Analysis of Gas Samples Collected from the 10 MWe Supercritical Transformational Electric Power (STEP) Demonstration Plant

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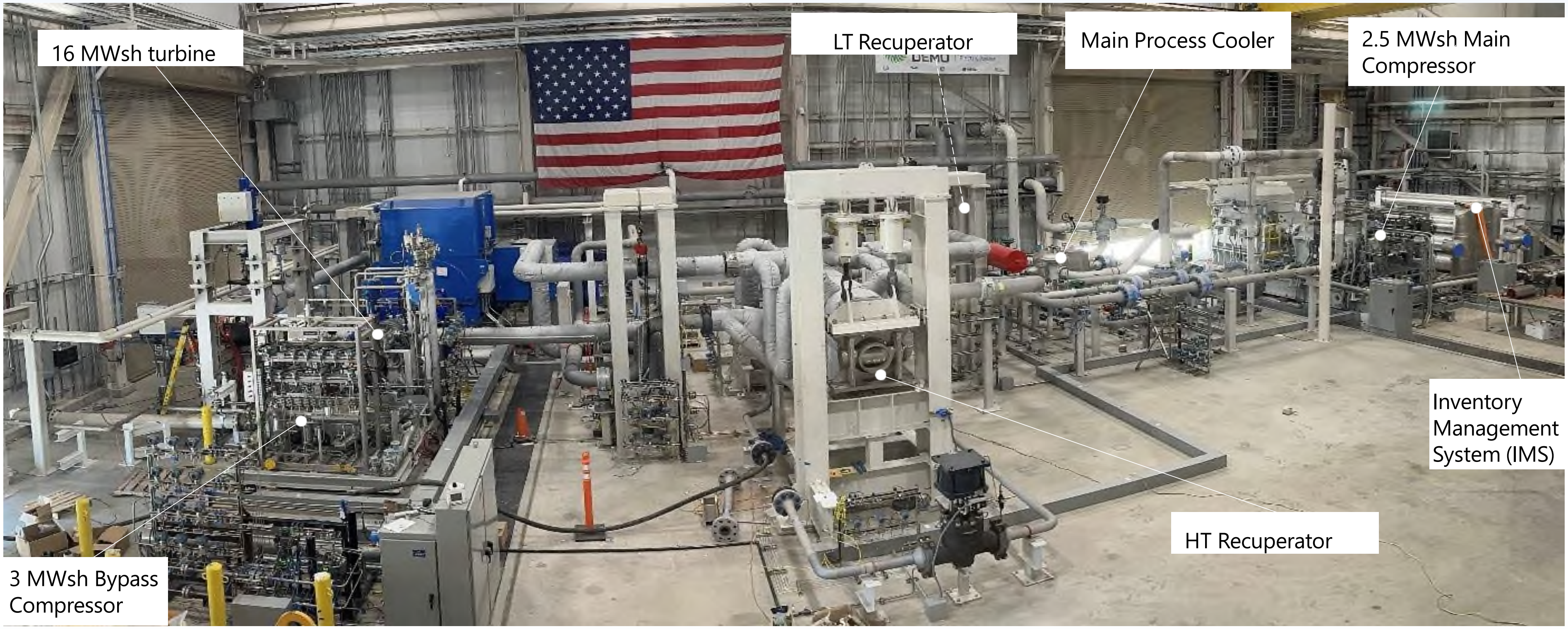
Supercritical Transformational Electric Power (STEP) Demo Project

- **Objectives:**
  - Advance sCO_2 power from TRL3 to TRL7
  - Demonstrate pathway to net plant efficiency > 50%
  - Demonstrate control and operability at **500°C** and **715°C** turbine inlet temperature with **10 MWe** power generation
- **Accomplished:**
  - Simple Cycle (SC) operation – 4 MWe to grid
  - Reconfiguration to RCBC – Ready to test
- **Project Partners:**

www.STEPdemo.us

U.S. Department of Energy | National Energy Technology Laboratory, GTI Energy, SwRI, GE Vernova, KEPCO, Petrobras, Natural Resources Canada, Southern Company, Texas Commission on Environmental Quality, ENGIE, Spectrum Impact, CSIRO, American Electric Power, EGAT

