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Supersonic Post-Combustion Inertial CO_2 Extraction System

Bench Scale Project Status Update

2014 NETL CO_2 Capture Technology Meeting

Pittsburgh, PA

30 July 2014

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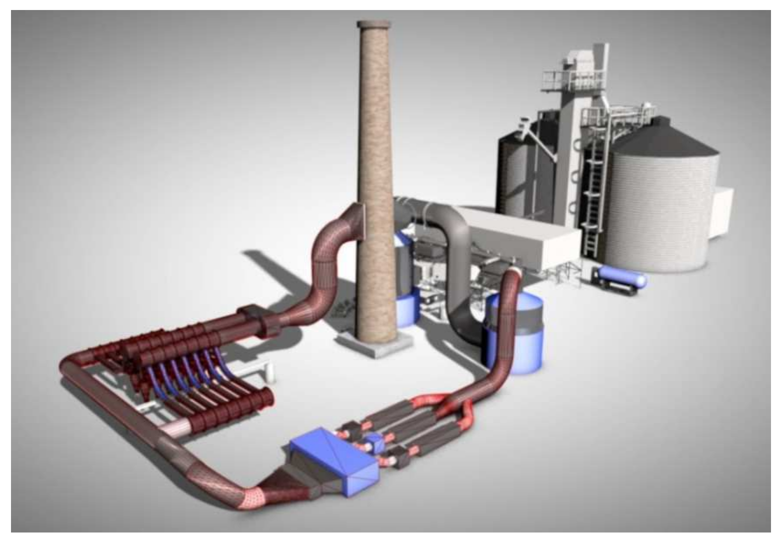

Project Overview

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- **Award DE-FE0013122**

- **Funding**
  - NETL: $ 2,999,951
  - Cost Share: $ 749,640
  - Total: $ 3,749,591

- **Project Performance Dates**
  - 1 Oct 2013 - 30 Sep 2016

- **Project Participants**
  - ATK & ACENT Laboratories
  - Ohio State University
  - EPRI and WorleyParsons
  - NYSERDA and NYSDE

- **Project Objectives**
  - Demonstrate inertial CO_2 extraction system at bench scale
  - Develop approaches to obtain condensed CO_2 particle size required for migration
  - Demonstrate pressure recovery efficiency of system consistent with economic goals
  - Demonstrate CO_2 capture efficiency

ICES Technology Background

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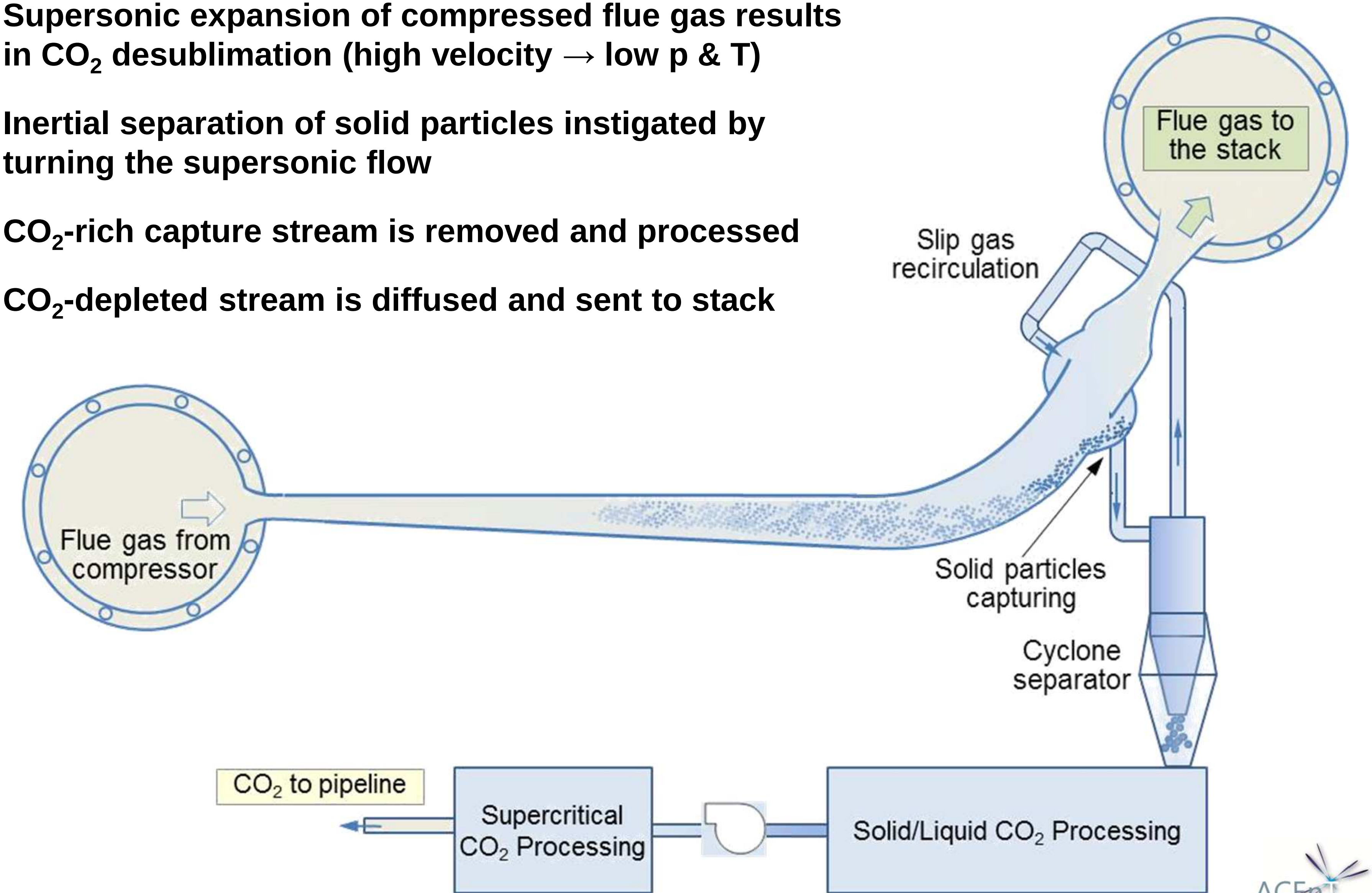
- **Supersonic expansion of compressed flue gas results in CO_2 desublimation (high velocity → low p & T)**
- **Inertial separation of solid particles instigated by turning the supersonic flow**
- **CO_2-rich capture stream is removed and processed**
- **CO_2-depleted stream is diffused and sent to stack**



