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

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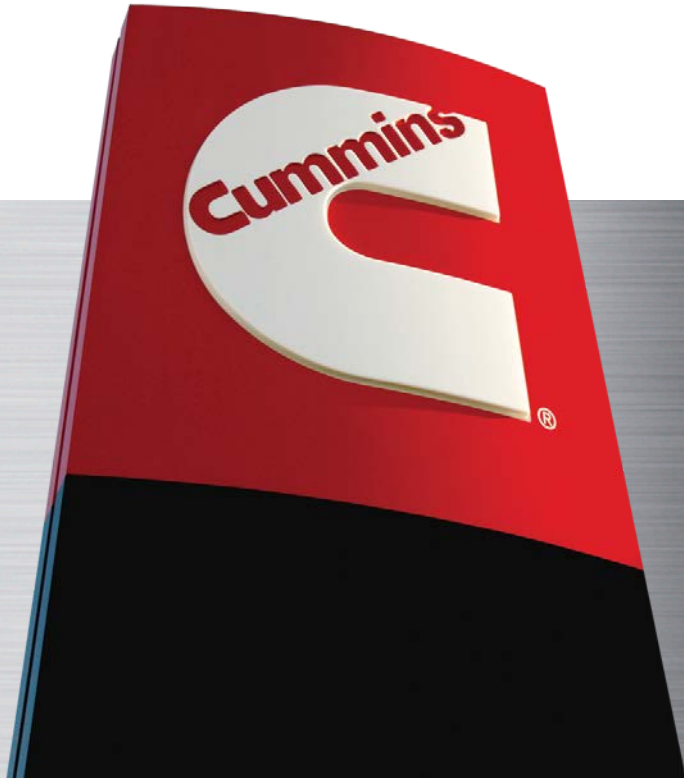
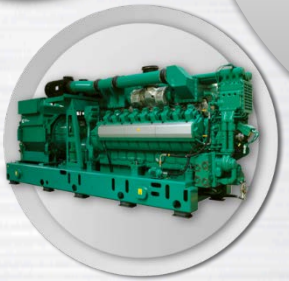
12-June-2017