STEP Power Cycle Equipment



Objectives for CO_2 Sampling

- The efficiency of sCO_2 power cycles can be influenced by working fluid composition
- Impurities impact corrosion and carburization rates
- The goal is to establish a reliable baseline for impurity detection in sCO_2 cycles, enabling future impact assessments of long-term operation on system performance and material integrity
- Establish a gas sampling procedure to analyze and quantify sCO_2 impurities in STEP
- Apply this baseline sampling and analysis procedure to longer hours of operation (RCBC)

Effects of Impurities on sCO_2 and Materials

- Impurities (e.g., N_2, O_2, H_2O, etc.) in sCO_2 alters its thermodynamic properties (generally different effects in gas, liquid, and supercritical phases)
  - Critical point
    - Raise critical pressure and lower critical temperature
    - Can move operating conditions to subcritical, two-phase, or liquid regions
  - Density and compressibility
    - Decrease: increase (compressor) specific work, reduce mass flow and efficiency
  - Specific heat and enthalpy
    - Decrease: increases (compressor) specific work, reduces efficiency
  - Speed of sound
    - Decrease: detrimental to compressor aerodynamics

- Impurities can affect material compatibility
  - Can accelerate corrosion
    - Disrupting protective oxide layers
    - Promoting breakaway oxidation
    - Enhancing carburization
- Leading to
  - Decreased material lifetime
  - Decrease heat-transfer efficiency in heat exchangers
  - Increased component degradation
    - Increased maintenance and component replacement

