

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

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30-April-2019

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Agenda

- Cummins' emerging SOFC strategy
- Ceres SOFC overview and plans for scale up
- FE27844 Objectives
- 5kW and demonstrator system updates on progress
- Acknowledgements

Cummins' Market Segments aligned to Fuel Cells



Mining



Marine



Oil & Gas



Rail



Defense



Consumer



Commercial & Industrial



Mission Critical



Prime Power



Components

Cummins Evaluation Of Data Center Applications

- Evaluation of Microsoft's vision for data centers of the future at small scale
- First phase of evaluation commenced October 2017
- Ceres and Cummins DoE demonstrator engineered for Microsoft's operational and physical targets



Ceres Power

- Unique Fuel Cell Technology
- 50 patent families
- c. 200 employees
- Fully funded with £30m order book



World leading developer of SteelCell® low cost, non combustion power generation technology

- High efficiency distributed generation
- Lowers CO2 emissions
- Improves Air Quality
- Provides energy security
- Enables EV's and balances renewables
- Uses existing fuel infrastructure today, e.g. Natural Gas, bio fuels and H2 ready

MULTIPLE DEVELOPMENT PARTNERS for MULTIPLE APPLICATIONS



CONFIDENTIAL PARTNER 1

- European-based Global OEM co-developing multi-kW prototype for multiple applications
- Strategic collaboration – buses and other China markets - targeting equity investment and JV
- Honda Power Systems – several applications
- SOFC Stack to Extend Range of Electric Vehicles
- Data Centre & Commercial Scale Opportunity
- Commercial Scale CHP Development with aim to market launch