Thermodynamics of ICES

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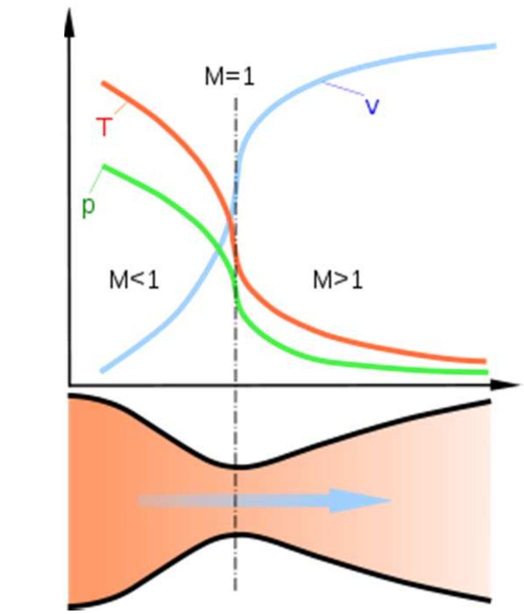
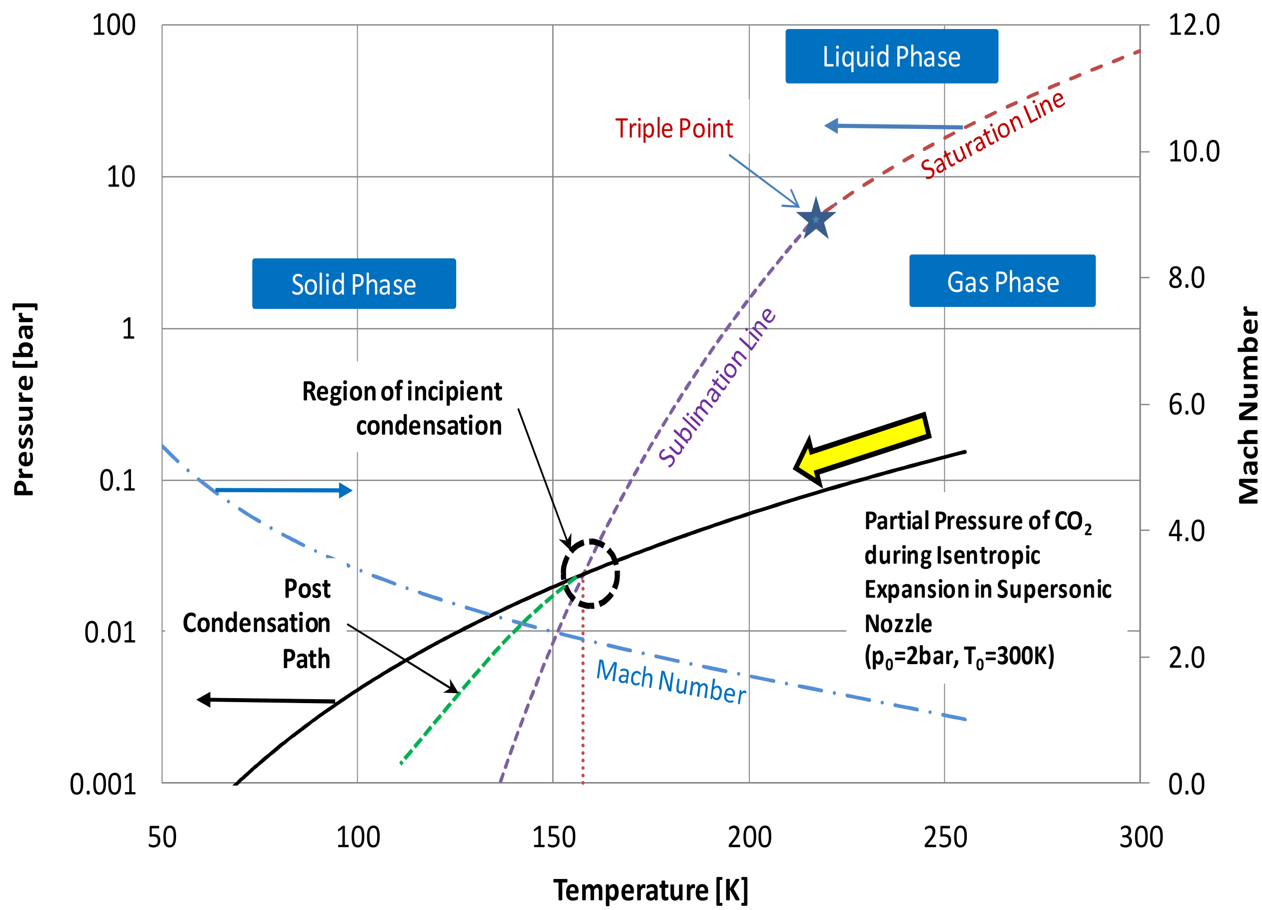


Static pressure (p), static temperature (T) and velocity (v) in a converging-diverging nozzle

Isentropic Expansion of 14mol% CO_2 in N_2 Relative to Phase Diagram of CO_2



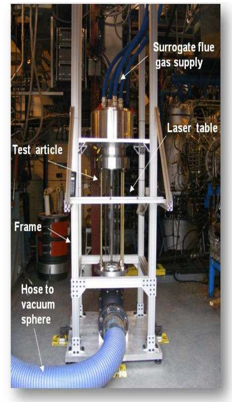
Low static pressure and temperature in supersonic nozzle causes CO_2 to precipitate as a solid – need to remove before diffusing back to low speed

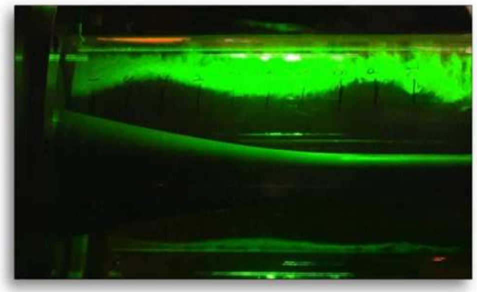
Key Advantages and Challenges

Advantages	Challenges
No moving parts, chemicals/additives or consumable media	Maximization of CO_2 particle size with limited residence time
Inexpensive construction (sheet metal, concrete)	Minimization of “slip gas” removed with solid CO_2
Small footprint (current bench scale test article is 250kW, 3” x 24” x 96”	CO_2 purity (all condensable material will be removed with CO_2)
“Cold sink” availability in solid CO_2	Solid CO_2 processing
Costs primarily driven by flue gas compression	Optimization of flowpath pressure recovery

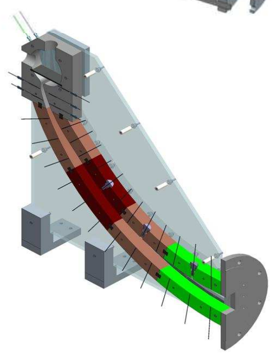
Summary of test activity under ARPA-e IMPACCT

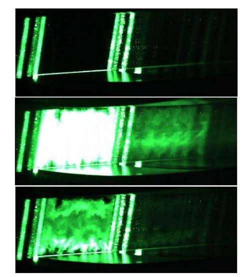
Gen1a and 1b (swirl)



