Pilot Testing of a Heat Integrated 0.7 MWe CO_2 Capture System with Two-Stage Air-Stripping

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http://www.caer.uky.edu/powergen/home.shtml

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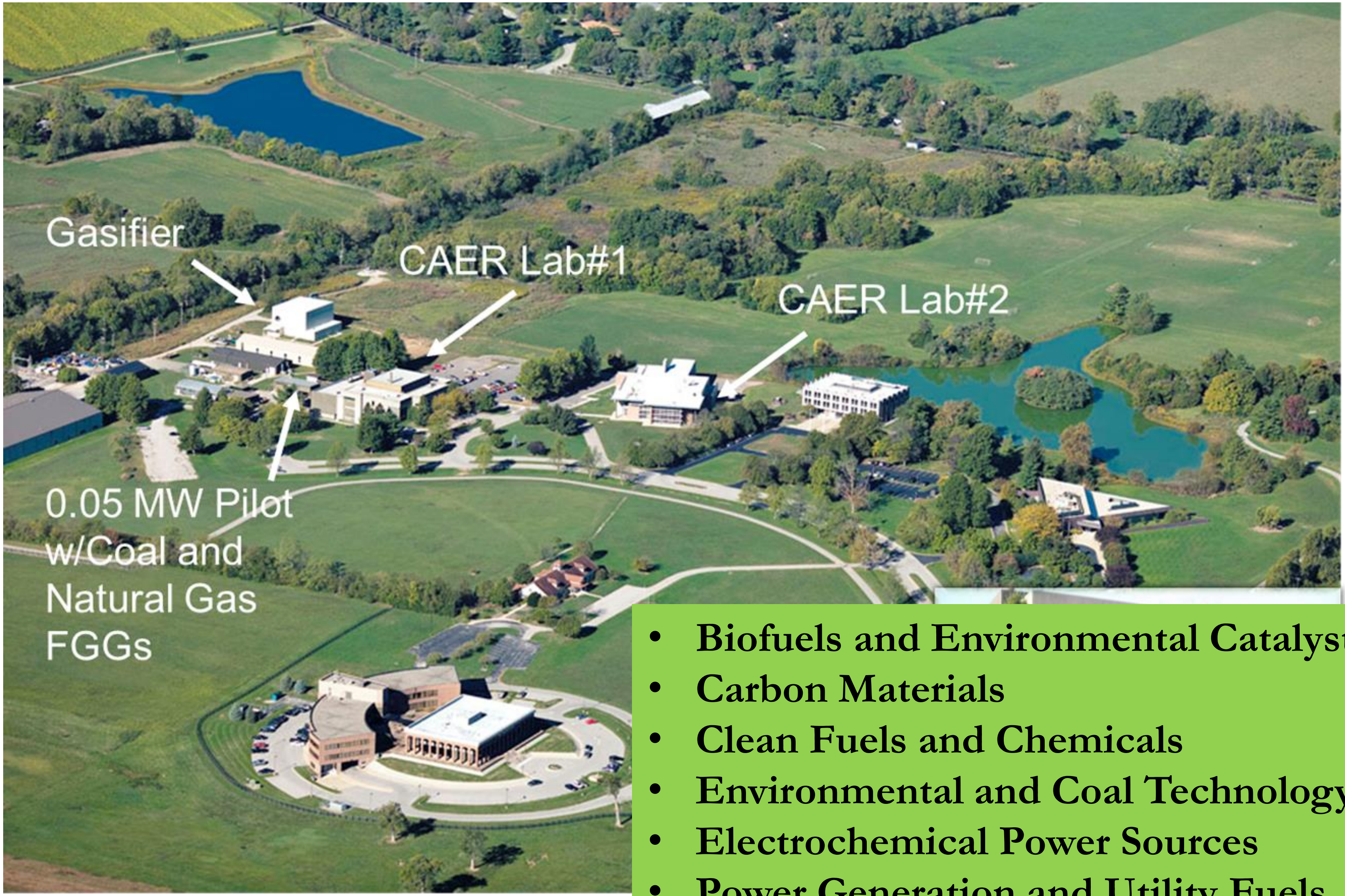


- Biofuels and Environmental Catalysts
- Carbon Materials
- Clean Fuels and Chemicals
- Environmental and Coal Technology
- Electrochemical Power Sources
- Power Generation and Utility Fuels

Areas of Research

Corrosion
- Non-metallic coating
- Inhibitors
- Localized effects

Conversion
- Gasification
- CO_2 Utilization
- NG Upgrading

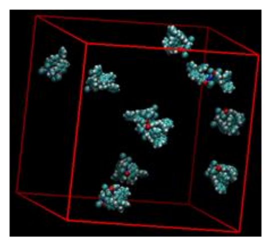
Pilot Plants
- Heat Integration
- Hybrid Processes
- Solvent & process testing

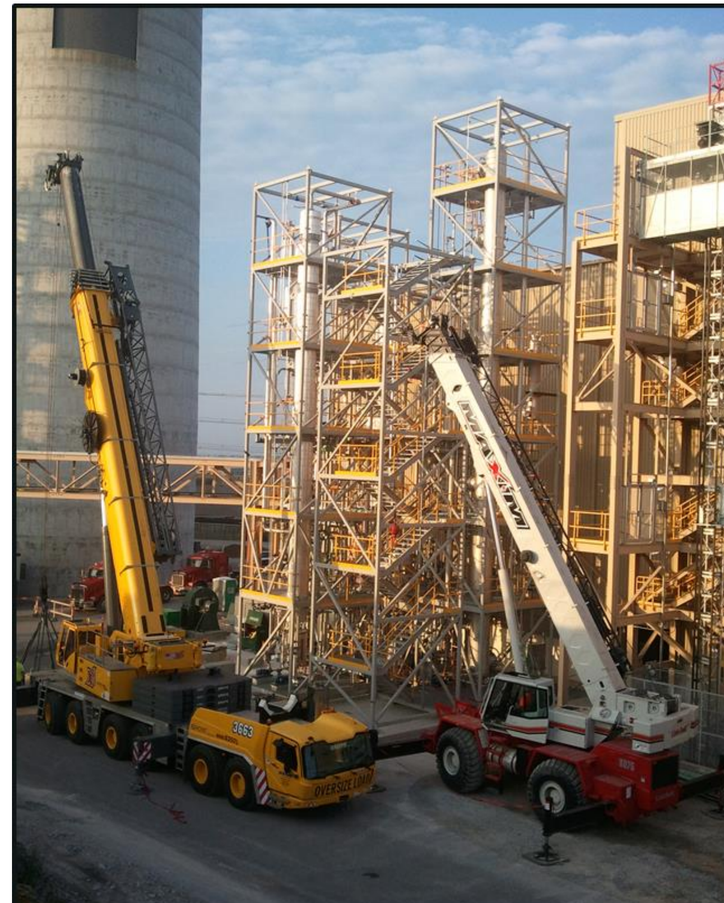
Membrane Separations
- Zeolite membranes
- Solvent enrichment

Solvents
- Chem/Physical Properties
- Emission
- Degradation

Chemical Looping
- Spouting Fluidized bed
- Combustion/ gasification
- Solid particle handling

