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

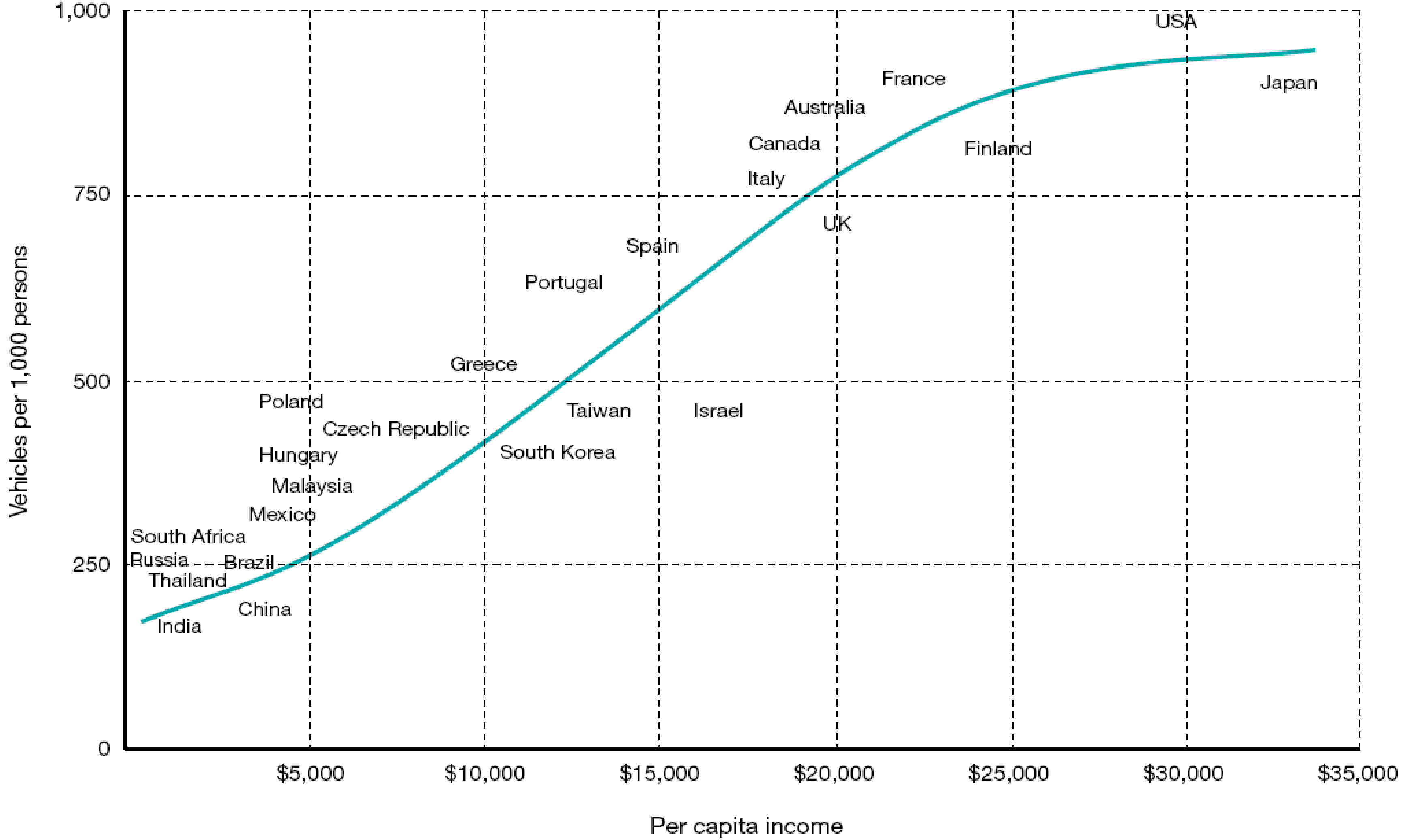
Infrastructure

Vehicle Programs

The Challenge
Personal Mobility & the Auto Industry

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

Megatrends – Vehicle Ownership



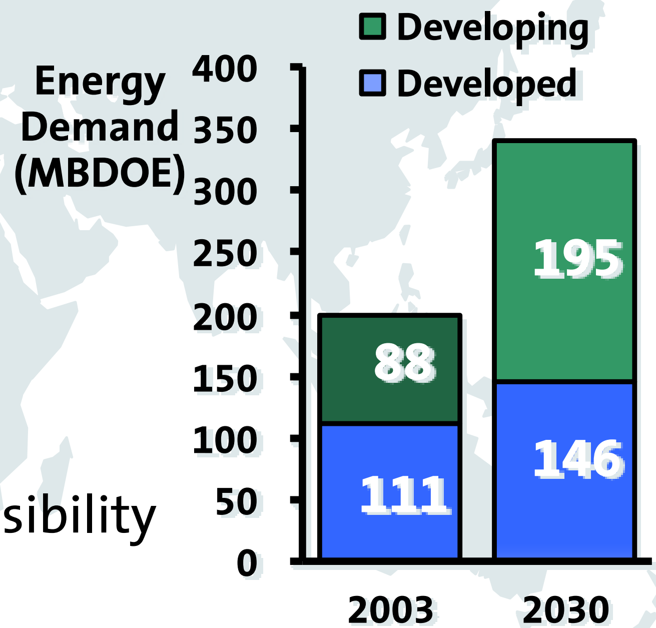
Economic growth is leading to larger global car parc

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 CO_2
- Potential for regulations that exceed both technical capability & business feasibility

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

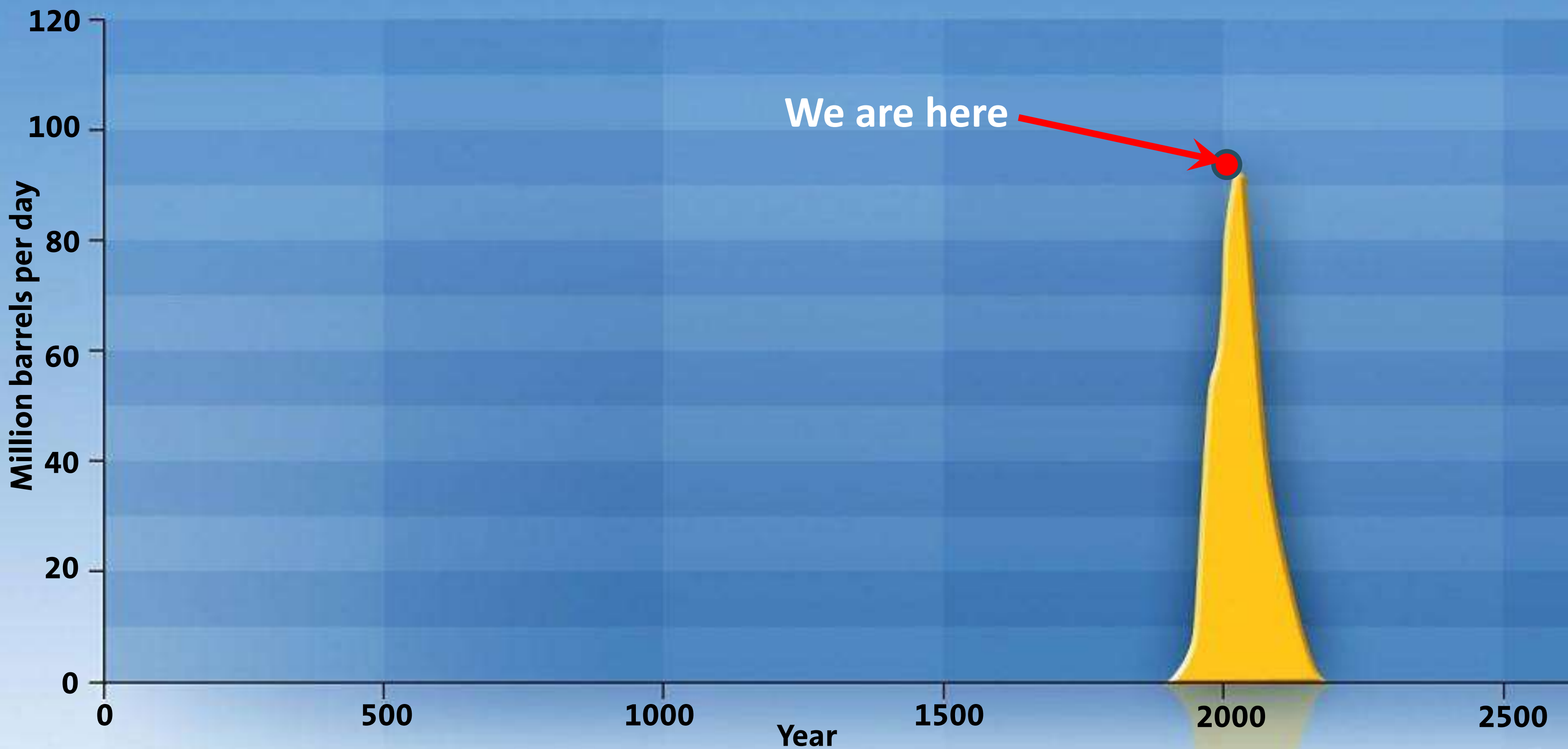


Source: DOE Energy Information Agency

MBDOE: Millions of barrels per day oil equivalent

The Petroleum Age

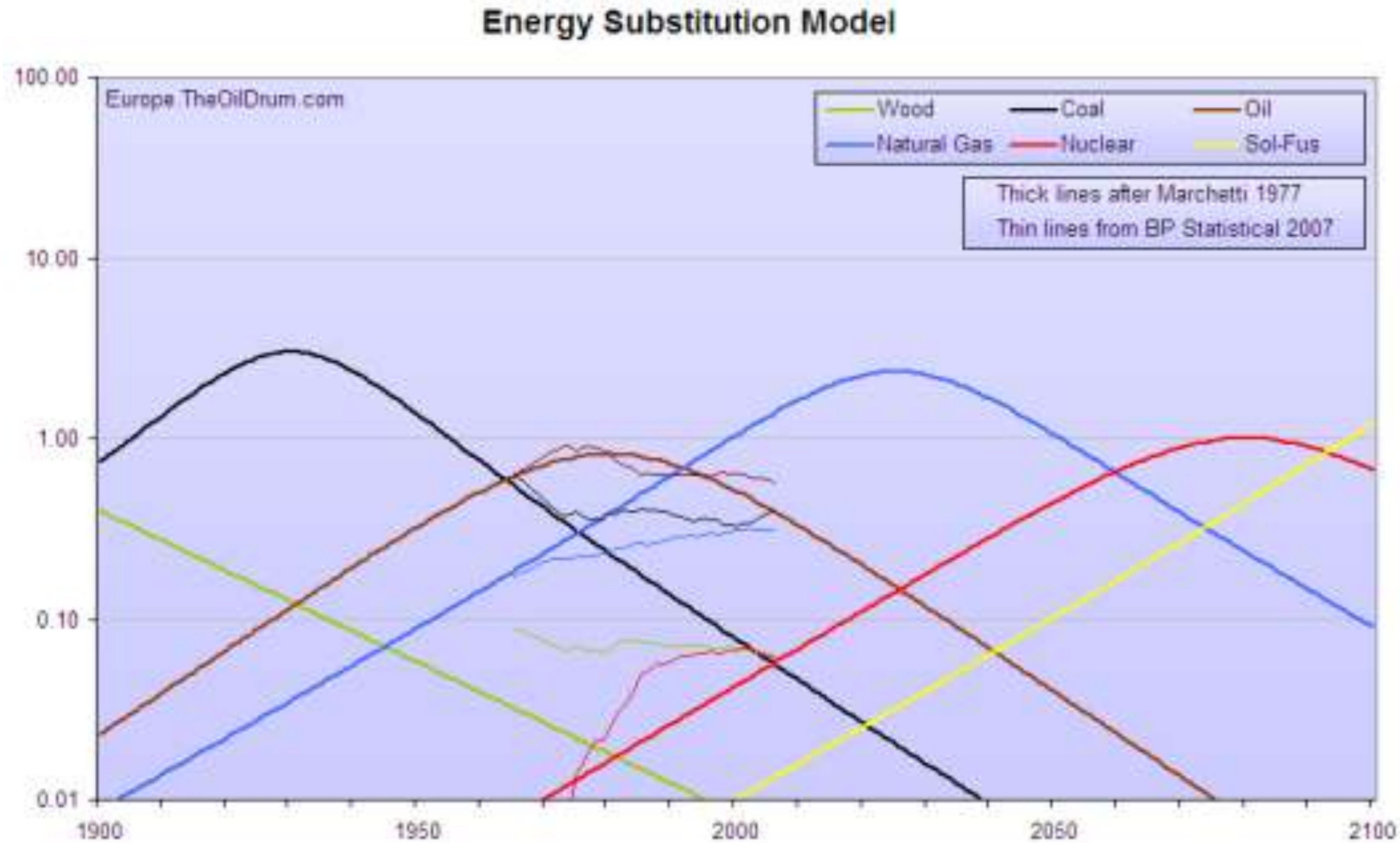
Hubbert Curve & Peak Oil – Keeping things in perspective