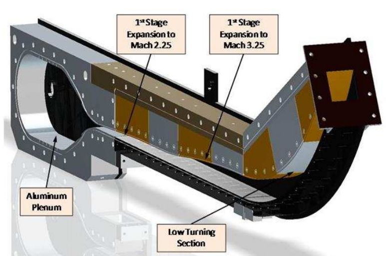


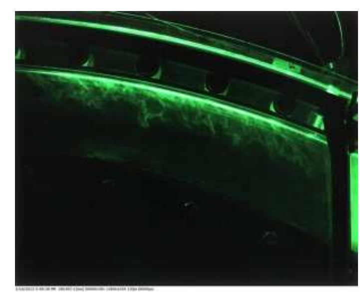
Gen2 (2D)





Gen3 (2D - long)





Principal conclusion of this effort was that CO_2 particles >2.5μm are required for efficient operation - need to control particle size generated

Program Plan for Current Effort

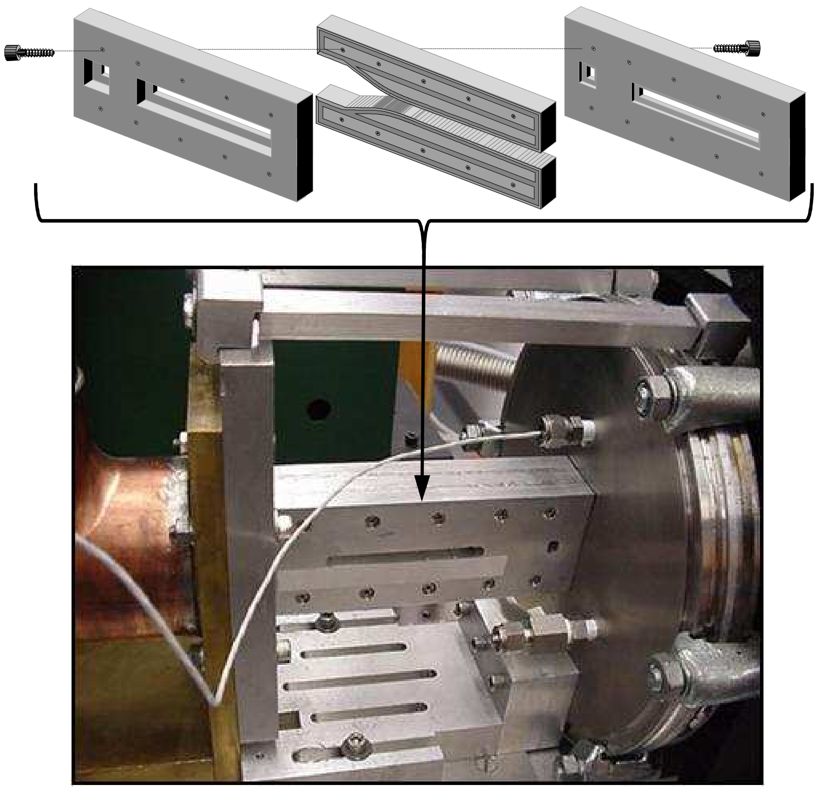
- **Year 1**
  - Lab-scale tests (OSU) to develop understanding of factors controlling particle size and methods to increase
  - Bench scale tests at ATK to demonstrate capture efficiency and diffusion with surrogate CO_2 injection (liquid throttle of CO_2 to produce controlled particle size)
  - Success criteria: Demonstrate 50% capture, show path to pressure recovery required

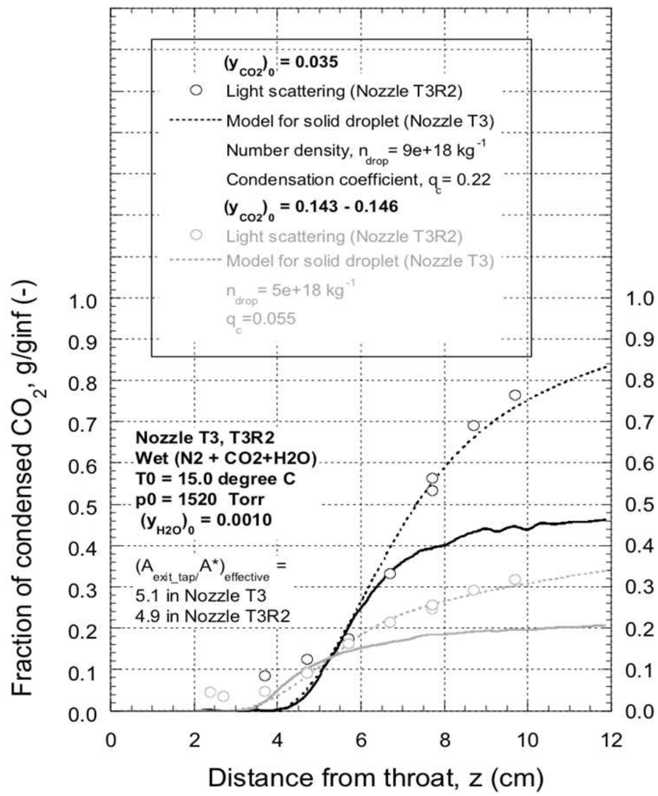
- **Year 2**
  - Integrate methods to increase particle size in bench scale test article
  - Test with surrogate flue gas (Air + CO_2 + H_2O)
  - Success criteria: Demonstrate migration of 80% of CO_2 to 20% of duct height pressure recovery

- **Year 3**
  - Integrated bench-scale testing with capture + diffuser
  - Success criteria: 75% capture with path to 90%, path to full scale pressure recovery

Lab-scale Testing at OSU

- Tests ongoing in OSU supersonic aerosol facility to gain better understanding of nucleation process, condensation rates, and particle size behavior





Particle size diagnostic has been demonstrated and calibrated – will be moving into particle growth testing next

Current Bench Scale Test Arrangement (250kW)