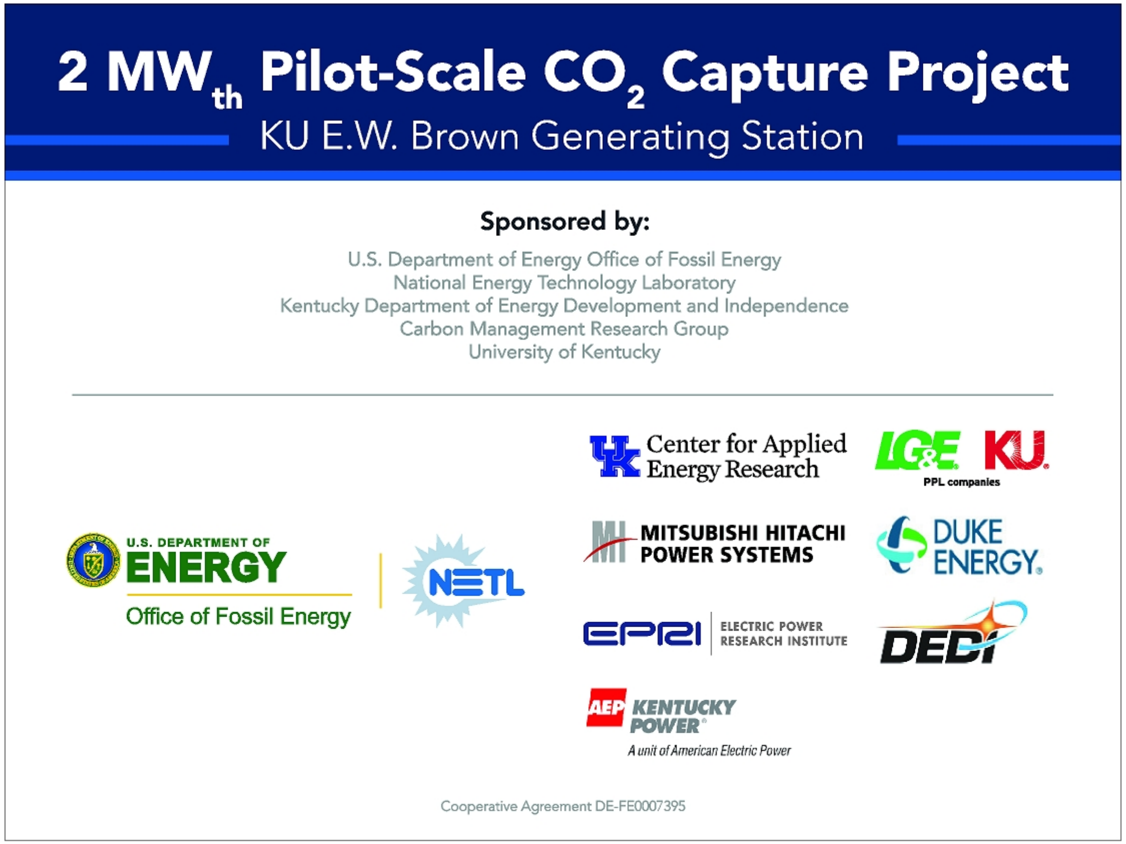
Electrochemistry
- Water treatment
- Solvent enrichment





Presentation Outline

- Overview of Project
  - Technology Description
- Emission and Degradation assessment



Current UKy-CAER CO_2 Capture Project

- Host site at Kentucky Utilities EW Brown Generating Station, Harrodsburg, KY
- 0.7 MWe advanced post-combustion CO_2 capture pilot plant
- Capture and release program (~1400 scfm flue gas)
- Designed as a modular configuration
- Includes several UKy-CAER developed technologies
- Tested two different amine solvents (MEA and H3-1)
- Funded in part by DOE-NETL (DE-FE0007395)

Small Pilot (1400 scfm) CO_2 Capture

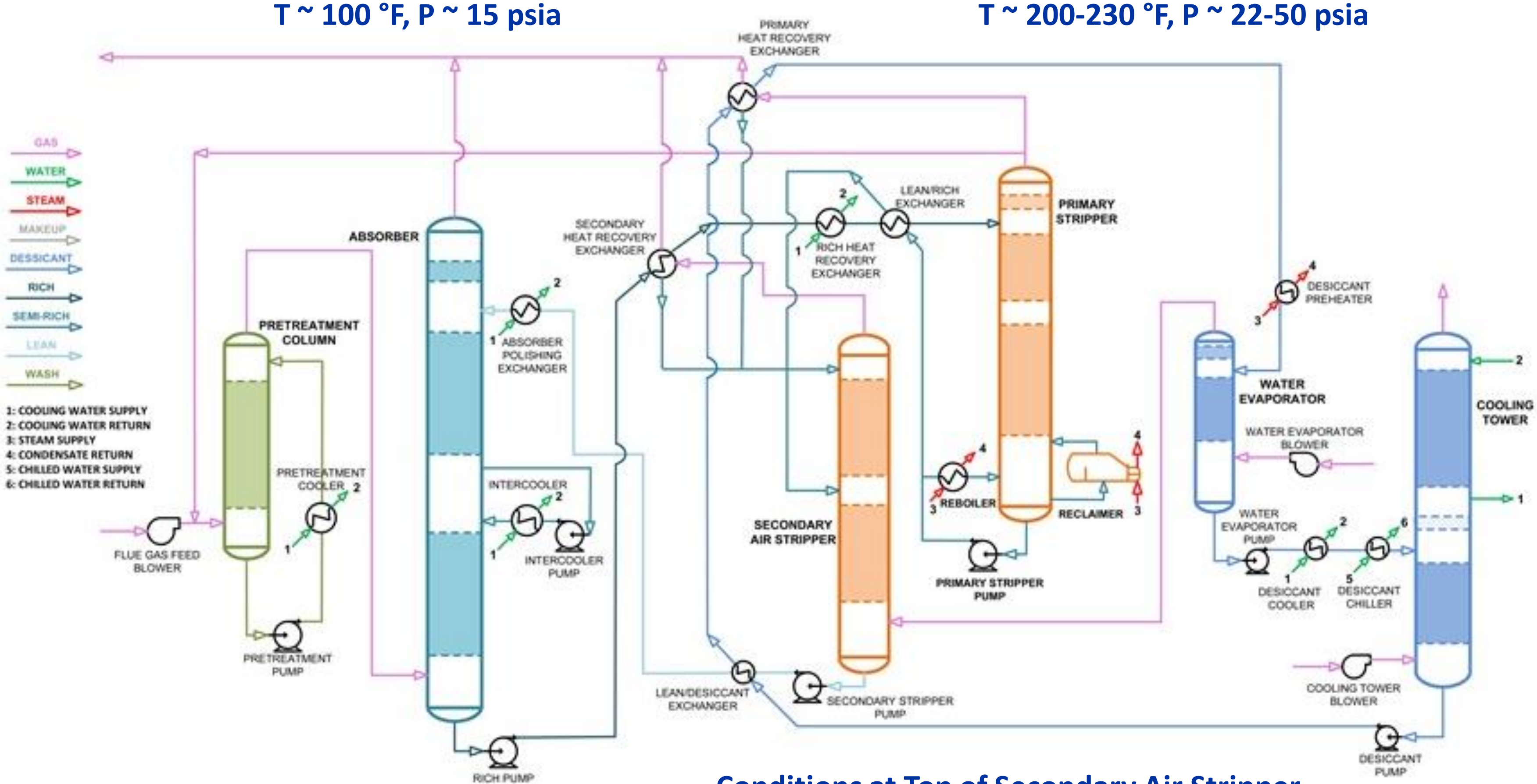
- Unique UKy-CAER CO_2 Capture Process
  - **Heat integrated cooling tower** and liquid desiccant air drying system for decreased energy consumption
  - **Two-stage stripping** for increased solvent working capacity
- Continuous gas stream composition monitoring (**CEMS**)
- Continuous **steam usage** measurement
- Continuous **energy consumption** measurement
- Comprehensive liquid sampling ports for **solvent quality analyses**
- Comprehensive **gas sampling** ports for emissions and degradation analyses
- Liquid/gas **column profile** sample ports for absorber profile validation
- **Corrosion coupon** testing locations for material evaluation
- On-site **analytical laboratory** for routine liquid sample analysis

