Project ID: FC350

High Efficiency and Transient Air Systems for Affordable Load-Following Heavy-Duty Truck Fuel Cells

DOE Hydrogen Program
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Doug Hughes, Eaton

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Project Goal

To develop a highly efficient and responsive air system for on-highway commercial vehicle fuel cells

- Use positive-displacement Roots machines to extend range of efficient system operation
- Maximize waste energy recovery
- Manage water to enhance Roots machine performance
- Apply state-of-the-art motor and inverter technology

If successful, the project would deliver a roughly 50% improvement to air system power consumption and a path to improved reliability, durability, and affordability

Any proposed future work is subject to change based on funding levels.

Overview

Timeline and Budget

- Project Start Date: TBD
- Project End Date: TBD
- Total Project Budget: $3.69M
  - DOE Share: $2M
  - Cost Share: $1.69M
  - DOE Funds Spent*: $0
  - Cost Share Funds Spent*: $0

* As of ~15 Apr 2022

Partners

- Project Lead: Eaton
- Ballard Power Systems
- National Renewable Energy Laboratory

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Relevance and Potential Impact

Existing fuel cell air systems

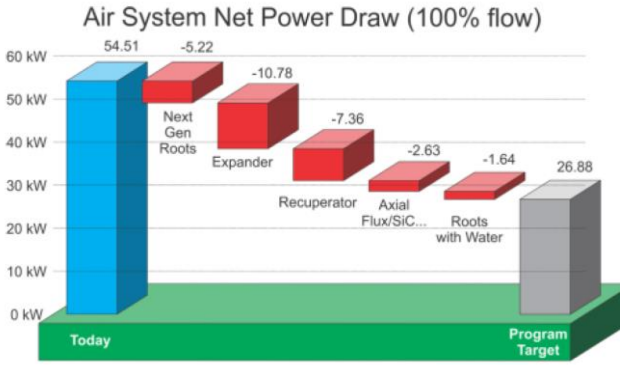
- Are a leading source of parasitic power loss
- Account for ~25% of fuel cell cost
- Limit fuel cell system durability and reliability

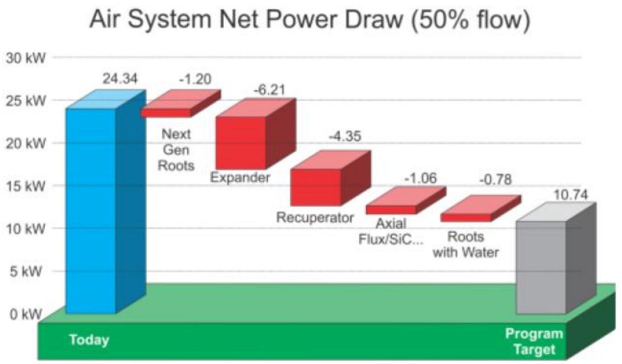
The proposed system innovation would deliver

- ~50% improvement in air system power consumption, equivalent to 9% fuel cell output improvement
- A path to improved durability, reliability, and affordability due to lower-speed rotating machinery

Decarbonizing commercial vehicle transport

- US HD freight emits 2642 MMmt CO2 per year (2019), 5% of US total
- Hydrogen fuel cells enable zero emission transformation in freight sector





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Approach

Optimize air system architecture in simulation

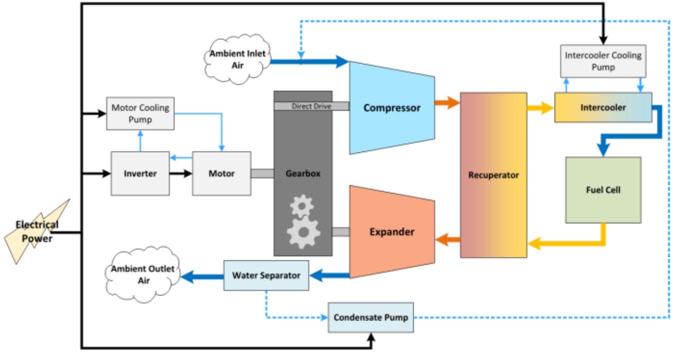
- NREL system model utilizing Eaton and Ballard component physics expertise
- Define system and components that deliver air flow with minimum electrical power consumption

Design and build Sub-Scale Test System

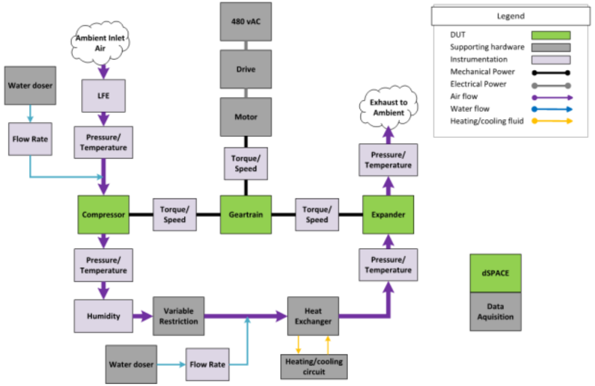
- Use existing components to experimentally validate critical physics (see next slide)
- Analytically adjust for effects that are outside of project test scope (see next slide)
- Quantify system power consumption and efficiency