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)

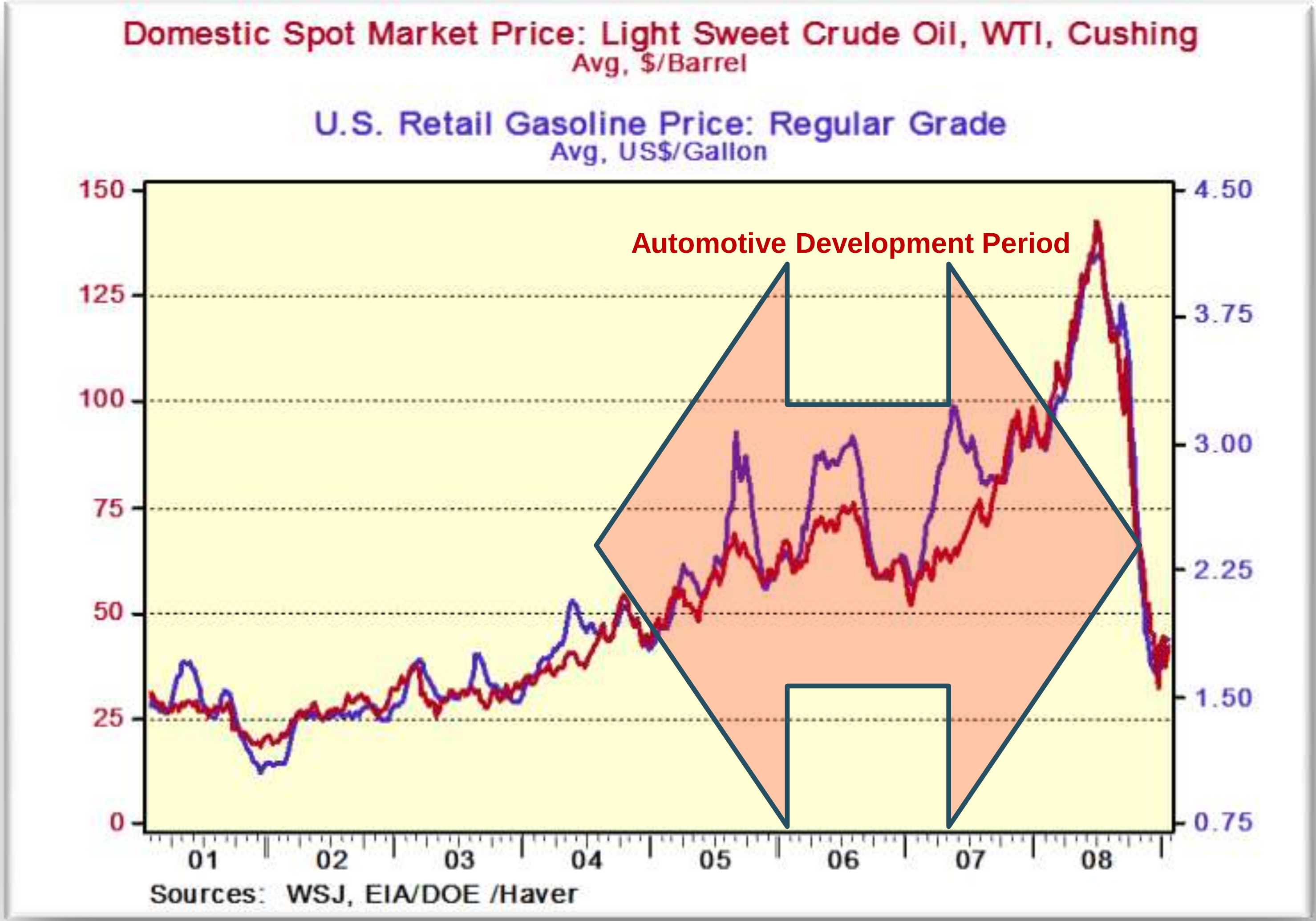


The Energy Substitution Model from 1977 and data from the BP Statistical Review of 2007. Wood fuel data from FAOSTAT.

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

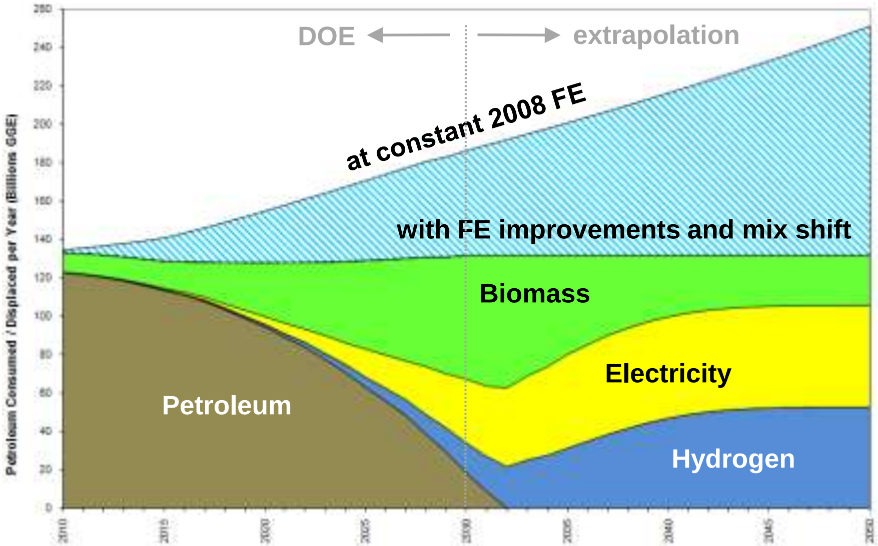
Commodity Prices Followed Similar Patterns



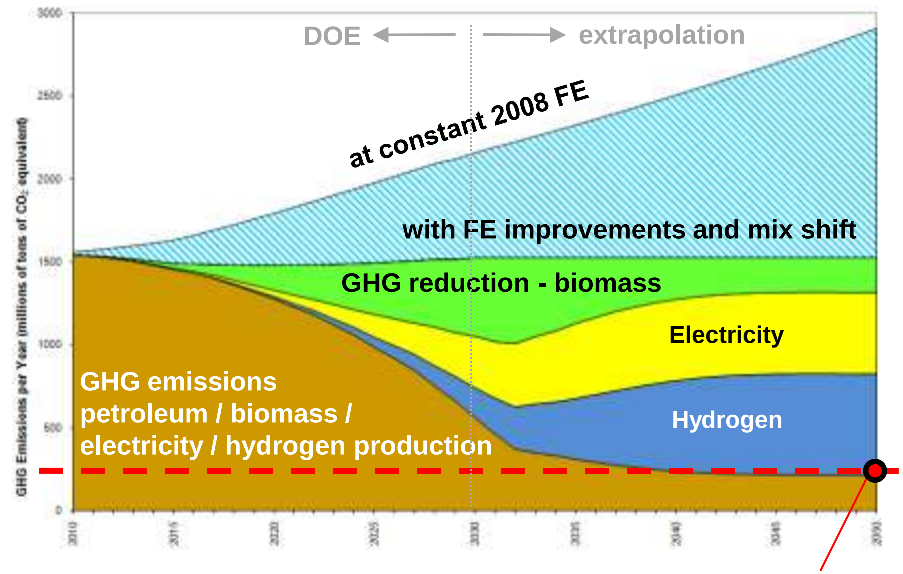
Price volatility Inhibits technologies that require longer term investment

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

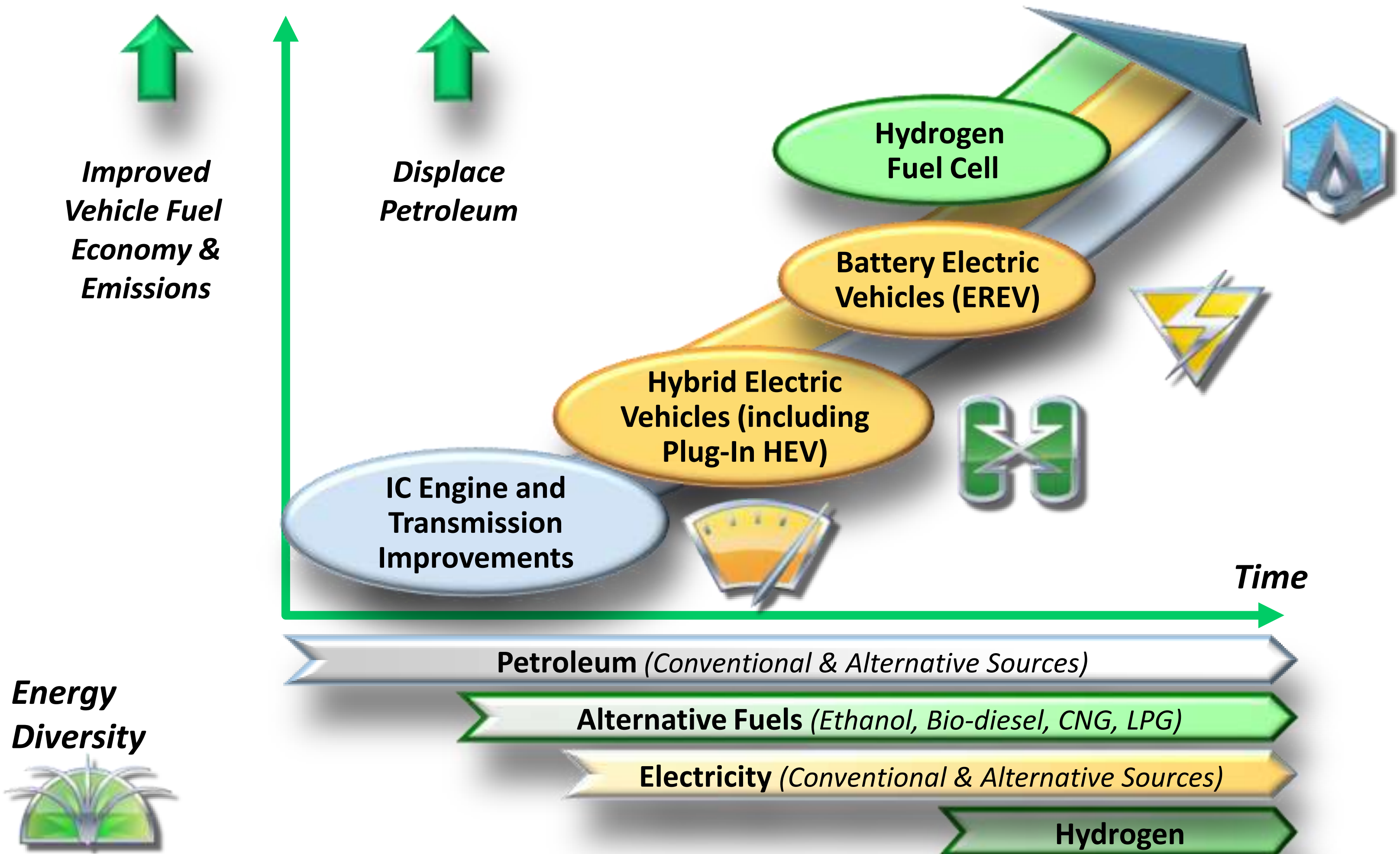
- LDV parc mostly transitioned to electric drive and ZEV solutions
- U.S. grid GHG modeled at 80% lower than 2008 levels
- Hydrogen from cellulosic biomass or clean electricity

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

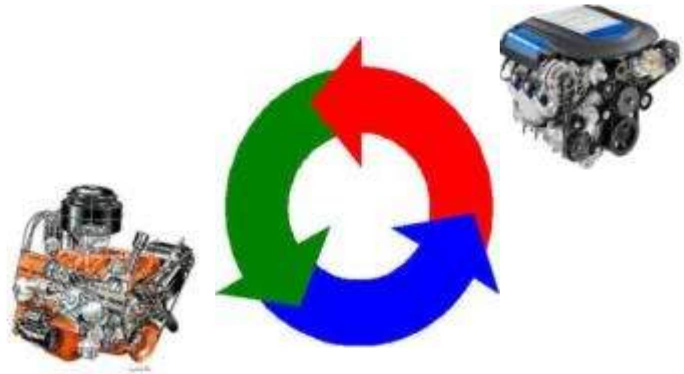
Advanced Propulsion Technology Strategy
No single silver bullet exists



