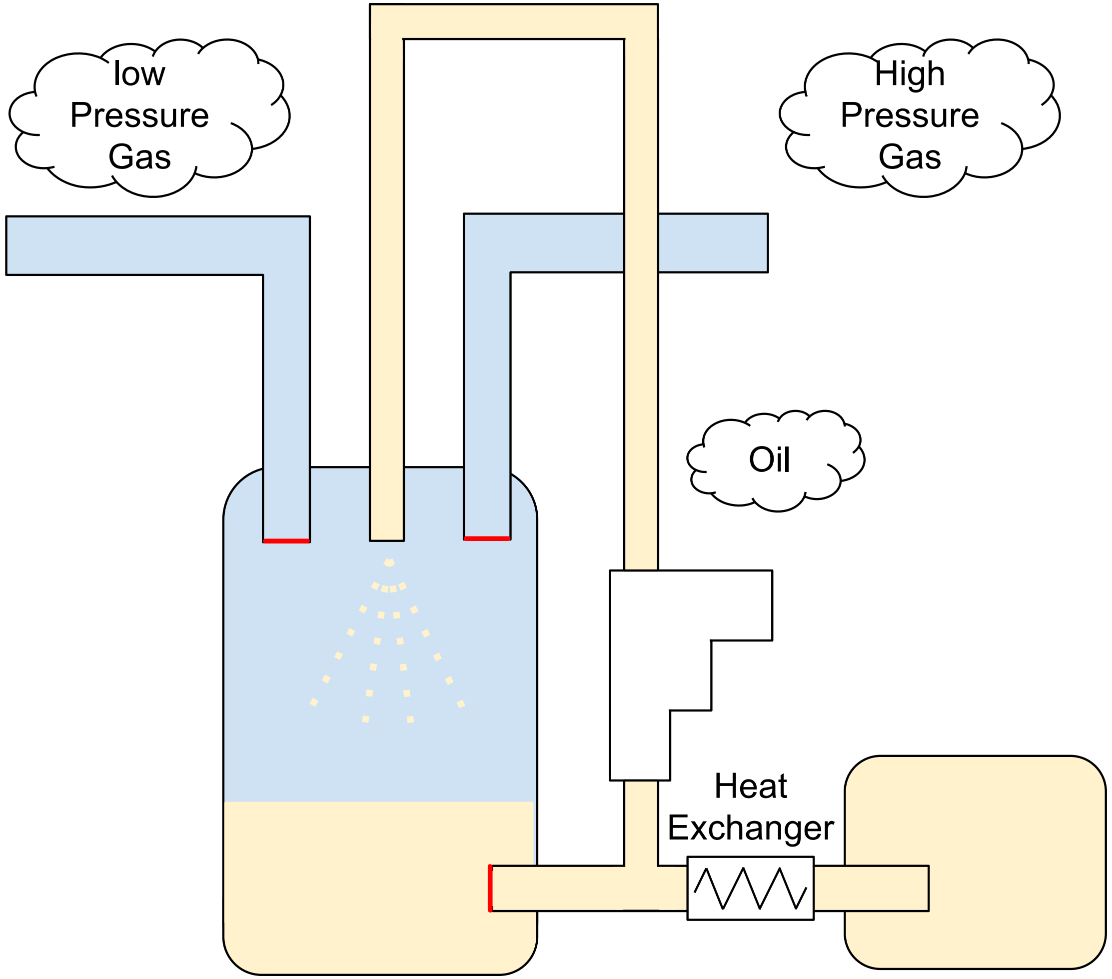
Liquid piston with spray cooling near isothermal compressor (IsoLiqComp)



Oak Ridge National Laboratory
Ahmad Abuheiba, R&D Staff
abuheibaag@ornl.gov

Project Summary

Timeline:

Start date: 10/1/2019

Planned end date: 9/30/2022

Key Milestones

1. Assemble second prototype of IsoLiq compressor (9/30/2021)
2. Demonstrate heat pump using IsoLiq compressor (6/30/2022)

Key Partners:

Discussions are underway with large HVAC&R OEMs

Budget:

Total Project $ to Date:

- DOE: $321K
- Cost Share: $0

Total Project $:

- DOE: $900K
- Cost Share: $0

Project Outcome:

To design and demonstrate near-isothermal compressor in laboratory environment, identify and demonstrate a viable application and engage an industry partner to commercialize the identified application.

