PEM Fuel Cell Readiness for Light Duty Vehicles

Margaret Steinbugler

Manager, Transportation Fuel Cell Product Development

California Air Resources Board

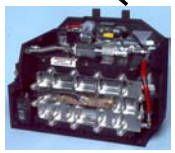
Zero Emission Vehicle Technology Symposium

September 25, 2006

UTC POWER FUEL CELL BUSINESS

Transportation Activities - Autos

Hyundai Santa Fe "Best in Class" in noise and efficiency ratings at the Michelin Challenge Bibendum 2001



1997
BENCH TEST

1998
5 kW, HYDROGEN / AIR
APU

1999
40 kW, HYDROGEN / AIR

2000
75 kW, HYDROGEN /AIR

2003
65 kW, HYDROGEN / AIR

2005
80 kW
HYDROGEN / AIR

March 29, 2004
Cosmo Oil Leases First Unit of Nissan's X-TRAIL FCV

Tokyo – Cosmo Oil Co., Ltd. today announced that it has leased the first unit of the X-TRAIL FCV fuel cell vehicle manufactured by Nissan Motor Co., Ltd.

December 15, 2005

Hyundai delivers freeze-capable fuel-cell-powered Tucson to AC Transit

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Transportation Activities - Buses

1998	2002	2004	2005
Georgetown University	California transit agencies	EMT Madrid, ATM Torino	AC Transit Sunline
40 ft NOVA Bus	30 ft Thor "Thunder Power" Bus	40 ft Irisbus	40 ft Van Hool bus
100 kW phosphoric acid	60 kW S300 PEM	60 kW S300 PEM	120 kW S900 PEM
Methanol	Hydrogen	Hydrogen	Hydrogen
FC/battery hybrid	FC/battery hybrid	FC/battery hybrid	FC/battery hybrid

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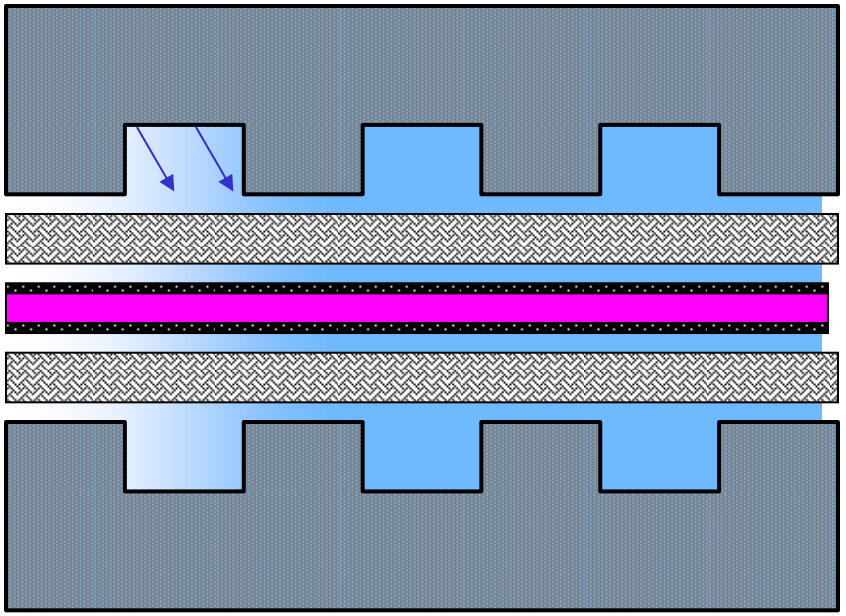
UTC Power's water management approach

Instead of solid bipolar plate, we use a porous, hydrophilic plate with wet seal to facilitate water management

In inlet region,
water in plates humidifies
inlet gas streams and
saturates membrane



- The key to fuel cell performance and durability is **water management**
- Proper humidification of membrane for high conductivity, long membrane life
- Efficient removal of product water to facilitate transport of oxygen to cathode catalyst and prevent localized fuel starvation on anode

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Key Automotive Requirements

- **Durability**
  - Load hour durability
    - 5000-6000 hours
  - Start / stop durability
    - 17,000 start / stop cycles
  - Load cycle durability
    - Expect 10^6 cycles over lifetime
- **Performance / Fuel Cell Stack Power Density**
  - Power per area (V-i performance)
  - Power per volume (cell thickness aka “pitch”)
- **Operability / Freeze**
  - Tolerant to wide range of inlet conditions
  - Start at -20ºC / No performance loss
  - Survive -40ºC / No performance loss
- **System Power Density**
- **Cost**

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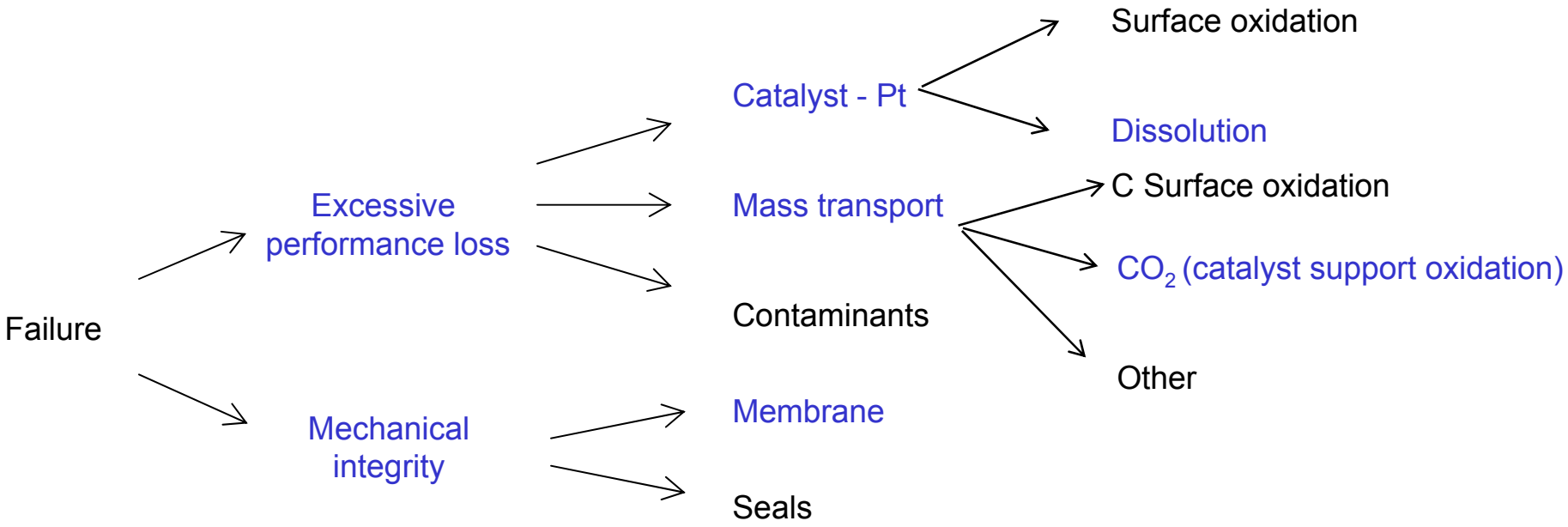
Durability: Overview of Cell Stack Failure Modes



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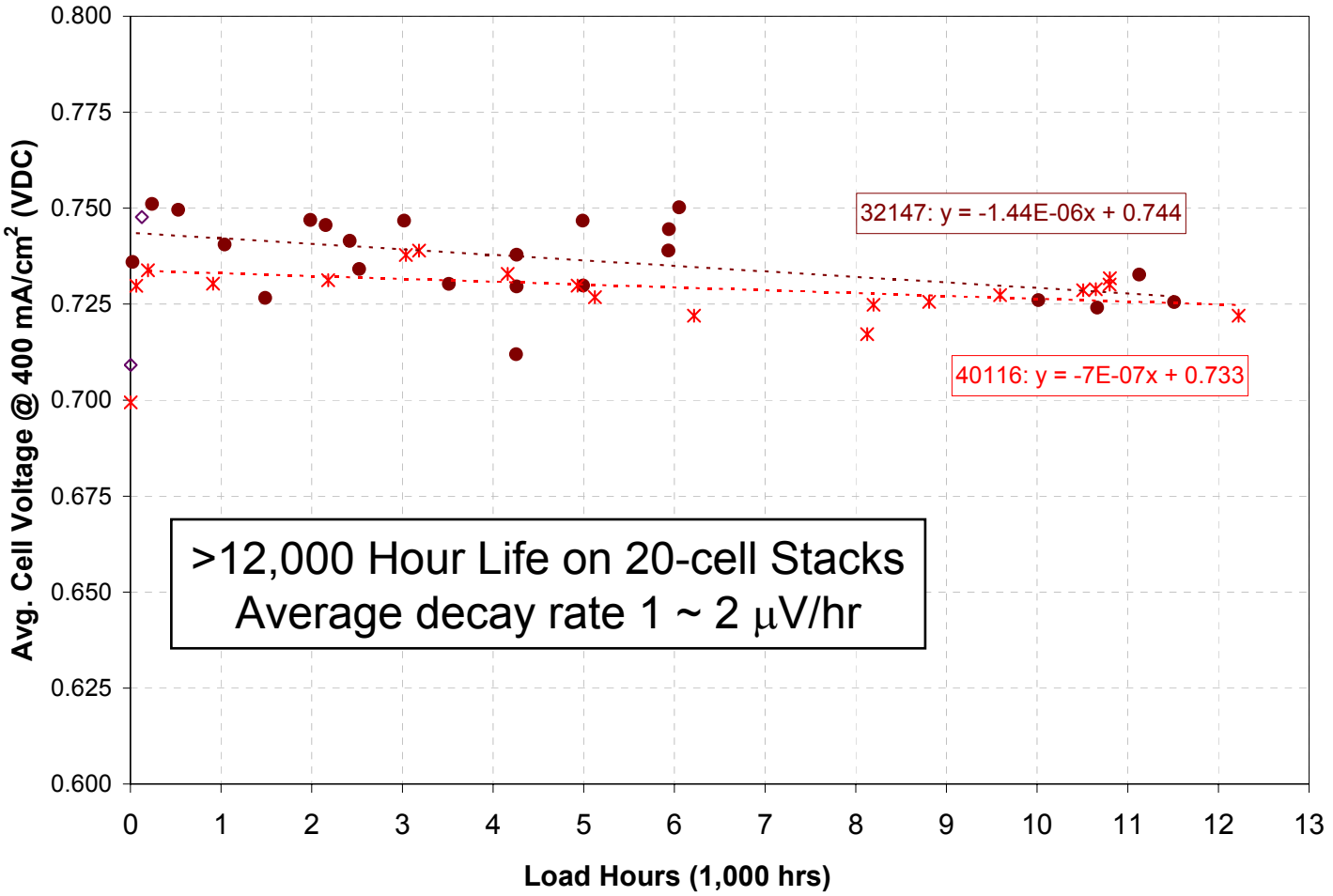
Long-term Load-hour Durability – 20-Cell Stack Data



