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Recent Advances in PEM Water Electrolsyis

First International Workshop on Endurance and Degradation Issues in PEM Electrolysis

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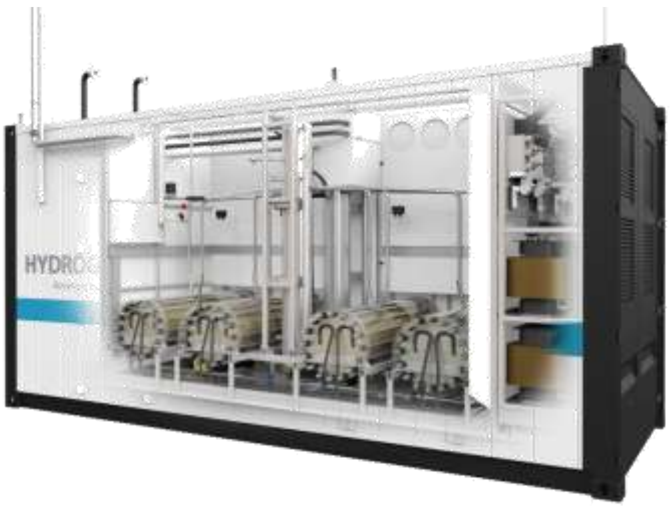
Strategic Electrolysis Focus

- We have a wealth of experience and expertise that makes us a worldwide leader in Alkaline and PEM water electrolysis
- Hydrogenics and its partners are committed to the development and commercialization of Power-to-Gas
- Our MW scale PEMWE is entering a phase where engineering and manufacturing will become as important as technical leadership

HySTAT™

Onsite Hydrogen Generation “Workhorse”



HySTAT™-60 (Outdoor)

HySTAT™-30 (Indoor)

HySTAT™-15 (Indoor)

Compliant to all major international standards (CE, GOST, US NRTL)

Products designed to meet the challenges of industrial on-site hydrogen gas users.