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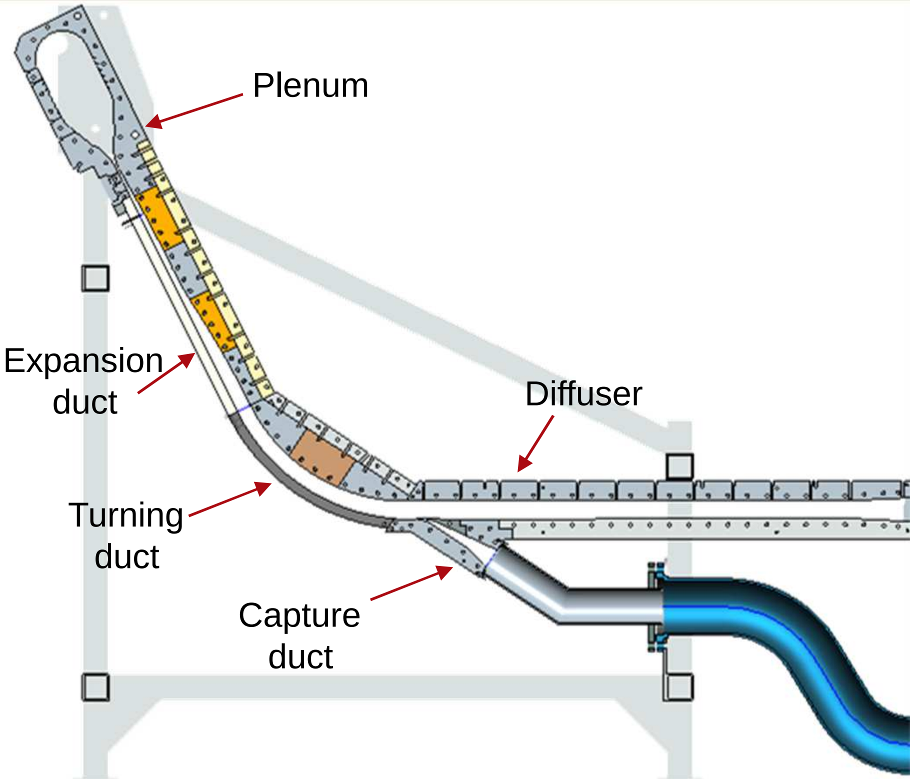
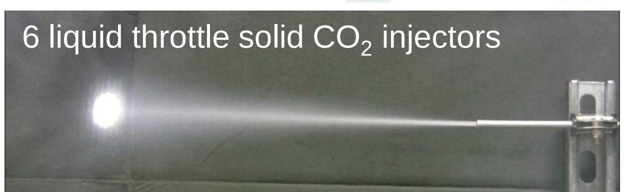
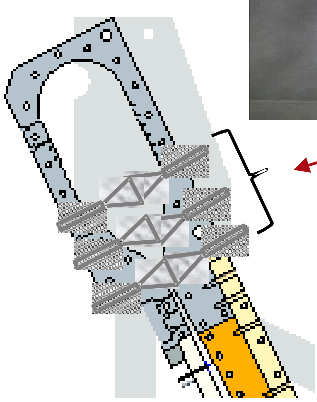
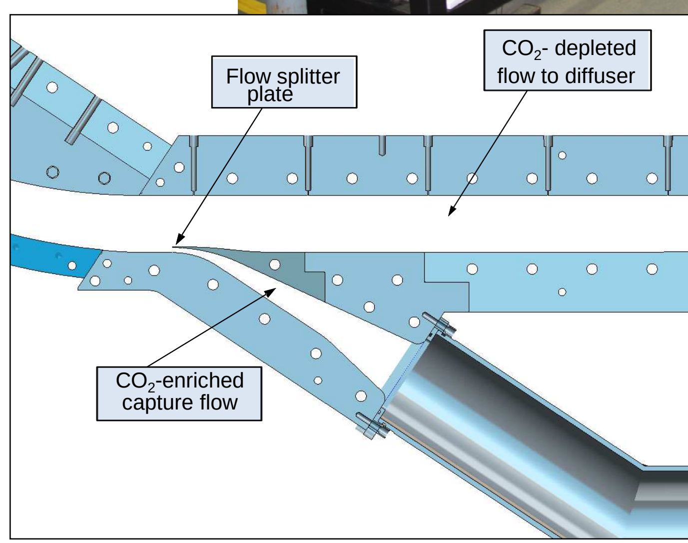
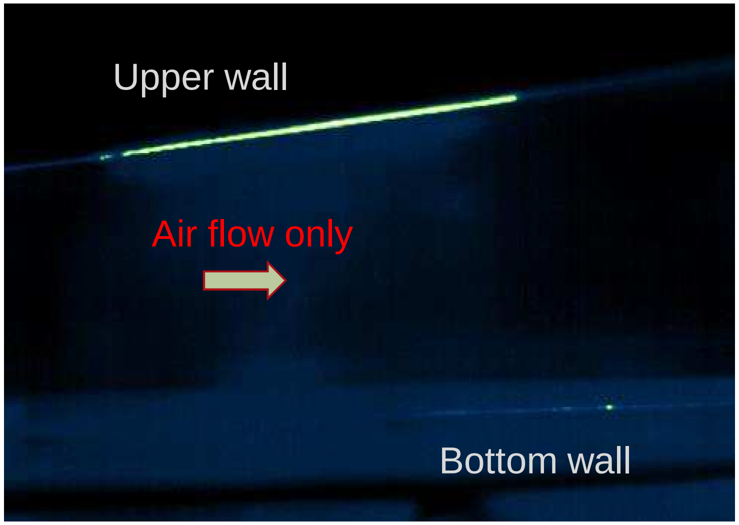