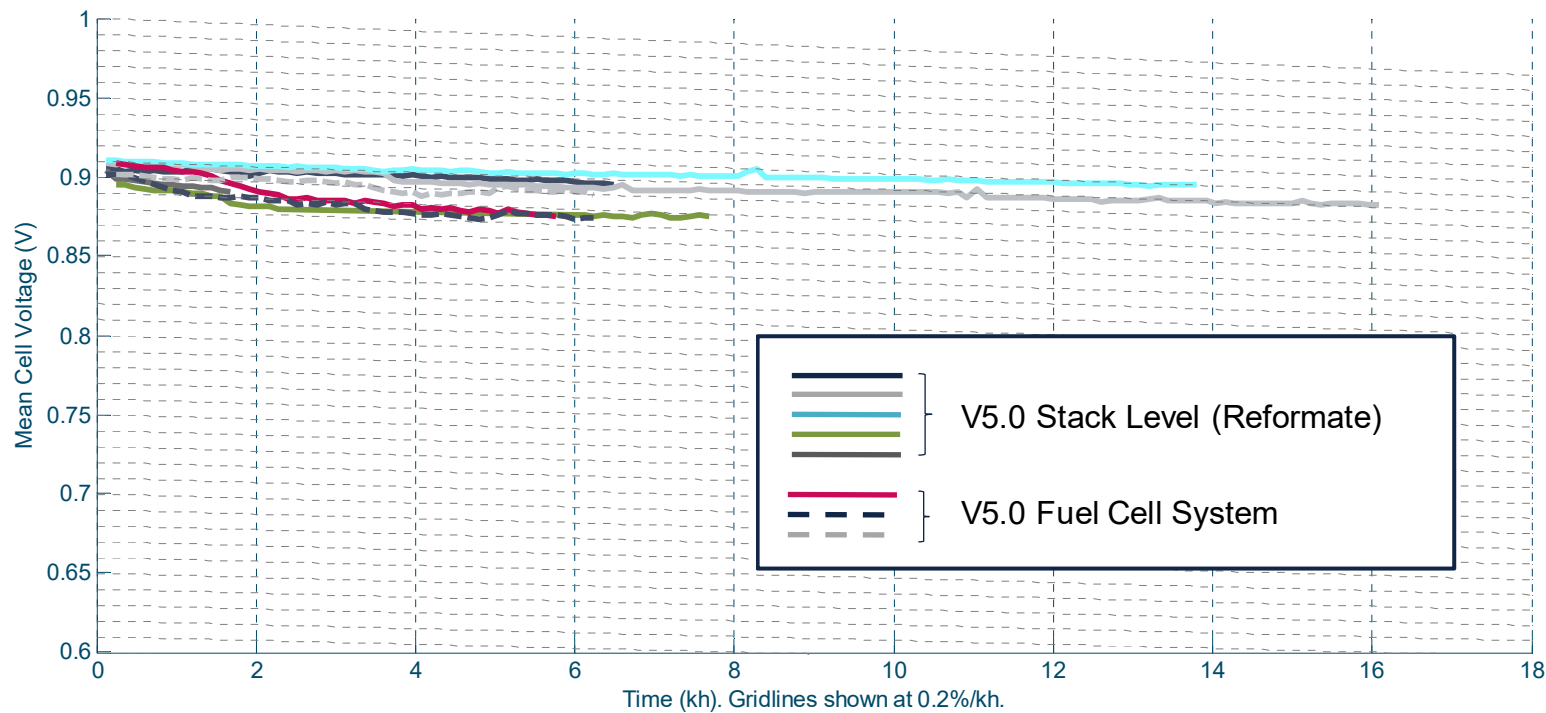
Ceres Production and Capacity Increase

- £7.5m programme for manufacturing capacity increase at Ceres:
 - To accommodate increasing customer demand
 - To demonstrate the potential for scale up and higher production rates
- First machines delivered to site, siting & connections commenced in April 2019
- Production Validation builds on schedule for Q3
- Production ramp up on schedule for Q4

