Leveraging ICE Air System Technology for Fuel Cell System Cost Reduction

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Project ID: FC352

DOE Hydrogen Program

2022 Annual Merit Review and Peer Evaluation Meeting

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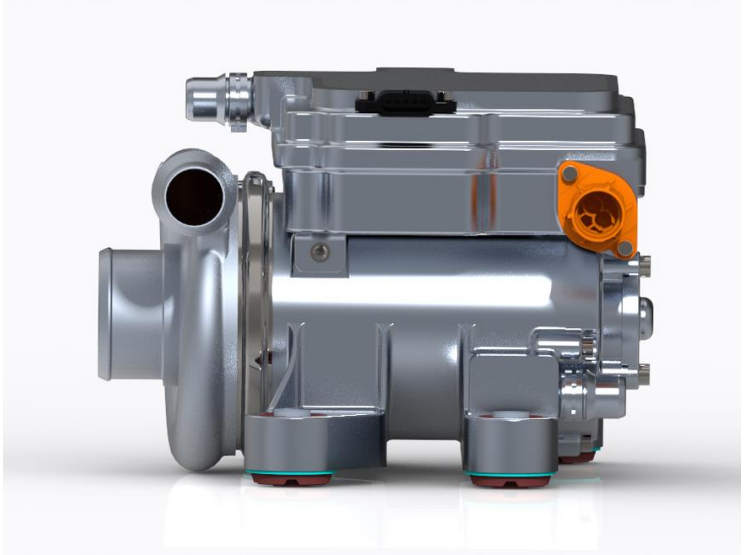
Project Goals

- Research, develop and demonstrate a high efficiency air boosting system to enable a lower cost 350kW Polymer Electrolyte Membrane Fuel Cell (PEMFC) system.
  - Evaluate and implement candidate supporting technologies to achieve DOE targets for performance, cost, reliability, durability, noise, size, and weight.



- Demonstrate, via vehicle-level simulations, fuel cell system performance with the developed air system over real-world transient machine application cycles. Compare to diesel and diesel-hybrid alternatives.

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Overview

Timeline

- Start date: TBD
- Project Duration: 36months

Budget

- Total Funding: $2.5M
  - DOE share: $2.0M
  - Industrial share: $0.50M
  - DOE Funds spent*: $0.0M
  - Cost share funds spent*: $0.0M

*As of 31March2022

Partners

- Project Lead: Caterpillar Inc.
- BorgWarner Emissions, Thermal and Turbo Systems
- Ballard Power Systems

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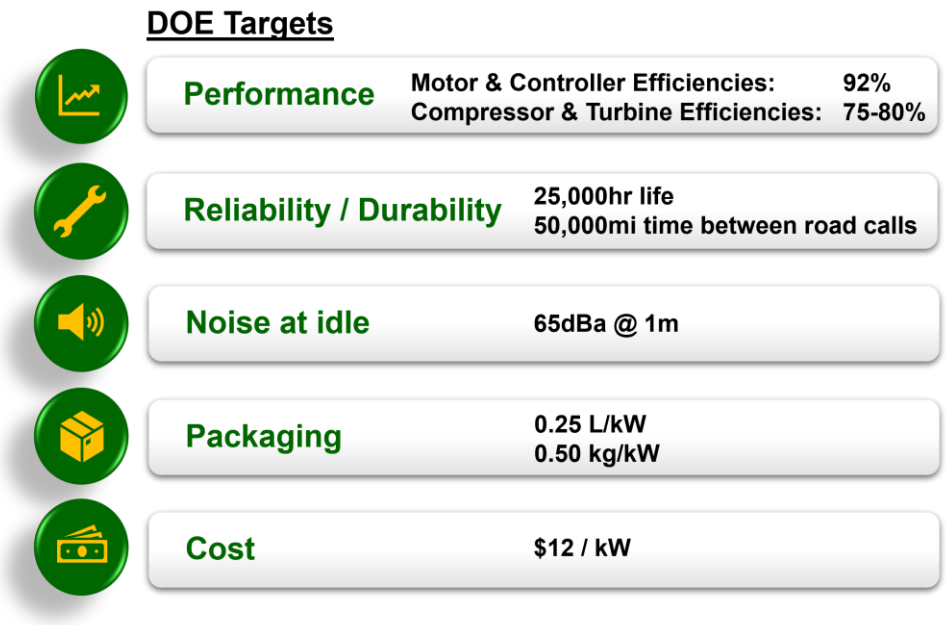
Relevance / Potential Impact

