Low–Global Warming Potential Refrigerant Leak-Sensing Methods for Commercial Refrigeration

Oak Ridge National Laboratory
Vishaldeep Sharma, R&D Staff (PI)
Praveen Cheekatamarla, R&D Staff (speaker)
865-574-5810, sharmav@ornl.gov
WBS # 3.2.2.38

Project Summary

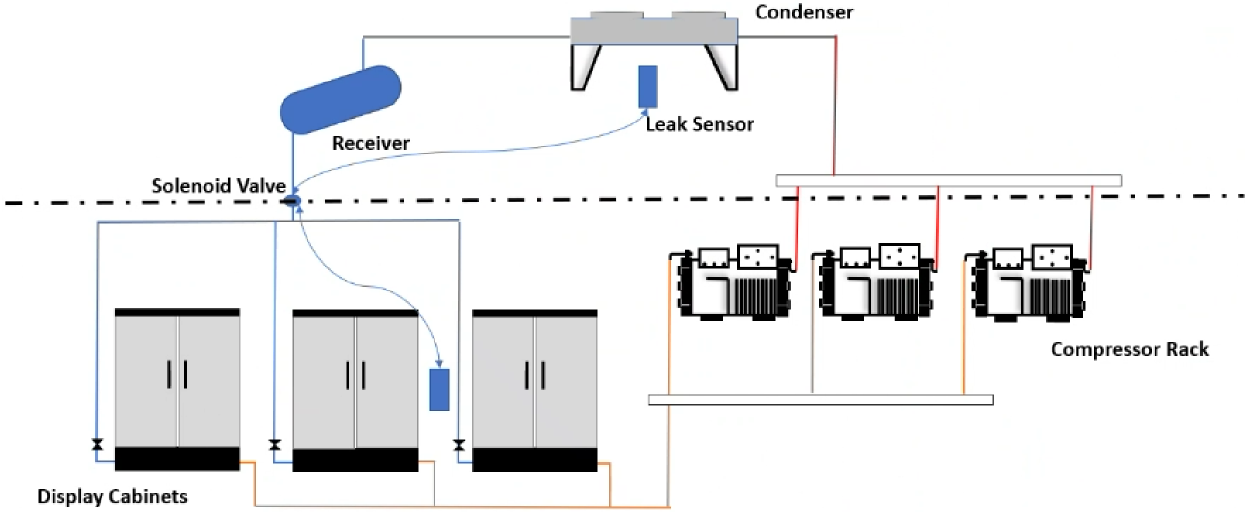
Objective and outcome

Enable successful adoption of low-GWP (<150) refrigerants in commercial refrigeration.

- A2L sensor, standards and equipment design are parallelly evolving
- Holistic approach to realize A2L refrigeration system complying with existing standards and beyond
- Development of low-cost and highly reliable sensors for A2L refrigerants.
- Smart control, leak detection/isolation - multiple refrigeration system architectures
- $CO_{2,eq}$ impact – 44 MMT/year

Team and Partners

- ORNL
- Collaborators – Nevadanano, Emerson, Sensata, Figaro, Senseair



Stats

Performance Period: 10/1/2022 – 3/31/2025

DOE budget: $1400k

FY23 Q1 MS: Commercial sensor options

FY23 Q2 MS: Comprehensive test setup

FY23 Q3 MS: Baseline performance of commercial sensors

Problem

- **Direct emissions from supermarkets and other large food retail stores**
  - commonly use multiplex direct expansion refrigeration systems
  - refrigerant charges of > 1000 lb
  - long refrigerant piping
  - annual refrigerant leaks of 25%[1]
  - R-404A (**GWP 3922**), R-448A (**GWP 1273**)
  - centralized refrigeration systems (80% of current commercial refrigeration market)

[1]ICF Consulting, Revised draft analysis of US commercial supermarket refrigeration systems, United States Environmental Protection Agency Stratospheric Protection Division, 2005.

