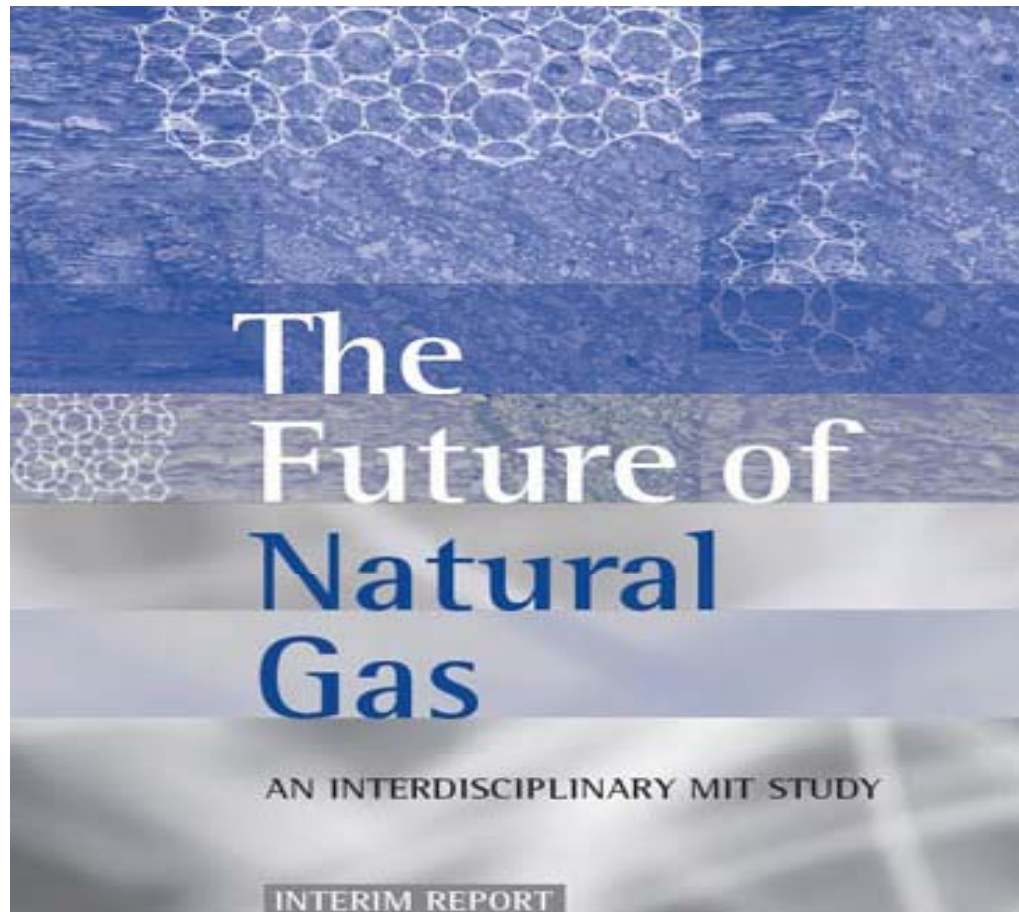




Natural Gas as a Vehicle Transportation Fuel: Illustrative Analysis on Light-Duty CNG Vehicles

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<http://web.mit.edu/mitei/>

Context for Work

- Research part of MIT's Future of Natural Gas Study
 - Study examines key factors in NG supply/demand in a carbon constrained world
 - Recent development of large unconventional NG resource in US
- NG as a Transportation Fuel
 - Currently area of small demand
 - 0.15% of all US Natural Gas Use
 - Area of Significant Interest for Expanded Use
 - 2 bills in US Congress to increase NG in transportation

This Presentation

- Illustrative analysis focused on the impact of CNG vehicle cost on market penetration in the light-duty sector
- Simplified analysis that does not take into account fueling infrastructure

The Potential Markets

Direct Use of Natural Gas in Transportation

1. **Light Duty Compressed Natural Gas (CNG) Vehicles**
2. Heavy Duty CNG Vehicles
3. Heavy Duty Liquefied Natural Gas (LNG) Vehicles

Indirect Use of Natural Gas in Transportation

4. Diesel and Alcohol Based Fuel, Electricity, and Hydrogen

CNG Conversion: C.W. Melchers (Singapore)