Market Segmentation Drives Product Strategy

South Africa: Chemicals

Russia: Float Glass

Greece: Solar Industry

Ukraine: Metallurgy

China: Merchant Gas

Argentina: Renewable

Our Power-to-Gas Product Roadmap

Today

Among the most proven and utilized technology

2 MW Installation

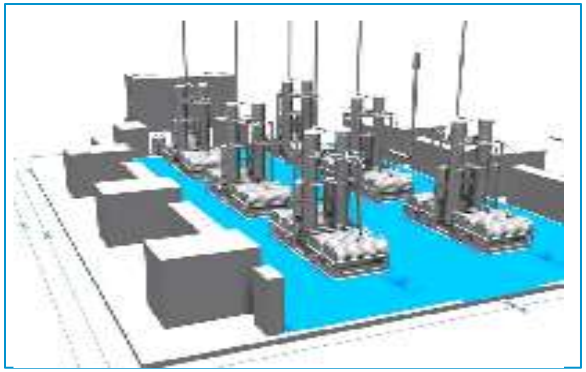
Needs…

Products optimized for grid energy storage scale and cost

5 to 100 MW Solutions

Tomorrow

Advanced MW-scale PEMWE plant solutions

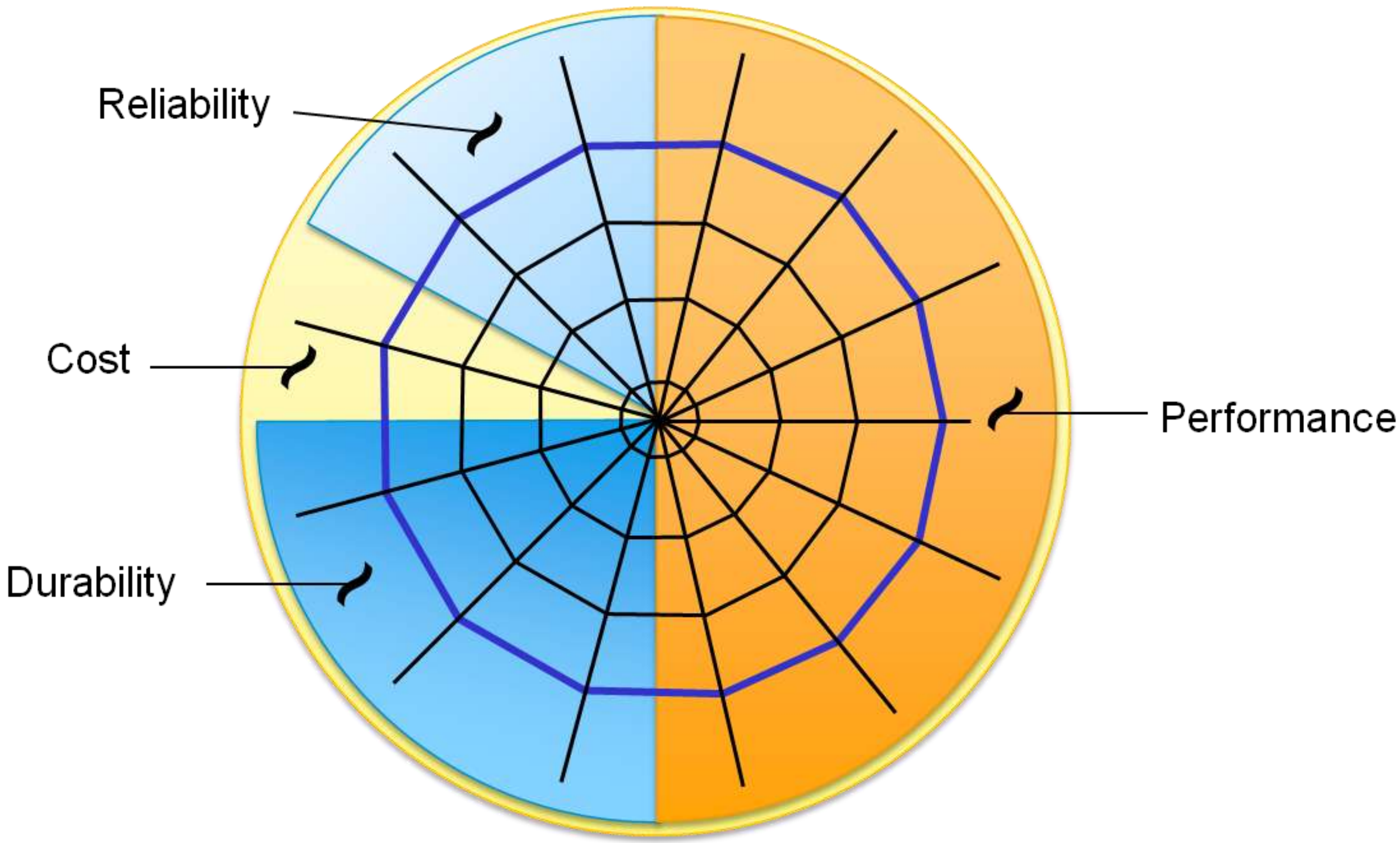


5 MW Building Block

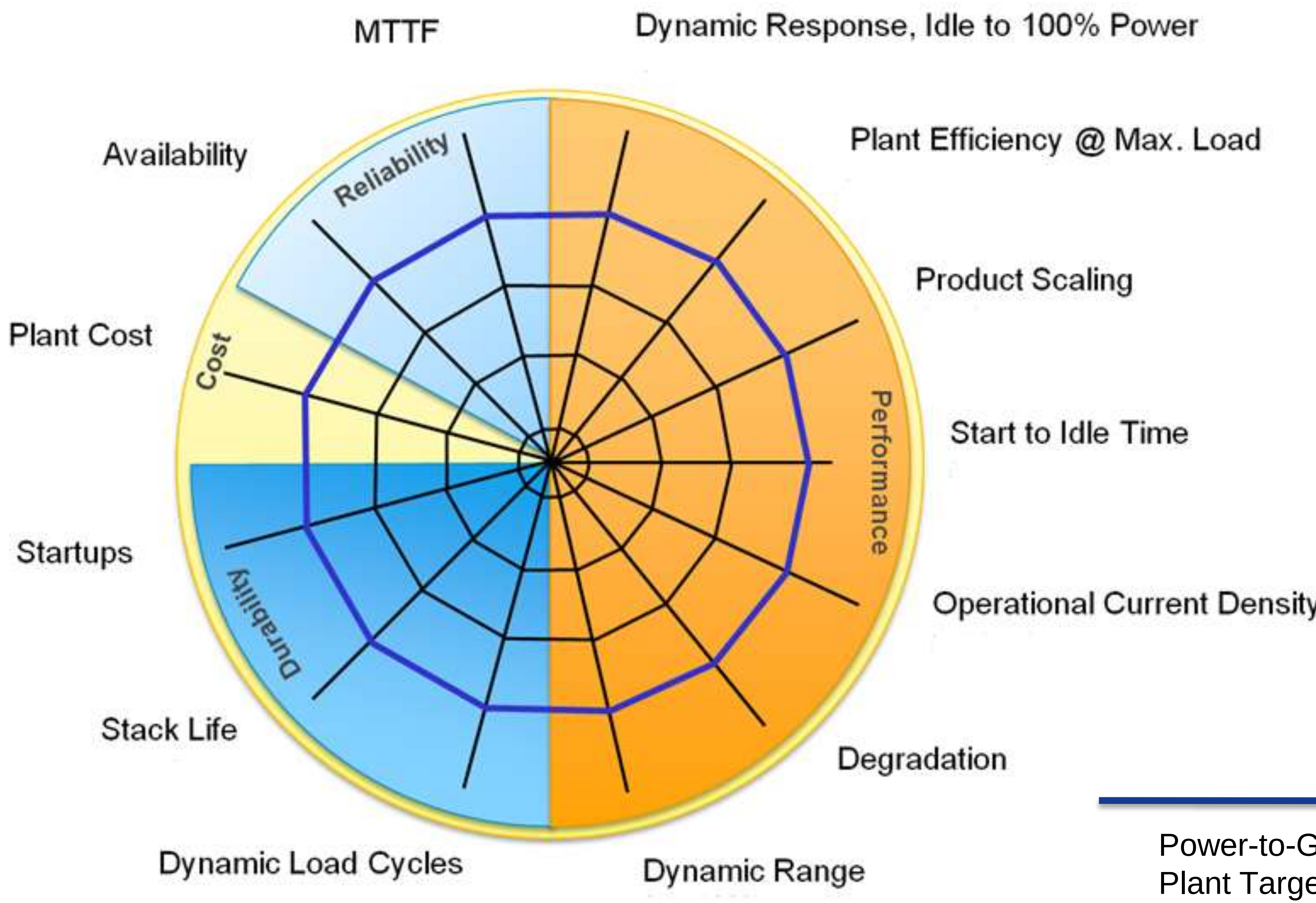
Hydrogenics' HySTAT^{TM} Provides Frequency Regulation on Ontario Grid

HySTAT^{TM} electrolyzer provided frequency regulation by responding to real-time frequency regulation signals from the IESO on a second-by-second basis.

Power-to-Gas Needs - Basis for Innovation



MW PEMWE Must Address Job-To-Be-Done



Power-to-Gas
Plant Targets

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Our PEM Electrolysis Technology Focus

1

MW Scale Electrolyzer Technology

2

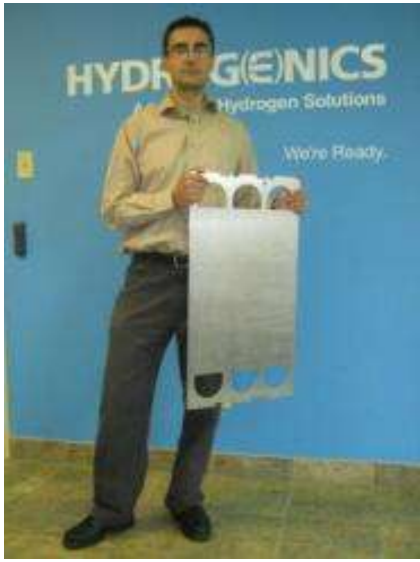
Reduction of System Capital Costs

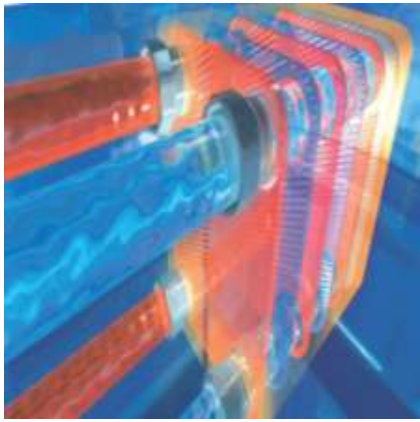
3

Stack Efficiency Improvements

4

Fast Response and Dynamic Operation

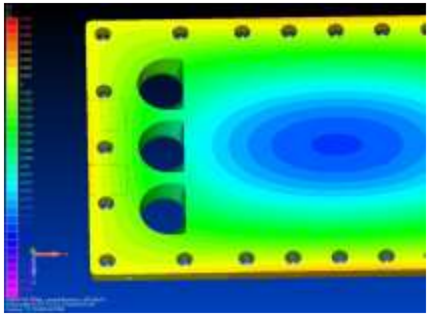




MW PEMWE Technology Development

Stack Design Factors

- Electrochemistry
- Heat Transfer
- Fluid Dynamics
- Component Manufacturability/Supply Base
- Material Selection
- Cost



