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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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Ultra-Efficient CHP with High Power/Heat Ratio Using a Novel Argon Power Cycle| IEDO

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Project Overview

This project enforces a breakthrough in the development of **Argon Power Cycle (APC)**, a retrofittable thermodynamic power cycle delivering **zero-emissions** (i.e., GHG, NOx) and **ultra-high efficiency combined heat** and **power** from reciprocating engines.

Successful development of the APC will:

- ❑ **Promote broad and rapid adoption of low-carbon-input flexible CHP** across multiple industries,
- ❑ Dramatically **reducing air pollution** and **GHG emissions** and
- ❑ **Strengthening the U.S. industrial sector's economic competitiveness**.

MAIN BARRIERS

- ❑ CHP plants are generally designed to **meet thermal demand**, leaving out a significant population of manufacturing plants which are dominated by electrical needs.
- ❑ CHP plants in the U.S. generally operate on natural gas or diesel and **emit great amount of CO_2 and other GHGs** as a result.
- ❑ CHP plants are most often sited where the heat/power are consumed, **emitting criteria pollutants (e.g., CO, NOx, PM)** and **impacting the surrounding communities' air quality**. Switching to low-carbon fuels does not generally address this issue and in some cases (e.g., hydrogen) exacerbates it.

IMPACT

- ❑ Radically **increase** the electricity **generation efficiency** of CHP plants.
- ❑ **Enable cost-effective carbon capture** in CHP plants of all sizes.
- ❑ **Eliminate air polluting** emissions from CHP plants.
- ❑ **Enable** CHP plants to cleanly and cost-effectively **transition to low-carbon fuels** (Hydrogen).

Project Outline

Innovation: Argon Power Cycle based CHP

Project Lead: Noble Thermodynamic Systems, Inc.

Project Partners:

Membrane Technology Research, Inc.

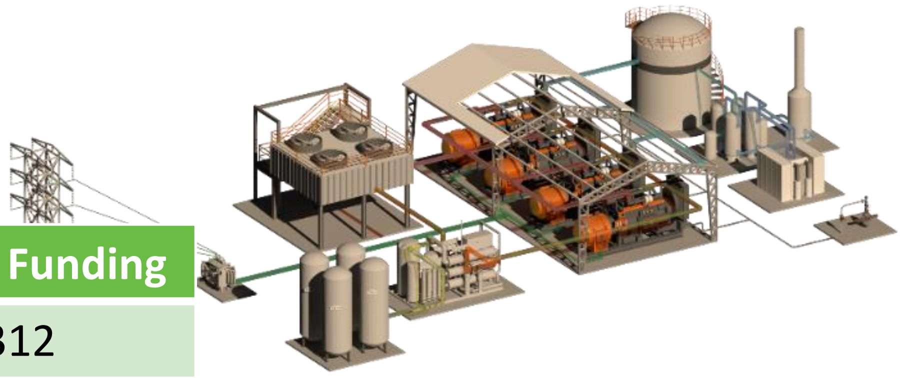
University of California at Berkeley

Susteon, Inc.

Trimeric, Inc.

Timeline: September 2020 to February 2024, 75% completed

Budget: $3,842,312 (+24% Cost-Share)