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



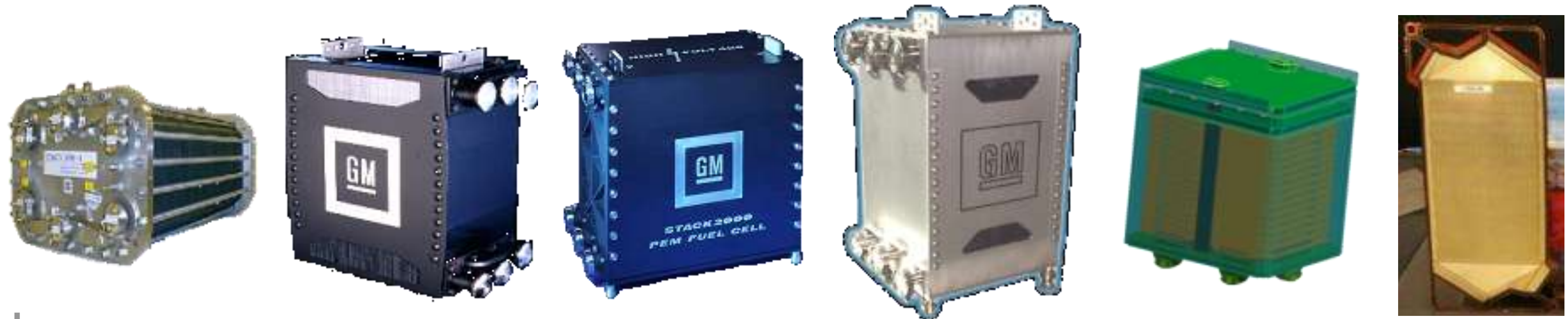
Infrastructure Investment Required

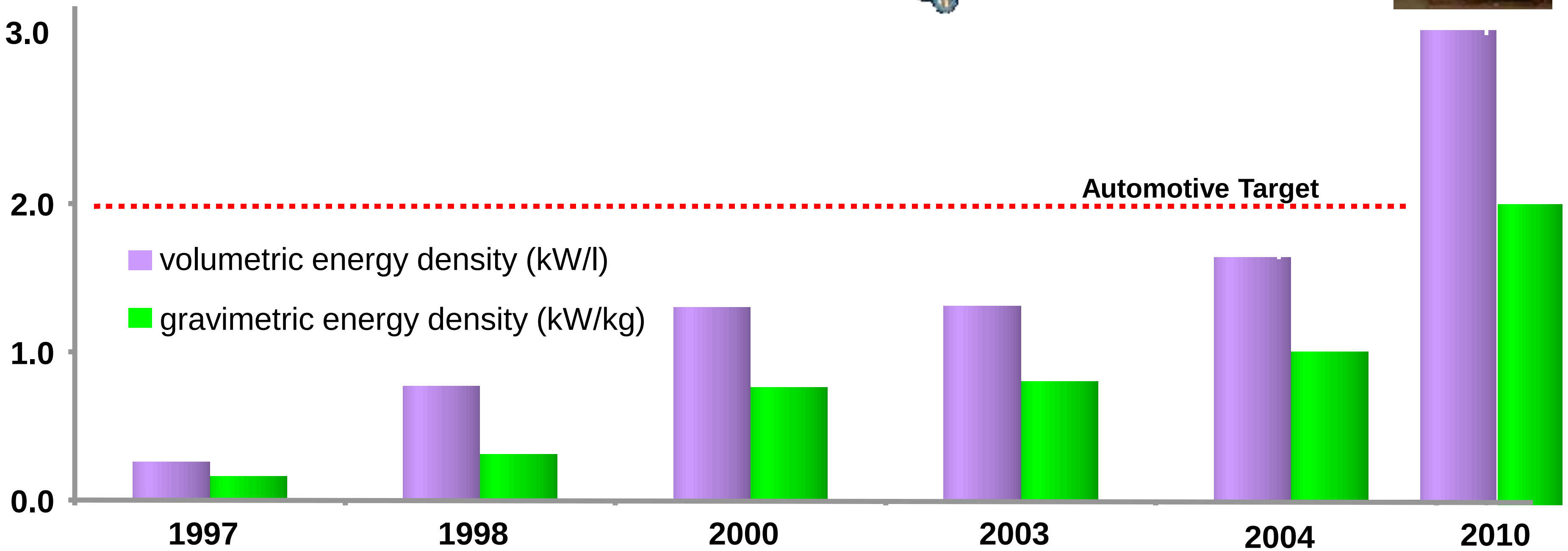
- Requires field infrastructure investment
- Must develop manufacturing & suppliers

Cycles of Learning

GM Fuel Cell Stack – Pre-Development
Cycles of Learning

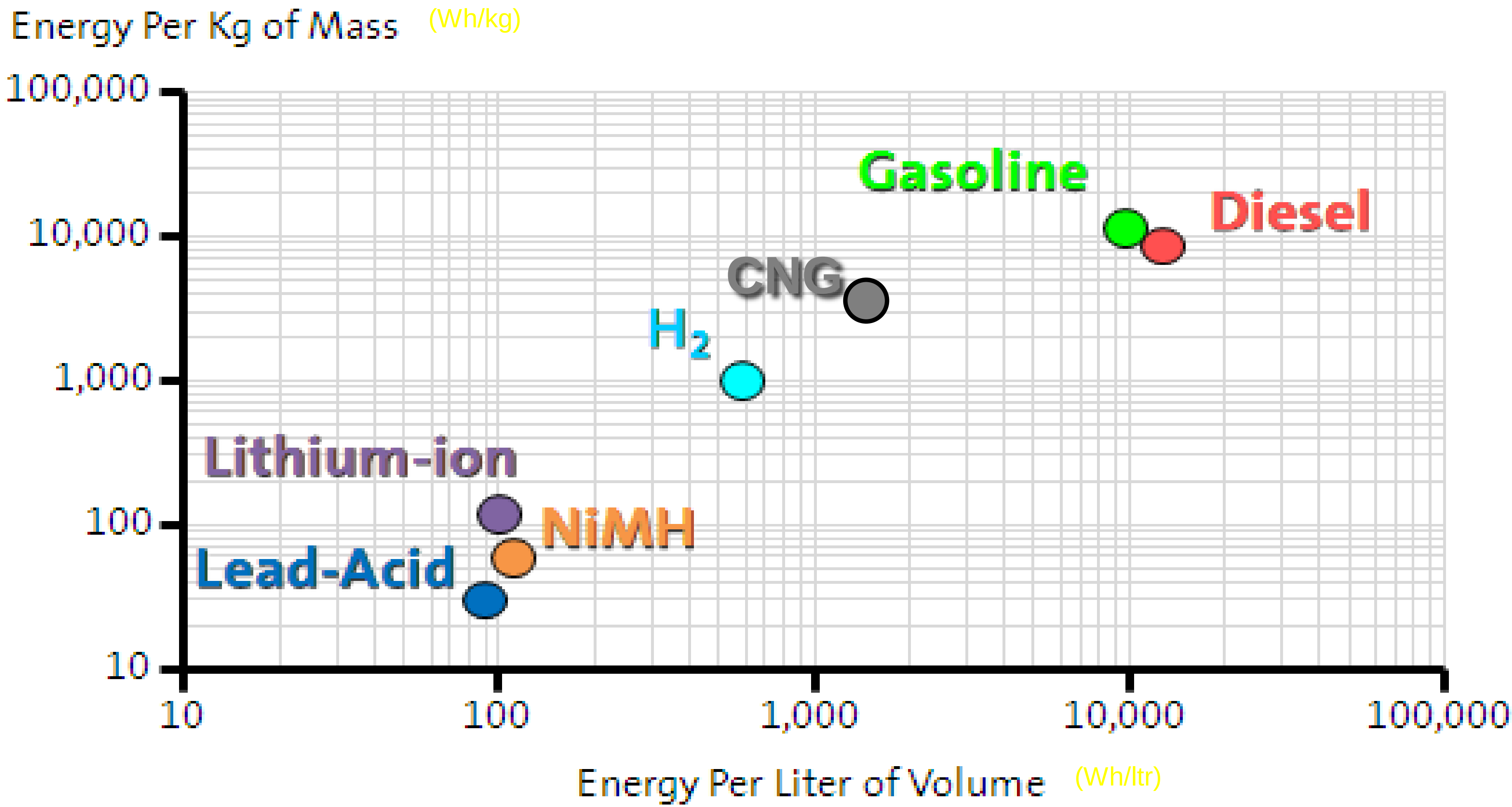
St 3 - 1997 | St 4 - 1998 | Stack 2000 | S2.1 - 2003 | S4 - 2004 | Current