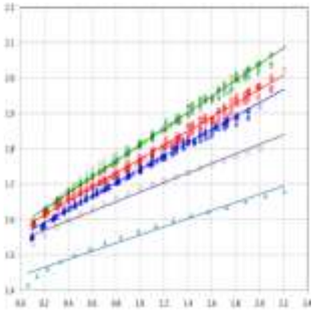
Operating Conditions

- Temperature
- Pressure
- Current Density

MW-Scale PEMWE Will Have a Broad Impact

Surface Area

Efficiency



Power Density

B.O.P. Cost

MW PEMWE Technology Challenges

Technology Area	Critical Focus Areas	Importance	Understanding	Opportunity	Classification
Membrane	Reduce membrane thickness	9	High	High	High Priority Research
	Membrane mechanical reinforcement	5	Medium	Medium	High Priority Research
	Membrane edge protection	7	High	Medium	Engineering
	Improve membrane dimensional stability	9	High	High	High Priority Research
	Lower cost membrane material	5	Medium	Medium	Medium Priority Research
Catalyst	Catalyst loading reduction (O2)	7	Medium	High	High Priority Research
	Catalyst loading reduction (H2)	3	Medium	Medium	Medium Priority Research
	Non-precious metal catalyst	3	Low	Low	Mature Technology
GDL	Optimize GDL thickness & porosity	3	High	Low	Mature Technology
	Improved GDL support to membrane	9	High	Low	Mature Technology
	GDL thickness tolerance	3	Medium	Low	Mature Technology
	Carbon GDL mechanical strength	3	Medium	Medium	Engineering
Bipolar Plate	Plate material compatibility	5	High	Low	Mature Technology
	Low cost large active area plate	5	High	Medium	Engineering
Protection Coating	Alternate lower cost coating materials	7	Medium	High	High Priority Research
	Existing coating cost reduction	7	High	Medium	Engineering
Cell Design	High precision seal design/manufacturing	9	High	High	Engineering
	Reduce pressure drop	3	High	Low	Low Priority Research
Testing Area					
Accelerated Life Testing	Reduce design and material validation test time	9	Low	High	High Priority
	Remover barriers for new materials market acceptance	9	Medium	High	High Priority

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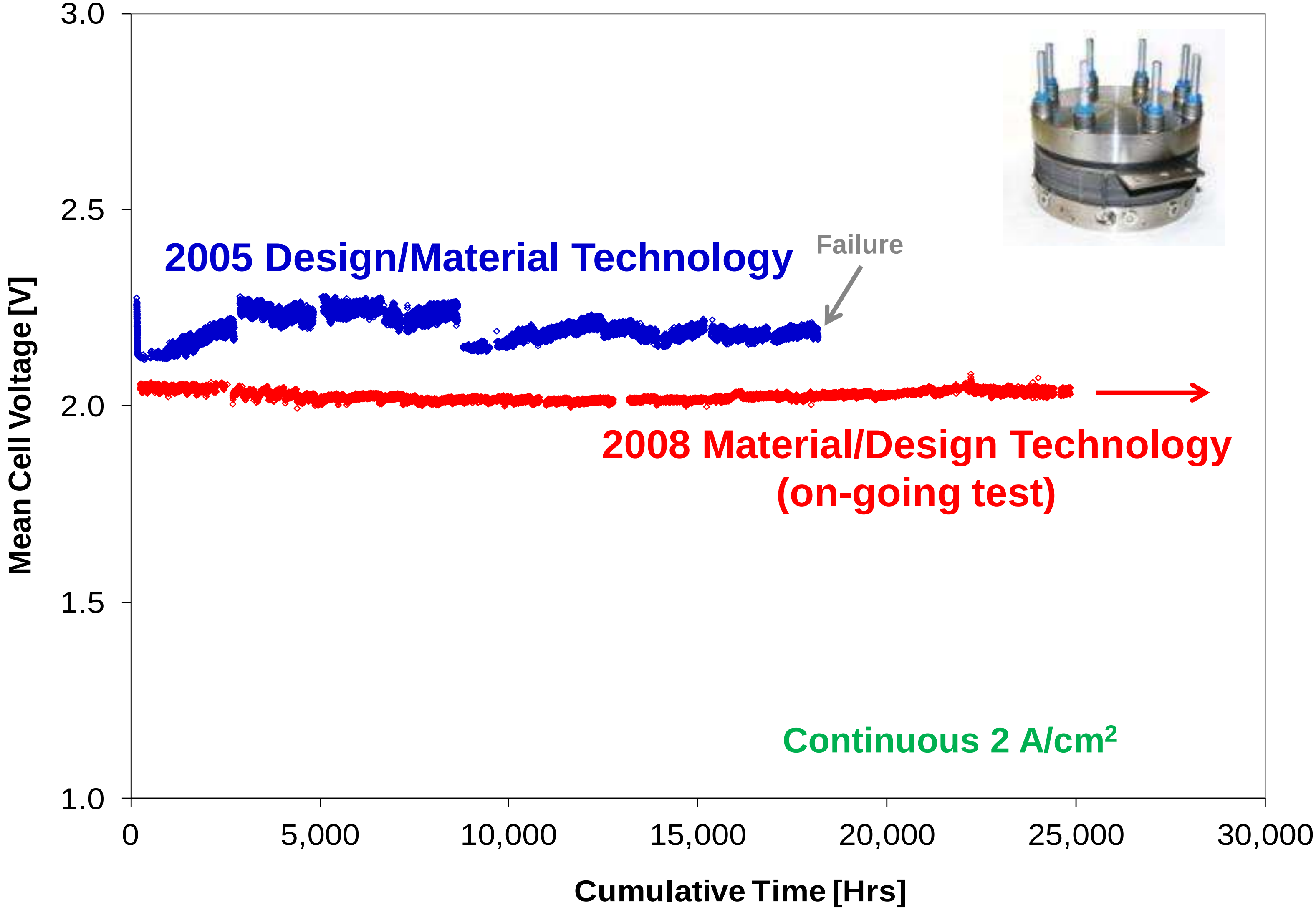
Challenges Facing PEM Electrolysis *vs* PEM FC

