Physical Solvent Development for Pre-Combustion Carbon Capture

CO_2 Capture Technology Review Meeting 2019

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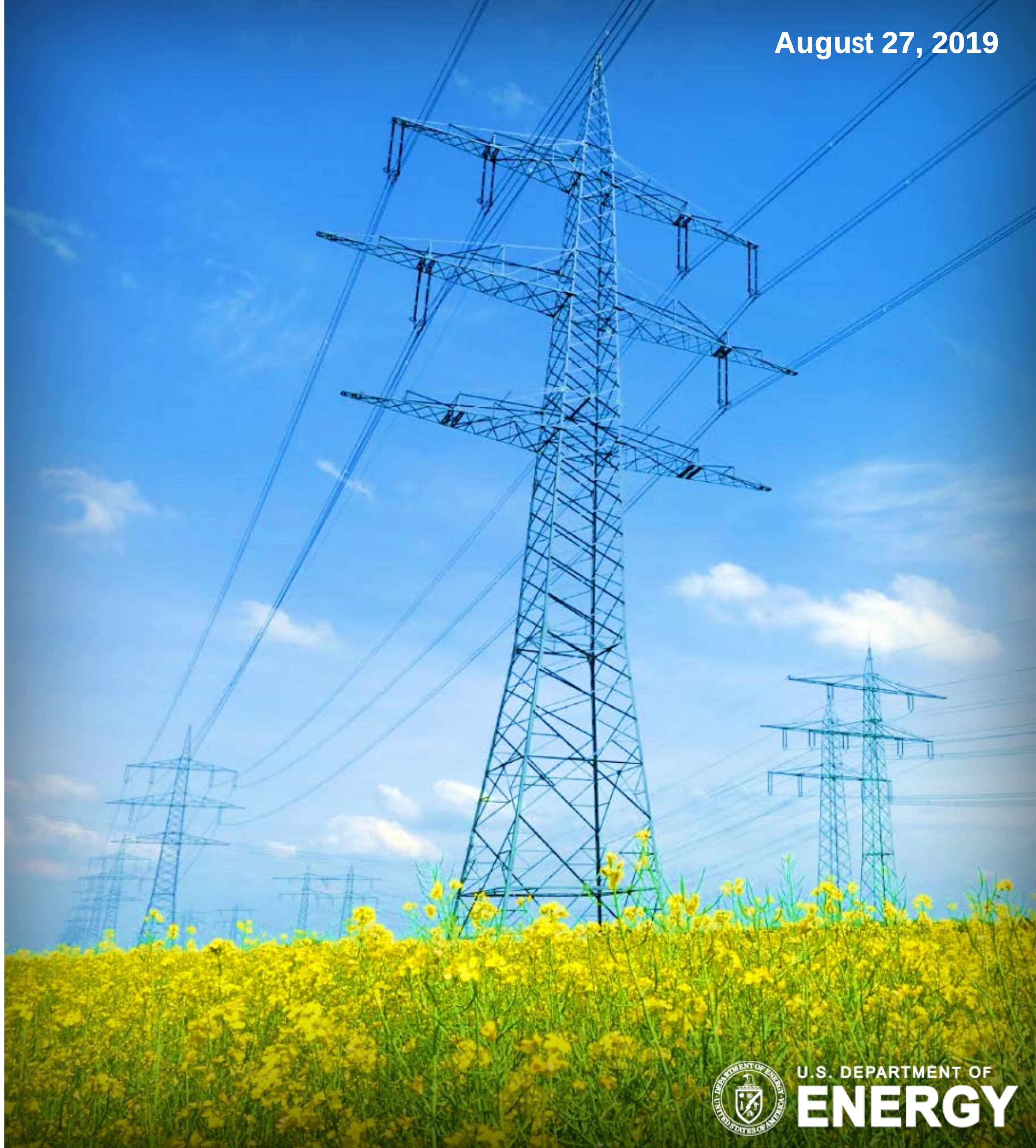