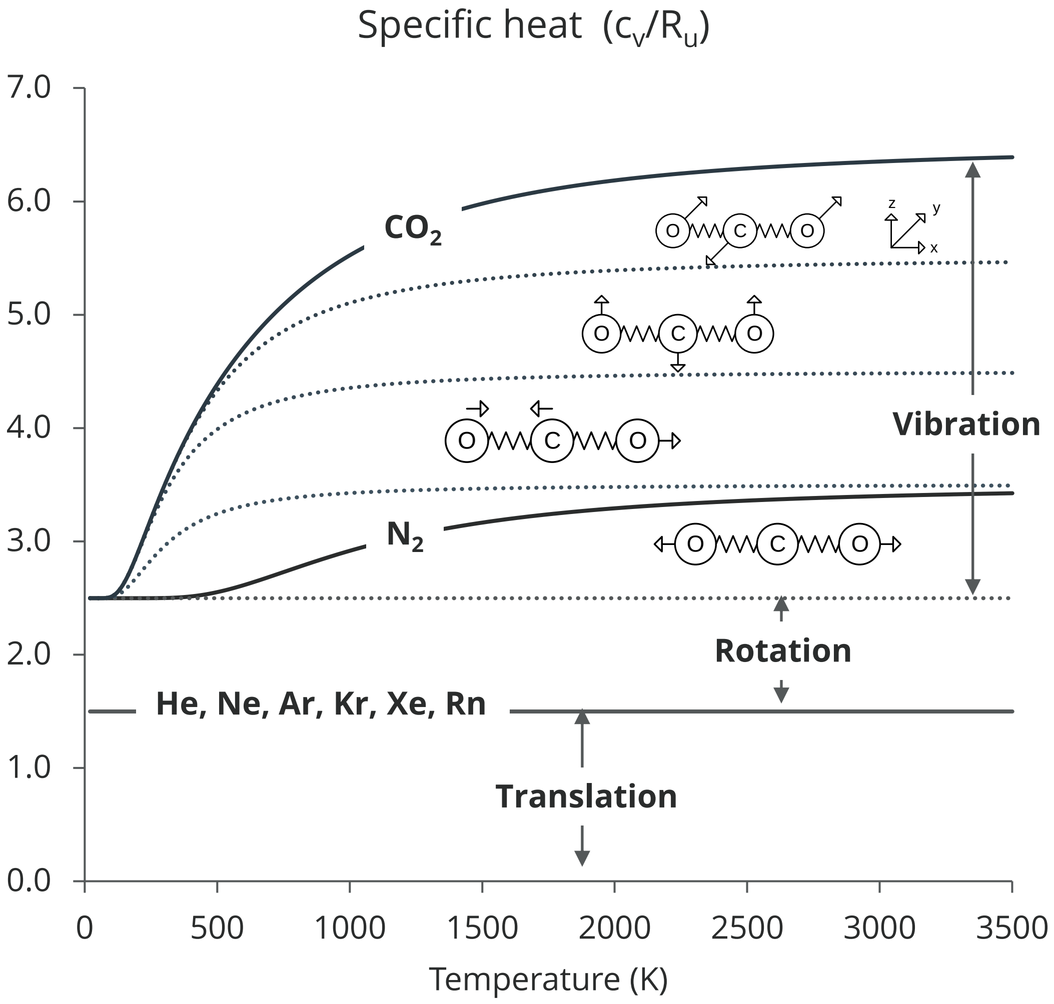


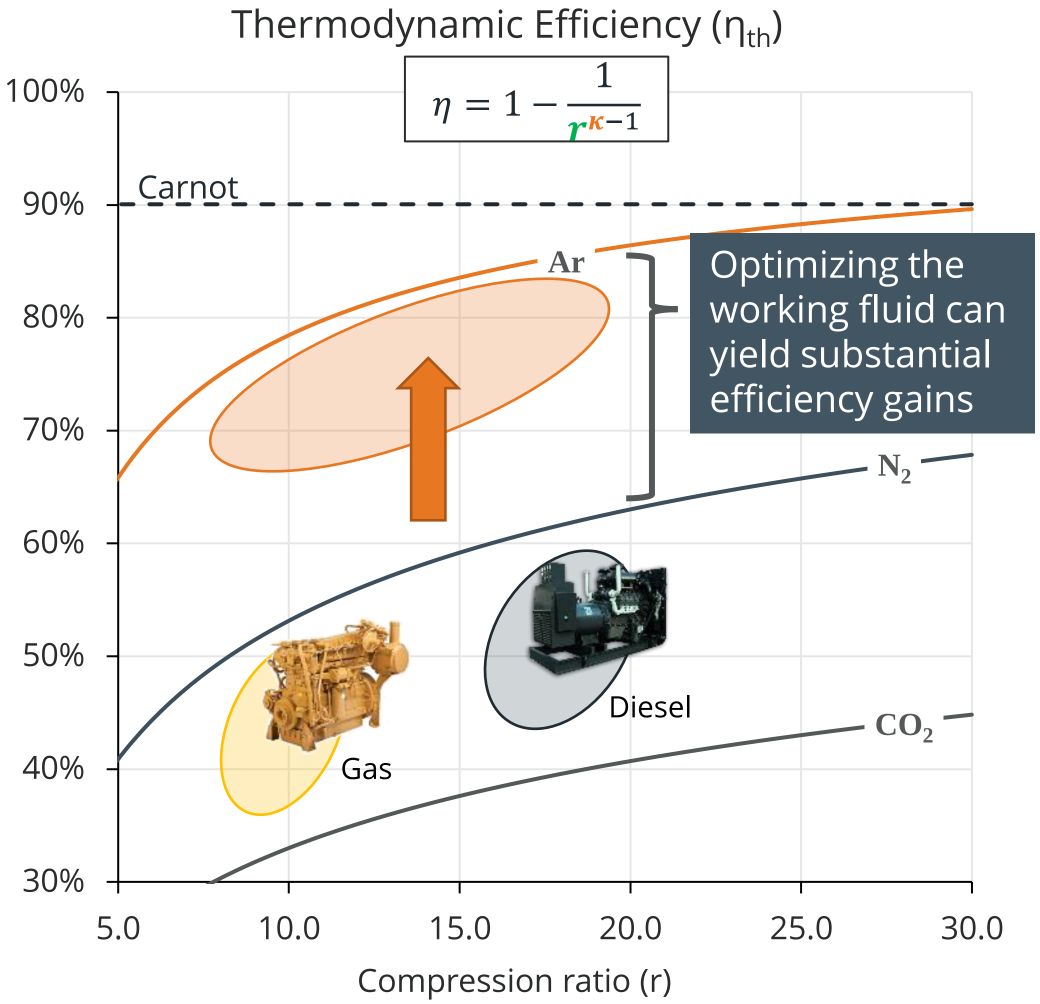
	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$578,421	$1,638,905	-	$3,842,312
Project Cost Share	$274,287	$433,418	-	$1,237,904

End Project Goal:

Validate and **demonstrate the Argon Power Cycle's** emissions, performance, and cost characteristics as a natural gas fueled CHP solution, specifically the APC's **ability to render higher than ≥ 70% overall CHP system efficiency** while maintaining a **power to heat ratio above ≥ 1.5** and **capturing 100% of the CO_2 generated**.