Energy Storage Density is a Key Challenge

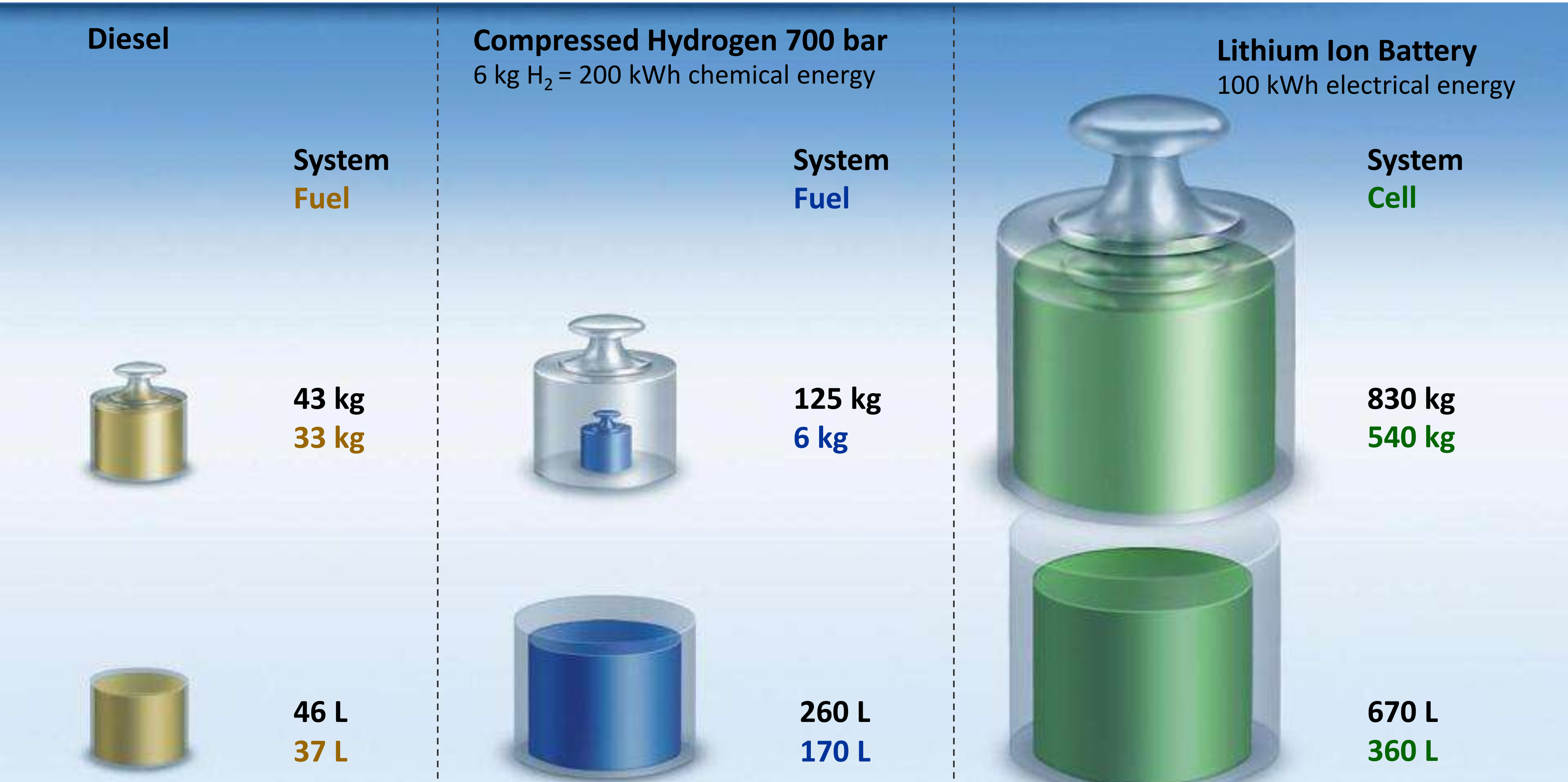
Energy Density on a Logarithmic Plot



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

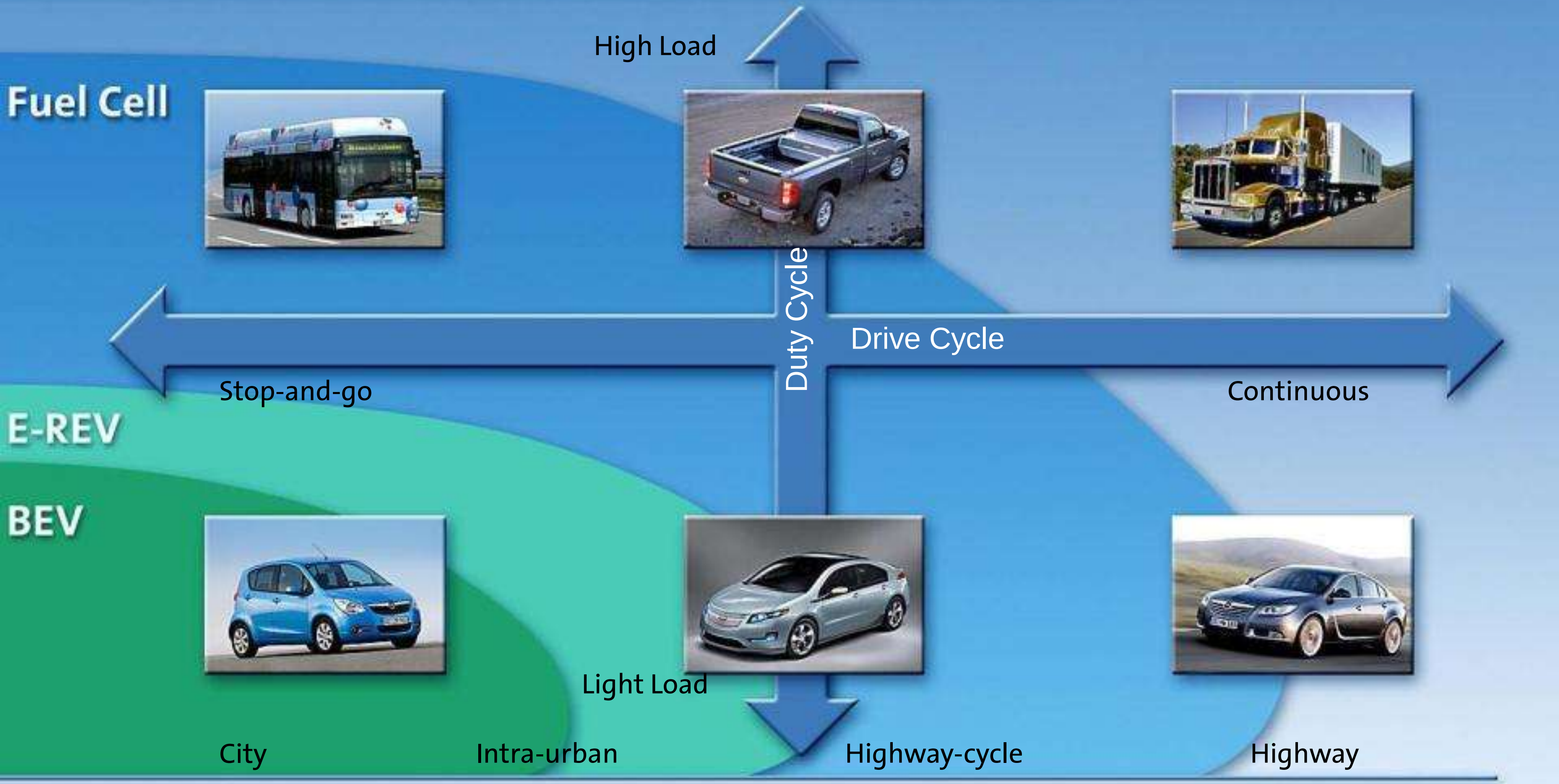


The challenge is to balance electric drive efficiency & energy cost advantages versus energy system storage mass, volume & refuel time penalties

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

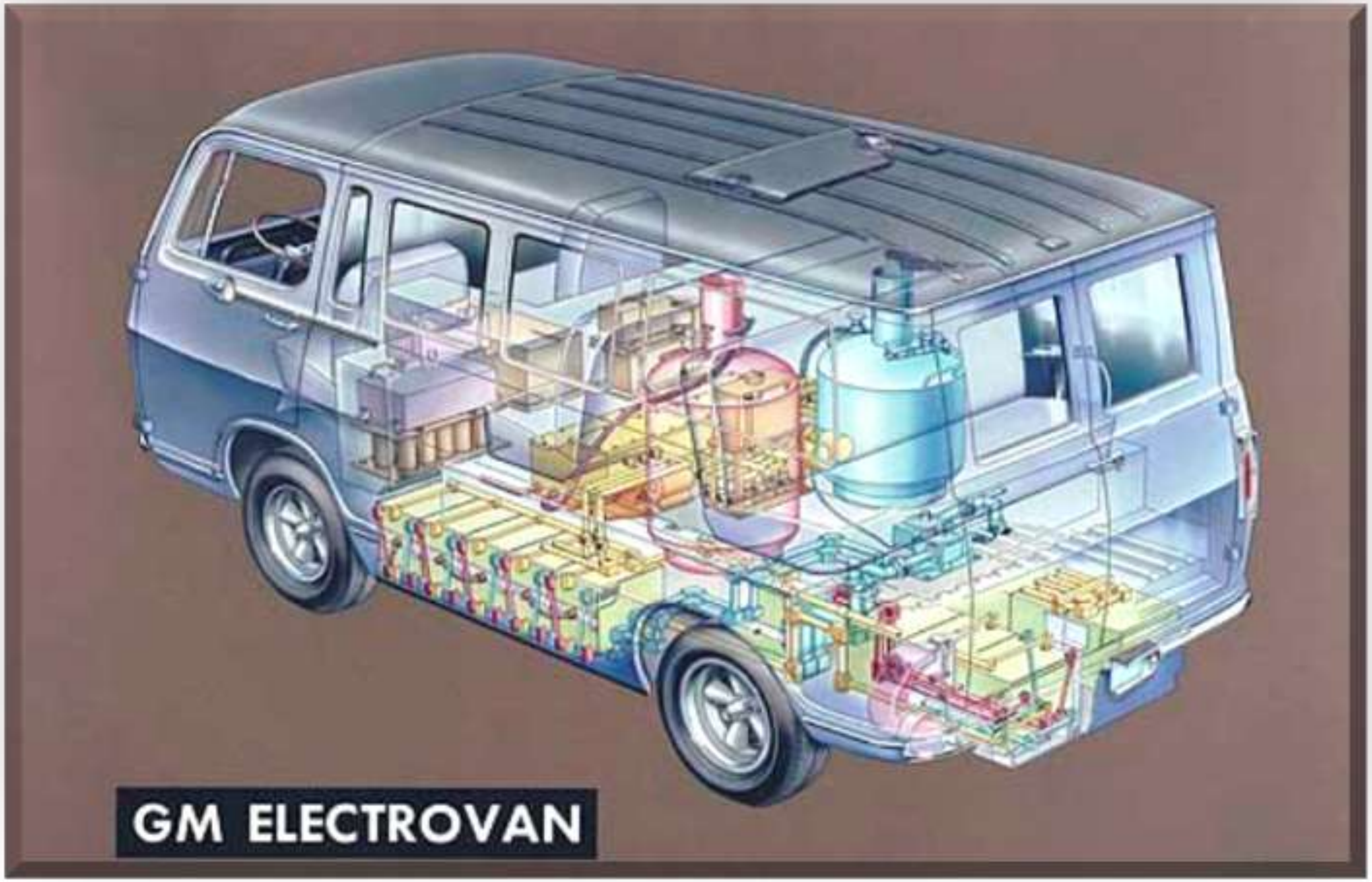
Fuel Cell Benefits:

- 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

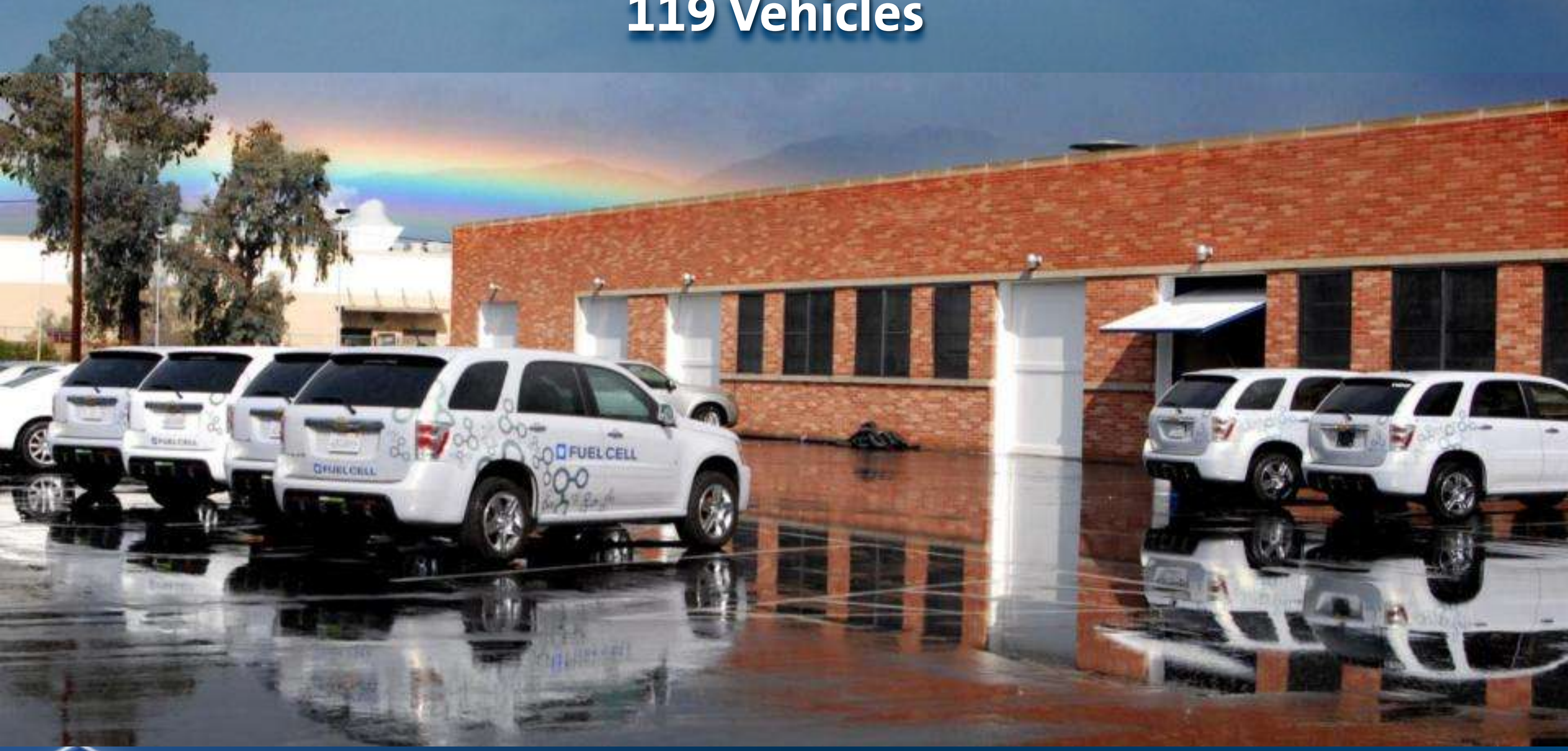
GM Fuel Cell Equinox – Hydrogen 4

- 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 $-20^{\circ}C$

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 H_2 fueled

Hydrogen & Fuel Cell Education
Real World Experience

GM Chevrolet Fuel Cell Equinox

Real World Experience

OnStar

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

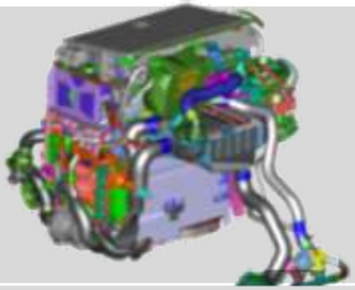
Over 1.4 Million miles & counting

Production Intent Design
Fuel Cell Propulsion System

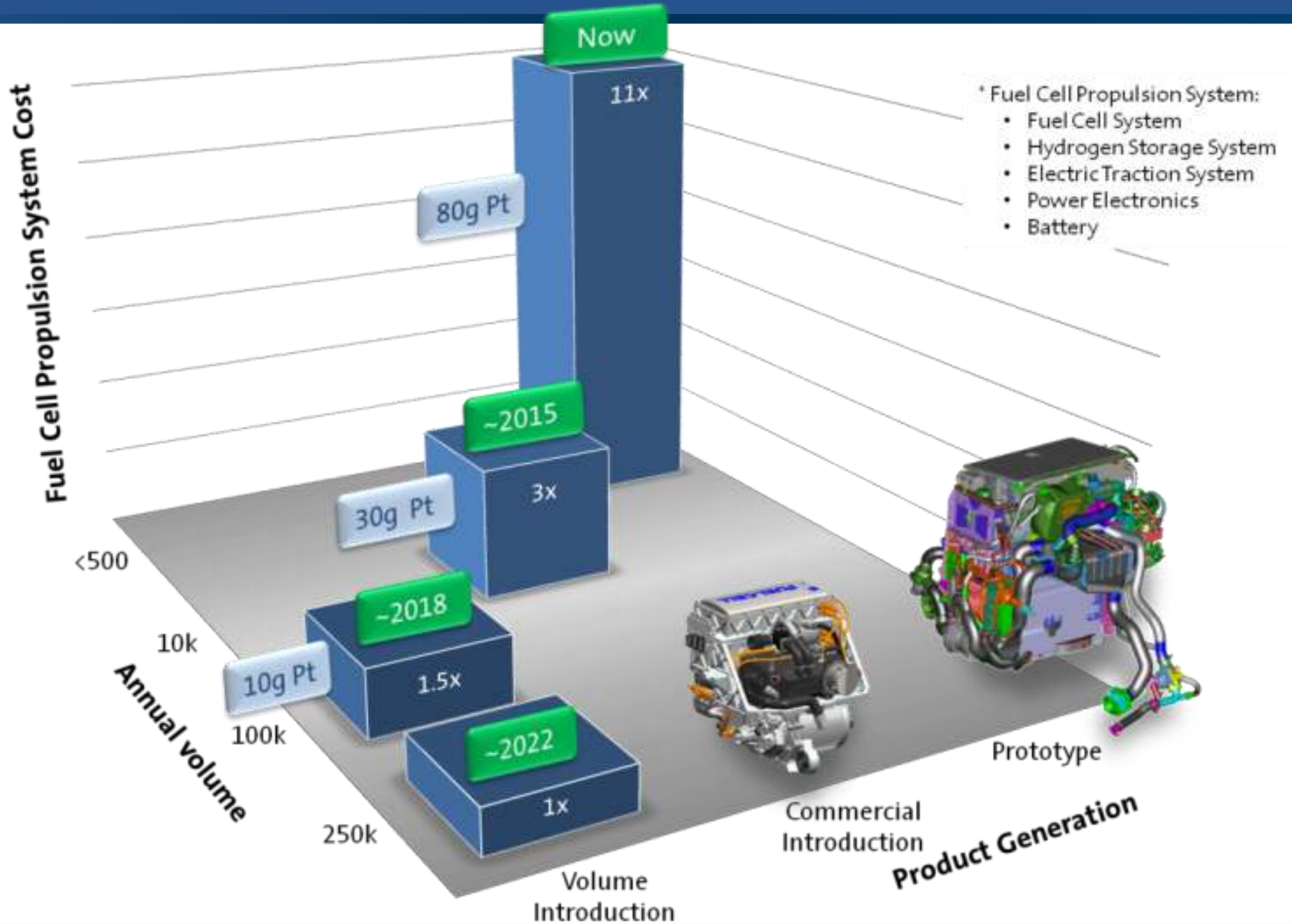
Design Evolution

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 **Plates** **UEA**	440-cells Composite **80g Platinum / FCS**	320-cells Stamped Stainless Steel **26g Platinum / FCS**
Fuel Subsystem	Flow shifting (series of injectors)	Single injector / ejector
Design Integration	**Semi-Integrated**	**Highly Integrated for Thermal Performance**

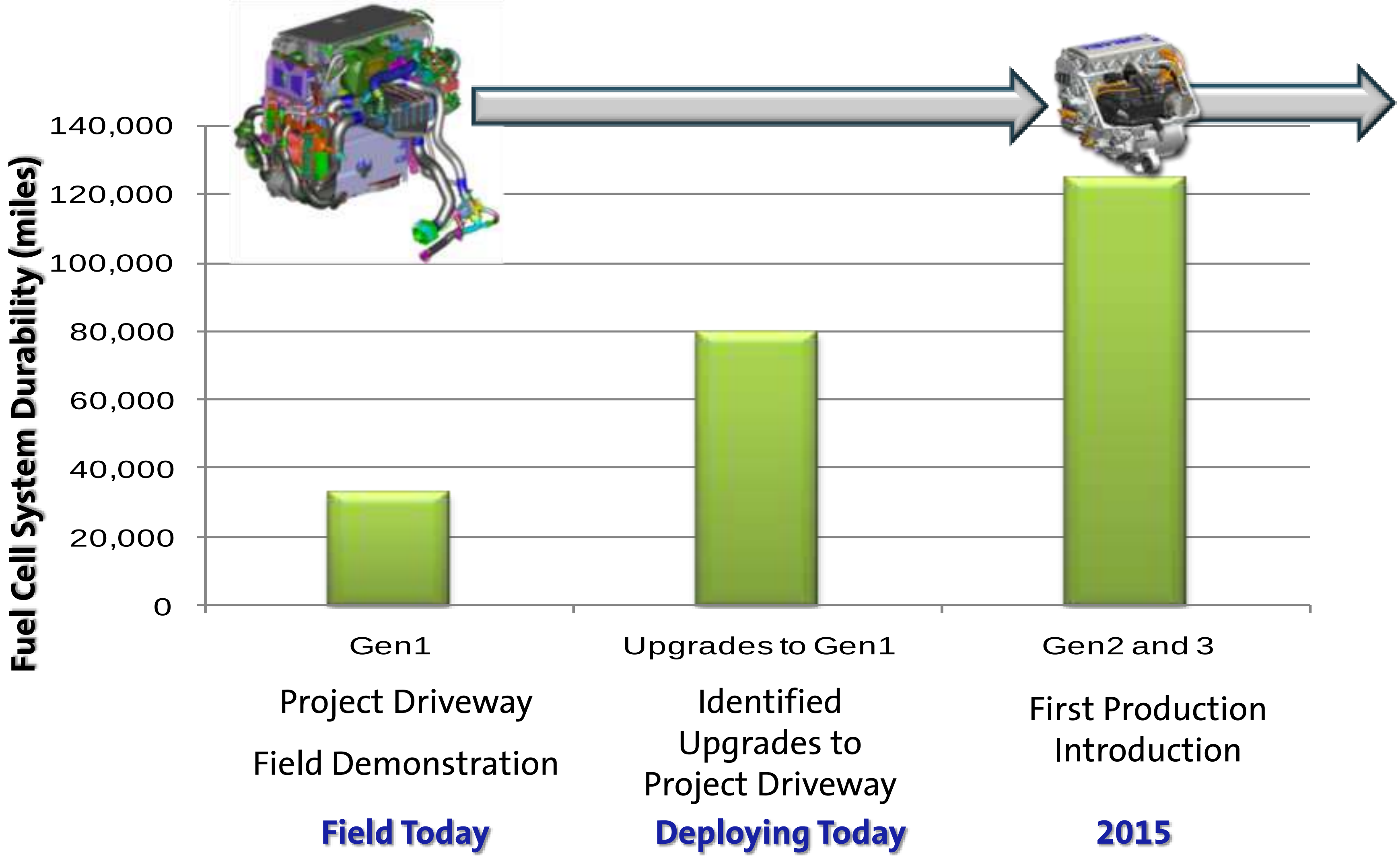
Automotive Competitive Cost Glide Path



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

DAIMLER Ford GM OPEL HONDA
HYUNDAI KIA RENAULT NISSAN TOYOTA

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 CO_2 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 CO_2 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.

“H_2 Mobility“: Infrastructure initiative (Sep 09)

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

DAIMLER EnBW THE LINDE GROUP NOW
OMV Shell TOTAL VATTENFALL AIR LIQUIDE

„H_2 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 H_2 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 H_2 & FC technology from former government → stability

Relationship between H_2 & 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**

1) DEWI Report, 30.6.2008

2) Bundesverband Windenergie e.V., 20.11.2008

Germany – Case Study
Wind Energy and the Electricity Grid

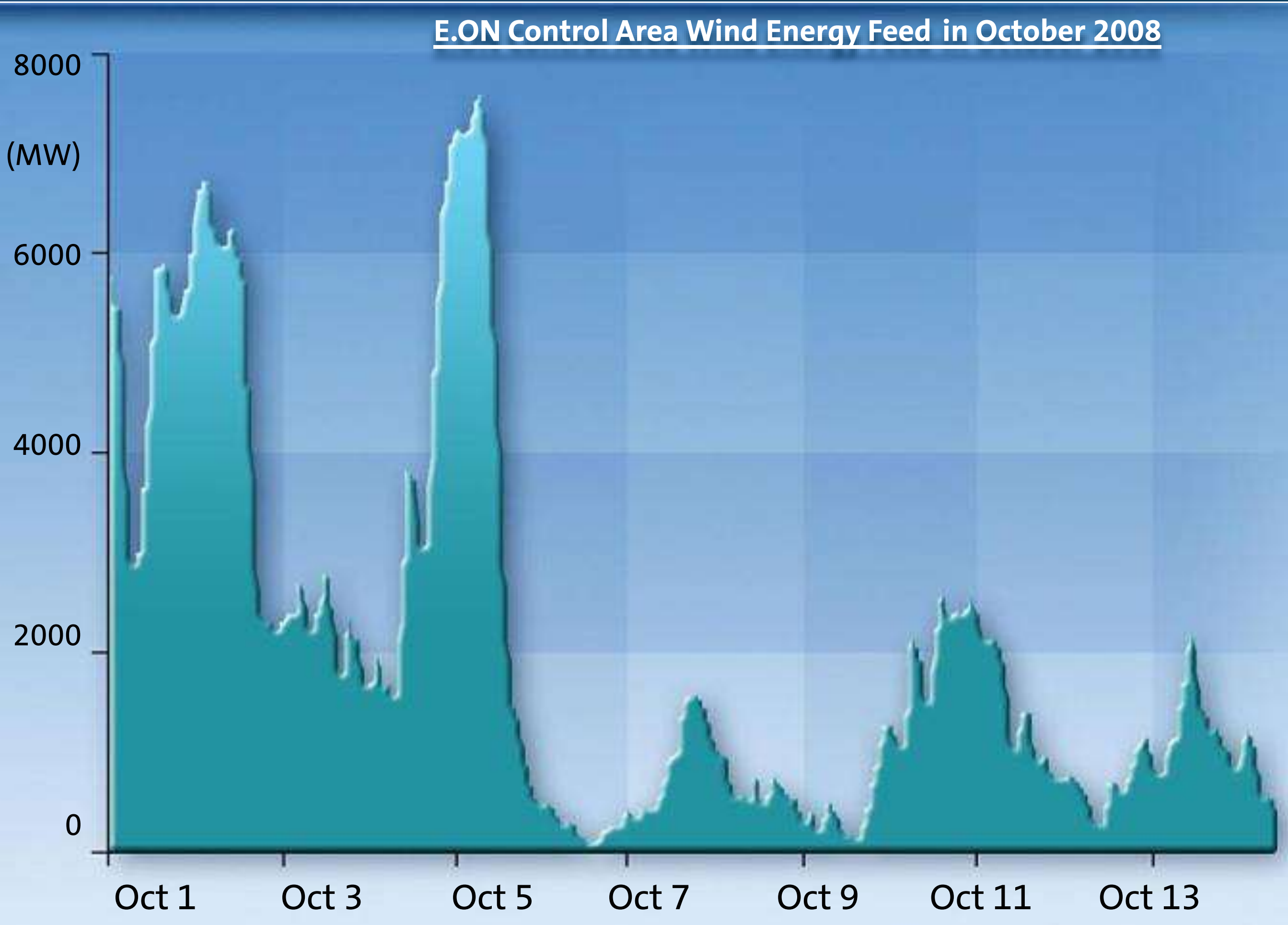
- German Wind Energy Example
- Quantity: 19,868 turbines
- Capacity: 23,044 MW[1)]
- Electricity production 2007: 39.6 TWh[2)] (7.2% of annual consumption)