Phase 2 Modifications: Install CO_2 pre-concentration membrane and emission reduction systems

Technology Description

Conditions at Top of Absorber
T ~ 100 °F, P ~ 15 psia

Conditions at Top of Primary Stripper
T ~ 200-230 °F, P ~ 22-50 psia



Conditions at Top of Secondary Air Stripper
T ~ 180 °F, P ~ 15 psia

Highlights

MEA Parametric Campaign

- Process can easily capture 90% of CO_2
- Solvent regeneration energy of 1200–1750 BTU/lb CO_2-captured, ~13% lower than Reference Case 10 (RC 10)

MEA Long-term Campaign

- Ambient conditions have an impact on CO_2 capture
- Absorber liquid/gas distribution has an impact on performance
- Lean/rich exchanger performance is critical
- Elemental accumulation in the solvent needs to be monitored

H3-1 Parametric Campaign

- Solvent regeneration energy of 900–1600 BTU/lb CO_2-captured, ~36% lower than RC10
- Secondary air stripper performs as expected

H3-1 Long-term Campaign

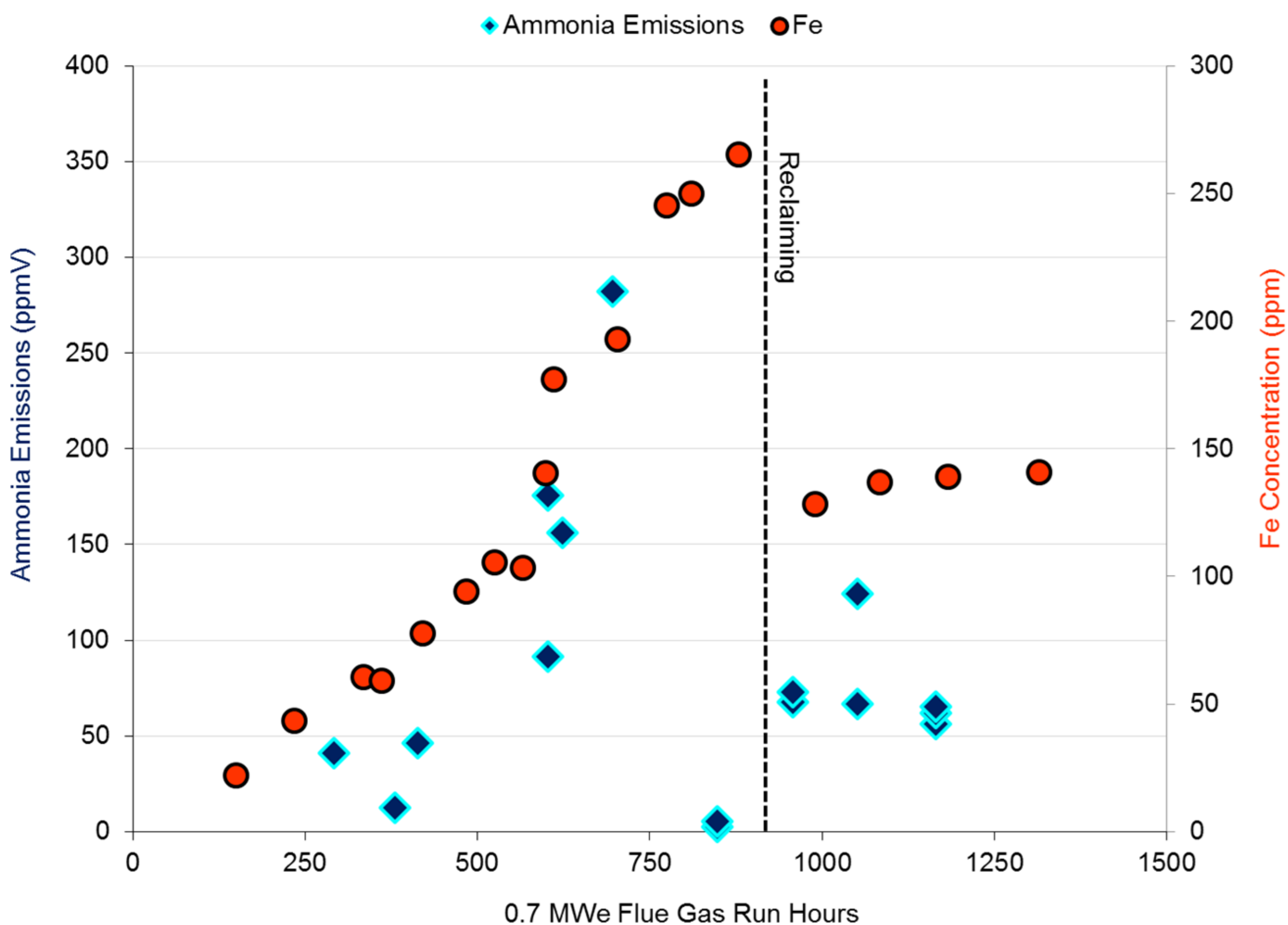
- 90% CO_2 capture and low solvent regeneration energies are possible with a range of solvent concentrations

The UKY-CAER Transformational CO_2 Capture technology has the ability to reduce regeneration energy with a variety of different solvents