Pushing the thermodynamic boundaries of performance





Optimizing the working fluid can yield substantial efficiency gains

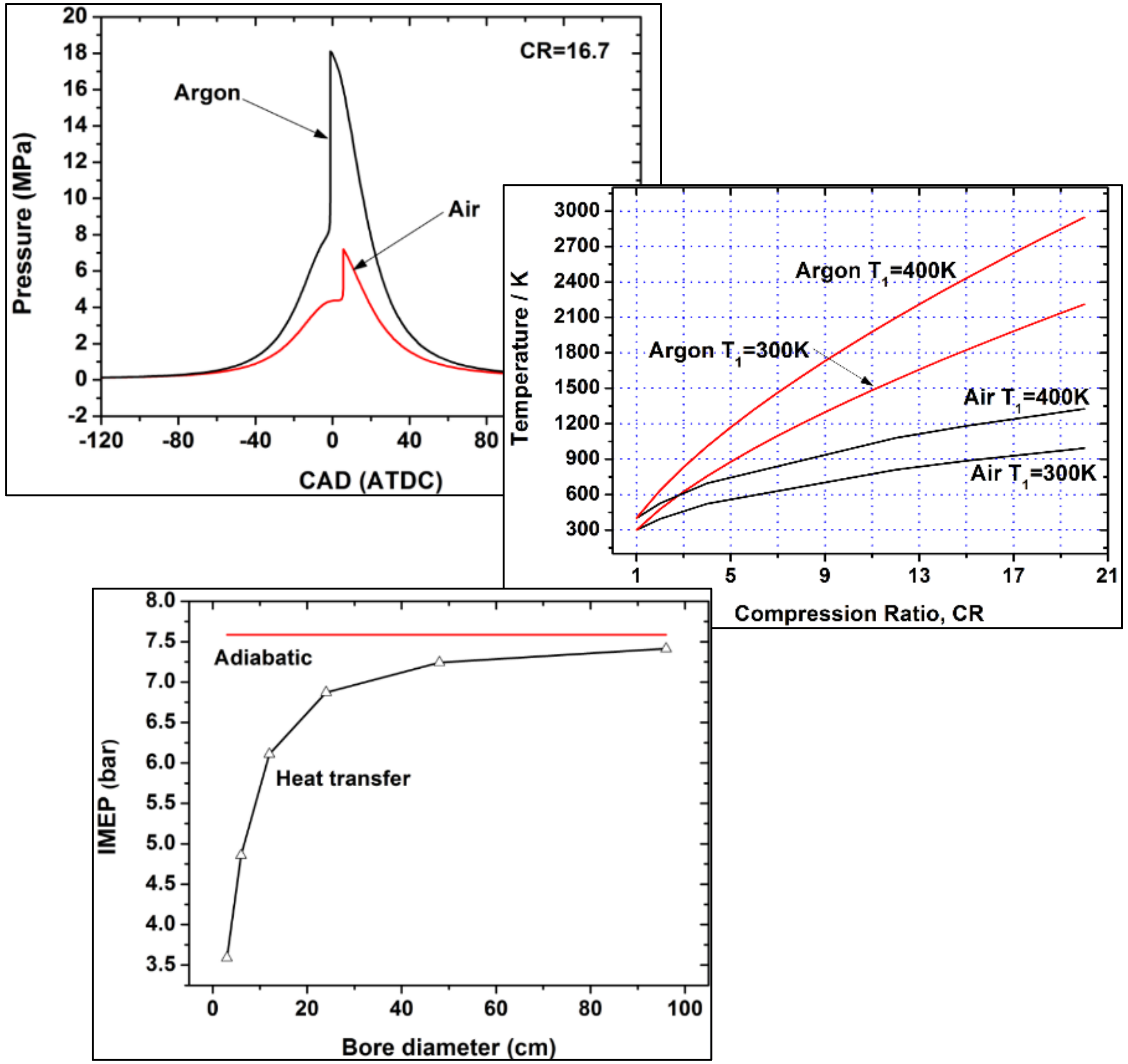
But there are challenges… hard ones!

Combustion in argon rich working fluids result in higher peak temperatures and pressures than air. For RICE, it means:

- ❑ Potential for **higher heat losses**
- ❑ Higher propensity to **knock**
- ❑ Smaller window of reliable combustion and thus **narrower operation range**.

For large RICE however this is not a deal breaker:

- ❑ Large bore (B) engines approach adiabatic, scaling with their surface to volume ratio (1/B)
- ❑ Compounded with the lower heat transfer quality of Argon
- ❑ Large RICE are less sensitive to higher in-cylinder temperatures.



Meet the Argon Power Cycle (APC)

A close-loop gas recirculated thermodynamic cycle delivering ultra-efficient, flexible, and zero emissions power.

Simple and versatile, intrinsically clean and agnostic to fuel source, retrofittable onto existing power generation assets.

1. Ultra-Efficient Power Generation

The use of a monoatomic gas as the working fluid radically increases the system conversion efficiency and **prevents** the formation of **harmful nitrogen oxides**.

