

BALLARD®

power to change the world

Fuel Cell Buses: Current Status and Path Forward



BALLARD POWER SYSTEMS

BUILDING A CLEAN ENERGY GROWTH COMPANY

WWW.BALLARD.COM

2010



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- **Ballard's fuel cell bus history.**
- **Ballard's current fuel cell bus deployments**
- **Targets for capital, maintenance and fuel costs for commercial fuel cell buses**
- **Definition of key areas to enable commercial targets**
- **Summary of Ballard's request for DOE support for commercializing fuel cell buses**

Previous Ballard Bus Programs



1991 - 1992



Phase 1
Proof of
Concept

1993 - 1995



Phase 2
Commercial
Prototype

1996 - 1999



Phase 3 Fleet
Demonstration
Alpha Sites

1999 - 2002



Phase 4 Fuel
Cell Engines
Beta Sites

2002 - 2009



Phase 5
Serial
Production

Power 90 kW /
125 HP

205 kW /
275 HP

205 kW/
275 HP

205 kW/
275 HP

205 kW/
275 HP

Location(s)

Vancouver

Vancouver

Chicago (3)
Vancouver (3)

California

5 Continents
Europe (30),
Perth (3)
California (3)
Beijing (3)

Lessons Learned

Proof of
concept

Full-size bus
integration

Field service
Site
homologation

System
optimization
Cost reduction -
single motor
concept

International
homologation
Reliability growth
Real world usage



Ballard's Current Bus Product - FCvelocity™-HD6

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■ FCvelocity™-HD6 fuel cell module:

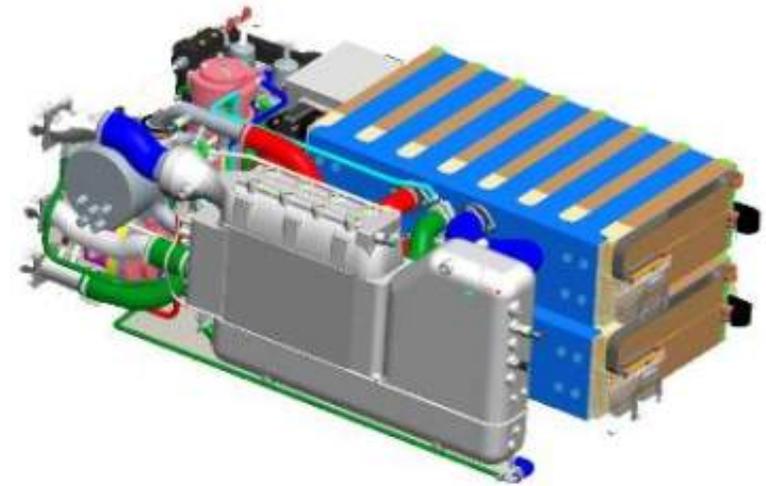
- Greater power density and durability while maintaining some of the time tested components of previous design.
- Featuring state of the art automotive fuel cell stack technology
- Offered with a 12,000 hr, or 5 yr warranty



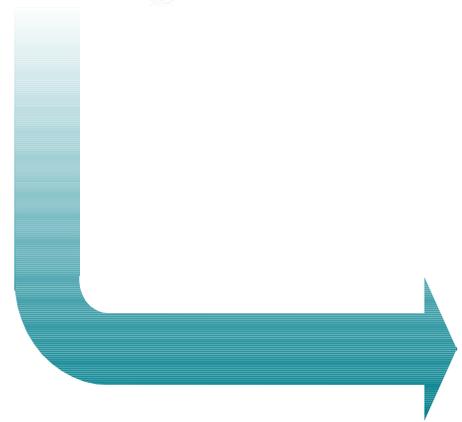
HD6 Module

■ Includes:

- air humidification system
- hydrogen re-circulation
- condenser for water management
- CAN and power supply connections
- control system
- 150 or 75 kW configurations



Integration into a Hybrid Drive



Courtesy of ISE Corp.



