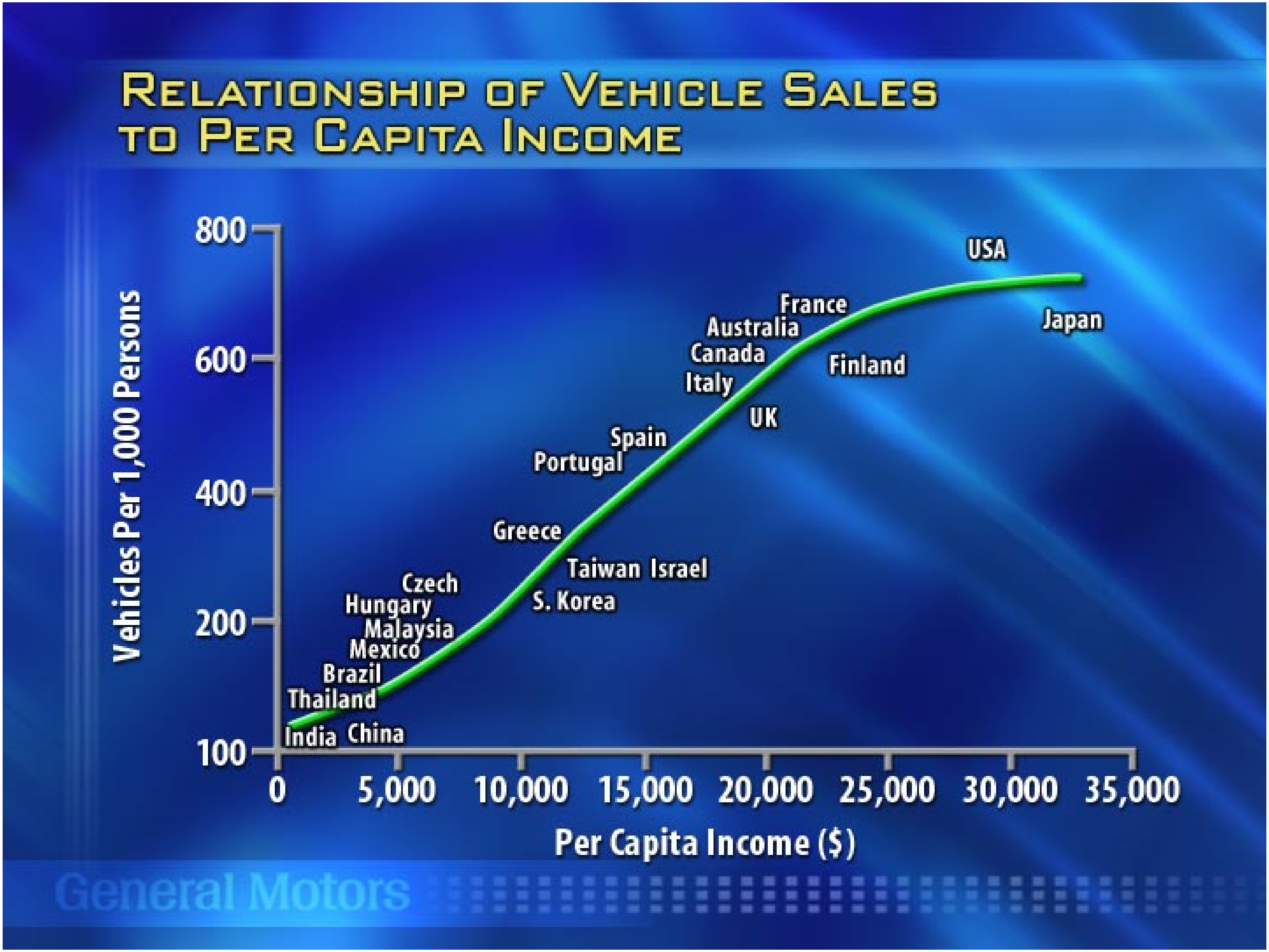
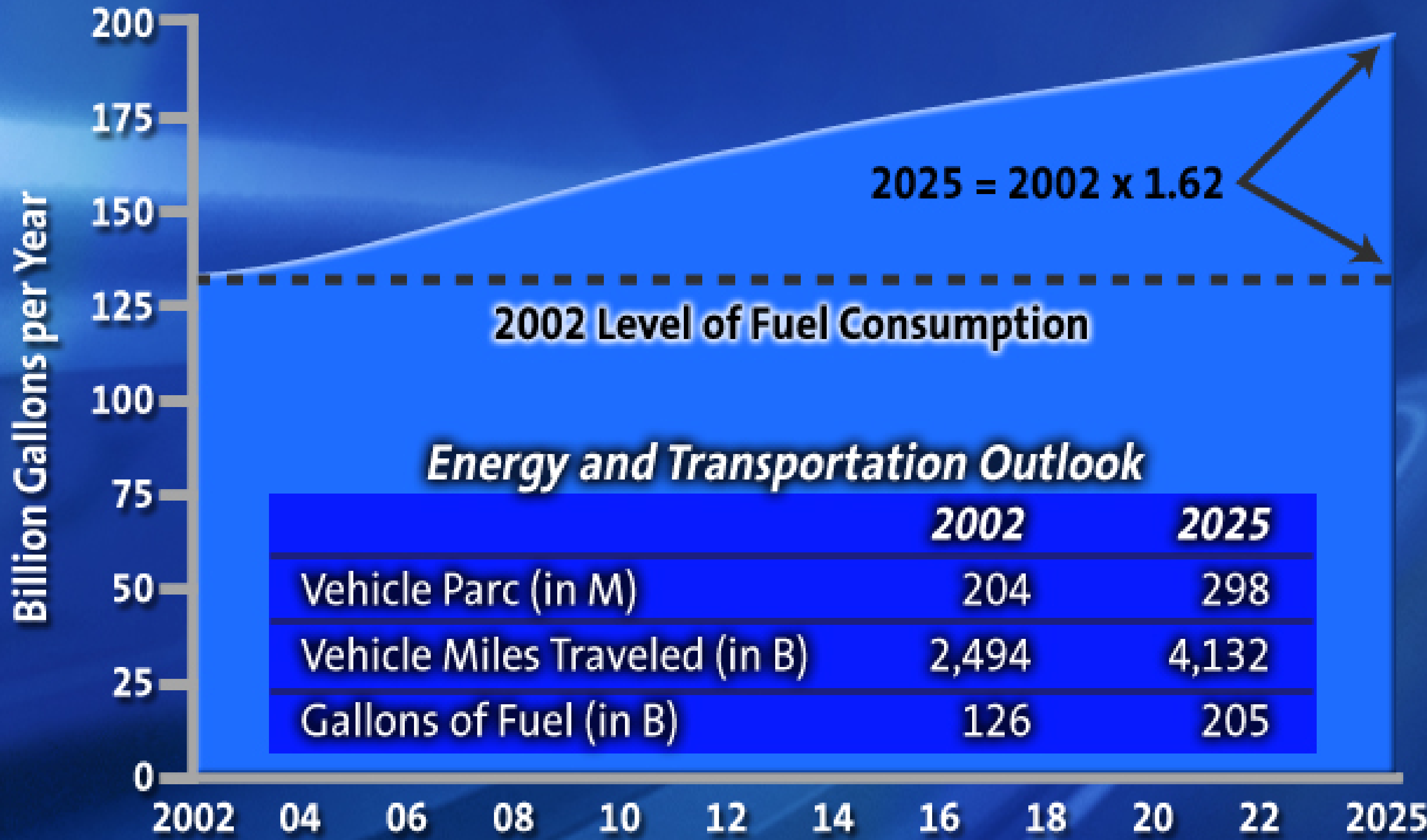
Sustainable Mobility

A Global Imperative



Relationship of Vehicle Sales to Per Capita Income
Vehicles Per 1,000 Persons
800
600
400
200
100
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
Per Capita Income ($)
USA
Japan
France
Australia
Canada
Finland
Italy
UK
Spain
Portugal
Greece
Taiwan
Israel
S. Korea
Czech
Hungary
Malaysia
Mexico
Brazil
Thailand
India
China
General Motors

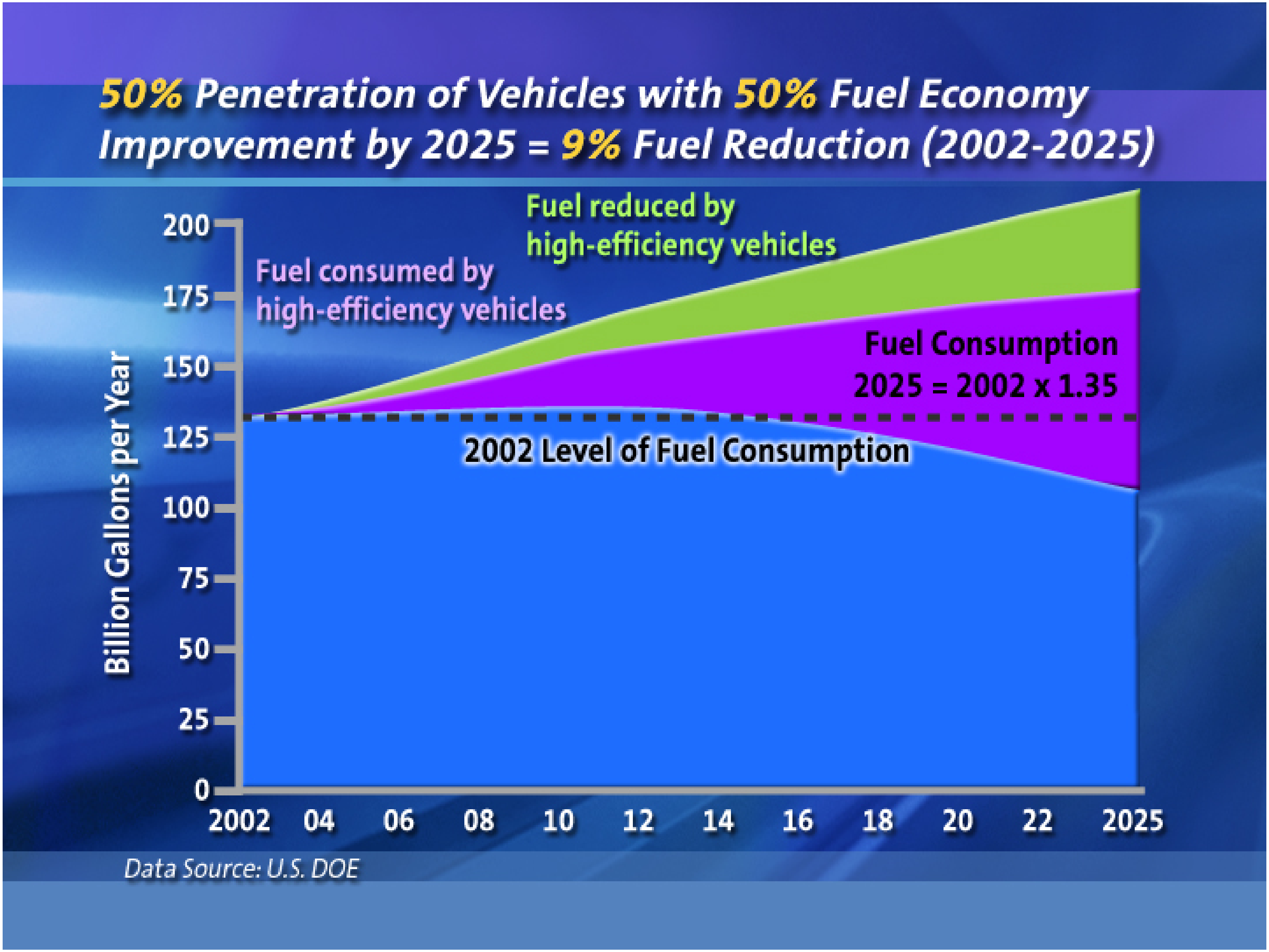
Fuel Consumed by U.S. Light-Duty Vehicles