2. Heat and Water Recovery

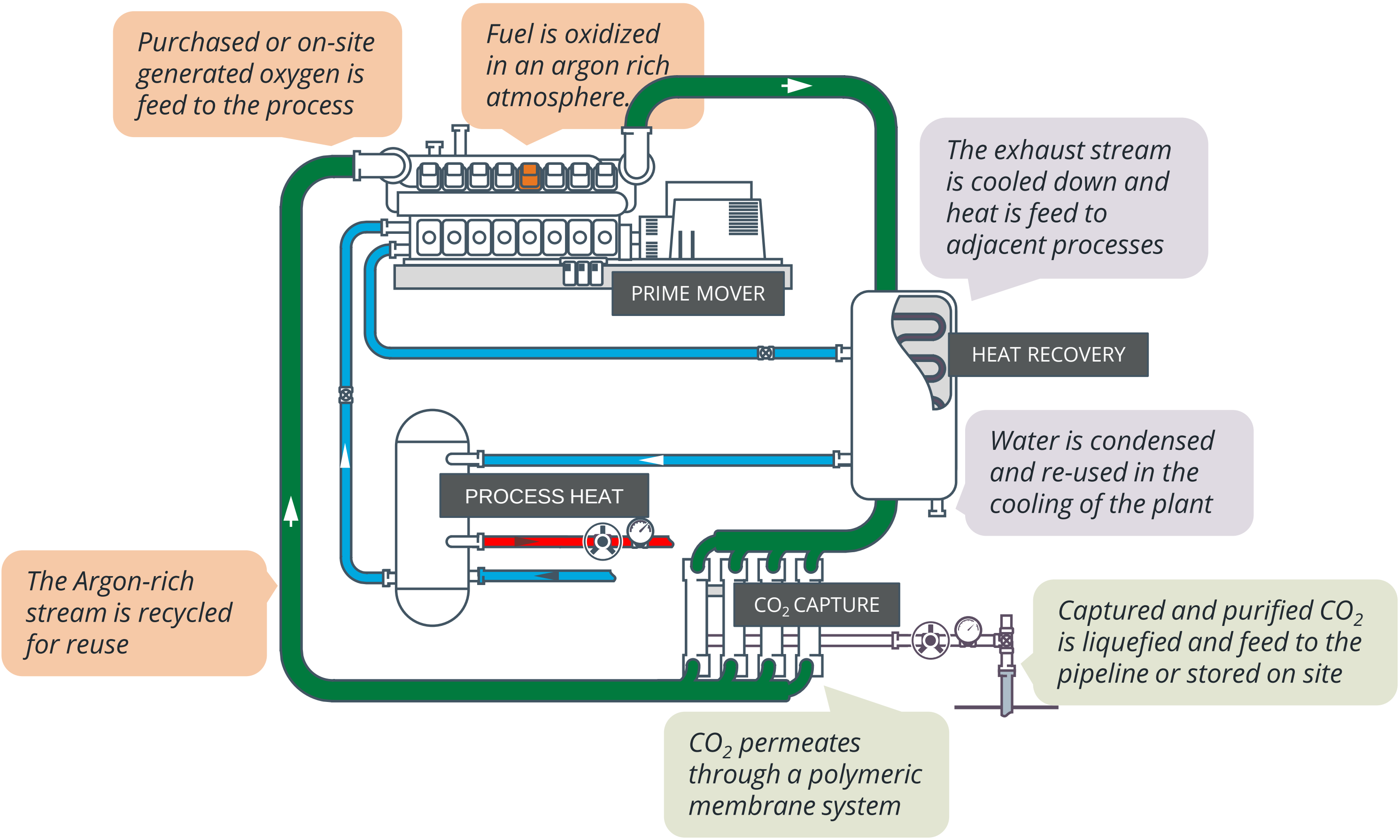
The recovery of water and heat **reduces** the **water consumption** and **improves** overall **plant efficiency**.

3. Carbon Capture and Purification

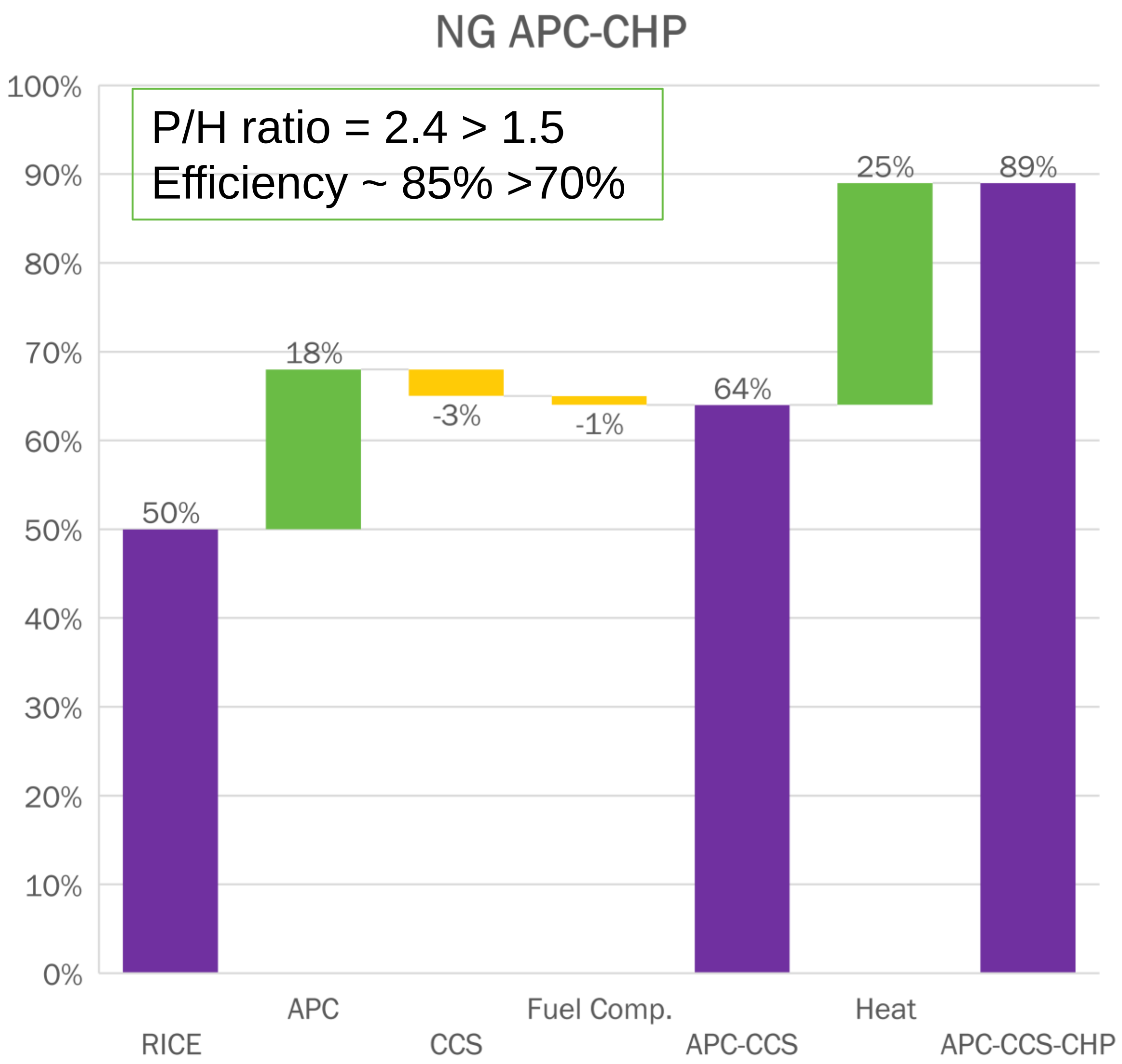
Control over the recycled argon stream composition enables the **lowest cost carbon capture** and real-time, and efficient **Hydrogen blending**.