Burning Platform / Relevance

Balance of plant (BOP) components generally, and air system components specifically, have a major impact on performance and reliability of fuel cell systems. Using current technology, the BOP air supply:

- Consumes 10-15% of fuel cell power output
- Comprises 15-25% of fuel cell system cost
- Contributes to ~25% of fuel cell system downtime

The air system developed under this project will meet DOE targets for first cost, efficiency, reliability, durability, and size and weight for heavy-duty applications.



Potential Impact

Deployed over half of Caterpillar's product line for the target machines, fuel cell systems could reduce CO2 emissions by 1.5 million tonnes over a 10-year period.

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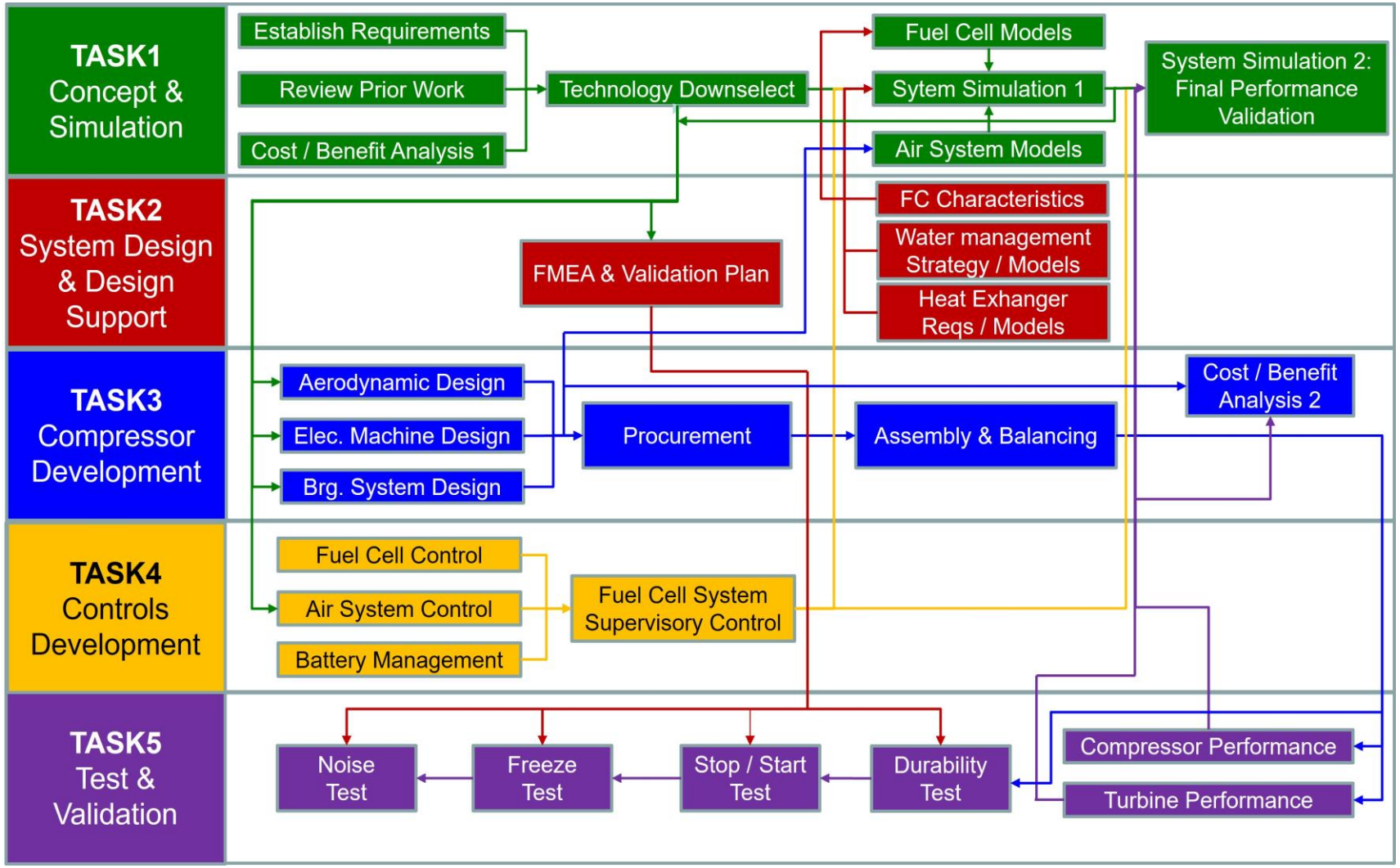
Approach