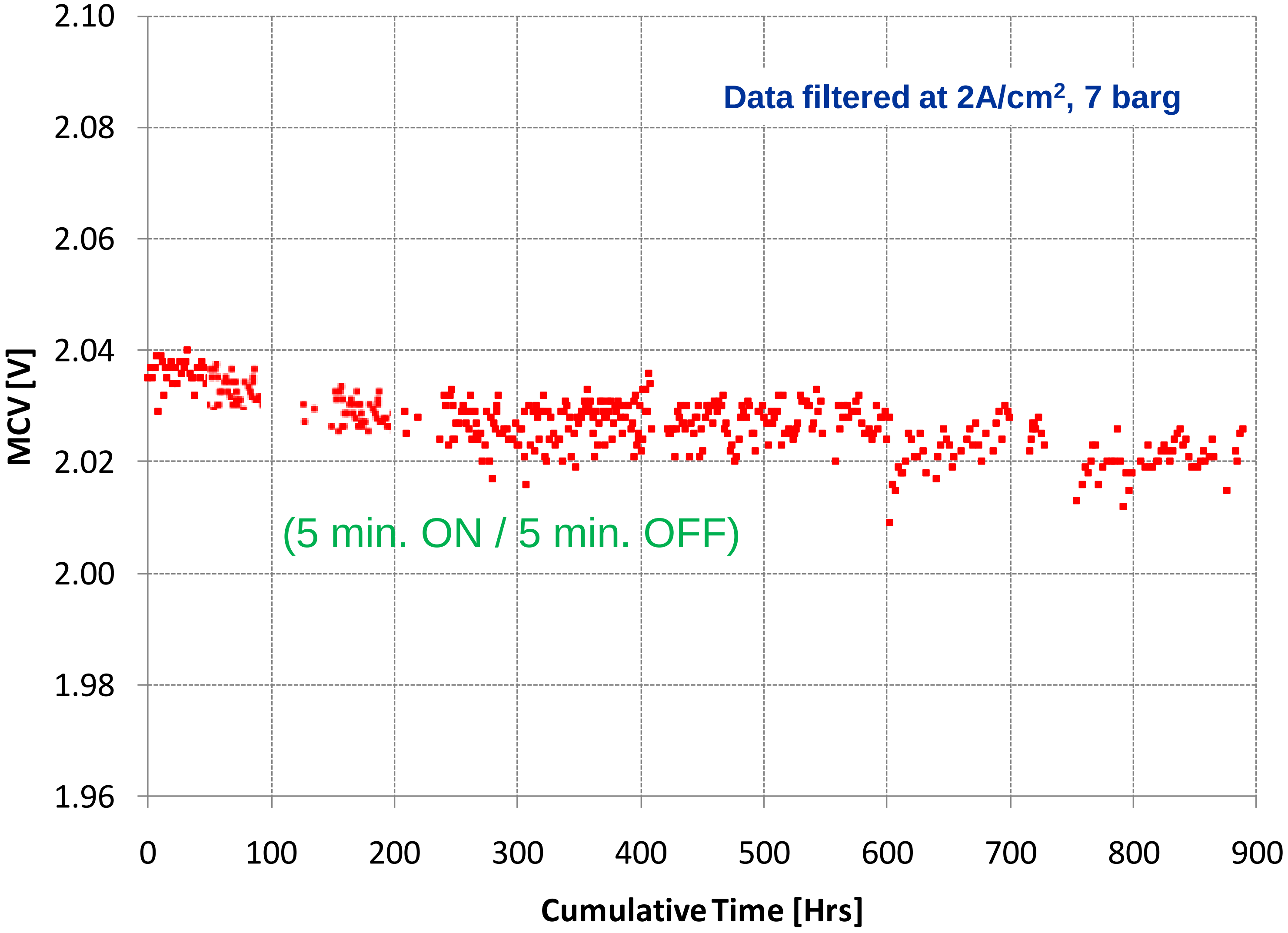
Failure Mode Details		PEM Fuel Cells	PEM Water Electrolysis
Mechanical	Cause	▪ Membrane shrinking/ expansion with fluctuations in temp & RH ▪ Stack compression variation	▪ Membrane expansion after build ▪ Differential pressure and pressure cycling ▪ Membrane thinning approaching EOL
	Mitigation	▪ Membrane mechanical reinforcement	▪ Membrane mechanical reinforcement ▪ Thicker membrane
	Research opportunity	Low	▪ Medium on thicker membrane (>130μm) ▪ High research opportunity for thin membranes (<50 μm) used in energy storage applications
Chemical	Cause	▪ Polymer function group attacked by radicals or other active species	▪ Polymer function group attacked by radicals or other active species
	Mitigation	▪ Chemically stabilized membrane	▪ Chemically stabilized membrane
	Research opportunity	Low	Low
Thermal	Cause	▪ Polymer break down due to overheating	▪ Polymer break down due to overheating at high current density
	Mitigation	▪ Chemically stabilized	▪ Stack component selection ▪ BOP design to prevent catastrophic failure
	Research opportunity	Low	High at overload operation

