



Hydrogen Fuel Cell Propulsion System

Hydrogen Technical Advisory Committee

June 03, 2010

Charlie Freese

Executive Director, Global Fuel Cell Activities





Overview

Challenges & Strategy

Overview of GM Fuel Cell Technology

Infrastructure

Vehicle Programs





The Challenge

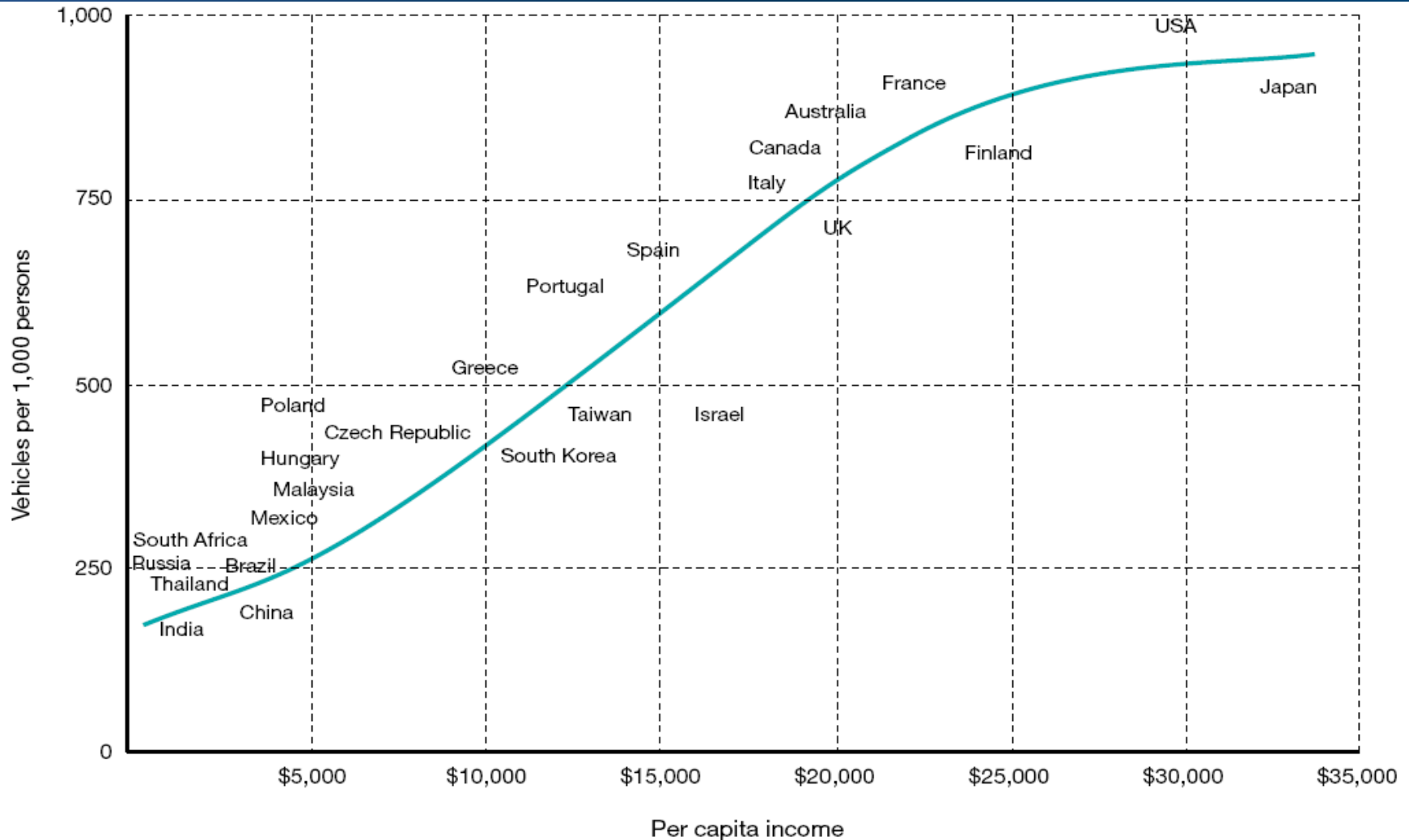
Personal Mobility & the Auto Industry

- Energy
- Environment
- Safety
- Congestion
- Affordability
- Sustainability





Megatrends – Vehicle Ownership



Economic growth is leading to larger global car parc

Source: UN Population Division



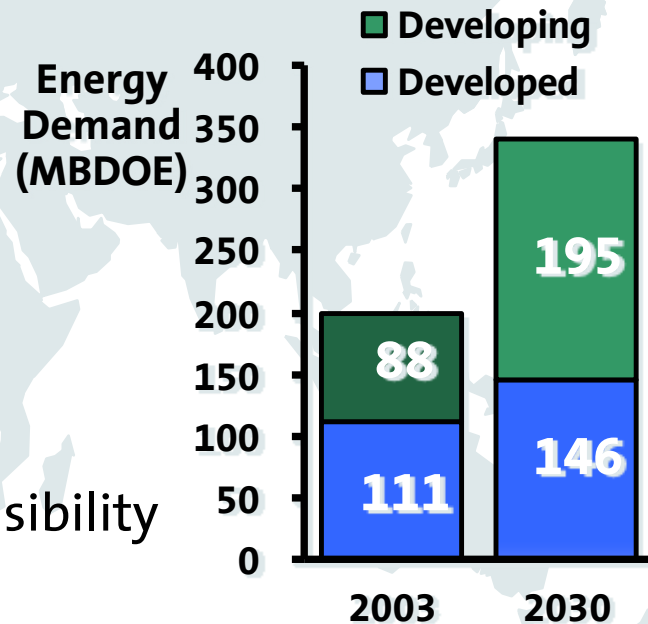


The Challenge

Global energy demand exceeds current supply glide path

- There are several risks that can disrupt the existing supply
 - Above ground infrastructure
 - Natural disasters
 - Wars
 - Hostile regimes
- Growing concern about global warming due to CO₂
- Potential for regulations that exceed both technical capability & business feasibility

**Global increase 2% / year,
71% increase over 2003**



Source: DOE Energy Information Agency

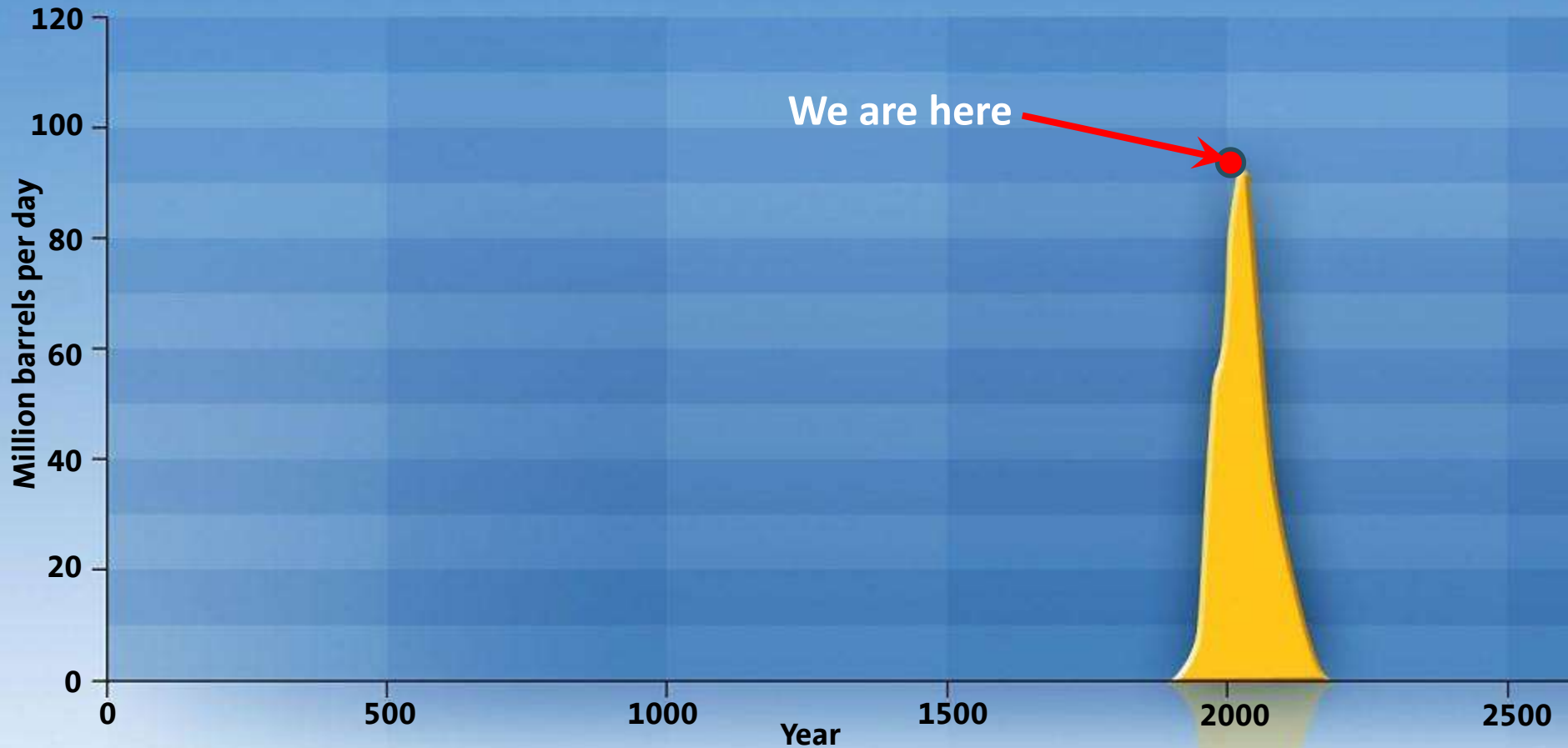
MBDOE: Millions of barrels per day oil equivalent





The Petroleum Age

Hubbert Curve & Peak Oil – Keeping things in perspective



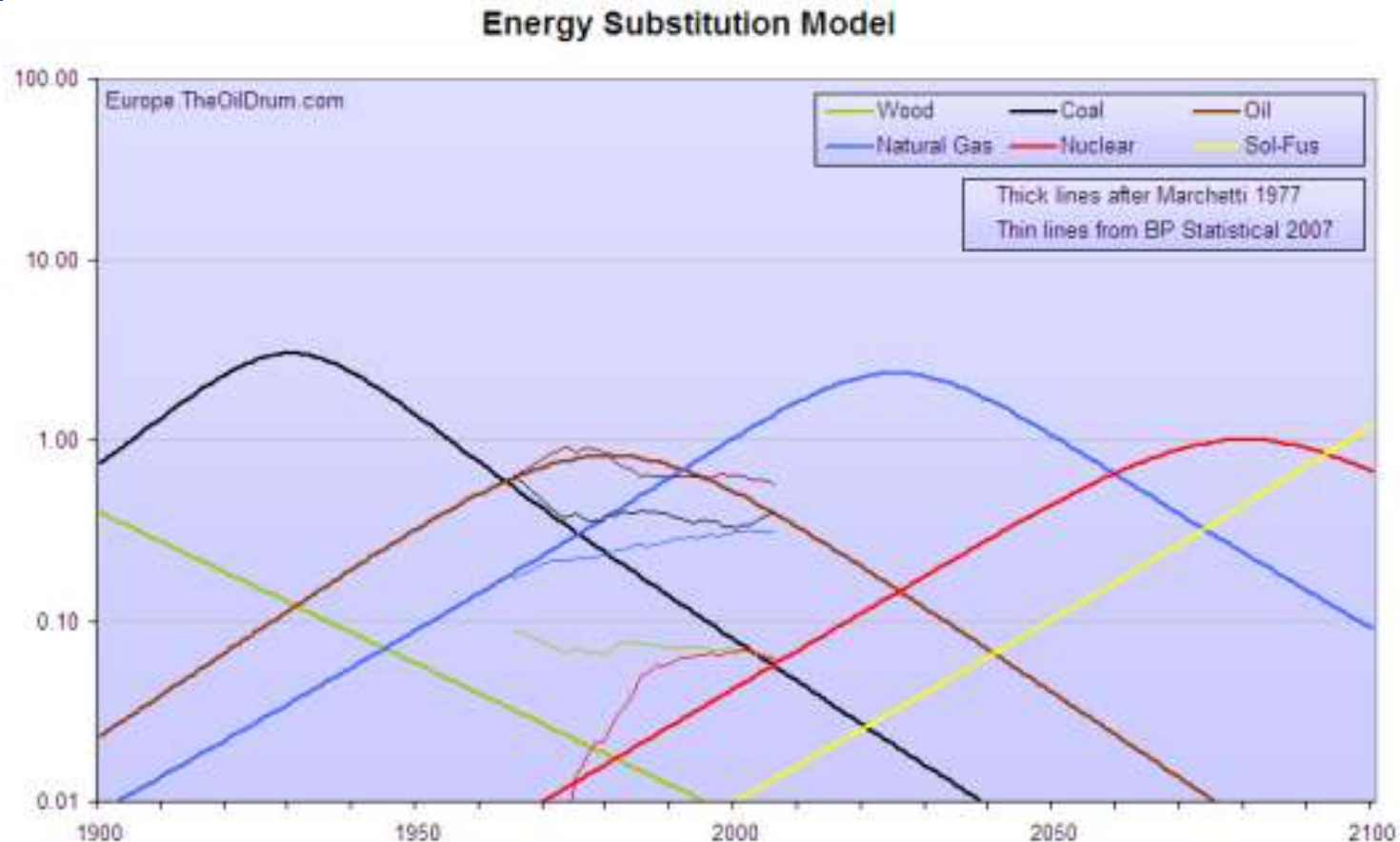
**Change will come & it may happen much faster than one might anticipate.
Can we react in time to adjust?**





Energy Substitution Model

1977 Marchetti – Updated (BP Statistical Review of 2007)



The Energy Substitution Model from 1977 and data from the [BP Statistical Review of 2007](#).
Wood fuel data from [FAOSTAT](#).