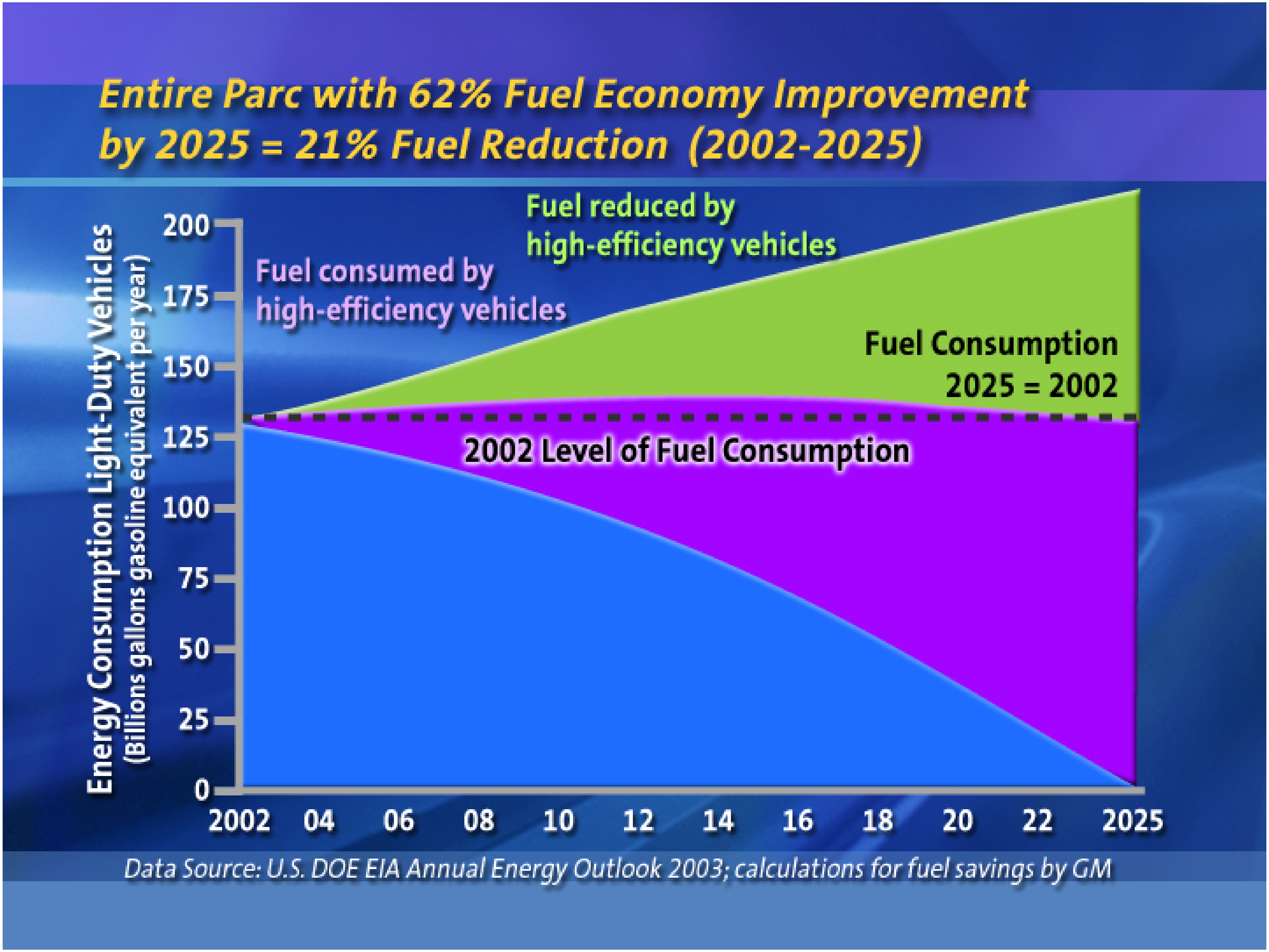


Energy and Transportation Outlook

	2002	***2025***
Vehicle Parc (in M)	204	298
Vehicle Miles Traveled (in B)	2,494	4,132
Gallons of Fuel (in B)	126	205

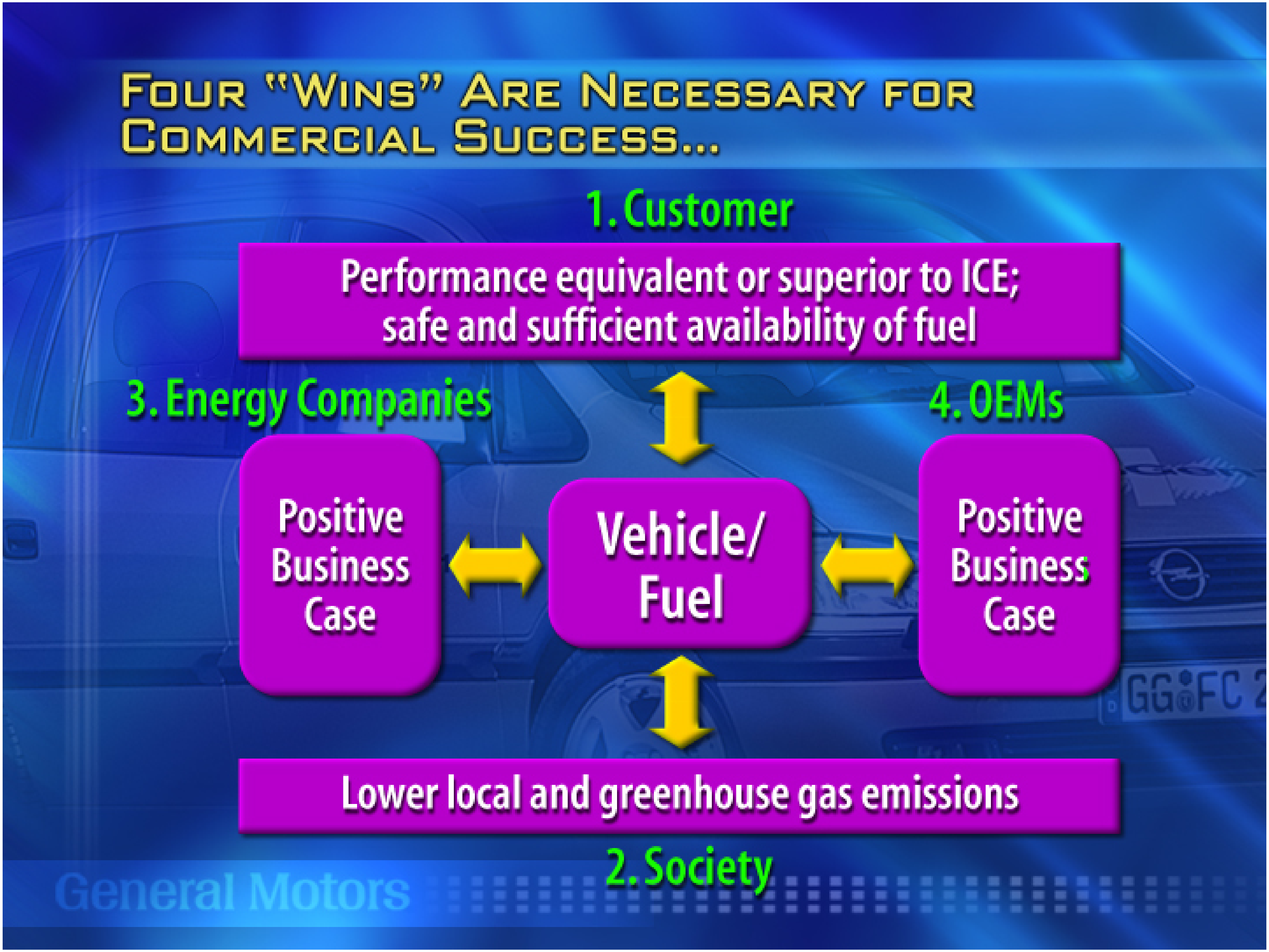
Data Source: U.S. DOE


50% Penetration of Vehicles with 50% Fuel Economy Improvement by 2025 = 9% Fuel Reduction (2002-2025)
Fuel reduced by high-efficiency vehicles
Fuel consumed by high-efficiency vehicles
Fuel Consumption 2025 = 2002 x 1.35
2002 Level of Fuel Consumption
Billion Gallons per Year
0
25
50
75
100
125
150
175
200
2002
04
06
08
10
12
14
16
18
20
22
2025
Data Source: U.S. DOE