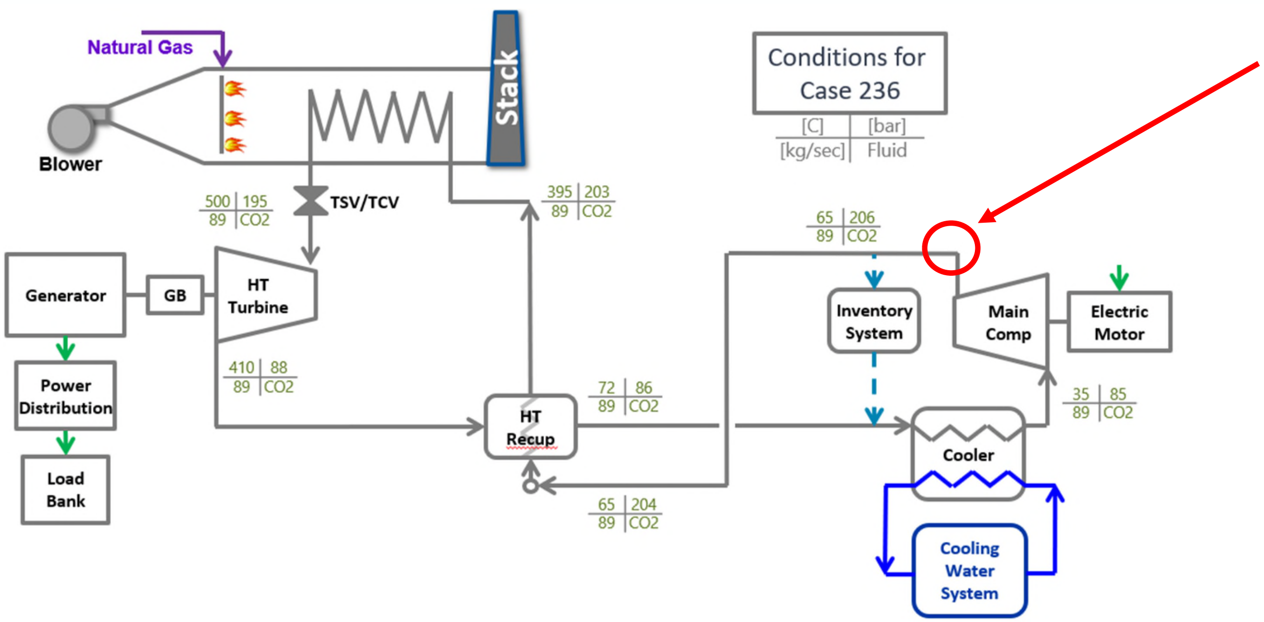
Impact on Cycle Efficiency

CO_2 Purity	Performance Loss (Net Power Reduction)
>99.8%	minimal (≤2%)
99%	5–11% loss
96%	up to 30% loss

TECHNO-ECONOMIC ANALYSIS OF CO_2 IMPURITIES' IMPACT ON A SCO_2 SYSTEM PERFORMANCE, The 6th European Conference on Supercritical CO2 (sCO2) for Energy Systems Delft, The Netherlands | 9 - 11 April 2025.

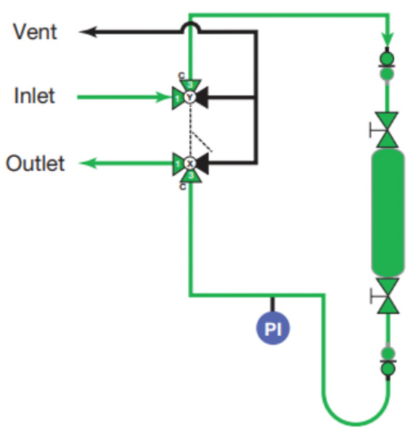
- Impurities alter thermodynamic properties of CO_2
  - E.g., specific heat, density
- System performance sensitive to presence of impurities
- Impurity levels must be considered
  - Levels and compositions in CO_2 supply
  - During operation – i.e., health monitoring

STEP Demo Gas Sample Points – Simple Cycle

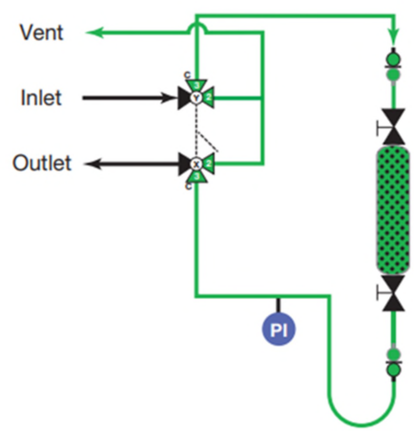


- Samples #1-8 taken from Main Compressor discharge flowmeter location
- Sampling panel is pressure limited (137 bar) so all samples were taken with machinery stationary
- Samples #9-10 were taken from the outdoor process vaporizer near the liquid CO_2 tank (not shown here).
  - Rarely depressurized area should indicate the purity of CO_2 that exists in the liquid storage tank.