Emissions and Solvent Degradation

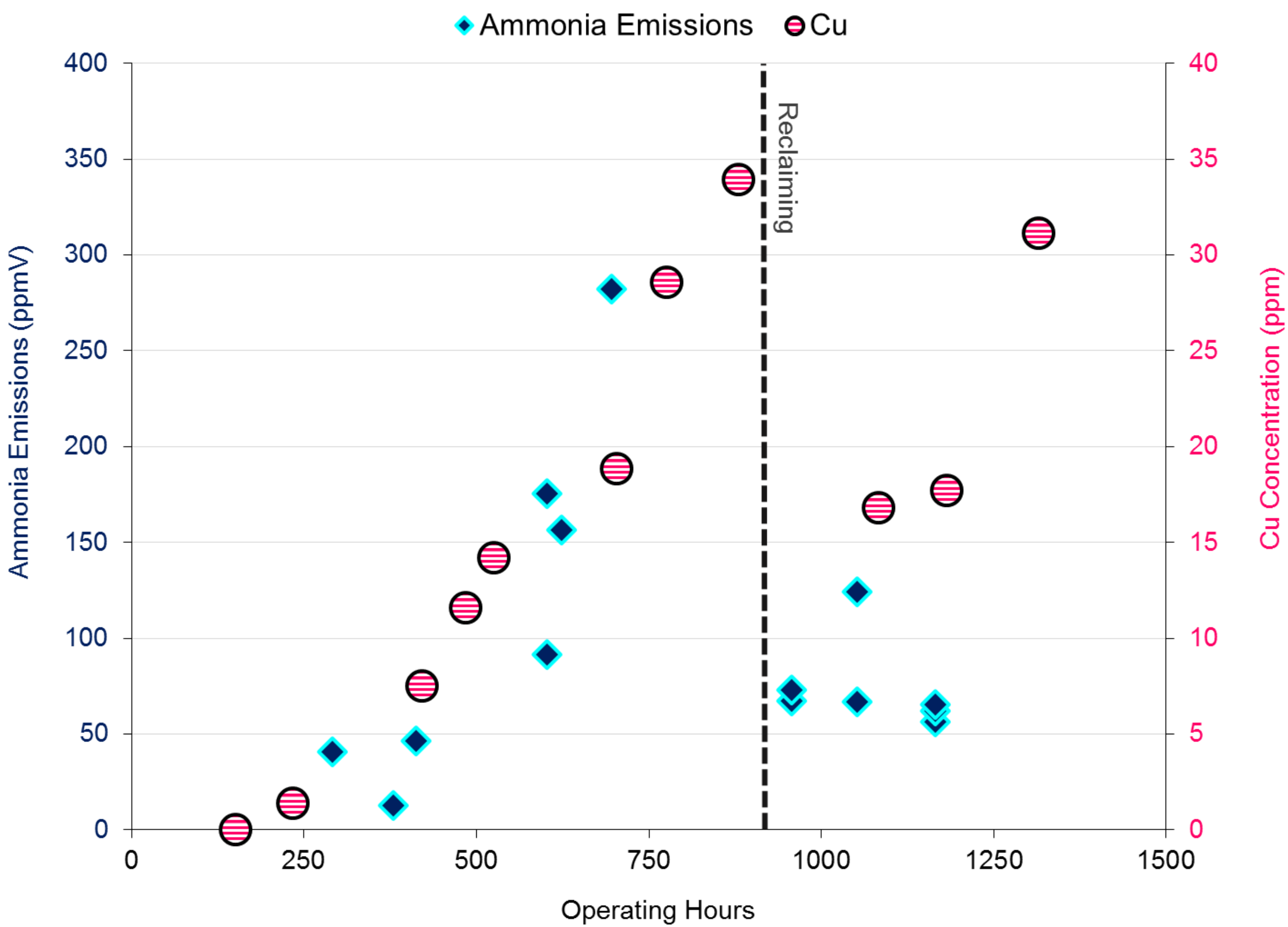
Full Environmental Study:
- Amine Degradation
- Heavy Metal Accumulation
- Nitrosamines
- Amine Emissions
- NH_3, Formaldehyde
- All Other Waste Streams
- 3rd party Emission and EH&S Assessment

NH_3 Emissions and Iron Correlation



Thompson et.al., Int J Greenhouse Gas Control, 2017, 64, 267-275.

NH_3 Emissions and Copper Correlation



Thompson et.al., Int J Greenhouse Gas Control, 2017, 64, 267-275.

Corrosion

An amine strainer was removed due to frequent leakage and was found to have brass internals. It was severely corroded and the likely source of the high copper levels observed during the MEA campaign.

Thompson et.al., Int J Greenhouse Gas Control, 2017, 64, 23-33.

Metal Accumulation

In addition to Fe and Cu, elevated levels of Cr, Ni were also observed –

This may be related to system commissioning as NCCC observed similar results in their initial MEA testing campaign, with significantly lower levels observed in subsequent solvent testing campaigns

<u>Se will need to be constantly monitored</u> to verify it remains below RCRA limits

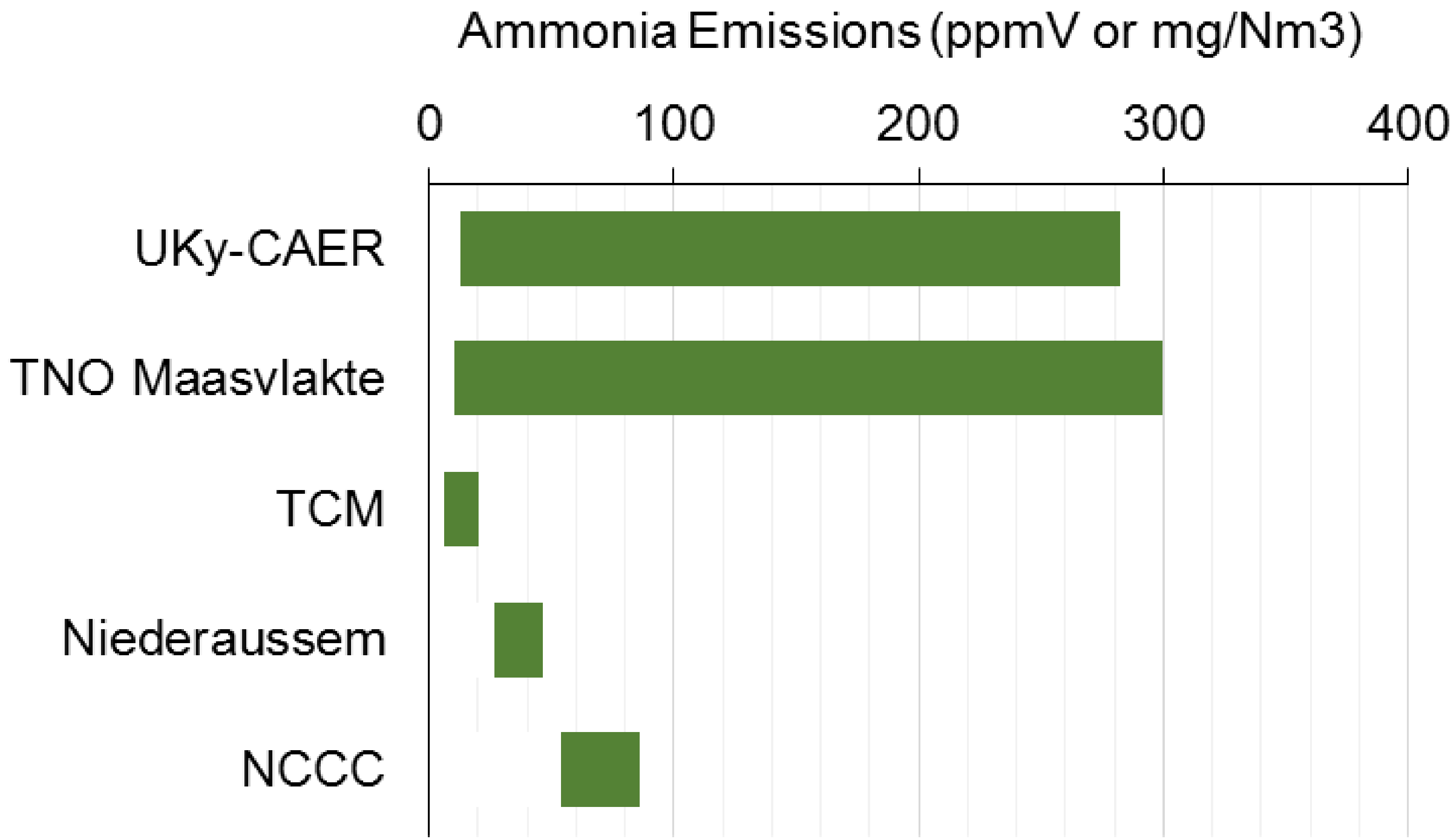
Elemental accumulation reported during pilot MEA solvent testing campaigns.

Elements	UKy-CAER (mg/L)	NCCC (mg/kg)	CSIRO (mg/kg)
Cr	29.382	45.90	4.20
Fe	265.248	137.20	199
Ni	28.024	28.77	4.6
Cu	33.898	< LOD	3.54
As	0.290	0.219	
Se	0.769	1.950	
Ba	0.982	0.265	
Pb	3.653	< 0.01	
Ag	< LOD	< 0.50	
Cd	< LOD	< 0.01	
Be		< LOD	
Mg		15.34	6.2
Al		4.060	
Zn		0.940	11.5
Mn		5.620	2.12
V			0.44
Mo			0.49
Co		1.020	
Flue Gas Source	Coal	Coal	Brown coal
Operating Hours	880[a]	1140	1476[b]
Reference		Carter (2012) and Wheeldon (2013)	Reynolds et al. (2015a)

[a] Values reported before reclaiming.
[b] Combined hours from 2 campaigns (640 h and 836 h) using the same solvent batch.