Entire Parc with 62% Fuel Economy Improvement
by 2025 = 21% Fuel Reduction (2002-2025)
Energy Consumption Light-Duty Vehicles
(Billions gallons gasoline equivalent per year)
200
175
150
125
100
75
50
25
0
2002
04
06
08
10
12
14
16
18
20
22
2025
Fuel reduced by
high-efficiency vehicles
Fuel consumed by
high-efficiency vehicles
Fuel Consumption
2025 = 2002
2002 Level of Fuel Consumption
Data Source: U.S. DOE EIA Annual Energy Outlook 2003; calculations for fuel savings by GM

Why Fuel Cells


FOUR "WINS" ARE NECESSARY FOR COMMERCIAL SUCCESS...
1. Customer
Performance equivalent or superior to ICE; safe and sufficient availability of fuel
3. Energy Companies
Positive Business Case
Vehicle/ Fuel
4. OEMs
Positive Business Case
Lower local and greenhouse gas emissions
2. Society
General Motors

Hydrogen Addresses the Societal Drivers

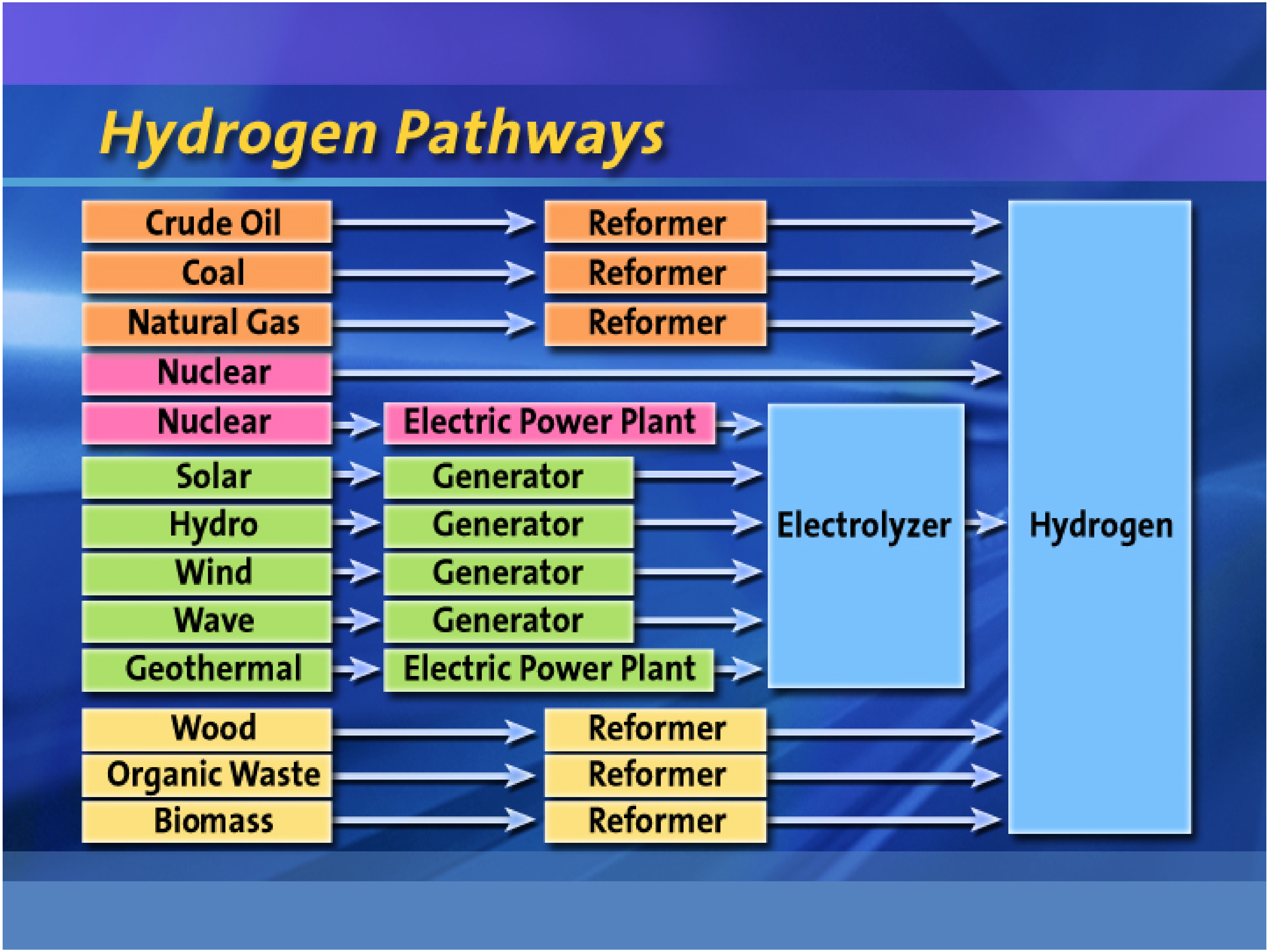
Petroleum Dependence

Balance of Payments

Hydrogen

Local Air Quality

Threat of Global Climate Change (CO_2)

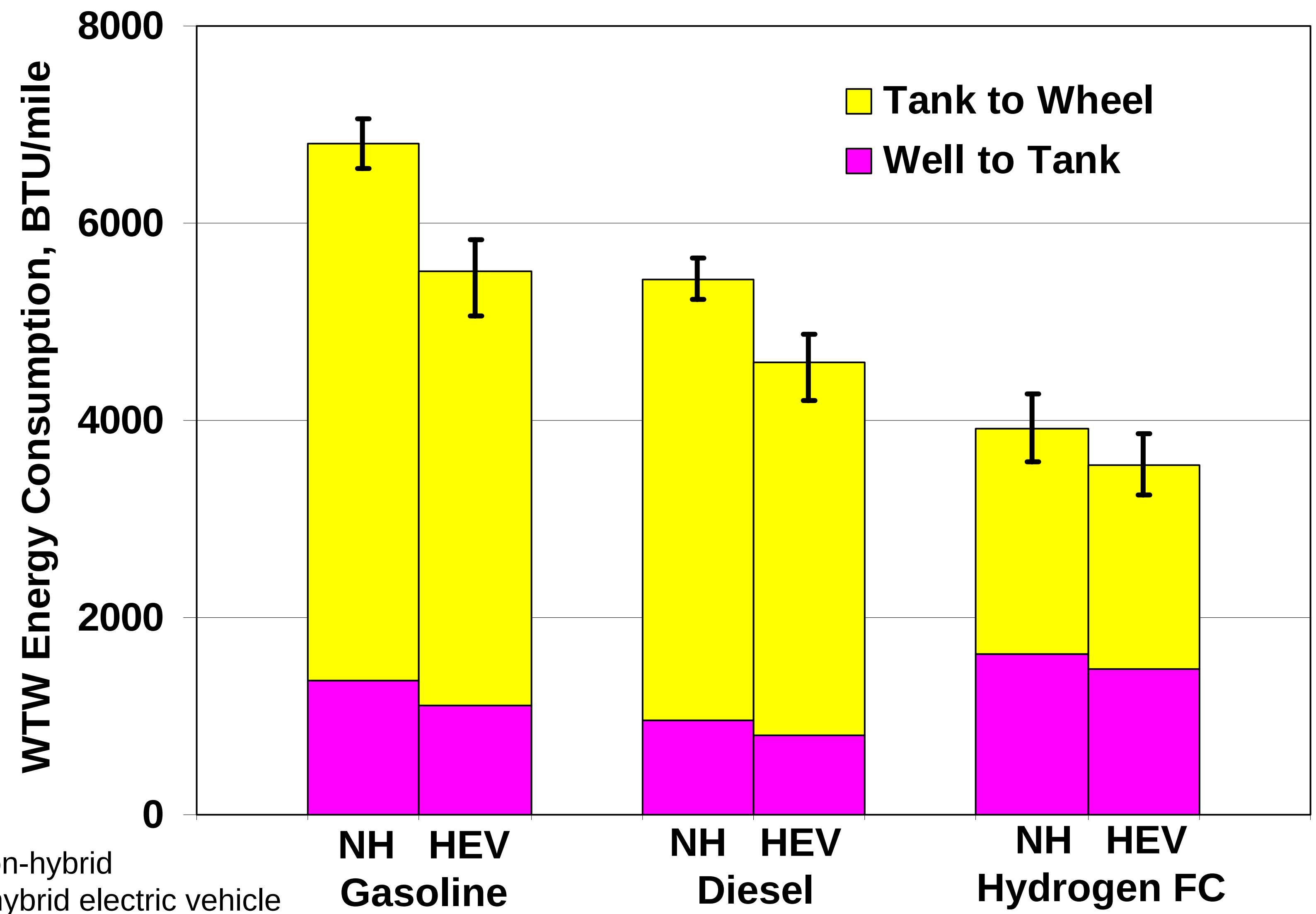


Hydrogen Pathways
Crude Oil
Reformer
Coal
Reformer
Natural Gas
Reformer
Nuclear
Nuclear
Electric Power Plant
Solar
Generator
Hydro
Generator
Wind
Generator
Wave
Generator
Geothermal
Electric Power Plant
Electrolyzer
Hydrogen
Wood
Reformer
Organic Waste
Reformer
Biomass
Reformer

