Use of Mixed Combustion and Electrochemical Energy for Engines

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Objective
The goal of this research is to develop a highly efficient, distributed generation- and transportation-scale engine system by combining a piston engine and a fuel cell. Internal combustion (IC) engine and fuel cell (FC) technologies can complement each other to increase the efficiency of a combined-cycle system to nearly 70%. Managing the exergy transfers – work from the engine, work from the fuel cell, heat transfer and exhaust from each device – and the interplay among them is the key challenge of this research.

Background
The research team previously investigated the operation of piston engines for high efficiency, analyzed conventional IC engines and proposed advanced systems that do not yet exist commercially. Figure 1a shows the results of an exergy analysis of two modern transportation engines—a spark-ignited gasoline engine and a turbo-charged diesel engine of comparable output. Figure 1b shows an exergy analysis of three low-heat-rejection (LHR) engines with turbocharging and turbo-compounding: a base case, an engine with steam injection and an engine with a Rankine bottoming cycle.

The results show that conventional systems achieve only 35% and 42% exergy efficiency, while state-of-the-art, aggressive systems could reach up to 60% efficiency. One strategy for improving efficiency beyond 60% is to combine IC engines and fuel cells, thereby reducing exergy loss due to combustion. Each device would provide a near-independent method of extracting work (electrical for FC and mechanical for IC), achieve low internal-exergy destruction and be well matched to the form of exergy transferred to it by upstream components.
**Approach**

Using exergy analysis, the research team will carefully select operating points and strategically implement thermodynamic devices to develop an engine architecture that realizes high efficiency at a scale suitable for distributed generation and transportation. Effective modeling and systems-design development will provide direction for suitable designs to be investigated experimentally.

Two system architectures will be explored to address the open-ended problem of how best to implement an IC/FC combined cycle: the low-temperature approach and the high-temperature approach (Figure 2). The low-temperature approach builds on previous research and takes advantage of the lower-temperature engine exhaust gases that match well with water-gas shift reactors and lower-temperature fuel cells. This approach should be able to operate over a wide load range with good ramping capabilities, while also providing high efficiency. The high-temperature approach builds on previous combustion research with high-temperature, high-energy exhaust gases. These gases are well matched to steam reforming and high-temperature fuel cells (such as solid oxide fuel cells). This approach is expected to be more efficient than the low-temperature approach, but more difficult to adapt to a wide load range for transportation applications.

![Figure 2: System configurations for mixed combustion/electrochemical engines](image-url)

(a) low-temperature port fuel injection and (b) high-temperature direct injection.

**References**