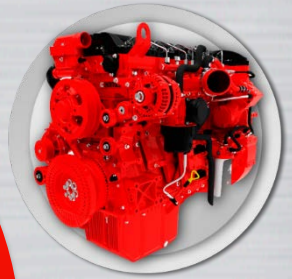


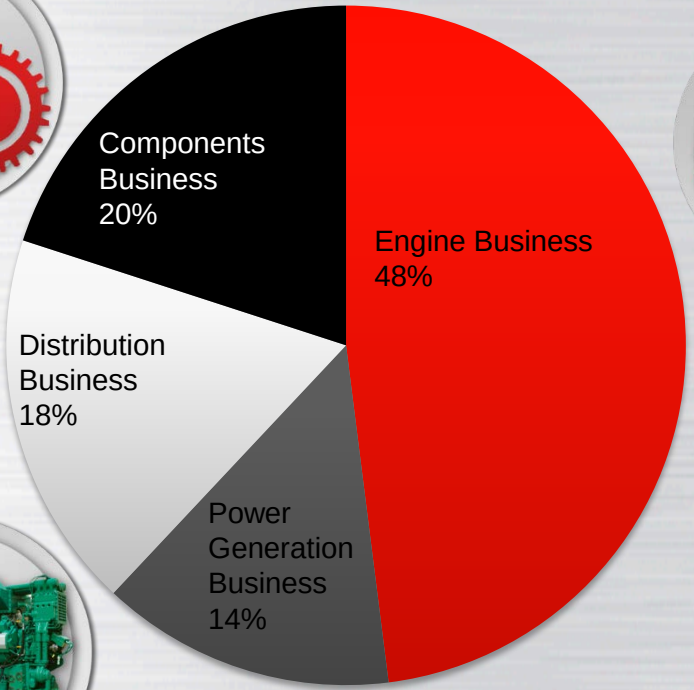
Agenda

- 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







Cummins' Market Segments aligned to Fuel Cells

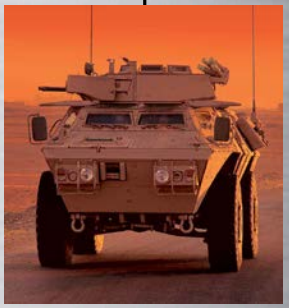
Mining

Marine

Oil & Gas

Rail

Defense



Consumer

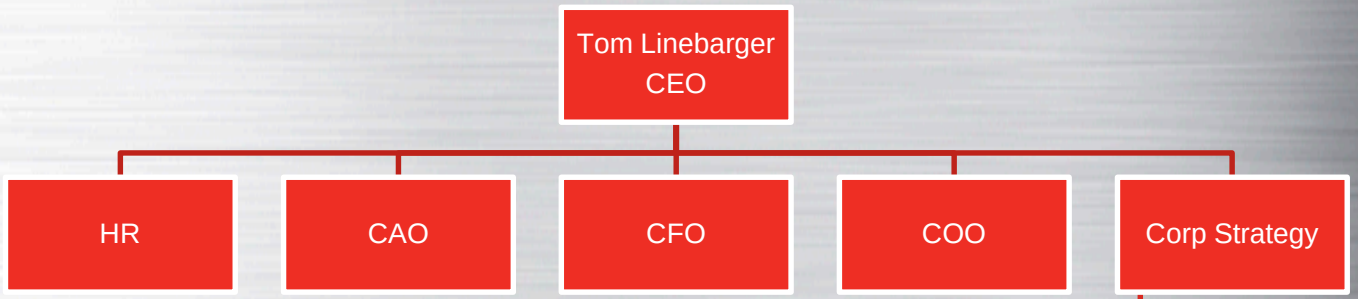
Commercial & Industrial

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)

Exec Director Electrification Business Development Initiative

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

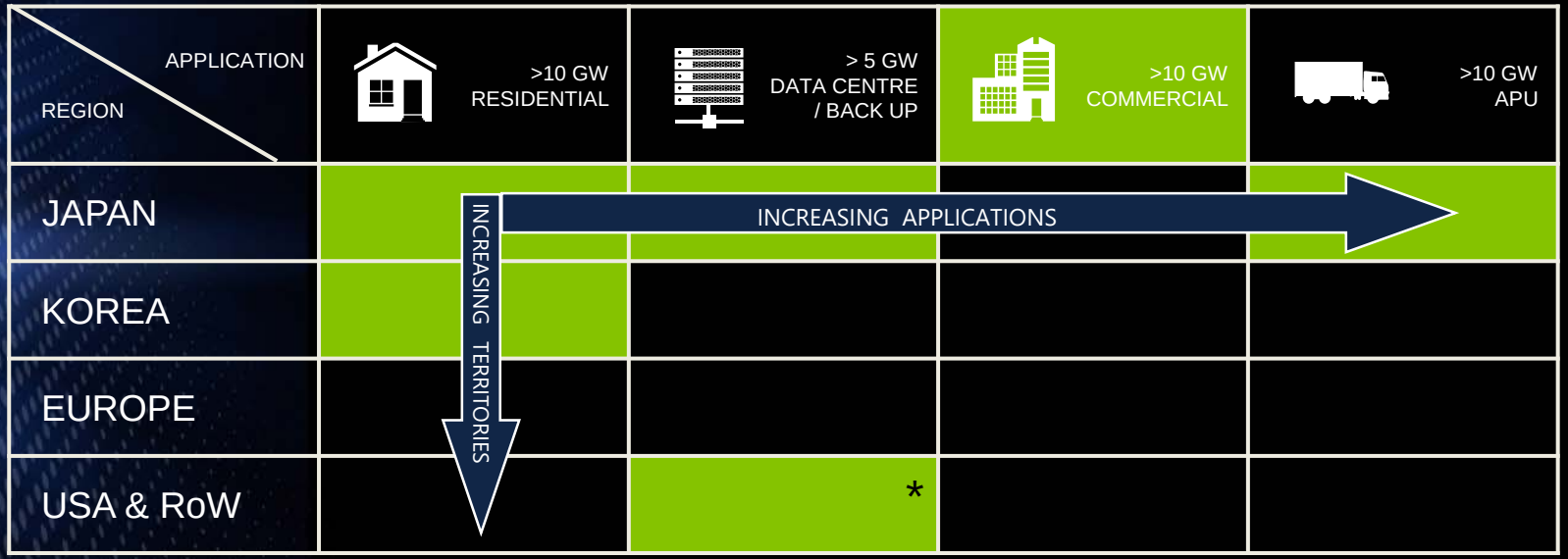
- Relationship commenced in 2013
- Mutual, long term goals centered on product excellence
- Complementary market focus