Wells to Wheels Analysis –
Key Assumptions

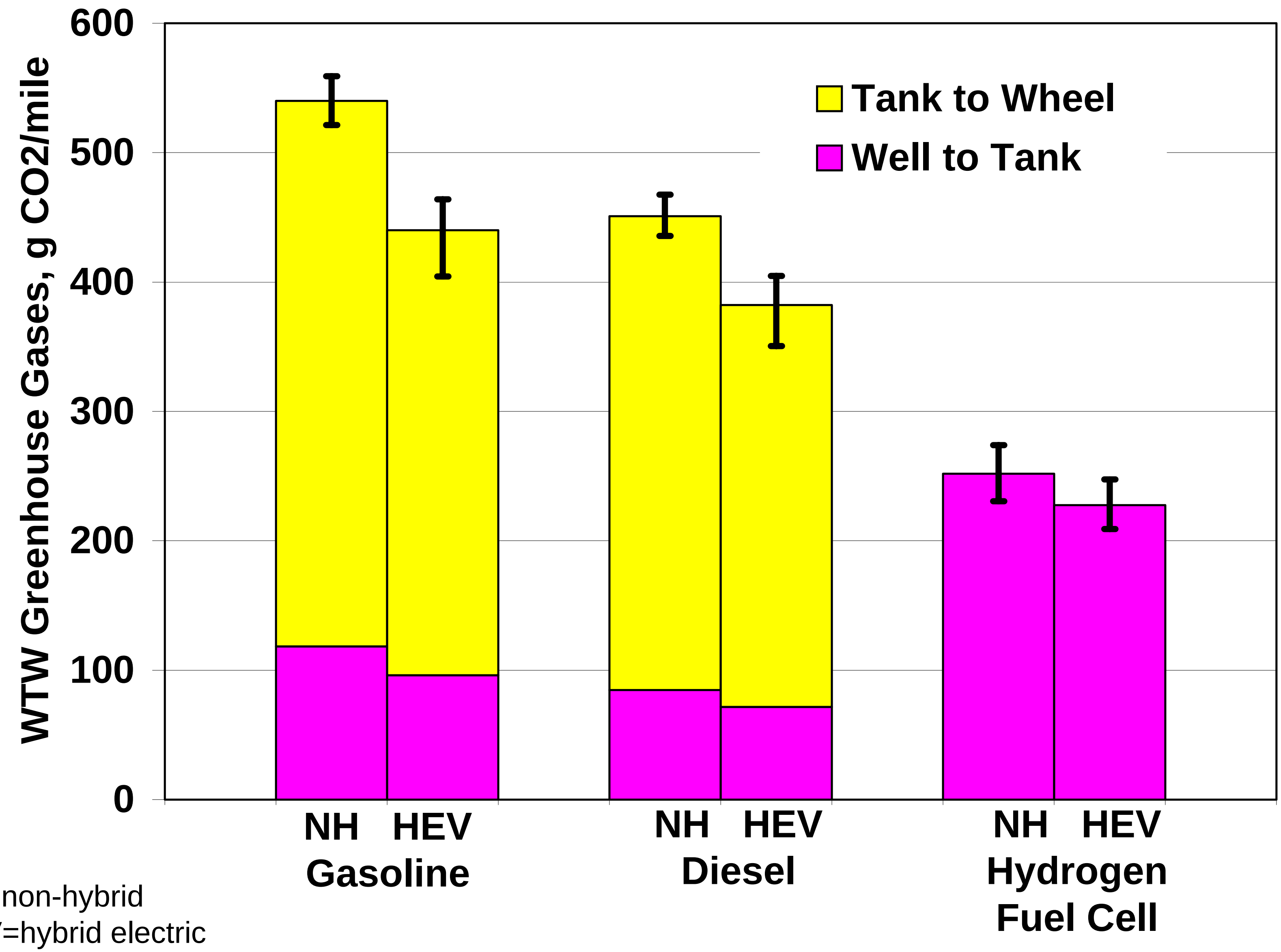
- **Systems approach**
- **Assessment of energy consumption and emissions**
- **Vehicle emissions targets**
  - Gasoline and diesel meet Tier 2 Bin 5
  - Hydrogen fuel cell meets Tier 2 Bin 0 (ZEV)
- **Hydrogen fuel cell vehicle**
  - Compressed hydrogen stored onboard at 5000 psi
  - Hydrogen reformed from natural gas at central plant
  - Electricity to compress H_2 from current U.S. mix:
    - 54% coal, 15% natural gas, 18% nuclear, 13% other

Well to Wheels Energy Consumption



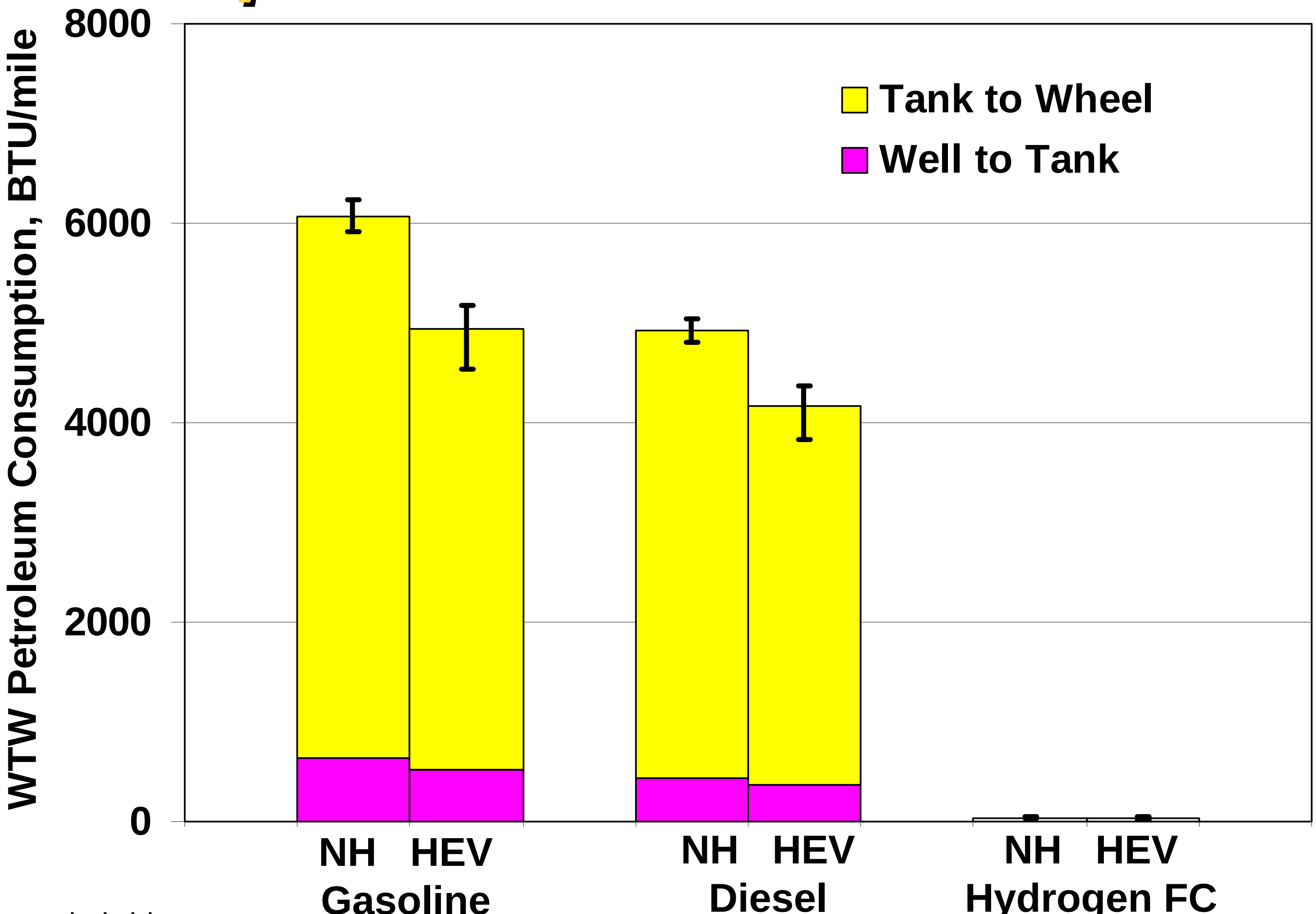
NH=non-hybrid
HEV=hybrid electric vehicle

Well to Wheels G-H-G Emissions



NH=non-hybrid
HEV=hybrid electric

Well to Wheels Petroleum Consumption



NH=non-hybrid
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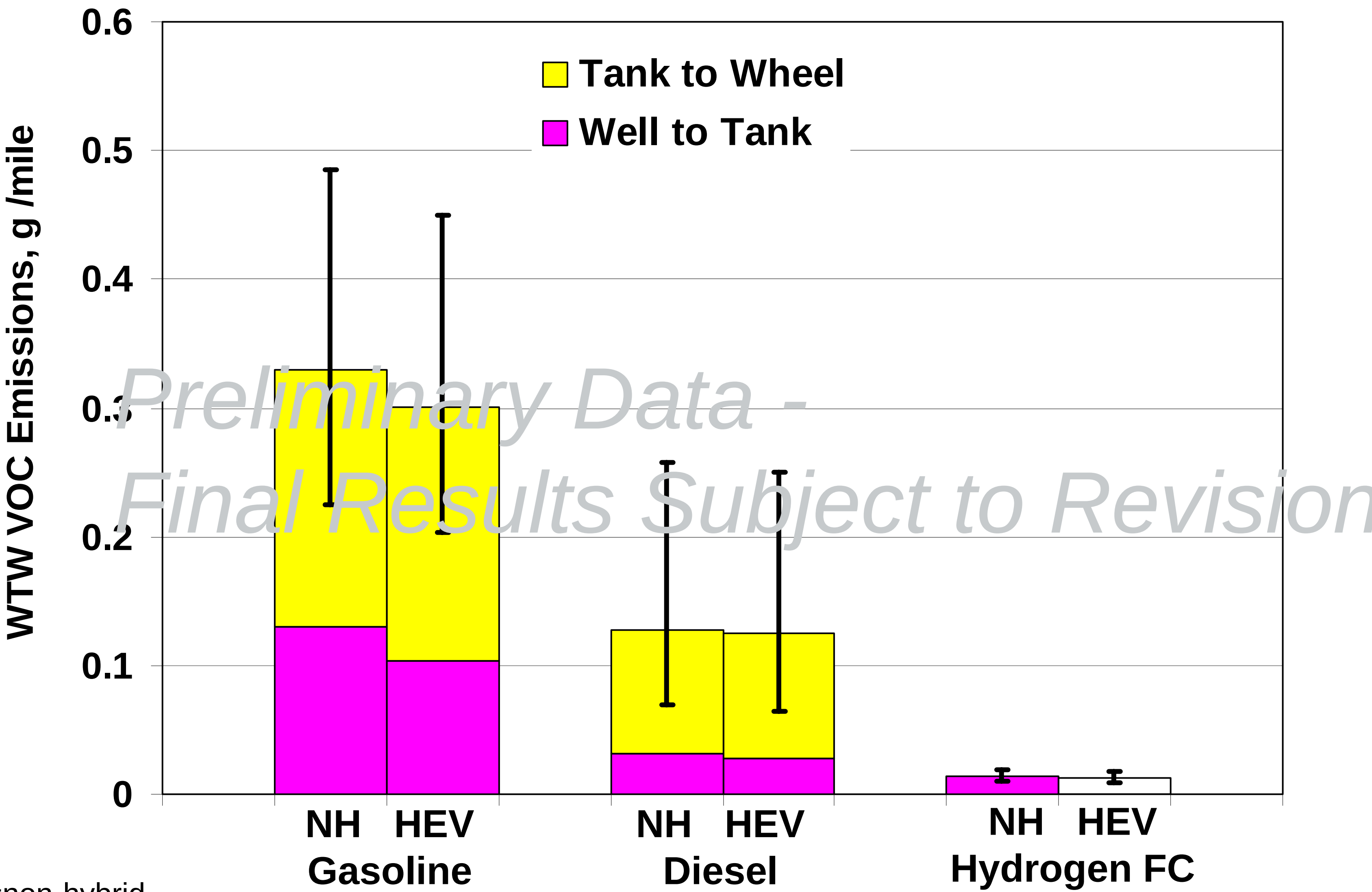
Estimation of Well-to-Tank Criteria Pollutants