Solution

- **A2L (GWP < 150) refrigeration system**
  - Replacement low-GWP (<150) options such as R454C, R455A in a distributed architecture
  - A2L class
  - Flammability concerns
  - Robust safety solutions are necessary
  - Reliable sensor integrated with engineered control system are required
  - Accuracy, sensitivity, fractionation, selectivity

Safety Classifications for Refrigerants

	Lower Toxicity	Higher Toxicity
Higher Flammability	A3	B3
Flammable	A2	B2
Lower Flammability	A2L	B2L
No Flame Propagation	A1	B1

Reference: ISO 817 Refrigerants — Designation and safety classification

[1]ICF Consulting, Revised draft analysis of US commercial supermarket refrigeration systems, United States Environmental Protection Agency Stratospheric Protection Division, 2005.

Solution

- Comprehensive leakage data from 5,500 stores has been collected
- Identify statistically relevant leak locations
- Refrigeration system architecture considerations
- Leak isolation strategies with refrigeration controls
- Sensor and control integration with multiple commercial refrigeration system architectures

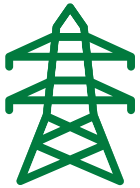
Refrigerant category	Example	Burning Velocity	Lower Heating Value, MJ/kg
A3	Propane	1.28 ft/s	46.4
A2	R-152a	0.75 ft/s	16.2
A2L	R-32	0.22 ft/s	9.1
B2L	R-717	0.24 ft/s	19.3

[1]ICF Consulting, Revised draft analysis of US commercial supermarket refrigeration systems, United States Environmental Protection Agency Stratospheric Protection Division, 2005.

Alignment and Impact

Successful implementation of A2L refrigerants enables electrification and decarbonization of commercial refrigeration systems

- Reduction in direct GHG emissions by 98%
- Lower operating expenditure via efficient refrigerant management approach
- Flexibility towards several low-GWP refrigerants
- Sensitivity, Response, Selectivity under all field environments is needed for a reliable and robust solution



Accelerate building electrification
Reduce onsite fossil-based CO_2 emissions in buildings – 25% by 2035 and 75% by 2050, compared to 2005

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Approach

- Holistic approach to realize A2L refrigeration system complying with existing standards and beyond, and suitable for multiple system architectures
  - Review the current test standard, methodology, and data to identify knowledge gaps (M3)
  - Develop a detailed test matrix (M6)
  - Investigate the features of commercially available sensors (M9)
  - Identify potential gaps in existing technology (M12)
  - Develop a new sensor (M18)
  - Analyze leak data from 5,500 stores (M21)
  - System design for multiple refrigeration architectures (M24)
  - Control system development for isolating leaks (M27)
  - Reliability testing and commercialization (M30)

Requirements

- Capable of operating safely with any A2L refrigerant without becoming an ignition source themselves
- Very high reliability during the lifetime (10+ years)
- Ready to operate with smart control and fault detection and diagnostics systems employed in these applications
- Wireless capabilities (Internet of Things connectivity) to simplify deployment in typical supermarket stores
- Capable of measuring refrigerant concentration with sufficient accuracy, and of providing adequate response time according to appropriate safety standards (UL 60335-2-40)

A2L Flammability, Toxicity

Refrigerant	20% LFL (ppmv)	RCL (ppmv)	GWP (AR4)
32	28,800	36,000	675
1234yf	12,400	16,000	4
1234ze(E)	13,000	16,000	6
444A	20,000	21,000	87
445A	18,000	16,000	129
451A	19,000	18,000	146
454B	19,500	19,000	465
454C	16,000	19,000	145
455A	30,000	30,000	145
457A	16,000	15,000	136
516A	35,000	27,000	142

