPEN
- Air and O_2-based ATR systems
- Combined cycle GT/ST
  - GE 9FA Gas turbine performance simulated from literature data
  - 3 pressure steam turbine system
  - HRSG
- Highly heat integrated processes
  - Cooling curve optimization

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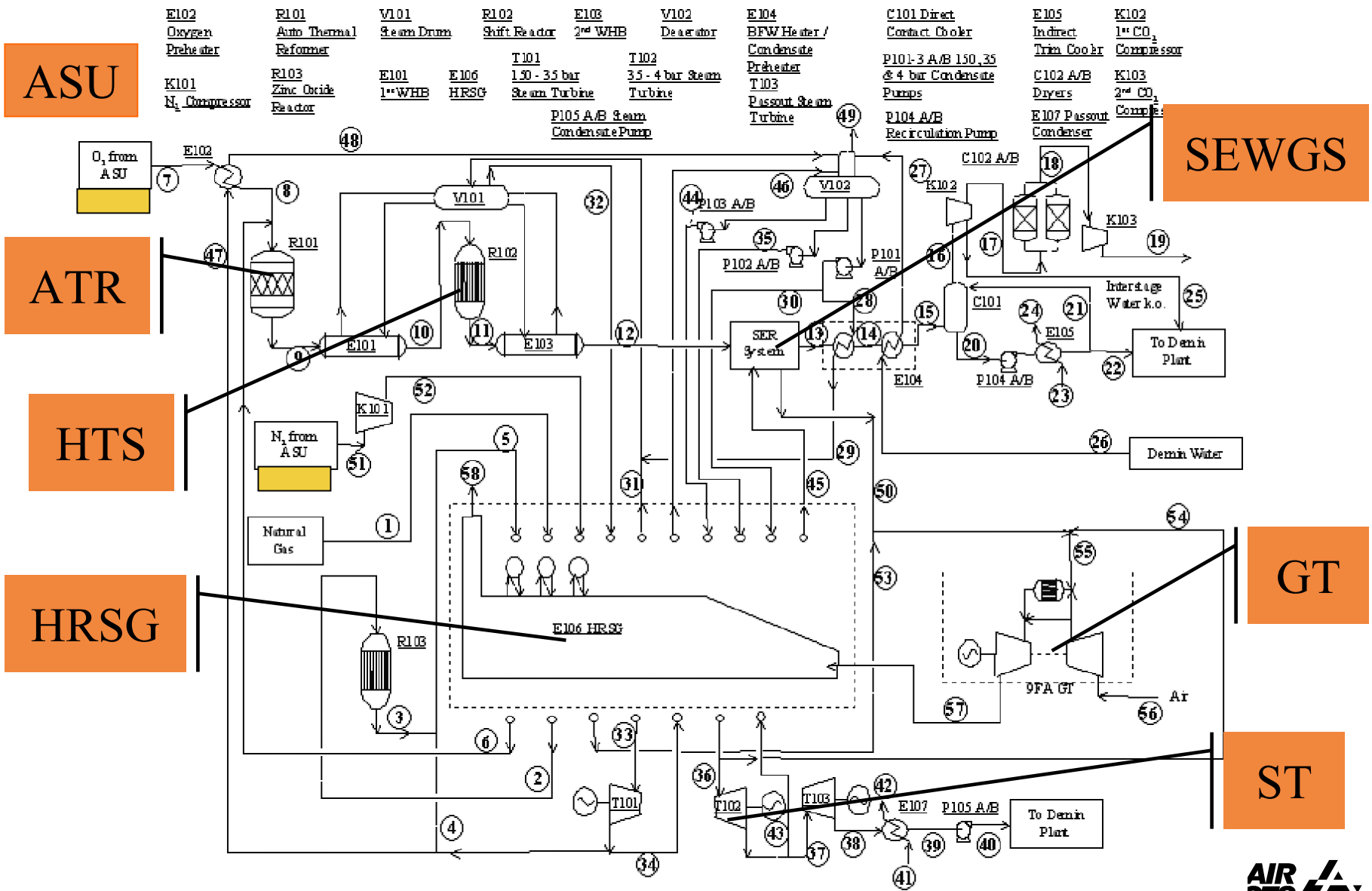
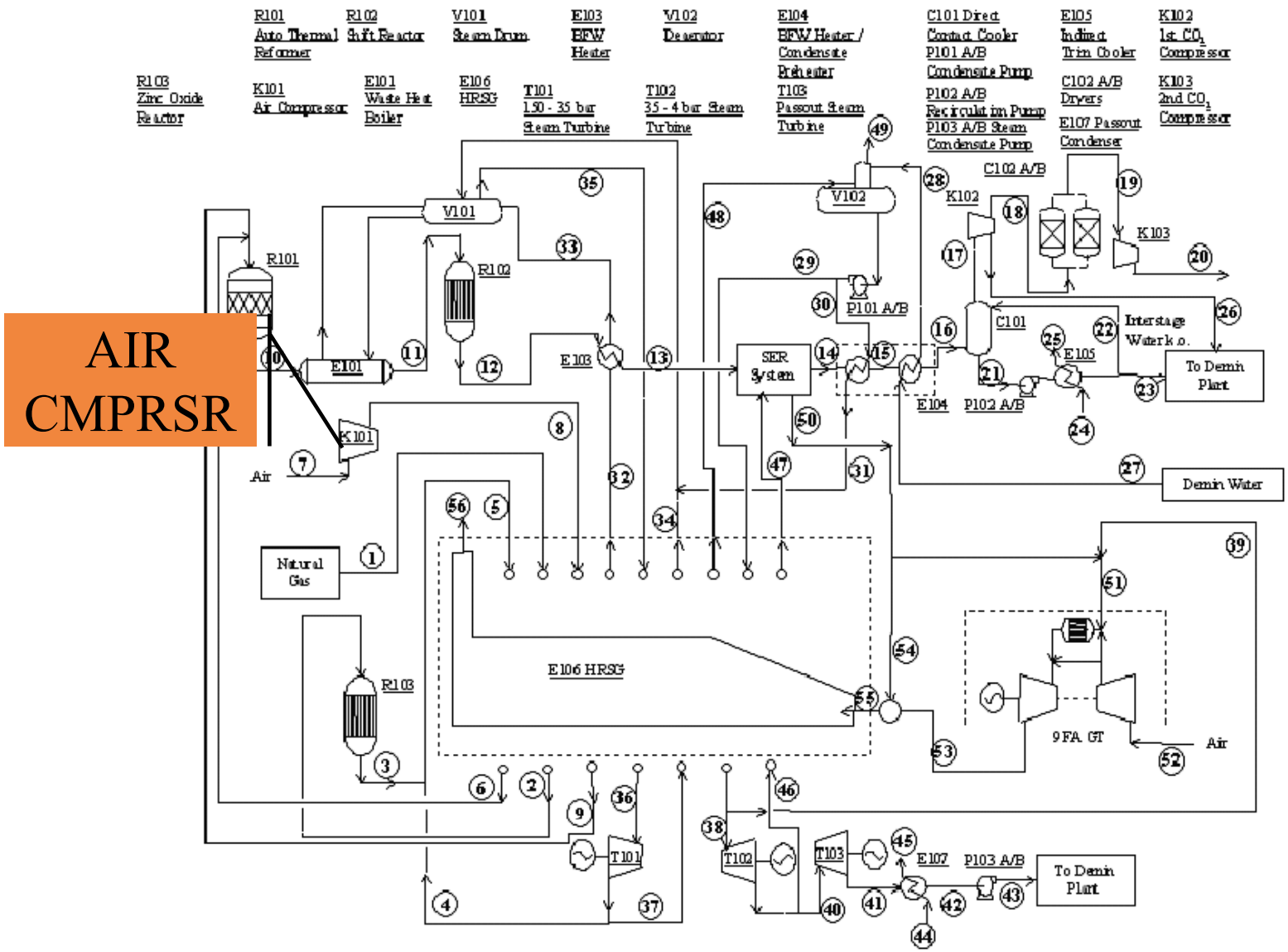
O_2-ATR / SEWGS Simulation