Transformation Carbon Capture FWP: Task 6

- **Task 6 – Experimental testing of novel solvents for pre-combustion using real syngas, $628K in EY19**
- **Partner: University of North Dakota's Energy & Environmental Research Center**
- **Synergistic Testing with TDA Research Inc.**
- **Focus of Presentation:**
  - Overview of Advanced Solvent Capture Applications
  - Experimental testing at UND EERC
  - Conclusions & Future Work

https://undeerc.org/research/demonstration/gasification.html

Applications for Physical Solvents for Gas Separation

<u>Tailored markets</u>

- Pre-combustion CO_2 Capture at IGCC-CCS
- Adjust CO/H_2 ratio for Coal & Biomass to Liquids
- Generation of H_2 from Reformed Natural Gas
- Remove CO_2 from syngas to produce Ammonia

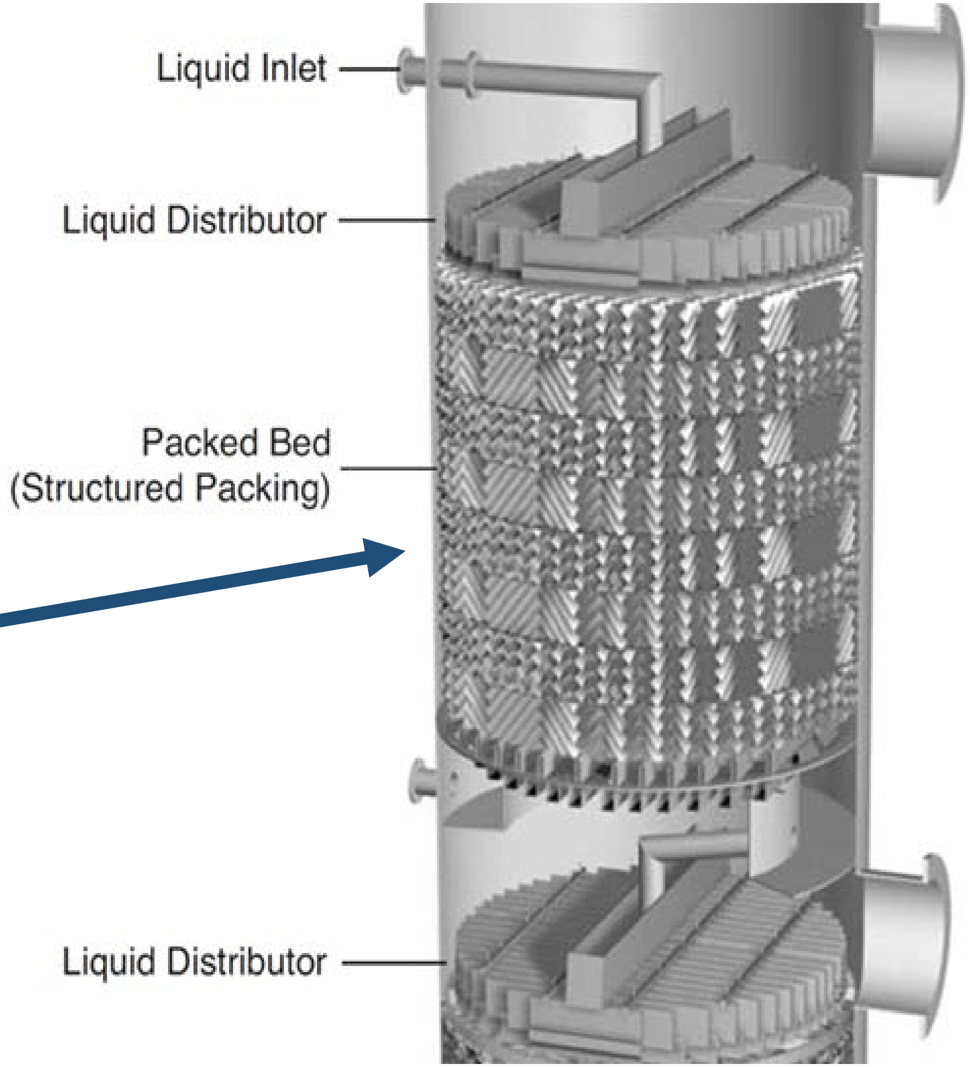
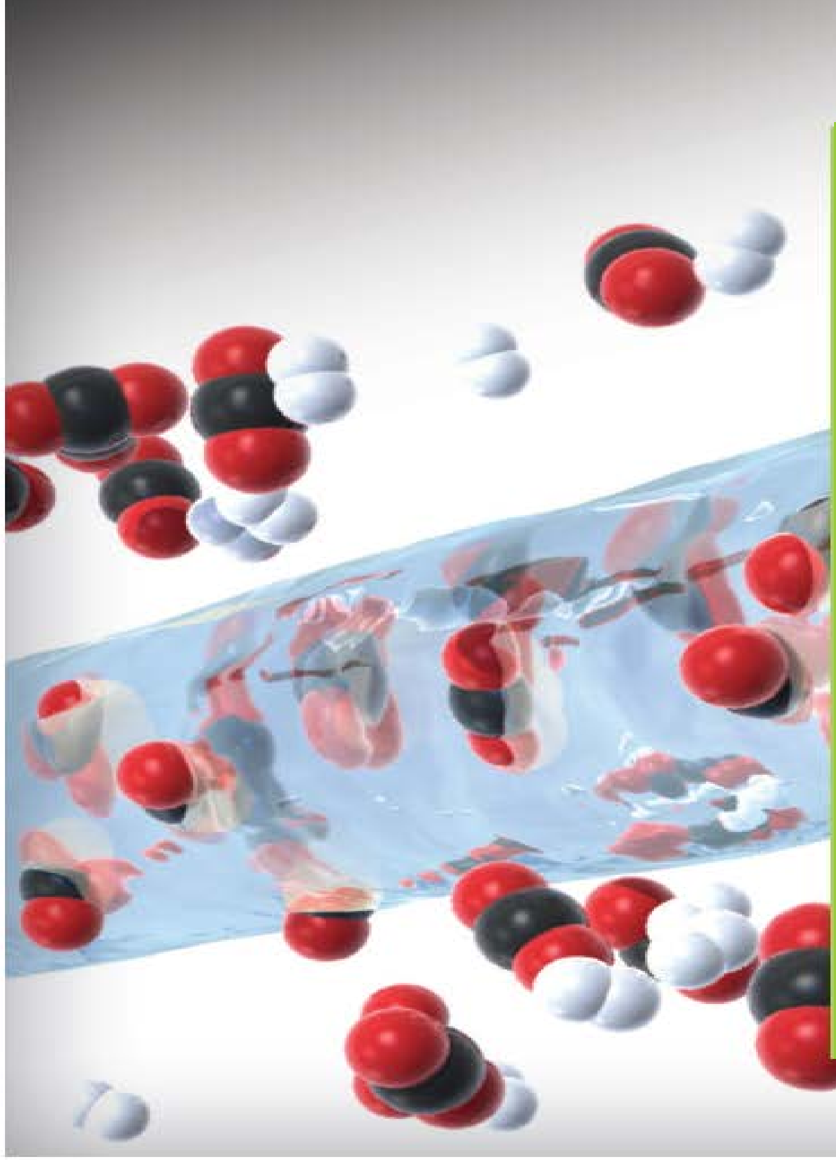