Team

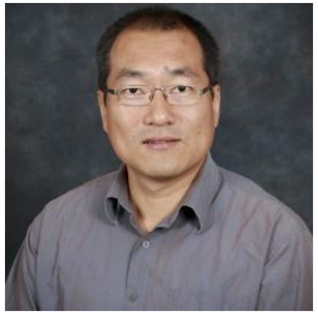
Ahmad Abuheiba, R&D Staff, Principal Investigator
Heat pump expertise

Praveen Cheekatamarla, Senior R&D Staff, system level integration
Expert in thermofluid systems design and integration

Joseph Rendall, Postdoc, experimental and modeling
Experience in experiment design, build and execution

Saiid Kassaee, ASTRO PhD candidate (graduated), modeling
Initial model development as part of dissertation

Bo Shen, R&D Staff, heat pump design and modeling
Heat pump expert and developer of HPDM

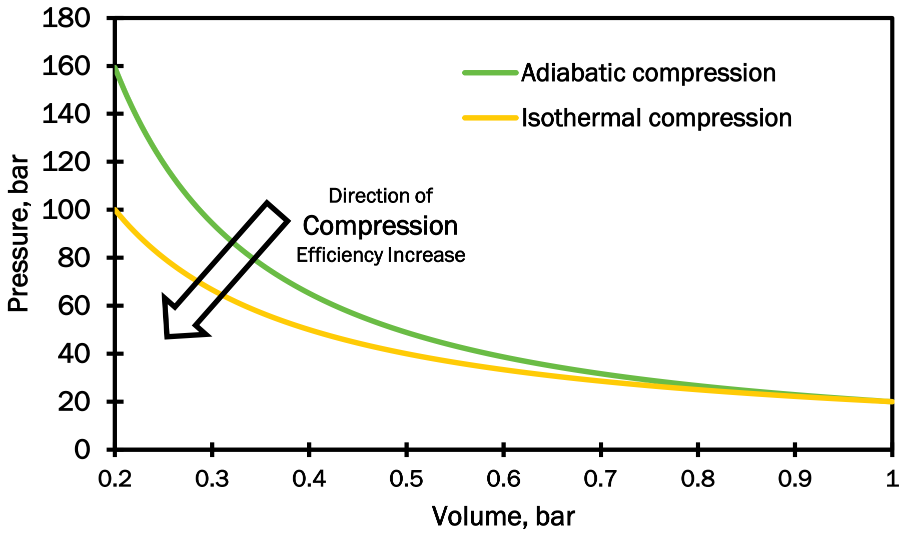


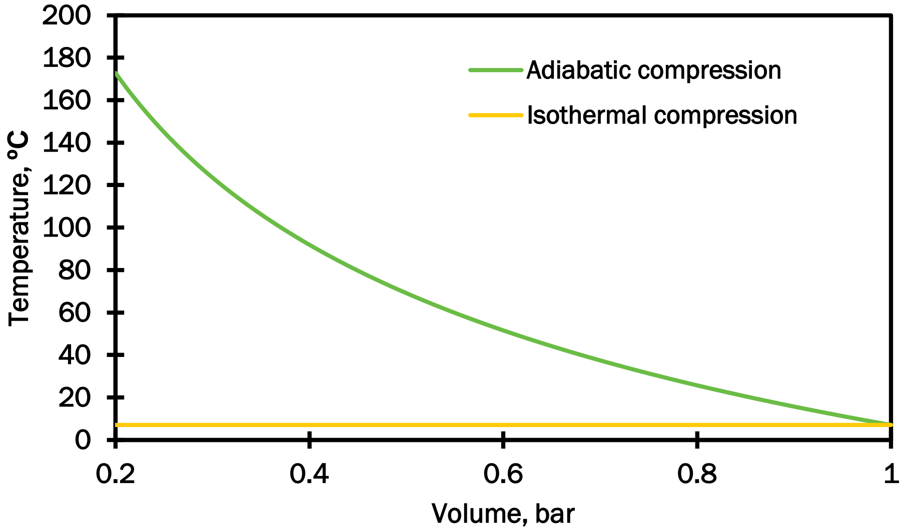
Steve Kowalski, Senior R&D Staff, prototype development lead
Expert in new HVAC residential and commercial product development

Challenge

Problem: ***Approximately 10 Quad of energy goes to compressors*** which is the heart of the vapor compression-based cooling or heating systems (***about 25% of whole U.S. electricity generation goes to the compressors***). Currently, compression is done mechanically at high frequency. This leads to:

- ***Large frictional dissipation power and very short residence time of the gas*** that is being compressed. Hence large fraction of the input power for compression is converted into heat that the gas absorbs and "keeps".
- ***Most mechanical compressors require lubrication. The lube circulates with the compressed gas*** causing issues. For example, in heat pumps, oil deteriorates heat transfer in the condenser and evaporator by as much as 20%. Another example is H2 fueling where purity is important.