BC Transit Fuel Cell Bus Fleet



- BC Transit Fuel Cell Bus Fleet at Whistler Canada
- 20 buses operational – main source of public transit
- Vehicles have now accumulated to date:
 - > 340,000 km's
 - > 18,000 hrs
 - Positive feedback from the drivers & transit riders



HD 6 Bus Programs:



London Bus Fleet



2010

UNDP Sao Paulo



Phase 2
2010

Palm Springs



2010
2012

Cologne/Amsterdam

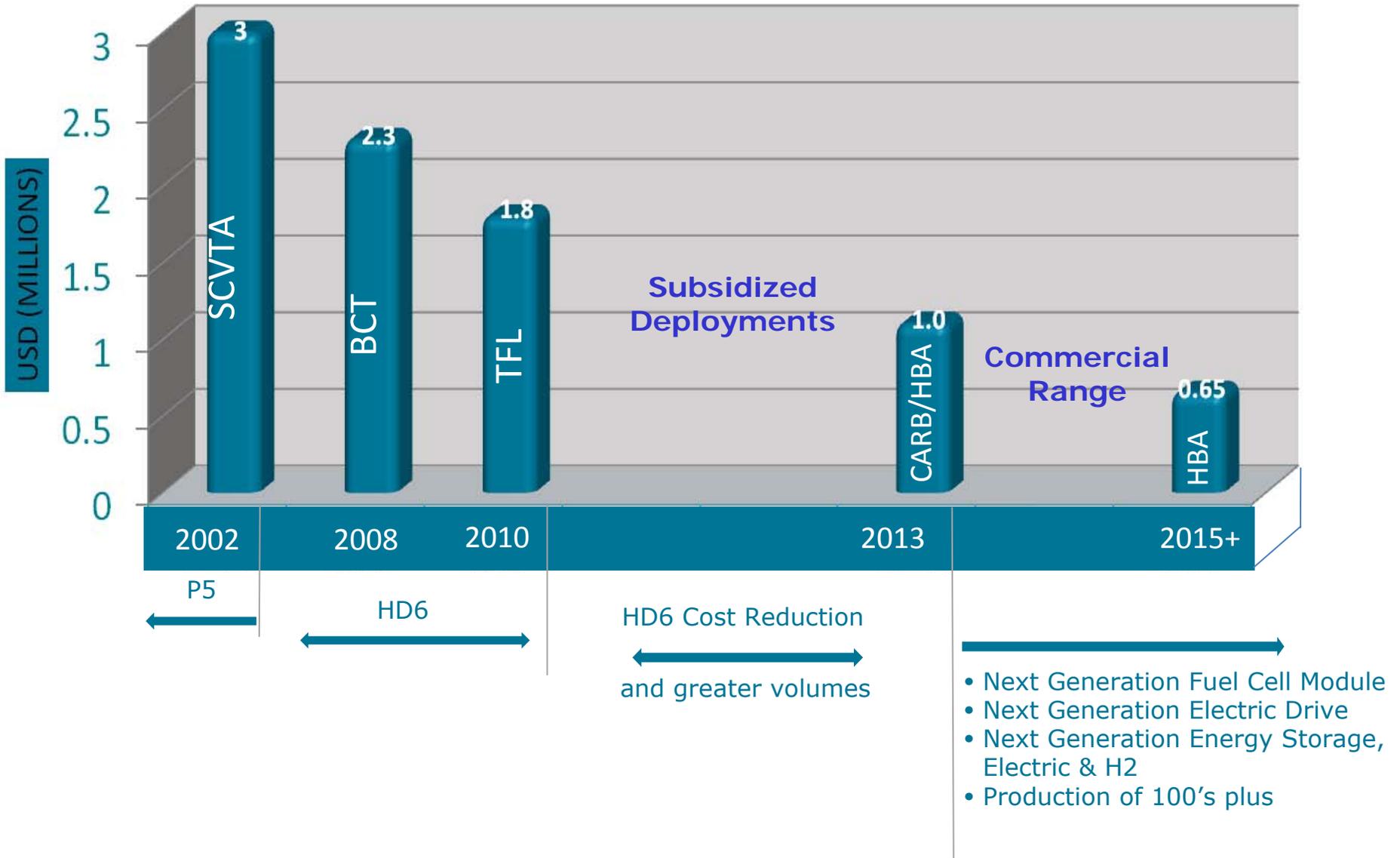