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

1) DEWI Report, 30.6.2008

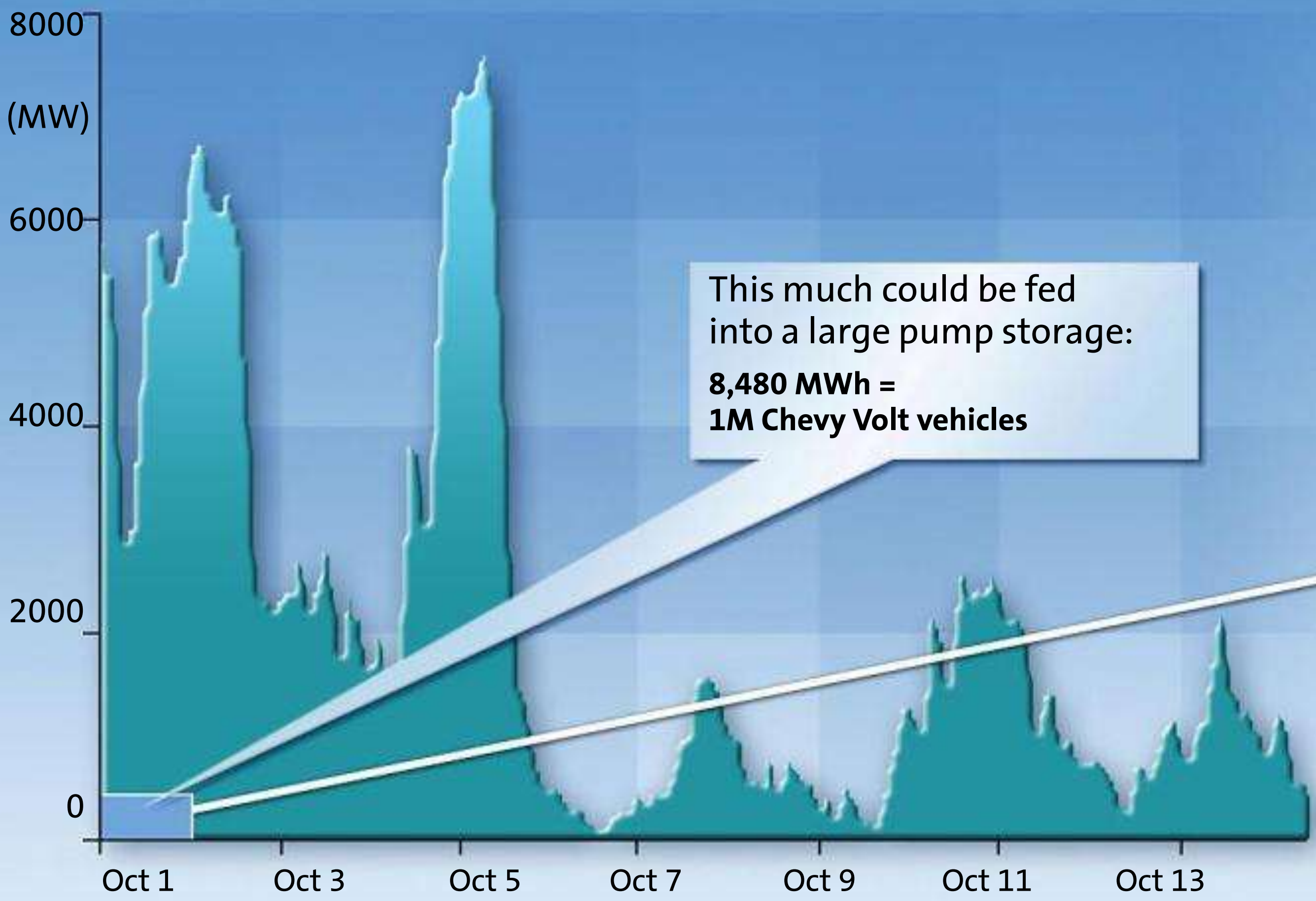
2) Bundesverband Windenergie e.V., 20.11.2008

Germany – Case Study
Sustainable Energy Generation & Fluctuating Energy Availability



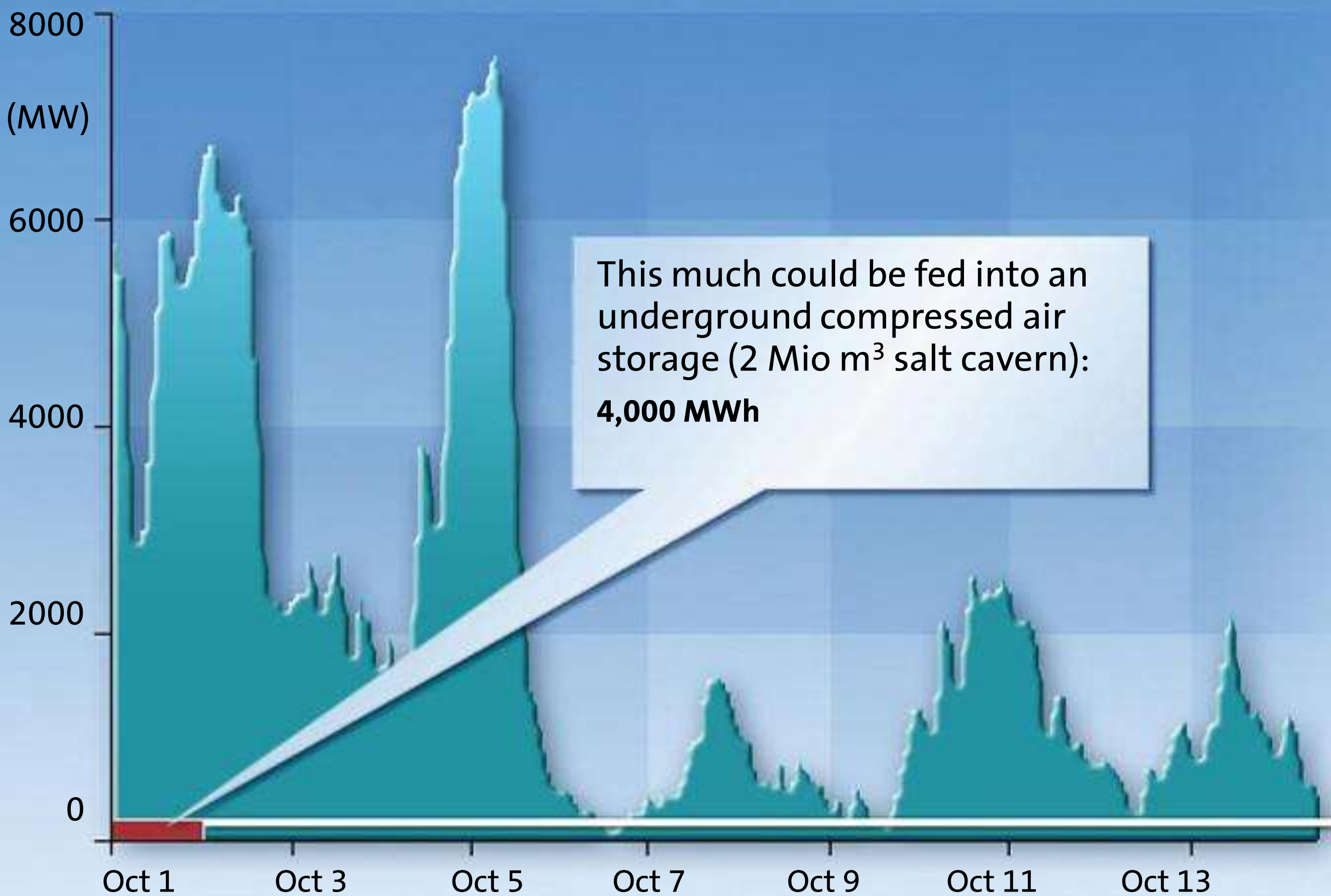
Fluctuating Wind Energy
Compared to Pumped Hydraulic Storage Capacity

Pump storage Goldisthal, Thüringen



➔ Buffer capacity for some minutes / hours

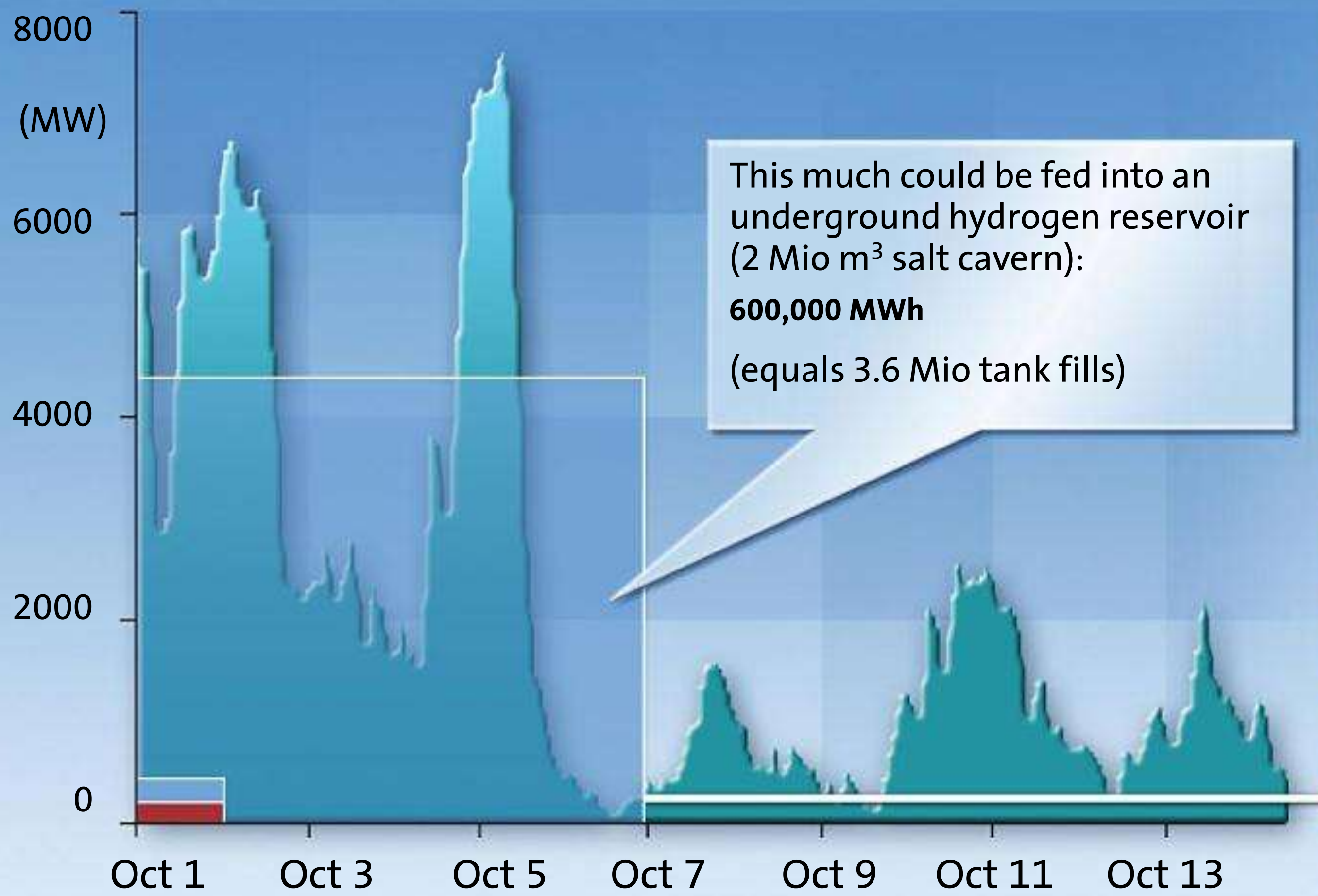
Store Fluctuating Wind Energy
Storage of Compressed Air in Salt Caverns