- 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

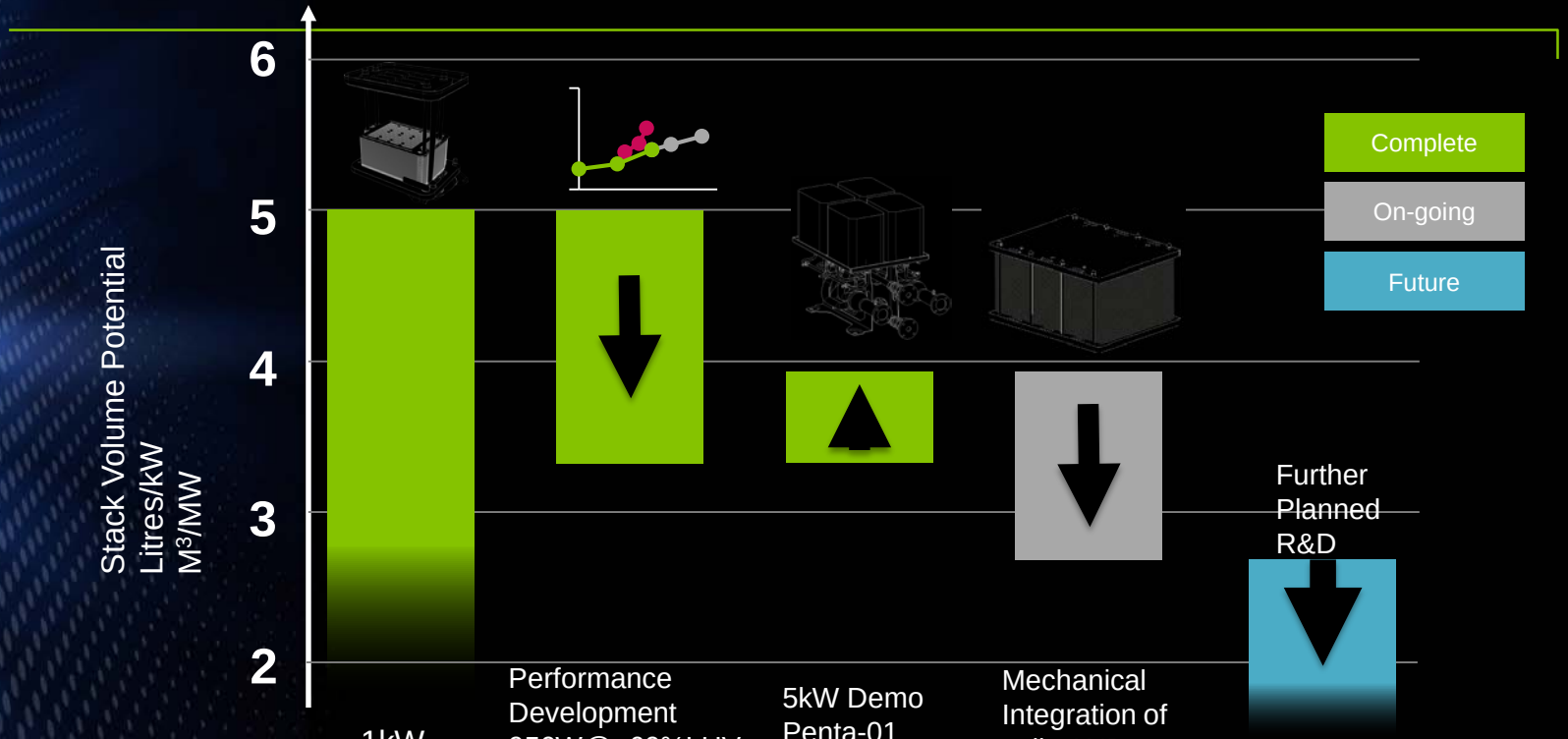
Commercial Progress