Air-ATR / SEWGS Simulation



Simulation Results

	O_2-ATR/ SEWGS	Air-ATR/ SEWGS
GT power, MW	290	290
ST power , MW	130	189
ASU/pump/ compressors , MW	(59)	(53)
Net export power , MW	361	425
Natural Gas, MW LHV	764	881
Efficiency, LHV	47.3	48.3
CO_2 Removed, MM tpy	1.28	1.47

Air-ATR SEWGS more energy efficient, but….

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Simulation Results

	O_2-ATR/ SEWGS	Air-ATR/ SEWGS
WHB, MW	96	171
HTS reactor, m^3	60	106
HRSG, MW	337	426
SEWGS adsorbent, MM lbs	2.4	3.8

Air-ATR SEWGS is also more capital intensive than O_2-ATR/SEWGS

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Process Economics

- SEWGS economics evaluated at APCI, generally based on H_2-PSA guidelines

- SEWGS-based power generation cost evaluated via CCP and found to be attractive compared to alternatives.

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Conclusions

- SEWGS approach looks promising for power generation with minimal CO_2 emissions.
- Hot CO_2 separation technique capable of yielding high H_2 recovery and high purity CO_2 stream for sequestration.
- Concept demonstrated, further characterization of process parameters at industrial scale needed.
- Application to coal-based power production to be considered.

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CCP

- Cliff Lowe
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DOE

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Thank you

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