- Five work streams.
- Assessment of broad range of technology building blocks. Adaptation of proven internal combustion engine technologies to minimize R&D costs.
- System simulation and component development work synergistically to establish optimum solution recipe.
- Validation of the developed air system versus DOE targets through extensive bench testing.

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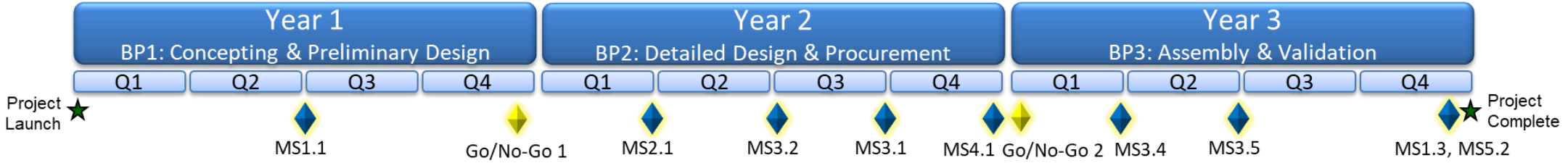
Milestones



Milestone Number	Milestone Description	Milestone Verification Process	Months from Start
MS1.1	Booster Concept finalized, including supporting technologies	Documentation of lit review/prior investigations, PUGH, cost-benefit analysis	6
Go/No-Go 1	Proposed concept demonstrates strong probability of meeting project targets	1D & Preliminary CFD analysis validates aero eff w/in 5% of target. E-machine analysis validates electrical eff w/in 5% of target. Cost estimate ≤ $50/kW with line-of-sight to ≤ $25/kW	12
MS2.1	FC, BOP subsystem models complete	Documentation of model architecture	15
MS3.2	Design of electric machine to meet performance & durability targets	Results of lumped thermal parameter analysis and 2D & 3D electromagnetic and thermal finite element analysis show predicted efficiencies w/in 1% of DOE target and predicted life ≥ 25,000hrs	18
MS3.1	Design of aerodynamic components to meet performance and durability targets	Documentation of 3D CFD performance assessment w/ predicted efficiencies within 1% of DOE target, and structural FEA and frequency analysis with predicted life ≥ 25,000hrs	21
MS4.1	Develop control system to maximize FC system efficiency over application work cycles and meet project transient response reqs	Documentation of control system simulation	24
Go/No-Go 2	Proposed concept predicted to meet project targets	Detailed design / analysis from MS3.1, MS3.2 confirm performance & durability targets can be met. Updated cost analysis indicates ≤ $25/kW with line-of-sight to ≤ $12/kW	24
MS3.4	Design of bearing system to meet performance / durability target	Results of bearing characterization and synchronous analysis showing predicted life ≥ 25,000hrs	27
MS3.5	Procurement of subcomponents followed by assembly and balancing to deliver device ready-to-test	Photographs of subcomponents and completed assembly. Results of balance testing documented	30
MS1.3	Final system performance documented using measured performance maps in vehicle simulation	Documentation of final system simulation results, including comparison to diesel and diesel-hybrid powersystems	36
MS5.2	Component validation against project targets complete	Documentation of 1) aero performance, 2) accelerated durability test results, 3) start/stop test results, 4) freeze test results, 5) noise results, 6) vehicle simulations over application work cycles	36