Failure mode: Membrane mechanical integrity

Water Transport Plate (WTP) technology protects membrane

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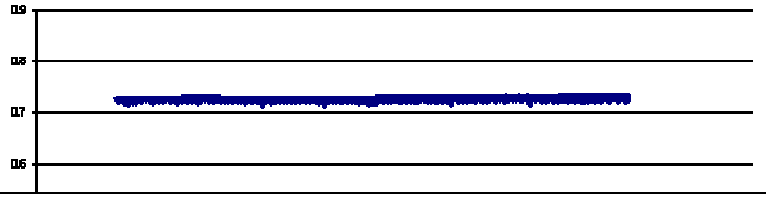
Water Management & Durability

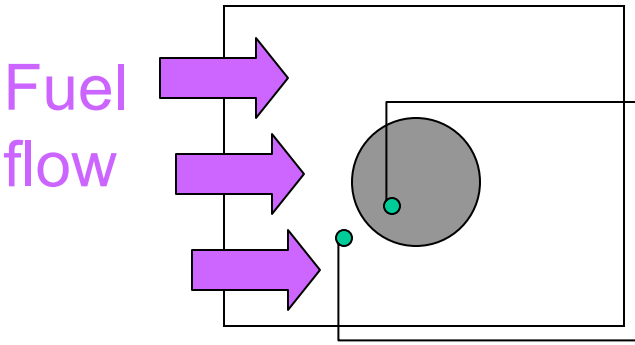
Localized fuel starvation causes extreme degradation of cathode

- Simulated localized fuel starvation by blocking access of fuel to local area on anode

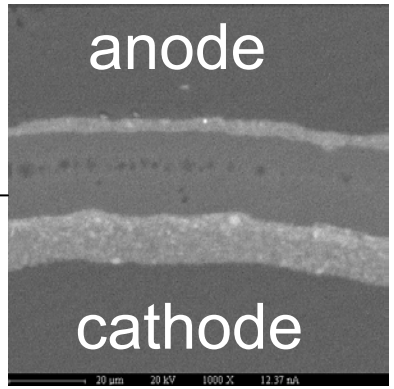


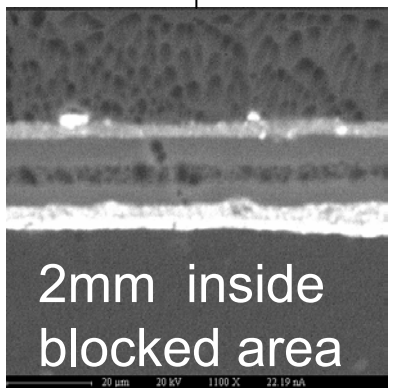
Failure mode: Performance loss / CO_2 (catalyst support oxidation)

Effective water management eliminates local fuel starvation



100-hr hold, 400 mA/cm^2





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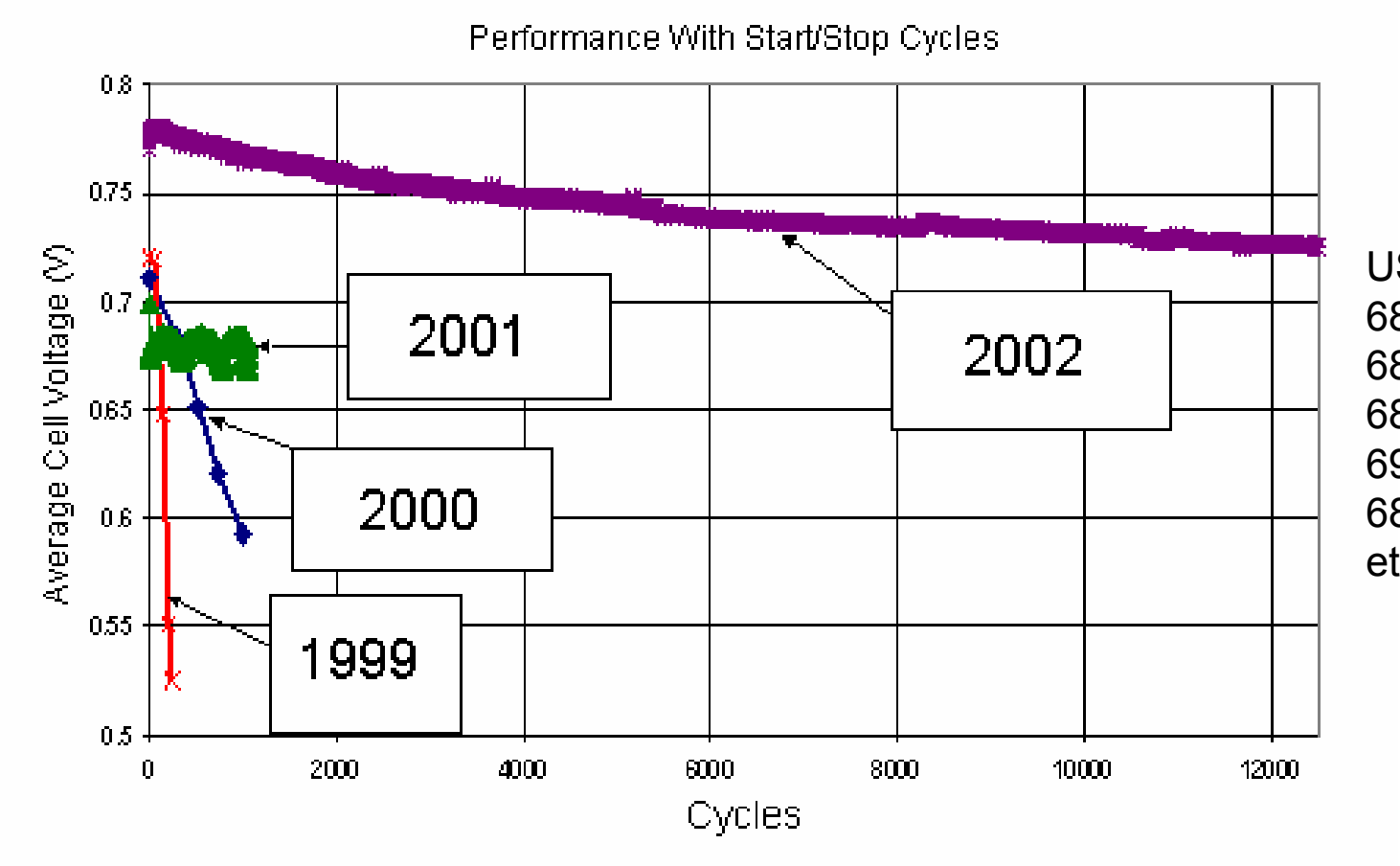
Start / Stop Cycle Durability – 20-Cell Stack Data



US Patents
6858336
6887599
6835479
6913845
6855453
etc…

Failure mode: Performance loss / CO_2 (catalyst support oxidation)

Voltage control can successfully mitigate start/stop losses

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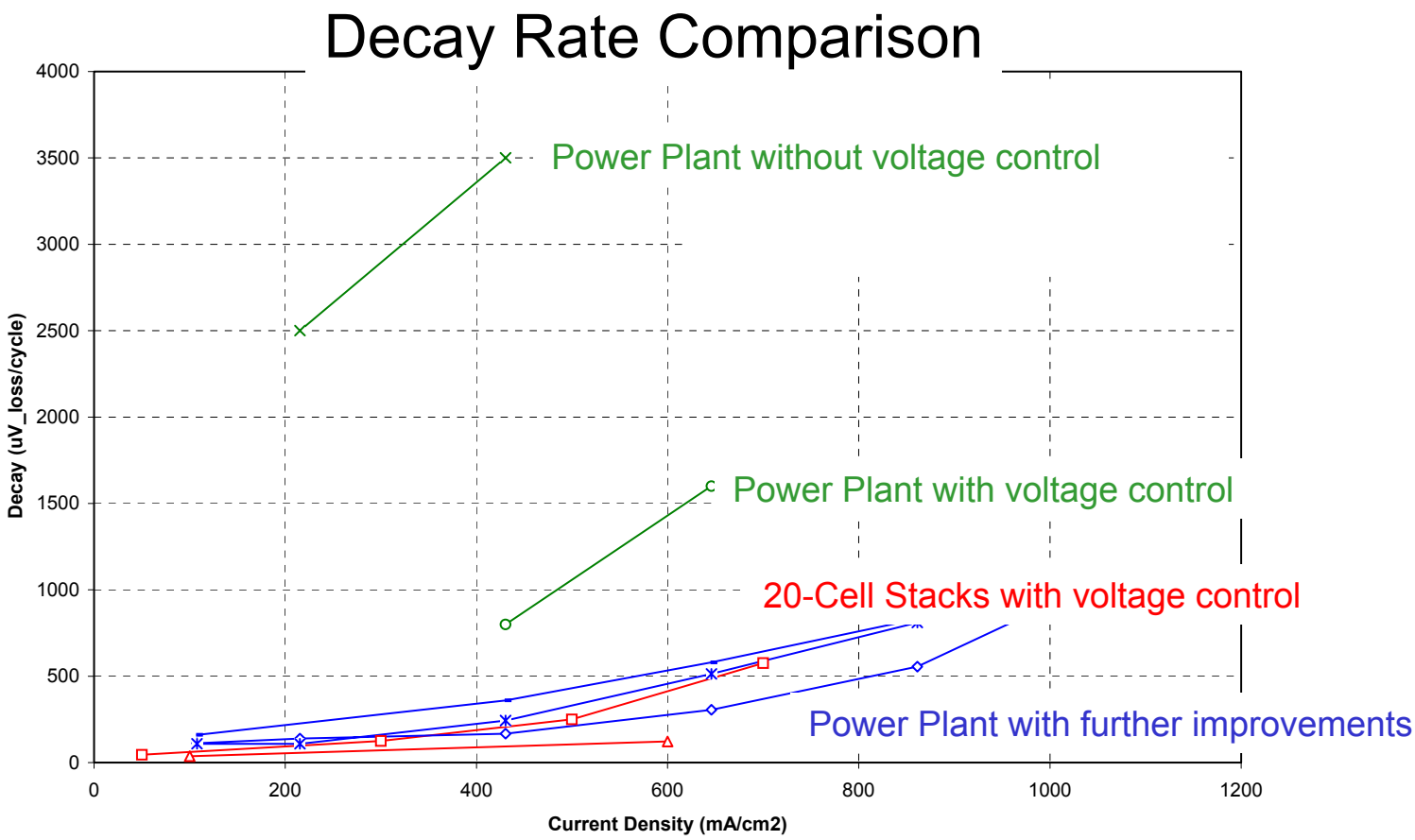
Start / Stop Cycle Durability 20-Cell and Full Size / Power Plant Data