Image from: https://dakotagas.com/sites/CMS/files/images/home-hero/DGC-aerial-homepage.jpg

PRE-COMBUSTION SOLVENTS FOR CARBON CAPTURE



Problem:

Commercially available physical solvents for CO_2 /H_2 separation operate at below room temperature. Hence, they incur a significant electrical cost to chill and can't efficiently be regenerated using waste heat.

These solvents are hydrophilic and have high vapor pressure.

Selexol® (UOP) operates at 10°C   Kemper County IGCC-CCS, MS

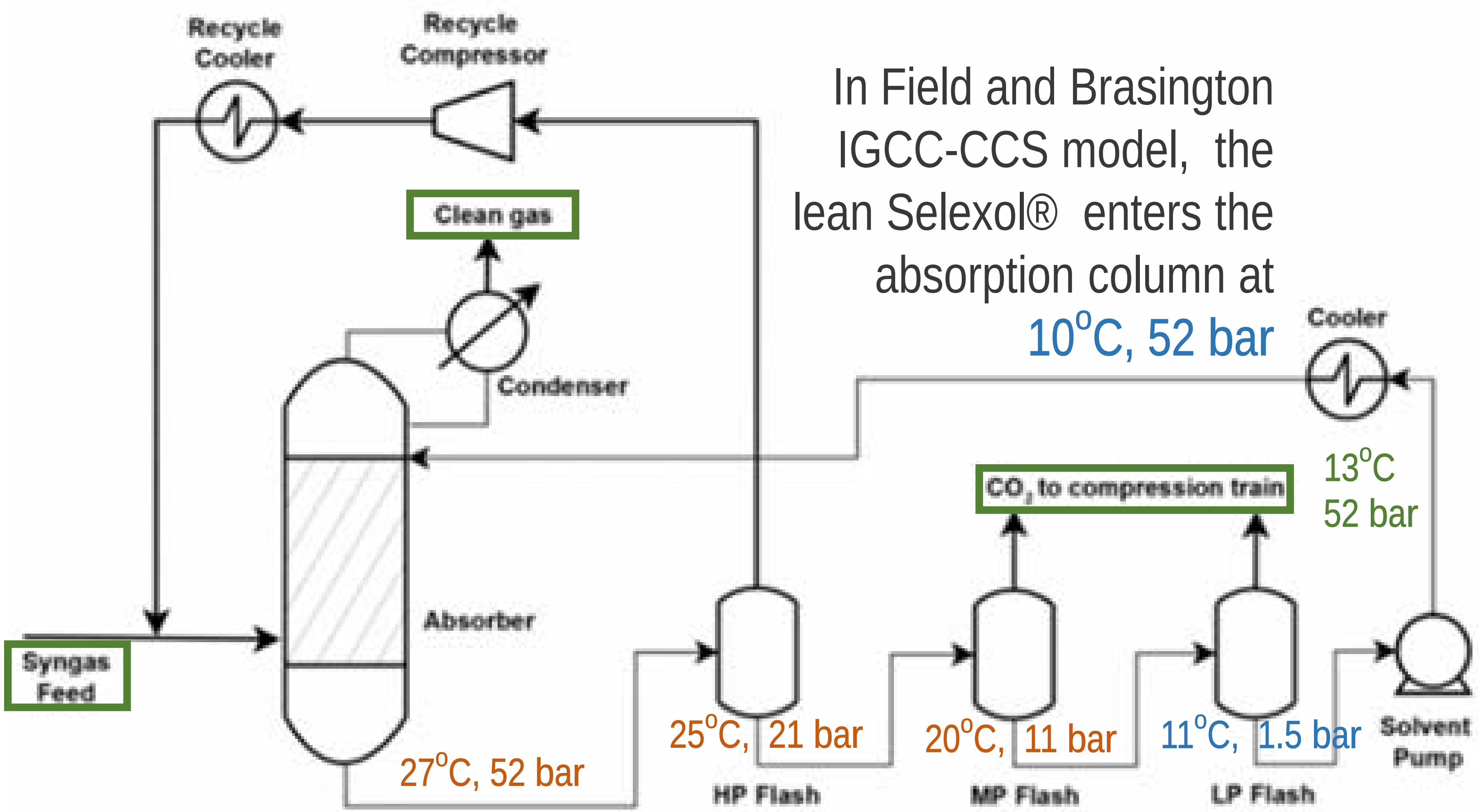
Rectisol® (Air Liquide) operates at -10°C   Great Plains Synfuels Plant, ND

Solution:

- Find new hydrophobic physical solvents that selectively absorb CO_2 at temperatures between 25°C and 100°C, and that can be regenerated using waste heat

Schematic of Baseline CO_2 Capture

In Field and Brasington IGCC-CCS model, the lean Selexol® enters the absorption column at 10°C, 52 bar



Problems with Traditional Approach

- Requires cooler to maintain inlet solvent temperature at 10°C
- The temperature of the solvent is highest where you want it to be lowest, and lowest where you want it high
- Electricity is the sole source of work rather than waste heat
- No pressure recovery (unlike in RO Desalination plants)