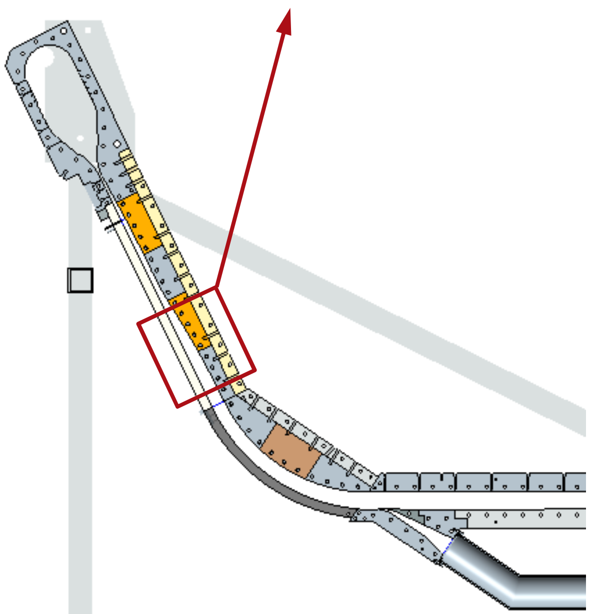


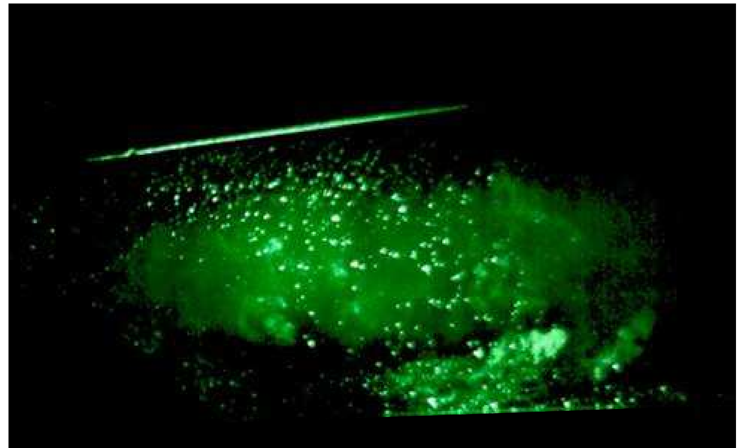




Laser Images – Flow Before Turn/Migration



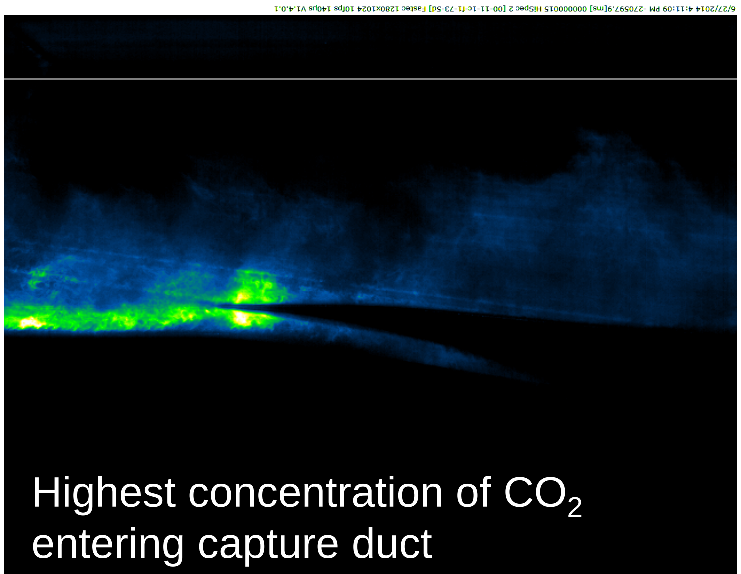


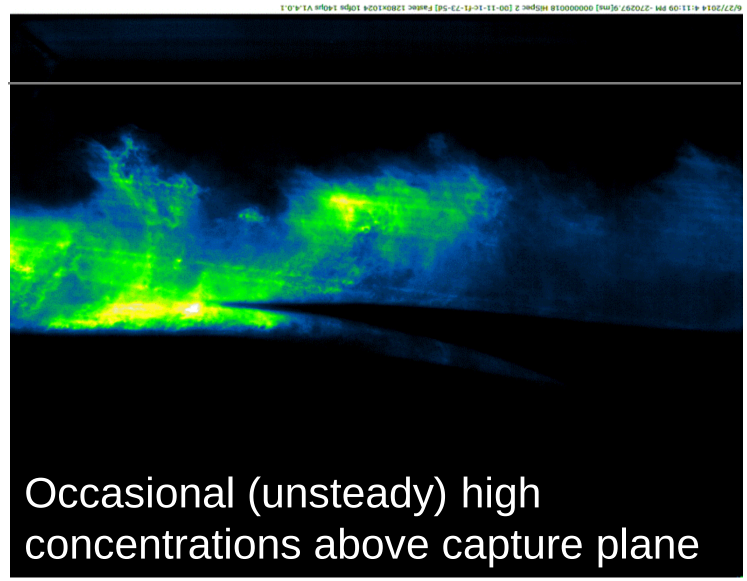


CO_2 relatively uniform across duct

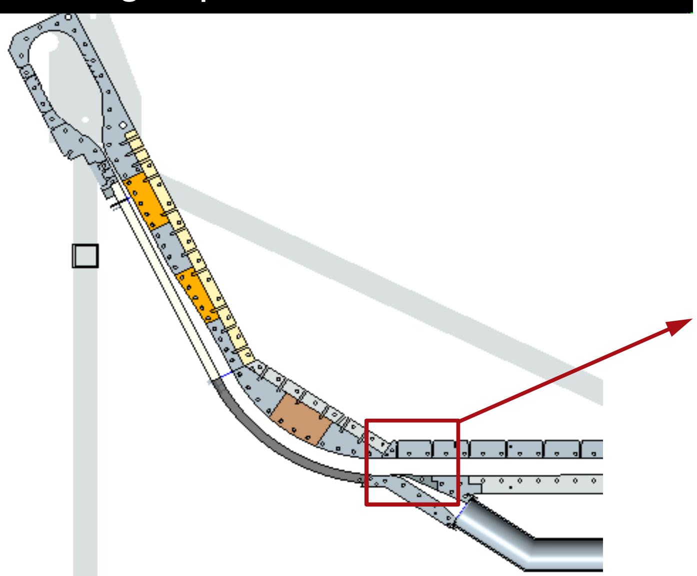
Some unsteadiness observed