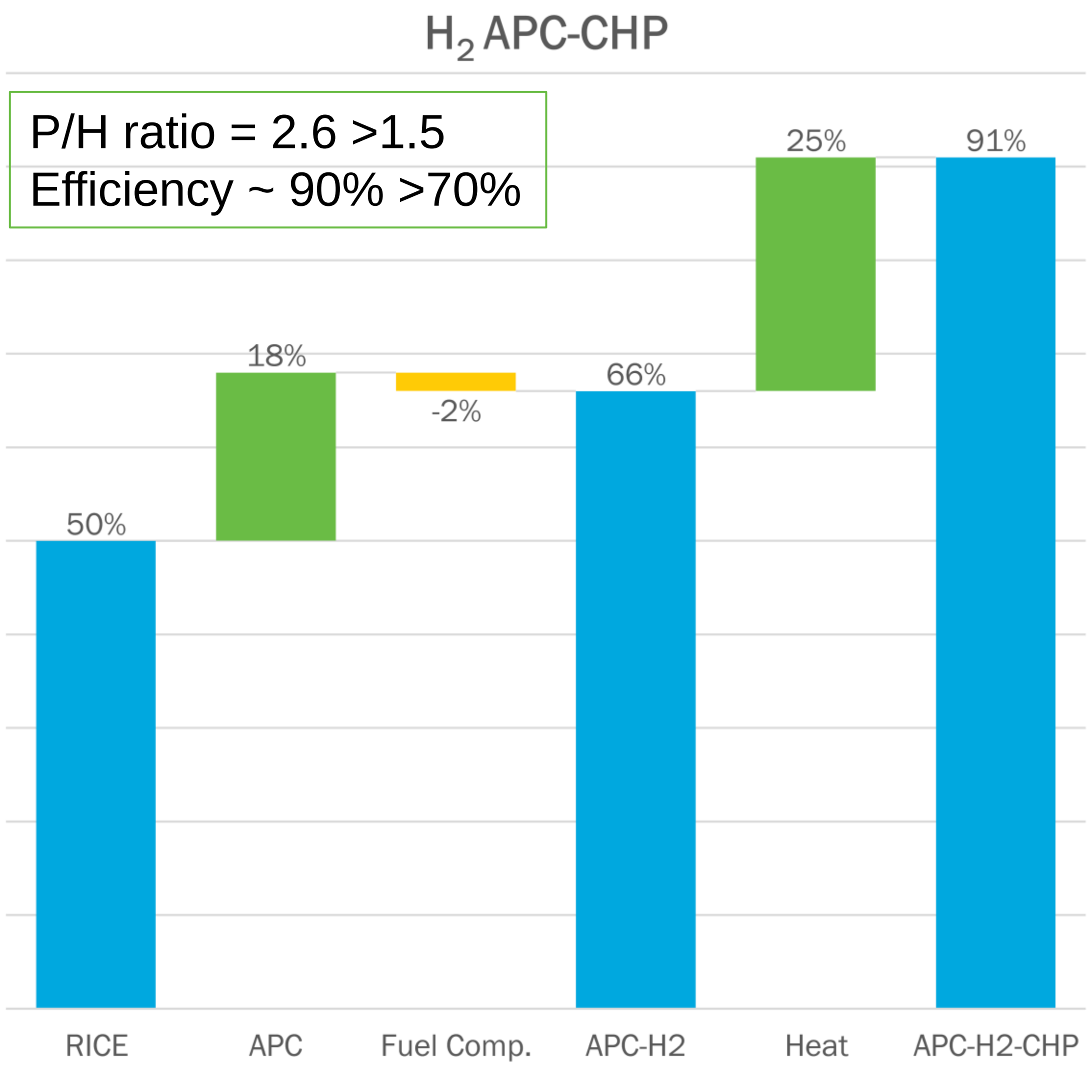
4. Seamless transition to 100% H_2

When **fueled with H_2**, the APC renders a mechanical equivalent to a Fuel cell, with similar performance but at a fraction of the cost, and scalable to utility scale.



Understanding the APC's net gains

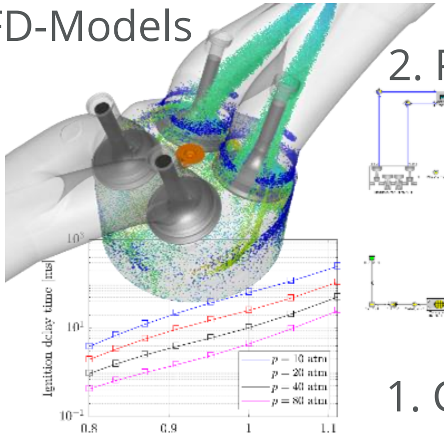




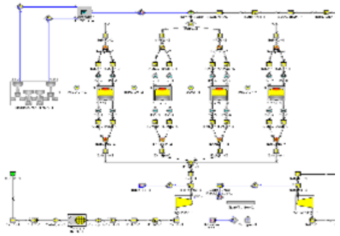
Phase I Approach: Design, Engineering and Preliminary Testing