Schematic of Advanced CO_2 Capture

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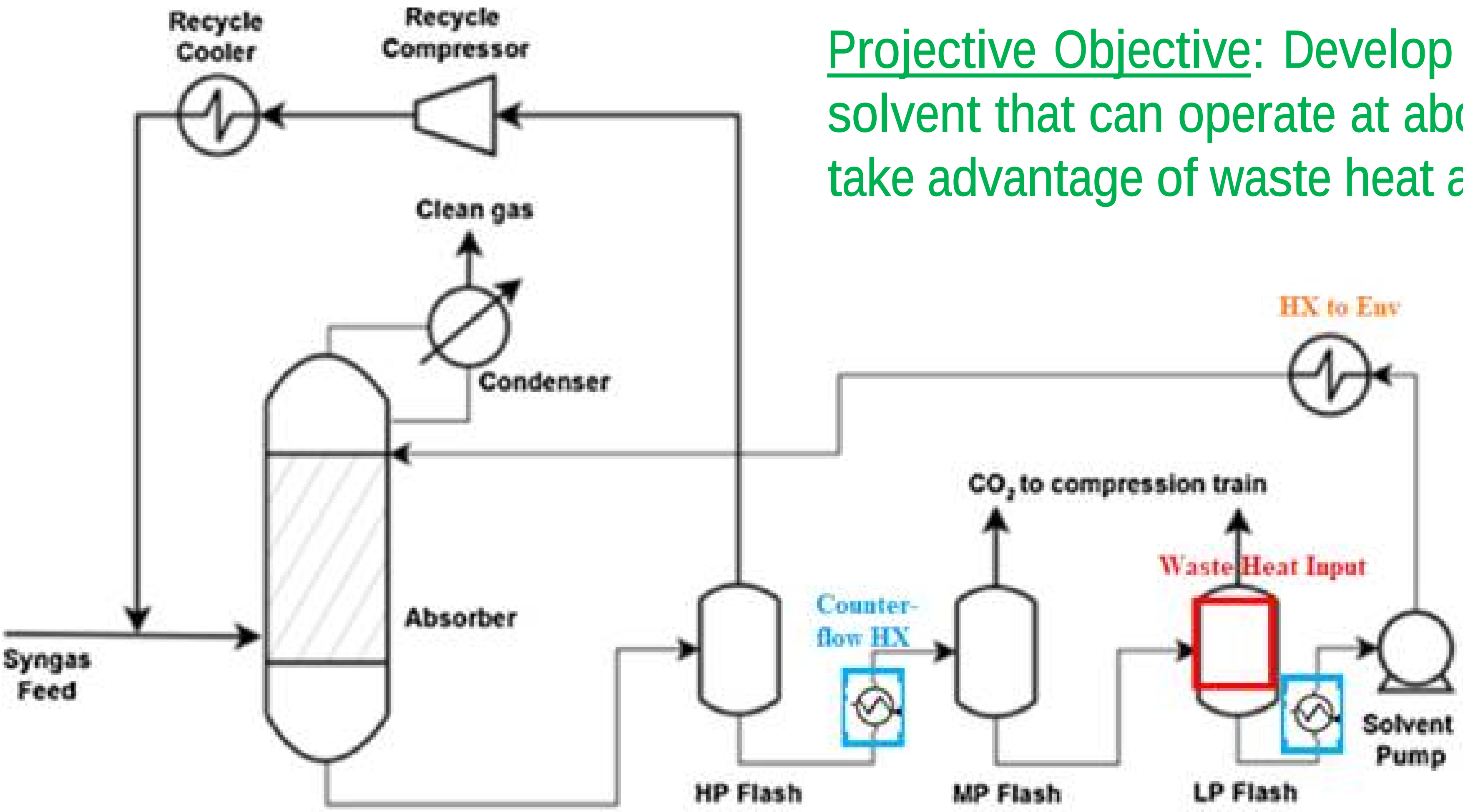