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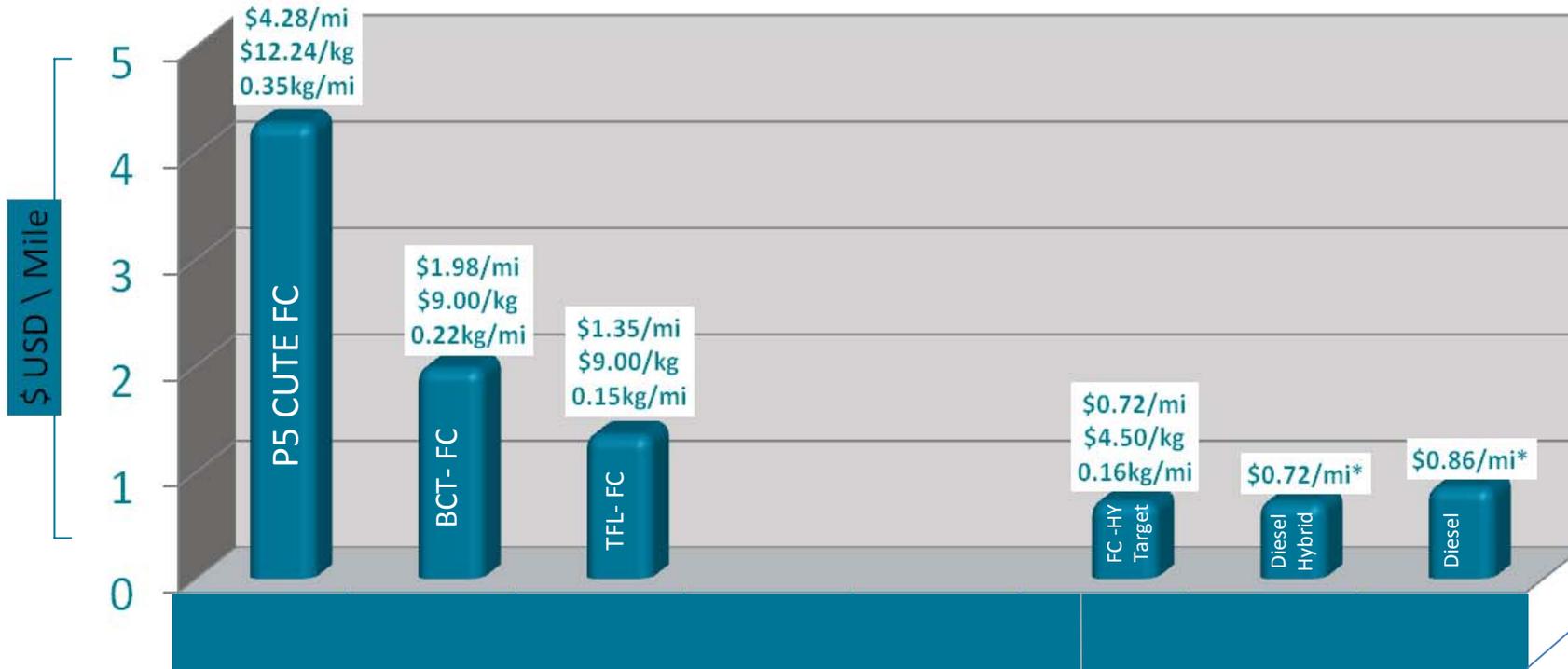
Fleet Size	5	3	2	4
Transit Agency	Transport for London	EMTU	SunLine TRANSIT AGENCY	KVB GVB
FC Power	75 kW	150 kW	150 kW	150 kW
Transit Bus OEM	THE WRIGHT GROUP	Marcopolo	NEW FLYER Eldorado National THOR	APTS Advanced Public Transport Systems Inc
Systems Integrator	ISE	tuttoTrasporti	ISE BAE SYSTEMS	vossloh