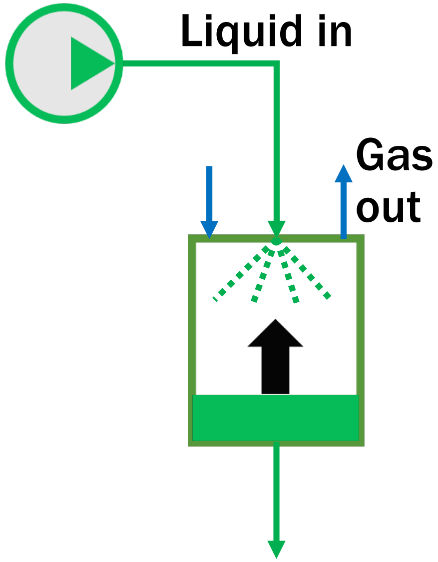




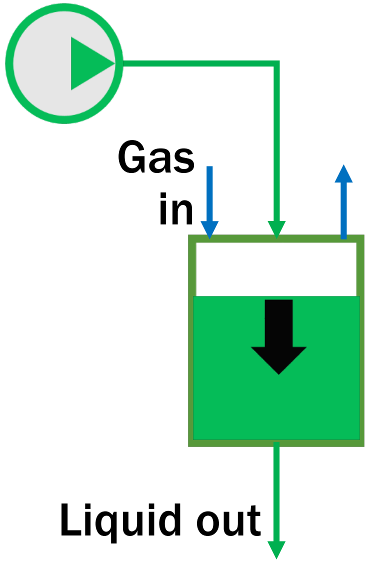
Approach - solution

The use of liquid piston to compress the gas (i.e., replace mechanical piston with liquid one). The liquid is sprayed into the compression chamber.

- The large surface area of the sprayed droplets results in very rapid heat transfer rate and the compression heat is removed nearly as fast as it is generated, achieving a nearly isothermal compression process.
- Careful design of the discharge ports and choice of droplet size ensures that the liquid is not entrained into the gas being discharged, i.e., preventing the liquid from circulating with the compressed gas.



Compression: Liquid is sprayed into the chamber



Suction: gas fills the chamber, forcing the liquid out

Approach – project plan

Modeling
- Physics-based model of the compressor
- Implementing the compressor model in an application model

Prototyping
- Build proof-of-concept prototype and Alpha prototype
- Demonstrate near isothermal compression and validate the model

Implementation
- Identify most viable applications
- Demonstrate at least one application

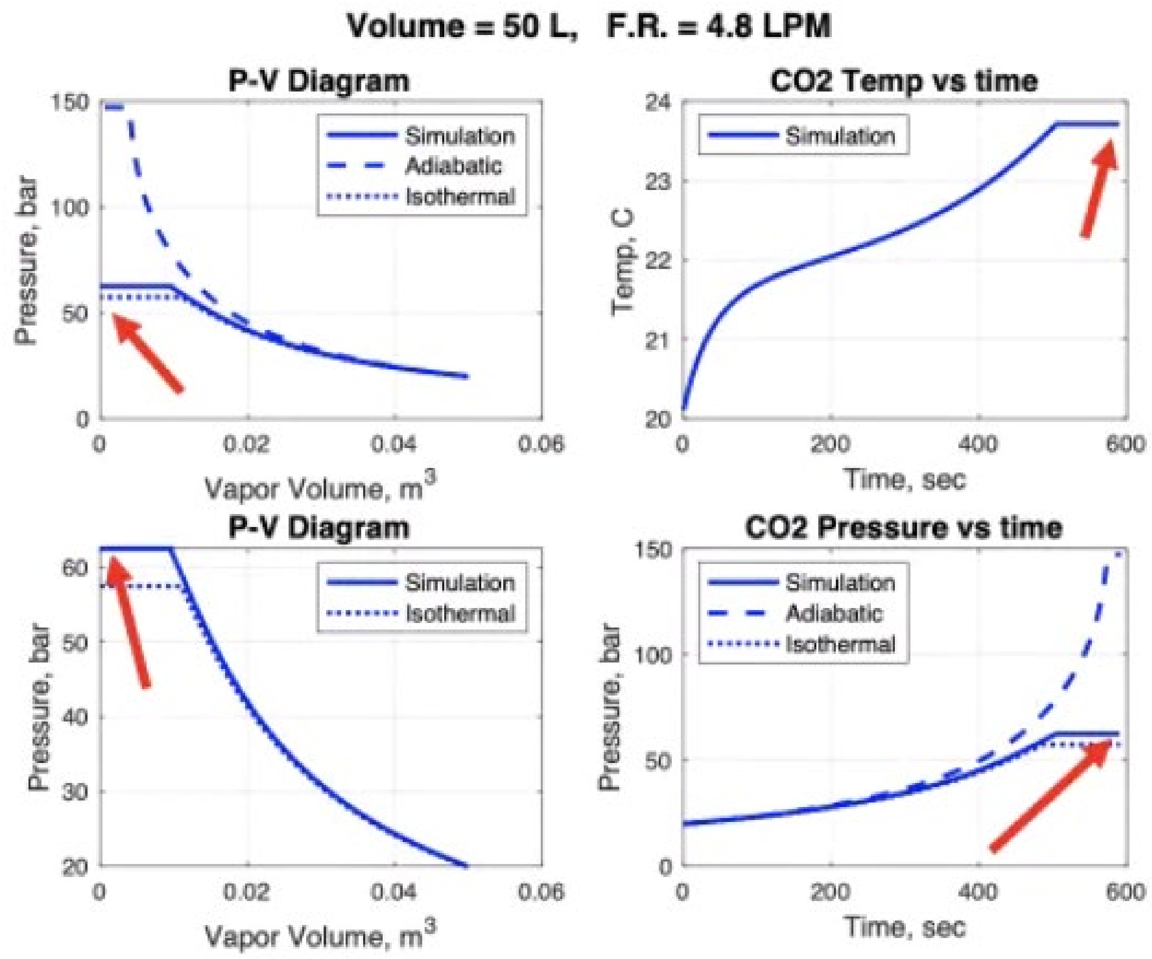
Commercialization
- Industry outreach
- Technology maturation and commercialization

