METAL-SUPPORTED CERIA ELECTROLYTE-BASED SOFC STACK FOR SCALABLE, LOW COST, HIGH EFFICIENCY AND ROBUST STATIONARY POWER SYSTEMS

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12-June-2017
Agenda

- Cummins’ emerging strategy
- Building a strong foundation with Ceres Power
- Ceres SOFC pedigree & sample data
- FE27844 Objectives
- 5kW building block fundamentals
- Acknowledgements
Cummins Inc Business Units

- Components Business: 20%
- Distribution Business: 18%
- Power Generation Business: 14%
- Engine Business: 48%
Cummins’ Market Segments aligned to Fuel Cells

- Mining
- Marine
- Oil & Gas
- Rail
- Defense
- Consumer
- Commercial & Industrial
- Mission Critical
- Prime Power
- Components
Corporate Expansion into New Technologies

- Direct report into CEO first line
- Responsible for electrification technologies
  - Energy storage systems
  - Power electronics
  - Electric machines
  - Fuel Cells (multiple applications)

Unlimited Rights Data
Cummins Fuel Cell Capabilities

- Cummins’ Core competency in SOFC Balance of Plant and System Integration building on existing ICE capability
  - Systems Engineering
  - Computational Fluid Dynamics
  - Heat Transfer
  - Catalytic Processes
- Advanced Controls capabilities
- Power Electronics design and manufacture
  - DC-DC
  - DC-AC Inverters
Cummins building strong foundations with Ceres Power

- Relationship commenced in 2013
- Mutual, long term goals centered on product excellence
- Complementary market focus

- Line of sight to first large scale application of fuel cells
- Cummins to lead system integration
- Builds on Cummins’ existing customer base and relationships
Cummins building strong foundations with Ceres Power

- Relationship commenced in 2013
- Mutual, long term goals centered on product excellence
- Complementary market focus and long term growth prospects
## Commercial Progress

<table>
<thead>
<tr>
<th>Region</th>
<th>Residential (&gt;10 GW)</th>
<th>Data Centre/Back Up (&gt;5 GW)</th>
<th>Commercial (&gt;10 GW)</th>
<th>APU (&gt;10 GW)</th>
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<tbody>
<tr>
<td>Japan</td>
<td><strong>INCREASING APPLICATIONS</strong></td>
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<td>Korea</td>
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<td>USA &amp; RoW</td>
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- **Customers**
- * includes DoE CCS and Power System applications
Volumetric Power Density Progress

Stack Volume Potential
- Litres/kW
- M³/MW

1kW Stack
- Performance Development
  950W@>60%LHV
  Gross Efficiency
  Complete (STK0215)
  May 2016

5kW Demo
- Penta-01
  Complete
  July 2016

Mechanical Integration of cells AND manifolds
- 5kW
  2017

Future
- On-going
- Complete
- Further Planned R&D

Unlimited Rights Data
Steady state degradation <0.3%  
Stack, FCM and Complete Fuel Cell Power System

Mean Cell Voltage (V) vs. Time (kh)

- V3.0-3.2 Stack Level (Reformate)
- V4.0 Stack Level (Reformate)
- Fuel Cell System

Grid lines show 0.3%/kh
Degradation Rate Improvement Through R&D

Degradation Rate

Year

2015 2016 2017 2018 2019

Released to

V3

V4

R&D Cell*

@ 20% higher current density & 15% higher fuel utilisation

Target

R&D Cell*

@ 20% higher current density & 15% higher fuel utilisation

V3

V4
SteelCell Stacks Show World Class Robustness to On-Off Cycles

Fuel: H₂/N₂
ΔT = 350°C

>2500 thermal cycles

Thermal Cycles

Mean Cell Voltage (V)
Robustness to Redox cycles and E-stops allows for new applications

10 years life

Cell Power (%) vs E-Stop Cycles
FE27844 Objectives

- Development of:
  - Complete internal fuel reforming capability
  - Larger active cell area to achieve integrated, compact, low cost 5kW stack
  - Integrated 5 kW modular stack platform scalable from 5 – 100kW
  - 5 kW FCPS demonstrator utilizing integrated 5 kW modular stack platform

- Demonstration of:
  - 5kW FCPS performance through minimum of 1,000 hours of real-time testing:
    - Galvanostatic Degradation: <0.5%/1000hrs
    - Robustness: >10 on/off cycles; >5 emergency stops (e-stops)
  - Cost modelling to show system cost of $1,500/kW (2011 currency basis) achievable at production volumes
  - Predictive modelling using demonstration test results to show system lifetime robustness capability of:
    - Galvanostatic Degradation: <0.1%/1,000hrs
    - Robustness: >2,000 on/off cycles; >60 e-stops
  - Partnership with PNNL for anode poison sensitivity
  - Partnership with UConn for cathode poison robustness
Move to Greater Internal Reforming

- Simulated low temperature reformate showing stable performance - tests continuing
- Testing commenced on methane and natural gas feedstocks
- Demonstration system will utilise internal reforming for system performance benefit

< 0.2% /khrs degradation
Larger Cell Area Roadmap

- Ceres plans a step by step approach to achieve large area cells
5kW system building blocks

- Proven 1kW technology scaled to 5kW stacks
  - Increase in cell area and cell count per stack
- DoE funded system to include 2 x 5kW stacks
- Design approach taken is scalable to 100-500kW
  - Flexibility designed-in to suit multiple fields and applications
5kW system modelling

- Building on the 1kW SteelGen technology, the target is for the power system design to produce electricity at >60%\(\eta\) net

- Matlab physical system simulation model used to conduct trade off analyses & optimise system design principles

- Focus on ability to further integrate BoP components to yield further minor improvements and lower cost
Progress & Accomplishments

- VoC work successfully completed
- Good team working dynamic
- System modelling supports 5kW, 60% $\eta$ & durability targets can be achieved
- Architecture design review of modular 5kW / 10kW system complete
- Sub-system component selection in progress
- Large area cell trials in progress – target for first demonstration Sep 2017
- Poison work progressing to plan with UConn & PNNL
Next Steps

- Continue to detailed design release
- Commence bench testing of sub-system BoP components
- Continue cathode & anode poison work
- Continue to develop pipeline of activities beyond end of DoE project
  - Create a springboard to next stage product development / field trials
Acknowledgements

- The work summarized in this paper was funded by the U.S. Department of Energy’s Solid Oxide Fuel Cell Program.
- NETL: Patcharin Burke, Angela Bosley, Shailesh Vora, Joseph Stoffa,
- PNNL: Jeffry Stevenson
- University of Connecticut: Prabhakar Singh