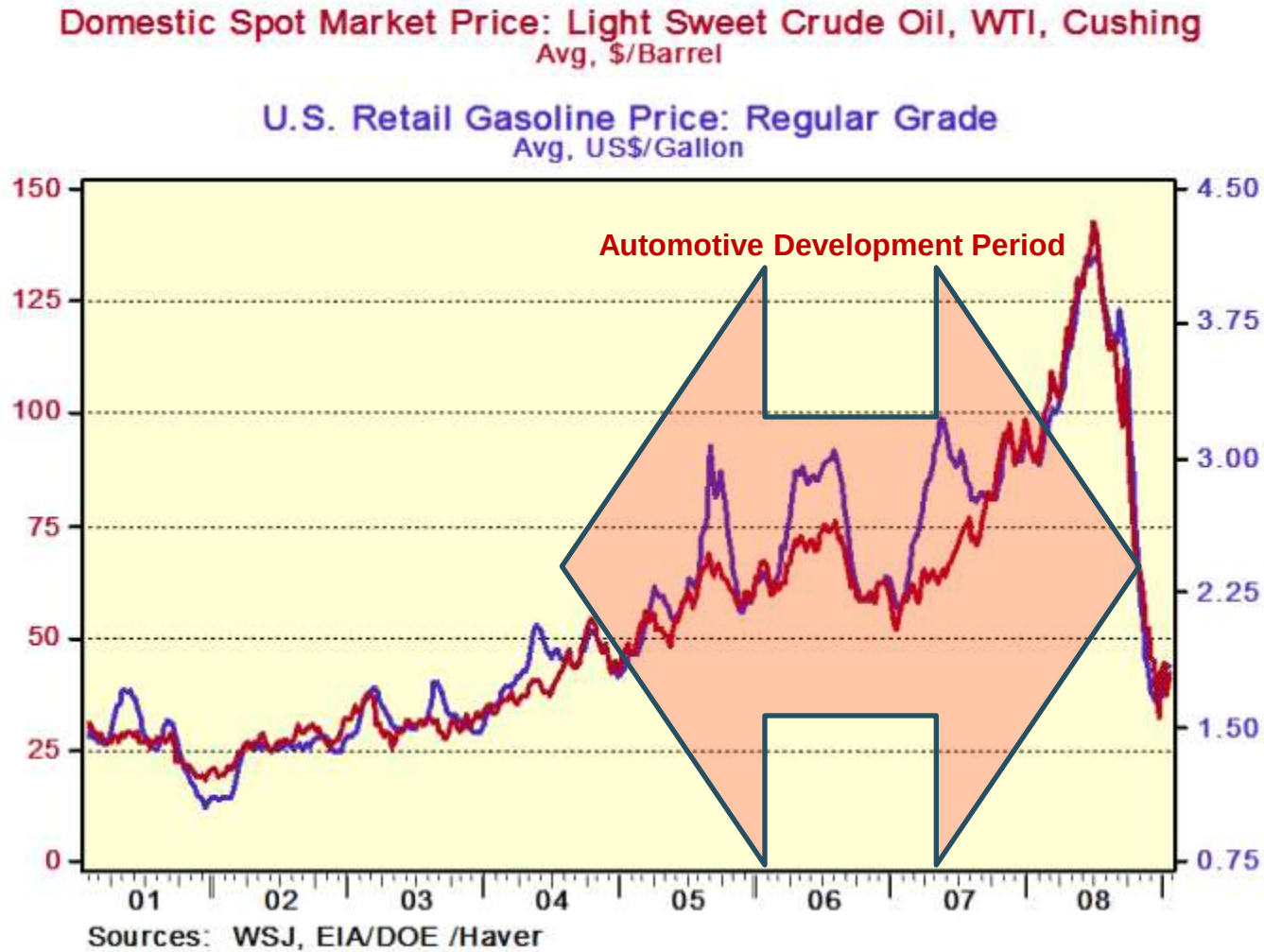
Progression in fuels with H:C ratios characteristic of wood to coal to oil to methane corresponded to periods requiring about 50 years.





Two Oil Shocks – One Up and One Down

Commodity Prices Followed Similar Patterns



Price volatility Inhibits technologies that require longer term investment

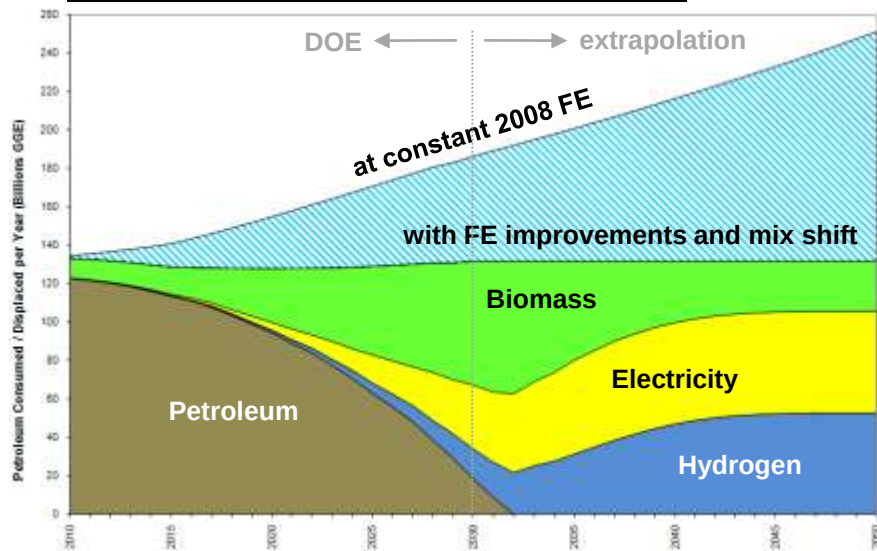




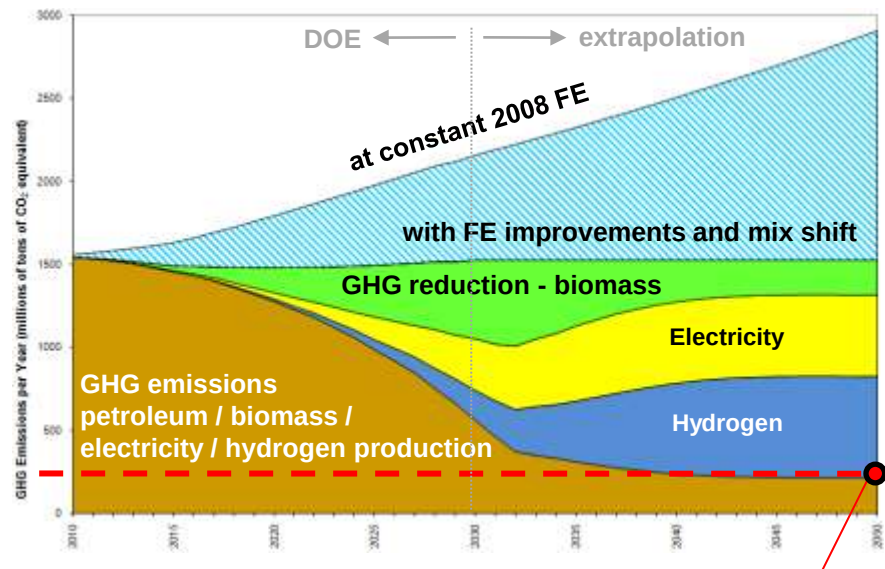
All Options in Play

One possible scenario

Petroleum Consumption



GHG Emissions



Goal – 80% reduction from 1990 level by 2050

Cellulosic biomass ramps to high volume; BEVs / EREVs make 40% of VMT electric; FCEVs penetrate to 40% of parc by 2050

- LDV parc mostly transitioned to electric drive and ZEV solutions
- U.S. grid GHG modeled at 80% lower than 2008 levels
- Hydrogen from cellulosic biomass or clean electricity

Start soon with early options; finish with strongest long-term portfolio





Development of Green Alternatives



Energy Diversity



Conventional Powertrain Advances



Hybrid Propulsion Systems



Battery Electric Vehicle Technology



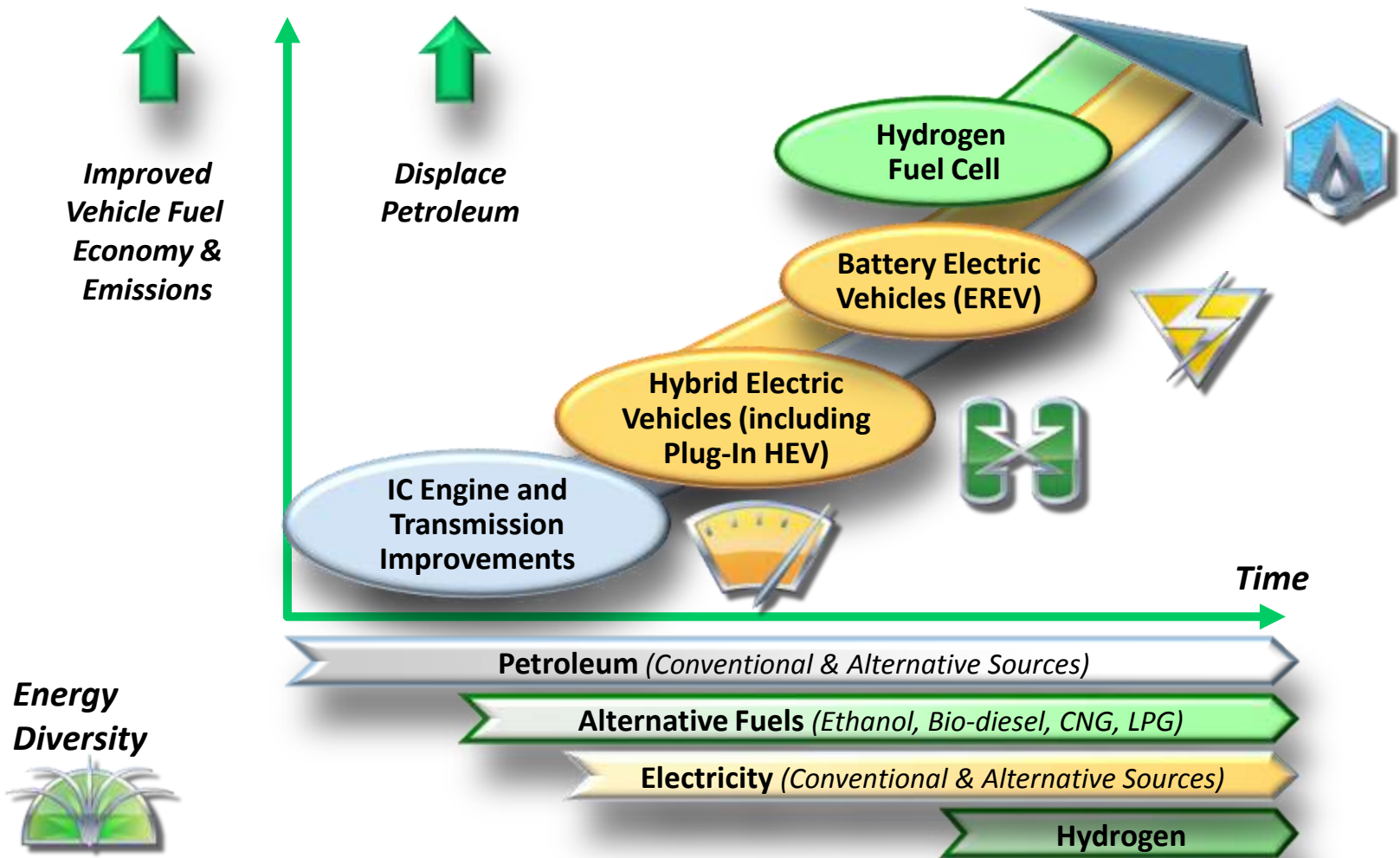
Hydrogen Fuel Cell Electric Vehicles





Advanced Propulsion Technology Strategy

No single silver bullet exists

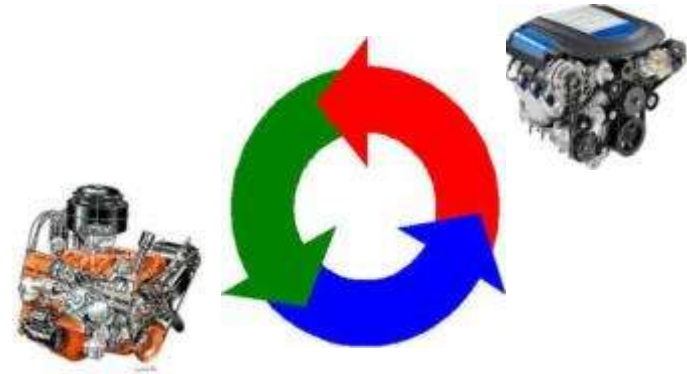




Advanced Technology Common Challenges

Cycles of Learning

- Technologies are more expensive at first
- Internal combustion engine (50 – 60 cycles)
- Requires 2-3 production cycles before cost effective
- Growth to scale economies required to achieve lowest cost potential