Impact

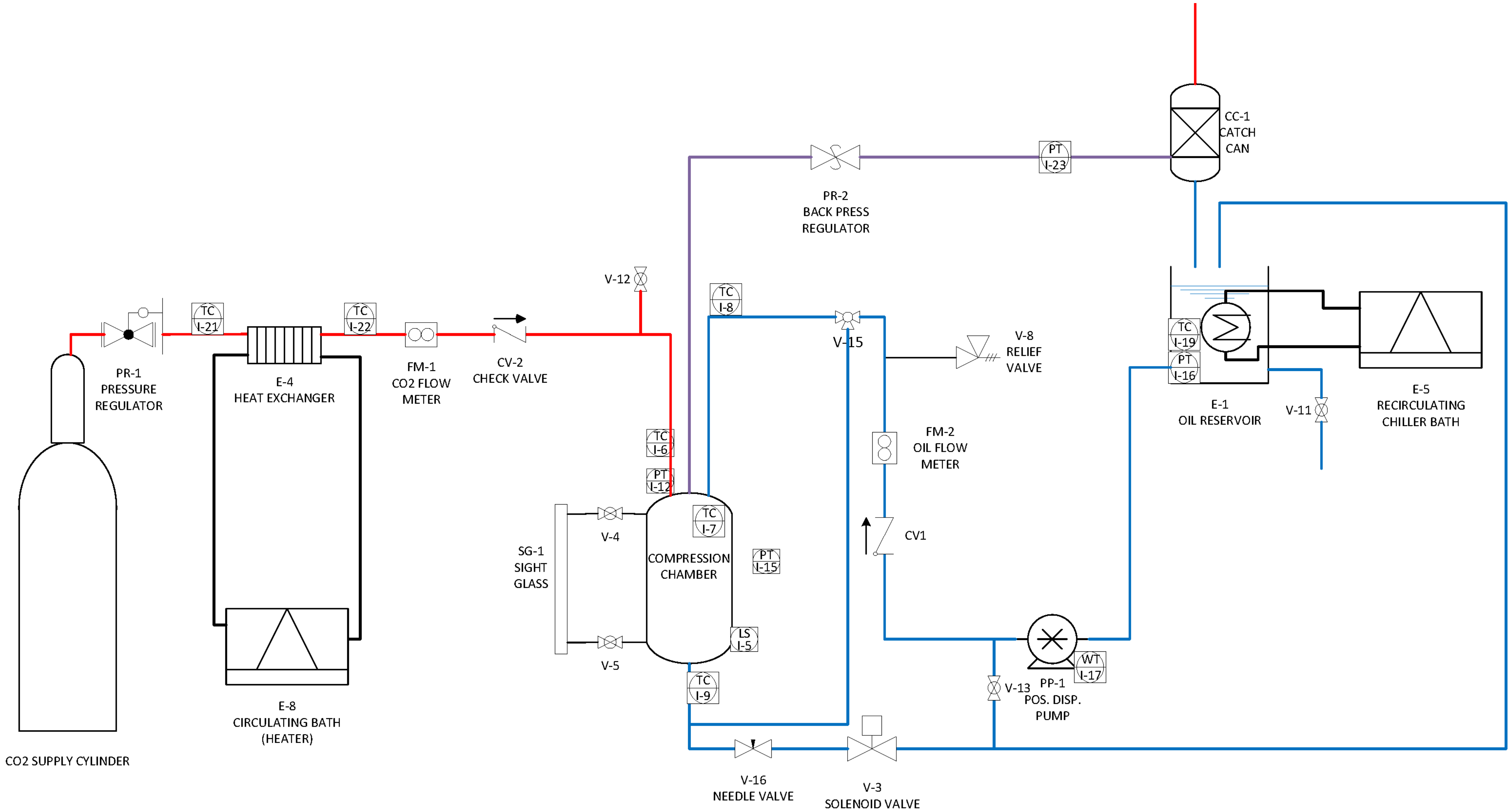
- **Near isothermal compression without intercooling**
  - The IsoLiqComp is equivalent to having very many intercoolers but at a much lower cost and much less complexity
- **The increase in compression efficiency has a technical potential of 2 Quads saving in energy consumption nationwide. This is only the direct energy benefits of the improvement in efficiency. Other indirect benefits:**
  - Enabling advanced heat pump cycles
  - Oil-less heat pumps
  - Hydrogen fueling
  - Natural gas transportation
  - CO_2 transportation

Progress – Modeling

- Physics-based transient model was developed
- Compression liquid flow rate, chamber diameter, chamber length, initial temperature, initial pressure and final pressure are user inputs
- The model predicts the time evolution of the pressure, temperature and gas volume
- The model was used to design proof-of-concept prototype