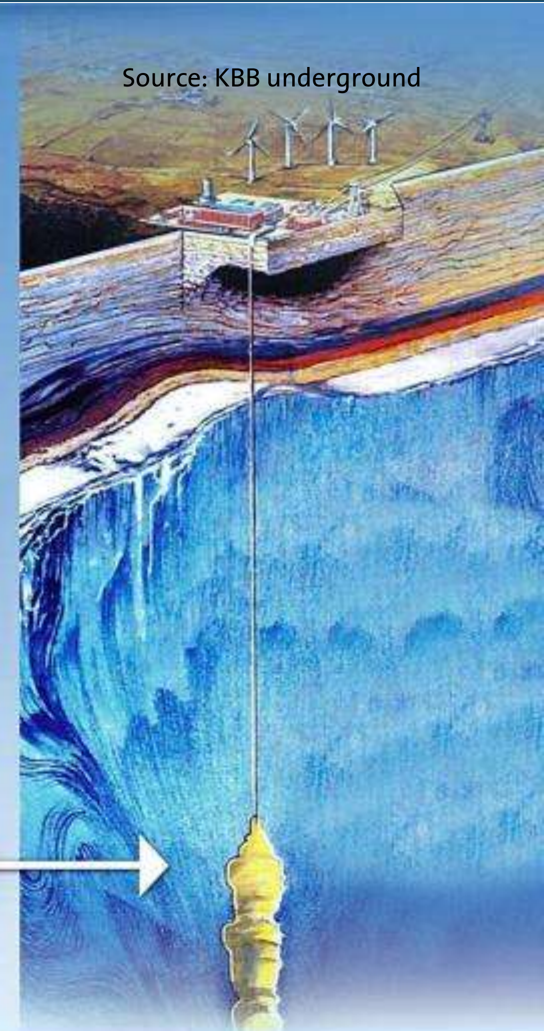


Source: KBB underground

➔ Buffer capacity for some minutes / hours

Hydrogen
The Energy Buffer in the Renewable Energy System





➔ Only hydrogen offers storage capacity for several days

German Wind-H_2-Plant Construction

Building 6 MW System in Northeastern Germany

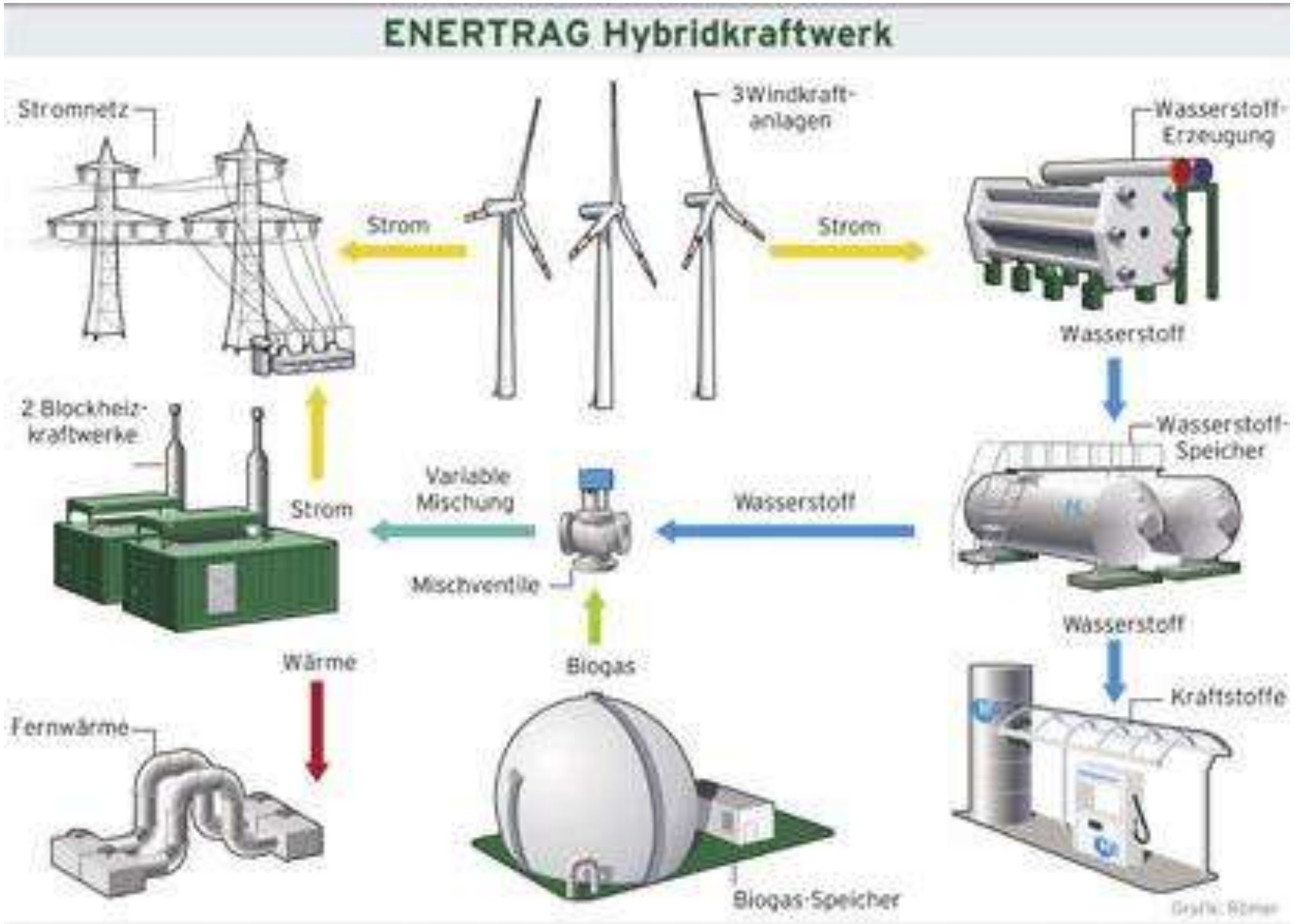
German Chancellor

Angela Merkel @

construction site

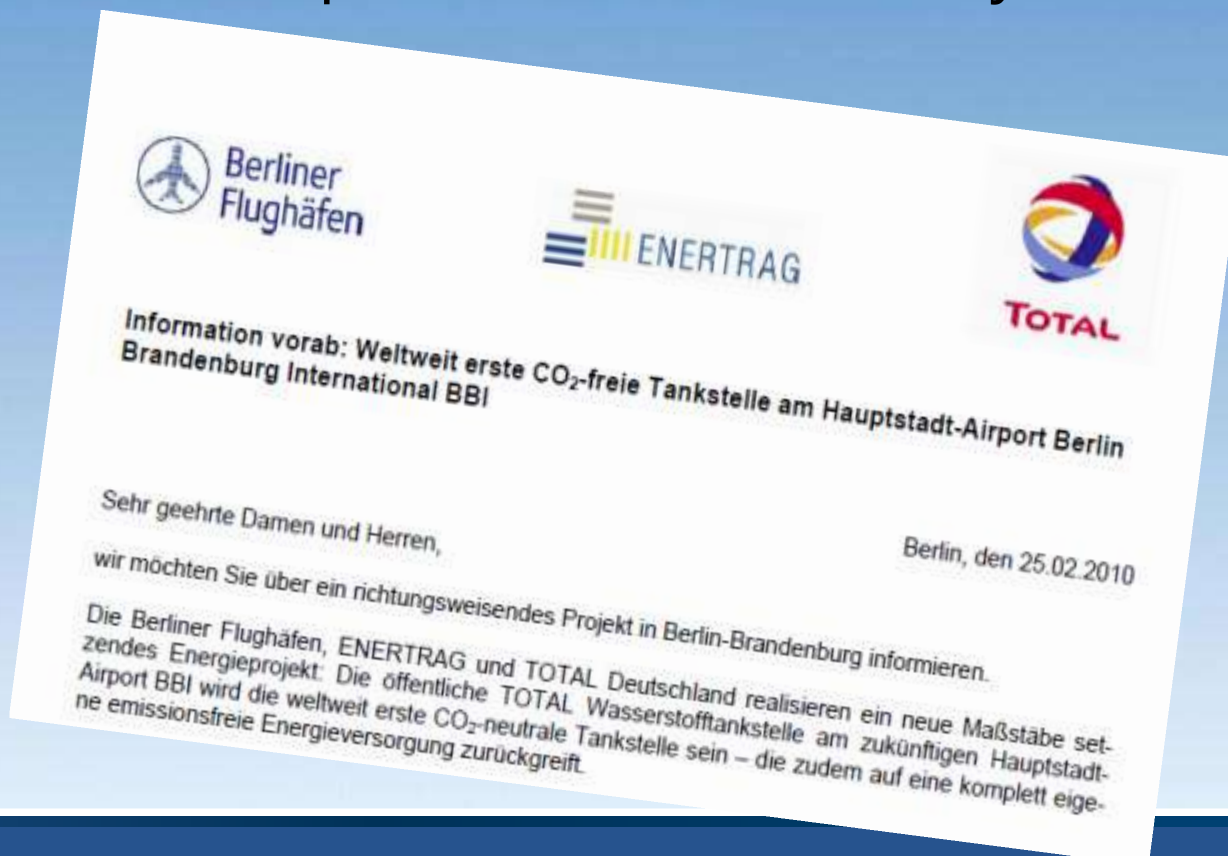
Minister President Matthias Platzeck

(State of Brandenburg)



Berlin Brandenburg International Airport
World's First CO_2-free H_2 Refueling Station

- Station will use wind energy with H_2 storage
- Transport Ministry:
  500,000 FCEVs of the 1 million planned electric vehicles by **2020**


Berliner Flughäfen

ENERTRAG

TOTAL

Information vorab: Weltweit erste CO_2-freie Tankstelle am Hauptstadt-Airport Berlin Brandenburg International BBI

Sehr geehrte Damen und Herren,

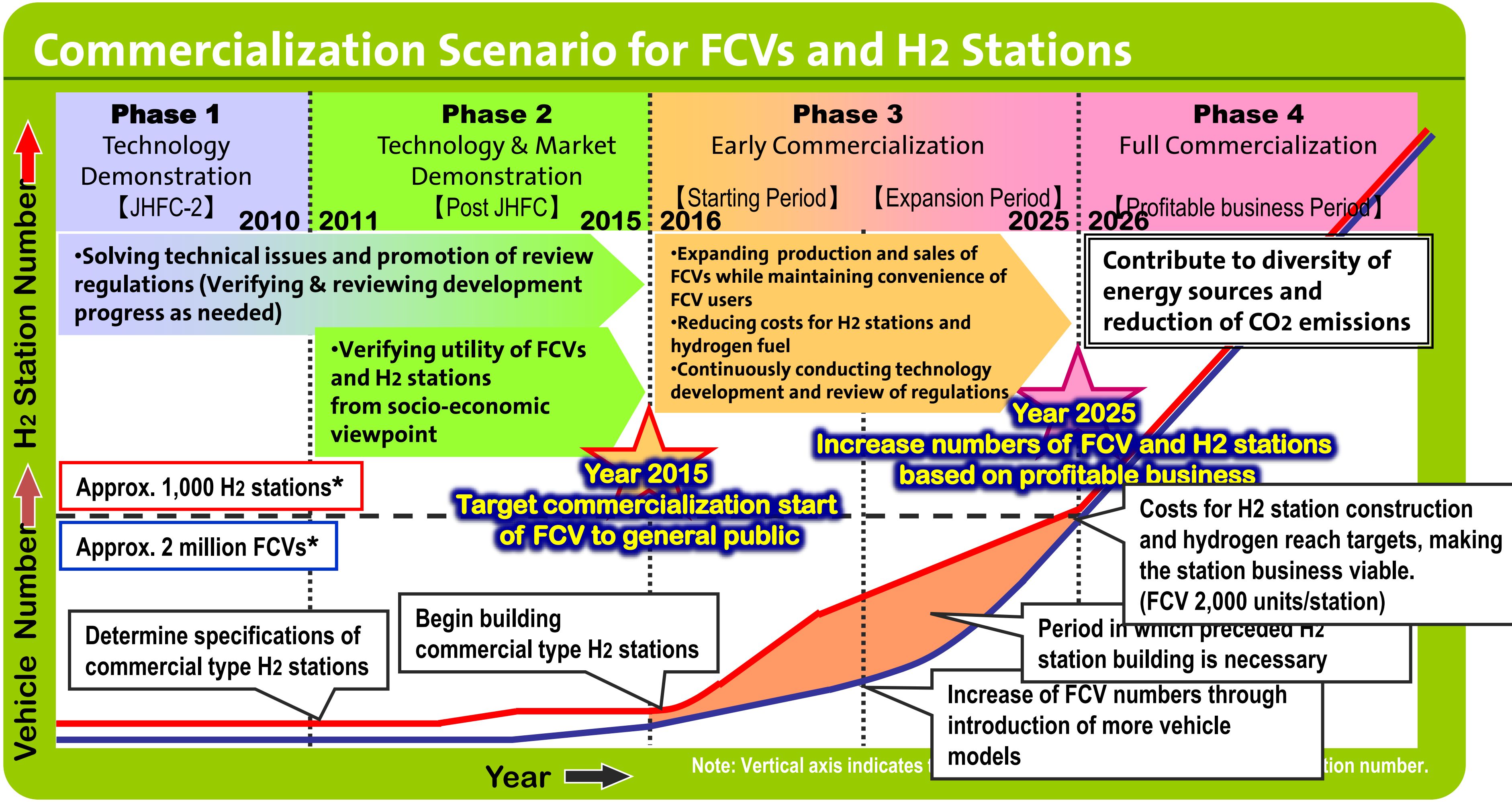
Berlin, den 25.02.2010

wir möchten Sie über ein richtungsweisendes Projekt in Berlin-Brandenburg informieren.

Die Berliner Flughäfen, ENERTRAG und TOTAL Deutschland realisieren ein neue Maßstäbe setzendes Energieprojekt: Die öffentliche TOTAL Wasserstofftankstelle am zukünftigen Hauptstadt-Airport BBI wird die weltweit erste CO_2-neutrale Tankstelle sein – die zudem auf eine komplett eigene emissionsfreie Energieversorgung zurückgreift.

Japanese FCEV Deployment Scenario

Fuel Cell Commercialization Conference of Japan FCCJ



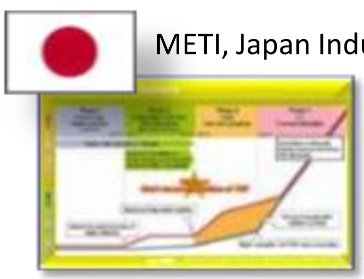
* Precondition: Benefit for FCV users (price/convenience etc.) are secured, and FCVs are widely and smoothly deployed

Hydrogen Infrastructure for the U.S.

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

Fuel Cell & H_2 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	Important Parameters	State Examples
NOW, National Plan  **1,000 Stations by 2018**	• Aggressive Greenhouse Gas Standards • Large renewable energy infrastructure • Bordered by non-participating nations	
METI, Japan Industry  **2 Million Vehicles by 2025** **1,000 Stations by 2025**	• Aggressive Greenhouse Gas Standards • Largely reliant on imported energy • Bordered by water • Available renewable energy resources	

Multiple countries are entering hydrogen infrastructure race

Hydrogen Infrastructure
Los Angeles Example

$100-200 million H_2 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 H_2 infrastructures can be achieved with 40-50 stations in metro areas & along major destination corridors

Hydrogen Infrastructure for Oahu (Illustrative)

20 - 25 Stations could Cover Oahu's Requirements

- At lest 6 stations in **Northwest Oahu**

  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*

HAWAIIGAS

Why Hydrogen Hawaii?