Infrastructure Investment Required

- Requires field infrastructure investment
- Must develop manufacturing & suppliers





Cycles of Learning





GM Fuel Cell Stack – Pre-Development Cycles of Learning

St 3 - 1997



St 4 - 1998



Stack 2000



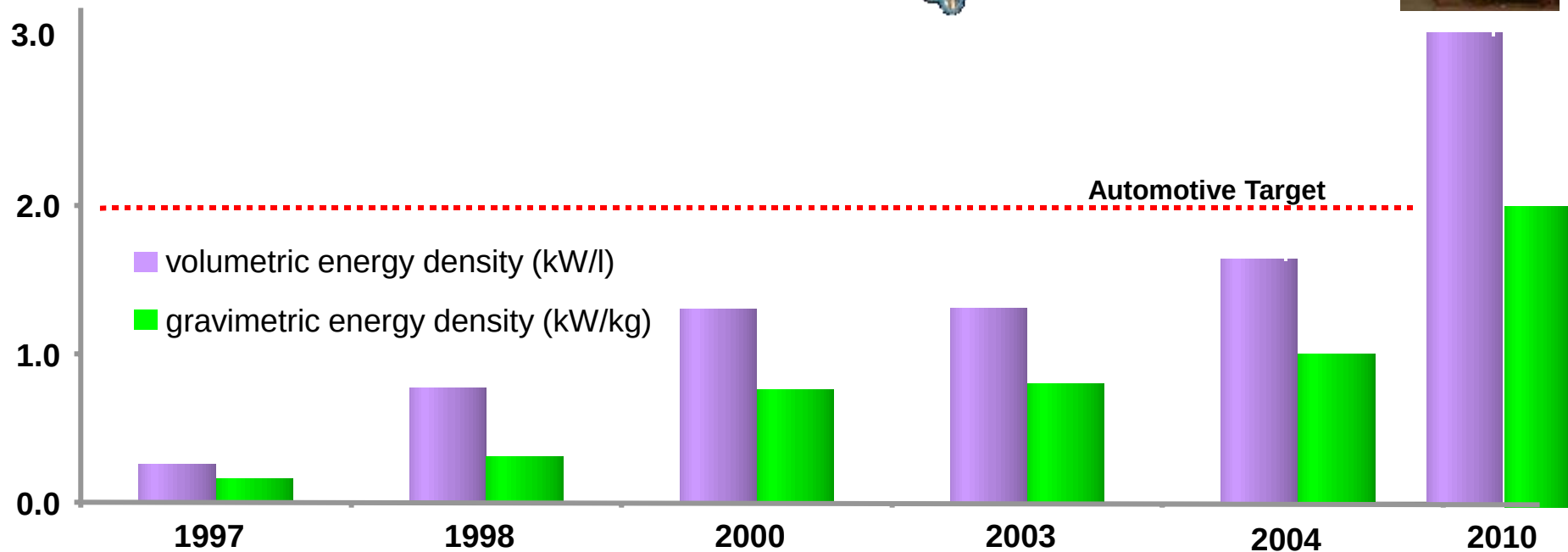
S2.1 - 2003



S4 - 2004



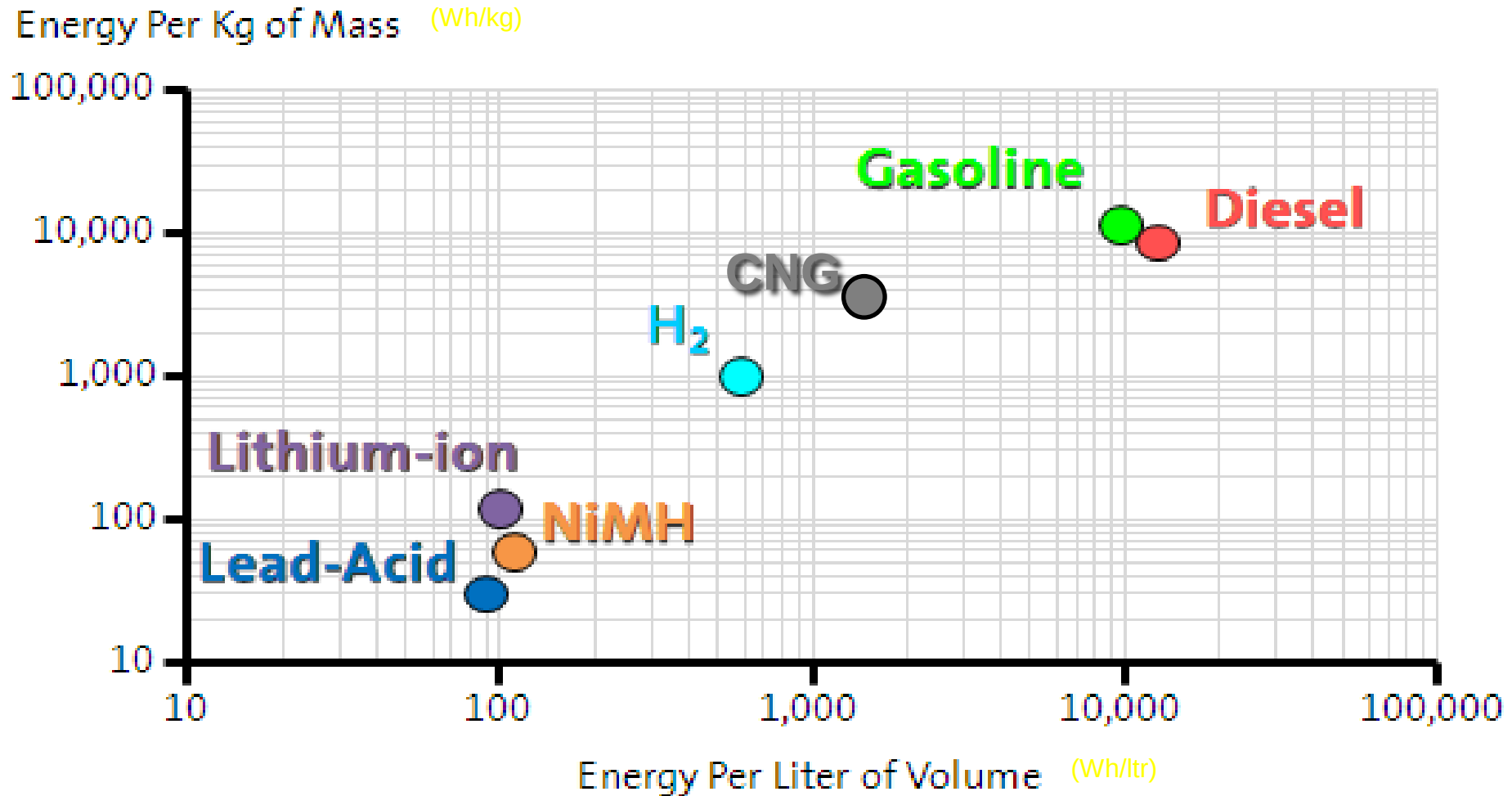
Current





Energy Storage Density is a Key Challenge

Energy Density on a Logarithmic Plot



Battery improvements are expected, but still 100X lower density than liquid fuel
Hydrogen has significantly higher storage density than batteries





Energy Carrier Properties: Onboard Storage

Why is petroleum the dominant transportation fuel?

Weight & Volume of Energy Storage System for 300 mile Range

Diesel

System
Fuel



43 kg
33 kg



46 L
37 L

Compressed Hydrogen 700 bar
6 kg H₂ = 200 kWh chemical energy

System
Fuel



125 kg
6 kg



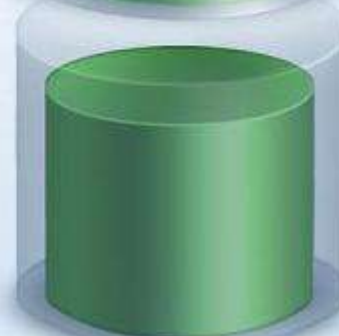
260 L
170 L

Lithium Ion Battery
100 kWh electrical energy

System
Cell



830 kg
540 kg



670 L
360 L

The challenge is to balance electric drive efficiency & energy cost advantages versus energy system storage mass, volume & refuel time penalties





Diverse Customer Needs

Hydrogen Fuel Cell Chevrolet Equinox – at Work



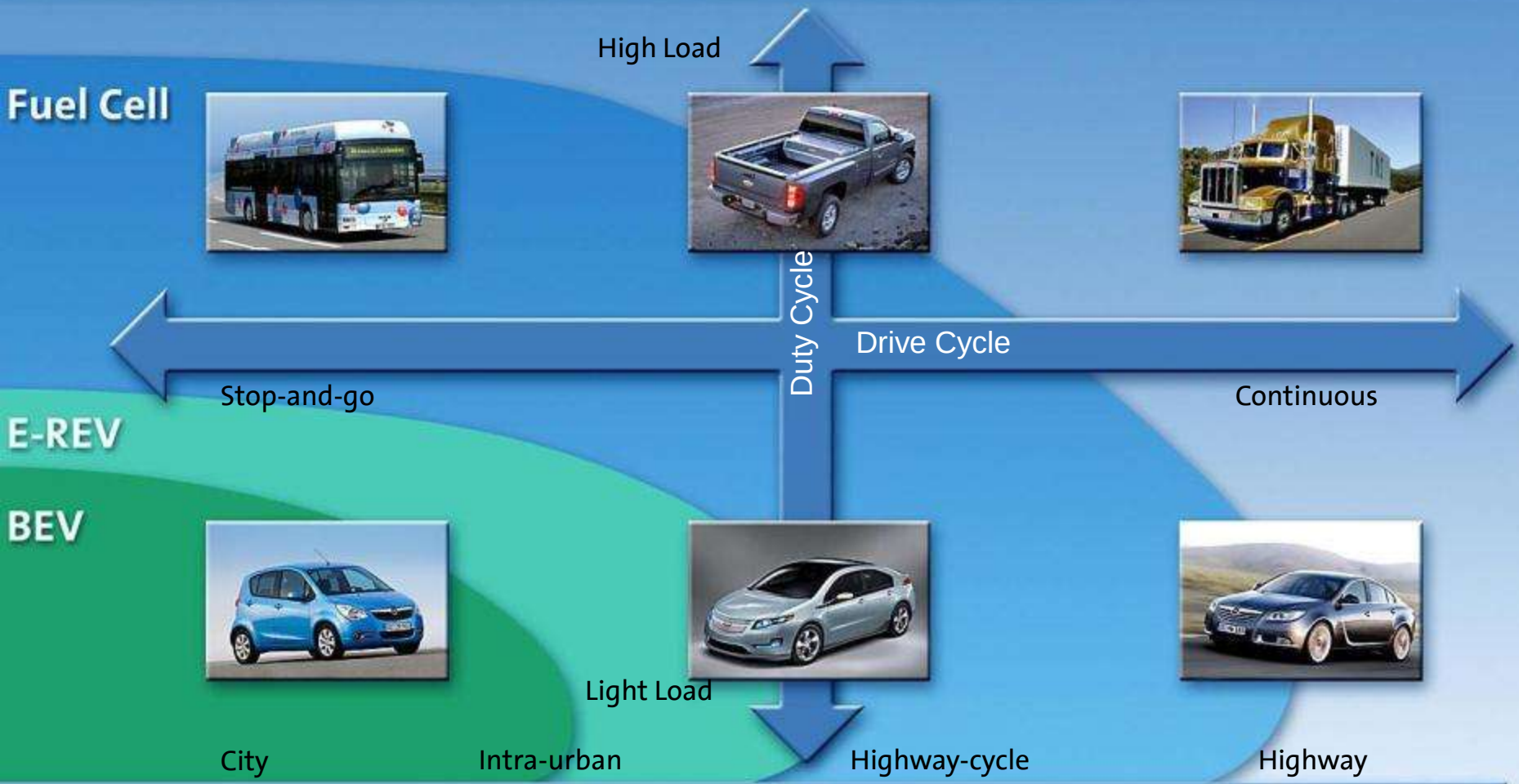
Customer Expectations: No Compromises





Application Map – Meeting Customer Needs

There is no single silver bullet



Battery & Fuel Cell Technologies are both required within the portfolio





Hydrogen Fuel Cell Technology

Zero Emissions, Zero Petroleum, 2X Efficiency



Fuel Cell Benefits:

- Zero emissions & Zero petroleum
- Compared to internal combustion engine:
 - More than twice as efficient
 - Comparable precious metal content
 - Comparable durability, range (300 miles) and performance
 - Fast refueling – within 3 minutes
 - 60% fewer part numbers
 - 90% fewer moving parts
- Cold and hot operation capability
- Family-sized vehicles
- Synergy with renewable energy sources





GM Electrovan (1966)

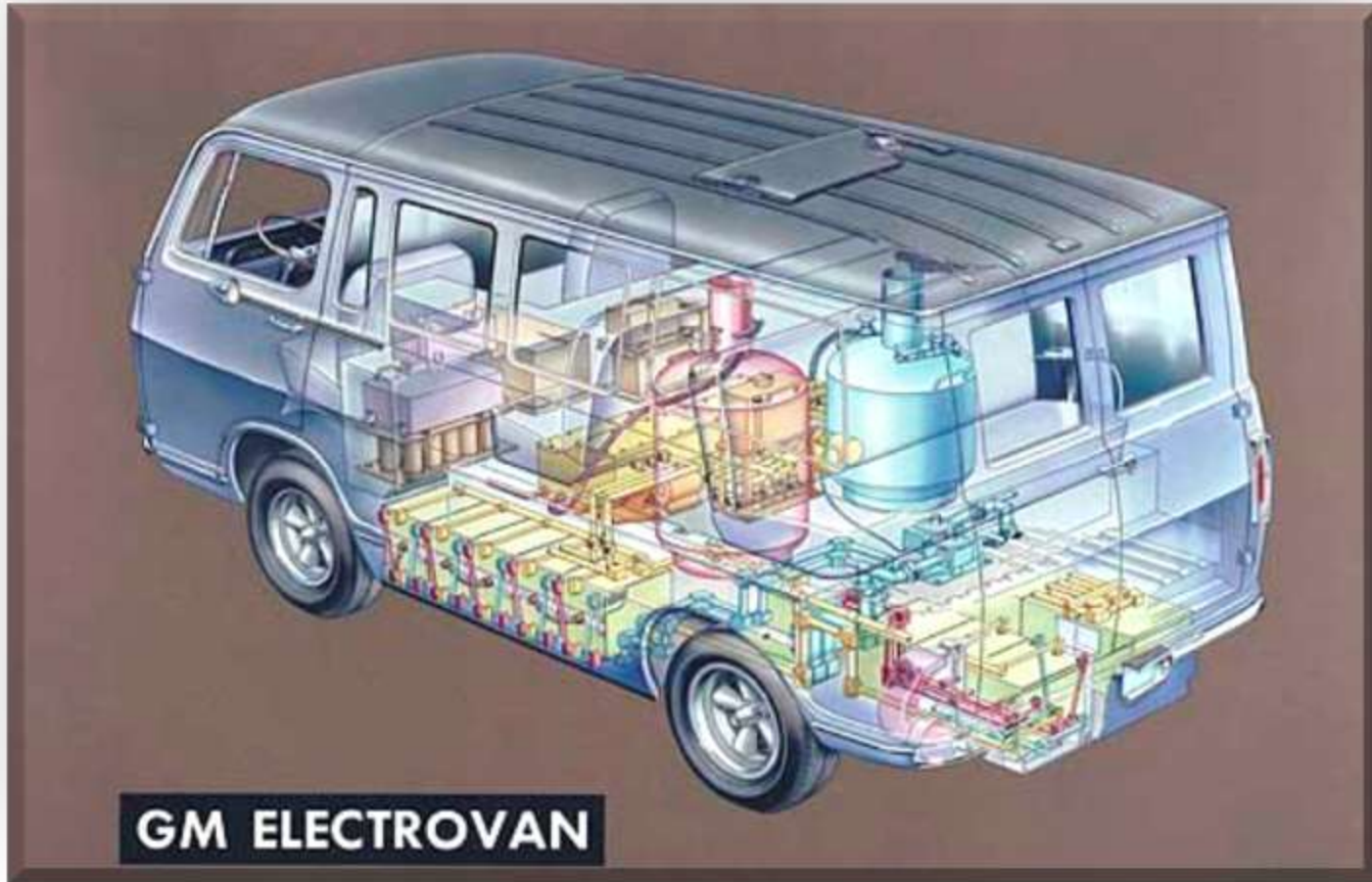
World's first hydrogen fuel cell vehicle





GM Electrovan (1966)

A humble beginning



Began with a full size van, because it took a van to carry propulsion system





Evolution of Fuel Cell Vehicles

HydroGen3



AUTOnomy



Hy-wire



Chevrolet Equinox Fuel Cell / HydroGen4



Sequel





GM Fuel Cell Equinox – Hydrogen 4

- Fourth generation fuel cell propulsion system
- Improved every-day suitability, performance & durability
- Able to start & operate in sub-freezing temperatures

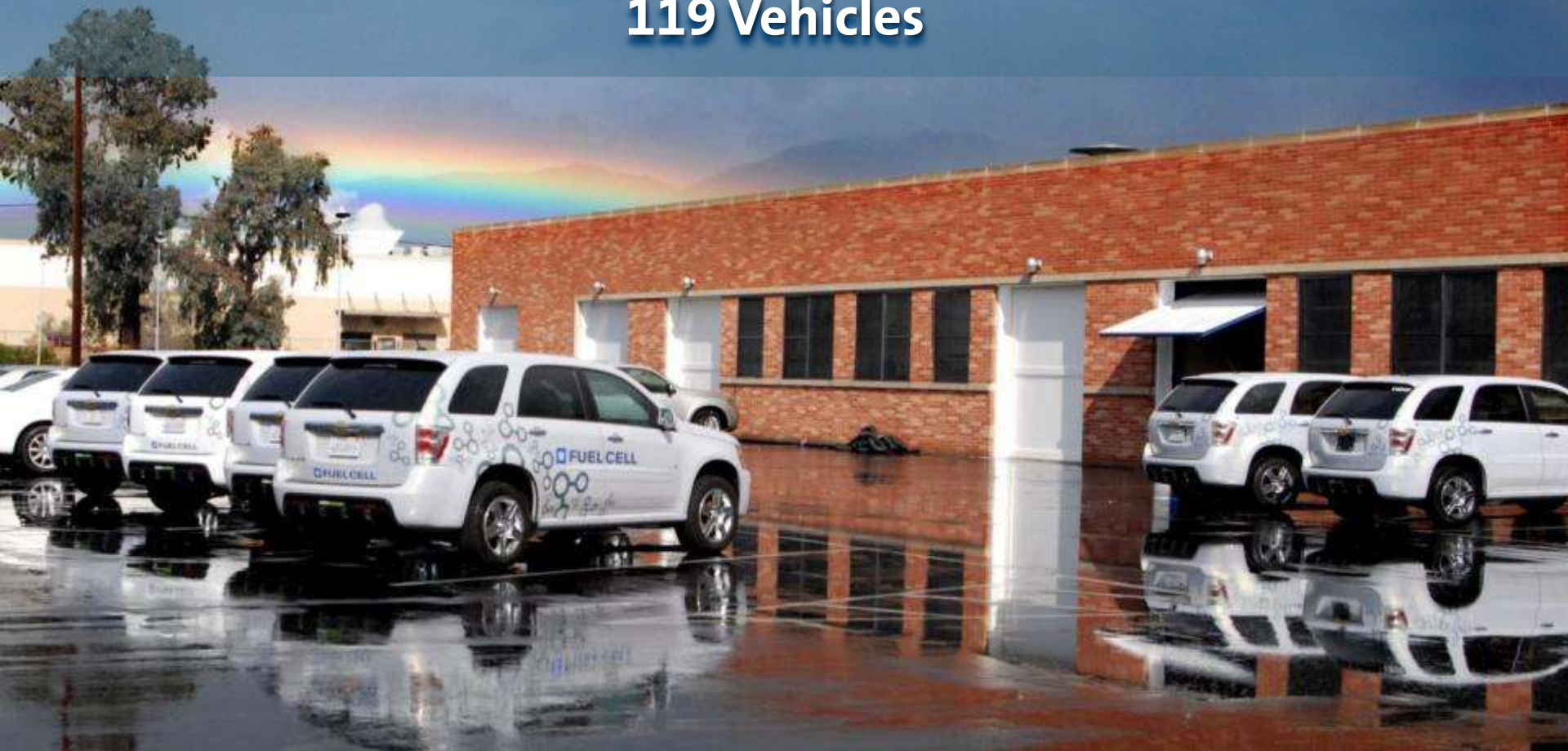




GM Project Driveway Vehicle Deployment

Real World Experience

World's Largest Fuel Cell Vehicle Fleet
119 Vehicles





GM Project Driveway Vehicle Deployment

Real World Experience

Over 80,000 applicants
80 Mainstream Drivers Using Fuel Cell as Personal Vehicle
Over 6,000 drivers





GM Chevrolet Fuel Cell Equinox

Real World Experience

Successful operation through 3 winters

Photo from Winter Testing in Northern Ontario – 2008
Field Operating Experience to -20°C





GM Chevrolet Fuel Cell Equinox

Real World Experience

Fleet Deployments to Post Office & Military





Business to Business Partnerships Real World Experience

Fuel Cell Vehicle Rescuing Stranded Internal Combustion Engine Drivers





Global Fuel Cell Fleet Deployments

Real World Experience

Deployed in US, Germany, Japan, China, & Korea





Hydrogen Fueling

Real World Experience

Over 19,750 refueling events
Over 41,720 kg of H₂ fueled





Hydrogen & Fuel Cell Education

Real World Experience





GM Chevrolet Fuel Cell Equinox

Real World Experience



Trained First Responders in Deployment Cities
Vehicles Equipped with Onstar
Hydrogen Fuel Cell Vehicles are Safe





GM Project Driveway

World's largest fuel cell vehicle demonstration

Field vehicles running with over 30,000 miles



Over 1.4 Million miles & counting





Production Intent Design Fuel Cell Propulsion System

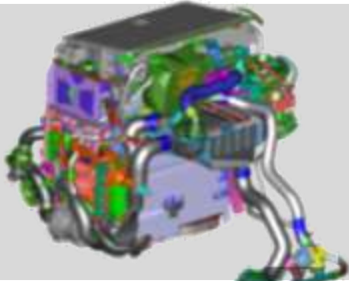




Design Evolution

Fuel Cell Propulsion System – “Power Cube”