Failure mode: Performance loss / CO_2 (catalyst support oxidation)

Voltage control can successfully mitigate start/stop losses

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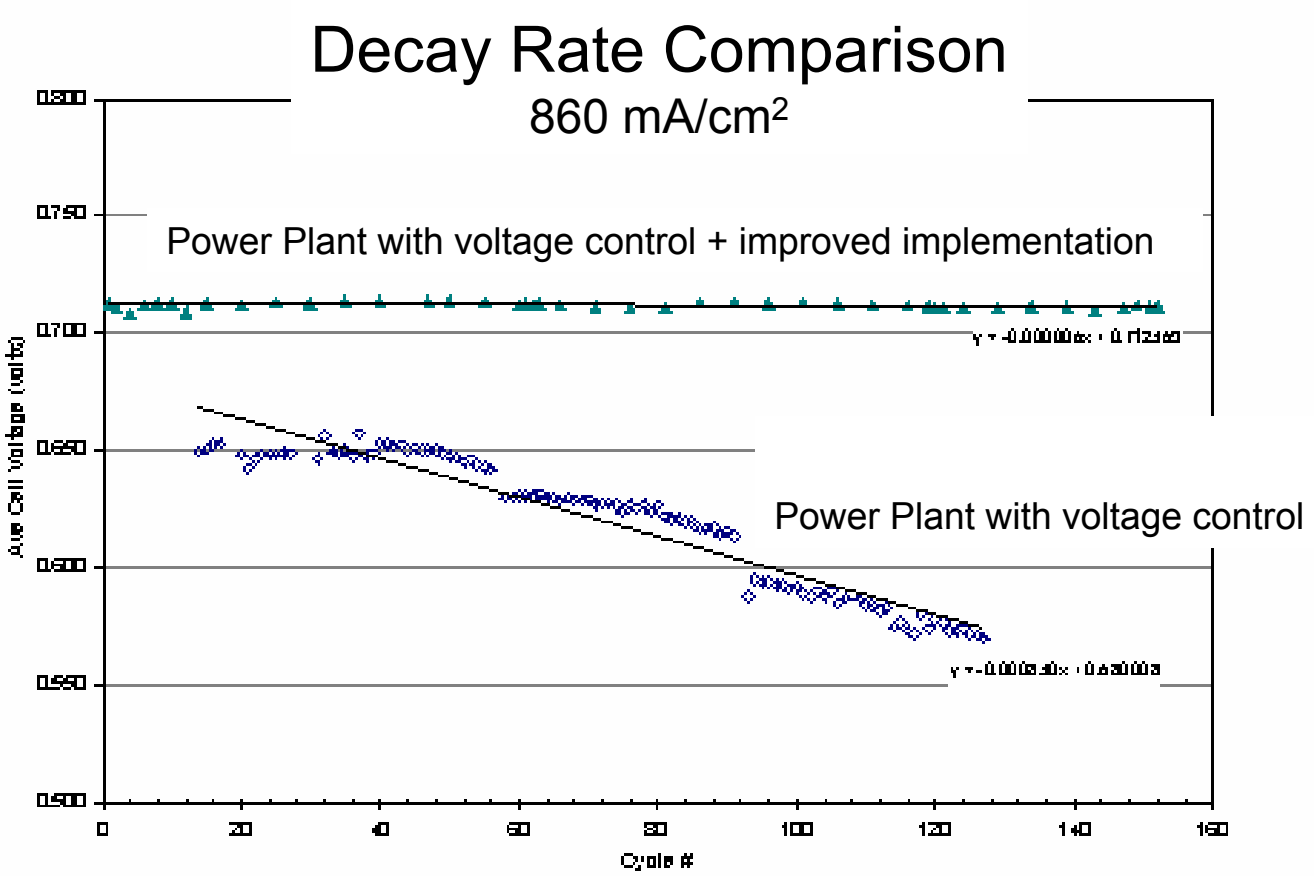
Start / Stop Cycle Durability – 20-Cell Stack Data



Failure mode: Performance loss / CO2 (catalyst support oxidation)
Voltage control can successfully mitigate start/stop losses
(Proper implementation is critical)

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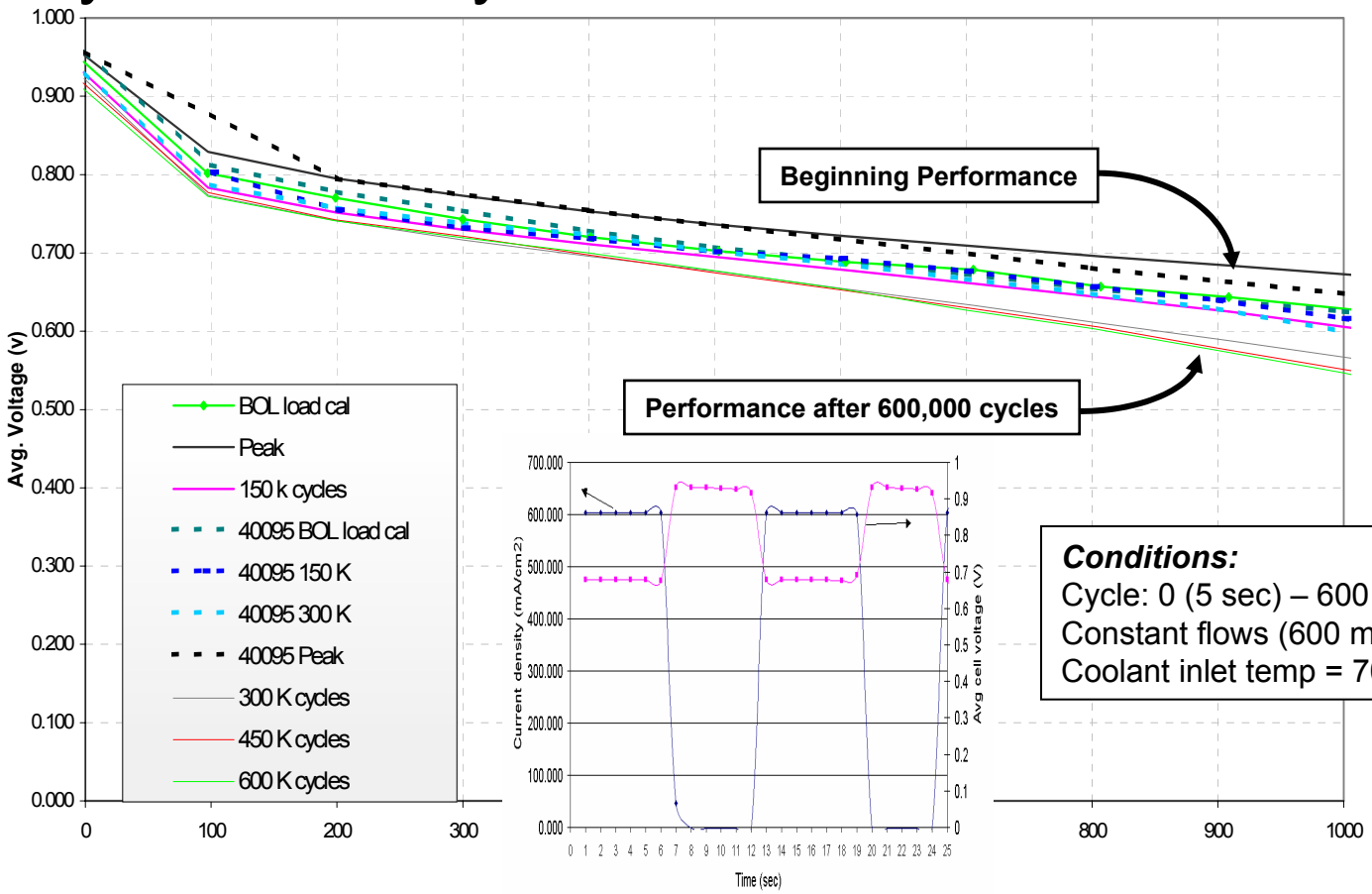
Load Cycle Durability – 20-Cell Stack Data



Failure modes: Membrane mechanical integrity and performance loss via catalyst dissolution

Test accelerates **membrane degradation** (chemical and mechanical), **Pt dissolution**

Best in class cyclic durability in the industry: 1,000,000 cycles, ~3000 hour test w/o failure

Water management prevents a 'load cycle' from being a humidity cycle

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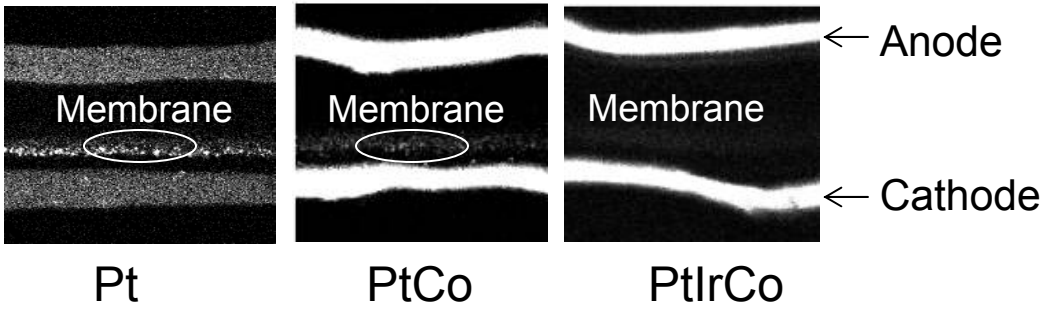
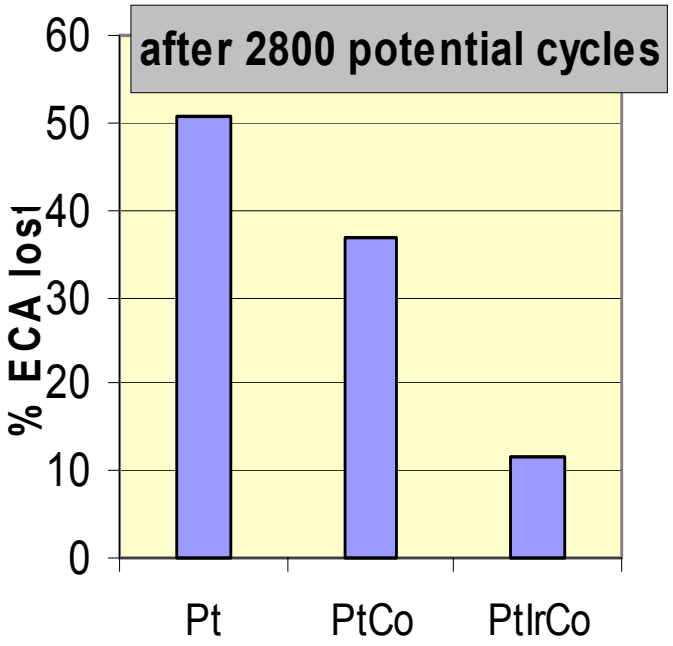
Durability – Platinum Dissolution