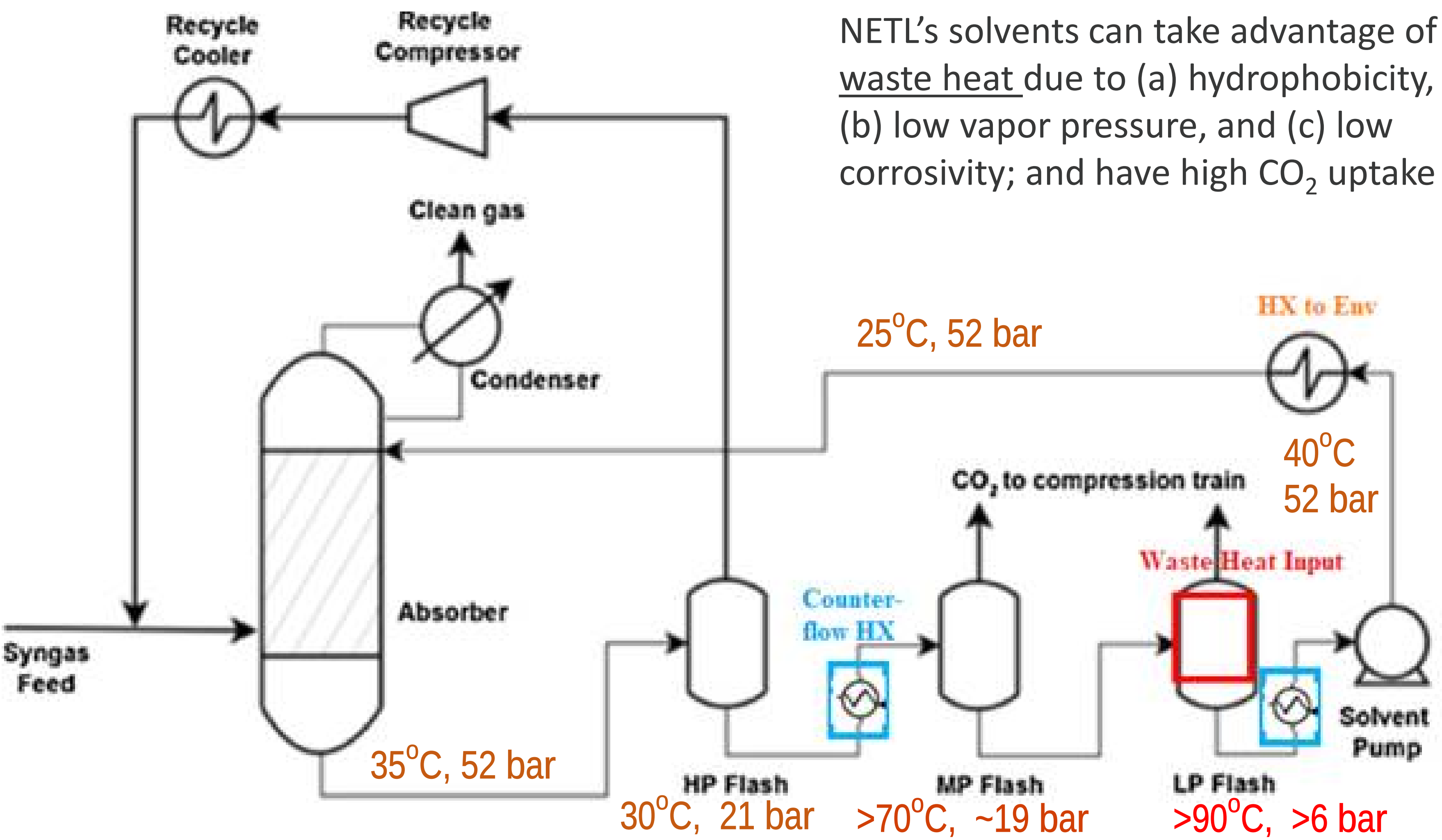
Projective Objective: Develop a process and a physical solvent that can operate at above room temperature can take advantage of waste heat at the IGCC power plant

Goal: Reduce by >35% the overall electricity consumption of the CO_2 Capture and Compression process at a 550 MW IGCC-CCS Power Plant

- Baseline electricity consumption = 55 MW

*Field and Brasington, Baseline Flowsheet Model for IGCC with Carbon Capture, Industrial & Engineering Chemistry Research 50(19) · August 2011

Schematic of Advanced CO_2 Capture



NETL's solvents can take advantage of waste heat due to (a) hydrophobicity, (b) low vapor pressure, and (c) low corrosivity; and have high CO_2 uptake

Advantages of New Approach

- Regeneration of the solvent at higher MP and LP Flash pressures reduces the electricity consumption and the capital cost of the CO_2 compressors

Waste Heat Locations

- Combined Cycle exhaust leaves stack at 140°C in Field and Brasington IGCC-CCS model
    - **55 MW$_{th}$** is available if exhaust heat exchanges down to 85 °C
- If Gypsum rather than Elemental Sulfur is the output of the Claus unit
    - **30 MW$_{th}$** is available