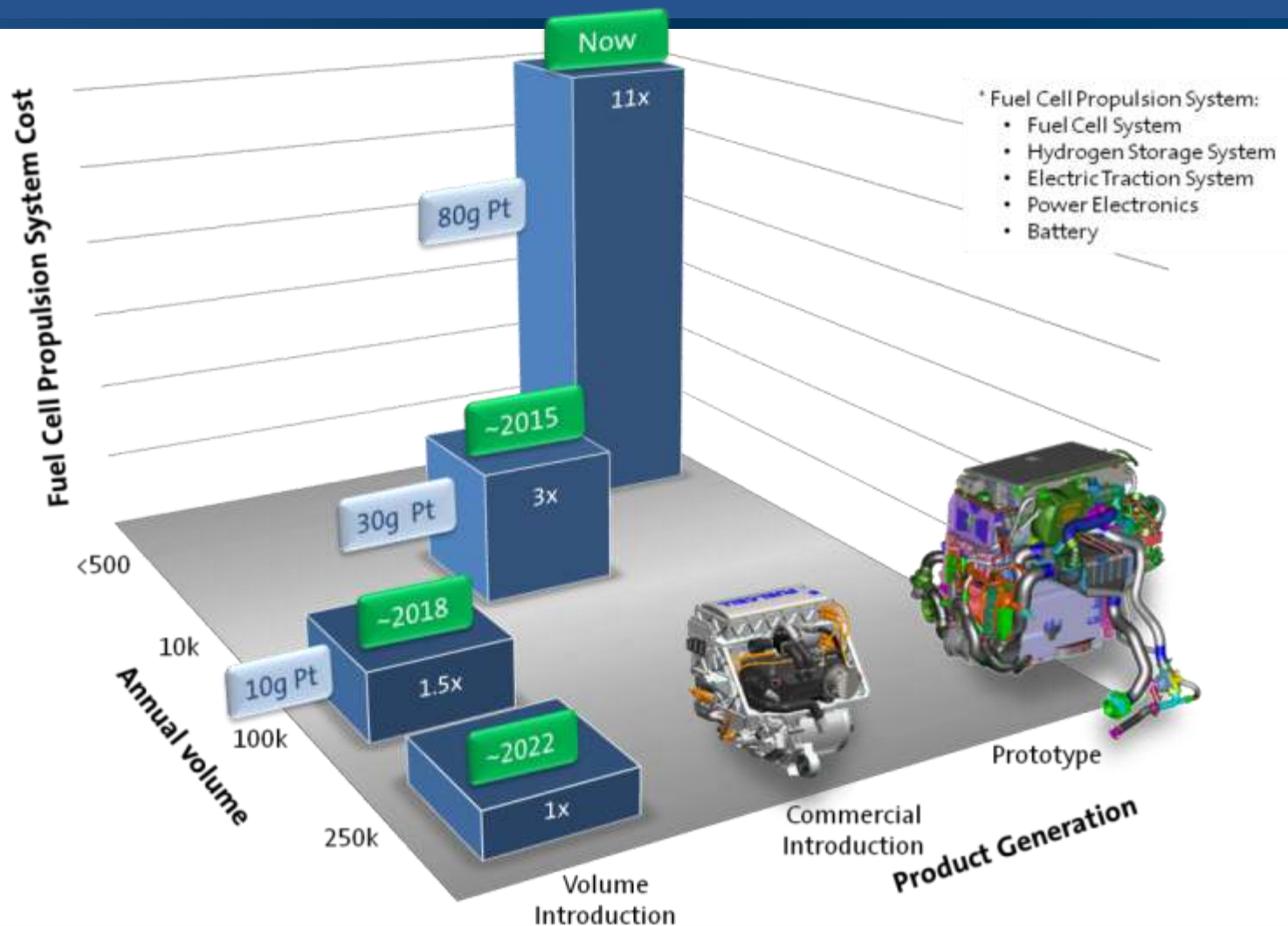
Path to Automotive Competitive Targets

	Project Driveway	Production Intent 2015
		
Net Power	124 kW - System	124 kW - System
Durability	1500-hrs	5500-hrs
Cold Operation	> -25°C	> -40°C
Mass	240 Kg	138 Kg
System Complexity	146 level-1 BOM components	2X reduction in part count
Stack Subsystem	440-cells	320-cells
Plates	Composite	Stamped Stainless Steel
UEA	80g Platinum / FCS	26g Platinum / FCS
Fuel Subsystem	Flow shifting (series of injectors)	Single injector / ejector
Design Integration	Semi-Integrated	Highly Integrated for Thermal Performance





Automotive Competitive Cost Glide Path



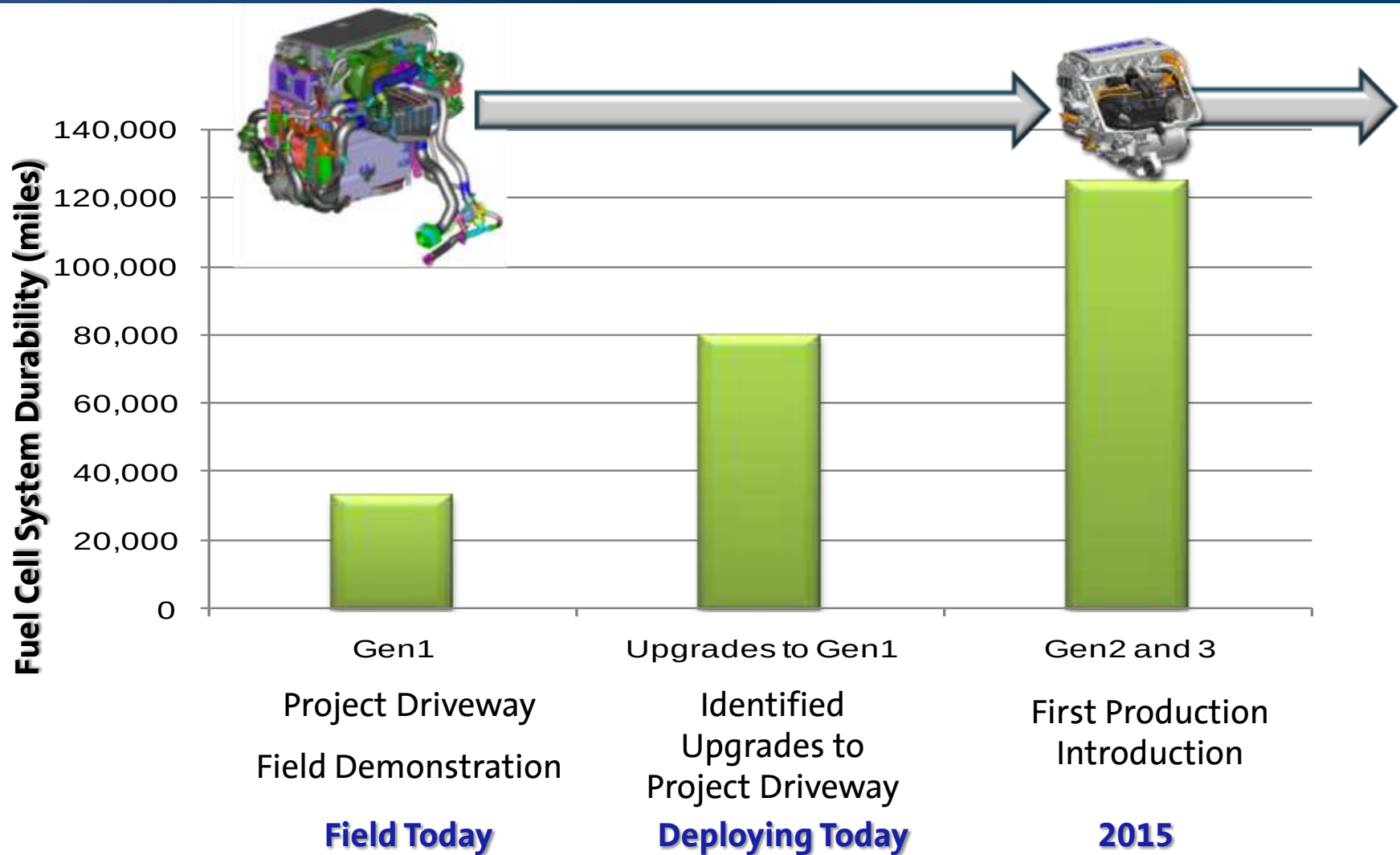
Clear roadmap to automotive competitive costs requires multiple learning cycles & scale volume





Hydrogen Fuel Cell Durability Improvement

2015 Production Intent System to Meet Durability Targets





A Few Key Points

Change to a new energy carrier typically requires 50 years

- Must begin now, to meet national petroleum & emission objectives

No single silver bullet

- Must satisfy customer needs
- Advanced propulsion technology portfolio required to satisfy range of applications
- Need batteries **AND** hydrogen fuel cells **AND** bio-fuels **AND** internal combustion engines

Require multiple learning cycles & scale to reduce costs

- Advanced propulsion technologies are more expensive than conventional alternatives
- The challenge is to push through first learning cycles & ramp volume to lower cost
- Stable policy & an appropriate incentive structure are required during early deployment





Infrastructure Update





Modern Hydrogen Fuel Stations

Meeting Customer Expectations - Affordability

Washington D.C.



Berlin, Germany (Total)



Grow Capable Infrastructure

Grow High Leverage Locations

- Los Angeles, CA
- Washington D.C.
- New York, NY
- Hawaii

Must be Accessible to Public

- Optimized deployments
- Unrestricted access

Fast Fueling Times (<3 min.)

Requires Modern Stations

- 700 bar
- Vehicle-to-Station Communications
- SAE J2601 Protocol
- Type A: (-40 deg. C)

Munich, Germany (Linde)



UC Irvine



Must maintain momentum supporting state-of-the-art station deployments and fleet users for existing network





Germany as Key Market for FCEVs & Hydrogen Infrastructure



“LoU“ of OEMs (Sep 09):

- Commercialization anticipated from 2015 onwards
- Germany as starting point

“H₂ Mobility“: Infrastructure initiative (Sep 09)

- Phase I (until 2011): Business plan development
- Phase II (from 2011): Built-up of area coverage



Letter of Understanding
on the Development and Market Introduction of Fuel Cell Vehicles

To: Oil and Energy Companies, Government Organizations and NOW GmbH
From: Daimler, Ford, GM/Opel, Honda, Hyundai/KIA, the Alliance Renault/Nissan, Toyota

Preamble
Road traffic has been steadily increasing in recent years and vehicle ownership is expected to grow. As a result, there will be increased priority on low and zero emission vehicles and an increase in overall CO₂ reduction goals. Over the last decade, governments, OEMs and the energy sector have given special attention to the introduction of hydrogen as a fuel for road transport as a priority option to reach several goals associated with emission management and CO₂ reduction.
Battery and fuel cell vehicles complement one another and can move us closer to the objective of sustainable mobility.

Development and Production Plan for Fuel Cell Vehicles
Based on current knowledge and subject to a variety of prerequisites and conditions, the signing OEMs strongly anticipate that from 2015 onwards a quite significant number of fuel cell vehicles could be commercialised. This number is aimed at a few hundred thousand (100.000) units over life cycle on a worldwide basis.



„H₂ Mobility“ - Gemeinsame Initiative führender Industrieunternehmen zum Aufbau einer Wasserstoffinfrastruktur in Deutschland

- Führende Industrieunternehmen verständigen sich über Aufbauplan einer flächendeckenden Infrastruktur zur Versorgung mit Wasserstoff
- Deutlicher Ausbau des Wasserstofftankstellennetzes bis Ende 2011 geplant
- Wichtiger Meilenstein auf dem Weg zu emissionsfreier Mobilität
- Führende Automobilhersteller arbeiten mit Hochdruck an der Kommerzialisierung von Elektrofahrzeugen mit Brennstoffzellenantrieb. Ab 2015 werden im Rahmen der Kommerzialisierung mehrere hunderttausend Einheiten antizipiert

Berlin, 10. September 2009 - Heute haben in Berlin Vertreter führender Industrieunternehmen im Beisein des Bundesministers für Verkehr, Bau und Stadtentwicklung, Wolfgang Tiefensee, ein Memorandum of Understanding (MoU) unterschrieben. Darin sollen Möglichkeiten für den Aufbau einer flächendeckenden Infrastruktur zur Versorgung mit Wasserstoff in Deutschland geprüft werden, um die

Former German Transport Minister Tiefensee: “We are aiming at establishing the nation-wide supply with hydrogen in Germany at around 2015 in order to support the serial production of fuel cell vehicles.”



German Government Starts H₂ Campaign

“Energie im Wandel” (Energy in Transition, Feb 17, 2010)

Grußwort vom Bundesverkehrsminister Dr. Peter Ramsauer zu “Energie im Wandel”



Bundesminister Dr. Peter Ramsauer
Quelle: www.peter-ramsauer.de

Emissionsfreie Brennstoffzellenautos mit mehr als 400 Kilometern Reichweite pro Wasserstofftankfüllung. Kleine Brennstoffzellenkraftwerke für Warmwasser und Heizung im eigenen Keller. Und das alles möglichst aus deutscher Produktion. So stelle ich mir die Zukunft vor!

Der Klimawandel ist eine riesige industriepolitische Herausforderung. Er bietet für unsere heimischen Unternehmen aber auch Chancen. Die Exportnation Deutschland kann zum weltweiten Leitmarkt für Elektromobilität werden. Neben der Batterie spielt die Wasserstoff- und Brennstoffzellentechnologie eine zentrale Rolle für die Mobilität und Energieversorgung von morgen. Hier sind die deutschen

Unternehmen Weltspitze. Diese Position wollen wir ausbauen. Dazu braucht es Akzeptanz in der Bevölkerung. Die Branche erhält aber noch nicht die öffentliche Aufmerksamkeit, die ihrer Stellung im internationalen Wettbewerb und ihrer Bedeutung für den Standort Deutschland gerecht wird.