- Platinum dissolves under potential cycling
- PtCo and PtIrCo show significantly less dissolution

Pt distribution (EMPA) after cycling





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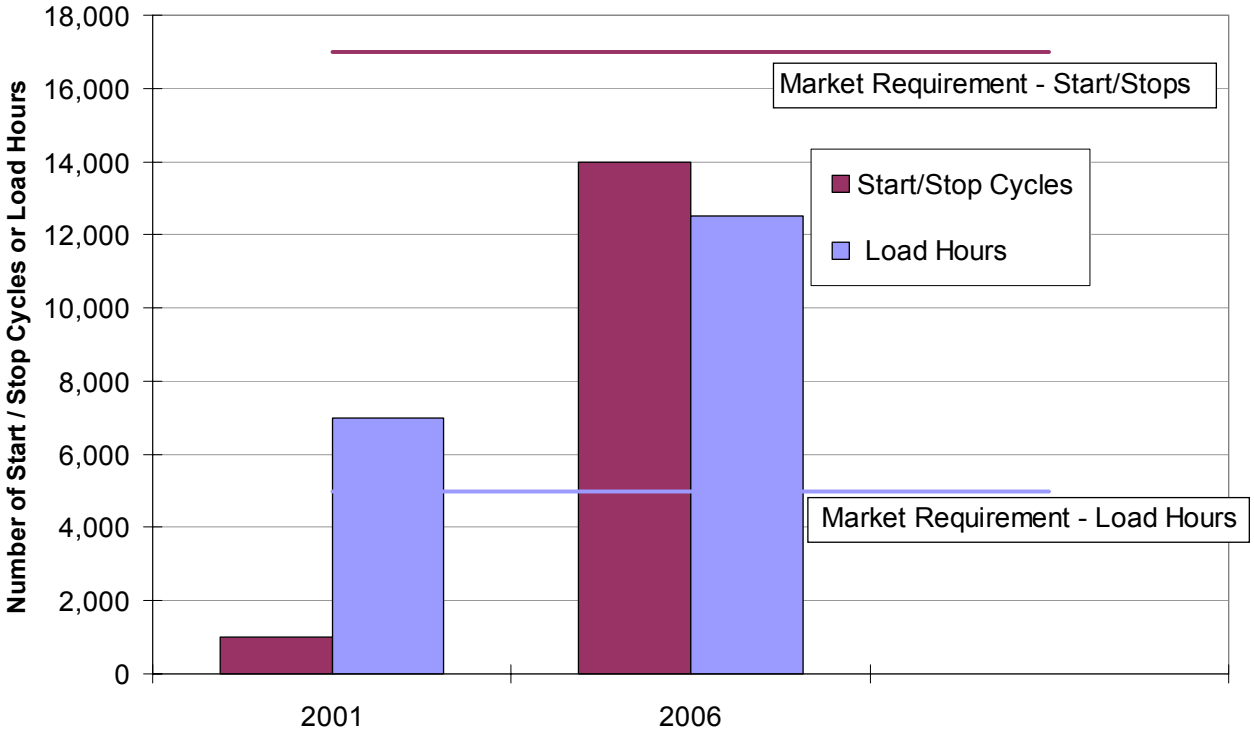
Long-term Load-hour Durability – 20-Cell Stack Data



Automotive Durability Summary

- Status: Technology is ready for automotive durability requirements
- Next Steps: Demonstrate lab-scale 20-cell results in on-road vehicles
- Prediction: >4000 designs in vehicles hours by 2008
  (Operation to 4000 hours may take >4 years of validation)

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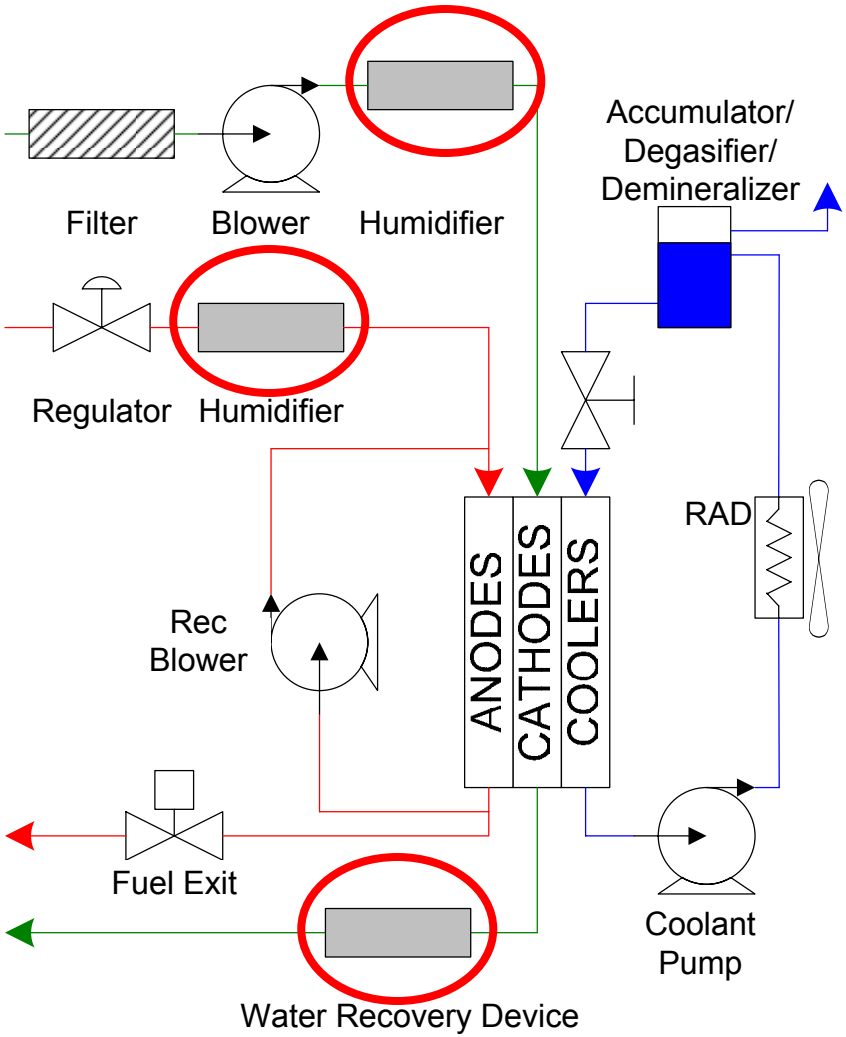
System Power Density

Keys to System Power Density

- Increase Cell Stack Power Density
  - –Increased areal power density
  - –Reduced cell pitch
  - –Increased active area ratio
- System simplification
  - –More functionality in cell stack
  - –Reduce part count
  - –Combine balance-of-plant functionality



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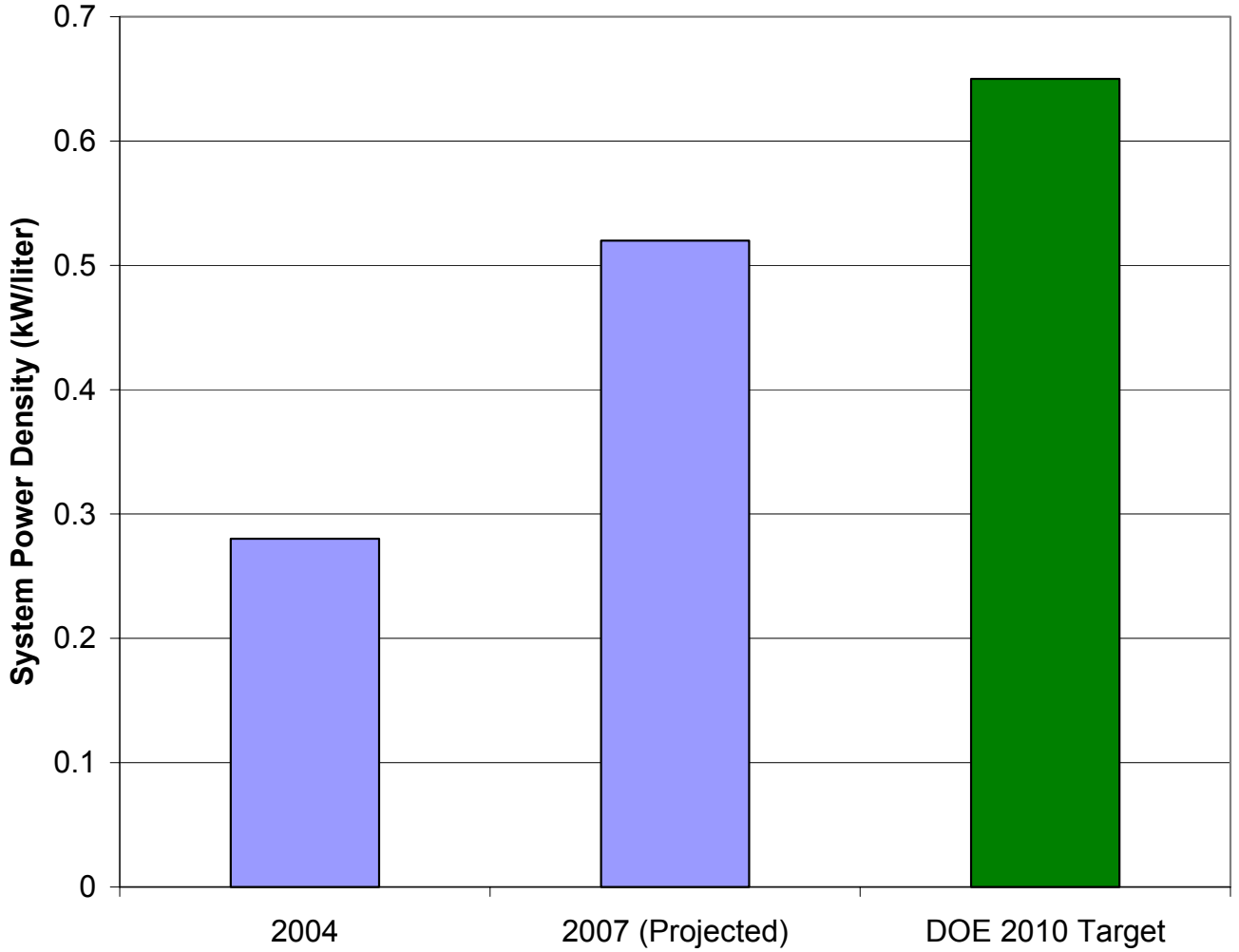
System Power Density