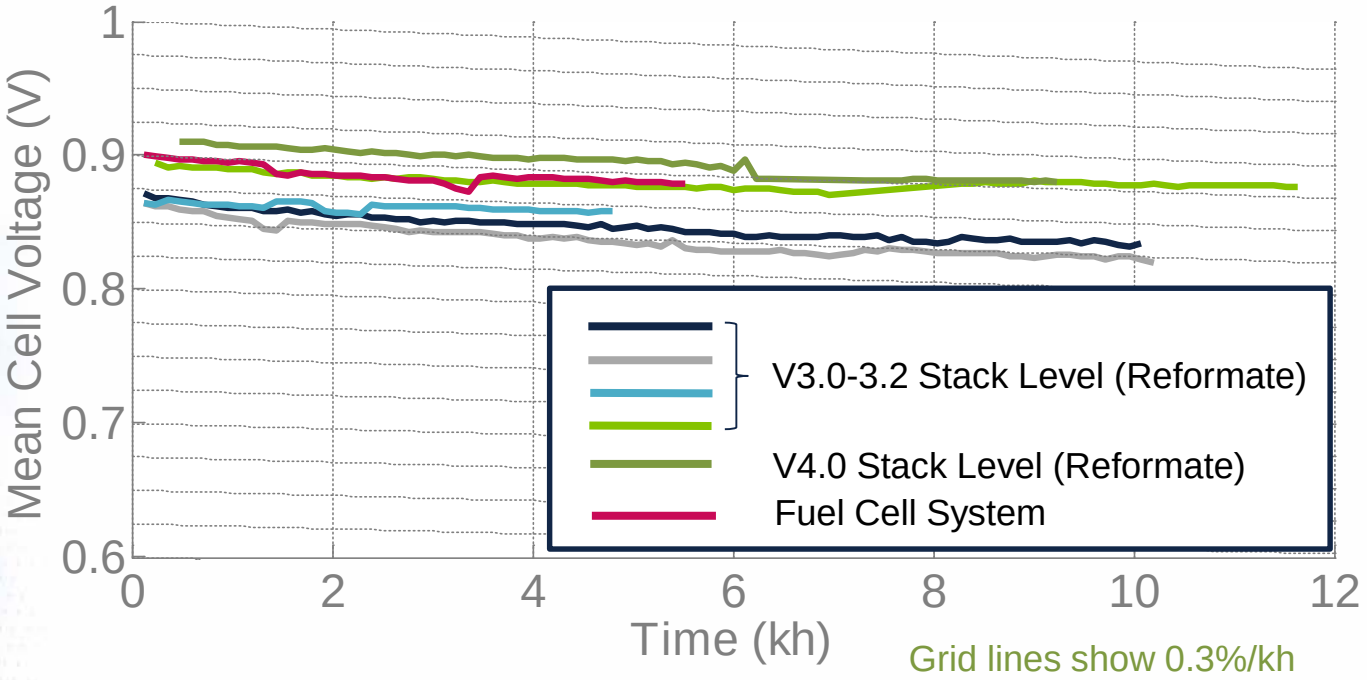
- **Customers**

*** includes DoE CCS and Power System applications**

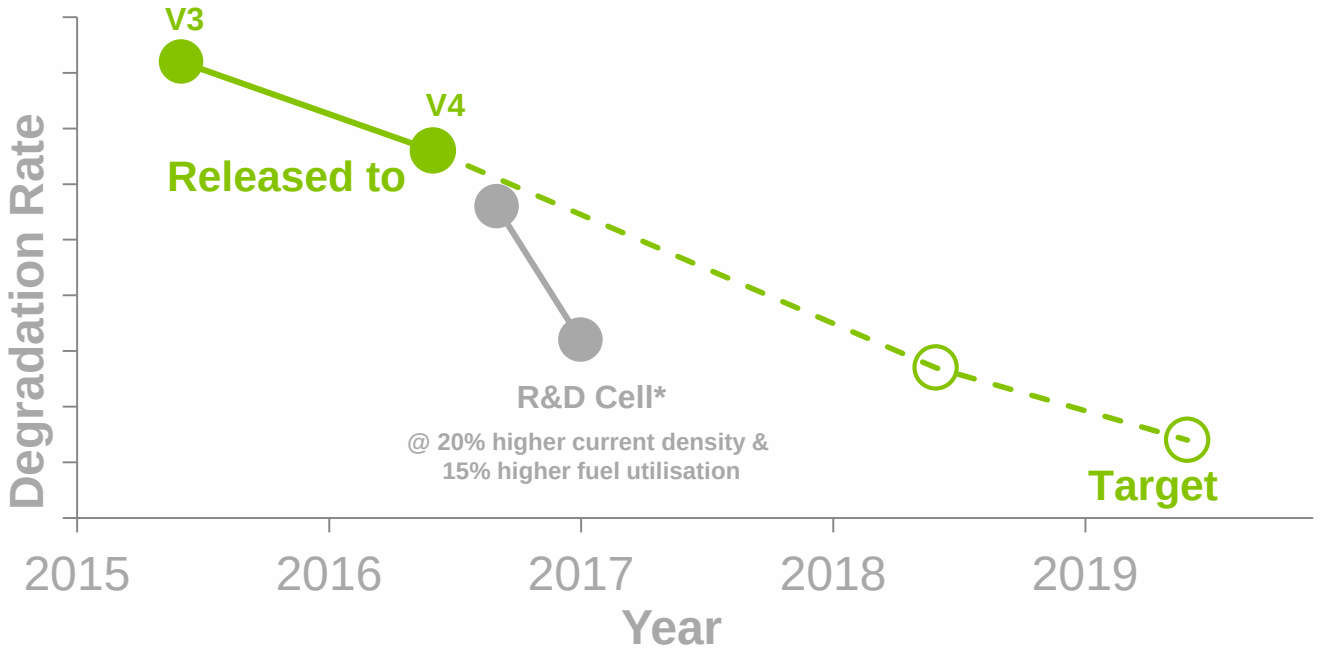