Mit der Kampagne „Energie im Wandel – Willkommen im Wasserstoff- und Brennstoffzellenland“ wollen wir das ändern. Für „Energie im Wandel“ öffnen unsere Unternehmen ihre Türen. Ich lade alle Interessierten Bürgerinnen und Bürger ein, die Veranstaltungen der Kampagne in ihrer Region zu besuchen. Machen Sie sich selbst ein Bild vom Stand der Technik in der faszinierenden Zukunftswelt von Wasserstoff und Brennstoffzelle.

German Transport Minister Ramsauer:

“Emission free **fuel cell cars** with over 400km (250miles) range. Small fuel cell power plants for warm water and heat in the basement. All this **manufactured in Germany**. That’s how I see the future!”

“The export nation **Germany** can become a **global lead market for electric mobility**. Together with batteries, **hydrogen and fuel cell technology** is playing a **central role** for tomorrow’s mobility and energy security. **German companies** are **world leaders** in this field. We want to expand this position.”

<http://energieimwandel.de/kampagne/>

New ministry picks up support for H₂ & FC technology from former government → stability





Relationship between H₂ & Renewables

Case Study – German Wind Energy (2008)

- Renewable energy sources fluctuate dramatically
- Although solar is more predictable, its \$/kWh is 5X more than wind
- Placing significant wind energy on line necessitates an energy buffering strategy - otherwise electricity generation costs can increase





Germany – Case Study

Wind Energy and the Electricity Grid

- German Wind Energy Example
- Quantity: 19,868 turbines
- Capacity: 23,044 MW¹⁾
- Electricity production 2007: 39.6 TWh²⁾
(7.2% of annual consumption)

E.ON control area:
40% of installed wind
energy in Germany



1) DEWI Report, 30.6.2008

2) Bundesverband Windenergie e.V., 20.11.2008



Germany – Case Study

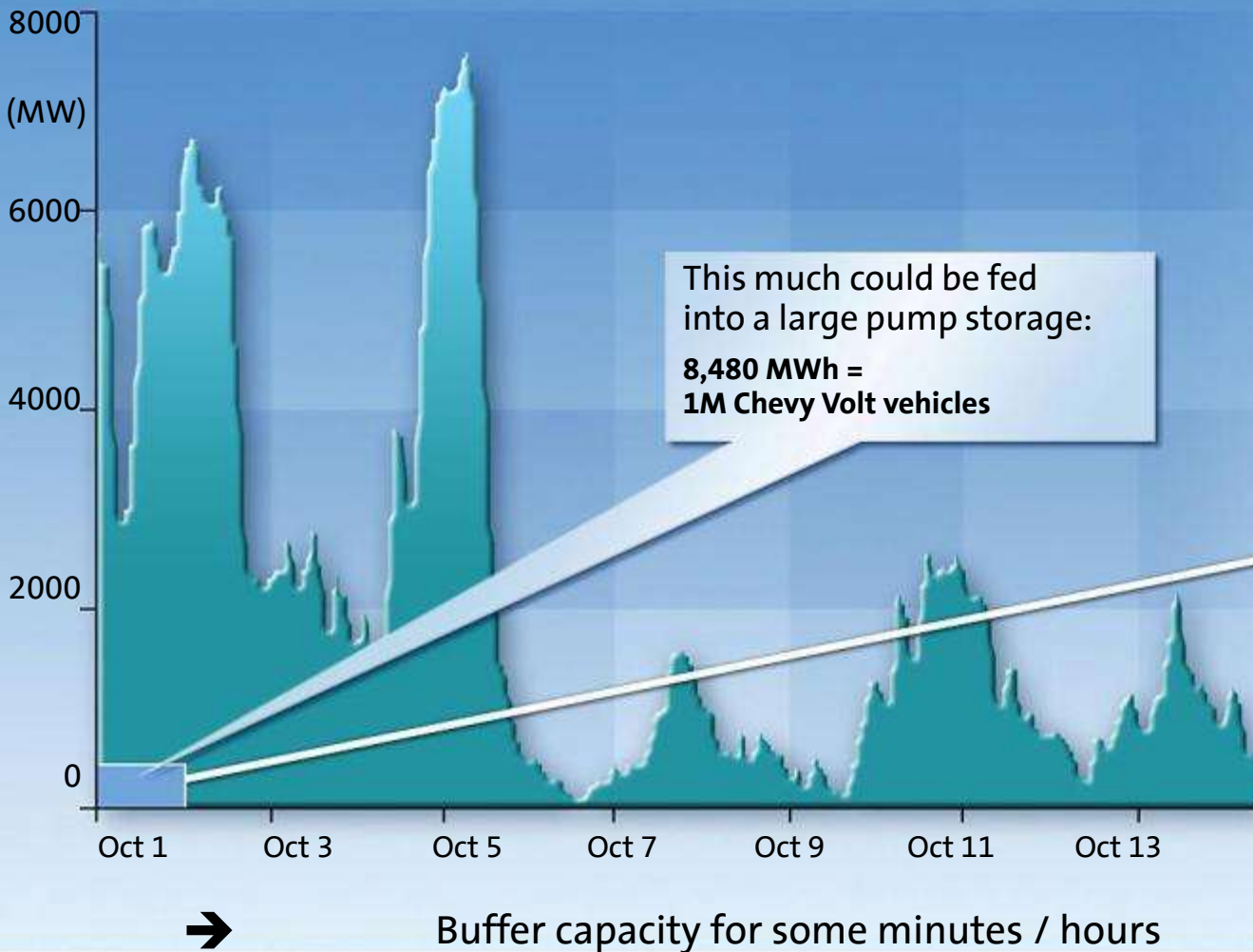
Sustainable Energy Generation & Fluctuating Energy Availability