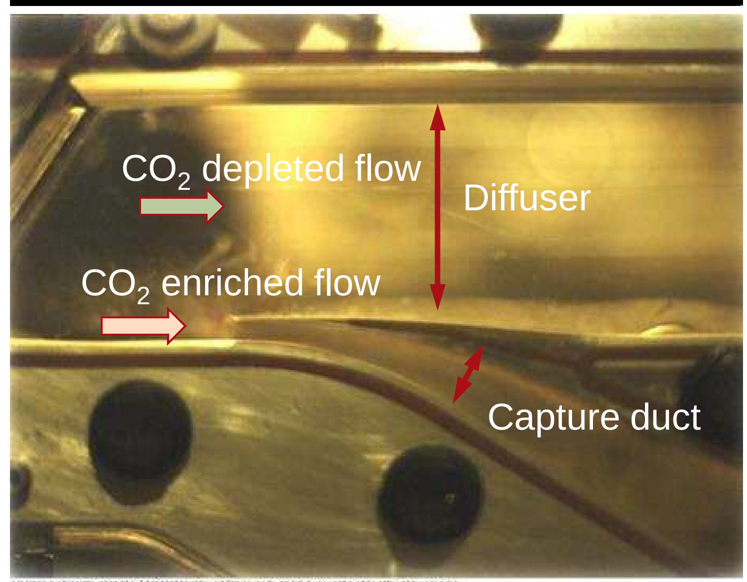
Laser Images from Capture Region





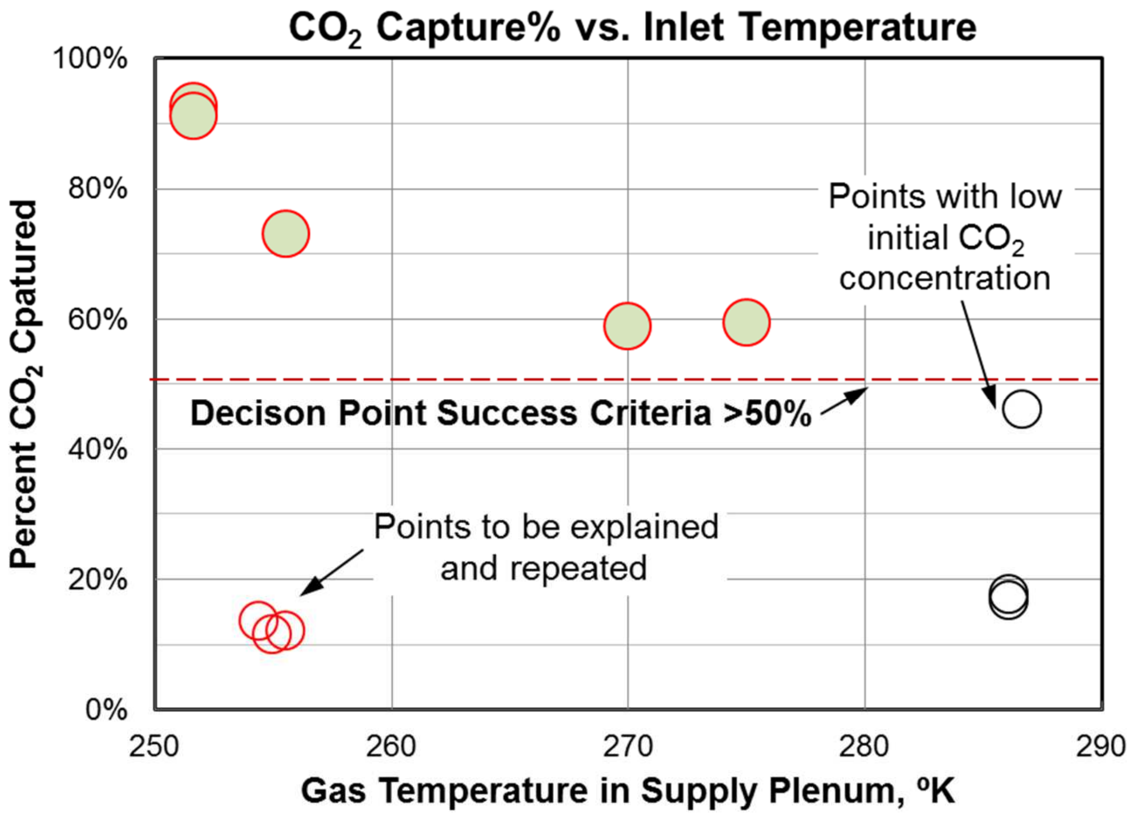
Video





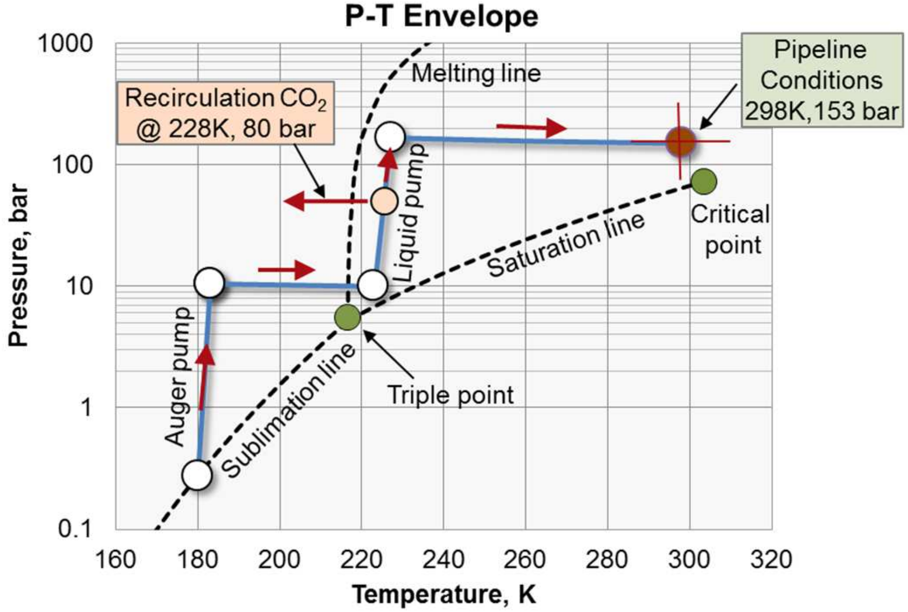
CO_2 Capture Results (Preliminary)

GC analysis of gas sample from primary (CO_2-depleted) flow stream used to calculate CO_2 Capture%