- **Data for relevant facilities extracted from EPA's 1999 National Emissions Inventory**
- **Total emissions divided by throughput to develop emissions factors**
- **Distribution curve fit through existing data**
- **Distribution adjusted to account for improved future technology and new source controls**

Well to Wheels VOC Emissions



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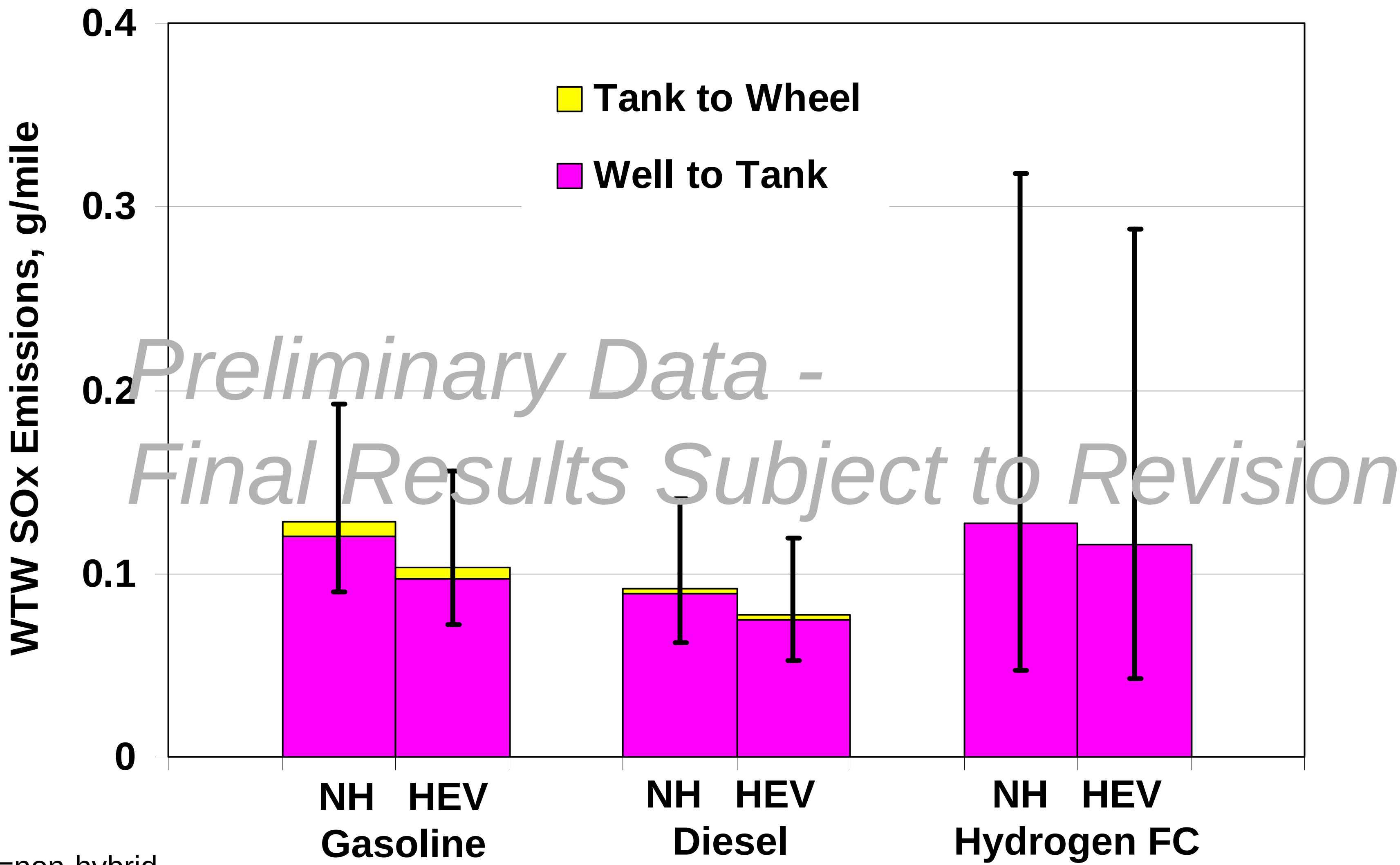
Well to Wheels SOx Emissions



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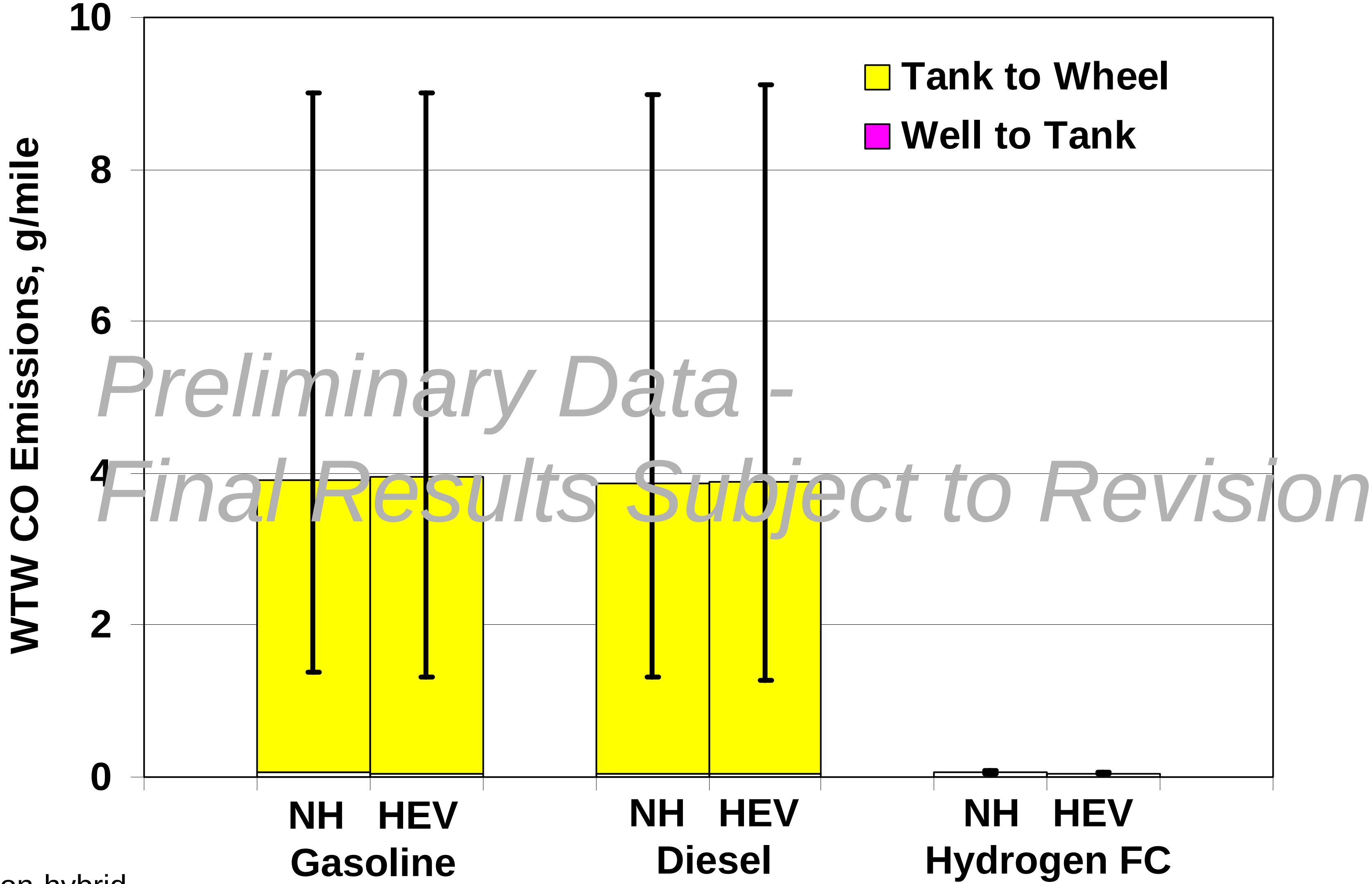
Well to Wheels CO Emissions