Volumetric Power Density Progress



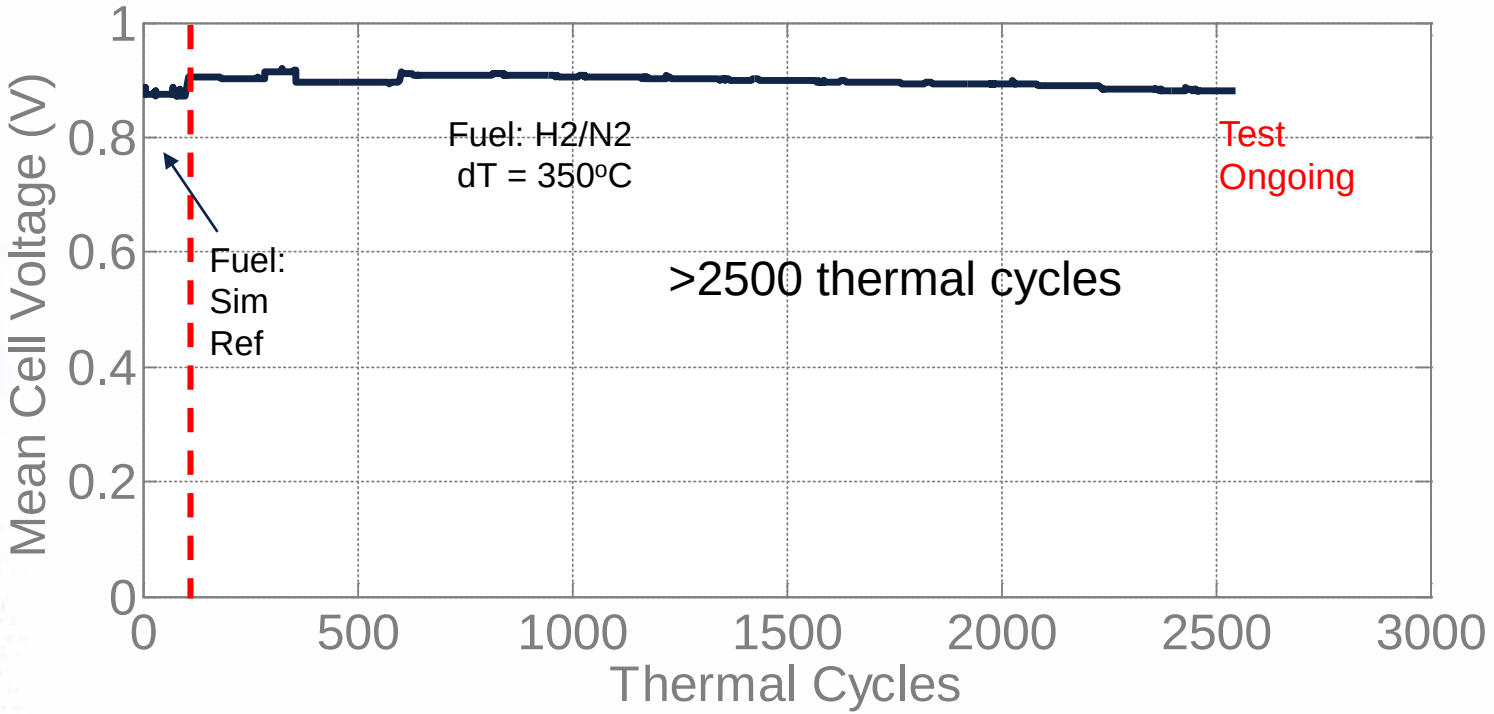
Steady state degradation <0.3%