*Field and Brasington, Baseline Flowsheet Model for IGCC with Carbon Capture, Industrial & Engineering Chemistry Research 50(19) · August 2011

Overview of Real Syngas Testing

- **4 Solvents were experimentally tested in a pre-combustion**
  - 2 Commercially-available solvents: Selexol Surrogate and Tributyl Phosphate (TBP)
  - 2 NETL chosen solvents: PEG-PDMS-3 (Synthesized by R. Thompson) and CASSH-1 (Computationally Screen by W. Shi)

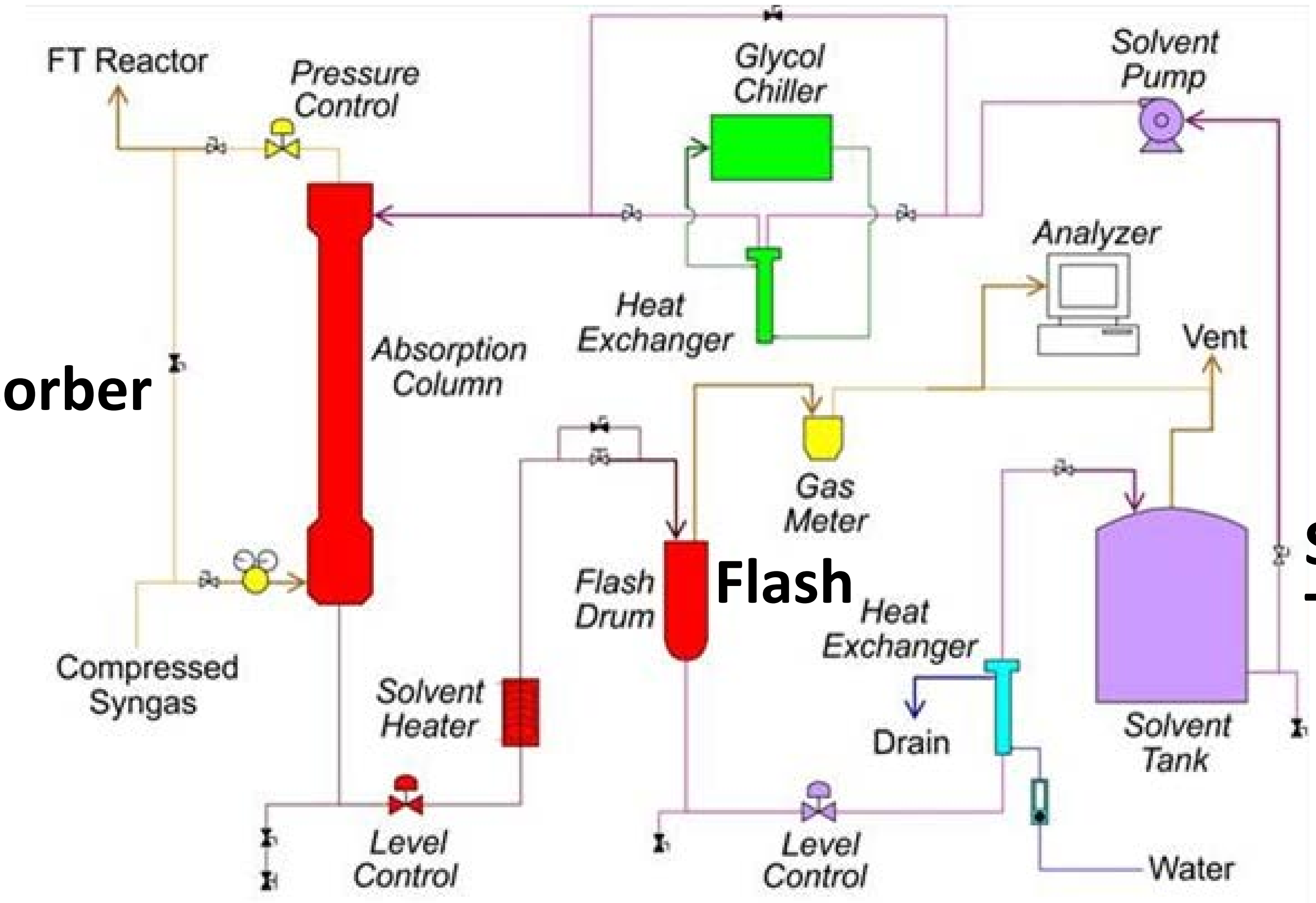
- **All 4 physical solvents were tested under real syngas generated at a UND EERC fluidized bed gasifier with fixed inlet syngas conditions**:
  - Total Pressure = 48 bar
  - Temperature = 40°C
  - Composition ≈ 50% CO_2, 18% H_2, 30% N_2, 1.4% CH_4, 0.4% H_2S, 0.2% H_2O