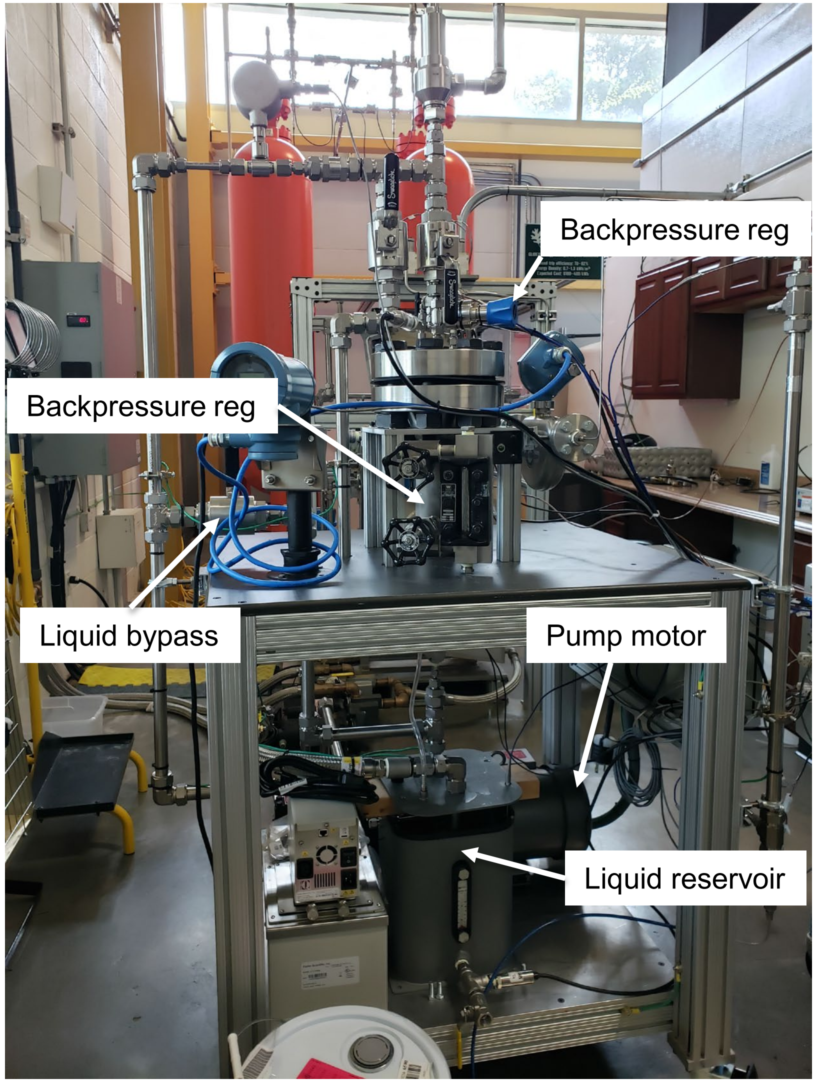


Progress – bench scale prototype

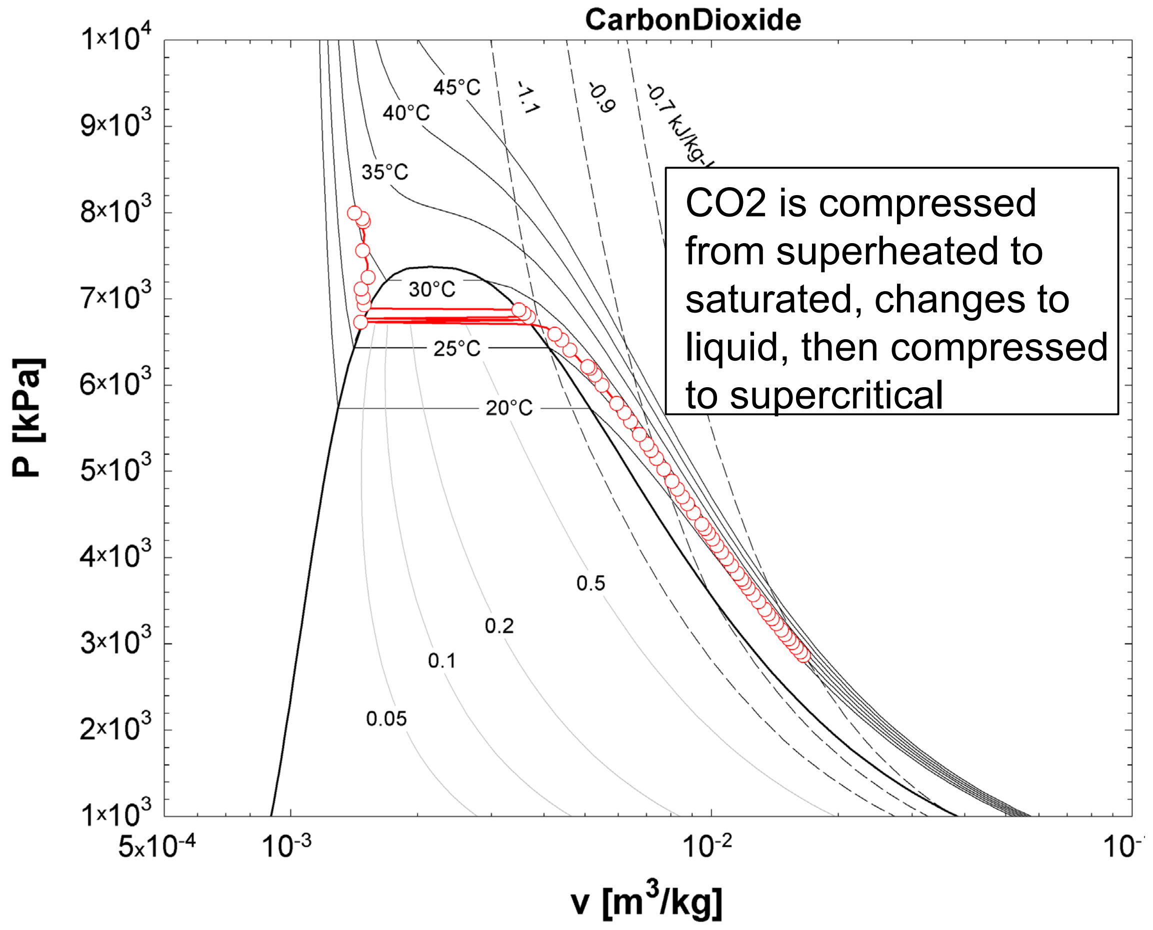


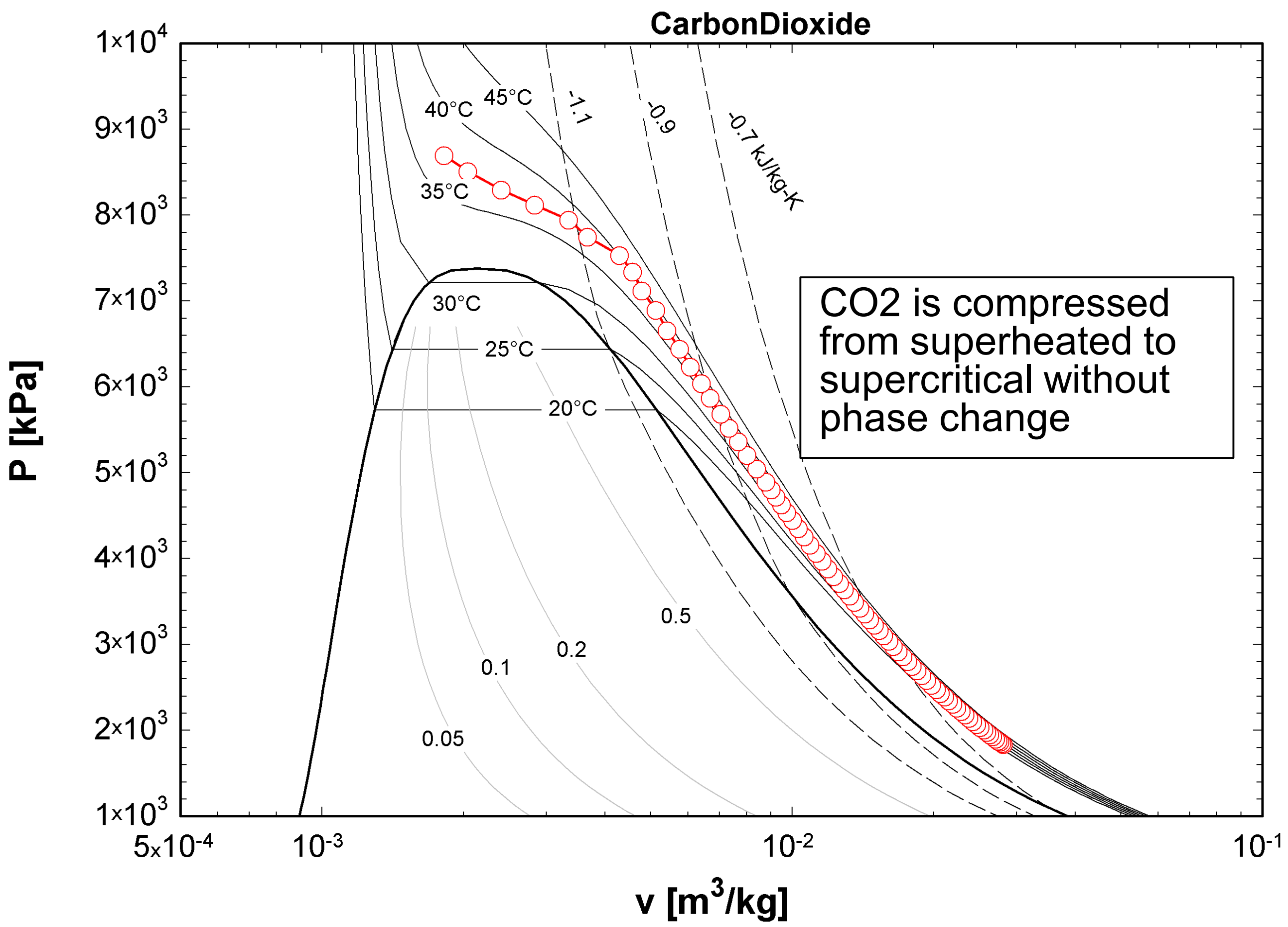
Progress – bench scale prototype

- Prototype was commissioned in March 2021
- One 1-liter chamber
- Compresses CO_2 using propylene glycol
- Compression liquid flow rate into the chamber is controlled through a bypass
- Discharge pressure was controlled via a back pressure regulator that simulated load
- Initial pressure and temperature of the CO_2 are adjustable
- Temperature of the compression liquid is adjustable