Durability: Significant Progress Made

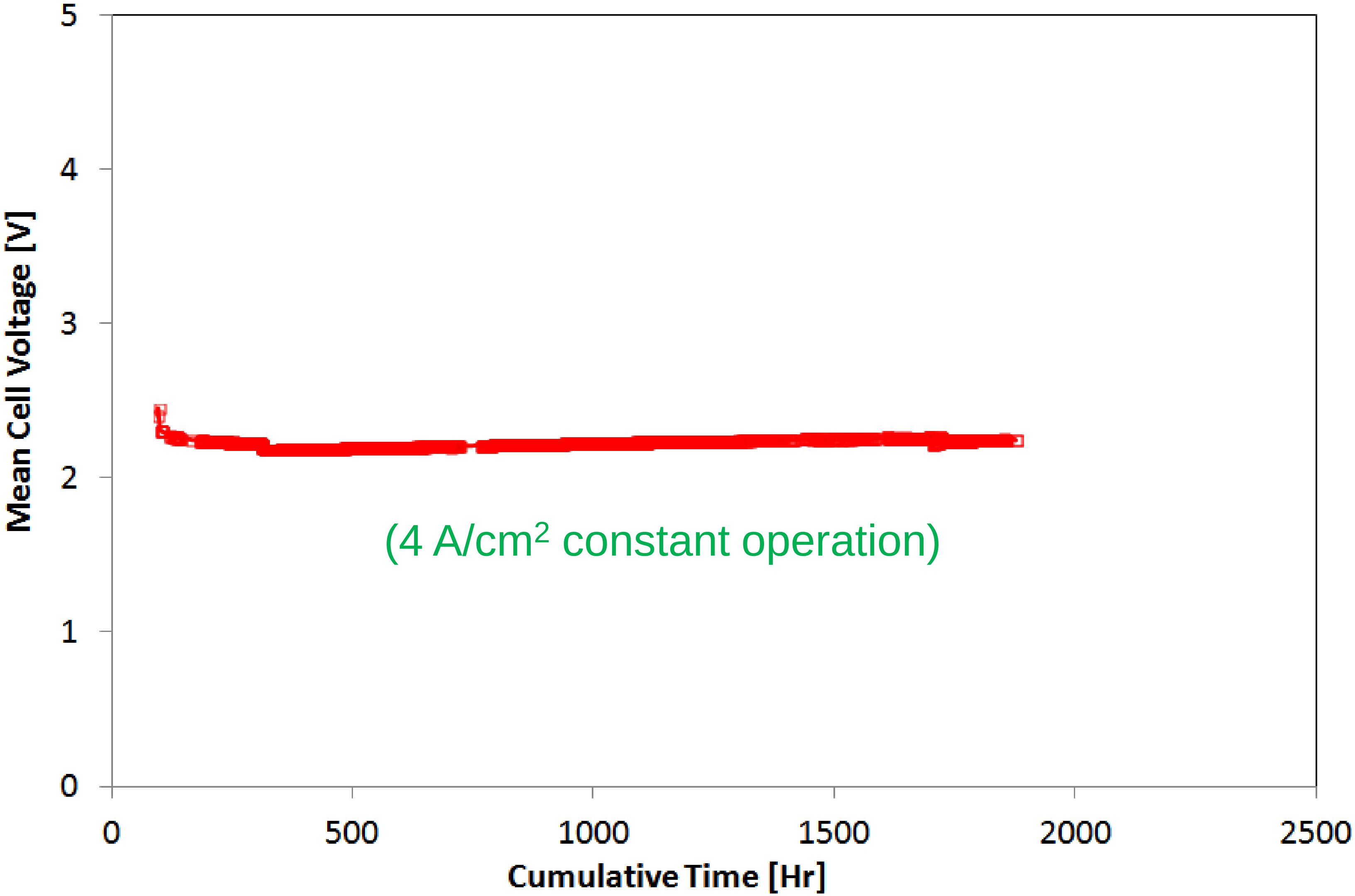


Durability: Full Load **On/Off** Cycling

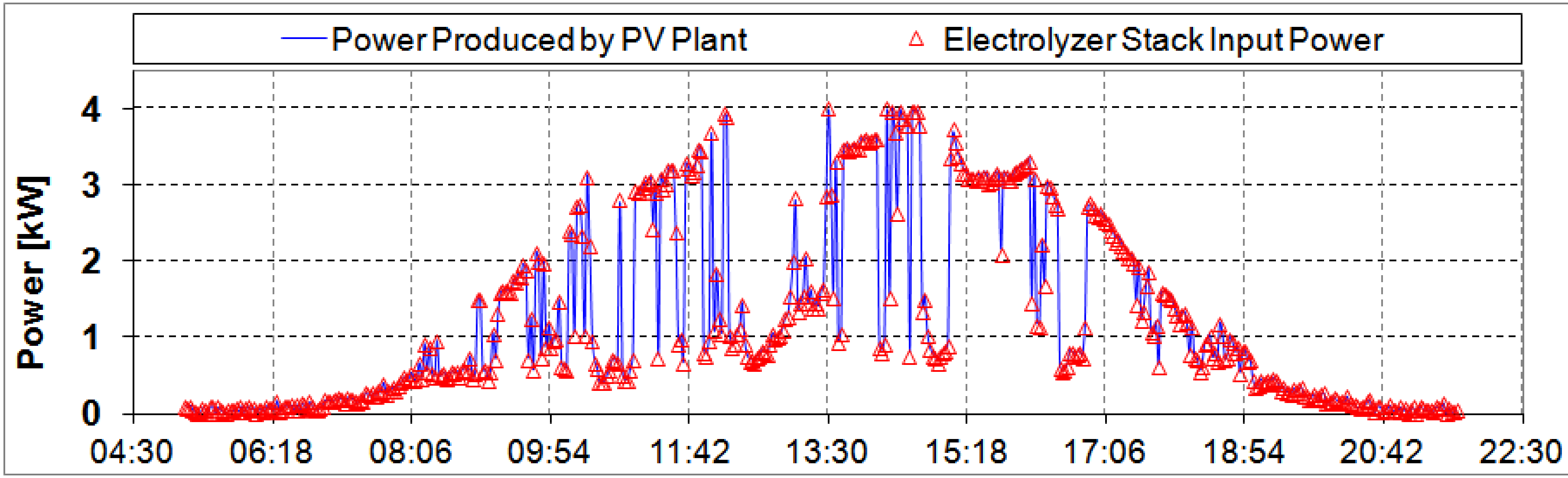
