U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

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

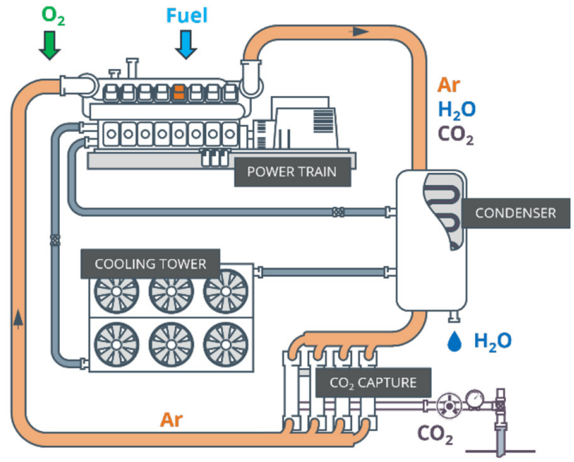

Diagram for a closed-loop gas recirculated Argon Power Cycle (APC) delivering ultra-efficient, flexible, and zero-emissions power. *Diagram courtesy of Noble Thermodynamics.*

According to the U.S. Department of Energy Combined Heat and Power Installation Database, approximately 80 GW of electrical power is produced in the United States using combined heat and power (CHP) systems. Studies have also shown that a potential market for CHP applications is larger than the existing market. Since fuel consumption is the most significant part of the operating cost for a CHP plant, higher efficiency translates to increased power output for the same quantity of fuel. Therefore, more efficient power conversion will decrease the price of electricity generated and improve the economic feasibility of new CHP applications.

A large part of the untapped CHP market is in the smaller scale applications (i.e., less than 20 MW). For CHP installations, reciprocating engines (RICEs) have capacities that typically range from 10 kW to 10 MW. Of the current CHP installations in the United States, RICEs account for more than 57% of the prime movers used at these sites. These reciprocating engines have a combined capacity of more than 2.7 GW.

Today's CHP systems are generally designed to meet the thermal demand of the energy user, which leaves out a significant population of manufacturing plants that are dominated by electrical needs. Analyses have shown that expanding the market applications for CHP systems to those driven more by electrical rather than thermal output could save an additional 144 trillion Btu of energy beyond existing CHP technologies alone.

The objective of this project is to use a novel Argon Power Cycle (APC) to demonstrate a CHP system able to deliver a high power to heat ratio (>1.5) with ultra-high electrical power generation efficiency and overall CHP system efficiency (as high as 70%) while simultaneously generating no air pollutants (nitrogen oxides, or NOx) and capturing 100% of the carbon dioxide generated. The results of this project will pave the way for this revolutionary technology to reach the marketplace.

Benefits for Our Industry and Our Nation

With the advent of relatively cheap renewable power, current and emerging power generation systems continue to integrate a larger share of renewable energy sources. As a result, an increasing demand for dispatchable power emerges with the added constraints of aligning with climate change and air pollution reduction goals, while remaining cost competitive. Current solutions, however, struggle to strike a balance between clean, dispatchable, and efficient power.

The APC combines three novel yet synergistic features: (1) efficient power generation, (2) cost-effective carbon dioxide capture, and (3) quick response to changing loads. Through the APC's realization, CHP systems will be provided with extra control knobs for load control, which, in combination with the efficiency gains and the lack of pollutant formation, will render a clean, reliable, and affordable method for producing heat and power and support a renewable grid.

The APC will be most impactful when used in a hydrogen energy storage system. During periods of low demand, surplus renewable energy can be used to electrolyze water, creating hydrogen and oxygen, and storing them for future use. When demand increases, the APC can convert these gasses at ultra-high efficiency, generating low-cost and zero-emissions electricity. The RICE will become a mechanical equivalent to a fuel cell, with comparable or superior cleanliness and overall efficiency but at a small fraction of the cost due to its relatively conventional, mass-produced components.

Applications in Our Nation's Industry

The APC will have a wide range of applications spanning from power generation all the way to marine transit, helping to decarbonize a wide range of sectors of the U.S. economy. The APC will have an initial impact among industrial users of CHP systems but will also positively impact utilities that need dispatchable, climate-change friendly, and cost-effective technologies.

Ultimately, the APC power system will become the foundation of the grid, enabling renewable energies to take over. This domination will allow the United States to power its economy without dependence on foreign energy resources and to increase its economic competitiveness by providing unrivaled low-cost electricity, while at the same time improving the health and safety of its citizens.

Project Description

The goal of this project is to further develop the APC by using it to demonstrate an ultra-efficient CHP system with a high power/heat ratio. This new cycle utilizes argon as the working fluid in a RICE. Like other monatomic gasses, argon has a specific heat ratio that is about 25% higher than that of air. Using argon allows the engine to theoretically approach simple cycle energy conversion efficiencies +24% absolute points higher than a traditional air breathing RICE.

In a natural gas-fueled APC system, 100% of the carbon dioxide from the exhaust gas is captured, and no air pollutants (e.g., NOx) are generated. Combustion strategies, which are often bound by NOx emission mitigation measures, will be fully optimized for highest conversion efficiency. This provides the flexibility to operate efficiently on hydrogen, effectively rendering the APC a pollution-free power system (no NOx or carbon dioxide).

Barriers

Using argon-rich working fluids results in high cylinder peak temperatures and pressures, which potentially translate into:

- Higher heat losses
- Higher propensity to knock
- Smaller window of stable combustion and thus narrower operational range

Pathways

This project consists of two main performance periods. In the first period, team members will develop and validate a high-fidelity model able to predict the performance of a fully integrated APC at relevant conditions. The work will be subdivided by powertrain + heat recovery development, numerical model tool development, carbon capture unit development, and bottoming cycle development. Successfully demonstrating the potential of the APC to accomplish the desired performance metrics will lead to the second period.

In the second period, team members will integrate all the necessary components and realize an APC prototype able to withstand relevant operating conditions. This prototype will serve as a validating tool for the numerical models with which realistic performance prediction at the industrial scale will be obtained. The work will be subdivided by full system integration, operation, and optimization; numerical model tool development; and techno-economic analysis (TEA).

Milestones

This four-year project began in late 2020:

- Complete validated numerical models of the APC system (2021)
- Numerically achieve performance gains over conventional systems as stipulated in the project goals (2022)
- Complete assembly and integration of the APC prototype plant (2023)
- Experimentally demonstrate performance gains meeting project goals (2023)
- Numerically achieve performance gains over conventional systems at industrial scale (2024)
- Complete TEA evaluating the cost effectiveness of the APC at industrial scale (2024)

Technology Transition

This project aims to use the APC to demonstrate a CHP system able to deliver a high power to heat ratio (>1.5) and overall CHP system efficiency (as high as 70%) with no emissions. A TEA will be carried out at the end of this project to showcase the economies of the APC, justify the competitiveness of the technology, and assess the near- and long-term potential of this technology to integrate into the global power portfolio.

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