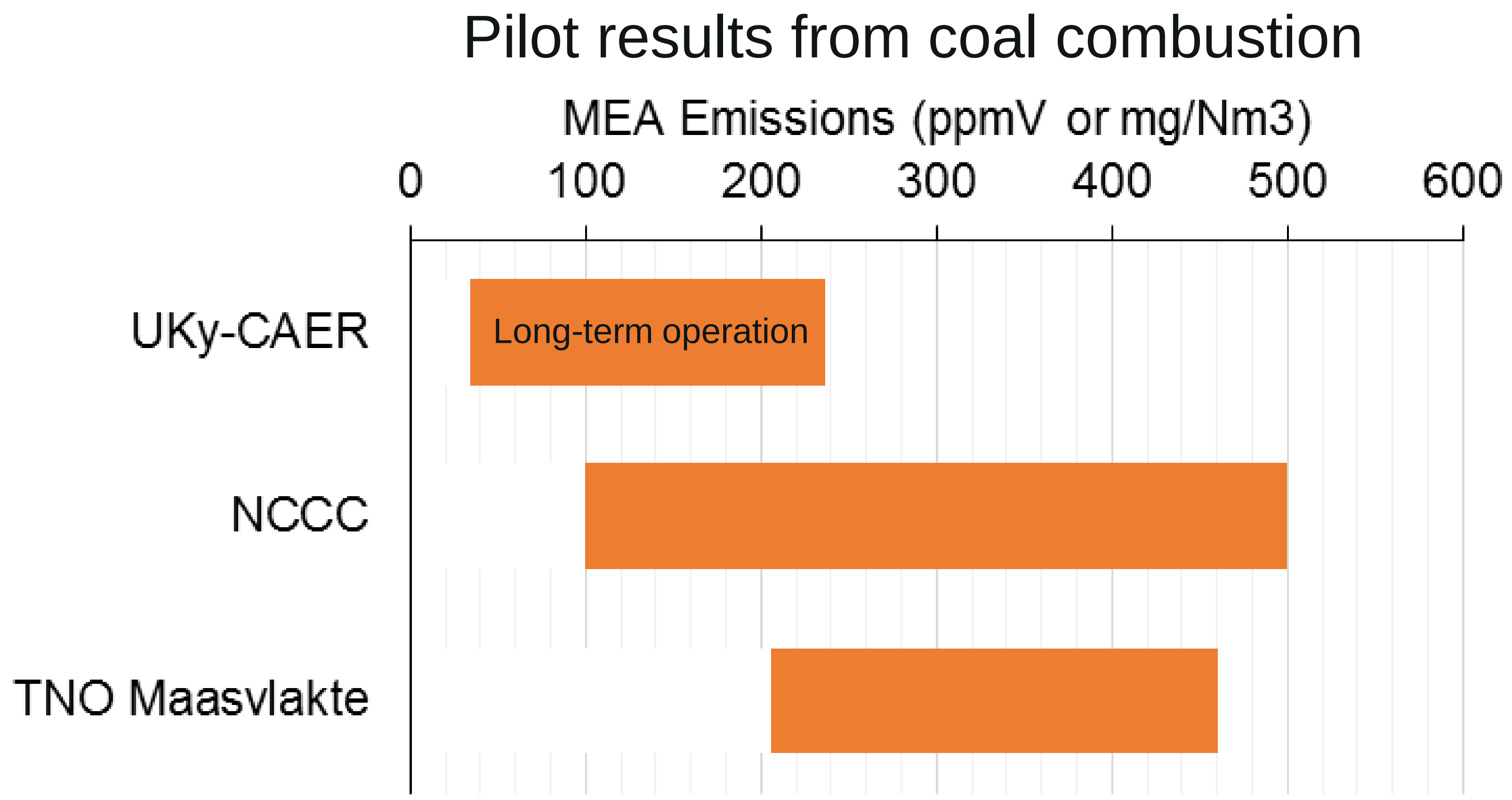
Thompson et.al., Int J Greenhouse Gas Control, 2017, 64, 23-33.

Comparative NH_3 Emissions



Thompson et.al., Int J Greenhouse Gas Control 2017, 64, 22-33.
Khakharia, et.al., Ind. Eng. Chem. Res. 2015, 54, 5336-5344.
Morkin et.al., Energy Procedia 2014, 63, 6023-6038.
Moser, et.al., Energy Procedia, 2010, 4, 473-479.
Carter, National Carbon Capture Center: Post-Combustion. Presented at the NETL CO2 Capture Technology Meeting, 9-12 July 2012, Pittsburgh, PA, USA..