High-pressure Sample Panel and Operating Modes



Purging and taking sample



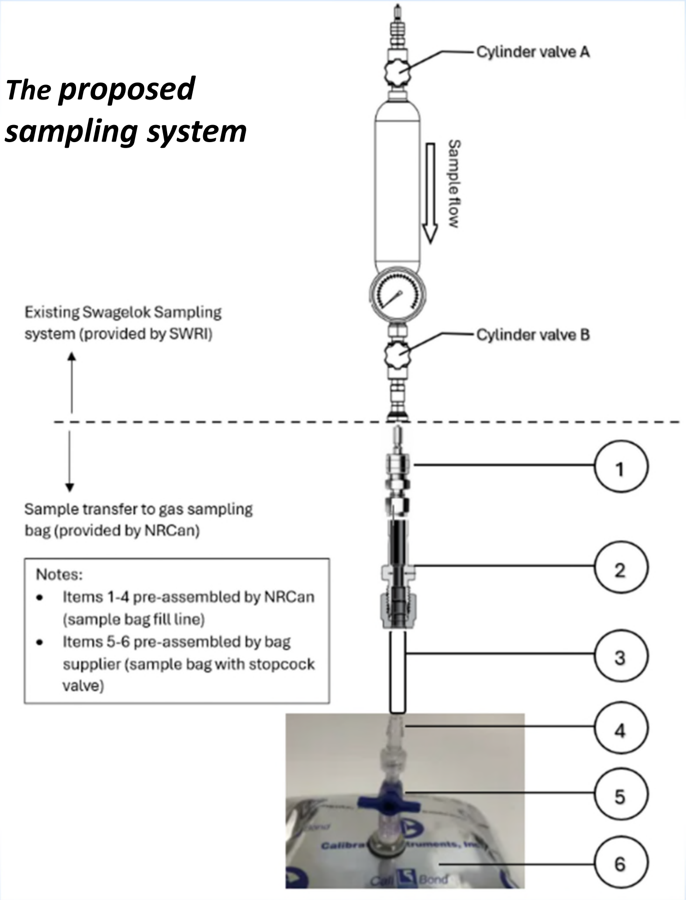
Isolating sample bottle, and sample lines depressurization

Gas Sampling Panel

Cylinder to Pillow-style Gas Sampling Bag

- Bags are easy to ship
- Low-cost
- Flexible
- No need to be returned (disposable)

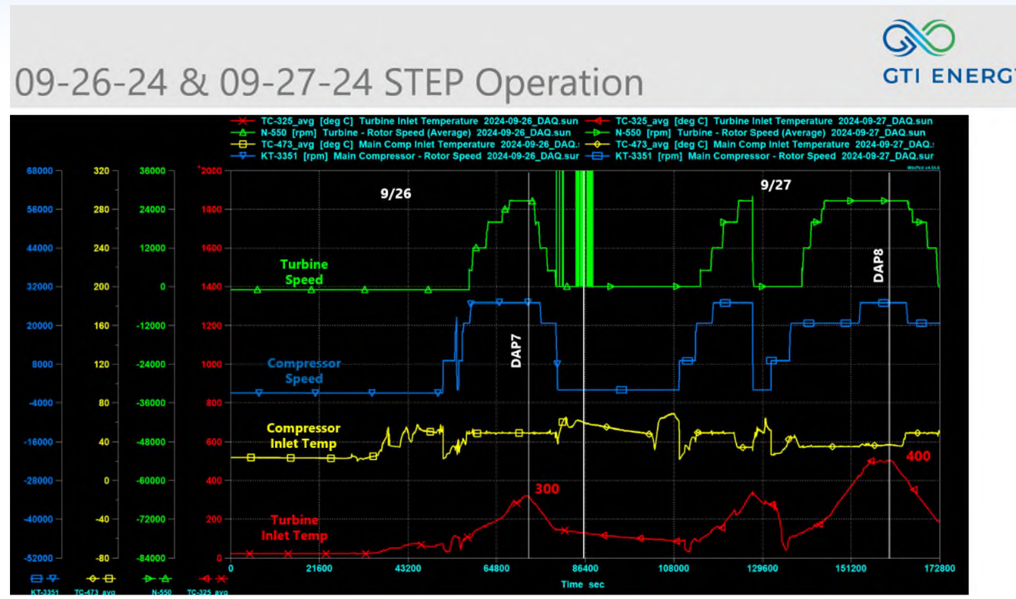
- Two-step filling method to minimize contamination: Fill → evacuate → refill
- 10 samples collected (GTI #1–10)