5,400 on/off cycles demonstrated

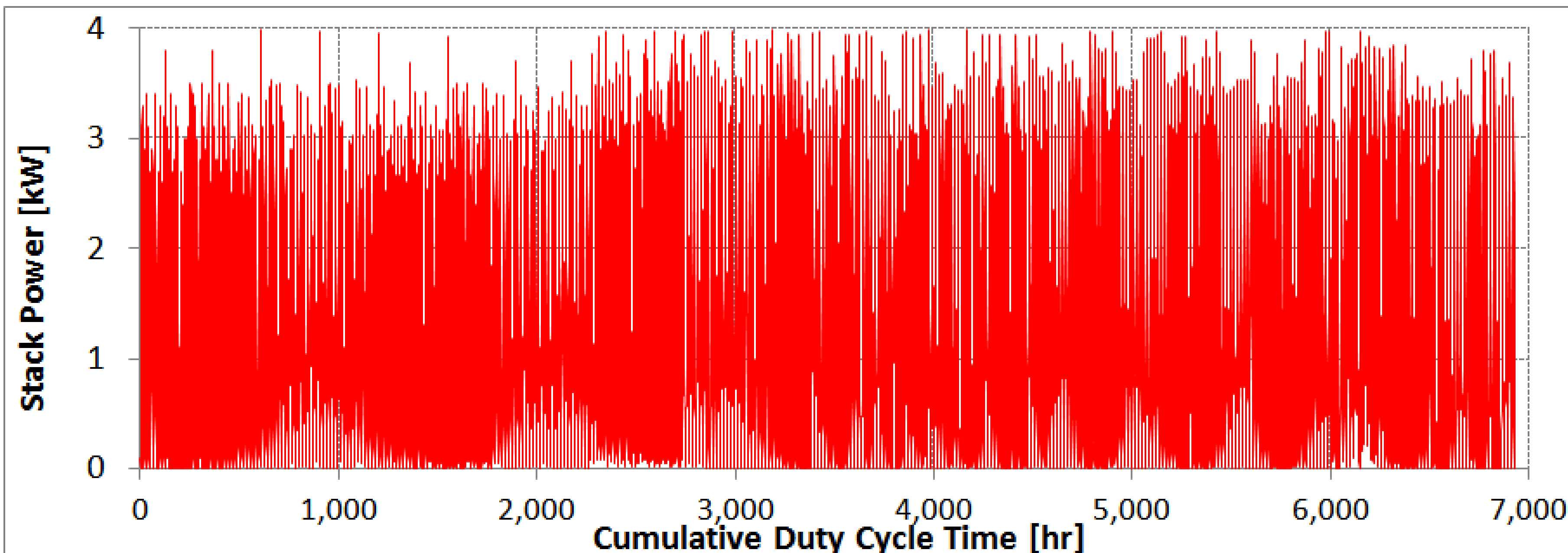


Durability: High Current Density, 4 A/cm^2, 70°C

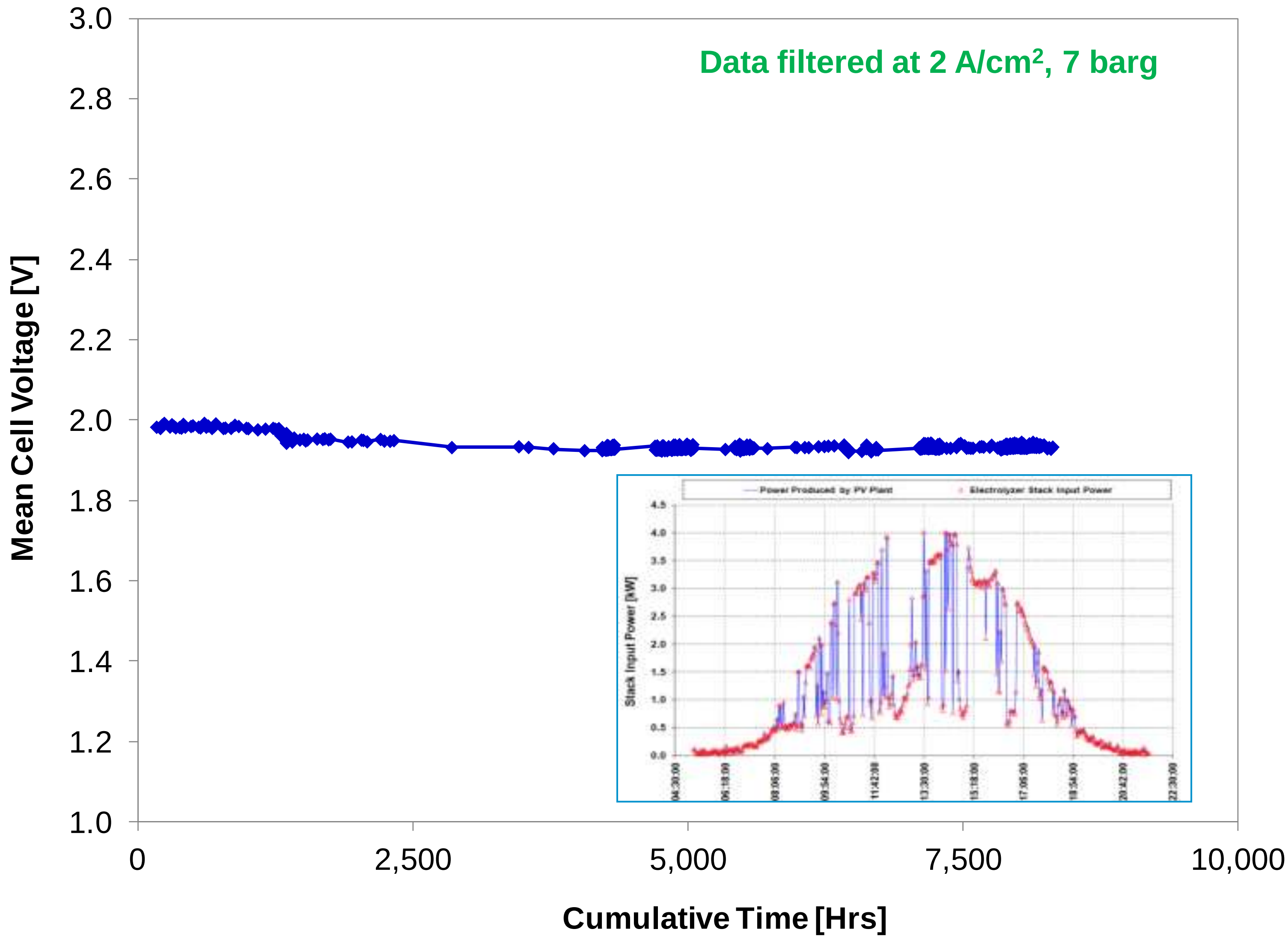


Durability: Dynamic Cycle Testing