Stack, FCM and Complete Fuel Cell Power System



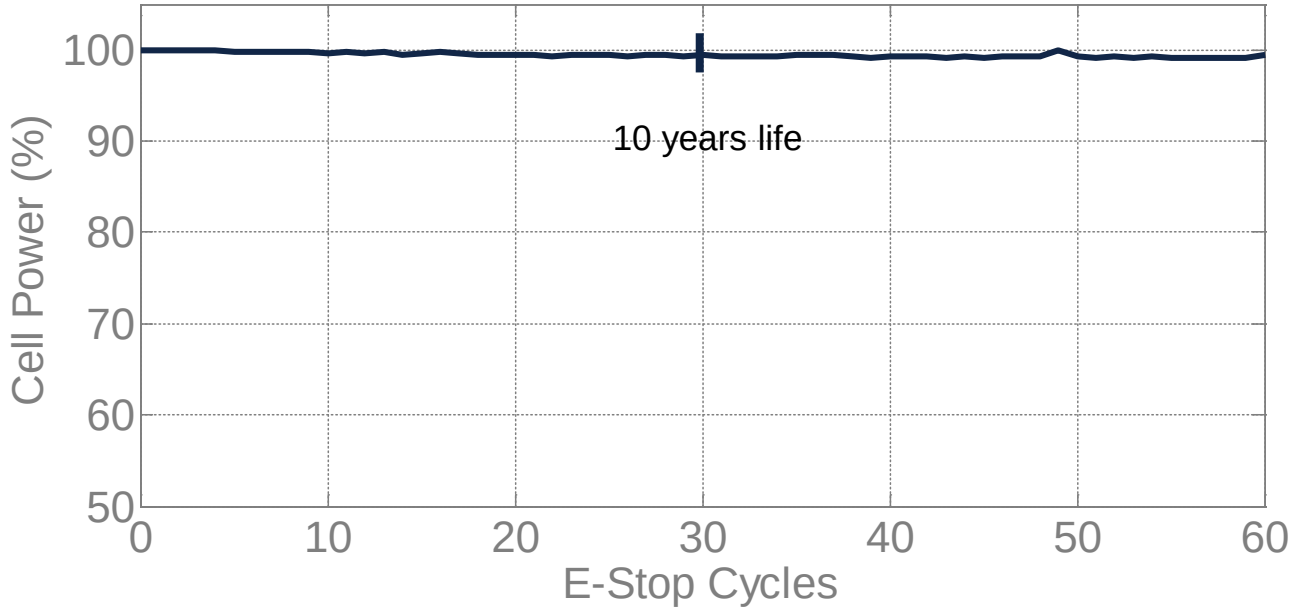
Degradation Rate Improvement Through R&D