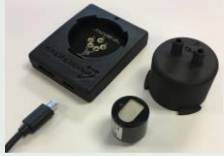
RCL – Refrigerant concentration limit

LFL – Lower flammability limit

Sensor Performance Test

Attribute	Range	Test method
Concentration/Accuracy	5% LFL – 25% LFL; ± 3%	Signal vs conc.
Time constant/response time	1% - 25% LFL	Signal response time after leak initiation
Sensitivity and Selectivity	Humidity (10%-90%); temperature (-30F to +275F); CO_2 (0.05% to 1%); refrigerant (134a, 404A, 407A); (NO_X – ppmv; CO – ppmv); impact of fractionation, oil, cleaning agents, engine exhaust	Presence of humidity, temperature, CO_2, other refrigerants, poison species: co-injection
Repeatability	Signal variance between sensors	Simultaneous evaluation
Reliability	1. Continuous exposure time 2. Oversaturation (pure refrigerant exposure) 3. On/off cycling 4. Powered sensor 5. Signal drift vs. time	Exposure to different test conditions
Location	Floor vs. Ceiling	Impact of density
Robustness (vibration/shock)	TBD	Vibration sensitivity Shock sensitivity
Flexibility	Multiple A2L blends	Cross compatibility feasibility

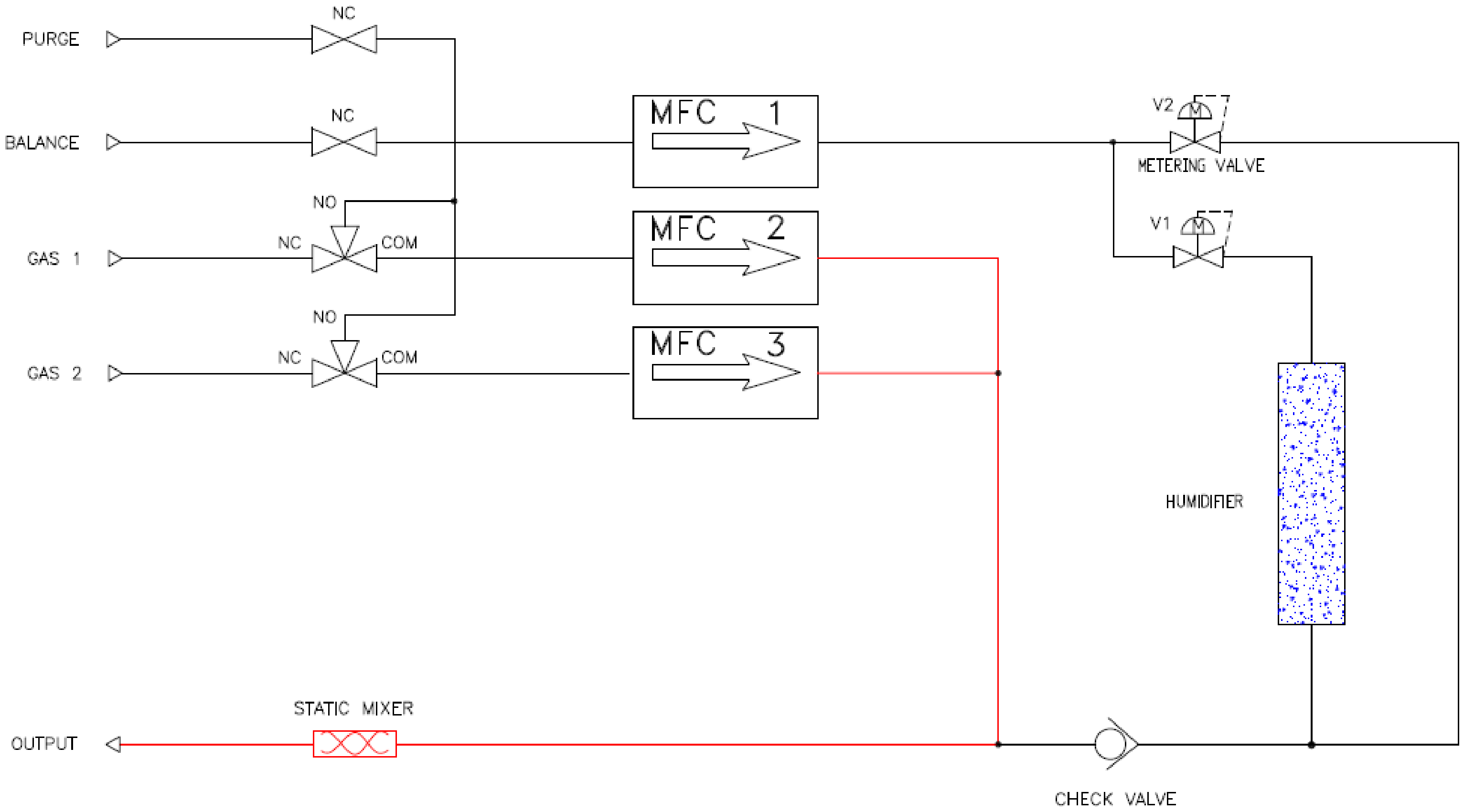
Sensors

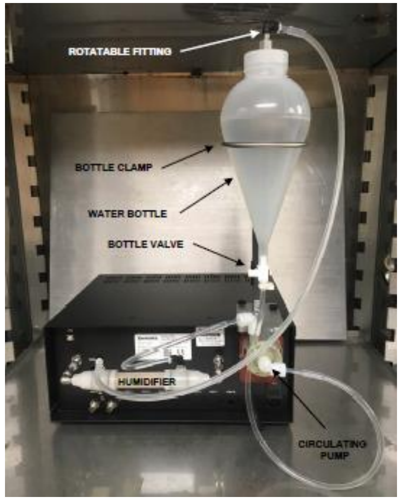
Model	Refrigerants	Sensing Element	
TGS2630	R-32, R-1234YF, R-290, R-404a, R-410a	SnO_2	
MPSXXX-MNXXX-XX	R-32, R-454B, R-454C, R-404A, R-407A	Molecular Property Spectrometer	
LDM150R	CFC, HFC, HFO, HCFC	Surface Reaction Sensor	
Resonix	A2Ls		
Sunlight R32	R-32	NDIR – Nondispersive infrared	
A2L sensor	A2L	TCD – Thermal conductivity detector	
080Z2803	A2Ls	MOS – Metal oxide semiconductor	

Test Facility - Mixing System

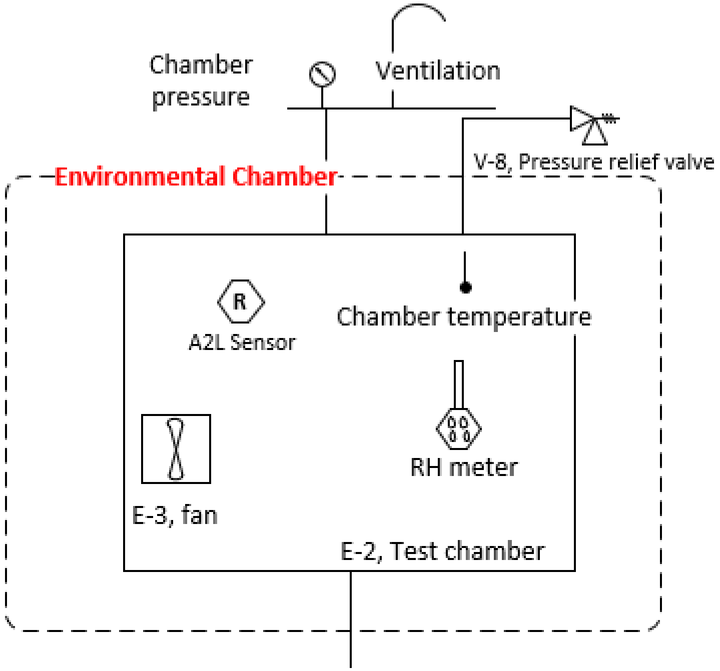
Portable Computerized Gas Mixing System has been designed and developed

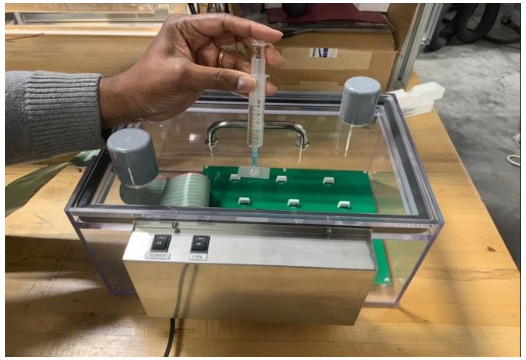
- Gas ports (4)
  - Purge (N_2)
  - Balance (air),
  - Component 1 (A2L)
  - Component 2 (trace poisoning species)
- **500 ppmv – 50,000 ppmv ($\pm$ 1%, sp)**
- **RH: 5 - 95%**
- **Up to 40ºC feed temperature**