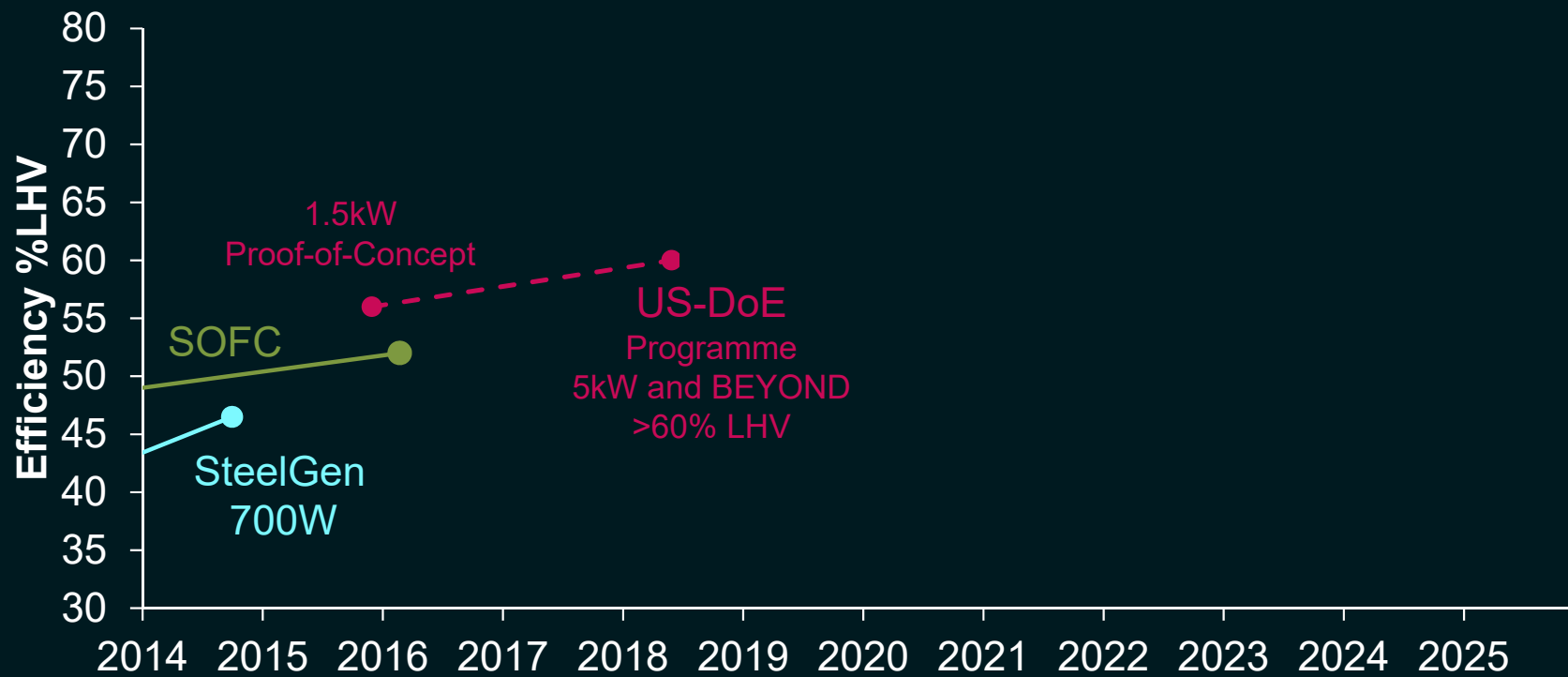


Steady state degradation at <0.2%

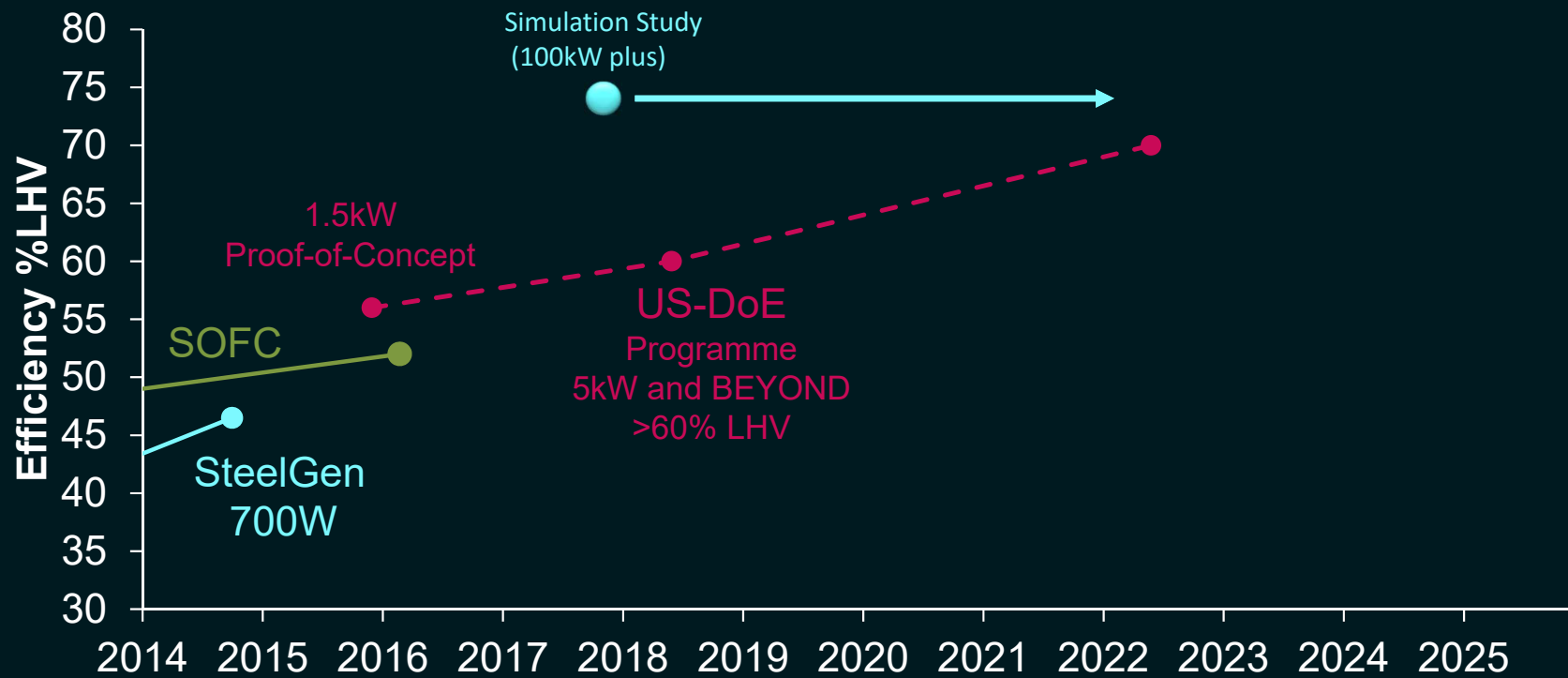
- Stacks consistently demonstrating improved degradation rates from 2018
- System degradation stabilises to ~0.2%/khr