SteelCell Stacks Show World Class Robustness to On-Off Cycles



Robustness to Redox cycles and E-stops allows for new applications

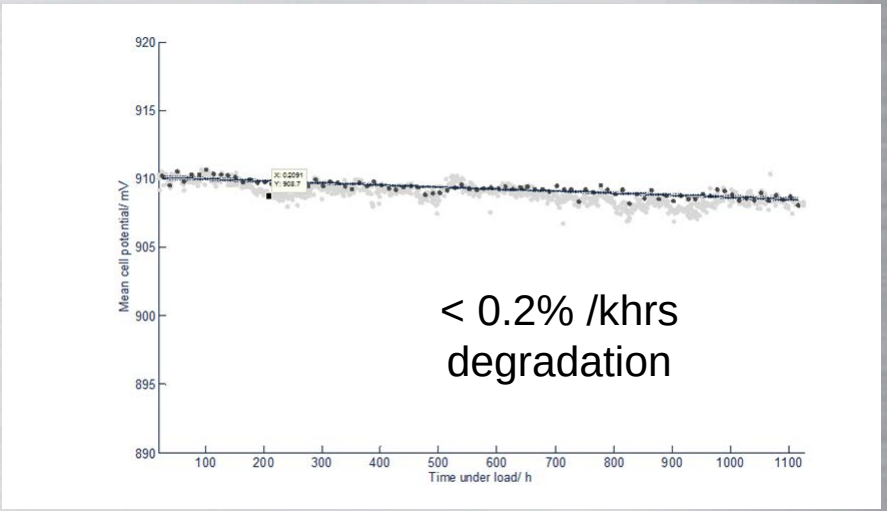


FE27844 Objectives

- 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

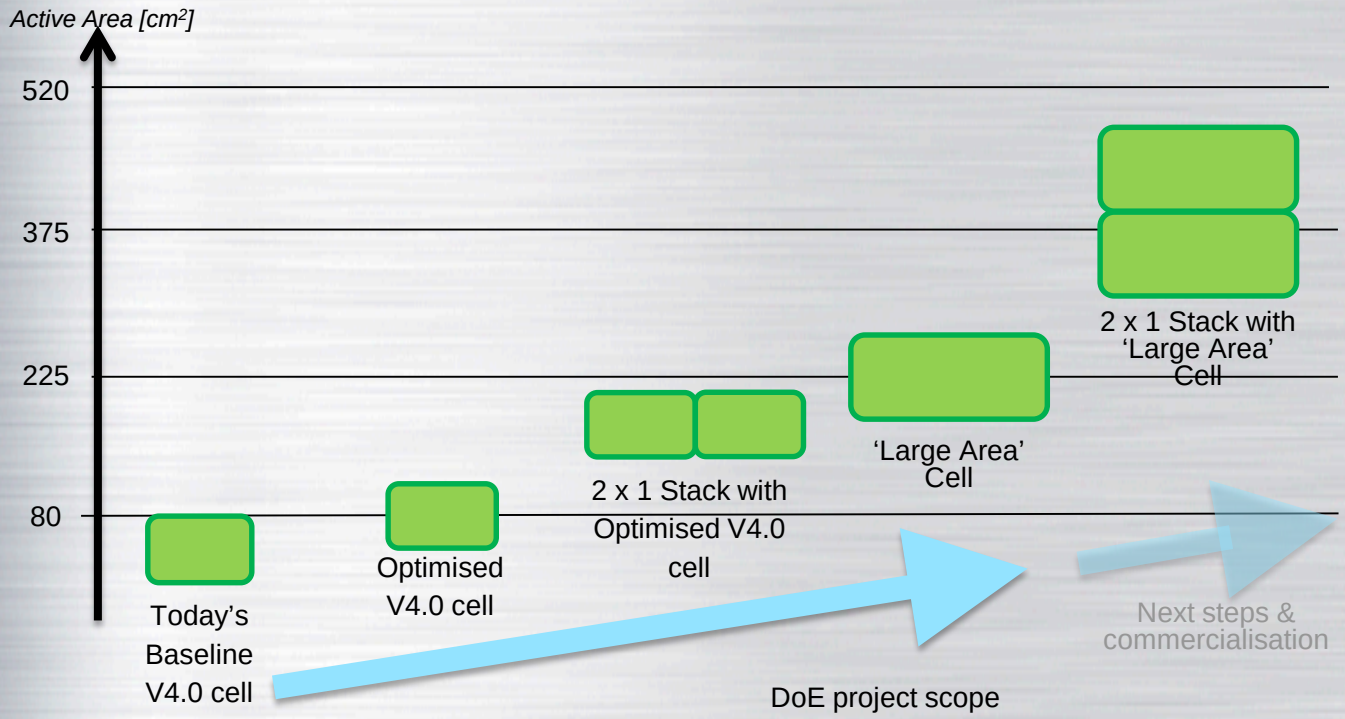
Move to Greater Internal Reforming

- 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