Conduct design studies to establish component specs that meet full scale system requirements

Proposed Air System



Sub-Scale Test System



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Approach

- Certain elements of the Proposed Air System (e.g., axial flux motor) would have very high development cost and very long development time if designed for this application
- To fit project funding and timing, the Sub-Scale Test System will use existing components where necessary and analytically adjust to predict performance of Proposed Air System

	Proposed Air System	Sub-Scale Test System
Motor & Inverter	Axial flux motor, SiC inverter	Commercially available motor and drive
Compressor	Application-specific Roots machine	Existing Eaton supercharger
Expander	Application-specific Roots machine	Existing Eaton supercharger
Gearbox	Application-specific gearbox design	Prototype design and fabrication
Recuperator	Additive manufacturing solution	Variable restriction, heater
Cooler	Current technology solution	Variable restriction
Water Dosing	Application-specific integrated water dosing system	Lab grade water flow control, sensing
System Manager	Embedded controller	Prototype realtime controller, software
Fuel Cell Stack	Fuel cell stack	Variable restriction, heater, water doser

Methods of Target Demonstration	
Key Metric	**Demonstration and Verification**
Electrical Power Consumption, 100% Flow	Measured result and motor efficiency calculation
Electrical Power Consumption, 50% Flow	Measured result and motor efficiency calculation
Electrical Power Consumption, Idle	Measured result and motor efficiency calculation
System Response Time	Measurement and calculation
Durability	Component life calculations
Reliability	Estimate based on current product baseline
Number of startup shutdown cycles	Estimate based on current product baseline
Noise at Idle	Correlation with existing product measurements
System Cost	Calculation
System Volume	Calculation
System Weight	Calculation
Turndown Ratio (max/min flow)	Measurement

Any proposed future work is subject to change based on funding levels.

Milestones

Date	Milestone	Completion as of Apr 2022
Month 6	Assess water dosing system risk/benefit	0%
Month 9	Define optimized system architecture in simulation	0%
Month 12	Define optimized electric drive system	0%
Month 12	Define optimized recuperator	0%
Month 15	Define optimized Roots machines	0%
Month 15	Define optimized geartrain	0%
Month 15	Go/No-Go decision point: are DOE performance targets met in simulation?	0%
Month 19	Build Sub-Scale Test System	0%
Month 27	Proof-of-concept test complete	0%

Go/No-Go Decision Criteria

- Electrical Power Consumption
  - <27.9 kW @100% flow
  - <10.8 kW 50% flow
  - <0.32 kW @ Idle
- System Response Time < 2s
- Turndown Ratio >20
- Roots product test data < 65 dB-A @ 1m
- Component life/cost assessments establish path to DOE targets.

Any proposed future work is subject to change based on funding levels.

Accomplishments and Progress

- Project has not yet started

Collaboration and Coordination

Partner	Type	Role
Eaton Vehicle Group	Prime	Project management Component modelling and simulation Sub-Scale Test System design and build Test execution
Ballard Power Systems	Sub-recipient	Component modelling and simulation System and component requirements definition
National Renewable Energy Laboratory	FFRDC	Air system modelling and simulation
Eaton Research Labs	Internal Supplier	Additive manufacturing recuperator design Axial flux motor design Silicon carbide inverter design

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Challenges and Potential Mitigations

High technical risk is associated with these performance targets.

Risk	Mitigation
Net system efficiency may be lower than expected	• Use modeling and simulation tools to optimize system architecture and component specifications according to technical targets. • Conduct Sub-Scale System tests
Recuperator meeting application requirements may not be feasible	Use "intelligent" computer-aided optimization of additive manufacturing techniques to define best tradeoff between heat transfer, flow restriction, and size
Motor and inverter meeting application requirements may not be feasible	Leverage state-of-the-art technology developed by Eaton and TARDEC to define a high efficiency axial flux motor and SiC inverter for this application
Geartrain size and weight may exceed targets	Use Eaton gear design optimization tools to search the entire design space for candidates that meet noise and reliability requirements while maximizing efficiency
Roots machine performance may be negatively affected by water	Assess Roots machine performance with water in Sub-Scale Test System
Water dosing system may have negative effect on fuel cell	• Feasibility assessment study and requirements definition by Ballard • Assess controllability of water dosing in Sub-Scale Test System

Any proposed future work is subject to change based on funding levels.

Proposed Future Work

FY 2022

- Complete contract negotiation
- Objectives for FY 2022 will be driven by project start date

FY 2023

- Objectives for FY 2023 will be driven by project start date

Any proposed future work is subject to change based on funding levels.

Summary

- The proposed development has high technical risk but could deliver a step-change in efficiency, durability, and reliability of heavy-duty fuel cell air systems
- Recipients plan to start the project once the contract negotiation phase is complete

Technical Backup and Additional Information

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Technology Transfer Activities

- No patent, licensing, or technology transfer activity has occurred
- Project has not yet started

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