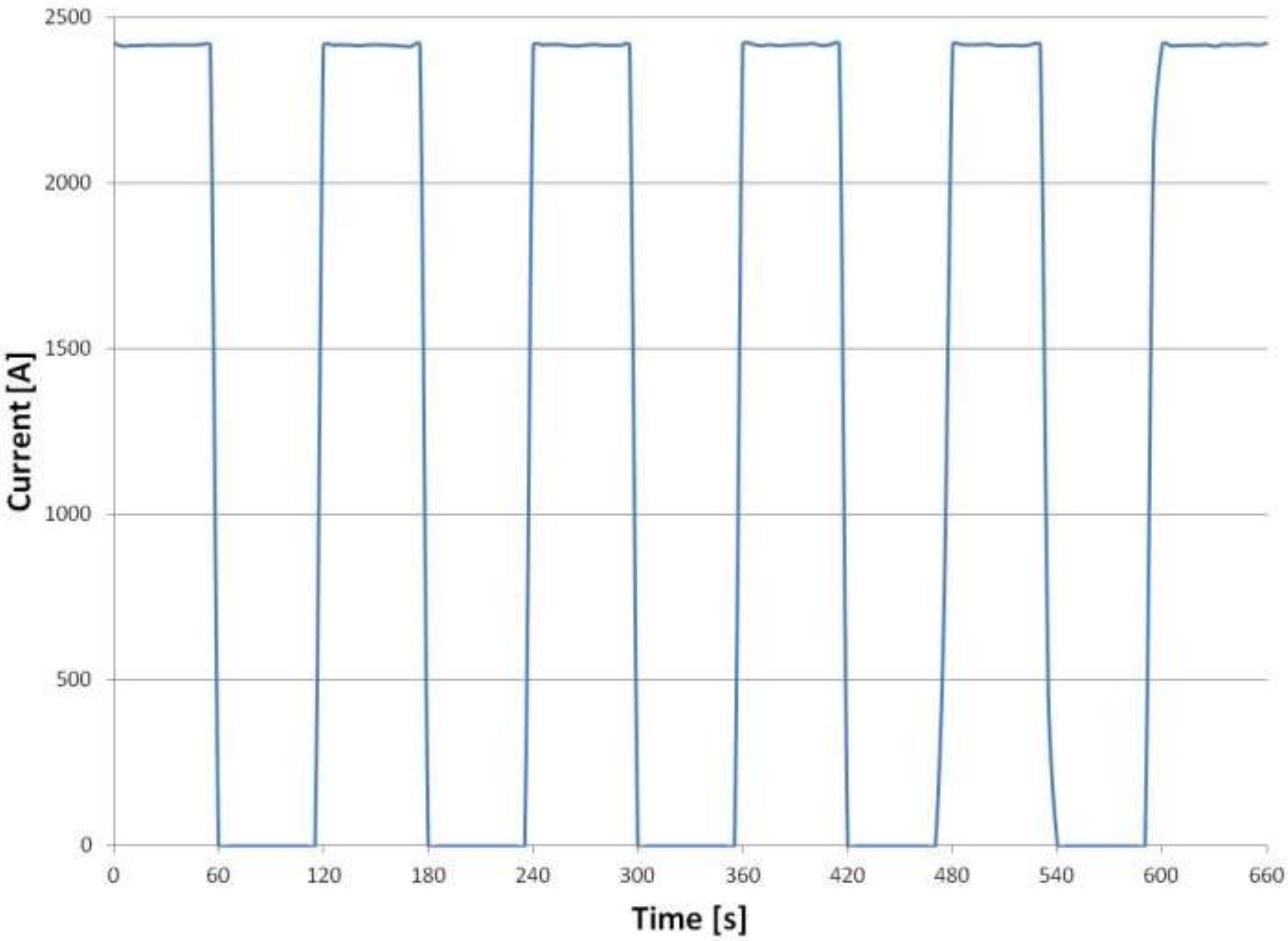
No Degradation after 400 PV Duty Cycles



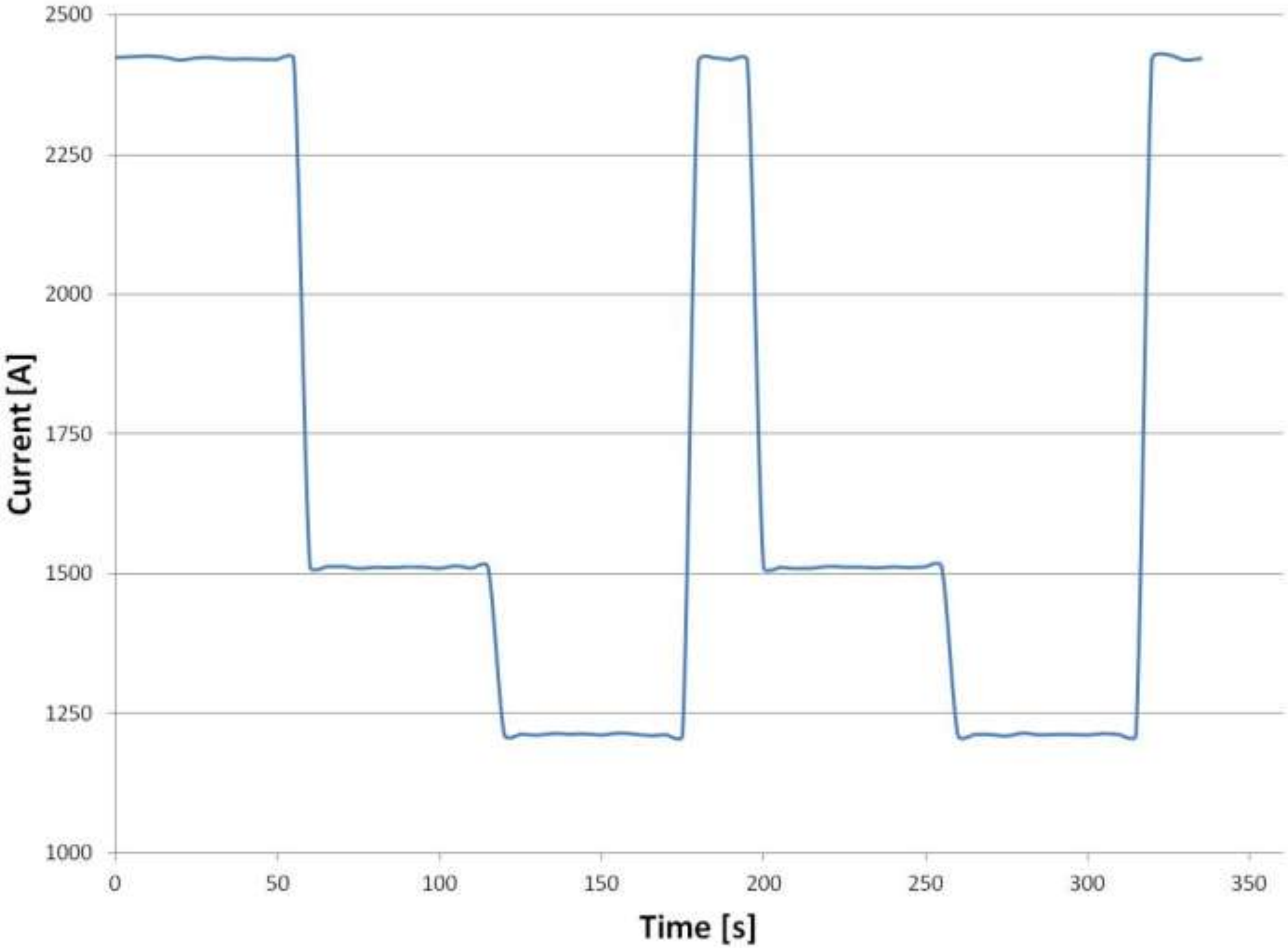
Hydrogenics Accelerated Testing Experience