2009 VW Passat TSI Eco-Fuel (Sweden)



CNG as a Transportation Fuel

- CNG is Predominantly Methane (CH_4) (80-99%) - Remainder inert gases
- Stored on Vehicles in a Steel or Carbon Fiber Tank at 200atm ($\sim 2,900$ PSI) (139 kilo-pascals)
- CNG has $\frac{1}{4}$ the energy density of gasoline
- CNG has a lower proportion of C to H (4:1) than gasoline (2.3:1)
 - Combustion of CNG produces about 25% less CO_2 for same energy
- CNG is more knock resistant than gasoline allowing engines to operate at a higher compression ratio
 - could improve the efficiency and horsepower of natural gas engines

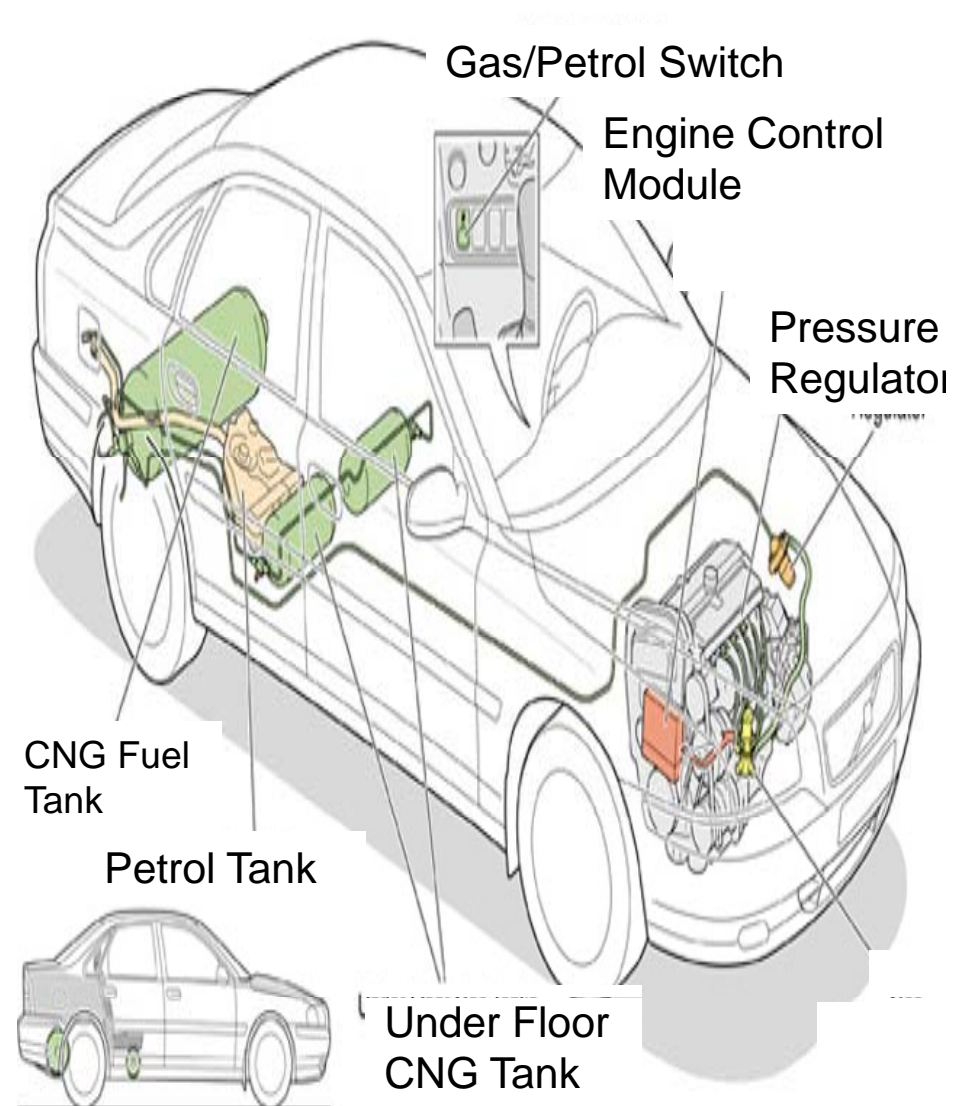
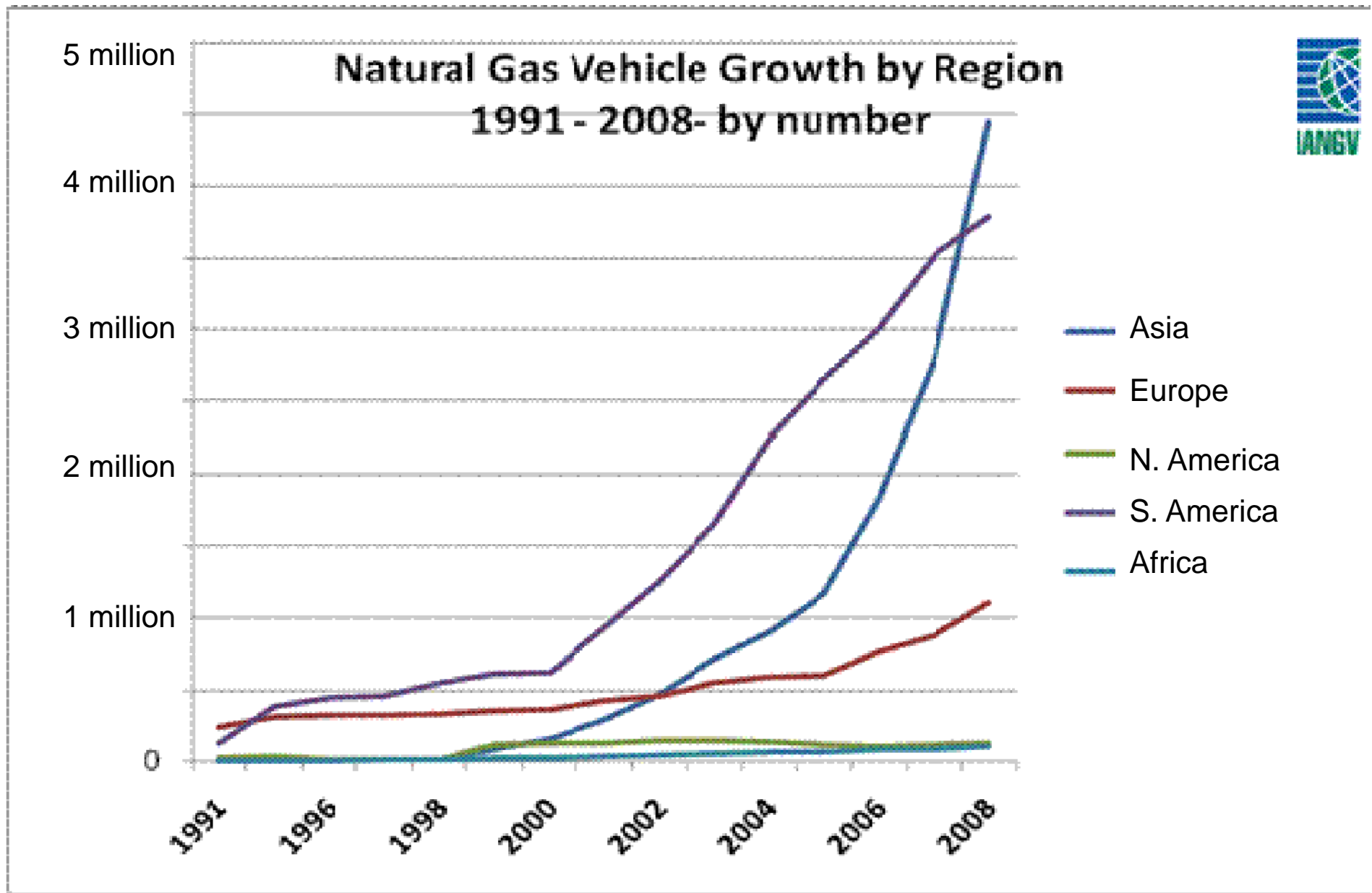
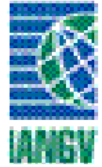
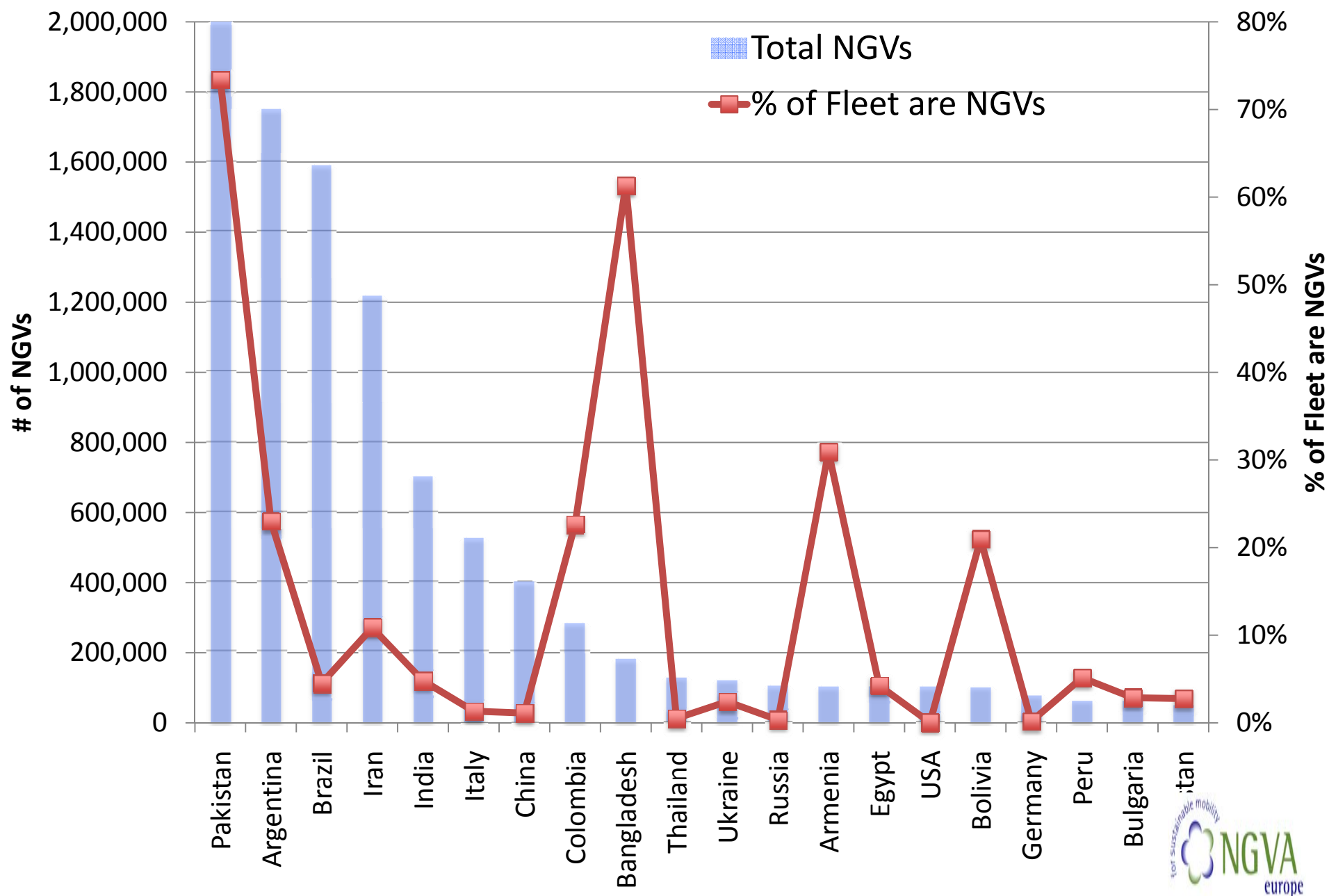