Numerical Modelling and System Optimization

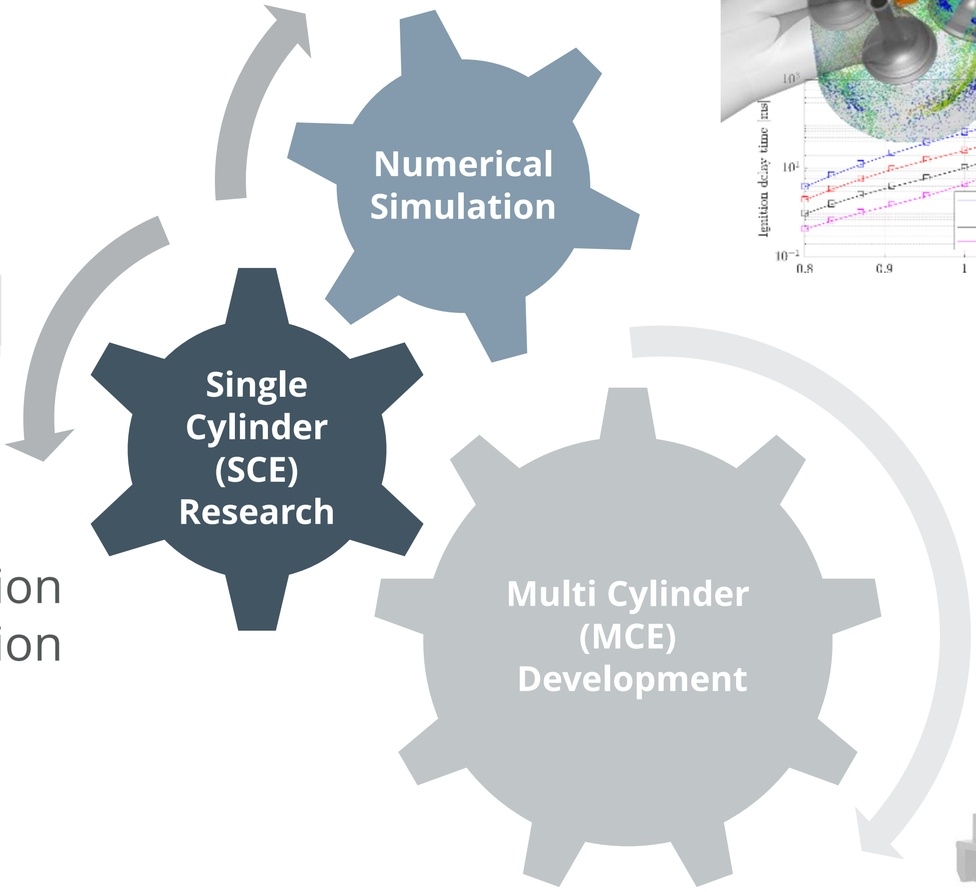
3. CFD-Models

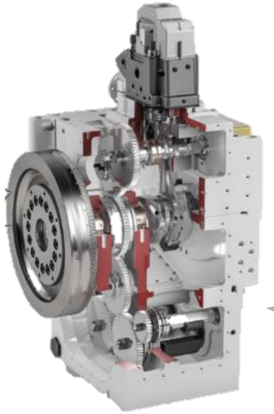


2. Process Models



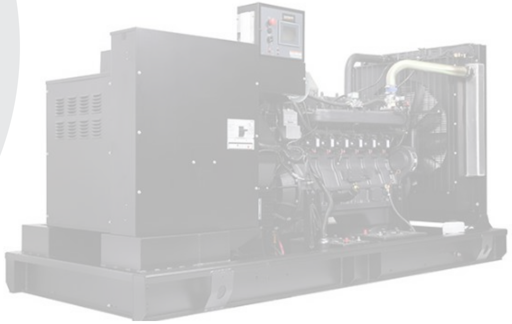
1. Chem. Kinetics Models



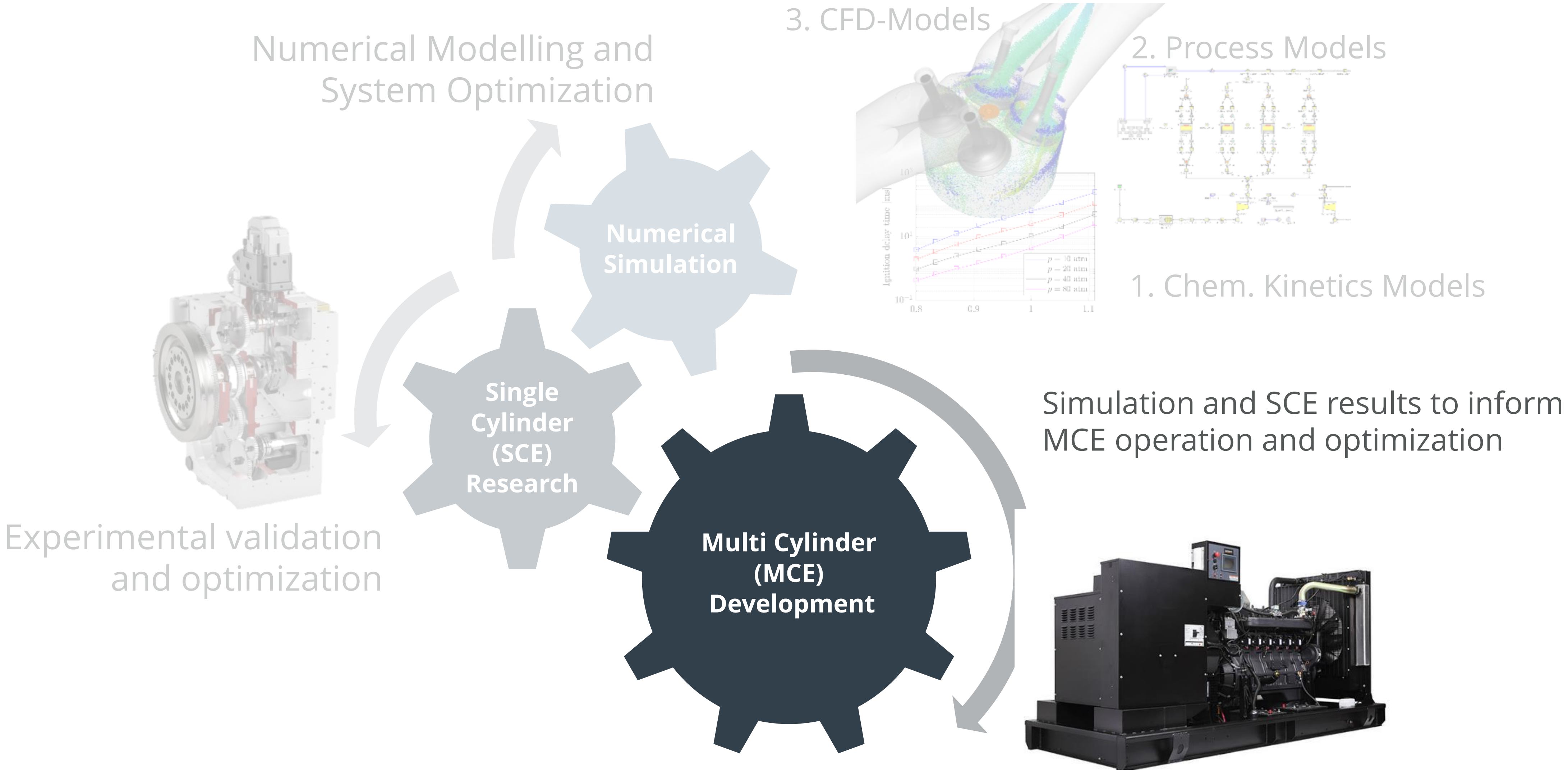


Experimental validation and optimization

Simulation and SCE results to inform MCE operation and optimization

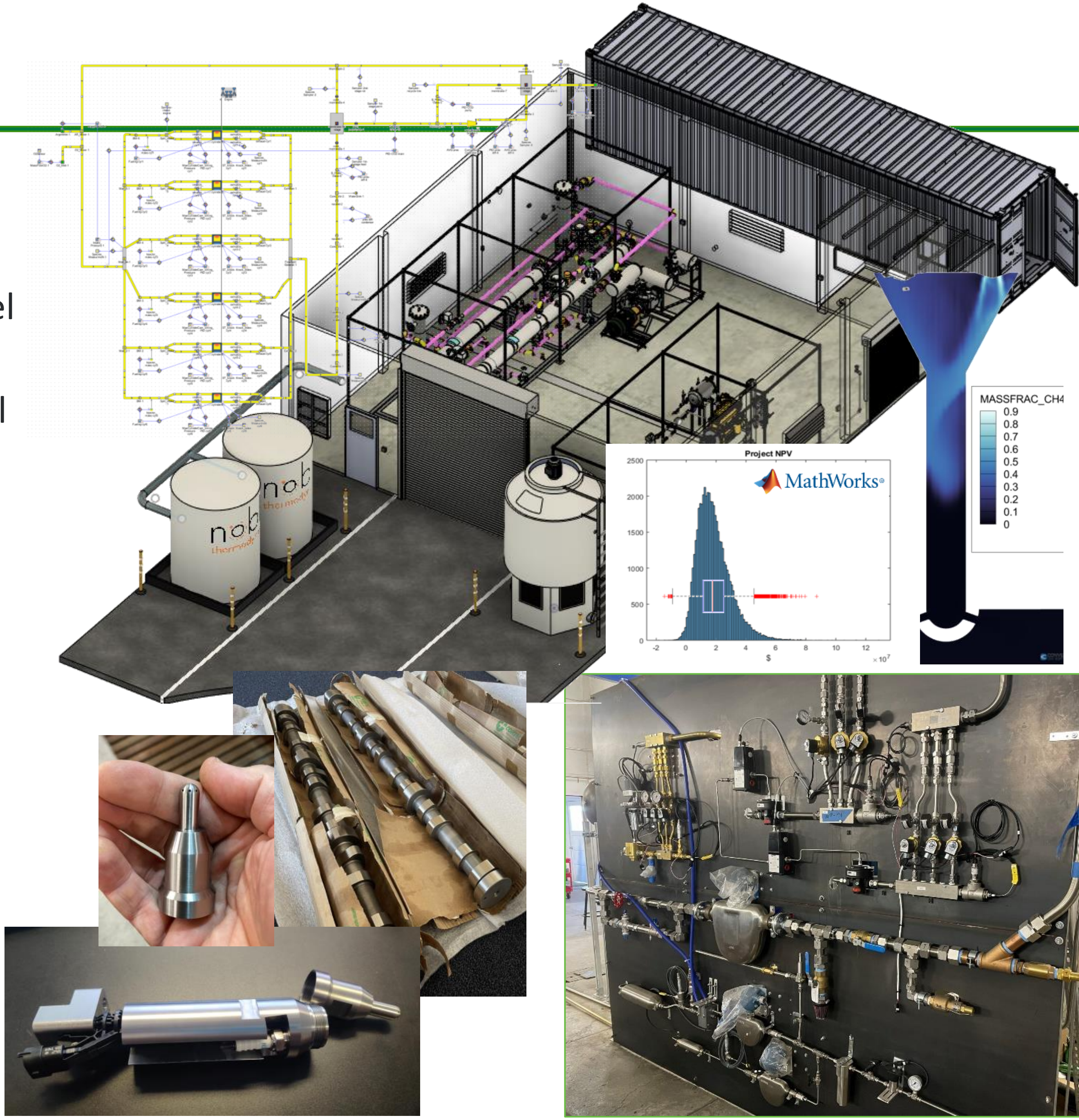


Phase II Approach: Integration, Operation and Analysis



Results and Achievements

- Developed **skeletal chemical mechanism** to simulate combustion on argon rich atmospheres.
- Developed a **high-fidelity 3D CFD model** able to model APC combustion conditions.
- Developed a **process model**, time resolved that model real time APC behavior including CO_2 capture.
- Characterized the capture **membrane selectivity** for Ar/CO_2 separation.
- Designed, fabricated and tested an **Engine Retrofit kit** to operate the APC with natural gas fuel