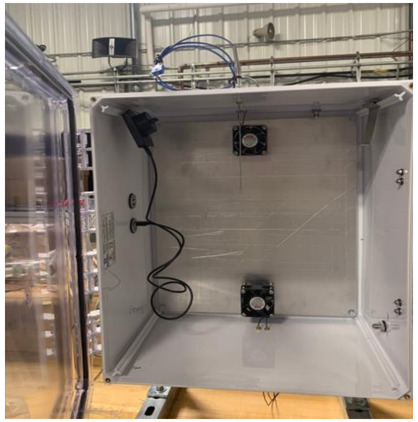




Test Chamber







Air-tight test chamber

- Housing up to 6 sensors simultaneously
- Static and flow-through environment
- Internal mixing
- Hazardous environment rated components
- Pressure relief device

Test scenarios

- Orientation
- Distance
- Diffusion
- Temperature
- Density
- Sensitivity
- Selectivity*
- Location
- Concentration*
- Accuracy
- Reliability

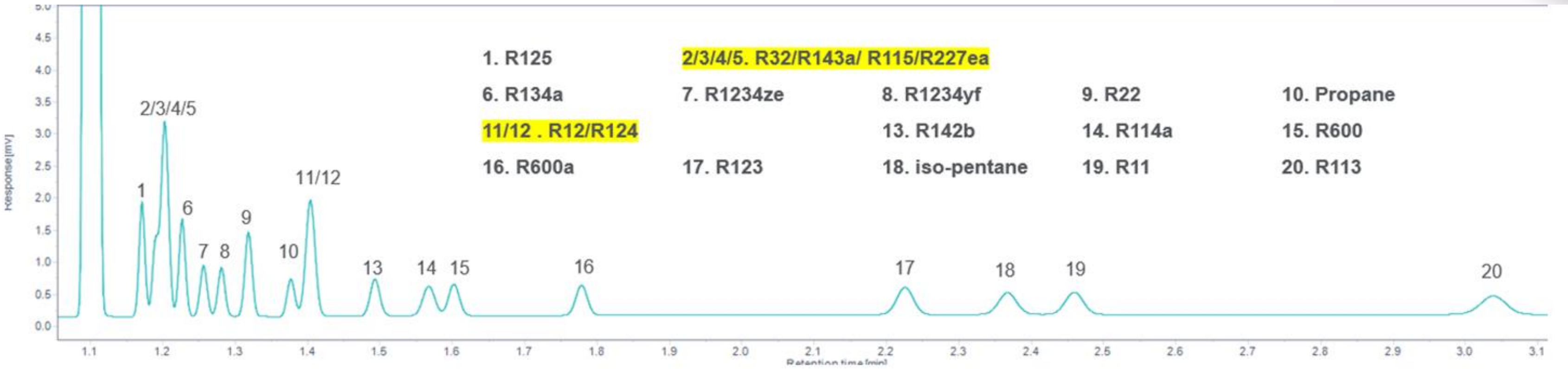
Gas Composition, Calibration and Analysis

Customized Micro Gas Chromatography to measure a wide range of refrigerant compositions in a short time period

- 3 Channels
- Single carrier gas
- Three detectors
- Capable of detecting a wide range of refrigerants and primary gases
- 3-minute sampling and analysis
- Packed and capillary columns