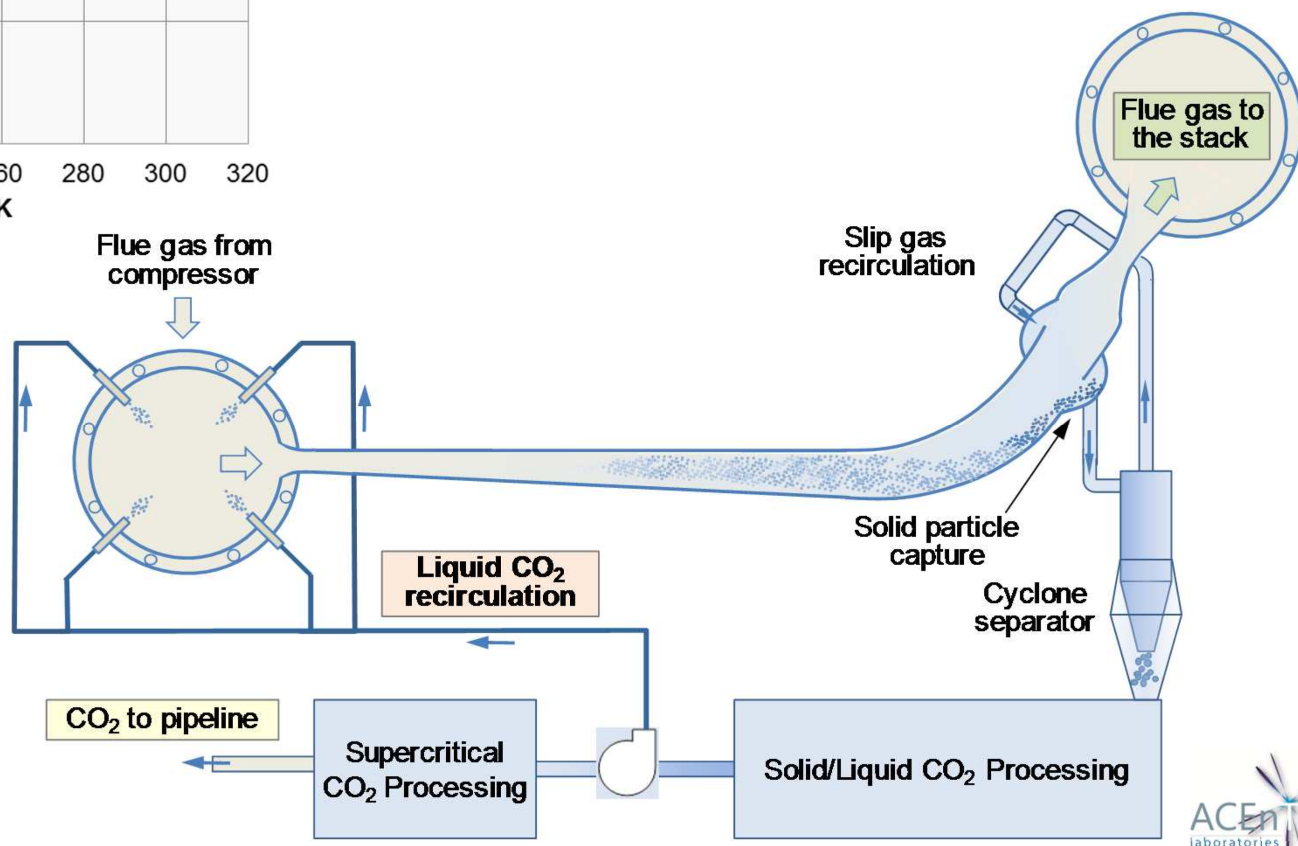


Most data consistent with good-to-excellent performance when incoming temperatures are somewhat colder. Thought to promote earlier heterogeneous nucleation onto existing CO_2 particles.

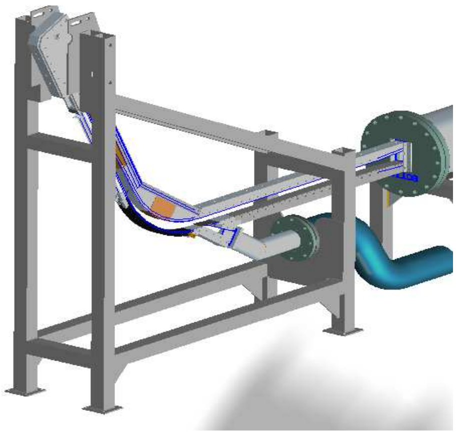
CO_2 Recirculation Approach



Recirculation of liquid CO_2 can achieve the desired results of additional cooling + creation of large particles to promote heterogeneous nucleation capable of migration.

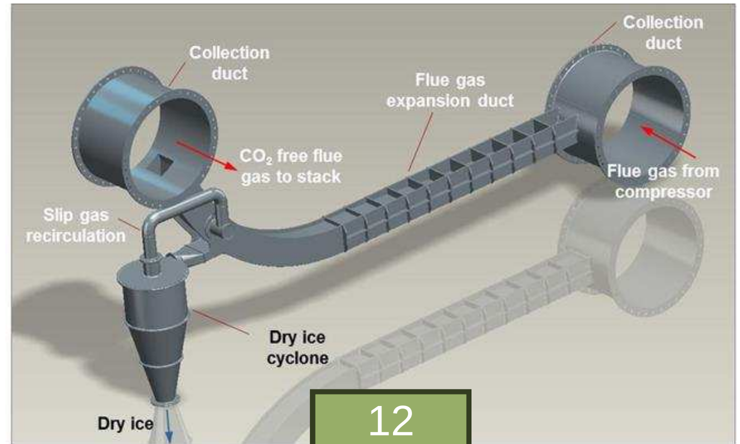


CFD Tool Benchmarking for Full Scale Pressure Recovery Predictions

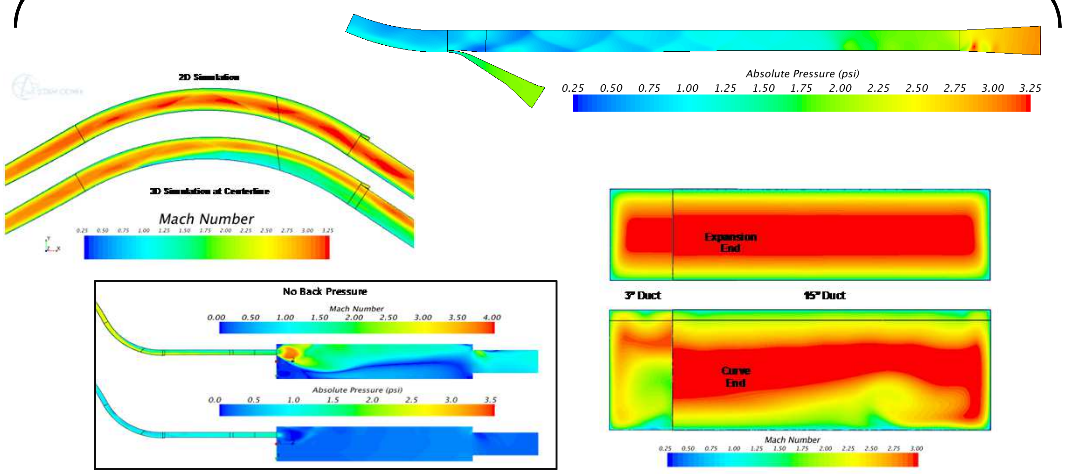


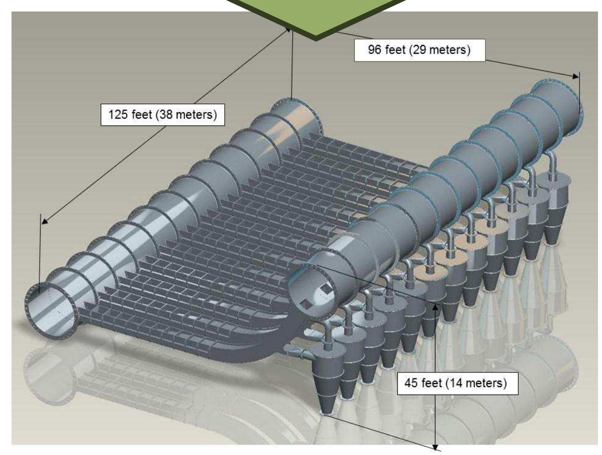
10X Photo Scale

CFD



12 Units





Current scale limits pressure recovery performance due to thick boundary layer relative to duct size. We are on track to show traceability and path towards target pressure recovery of 40% through

- CFD tool benchmarking using subscale test results (complete)
- CFD predictions of full scale performance

ICES Economic Impact

- A preliminary Techno-economic assessment by WorleyParsons (WP) was carried out in 2013
- Key efficiency/economic numbers are provided in the table below:

Metric	Case 11	Case 12, Amine Plant	ICES Plant
CO_2 capture	no	yes	yes
Net plant efficiency (HHV basis)	39.3%	28.4%	34.5%
COE % increase	base	77%	42%
Parasitic Load	5.5%	20.5%	7.3%
Cost per tonne of CO_2 captured	NA	US$ 62.8	US$ 41.8
Cost per tonne of CO_2 avoided	NA	US$ 90.7	US$ 48.4

A path to the DOE research goal of 35% COE increase is being developed based on a more detailed capex/labor model and reduced flue gas compression (PR=2.0 vs 2.5 used in WP analysis)