E.ON Control Area Wind Energy Feed in October 2008





Fluctuating Wind Energy Compared to Pumped Hydraulic Storage Capacity



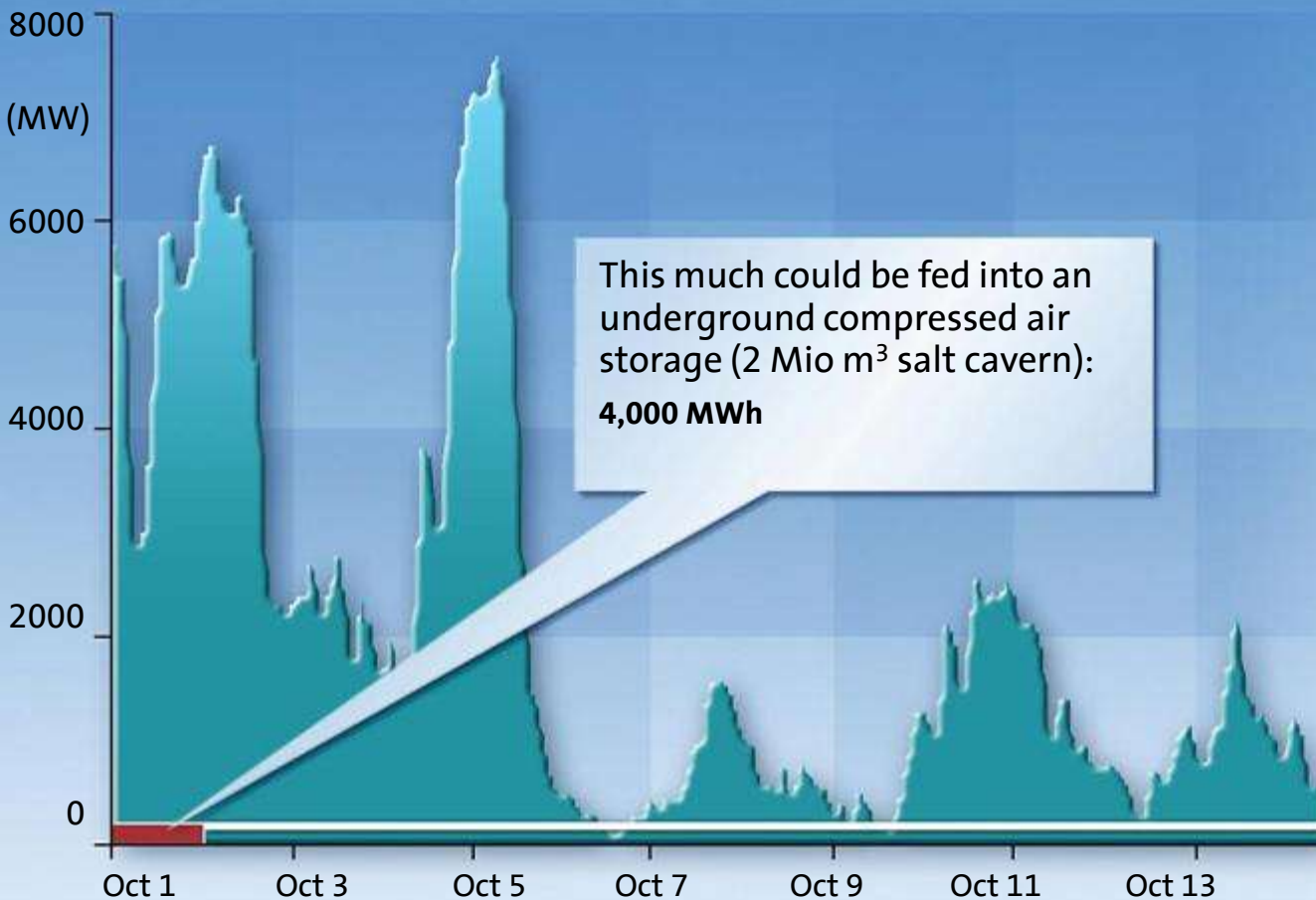
Pump storage Goldisthal, Thüringen



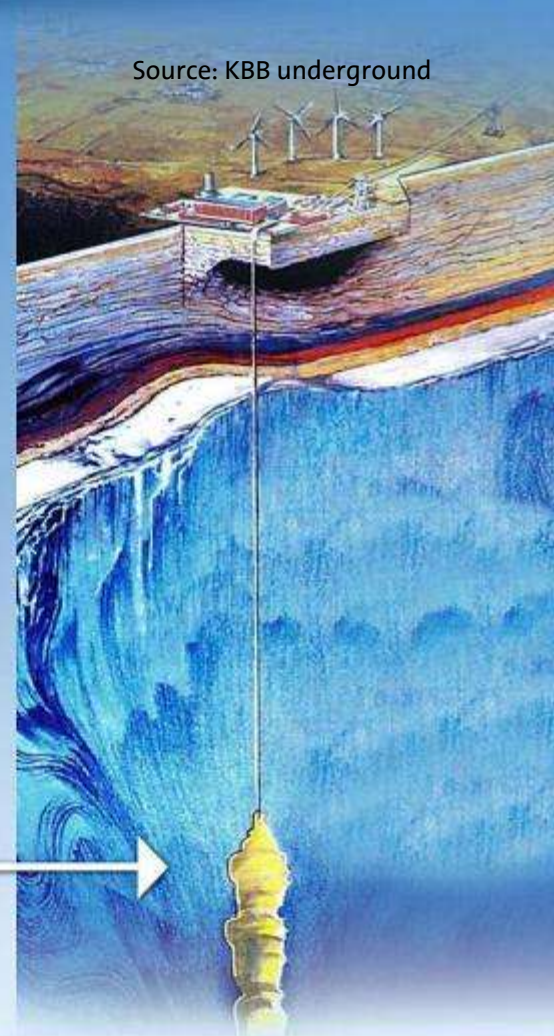


Store Fluctuating Wind Energy

Storage of Compressed Air in Salt Caverns



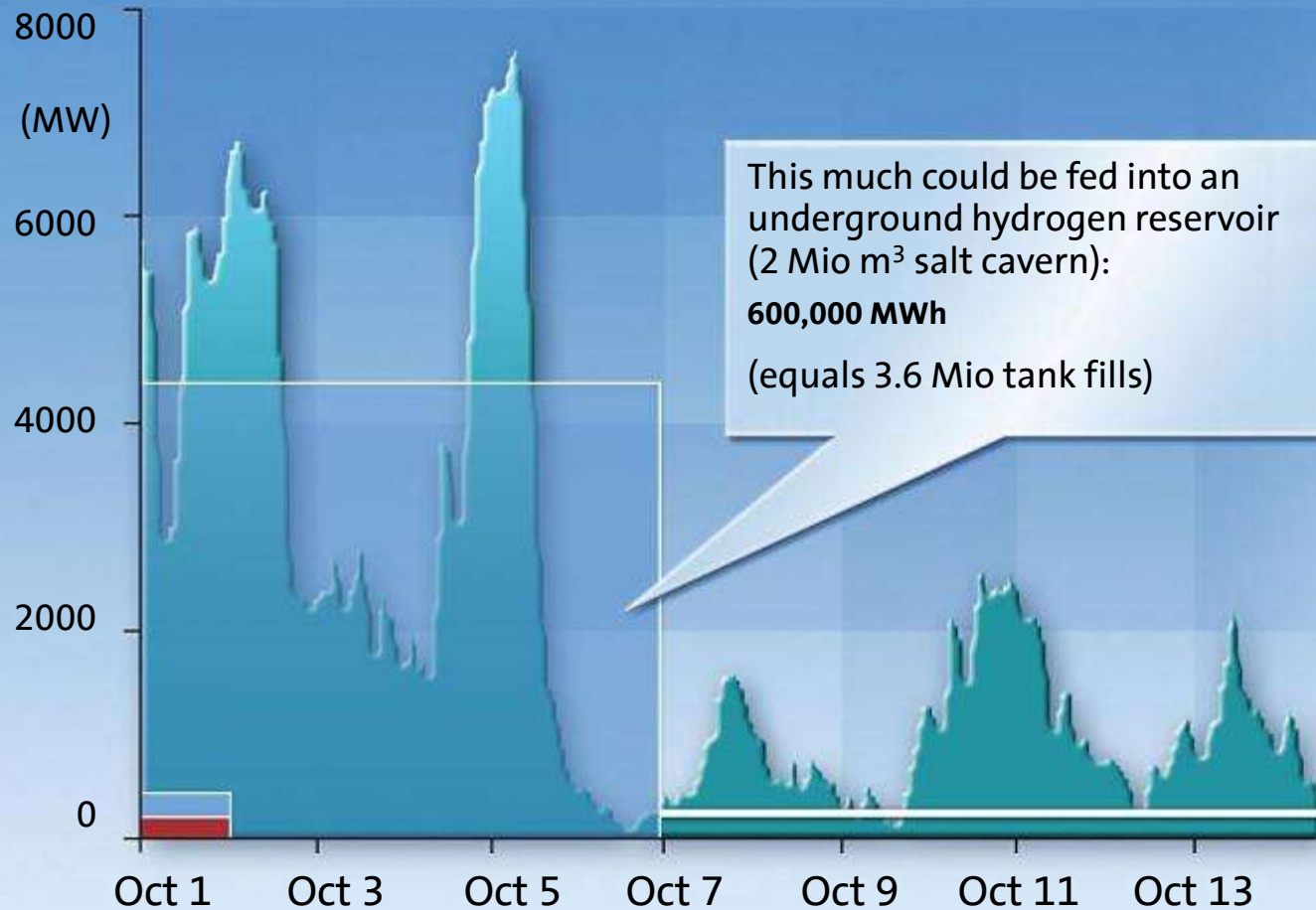
Buffer capacity for some minutes / hours





Hydrogen

The Energy Buffer in the Renewable Energy System



Only hydrogen offers storage capacity for several days

Source: KBB underground





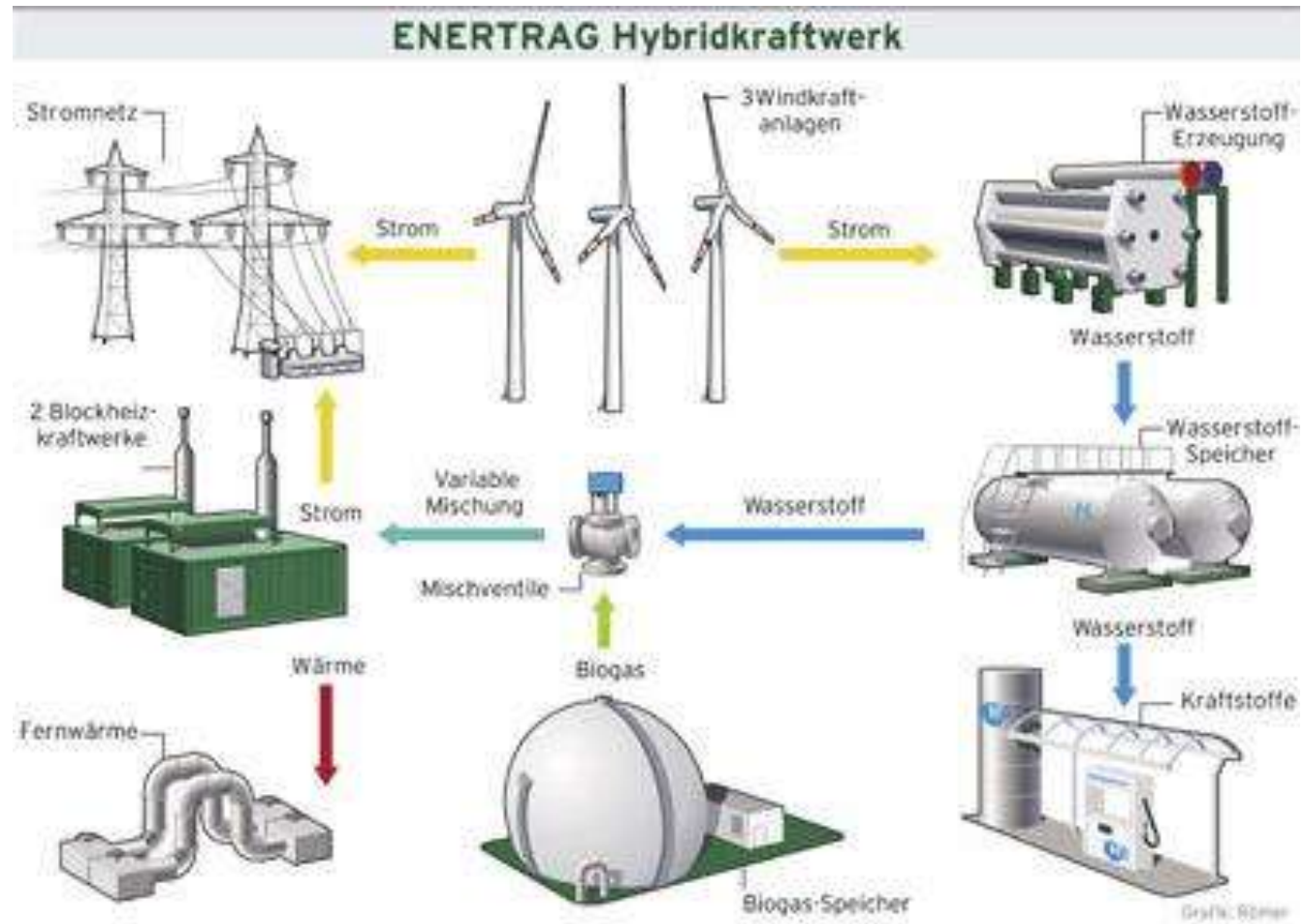
German Wind-H₂-Plant Construction

Building 6 MW System in Northeastern Germany

German Chancellor
Angela Merkel @
construction site



Minister President Matthias
Platzeck
(State of Brandenburg)





Berlin Brandenburg International Airport

World's First CO₂-free H₂ Refueling Station

- Station will use wind energy with H₂ storage
- Transport Ministry:
500,000 FCEVs of the 1 million planned electric vehicles by **2020**



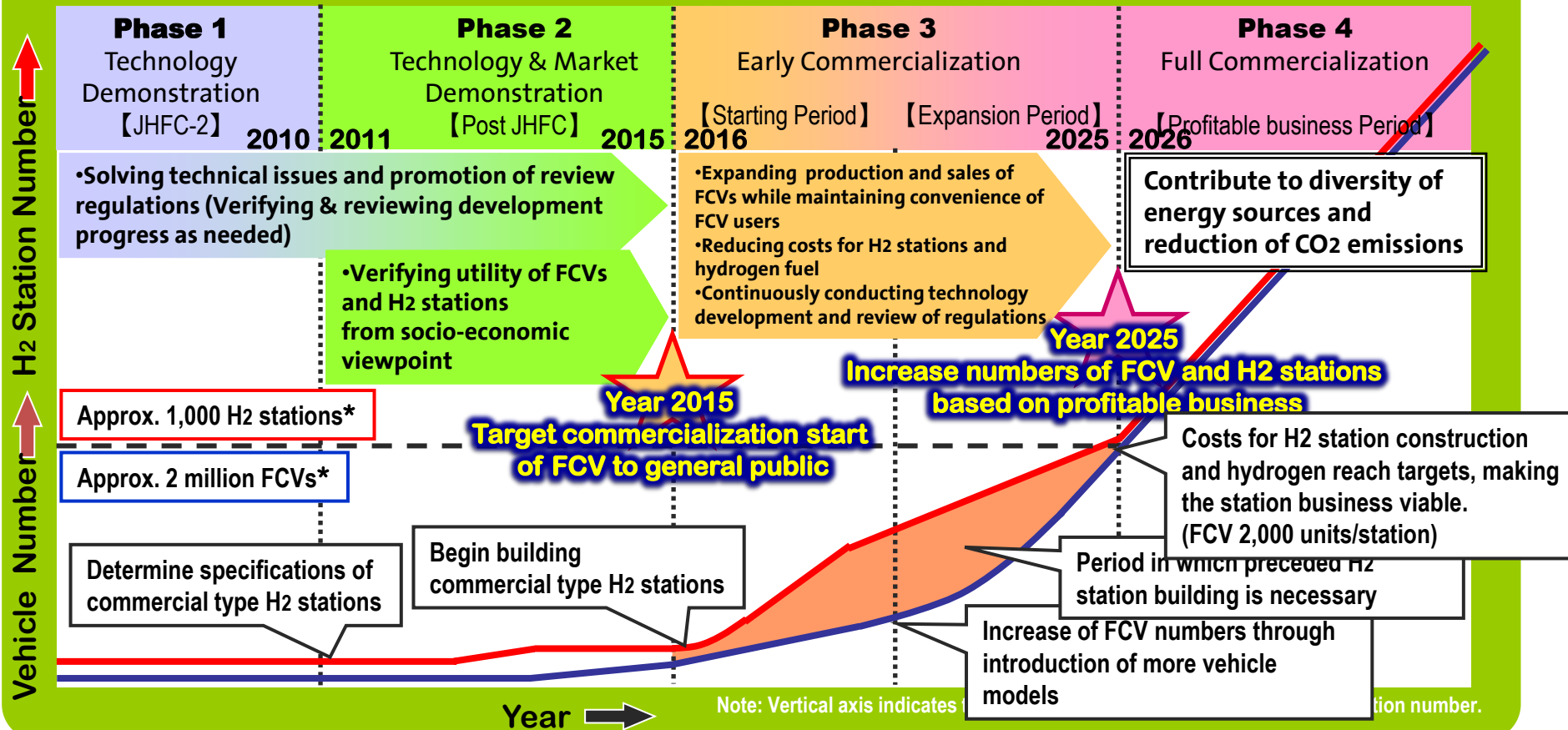


Japanese FCEV Deployment Scenario

Fuel Cell Commercialization Conference of Japan FCCJ



Commercialization Scenario for FCVs and H2 Stations



* Precondition: Benefit for FCV users (price/convenience etc.) are secured, and FCVs are widely and smoothly deployed





Hydrogen Infrastructure for the U.S.