Fuel Cell Power System – Multi-kW Prime Power



Fuel Cell Power System – Multi-kW Prime Power

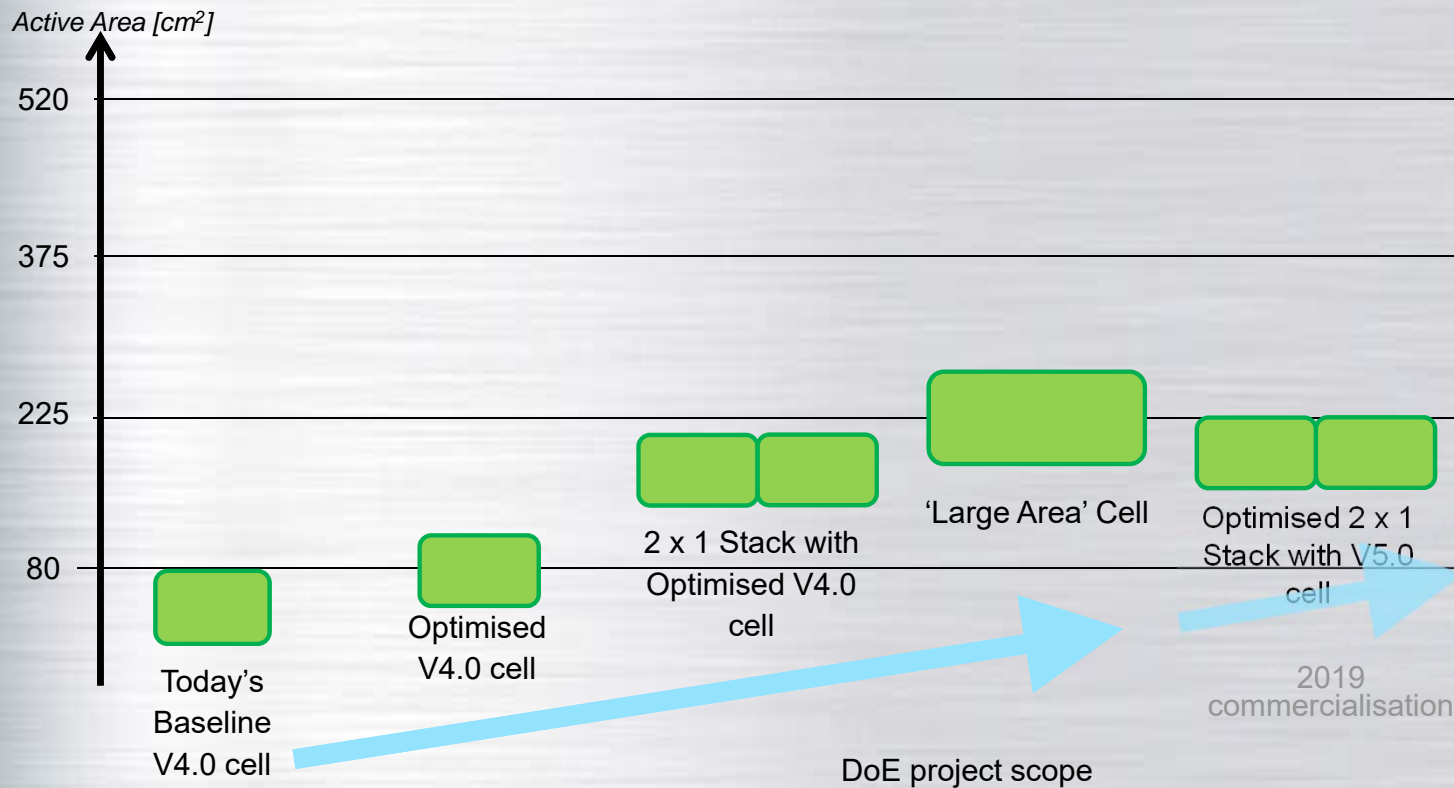


FE27844 Objectives

- Development of:
 - Complete internal fuel reforming capability ▪ Complete
 - Larger active cell area to achieve integrated, compact, low cost 5kW stack ▪ Complete
 - Integrated 5 kW modular stack platform scalable from 5 – 100kW ▪ Complete
 - 5 kW FCPS demonstrator utilizing integrated 5 kW modular stack platform ▪ Dec 2018
- Demonstration of:
 - 5kW FCPS performance through minimum of 1,000 hours of real-time testing:
 - Galvanostatic Degradation: <0.5%/1000hrs ▪ Dec 2019
 - Robustness: >10 on/off cycles; >5 emergency stops (e-stops) ▪ Dec 2019
- Cost modelling to show system cost of \$1,500/kW (2011 currency basis) achievable at production volumes ▪ Jun 2019
- Predictive modelling using demonstration test results to show system lifetime robustness capability of:
 - Galvanostatic Degradation: <0.1%/1,000hrs ▪ Complete
 - Robustness: >2,000 on/off cycles ; >60 e-stops ▪ Complete
- Partnership with PNNL for anode poison sensitivity ▪ Complete
- Partnership with UConn for cathode poison robustness ▪ Complete

Larger Cell Area Roadmap

- Ceres plans a step by step approach to deliver larger area cells



5kW Stack Builds

- 5kW Stacks now built and on test at Ceres Power



Scale-up to 5kW Delivers Class Leading Performance

- 5kW stack performance and degradation testing at Ceres in line with predictions

| Performance Attribute | 1kW Stack (109 cells) | 5kW Stack (250 WF cells) |
|--|--------------------------|-----------------------------|
| Power Density (W/l) | 195 | 299 342 by end of 2019 |
| Maximum fuel utilisation | 70% | 70% |
| Gross efficiency (@ NOC for stationary applications) | 65% | 65% |
| Hours on test | 40k | 3k |
| Degradation rate (%/1,000 hours) | <0.2% | <0.25% |

DoE / Cummins Project Demonstrator

- 2 x 5kW stacks
- Data Centre compatible
- >60% electrical efficiency predicted
- Unit size : Depth 1.25m,
- Width 0.6m, Height 1.9m