Comparative MEA Emissions

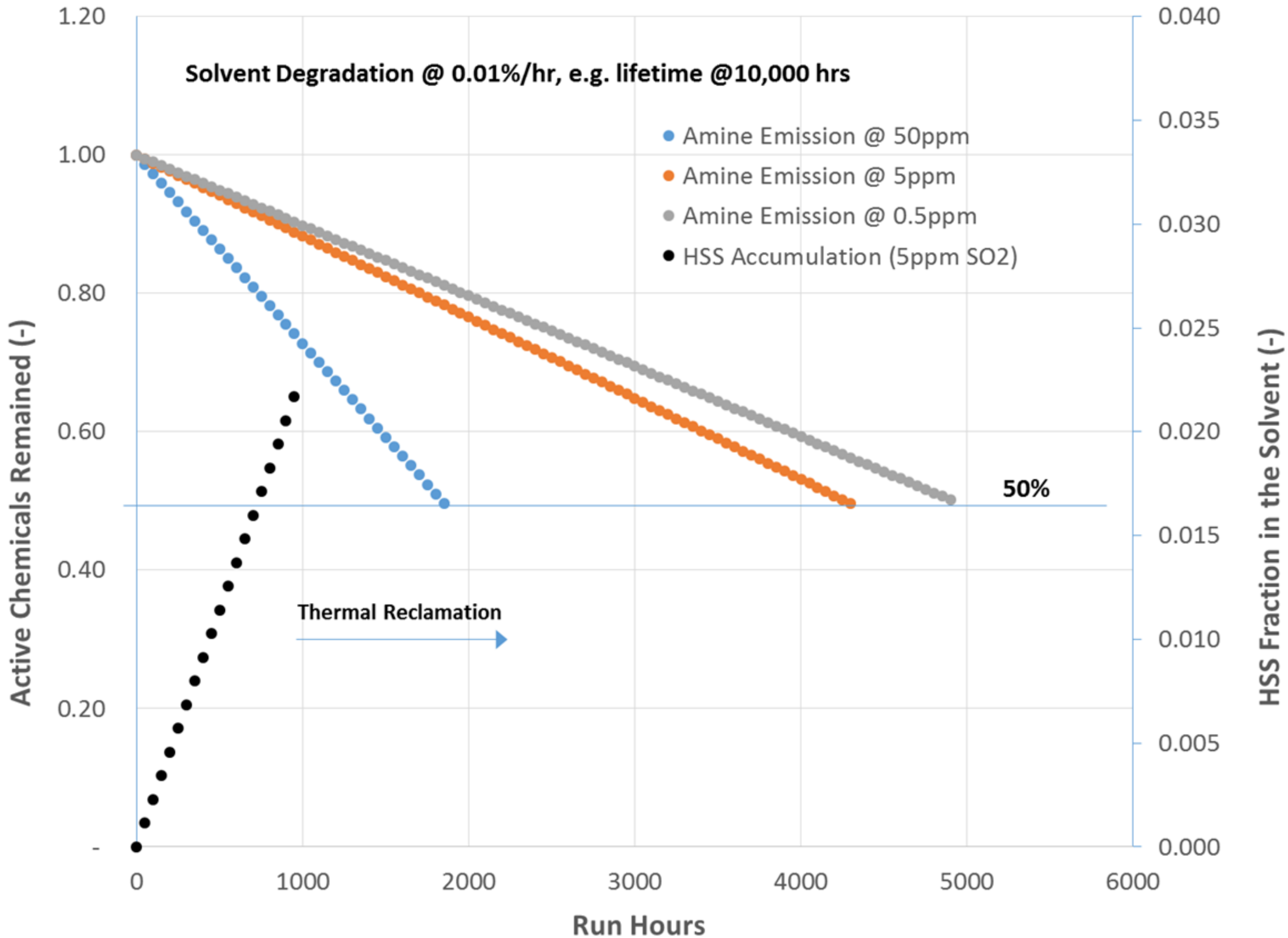


Some MEA emission observed over 1300 ppmV during parametric testing

Baghouse installed at Brown Station after MEA campaign

Thompson et.al., Int J Greenhouse Gas Control, 2017, 64, 267-275.
Wheeldon, J., National Carbon Capture Center: Post-Combustion CO2 Capture Program. Presented at the NETL CO2 Capture Technology Meeting, 8-11 July 2013, Pittsburgh, PA, USA.
Wheeldon, J., National Carbon Capture Center: Post-Combustion testing. Presented at the NETL CO2 Capture Technology Meeting, 29 July - 1 August 2014,Pittsburgh, PA, USA.
da Silva et al., Energy Procedia, 2013, 37, 778-783

Additional Solvent Considerations

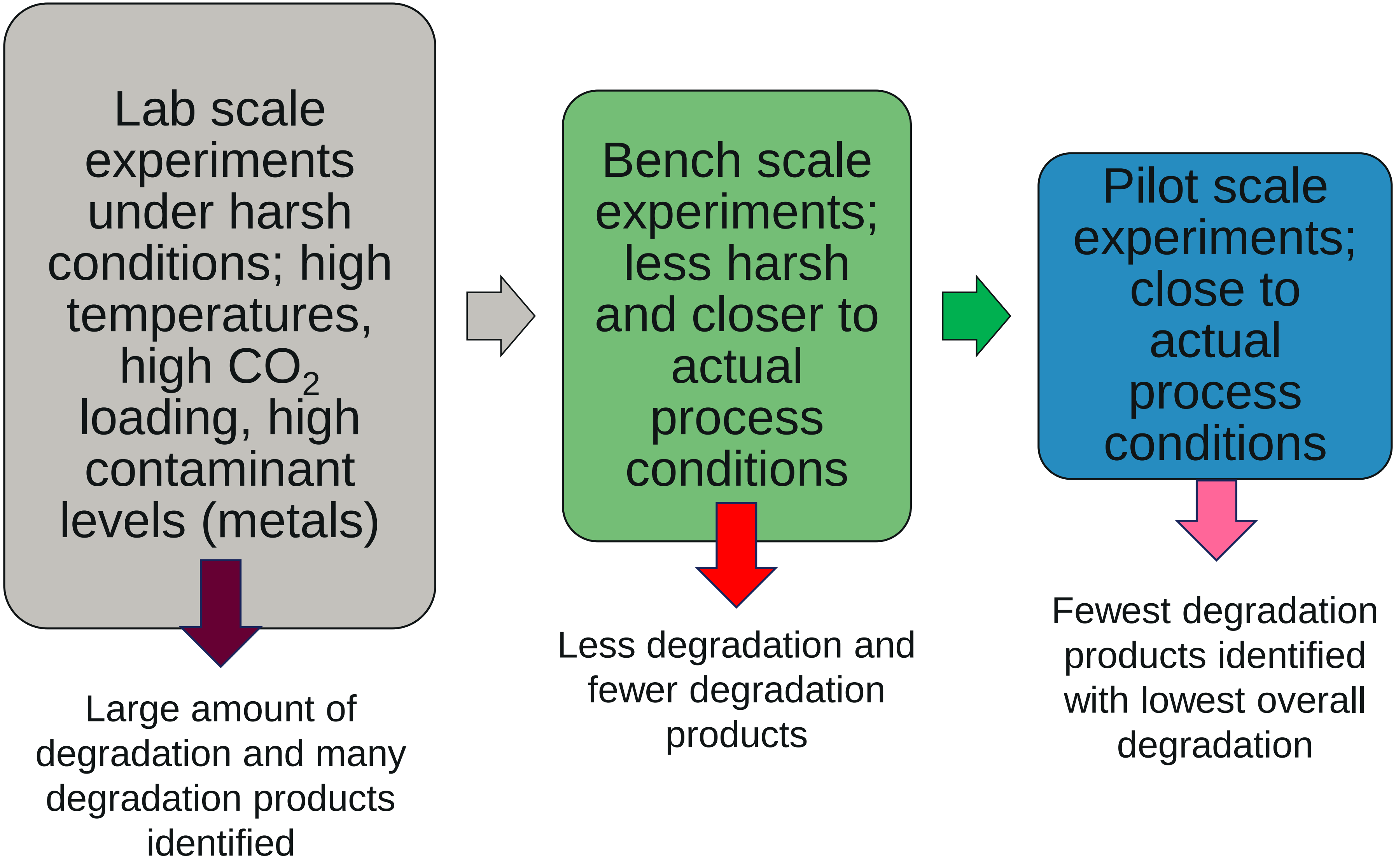


Cost needs to be addressed by 3rd generation solvents

Additional Highlights

- Heat Stable Salt (HSS) accumulation from flue gas as expected
  - Sulfate and nitrate are major species
- Service water usage did not lead to any operational problems
- MEA thermal and oxidative degradation very similar to other campaigns
  - Formate and HEI major oxidative species
  - HEIA major thermal degradation product
- Aldehyde emissions were also comparable to other MEA testing campaigns
- Nitrosamines emissions were not observed above the ~1 ppbV detection limit