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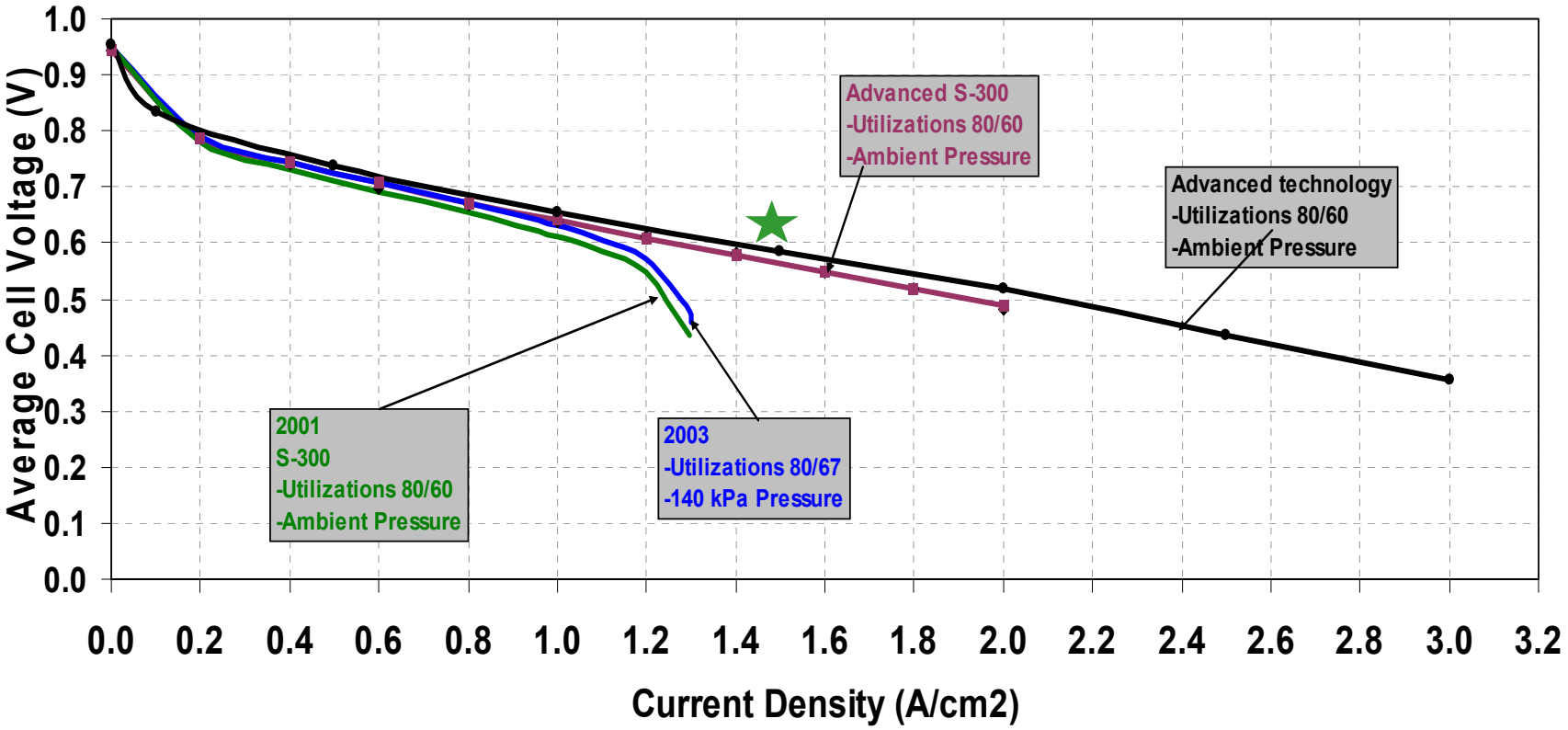
Stack Performance and Power Density Improvements



Water management is key to performance improvements

Target is >0.65 volts @ 1.5 A/cm2

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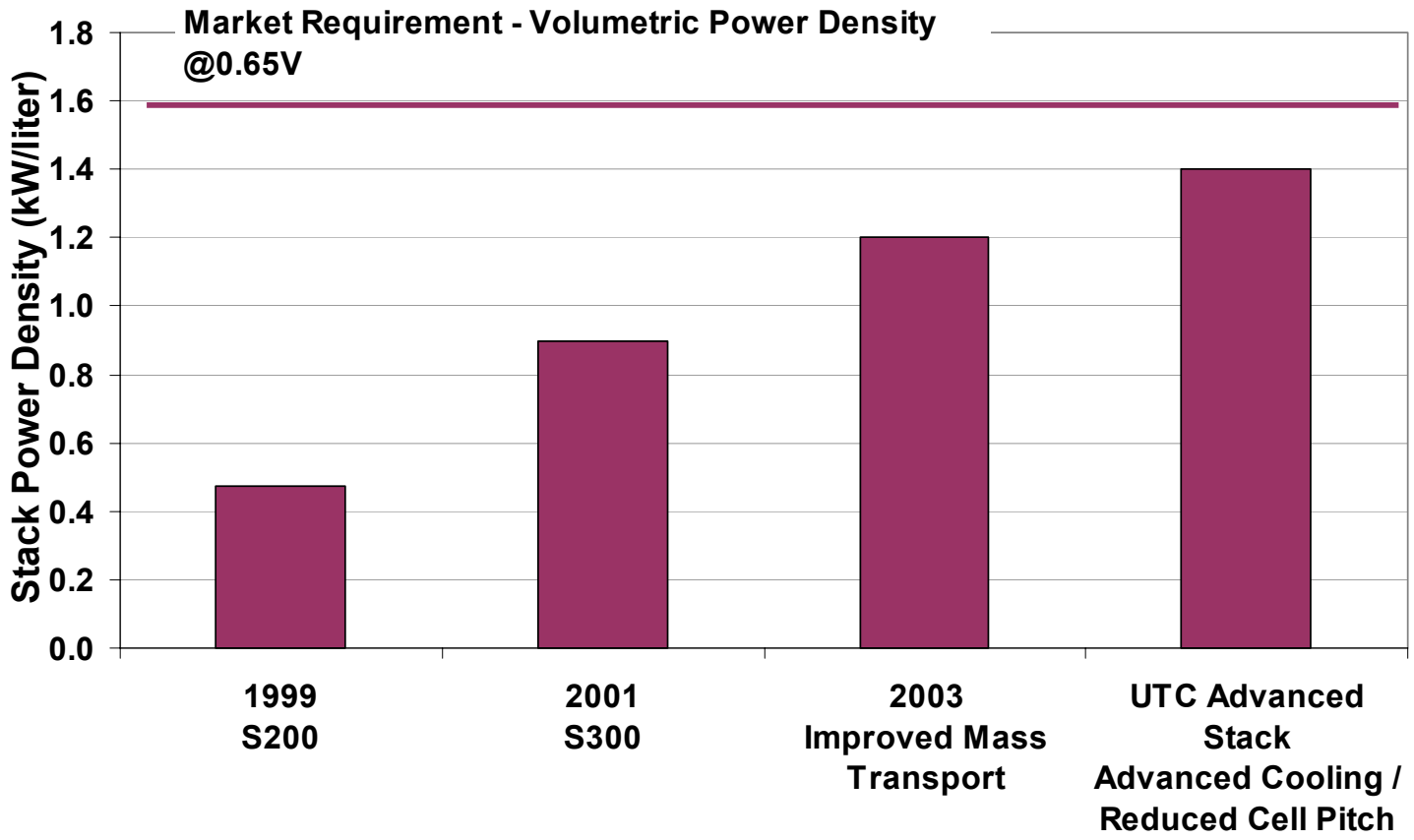
Stack Performance and Power Density Improvements



More Power per Area → More Power per Volume
Advanced technology reduces stack size