- 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)

GM THEGASCOMPANY

HAWAIIGAS

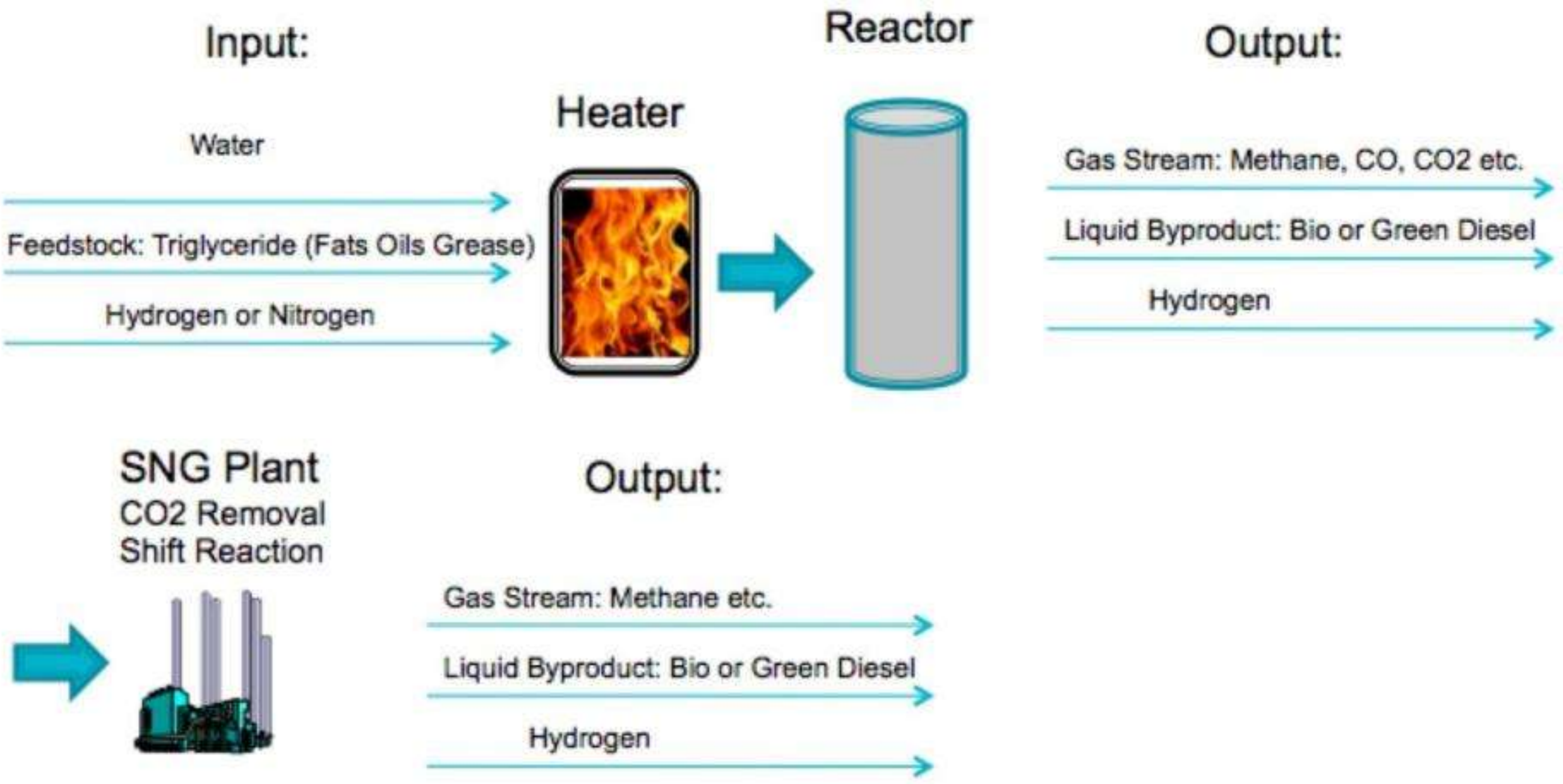
Why The Gas Company?

- TGC is currently delivering about 5 percent H_2 in its utility gas (SNG) stream
- TGC has capability to produce more H_2 through its renewable biogas initiative (now underway)
- H_2 is blended with the utility gas
- H_2 can be separated using Pressure Swing Adsorption technology, for delivery at H_2 fueling stations along Oahu's existing utility pipeline

GM

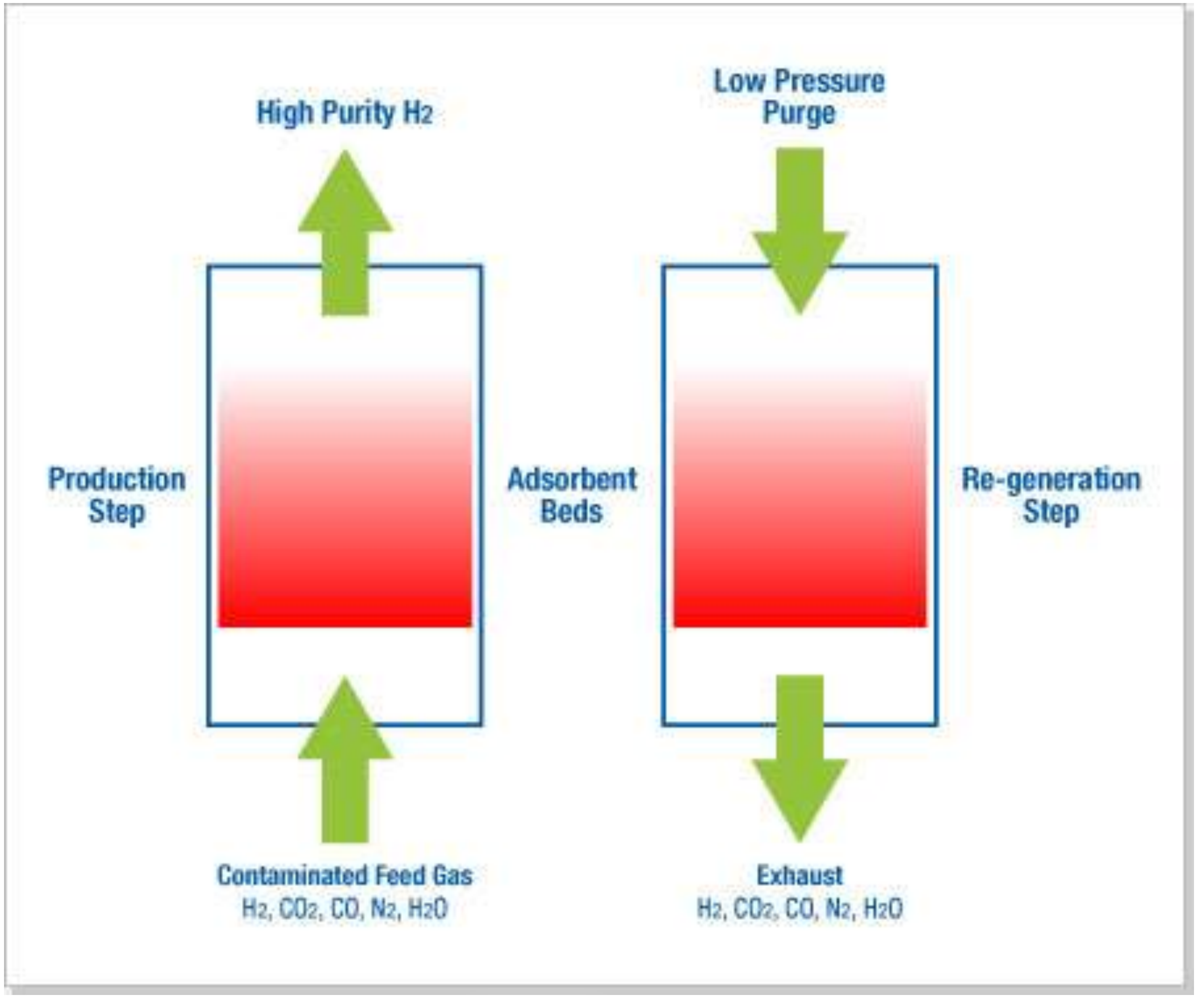
THE GAS COMPANY

Making H_2 from Renewables



HAWAIIGAS

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



GM

THE GAS COMPANY

HAWAIIGAS

Why Oahu?

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

GM

THE GAS COMPANY

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 H_2
- Gain federal and state attention for both H_2 and fuel cell
- Ability to leverage existing pipeline for H_2 distribution
- A pathway for a significant H_2 refueling infrastructure

Global Fuel Cell Competitors

GM

OEM Fuel Cell Programs

NISSAN

TOYOTA

SAIC

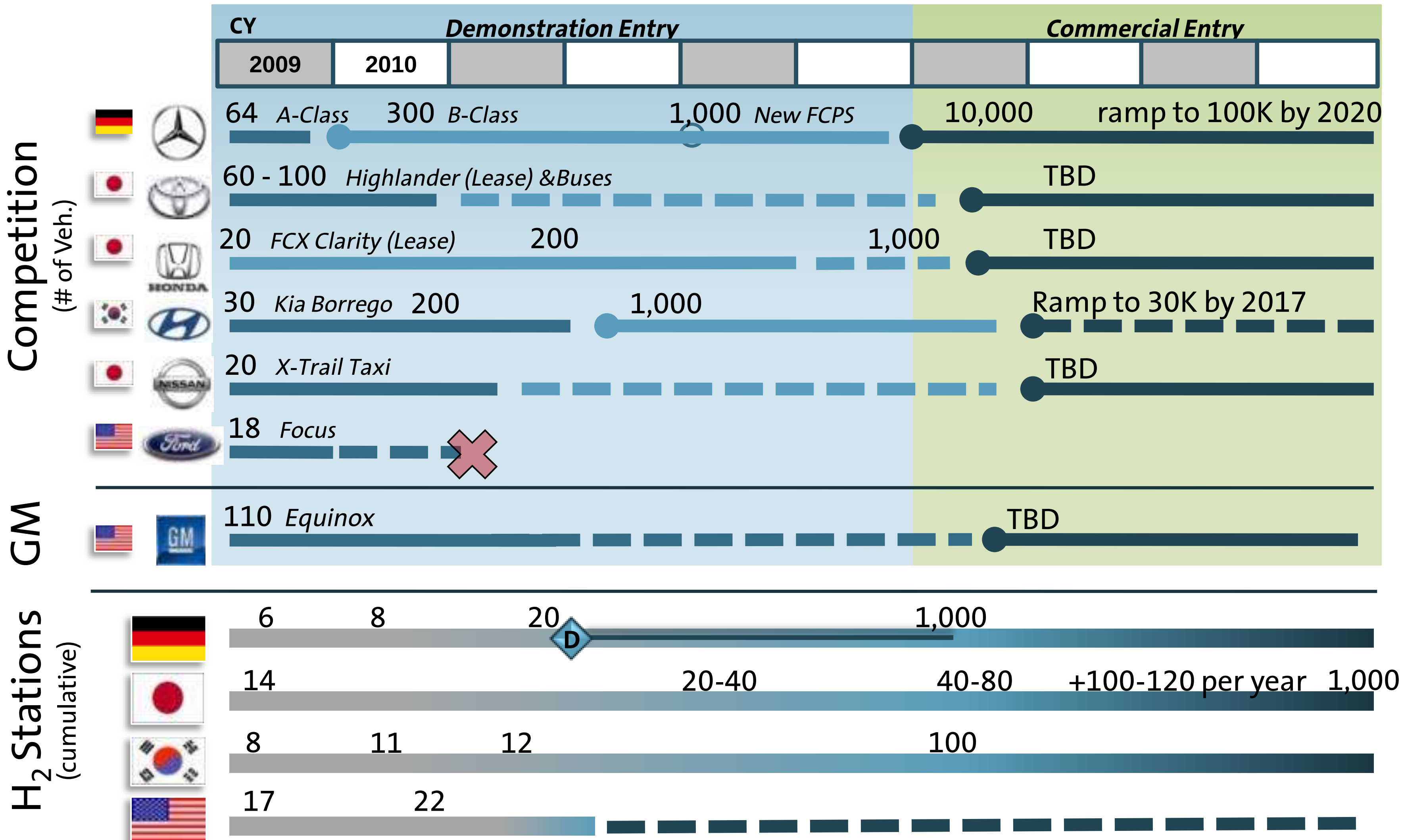
上汽集团

DAIMLER

HYUNDAI

KIA

Competitive Landscape Summary
Market Introductions in 2015/2016



Conclusions

H_2 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.)

H_2 infrastructure is achievable – Must Establish Momentum

- Germany & Japan implementing H_2 infrastructure plans
- U.S. H_2 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 f Energy role to support early market introduction phases
- Germany's H_2 Mobility Template
- Market incentives
- Establish customer pull-through for vehicles

Thank you

Questions