Commercial Barriers - Capital Cost



Commercial Barriers - Operating Cost, Fuel Only



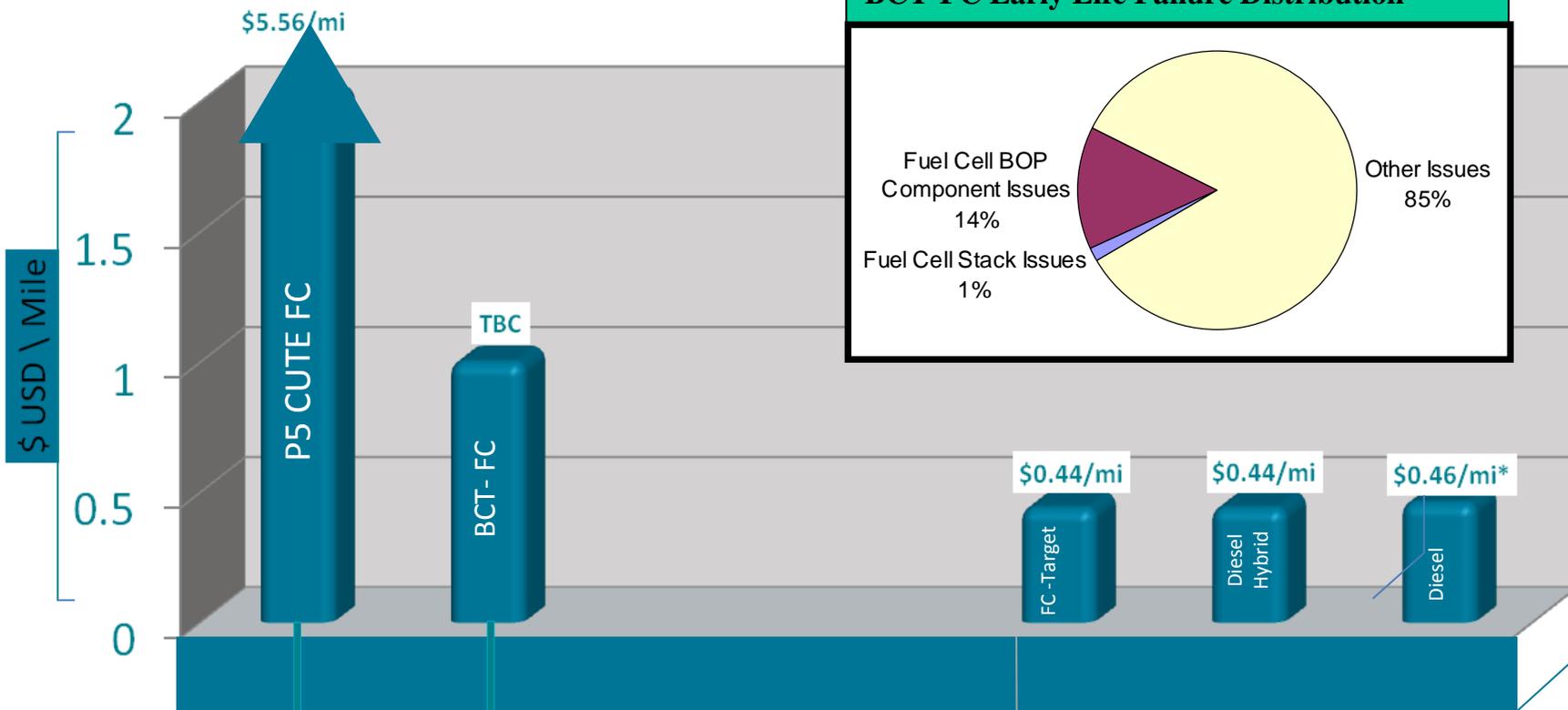
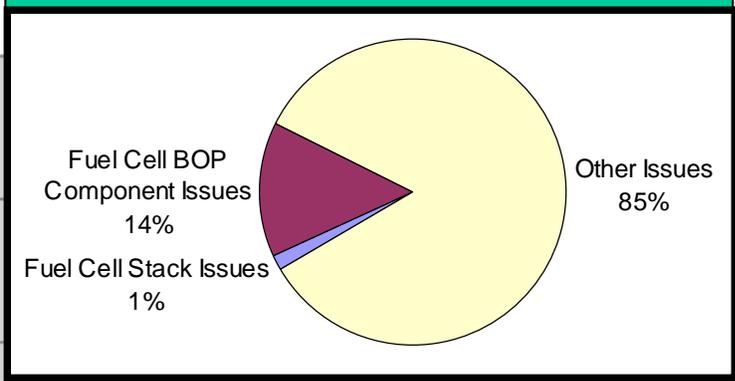
- Modest improvement of FC module efficiency →
- Considerable improvement of hybridization strategy →
- Considerable reduction of H2 cost at the pump →