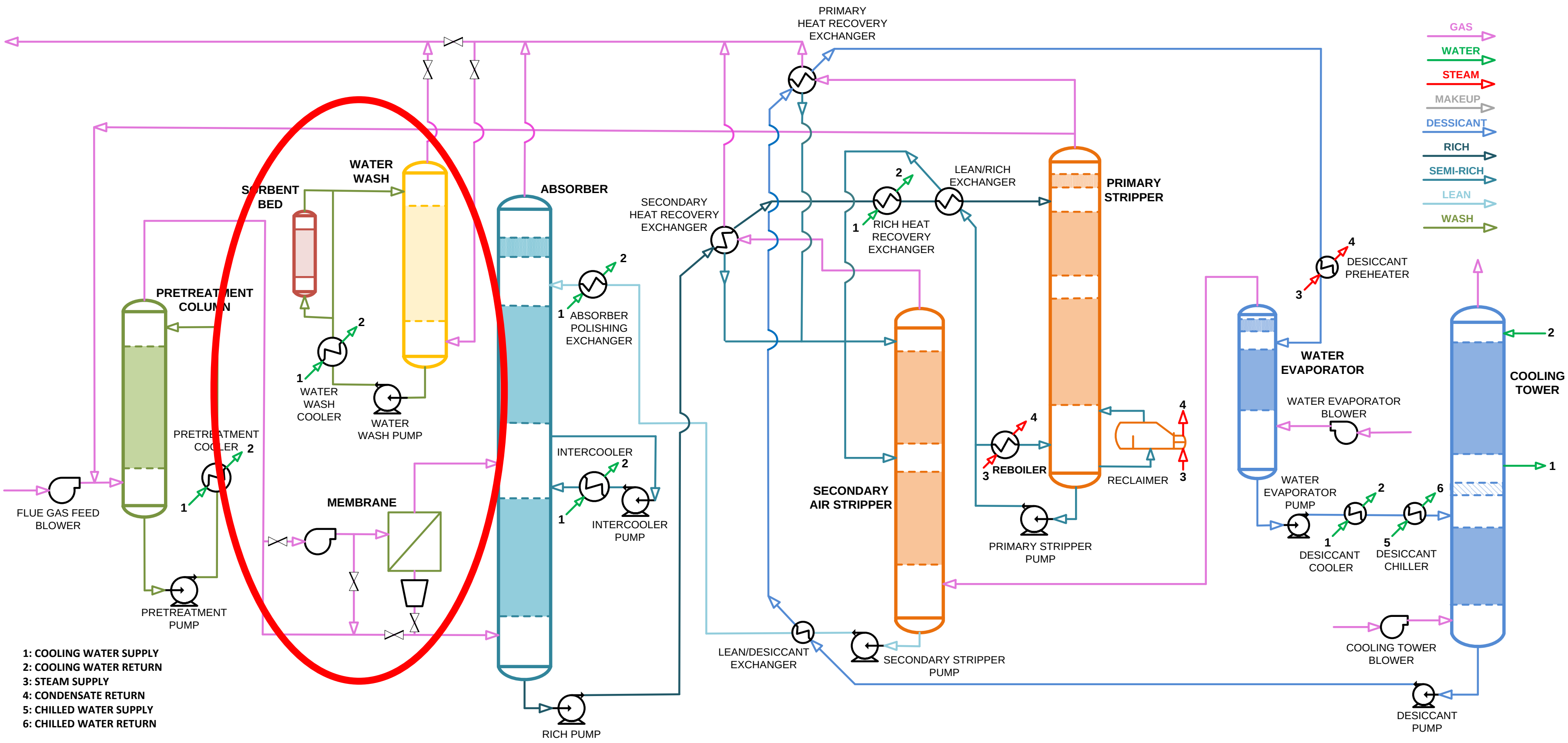
Amine Degradation



Key Knowledge Gained

- Liquid/gas distribution can significantly reduce the absorber efficiency.
- It is important to consider the L/R exchanger performance when reporting and comparing solvent regeneration values.
- Thermal reclaiming may be needed for RCRA element management.

Hybrid 0.7 MWe CCS Flow Diagram



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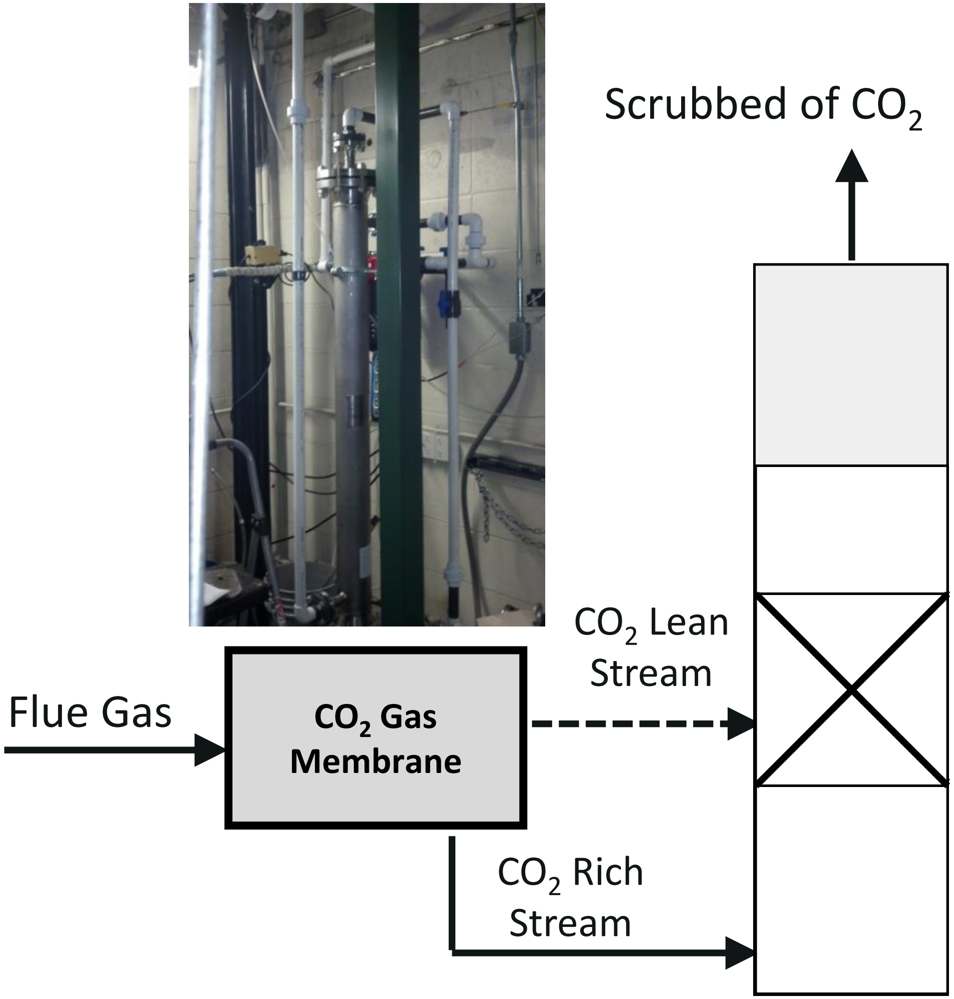
Pre-Concentration Membrane



Major Achievements

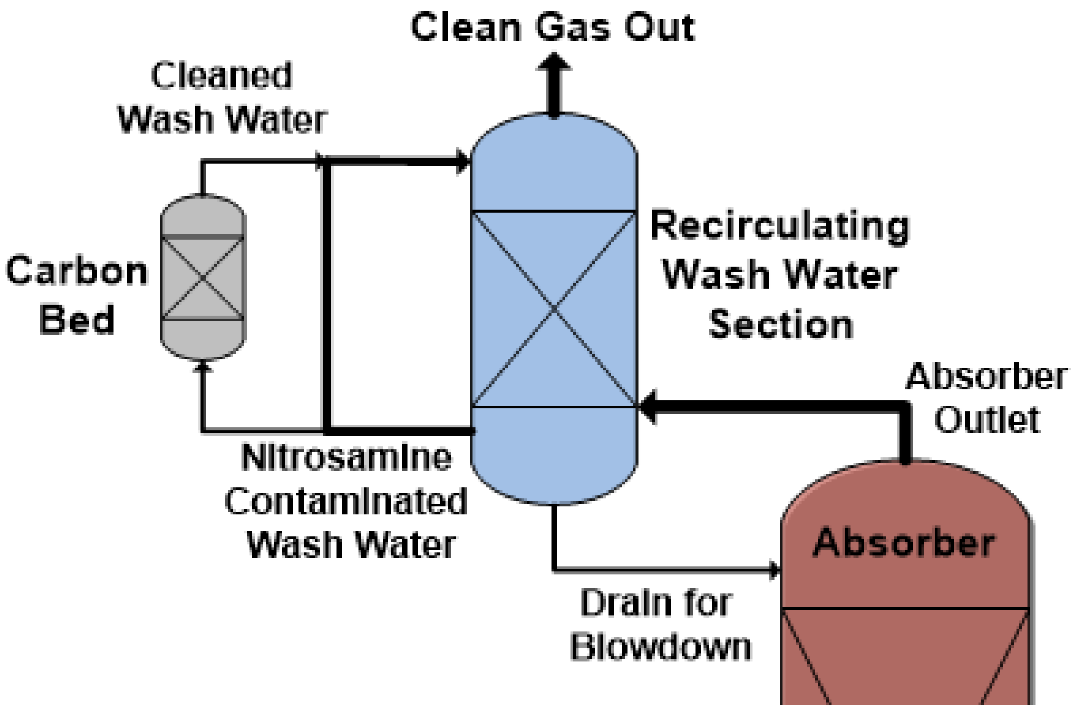
- 2x increase in vol% CO_2
  14% → 28%
- Engineered solution to utilize the increased driving force and realize energy savings – pump around