Samples Date and Time

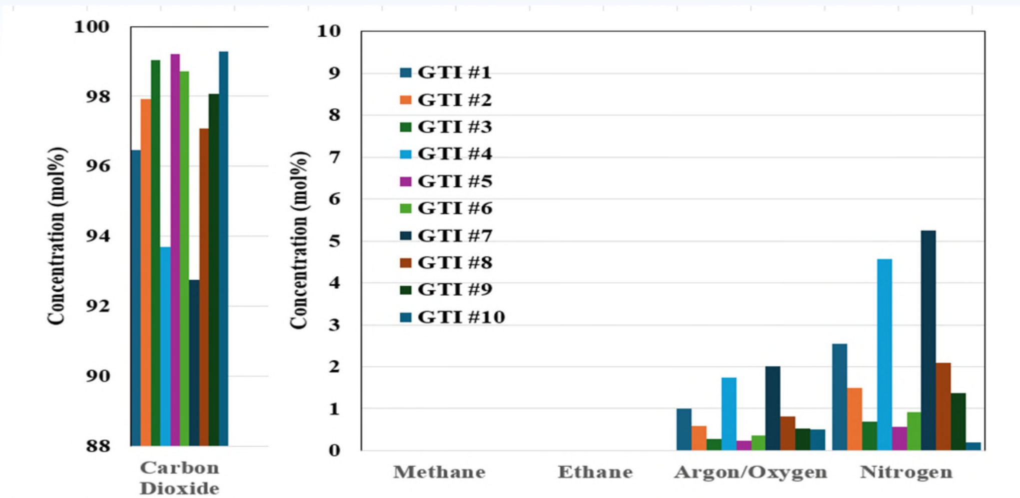
	Assigned Name*	Date and Time of Sampling	Time (sec)	GC	MS
1	GTI#1	9/26/2024 23:09	83,340	X	
2	GTI#2	9/26/2024 14:15	51,300	X	
3	GTI#3	9/26/2024 14:14	51,240	X	X
4	GTI#4	9/26/2024 23:09	83,340	X	X
5	GTI#5	9/27/2024 22:30	167,400	X	X
6	GTI#6	10/2/2024 18:30	N/A	X	X
7	GTI#7	10/2/2024 18:30	N/A	X	X
8	GTI#8	9/27/2024 22:30	167,400	X	X
9	GTI#9	12/30/2024 11:00 Sample1 CO_2 Sample of Process Vaporizer	N/A	X	X
10	GTI#10	12/30/2024 11:00 Sample2 CO_2 Sample of Process Vaporizer	N/A	X	X

The list of received gas samples and the corresponding gas analysis performed



STEP operating data plot relevant to the gas sampling

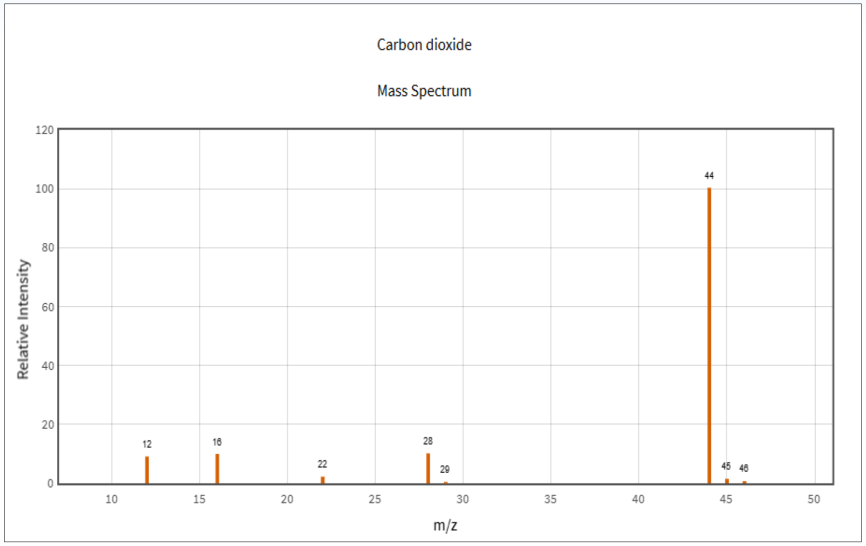
Gas Chromatography Results (GC)