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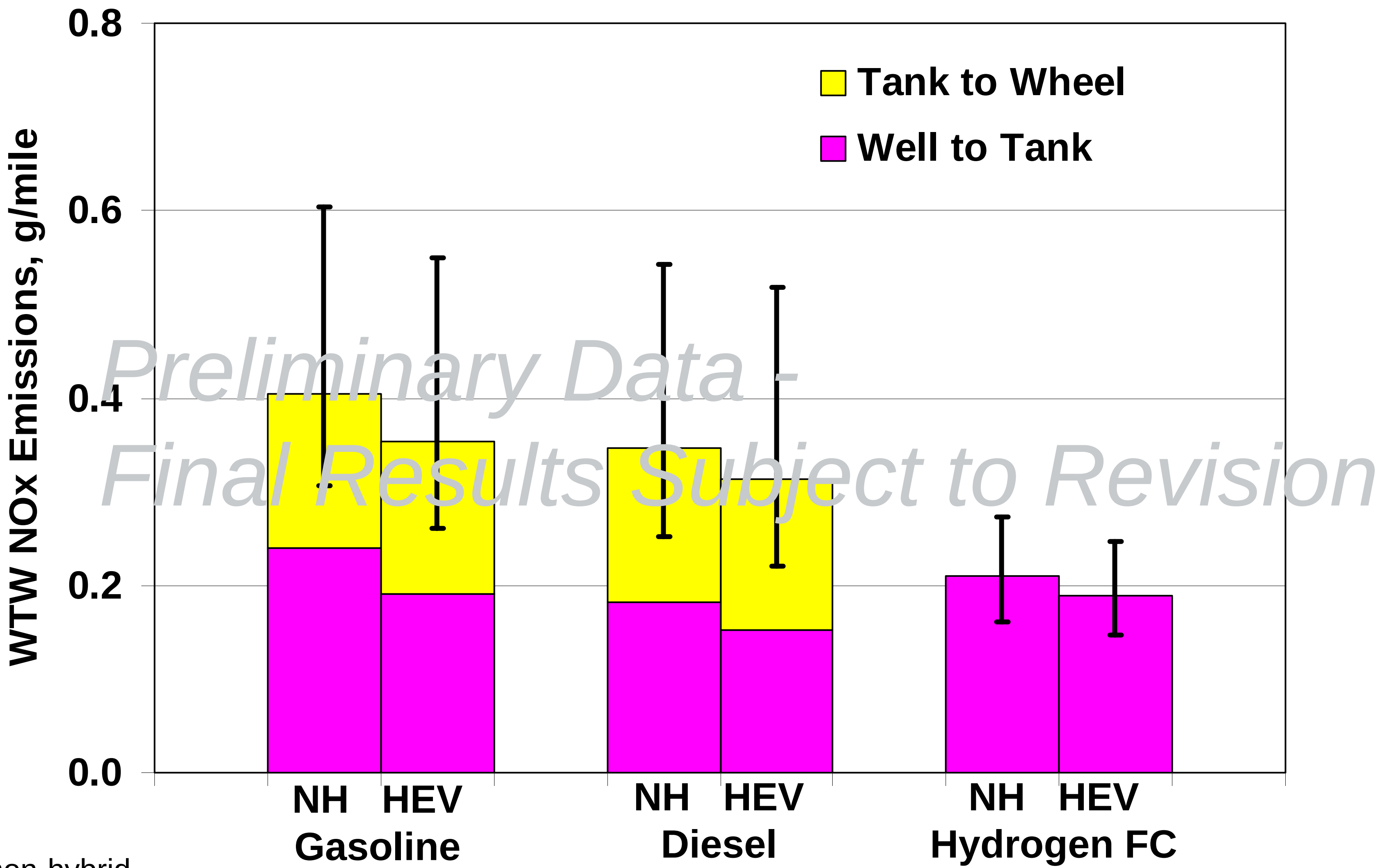
HEV=hybrid electric vehicle

Well to Wheels NOx Emissions



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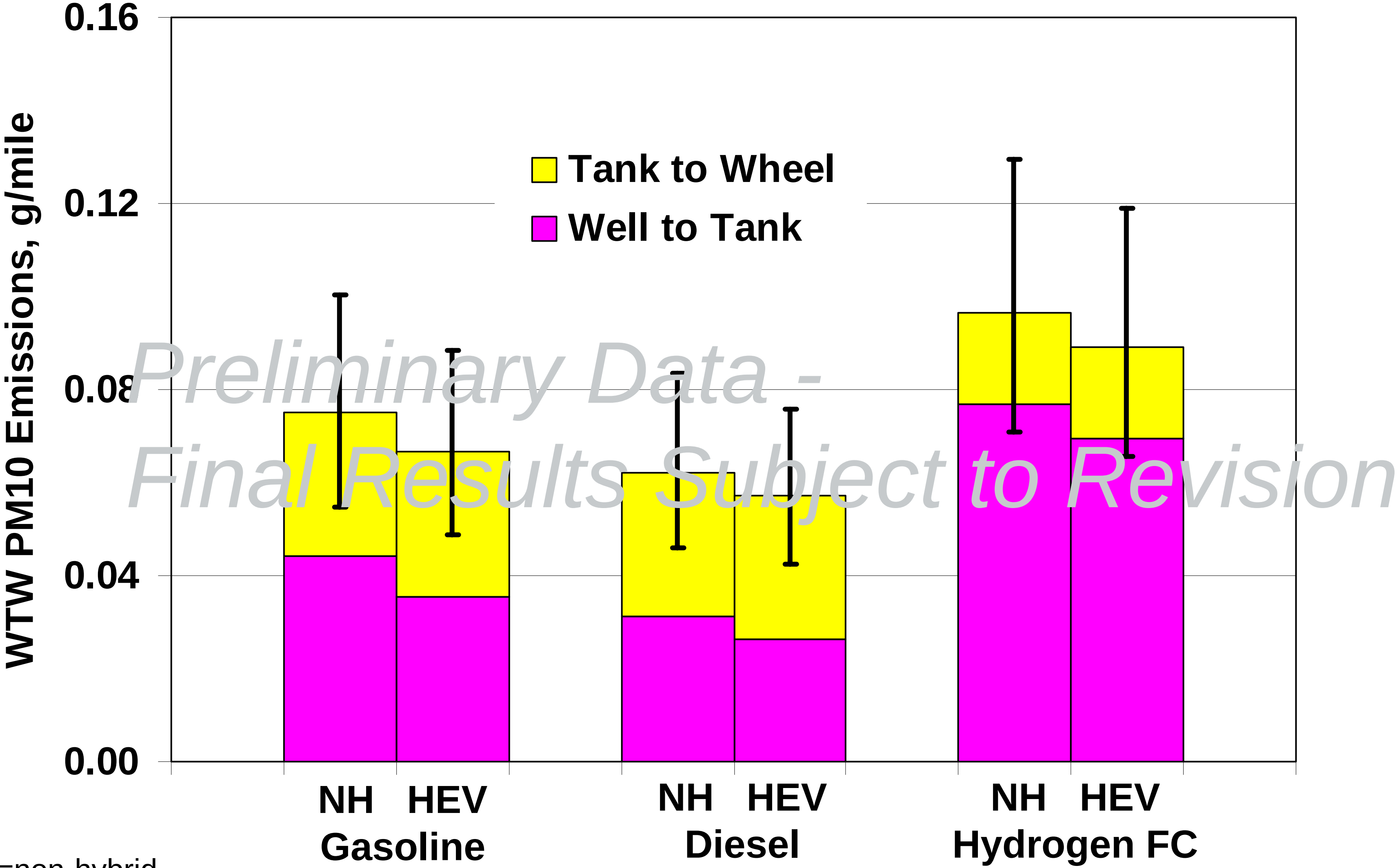
Well to Wheels Particulate Emissions



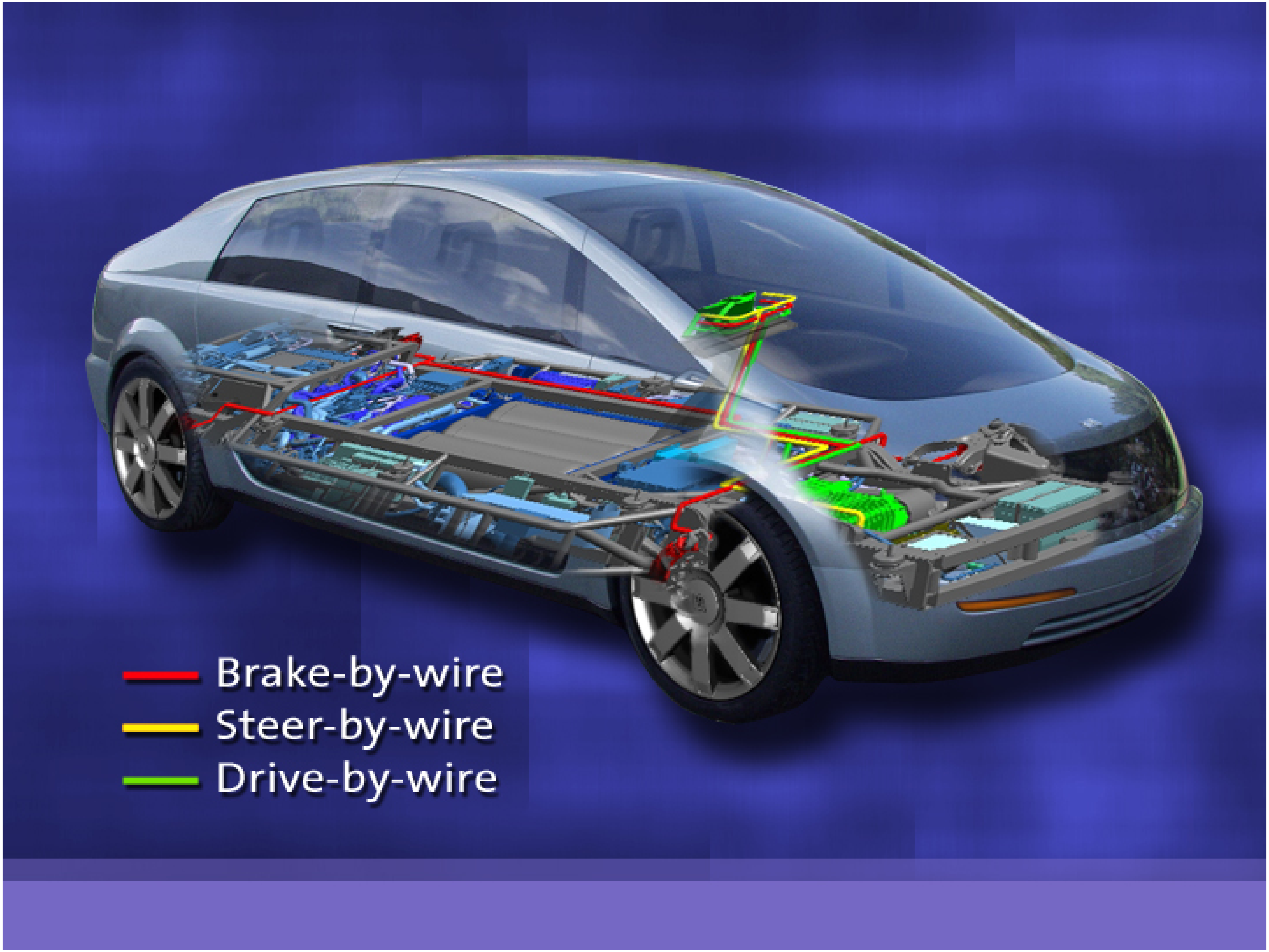
NH=non-hybrid
HEV=hybrid electric vehicle