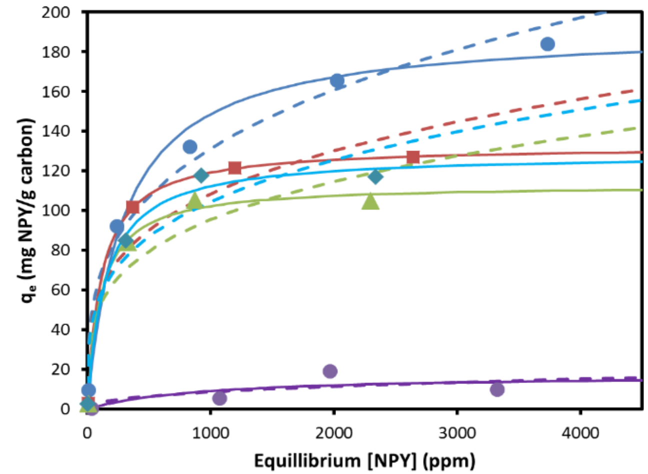
Major Challenges

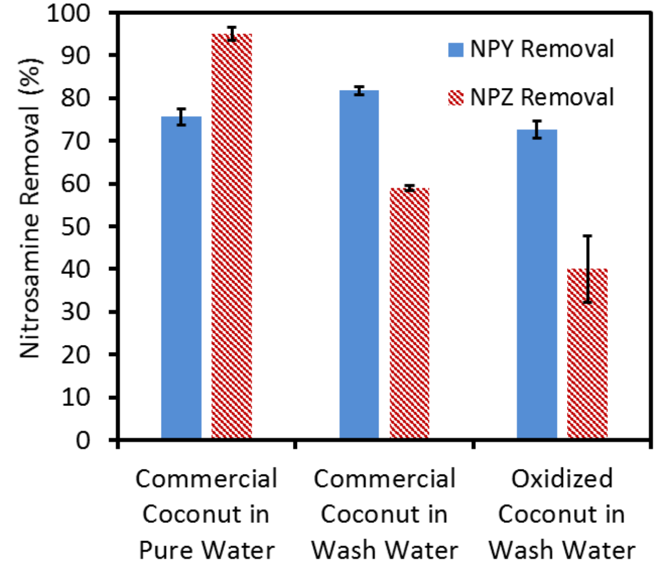
- Pressure drop across membrane giving low gas flow rates
- Not straight forward integration/installation to realize benefit from higher vol% CO_2

Funded in part through DE-FE0012926

Modified WaterWash (WW)



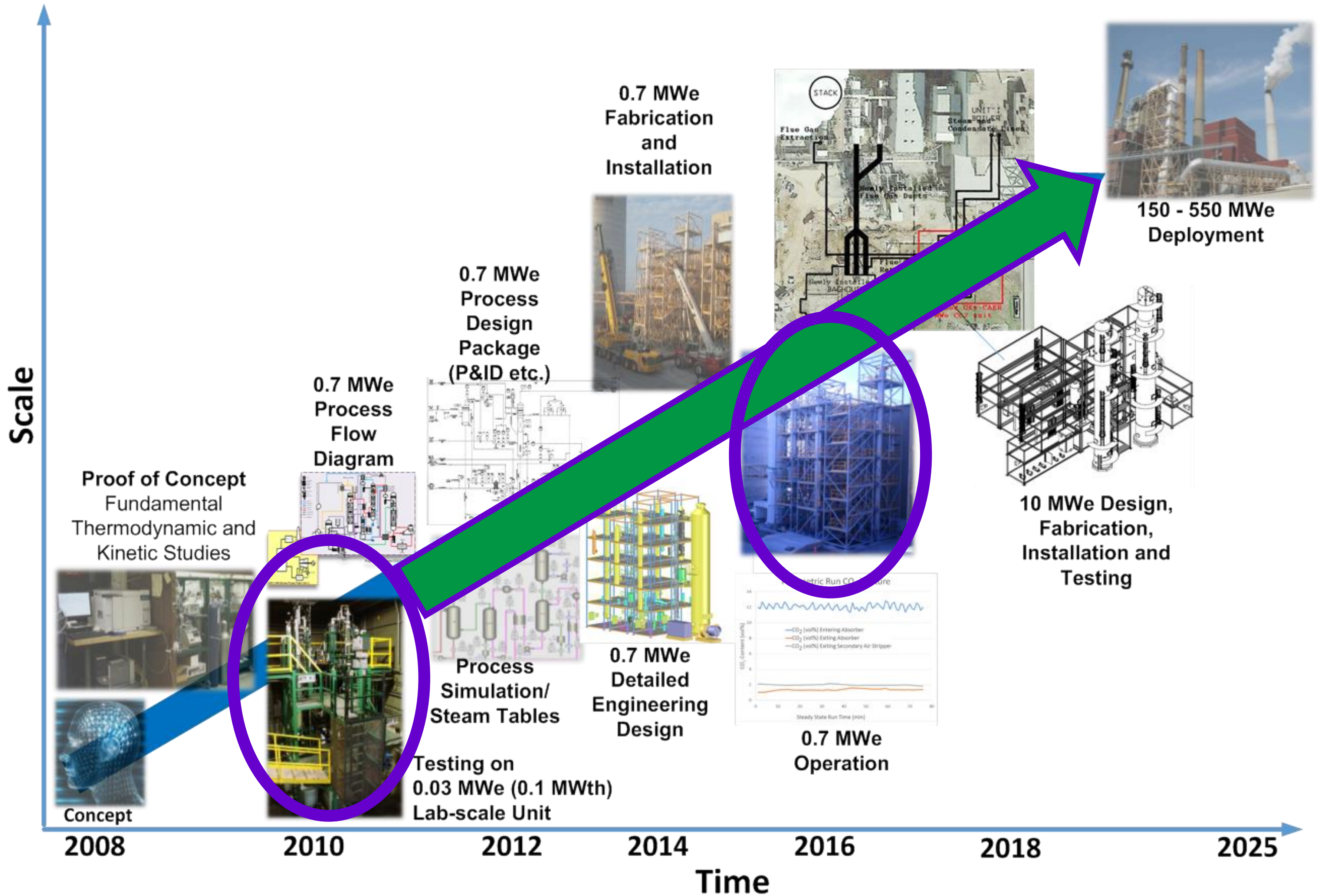




Sorbent properties that can maximize N-nitrosamine adsorption while minimizing amine adsorption

Widger, et.al., Environ. Sci. Technol. 2017, DOI: 10.1021/acs.est.7b02806

Technology Development Pathway



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UKy-CAER Slipstream Team