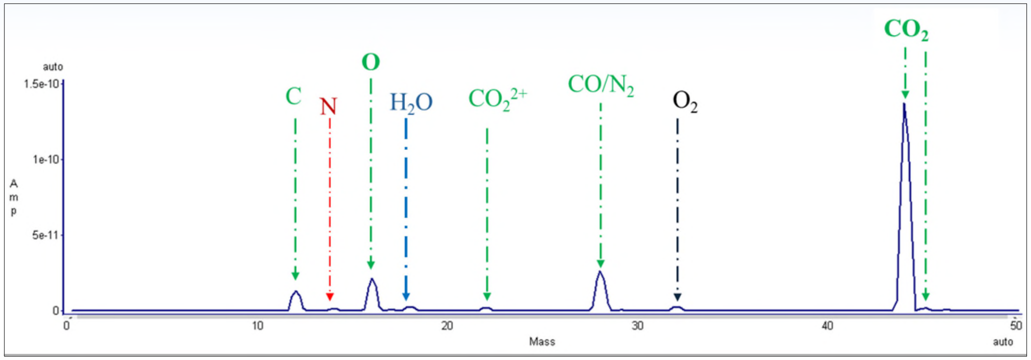
Components	Amount [mol %]									
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Carbon Dioxide	96.47	97.92	99.03	93.69	99.21	98.71	92.75	97.08	98.8	99.28
Methane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Argon/Oxygen	0.99	0.58	0.28	1.74	0.23	0.36	2	0.82	0.53	0.51
Nitrogen	2.55	1.5	0.68	4.56	0.56	0.92	5.25	2.1	1.38	0.2
t-2-butene	-	-	-	-	-	<0.01	-	-	-	-
1-butene	-	-	-	-	-	<0.01	-	-	-	-
3-Methyl-1-Butene	-	-	-	-	-	<0.01	-	-	-	-
t-2-Pentene	-	-	-	-	-	<0.01	-	-	-	-
C6 Plus	-	-	-	-	-	<0.01	-	-	-	-

- Limited to dry gas only, i.e., water cannot be detected
- Concentrations <0.01% reported as zero due to method limits
- Lower detection limit for He, H_2, CO, CO_2, COS, H_2S = 0.04% (detector sensitivity constraint)

Mass Spectrometry (MS)



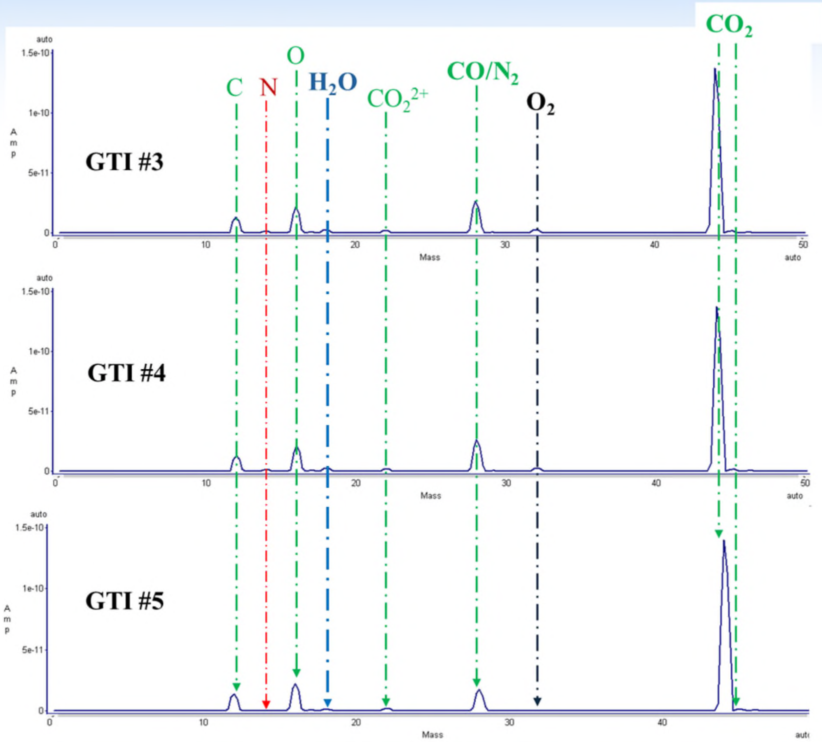
The NIST mass spectrum of CO_2 (NIST webbook-SRD69)