*Note: FTA-wv-26-7006.2008.1 diesel fuel @ \$2.27/gallon

Commercial Barriers - Operating Cost, Maintenance Only



BCT-FC Early Life Failure Distribution



- Regular site support
 - Longer stack life
 - Leveraging Diesel Hybrid technology
-
- Intensive site support
 - Short stack life
 - Complex immature technology

- ← Continuous improvement of Coach integration, System Integration and FC Module life and reliability
- ← Next Generation System Integration & FC Module
- ← Further improvement of Hybrid architecture for FC application

*Note: FTA-wv-26-7006.2008.1



Cost Reduction Opportunities through Volume

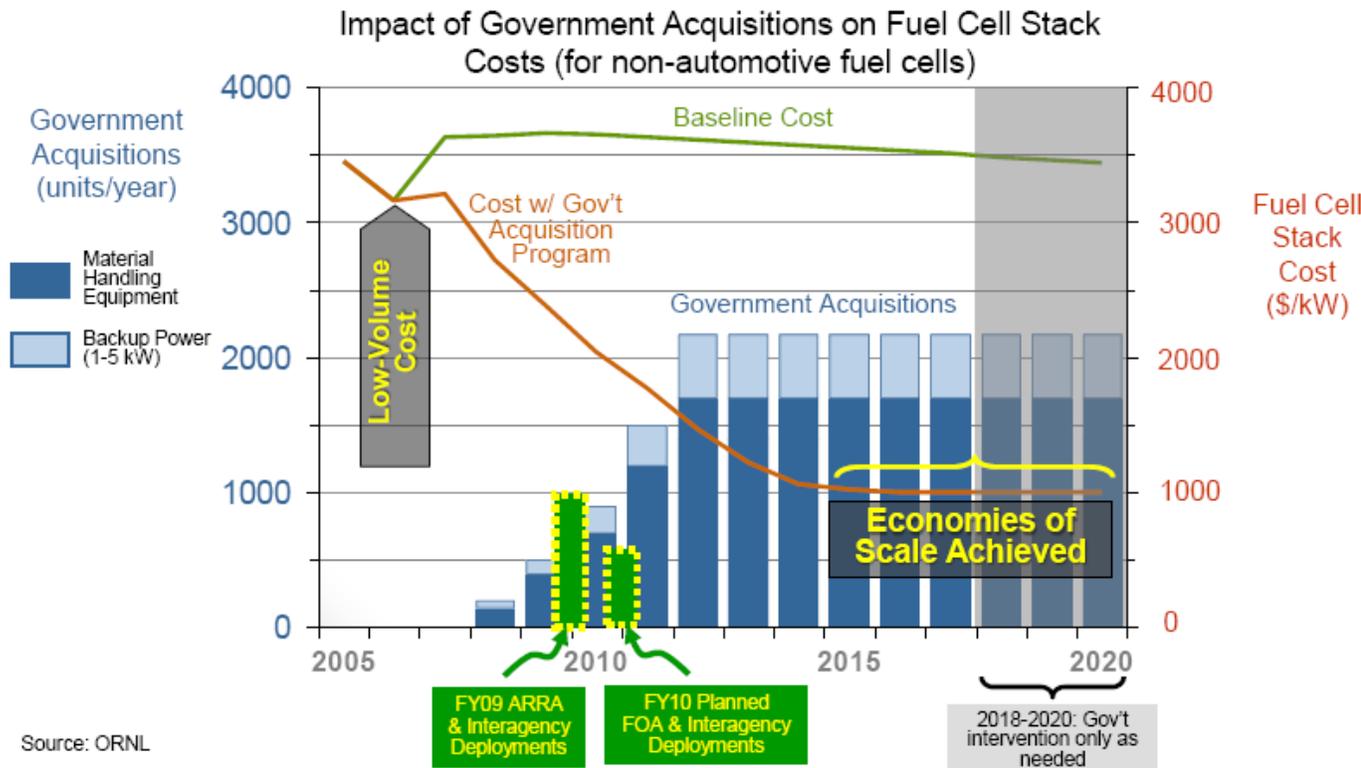


Market Transformation

U.S. DEPARTMENT OF ENERGY

Government acquisitions could significantly reduce the cost of fuel cells through economies of scale and help to support a growing supplier base.

Key Market Transformation Goals: Enable cost reductions from ~\$3500/kW to ~\$1000/kW for backup power and lift-truck power and from ~\$5500/kW to ~\$3000/kW for CHP systems



Driving volume through subsidies and/or purchases can have a big effect on achieving commercial cost targets.

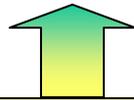
Suggest similar study as done in Material Handling & Back-up Power

Source: WHEC Conference May 20, 2010
 US Hydrogen and Fuel Cell Policy and Analysis Review
 Michael Mills

Optimized Fuel Cell Bus Design for End Operators



Integrated System Model



Bus Driving Profiles



Electric Drive & Energy Storage



Fuel Cell Module

Drive for holistic integrated system approach across operators, integrators, energy storage suppliers and fuel cell module suppliers

- ▶ Model drives both capital, operating (fuel) and maintenance costs
- ▶ Focus capital & development money in highest value areas
- ▶ Derive optimum hybridization strategies
- ▶ Validates commercial fuel cell business and defines key targets for supply base

Capital Cost Reduction Via Component Development



Component Development	Component Testing	Validation Under Bus Operation