Gas standards

- Secured A2L calibration standards

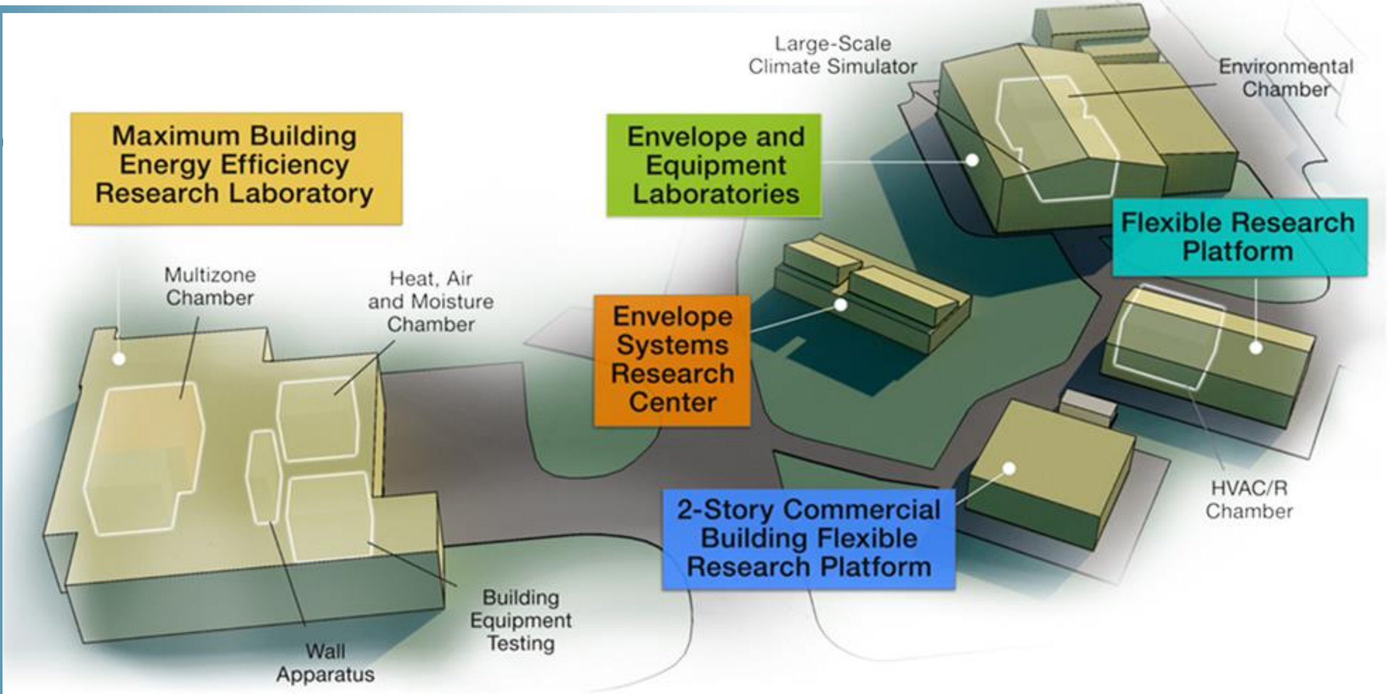


Thank you

Oak Ridge National Laboratory

Vishaldeep Sharma, Praveen Cheekatamarla, R&D staff

sharmav@ornl.gov, cheekatamapk@ornl.gov



ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$600,000				$600,000				$200,000			
Spent budget	$400,000											
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Completed work												
Q1 Milestone: Commercial sensor screening												
Q2 Milestone: Lab setup complete												
Current/Future Work												
Q3 Milestone: Performance evaluation complete												
Q4 Milestone: Data analysis and gap identification												
Q1 Milestone: Prototype development												
Q2 Milestone: Prototype evaluation												
Q3 Milestone: Controller development												
Q4 Milestone: Final report												

- GNG 1 - Complete sensor evaluation – compliance with safety standards (5/31/2023)
- GNG 2 - Complete prototype sensor development (12/30/2023)

Team

- **Vishaldeep Sharma** – PI, sensor and refrigerants, system development, industry engagement
- **Viktor Reshniak** – Commercial sensors review
- **Praveen Cheekatamarla** – Test setup design and development, sensor evaluation and controls integration
- **Tugba Turnaoglu** – Sensor evaluation
- **Junjie Luo** – Environmental impact analysis
- **Samuel Yana Motta** – Industry requirements, refrigerants, commercial systems, senior advisor