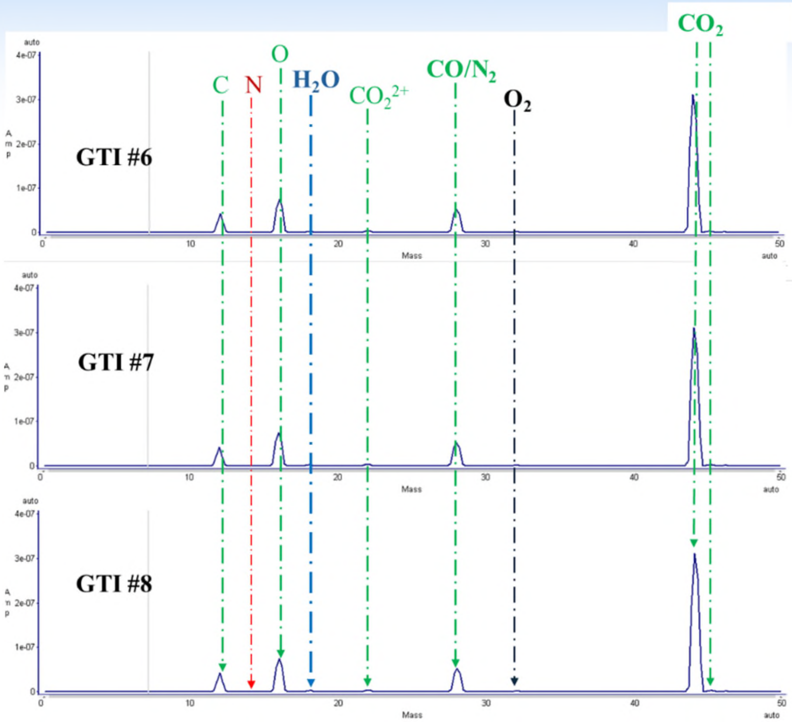
Mass spectrum of GTI#3 sample and relevant components

Confirmed presence of:
- H_2O (18 amu)
- N_2 (28 amu)
- O_2 (32 amu)
- CO_2 fragments (12, 16, 28, 44, 45 amu)

Comparative Mass Spectrum of the Samples



Comparative mass spectrum of samples GTI #3-5 and the components



Comparative mass spectrum of samples GTI #6-8 and the components

Conclusions and Recommendation

Conclusions:

- Air ingress likely during sampling due to the presence of trace amounts of oxygen (O_2) and nitrogen (N_2)
- Moisture presents in process gas, not detectable by GC
- Hydrocarbons extremely low → no immediate concern
- Results represent limited operating hours → not a representative of long-term trends