<p>Electric Drive</p> <p>Energy Storage – H₂ & Electric</p> <p>Fuel Cell Module -Non Stack</p> <ul style="list-style-type: none"> a) Air & Fuel pumps b) Electric motors c) Hydrogen Sensors d) Humidifiers e) etc <p>Fuel Cell Stack</p> <ul style="list-style-type: none"> a) Low cost materials b) Improved MFG processes c) 2-3X life improvement d) Maintain current performance level 	<p>Develop detailed test plans</p> <ul style="list-style-type: none"> a) Functional tests b) Robustness tests c) Accelerated test <p>Design & Build Test Equipment</p> <ul style="list-style-type: none"> a) Purpose built b) Multi sample testing for statistics <p>Perform detailed failure analysis</p> <ul style="list-style-type: none"> a) Root cause determination b) Measurement of wear 	<p>Build components into operational bus and test under actual bus route conditions</p> <ul style="list-style-type: none"> a) Catch component interaction issues b) Allows opportunity to maximize benefits of new components c) Works out infant mortality to allow for smooth transition to larger fleet operation <p>Note, this is one of the most critical yet underfunded part of fuel cell bus development</p>

Select components with biggest impact on fuel efficiency, capital cost & maintenance cost
 Extremely important to validate in final bus configuration on actual bus routes



- **Funding for system analysis across coach, integrator, and fuel cell provider**
 - Holistic approach across all elements of the bus including driving profiles, energy management, electric drive and fuel cell module options
- **Funding for development of low cost, highly reliable, long lasting components**
 - Fuel cell stack and module components
 - Energy storage – fuel and electrical
 - Electric drive systems
- **Funding for bus level “Design Validation” testing before releasing larger fleet sizes into revenue service**
 - Critical step in typically underfunded part of development cycle
 - Sets up commercial adoption of fuel cell buses due to ease of integration into normal bus service
- **Subsidies for larger scale bus deployments**
 - Allows for capital cost reduction across the bus through higher volume manufacturing processes
 - Provides incentive for supply base to engage (from coach manufacturer through component manufacturing through hydrogen supply companies)

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Thank you!



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