100 Metro Areas = 70% of U.S. Population

THE BAHAMA

22 September 2003

Hart World Fuels Conference, Washington, DC





Fuel Cell & H₂ Infrastructure Deployment

Germany & Japan - firm plans for 1,000 stations each

Japan announced firm plans for 2 MILLION vehicle fleet plan by 2025

National Plans



NOW, National Plan



1,000 Stations by 2018



METI, Japan Industry

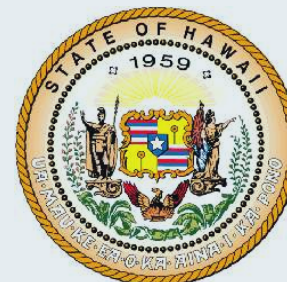


2 Million Vehicles by 2025
1,000 Stations by 2025

Important Parameters

- Aggressive Greenhouse Gas Standards
 - Large renewable energy infrastructure
 - Bordered by non-participating nations
-
- Aggressive Greenhouse Gas Standards
 - Largely reliant on imported energy
 - Bordered by water
 - Available renewable energy resources

State Examples



Multiple countries are entering hydrogen infrastructure race





Hydrogen Infrastructure

Los Angeles Example

\$100-200 million H₂ infrastructure investment opens 15 million driver market

 30-40 stations ~3.6 miles apart

- Los Angeles Metro Area

 10 stations ~25 miles apart on destination corridors

- San Diego
- Palm Springs
- Las Vegas
- Santa Barbara



Regional H₂ infrastructures can be achieved with 40-50 stations in metro areas & along major destination corridors



at: Barbers Point
Waianae
Wahiawa
Waialua
Kahuku
Kaaawa

- At least 15 stations in **Southeast Oahu Metro Areas** (illustrative placement)





Hawaii's Energy Challenges

- Most of Hawaii's energy is imported
- Gasoline prices are among the highest in the United States
- Electricity costs are the highest within the United States
- Fuel surcharges affect the cost of more than 80% of the goods sold in Hawaii
- High percentage of renewable energy resources, which challenges electrical grid stability



Hawaii Clean Energy Initiative

National Partnership to Accelerate System Transformation

The goals are:

- Achieve a **70% clean energy economy** for Hawaii within a generation
- Increase Hawaii's **security**
- Capture **economic benefits** of clean energy for all levels of society
- Foster and demonstrate **innovation**
- Build the **workforce** of the future
- Serve as a **model** for the US and the world

- Hawaii has an urgent need for new & renewable energy resources to meet its goal of reduced petroleum usage
- Oahu is ideally suited for hydrogen vehicle fueling
- The Gas Company (TGC) is unique within the United States
- TGC produces hydrogen as part of its synthetic natural gas (SNG) production process, from petroleum refining byproducts & renewable resources (plant oils, animal fat)



- TGC is currently delivering about 5 percent H₂ in its utility gas (SNG) stream
- TGC has capability to produce more H₂ through its renewable biogas initiative (now underway)
- H₂ is blended with the utility gas
- H₂ can be separated using Pressure Swing Adsorption technology, for delivery at H₂ fueling stations along Oahu's existing utility pipeline



Input:

Water

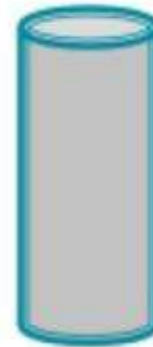
Feedstock: Triglyceride (Fats Oils Grease)

Hydrogen or Nitrogen

Heater



Reactor



Output:

Gas Stream: Methane, CO, CO₂ etc.

Liquid Byproduct: Bio or Green Diesel

Hydrogen

SNG Plant
CO₂ Removal
Shift Reaction



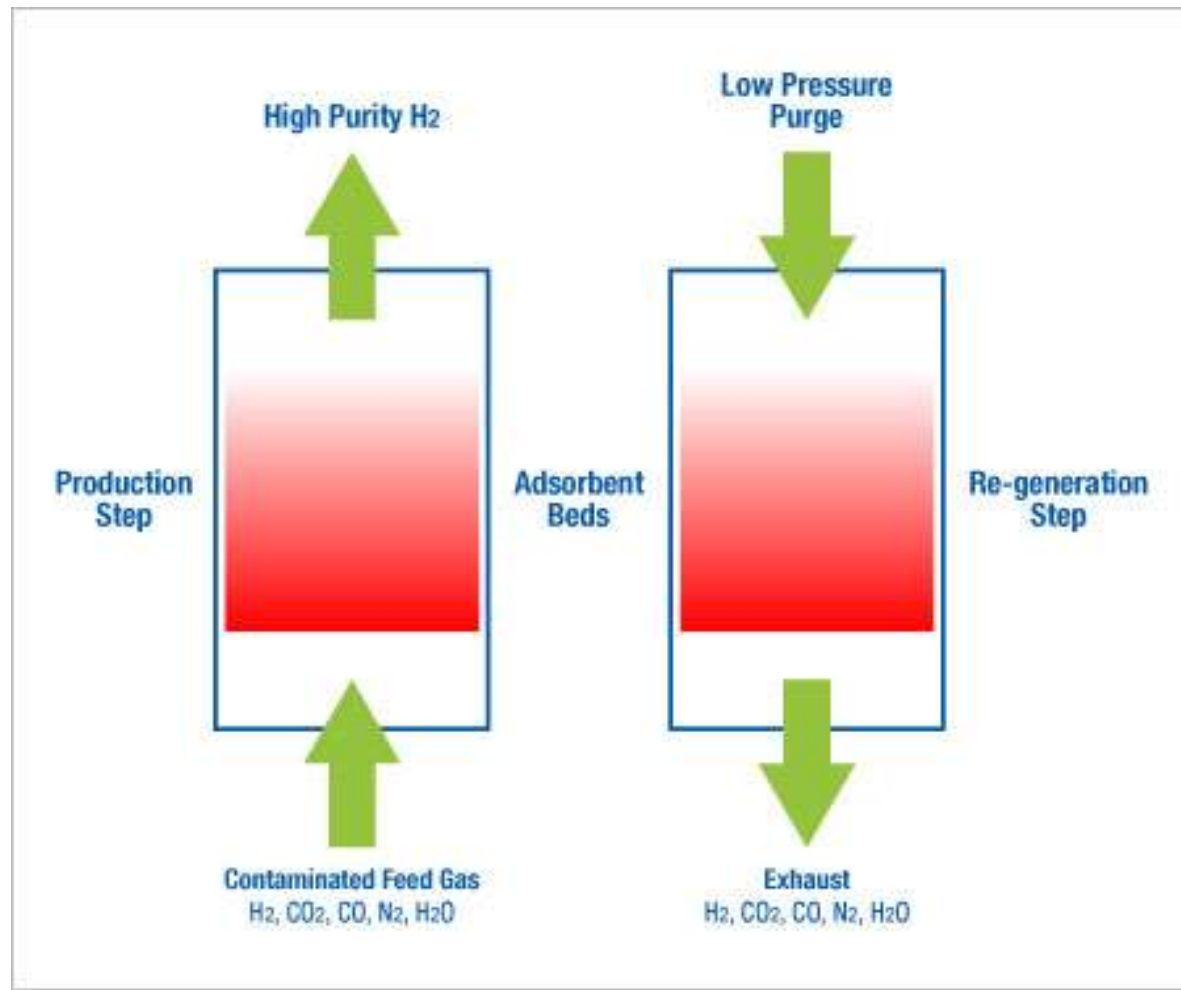
Output:

Gas Stream: Methane etc.

Liquid Byproduct: Bio or Green Diesel

Hydrogen

Pressure Swing Adsorption: Separating High Purity H_2 from Pipeline Gas Stream



Why Oahu?

- Controlled environment
- Fuel no farther than a 10-minute drive
- Fleet users available
- Safe place to perfect business model and process





Hawaii – Leveraging Existing Infrastructure

The Hydrogen Highway on Oahu

TGC infrastructure follows the populated core on Oahu





Key Elements of the Collaboration

- Public announcement in Hawaii for H₂
- Gain federal and state attention for both H₂ and fuel cell
- Ability to leverage existing pipeline for H₂ distribution
- A pathway for a significant H₂ refueling infrastructure





Global Fuel Cell Competitors





OEM Fuel Cell Programs

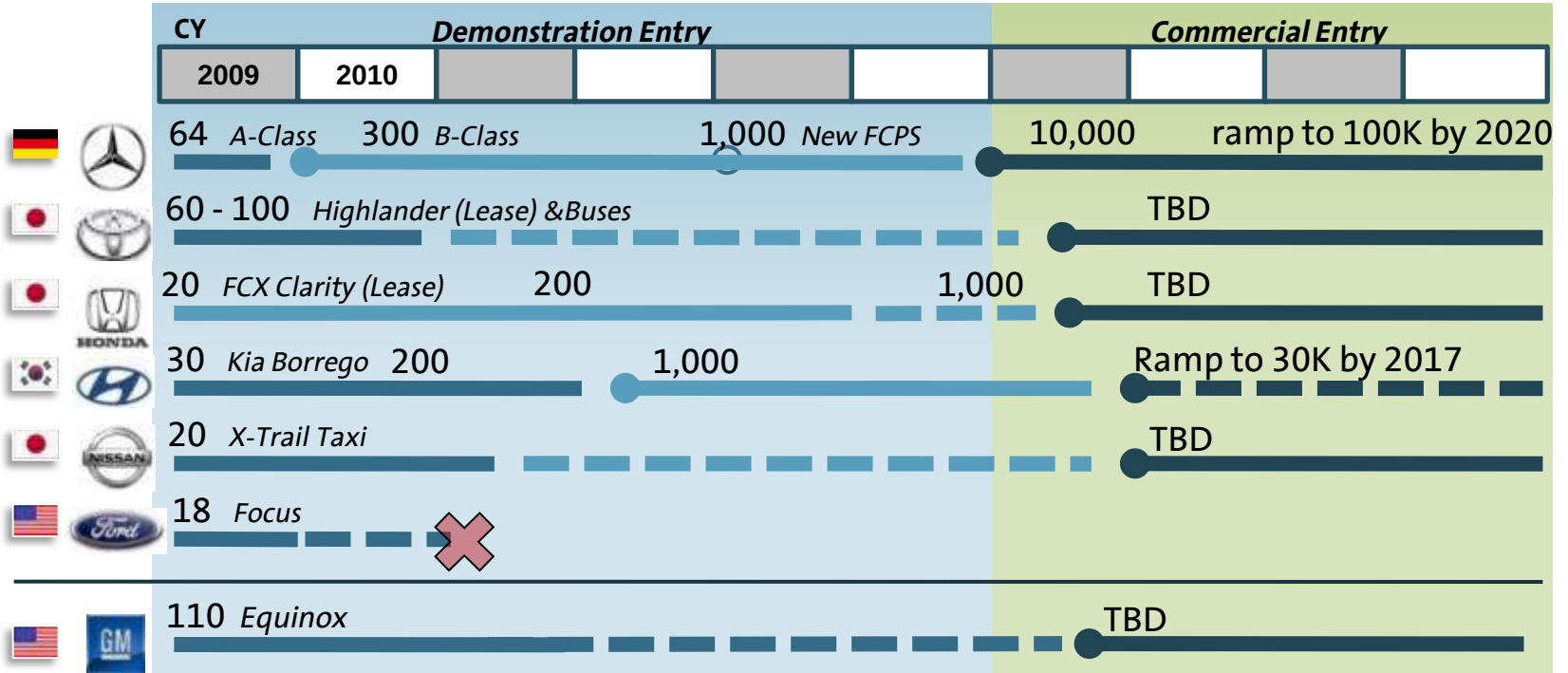




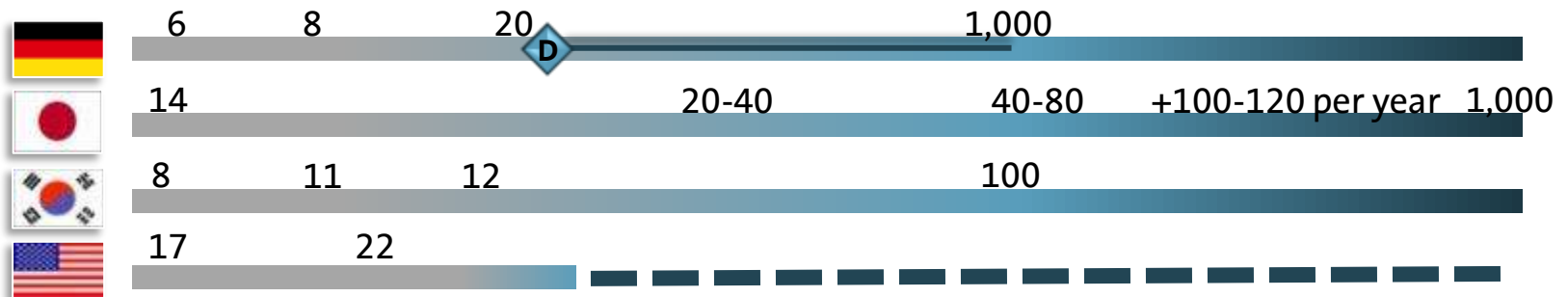
Competitive Landscape Summary

Market Introductions in 2015/2016

Competition
(# of Veh.)



H₂ Stations
(cumulative)





Conclusions

H₂ Fuel cell technology is commercial ready

- Performance proven in field, durability proven in labs
- Cost pathway identified, (higher than ICE, but comparable to other adv. tech.)

H₂ infrastructure is achievable – Must Establish Momentum

- Germany & Japan implementing H₂ infrastructure plans
- U.S. H₂ infrastructure is achievable, with close Government-Industry cooperation
- Develop technology & business models to drive down infrastructure costs

Stable government policy is key to infrastructure & vehicle programs

- Expanded Department of Energy role to support early market introduction phases
- Germany's H₂ Mobility Template
- Market incentives
- Establish customer pull-through for vehicles





Thank you



OBJECTS IN MIRROR ARE CLOSER
THAN THEY APPEAR

8FL07





Questions