Progress – experimental data



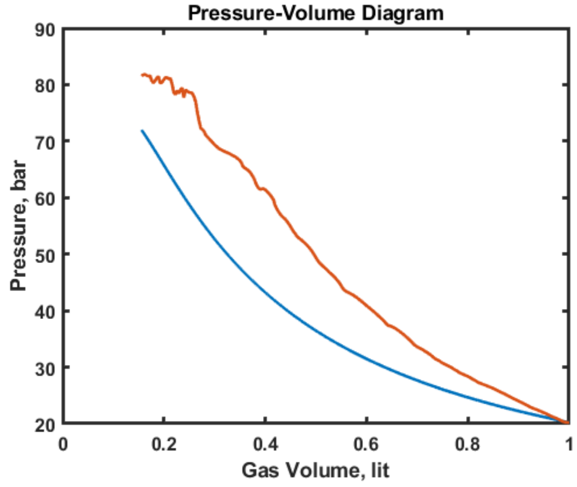


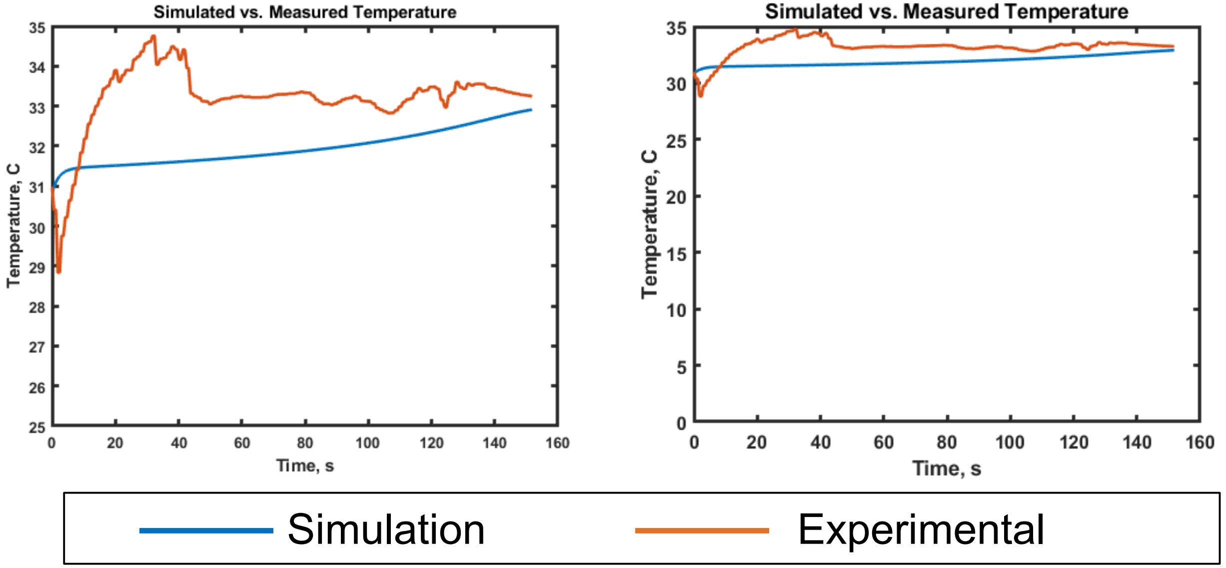
Temperature of the compression liquid determines the compression path

Progress – model validation

- CO_2 is compressed from **<u>20 to 80 bar</u>** with corresponding *<u>temperature rise of only 4 ºK</u>*. Using conventional mechanical compression, the *<u>temperature rise would exceed 60 ºK</u>*.
- Calibration is ongoing. Currently, model underestimates pressure and temperature
- Additional instrumentation are being added to better measure
    - Liquid flow measurement
    - Gas volume calculations

Pressure and temperature of the same experimental run. CO2 was compressed from superheated vapor to supercritical fluid without going through phase change





Progress - implementation

- **An HVAC&R application has been identified where the IsoLiqComp:**
  - Eliminates major technical barriers by eliminating its most problematic components
  - Enables easy integration of energy storage to the identified application at low cost (much lower than batteries and PCM)
- **Large total market (Billions of US dollars)**
- **Prototype of the application will be built in FY22**