GM
AUTONOMY
Reinventing the Automobile


AUTONOMY

HY-WIRE

Hydrogen By-wire


Brake-by-wire
Steer-by-wire
Drive-by-wire

Making Fuel Cell Vehicles a Reality

GM's Fuel Cell Goals

- Make fuel cell vehicles commercially viable by 2010
- First company to sell 1 million fuel cell vehicles profitably

Fuel cell vehicles on track to become competitive in the market

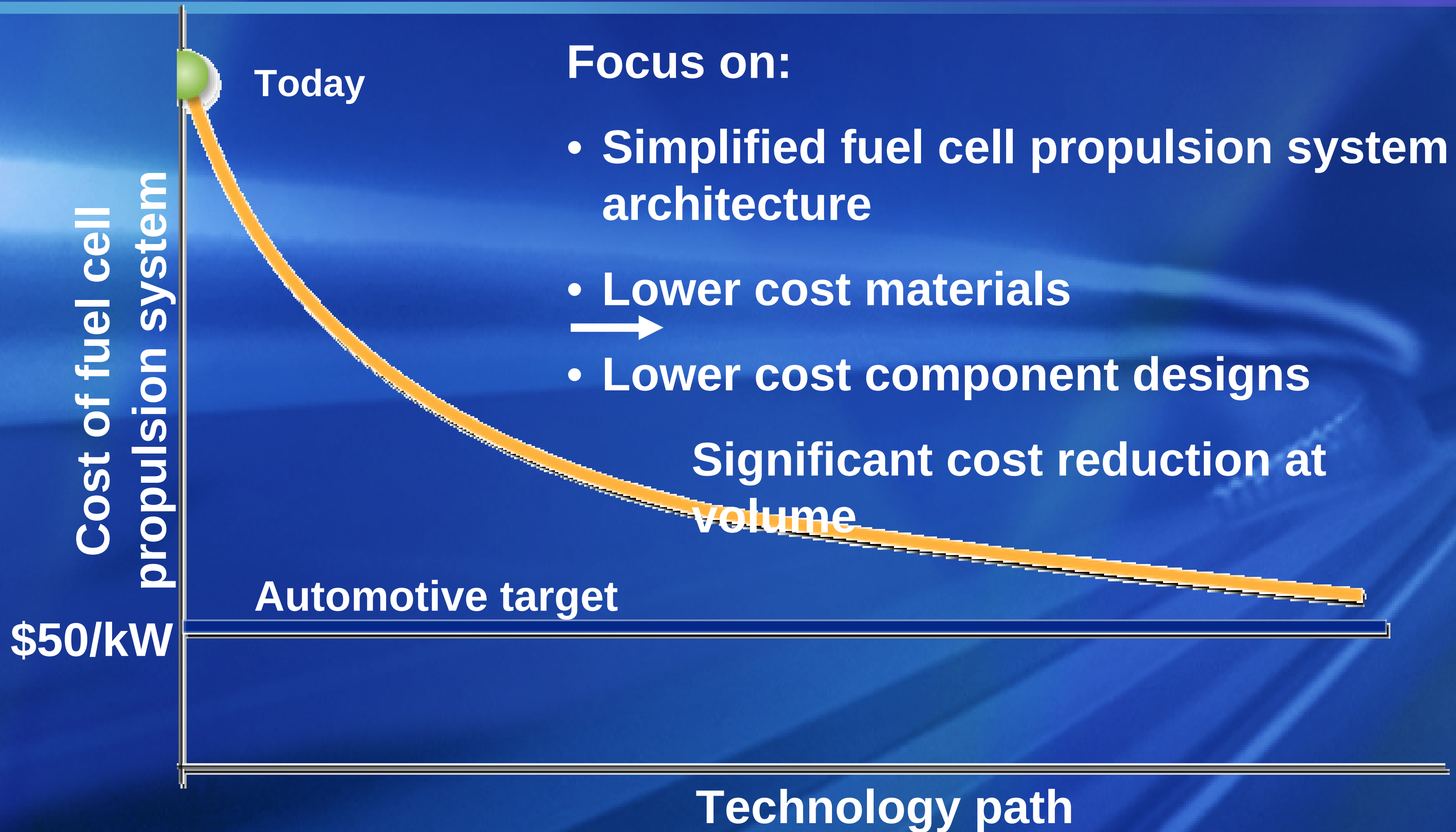
High confidence to achieve technology and costs goals to reach volume commercialization

<u>**Vehicle Sub-system**</u>	<u>**Status to Reach Development**</u>
Fuel cell stack	**Green**
Power module sub-systems	**Green**
Vehicle integration	**Green**
Traction	**Green**
Hydrogen storage • LH_2 • CGH_2	**Green** / **Yellow**

Key Commercialization Challenges

- Cost
- Hydrogen Storage
- Fueling Infrastructure
- Codes and Standards
- Supplier Development

Cost Reduction



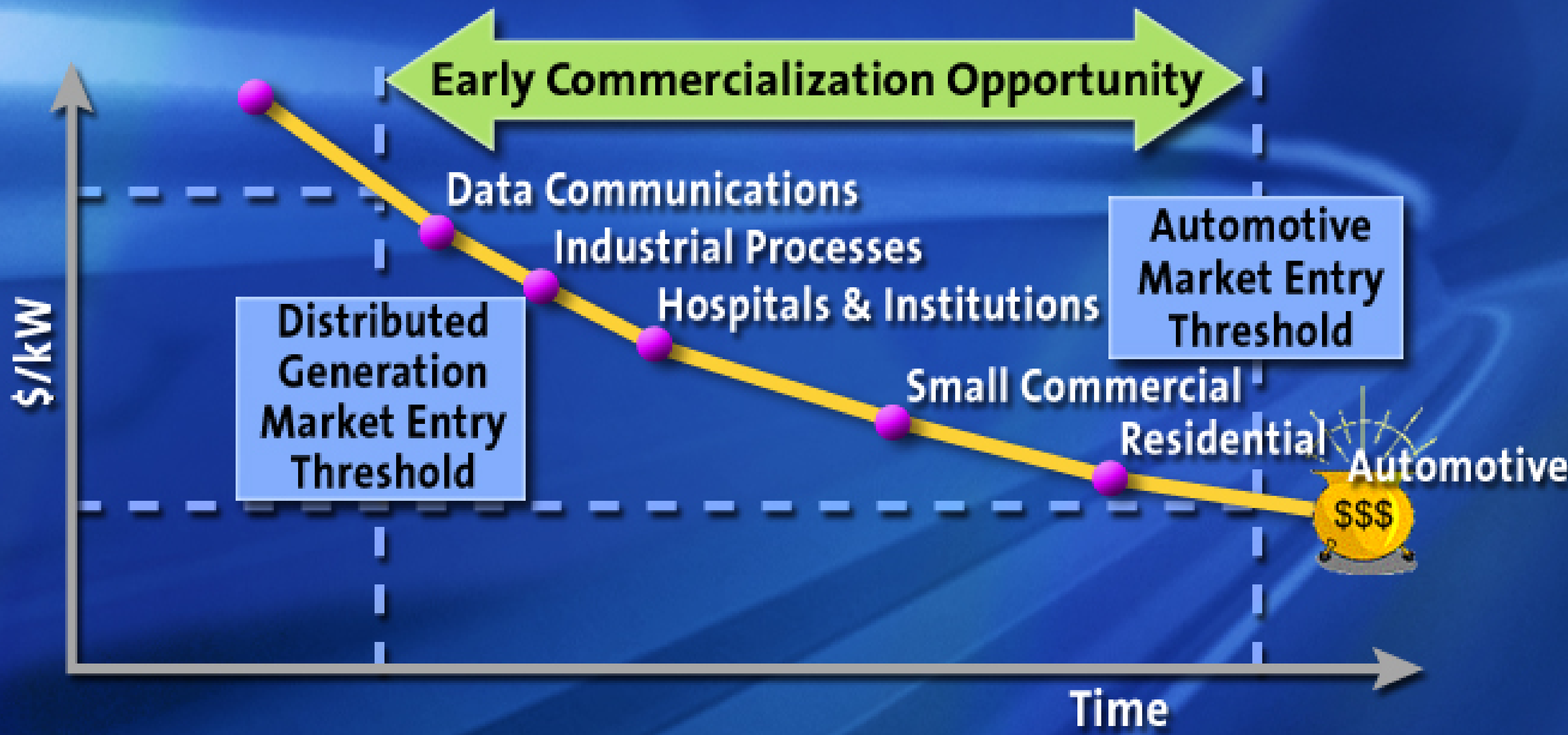
Focus on:

- **Simplified fuel cell propulsion system architecture**
- **Lower cost materials**
- **Lower cost component designs**