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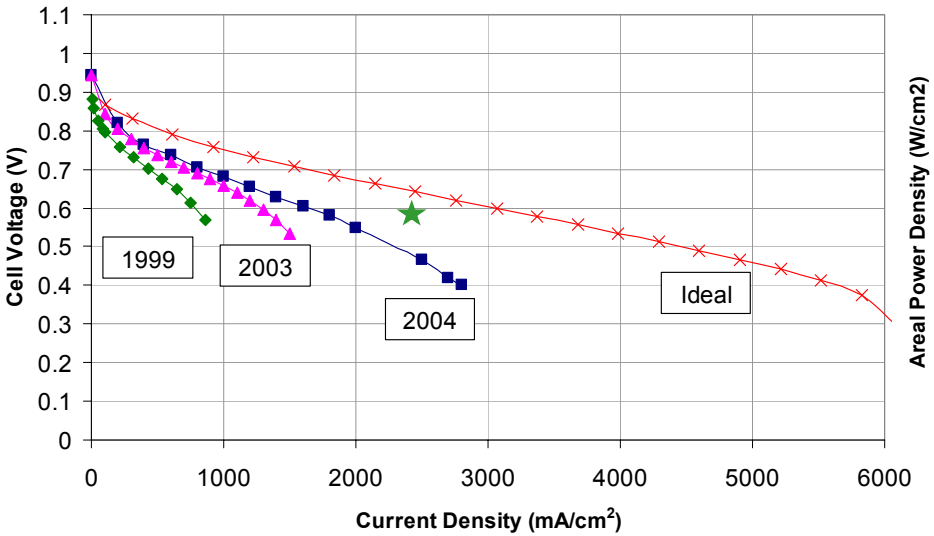
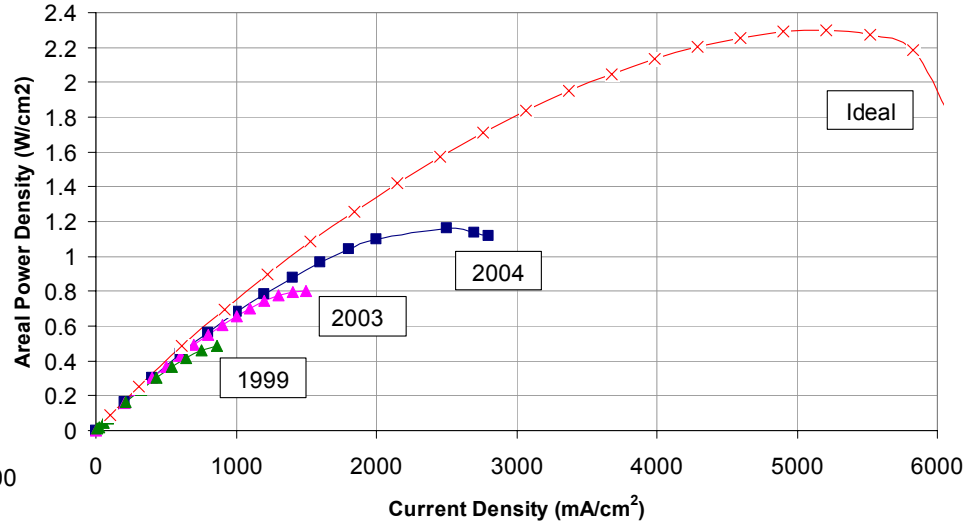
Stack Power Density – How High Will It Go?





Automotive Stack and System Power Density Summary

- Status: Current technology packages in automobiles

  Advanced stack technology will improve system power density to 0.52 kW/liter

- Next Steps: Develop advanced stack and system for vehicle integration
- Prediction: 0.52 kW/liter system ready for scale-up

  0.65 kW/liter feasible with further advanced stack and system concepts

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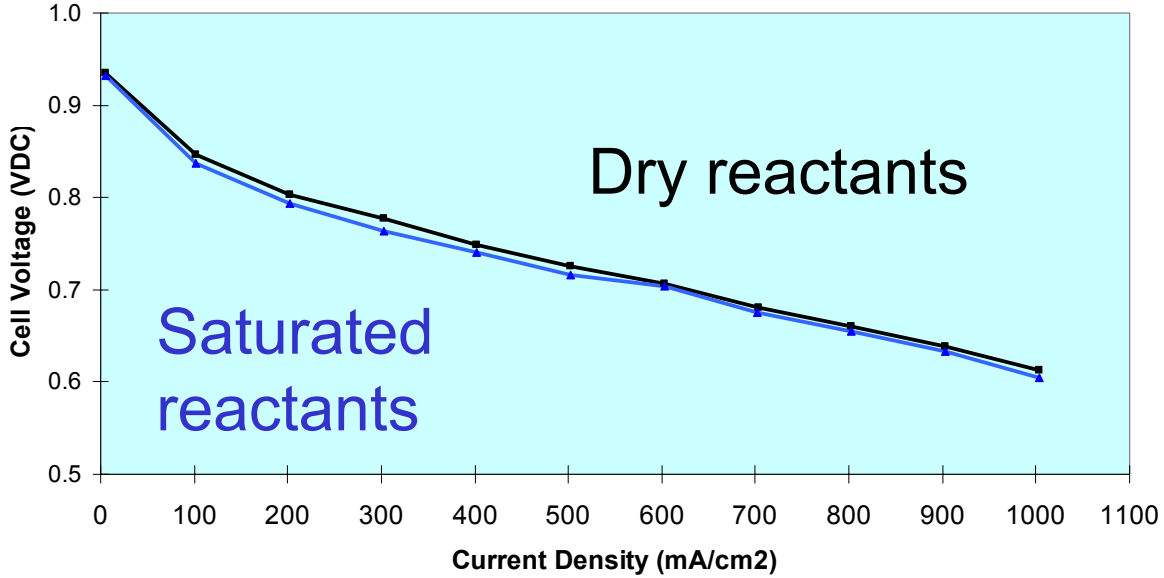
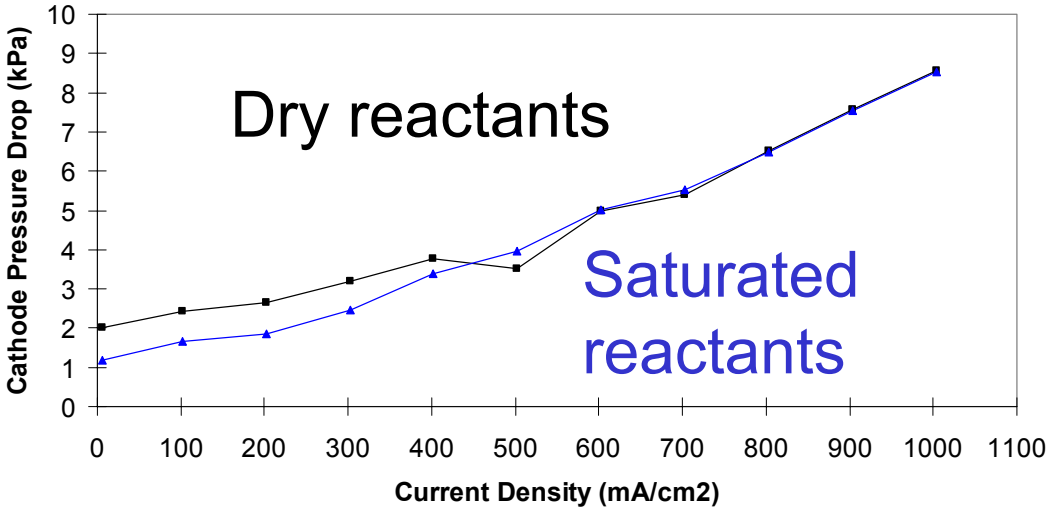
Operability – Tolerant to a Range of Inlet Conditions



Internally humidified cell is insensitive to reactant conditions



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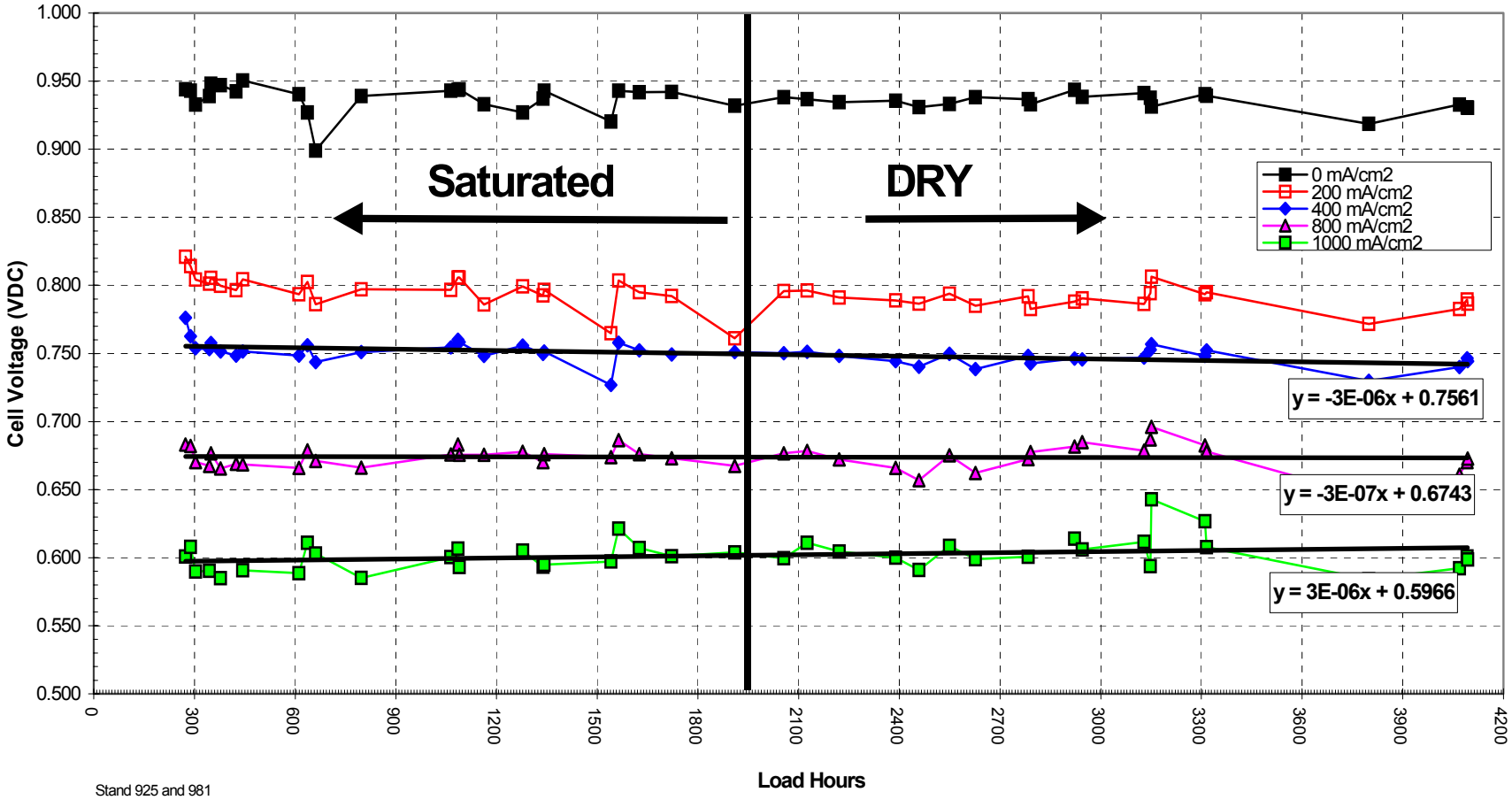
Operability – Tolerant to a Range of Inlet Conditions