Stakeholder Engagement

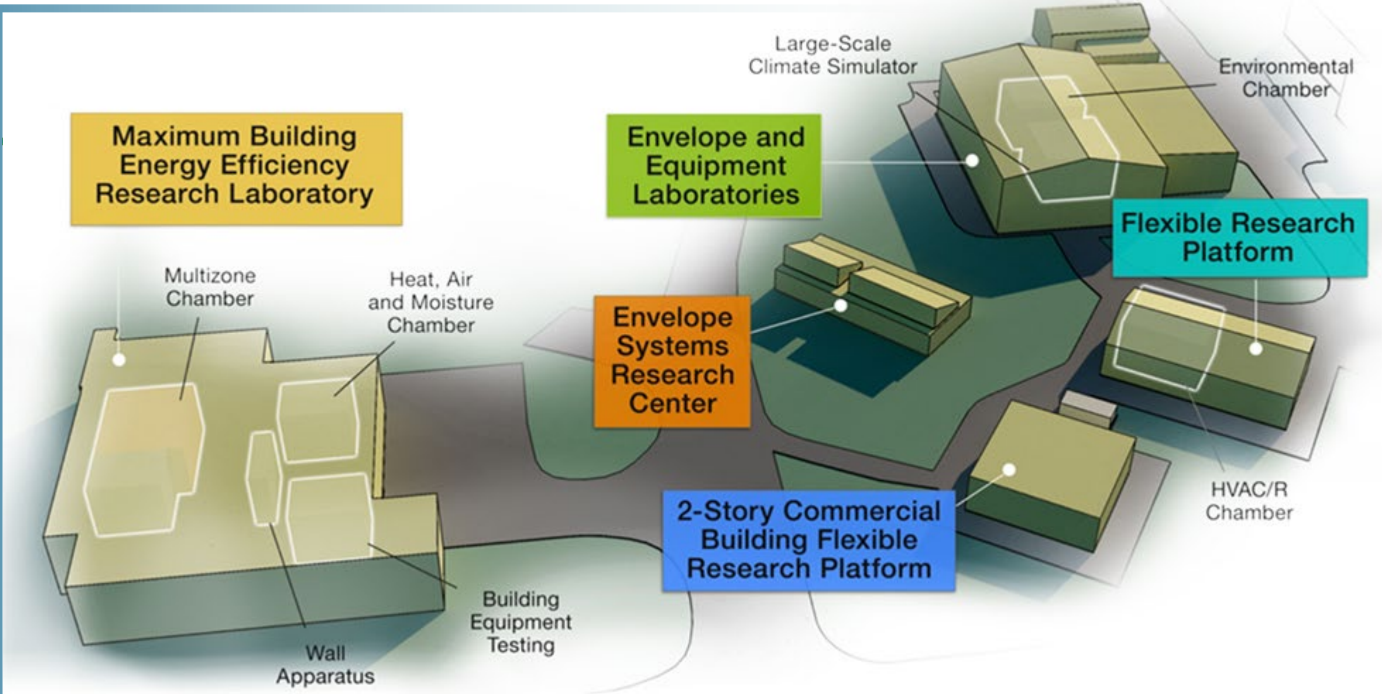
- **The project is in its mid-stage, transitioning from demonstrating the working principle to developing applications and commercialization**
- **Outreach to large HVAC OEMs has started. One OEM has been contacted**
- **At least two more OEMs will be contacted**
- **Goal of engaging OEMs**
  - Initiate CRADA to mature and commercialize application based on the IsoLiqComp
  - Use OEMs' feedback to guide technology development for later commercialization

Remaining Project Work

- Complete initial prototype and laboratory performance evaluation
- Complete model validation
- Continue outreach to OEMs to identify additional commercialization opportunities
- Build additional prototypes and demonstrate the identified applications based on OEMs' feedback
- Continue to focus on application maturation, demonstration and commercialization

Thank you

Oak Ridge National Laboratory
Ahmad Abuheiba, R&D Staff
(702)-372-5689 | abuheibaag@ornl.gov



ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ 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
238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget: $900K
Variances: planned spend through FY22 was $500K. Delays due to COVID restrictions slowed down the construction of the prototype and dependent tasks (model validation, industry outreach)
Cost to Date: $321K

Budget History					
Oct 1 - FY 2020 (past)		FY 2021 (current)		FY 2022 – Sep 30 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
100K	0	221K	0	500K	0

Project Plan and Schedule

- Start date: 1-Oct-2019
- Planned end date: 30-Sep-2022
- Construction of the proof-of-concept prototype was delayed due to COVID-19 restrictions
- Original plan for FY22 will be revised based on outcomes of OEMs’ engagement and findings of the current prototype

	FY21												FY22											
Task	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct2**	**Nov**	**Dec4**	**Jan5**	**Feb6**	**Mar**	**Apr8**	**May**	**Jun1**	**Jul1**	**Aug**	**Sep1**
Assemble the POC prototype and commission																								
Evaluate perfromance of the prototype																								
Design application based on IsoLiqComp																								
Design second prototype																								
Fabricate second prototype																								
Evaluate second prototype																								
Finalize design of identified application																								
Evaluate perfromance of application																								
Commercialization activities																								