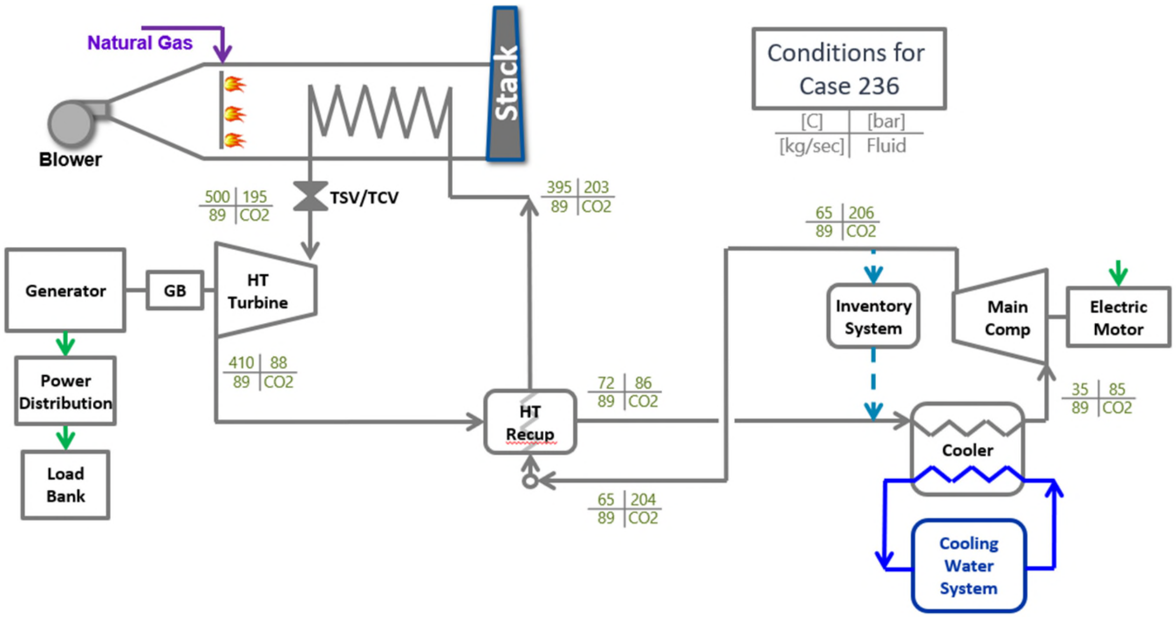
Recommendations:

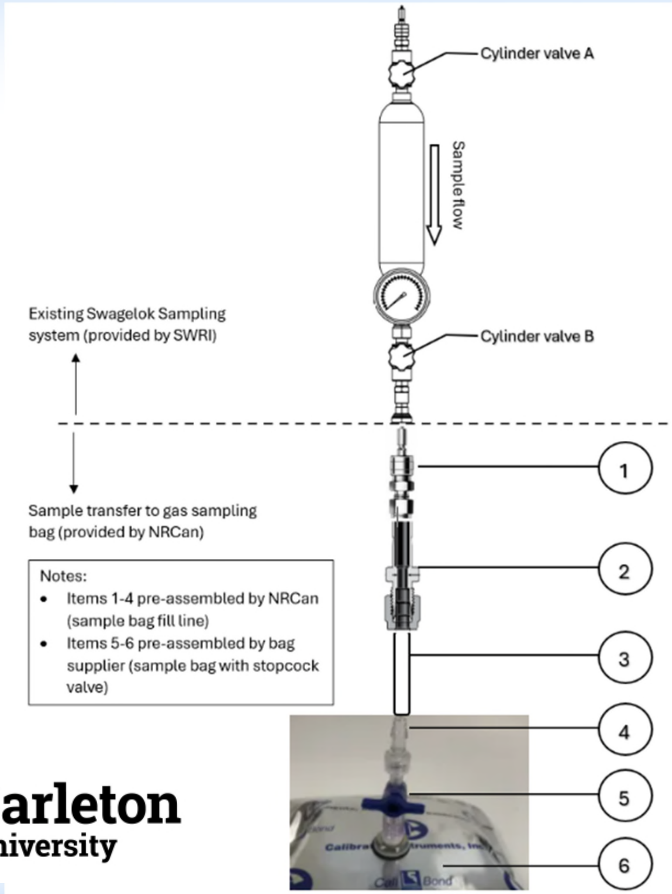
- Improve sampling to reduce air ingress (consider two-port flow-through bags).
- Use data to support materials testing and cycle performance modelling
- Combine GC/MS for future quantification
- Extend sampling during RCBC operation

Two-port, flow-through sample bag

sCO2

Questions?





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