Stand 925 and 981

Fuel cell stack performance is insensitive to inlet conditions

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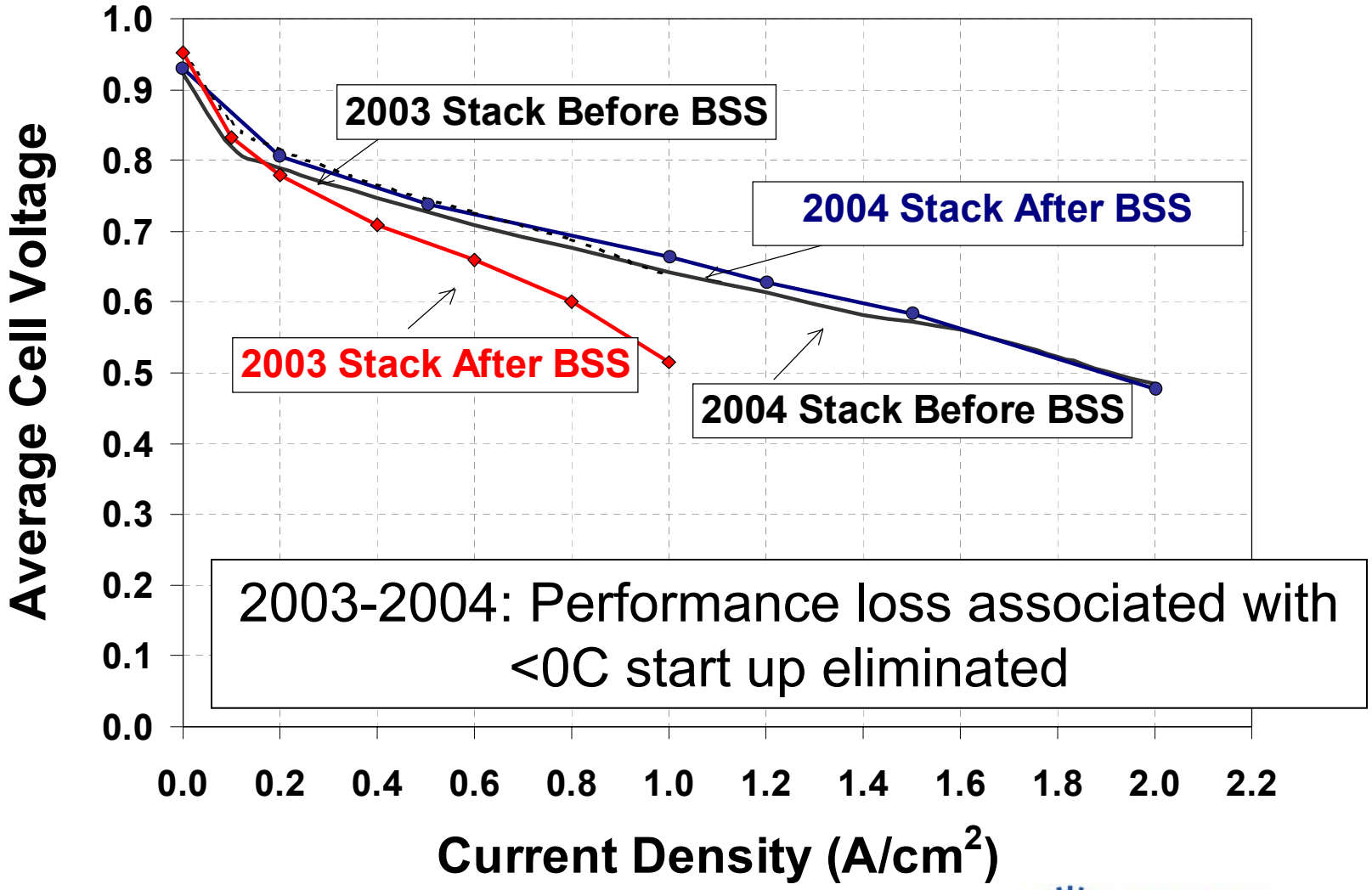
Freeze – Start from <0ºC, No Performance Loss: 20-Cell Stack Data



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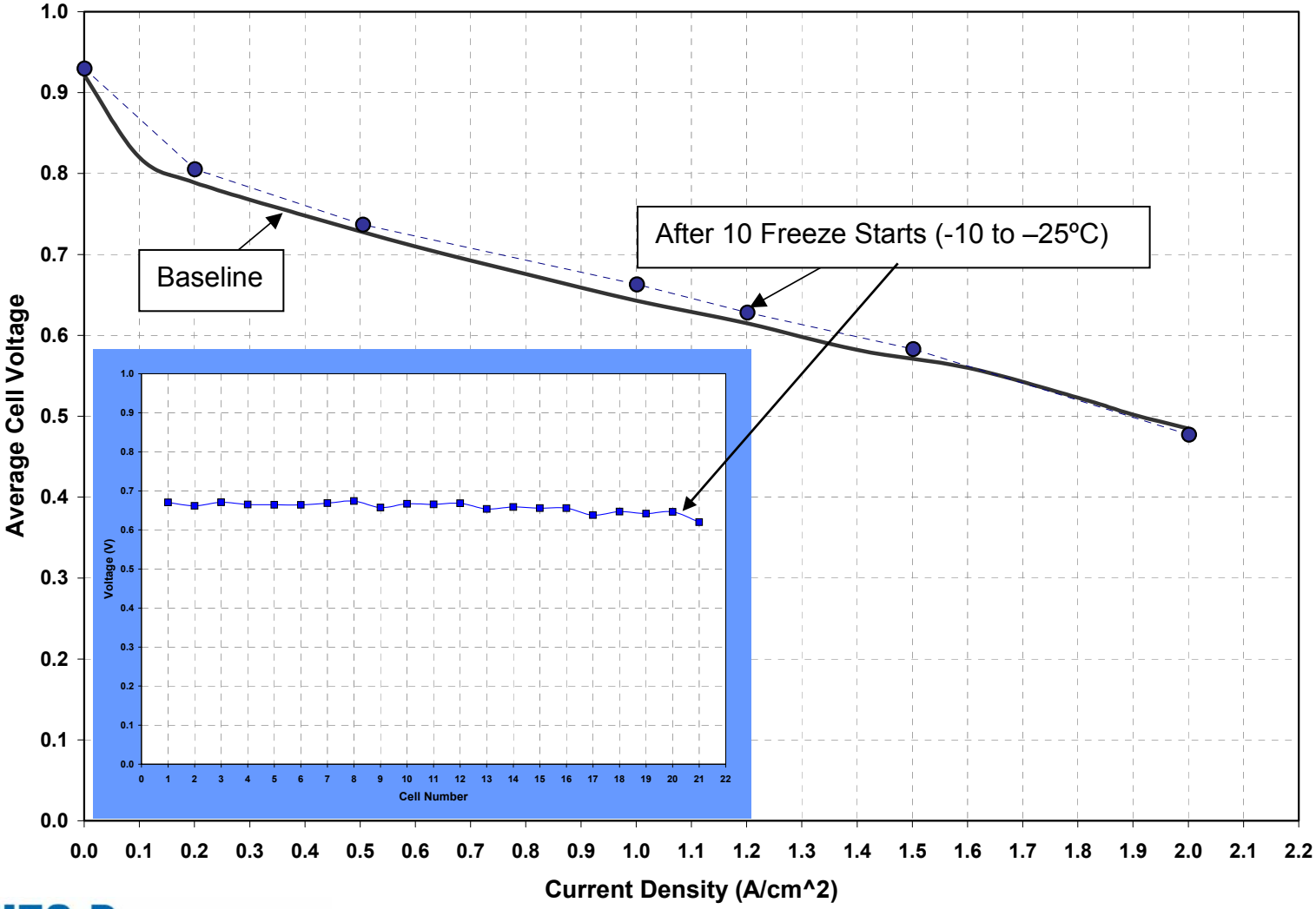
Freeze – Start from <0ºC, No Performance Loss: 20-Cell Stack Data



Target is 1,000 cycles with < 10% loss

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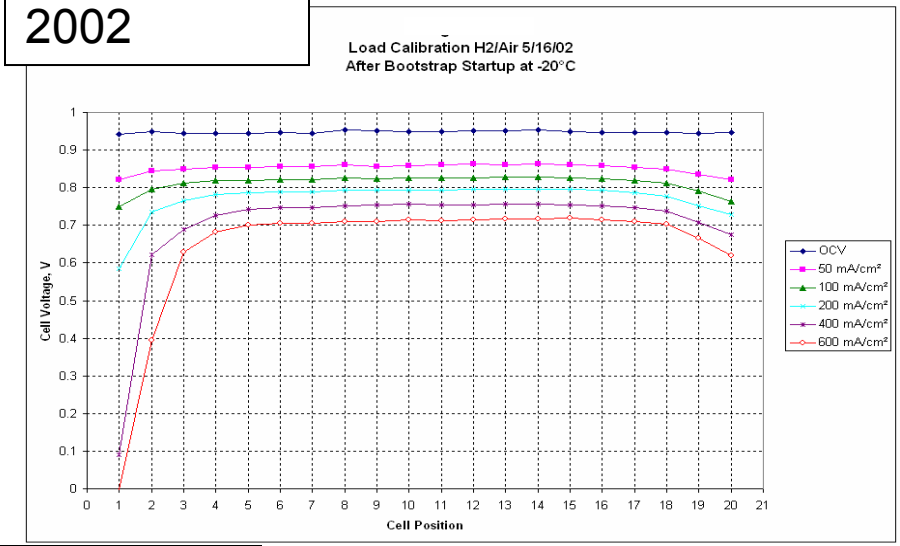
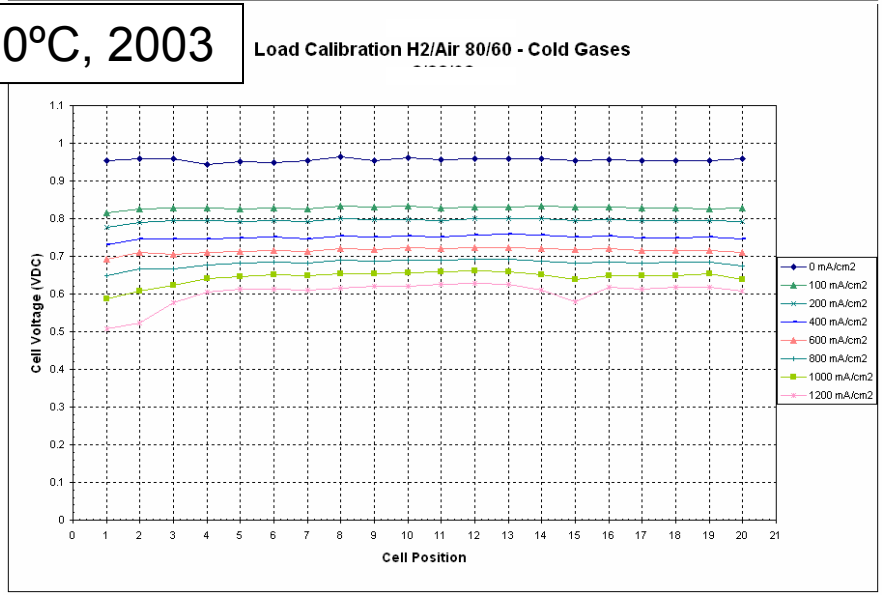
Freeze – Start from <0ºC, No Performance Loss: 20-Cell Stack Data