- Designed, engineered and fabricated the **CO_2 capture system** to enable flexible operation.
- Conditioned a facility to store and consume cryogenic O_2, CO_2, Ar gases.
- Developed a **montecarlo techno-economic modeling tool** to carry out TEAs.

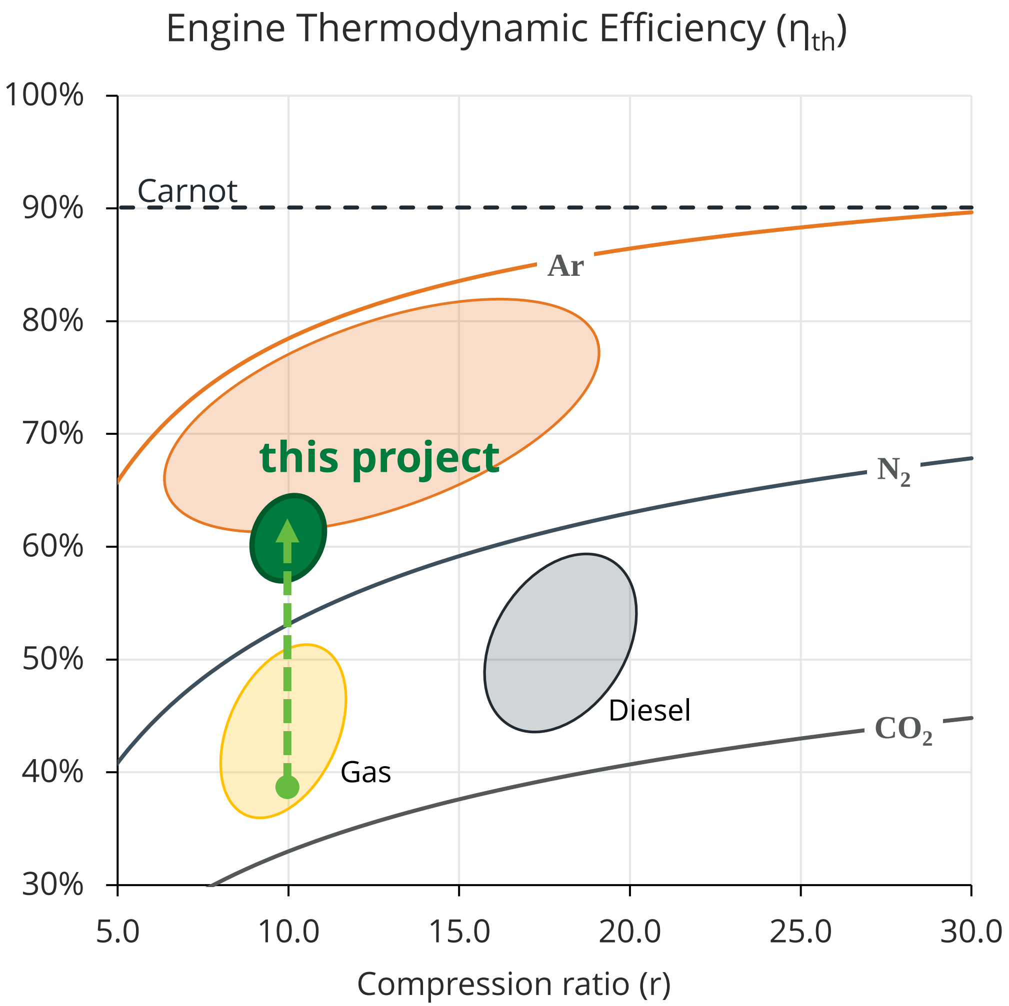


Results and Achievements

The CO_2carbon captured has been fabricated and is ready for phase II: integration and testing.

The SCE was built and tested. It is now being repurposed as a MCE to be integrated and operated in the coming months.

Reached +20% Efficiency gains at kW scale



Current experimental testing campaign has exceeded our expectations, reaching efficiencies 5 points above we expected we could achieve.

Future Work, Technology Transfer, & Impact

Future Work:

- ❑ Control system Optimization of the integrated Argon Power Cycle process.
- ❑ Carry out extensive experimental campaign to verify achievement of project target metrics, specifically efficiency and emissions profiles.
- ❑ Scale up existing models of the pilot unit to estimate the APC performance at MW scale.
- ❑ Complete Techno-economic analysis for a MW scale CHP plant.

Technology Transfer activities:

- ❑ Working with industrial partners on the development and deployment of natural gas and hydrogen fueled demonstrations across different industries and territories.
- ❑ Engaging with end-users for the development of pre-FEED and FEED studies with relevant partners.
- ❑ Investigating IP around several novel concepts key for the realization of the APC.
- ❑ Engaging in business development and customer outreach in the US and overseas.

Impact:

- ✓ **Promote broad and rapid adoption of low-carbon-input flexible CHP** across multiple industries,
- ✓ Dramatically **reducing air pollution** and **GHG emissions** and
- ✓ **Strengthening the U.S. industrial sector's economic competitiveness**.

Questions?

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