→ **Significant cost reduction at volume**

Distributed Generation Business Opportunities

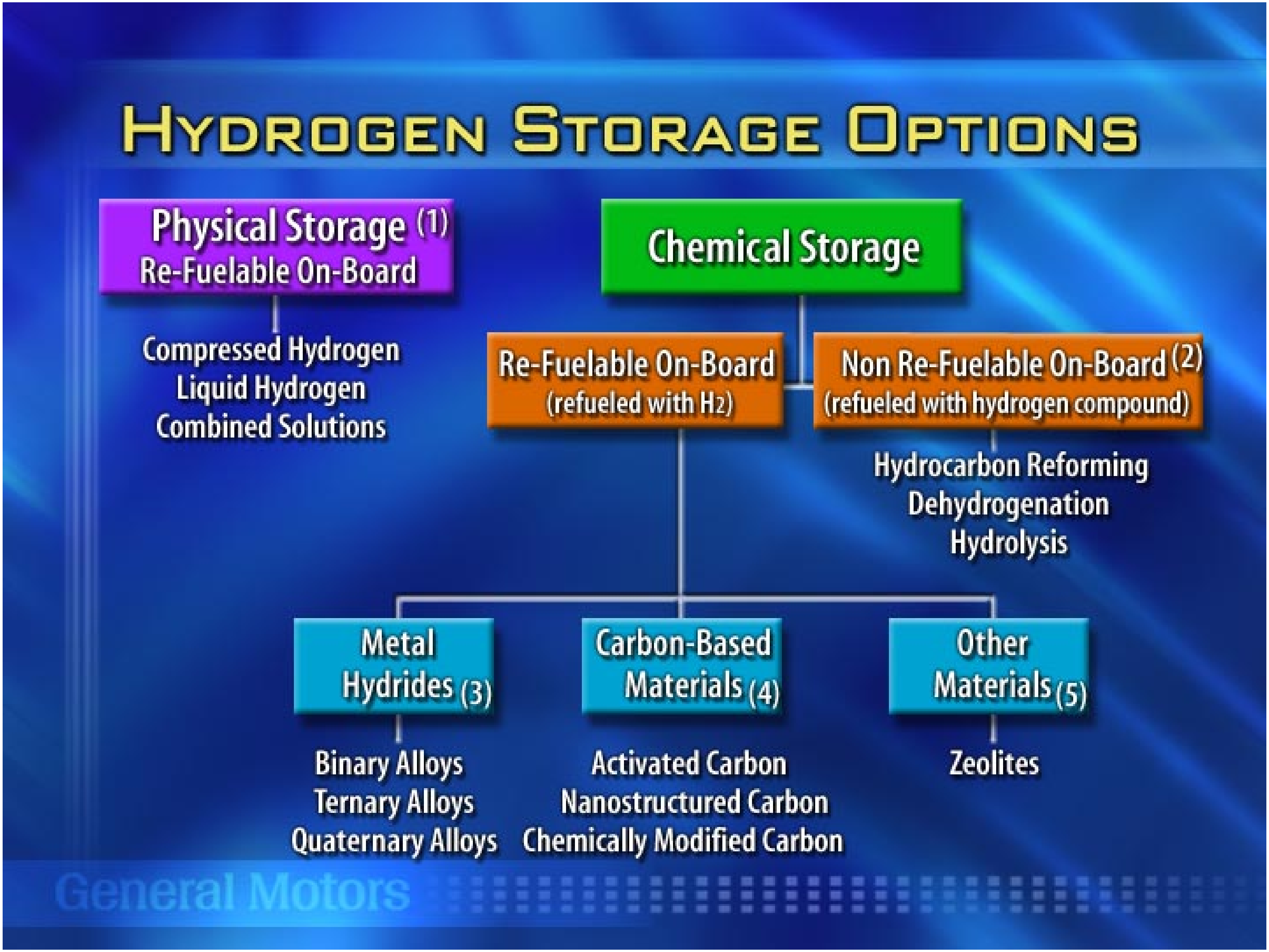
Interim Market Opportunities on GM's Roadmap



What Should Hydrogen Cost

Note:

- 1 Gallon gasoline = 1 Kg H2 fuel on energy-equivalent basis
- H2 / Fuel Cell vehicle is 2X more efficient versus today's ICE vehicles
- Assumes H2 vehicle fuel is initially untaxed


HYDROGEN STORAGE OPTIONS
Physical Storage (1)
Re-Fuelable On-Board
Compressed Hydrogen
Liquid Hydrogen
Combined Solutions
Chemical Storage
Re-Fuelable On-Board
(refueled with H2)
Non Re-Fuelable On-Board (2)
(refueled with hydrogen compound)
Hydrocarbon Reforming
Dehydrogenation
Hydrolysis
Metal Hydrides (3)
Carbon-Based Materials (4)
Other Materials (5)
Binary Alloys
Ternary Alloys
Quaternary Alloys
Activated Carbon
Nanostructured Carbon
Chemically Modified Carbon
Zeolites
General Motors

Safety of GM Fuel Cell Vehicles

CH2 tank testing (EIHP testing/validation)

Bonfire Test

Crash Tests

Assessment after Drop Test

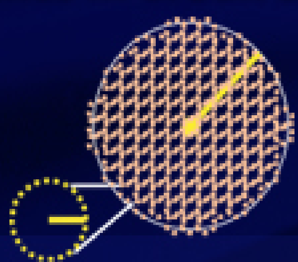
Vibration Test

Permeation Test

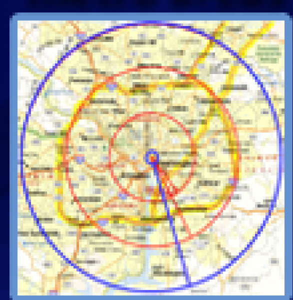
U.S. Infrastructure Development for First Million Fuel Cell Vehicles

- Hydrogen produced from many pathways
  - Hydrogen cost/mile approximately 1.3 times gasoline cost/mile
  - 1M fuel cell vehicles implies 0.2% natural gas demand increase
- $10-15B investment would establish network of 11,700 stations
  - Top 100 urban areas
  - 130,000 miles of highway
- Global codes and standards are key

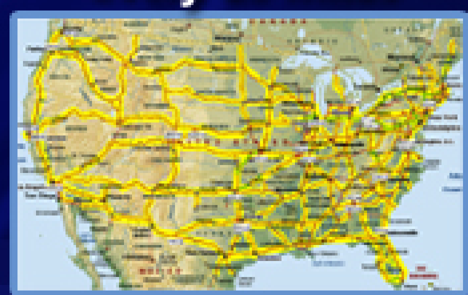
Station always within 2 miles in urban areas



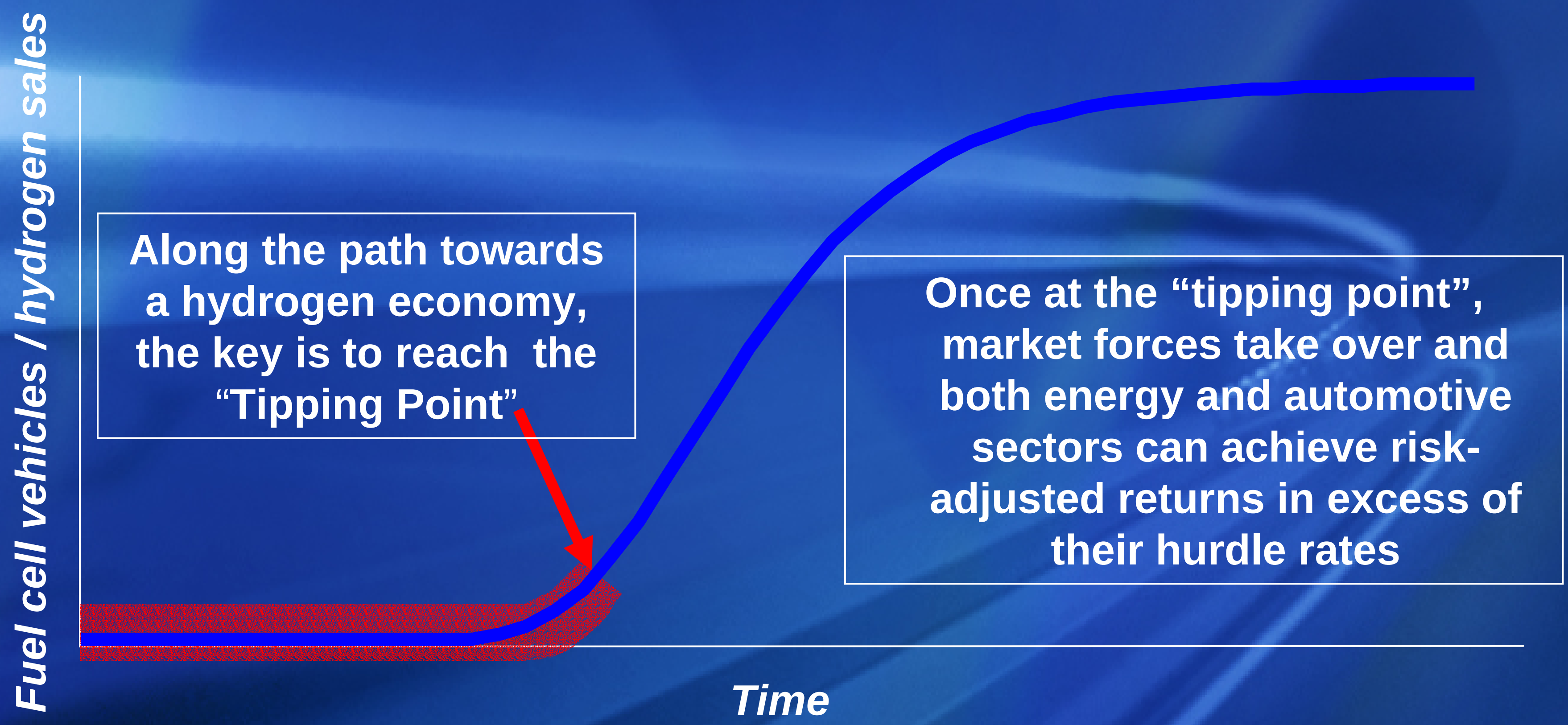
Top 100 U.S. metro areas



1 highway station every 25 miles



To start the transition to hydrogen, how much fueling infrastructure is needed?



"4 levers to pull" now to accelerate the time to reach the Inflection Point

Our Vision

- Fuel cells are the long-term power source
- Hydrogen is the long-term fuel
- Fuel cell vehicles price competitive by around 2010
- Stationary fuel cells pave the way for fuel cell vehicles
- Infrastructure means appliances, not just pipelines.

GM