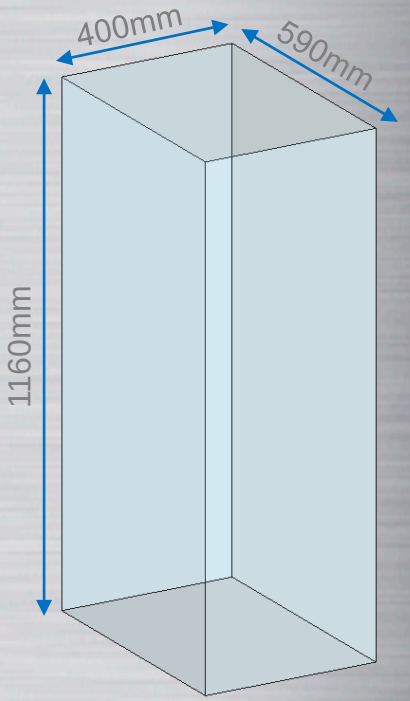
Larger Cell Area Roadmap

- Ceres plans a step by step approach to achieve large area cells



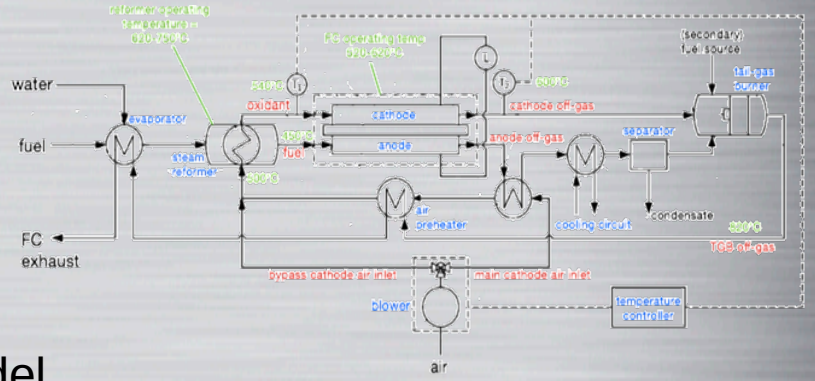
5kW system building blocks

- 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%η 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%η & 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

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