- **Bootstrap start cycles on 20-cell stacks**
- **Improvement Progress**
  - 2002 Status: Cells on one end performed poorly after BSS
  - Action:
    - Investigation of root causes and mechanisms
    - Change in design and procedures
  - 2003 Status:
    - Cell performance is more uniform after BSS
    - Up to 1200 mA/cm^2
    - Recovery procedure needed

2002



-10ºC, 2003



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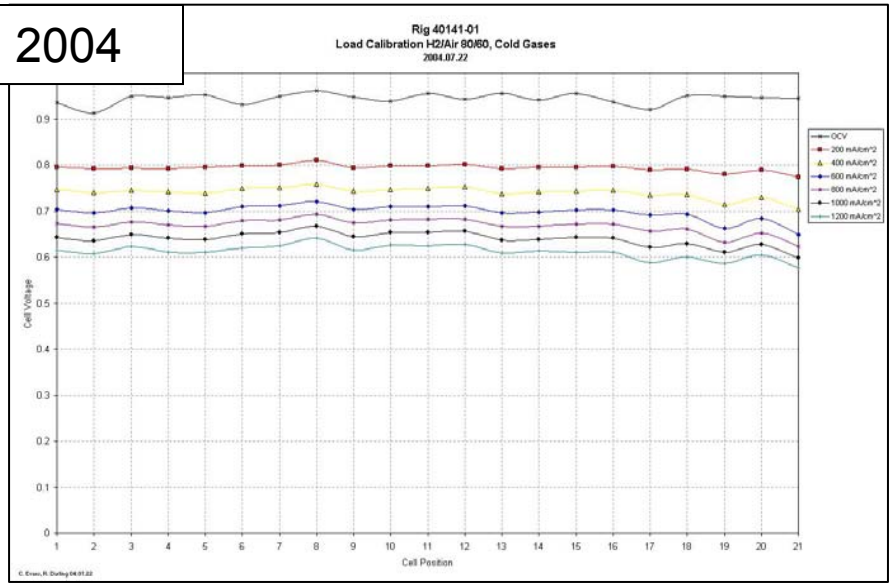
Freeze – Start from <0ºC, No Performance Loss: 20-Cell Stack Data

– 2004 Progress:

- Improved water management and transient response under subfreezing conditions
- No performance decay after starting from -15ºC
- No recovery procedure needed

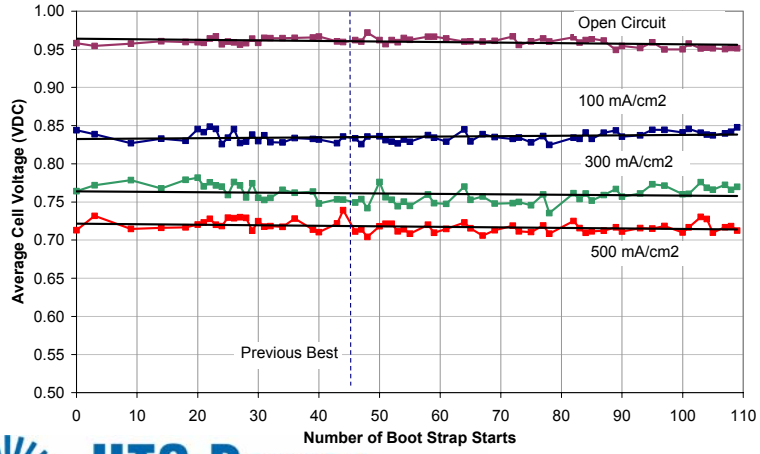
-15ºC, 2004

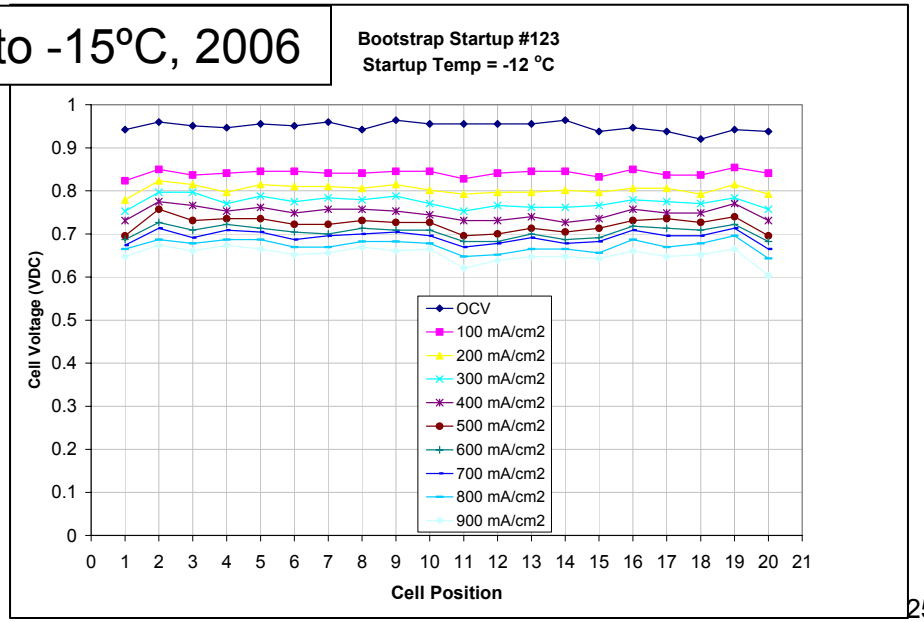


– 2006 Progress

- No performance decay after starting from frozen condition >125 times

-10ºC to -15ºC, 2006





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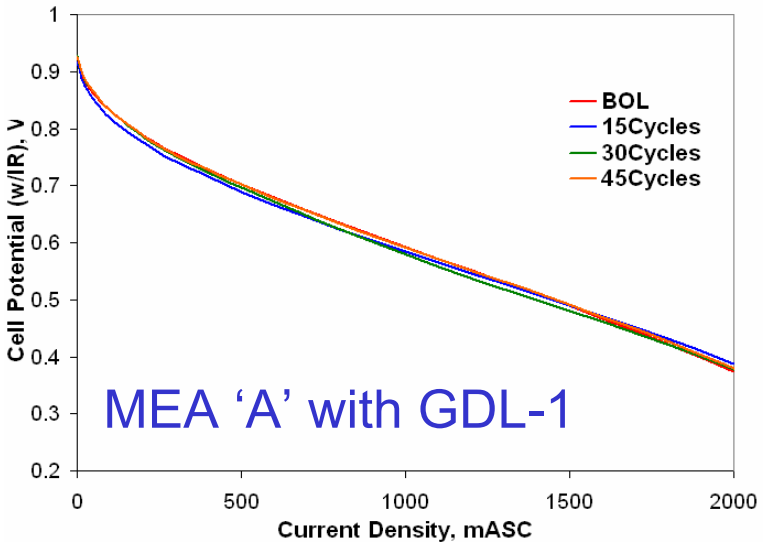
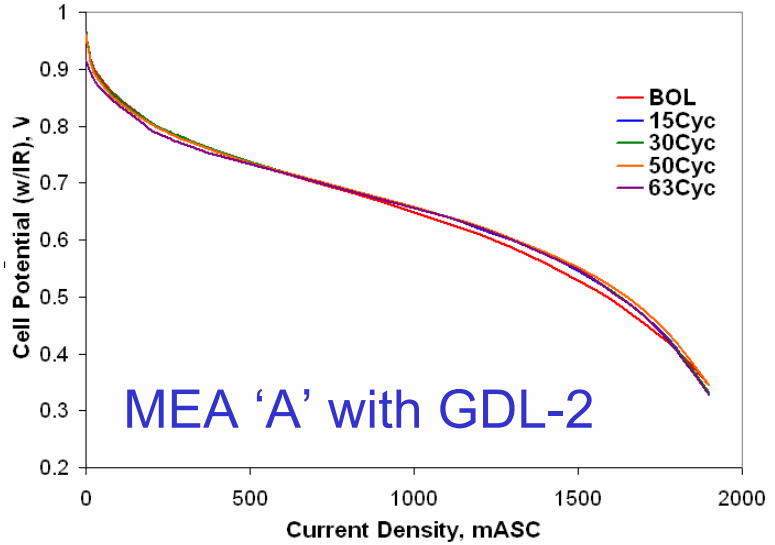
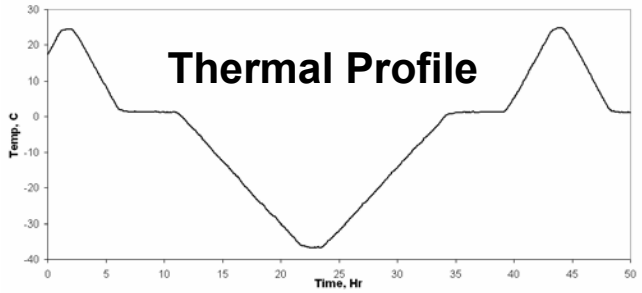
Freeze – Survivability from -40ºC: Sub-Scale Results







- Performance under normal operating conditions was measured every ~15 freeze / thaw cycles
- No freeze / thaw cycling induced decay was observed

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Automotive Fuel Cell Freeze Capability Summary

- Status: Current technology on a path to meet automotive freeze requirements
  - Stacks start up from -20ºC
  - Repeat parts survive from -40ºC
  - Performance is maintained over >125 sub-zero starts
- Next Steps: Demonstrate full auto-sized system in vehicle
  - Reduce below zero start time
- Prediction: Improved freeze-capable configuration ready for vehicle integration in 2008-2009
  - Starts from indefinite cold-soak at -20ºC
  - Survives from -40ºC

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Summary of Fuel Cell Technology Readiness for Light Duty Vehicles

	Technology Feasibility Demonstrated	Technology Verified In Vehicle
Durability	✓	Ongoing
Stack & System Power Density	✓	Ongoing
Freeze Capability	✓	Ongoing

Obstacles to widespread adoption and commercialization paced by

- continued support for development, scale-up, & vehicle integration
- cost
- fuel infrastructure

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