  - A Sour Water-Gas-Shift Catalyst by TDA Inc. was used to convert CO to CO_2+H_2

https://netl.doe.gov/sites/default/files/netl-file/N-Siefert-NETL-High-Performance-Physical-Solvent.pdf
https://netl.doe.gov/sites/default/files/netl-file/W-Shi-NETL-Solvent-Data-Mining.pdf

Facility Overview

Absorber



Flash

Storage Tank

Results for CO_2 Uptake and CO_2/H_2 Selectivity

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Calculation via Desorption Method

Uptake CO_2 [mol/L·bar] = Flow Rate of CO_2 leaving the desorption flash tank (mol/hr) divided by the partial pressure of CO_2 in the inlet syngas (bar) and also divided by the flow rate of the lean solvent entering the top of the absorption column (L/hr)

>90% Capture Cases	Units	Selexol Surrogate	PEG-PDMS-3	CASSH-1	TBP
CO_2 Uptake (10℃)	[mol/L·bar]	0.18	0.20	0.27	0.17
CO_2 Uptake (25℃)	[mol/L·bar]	0.15	0.18	0.21	0.18
CO_2 Uptake (40℃)	[mol/L·bar]	NA	0.19	0.21	0.21
CO_2/H_2 Selectivity (10℃)	[-]	20	19	25	11
CO_2/H_2 Selectivity (25℃)	[-]	17	17	20	13
CO_2/H_2 Selectivity (40℃)	[-]	NA	16	19	13

Selexol surrogate from Univar USA (Bunola, PA)

Comparison with Aspen Plus Simulations: Selexol 10℃

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Note Selexol enters at 10℃ and exits at 30℃ in the exp and simulation		Mixed Gas Simulation (Based on UOP data)	Experimental (Selexol Surrogate at UND EERC)
		AspenPlus	Desorption
CO_2 uptake 10℃	[mol/L·bar]	0.11	0.18
H_2 Uptake 10℃	[mol/L·bar]	0.002	0.009
N_2 Uptake 10℃	[mol/L·bar]	0.003	0.014
H_2S Uptake 10℃	[mol/L·bar]	0.18	0.17
CO_2 / H_2 Selectivity 10℃	[-]	55	20
H_2S / CO_2 Selectivity 10℃	[-]	1.7	1.0
CO_2 / N_2 Selectivity 10℃	[-]	33	13

*Field and Brasington, Baseline Flowsheet Model for IGCC with Carbon Capture, Industrial & Engineering Chemistry Research 50(19) · August 2011

Conclusions & Future Work

- **CASSH-1 and PEG-PDMS-3 at 40°C are out performing Selexol at 10°C**
  - Both solvents have great potential for reducing electricity consumption associated with CO_2 Capture from syngas applications

- **CO_2 uptake values were higher than expected from simulations and the CO_2/H_2 selectivity values were much lower than expected from simulations**

- **We will be looking to collect long-term data from both the fluidized bed gasifier at UND EERC and the entrained flow gasifier at U.Ky CAER**

- **Develop processes & solvents compatible with modular-scale gasification**

Acknowledgements

- **NETL/R&IC Solvents Teams**
  - Robert Thompson
  - Jeffrey Culp
  - Lei Hong
  - Wei Shi
  - Surya Tiwari
  - Jan Steckel
  - Kevin Resnik
  - Nicholas Siefert (PI)
  - David Hopkinson (TPL)
- **UND EERC Staff**
  - Michael Swanson
  - Joshua Stanislowski
  - Scott Klara
- **NETL & DOE/FE Project Management**
  - Lynn Brickett (HQ)
  - John Litynski (HQ)
  - Timothy Fout (TM)
- **NETL/R&IC Management**
  - Randall Gemmen
  - David Berry
  - David Alman