Test protocol	Expected acceleration mechanism
Elevated temperature (up to 90 °C)	▪ Chemical degradation due to temperature dependencies of degradation mechanism reactions ▪ Thermally accelerated membrane breakdown ▪ Mechanical failure caused by fatigue of other stack components at elevated temperature
Rapid On/Off cycling	▪ Chemical and mechanical degradation due to temperature and pressure cycling ▪ Chemical degradation caused by uncontrolled stack polarity
High current density (up to 5 A/cm^2)	▪ Chemical degradation due to high overpotential ▪ Mechanical degradation from high rate of gas evolution
Intermittent On/Off Cycling	▪ Chemical and mechanical failures caused by temperature and pressure fluctuations

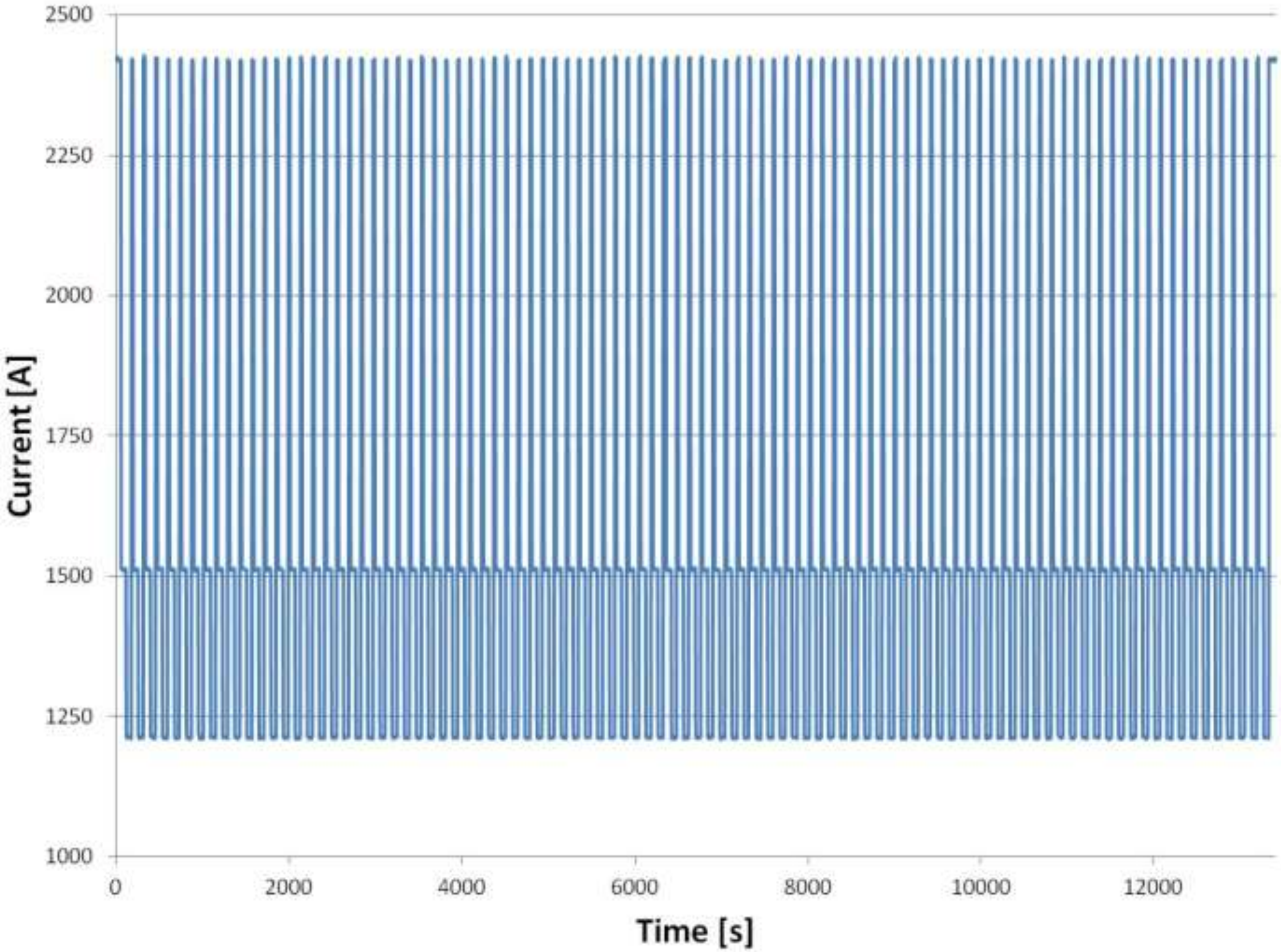
MW Scale PEMWE Short Stack
On/Off Cycling



MW Scale PEMWE Short Stack
Current Modulation (Isolated Cycle)



MW Scale PEMWE Short Stack
Current Modulation



Challenges of PEM Water Electrolysis

- Conventional stack materials and designs are too expensive for widespread acceptance
- Lower catalyst loading initiative (especially on the anode) required, similar to progress made in PEM fuel cell technology
- High efficiency membranes without compromise on lifetime required for Power-to-Gas market
- Design and material validation testing is too long.
  A reliable accelerated life testing protocol is required

WE'RE READY