ICES Plant Layout and Footprint

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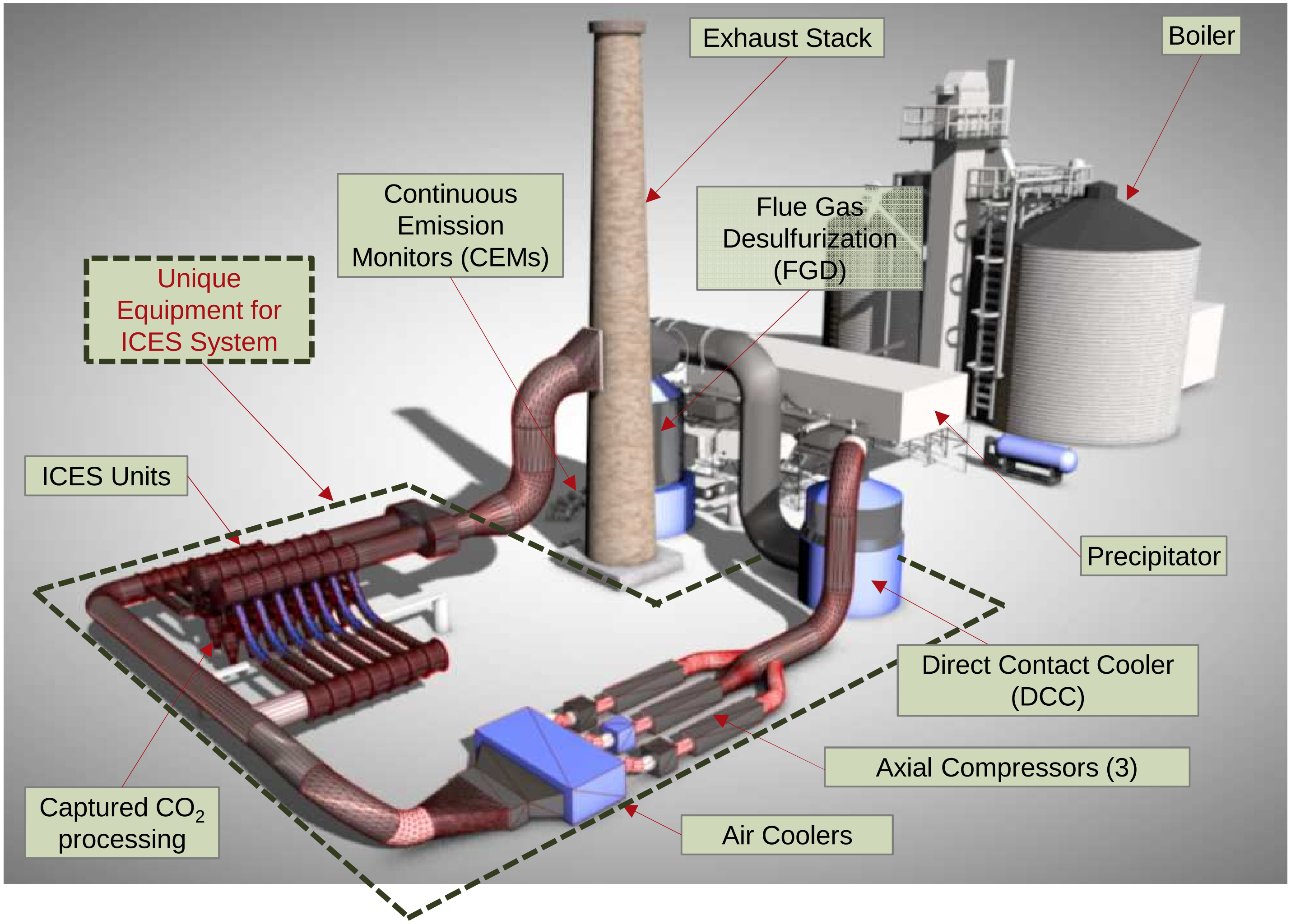

ICES footprint of ~8k m^2 compares to 20k to 30k m^2 for an amine plant of similar capacity. ICES nozzle and compressor stacking can further reduce footprint by 30-40%.

Project Schedule

	Budget Period 1				Budget Period 2				Budget Period 3			
	Quarters											
Tasks	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Task 1. Program Management												
Task 2. Lab-scale Condensation/Growth Investigation												
Task 3. Analytical and Computational Investigation												
Task 4. Bench-scale Capture and Diffuser Testing												
Task 5. Bench-scale Condensation/Growth Testing												
Task 6. Integrated System												
Task 7. Plant Integration and Techno-economic Analysis												

MS1 MS2 MS3

MS 1. Updated project management plan – **complete**
MS 2. Kickoff meeting - **complete**
MS 3. Capture duct/diffuser demonstration – **on track**

Summary

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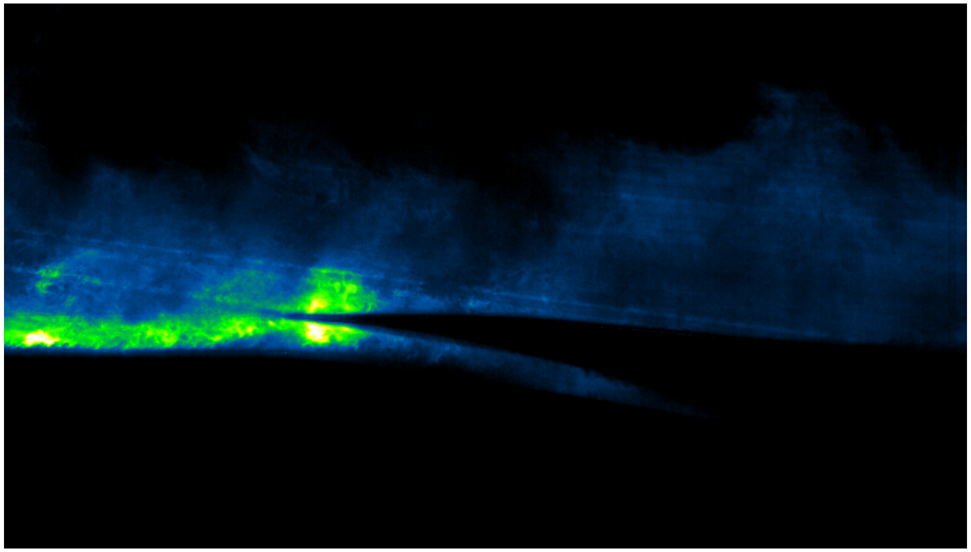
- ICES Technology holds considerable promise as an alternative to adsorbents and membranes
- Current NETL effort focused on solving key technical challenge of particle size
- Testing and analysis results to-date support project goals for capture efficiency and economics
- Program is on track to meet Budget Period 1 decision point success criteria
- We're moving fast (about Mach 3) and have promising results so far !



Acknowledgements

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- **NYSERDA**
- **NYS-DED**