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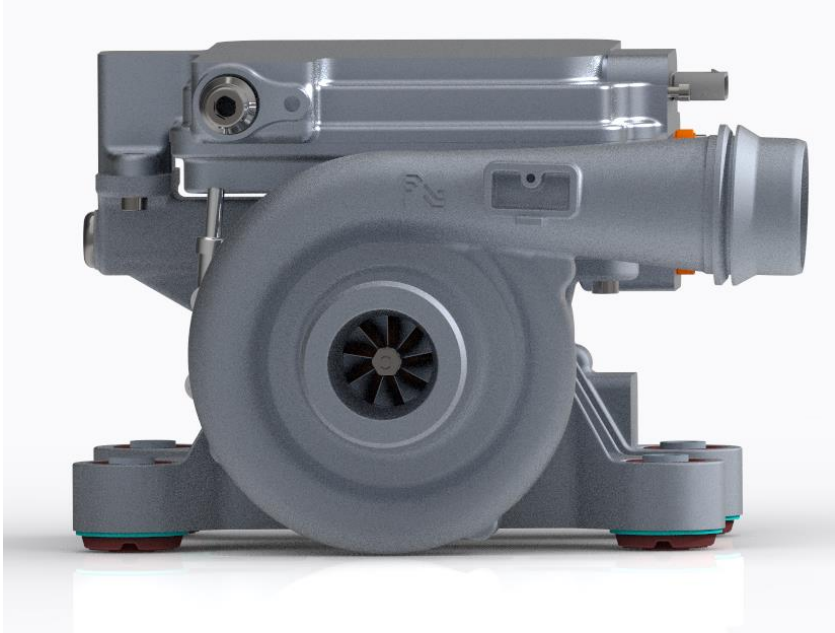
Accomplishments and Progress

Note: Project has not yet started (as of 31March2022)

Prime and Sub-Recipients have been meeting to discuss project plan and task breakdowns. The following tasks have started:

- Review of specifications
- Literature review
- Review of modelling approaches
- QFD / PUGH analysis of candidate technologies
- Basic compressor and turbine matching
- Initial bump foil bearing sizing
- Baseline electric machine design



Response to Previous Year Reviewers' Comments

New Project. This project was not reviewed last year.

Collaboration and Coordination

Partner	Type	Project Roles
Caterpillar	Prime	Project Management Model Development / System Simulation Control Development System Performance Optimization
BorgWarner	Sub-Recipient	Air System Design Component Procurement / Assembly / Balance Component Test and Validation
Ballard	Sub-Recipient	PEMFC Expertise Detailed Requirements and Specifications Model Development and Support

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Remaining Challenges and Barriers

- Development of fuel cell stack and system models capable of accurate performance predictions over highly transient machine application cycles
- Test station upgrades to assess booster performance versus DOE targets
- Testing apparatus suitable to isolate critical components for individual validation
- Matching oil free bearing technology to high project durability requirements
- Electric machine rotor temperature management

Proposed Future Work

Remainder of 2022:

- Officially launch project
- Develop fuel cell stack and BOP models
  - Calibrate/benchmark for steady-state simulations
  - Assess air system candidate technologies via impact on system performance
- Develop preliminary aero, bearing and electrical machine designs
- Perform preliminary cost/benefit analysis of candidate supporting technologies

2023:

- Refine fuel cell stack and BOP models
  - Calibrate/benchmark for transient simulations
  - Evaluate candidate air systems over machine application cycles
- Complete detailed aero and electrical machine designs
- Complete preliminary bearing system design

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

Summary

- Caterpillar is working with BorgWarner and Ballard to develop an air boosting device for high-power heavy-duty fuel cells that meets DOE requirements for efficiency, reliability, durability, cost, size, and weight
- Given the aggressive DOE targets for the developed boosting device, this project will assess a broad range of candidate technology building blocks so that a well-informed down-selection can be made
- System simulation and component development will work synergistically to establish an optimum technical recipe that meets performance requirements while maximizing commercial attractiveness
- Extensive bench-testing will validate the developed boosting device against DOE targets

Technical Backup and Additional Information Slides

Technology Transfer Activities

- Nothing to report.