- Progress made to schedule until Sep 2018
- During delivery to the UK, the demonstrator unit was damaged in transit



Demonstrator System Next Steps

- Decision to complete minimal rework, partly commission, develop SW & Controls
 - System completed c. 3 month repair and commissioning programme
- Progress made to date:
 - System fitted with a single fuel cell stack for hot commissioning
 - Stack has produced 5kW @ ~68% gross (on CH₄)
 - System has exported 4.2kW @ ~59% net to the grid
 - Results are in line with predictions for single stack operation
 - System has been returned to USA for full repair and installation of 2 new stacks
- Next Steps
 - System to return to UK for final commissioning
 - Then ship to US for installation at UConn for official DoE demonstration
 - Predicted performance → 10kW net @ 60% net

Other Workpackages

- Characterisation of anode contamination by PNNL
 - This learning will influence future anode and system development activities
- Assessment of next generation cathode getter materials by UConn
 - This learning will influence future system design and development
- Cost modelling due for completion by end Q2 2019:
 - DoE rules of the road applied to System BoP costing
 - Ceres in-house long term cost down roadmap in progress

Progress & Accomplishments

- Anode poison work completed at PNNL
- Cathode poison work completed at UConn
- Demonstrator system built with PEKO Precision
- In-transit damage has impacted test program
 - Commissioning completed with single 5kW stack
 - System has exported 4.2kW @~59% net efficiency to the grid
- Demonstrator rework and stack replacement completion in Q2 2019



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Next Steps

- Complete demonstrator system rebuild at PEKO Precision
- Commission demonstrator system at Ceres
- Complete demonstrator system evaluation at UConn
- Continue to develop pipeline of activities beyond end of DoE project



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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