Image Source: Greencarcongress.com



- There are ~10 million NGV in the World
- NGV are ~1% of the ~860 million on-road vehicles in the World

NGVs by Country

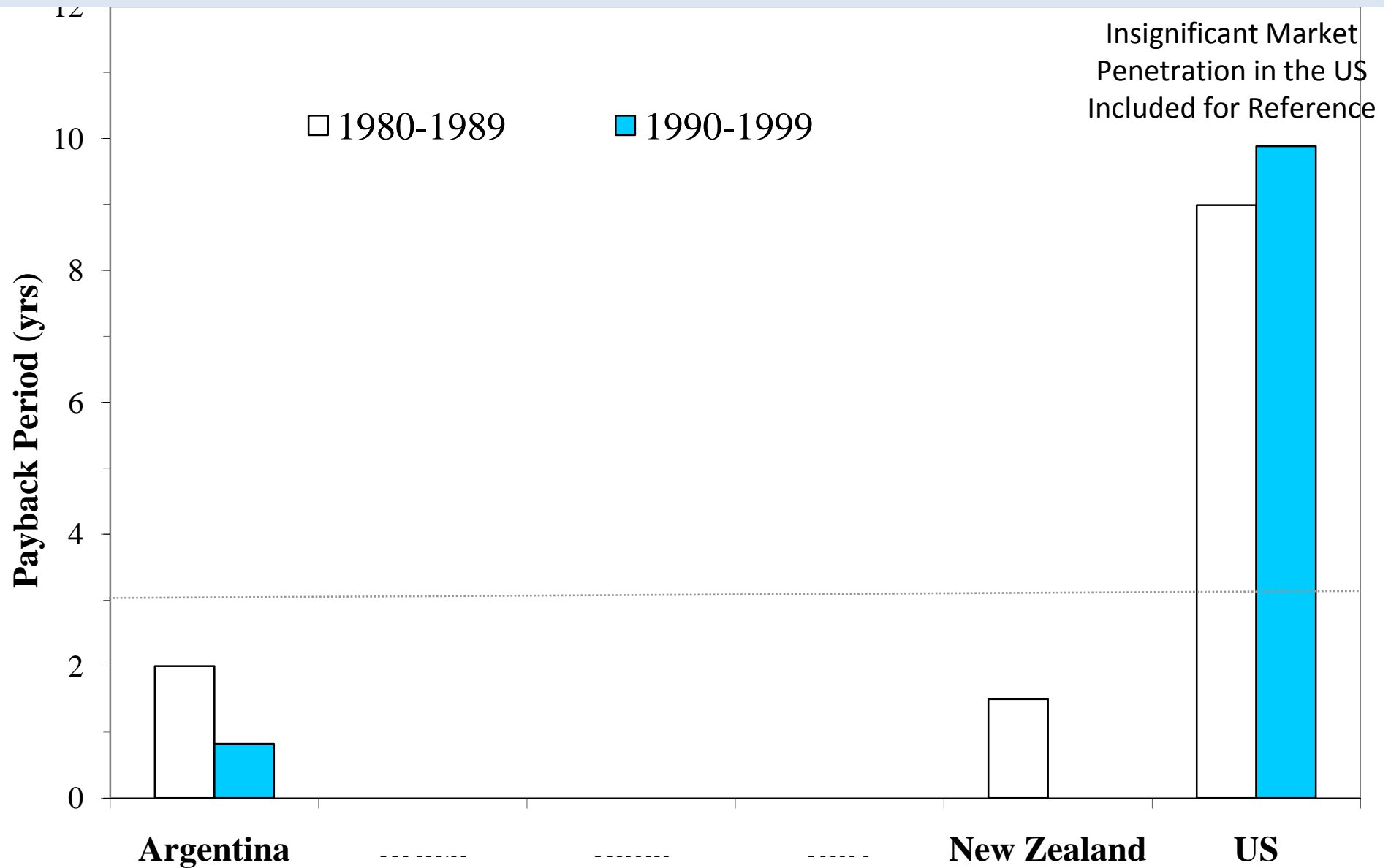


The Effect of Payback Period



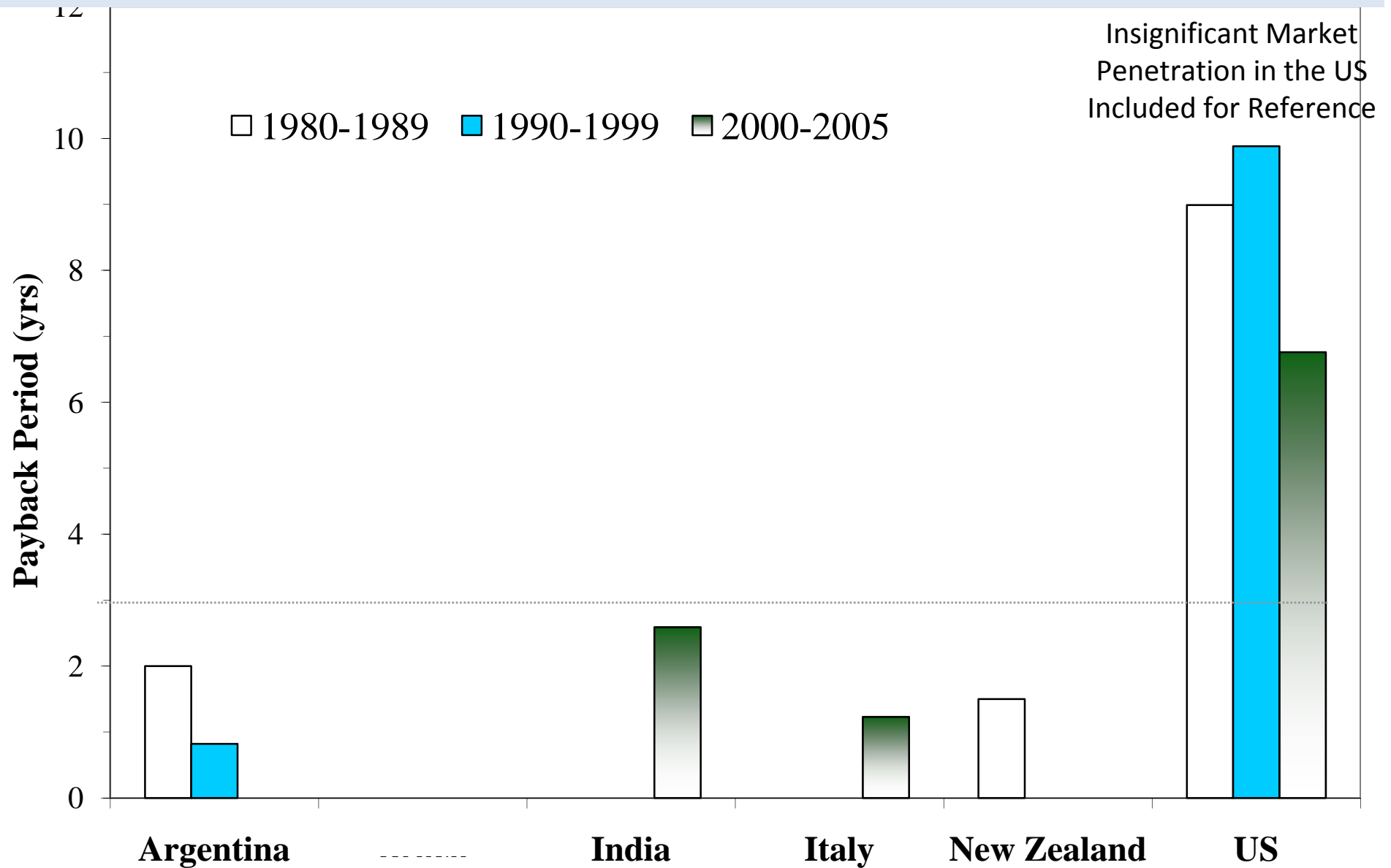
Yeh, Sonia (2007) An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles. [Energy Policy \(35\), 5865 - 5875](#)

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Surge in Natural Gas Has Utah Driving Cheaply

Source:
NY Times

By CLIFFORD KRAUSS
Published: August 29, 2008

SALT LAKE CITY — The best deal on fuel in the country right now might be here in [Utah](#), where people are waiting in lines to pay the equivalent of **87 cents a gallon**. Demand is so strong at rush hour that fuel runs low, and some days people can pump only half a tank.



George Frey/Bloomberg News

Bret Oliphant stopping to fill up in Salt Lake City.

The Energy Challenge
A Foreign Oil Alternative

Articles in this series are

It is not gasoline they are buying for their cars, but [natural gas](#).

By an odd confluence of public policy and private initiative, Utah has become the first state in the country to experience broad consumer interest in the idea of running cars on clean natural gas.

Residents of the state are hunting the Internet and traveling the country to pick up used natural gas cars at auctions. They are spending thousands of dollars to transform their trucks and sport utility vehicles to run on compressed gas. Some fueling stations that sell it to the public are so busy they frequently run low on pressure, forcing drivers to return before dawn when demand is down.

It all began when unleaded gasoline rose above **\$3.25** a gallon last year, and has spiraled into a frenzy in the last

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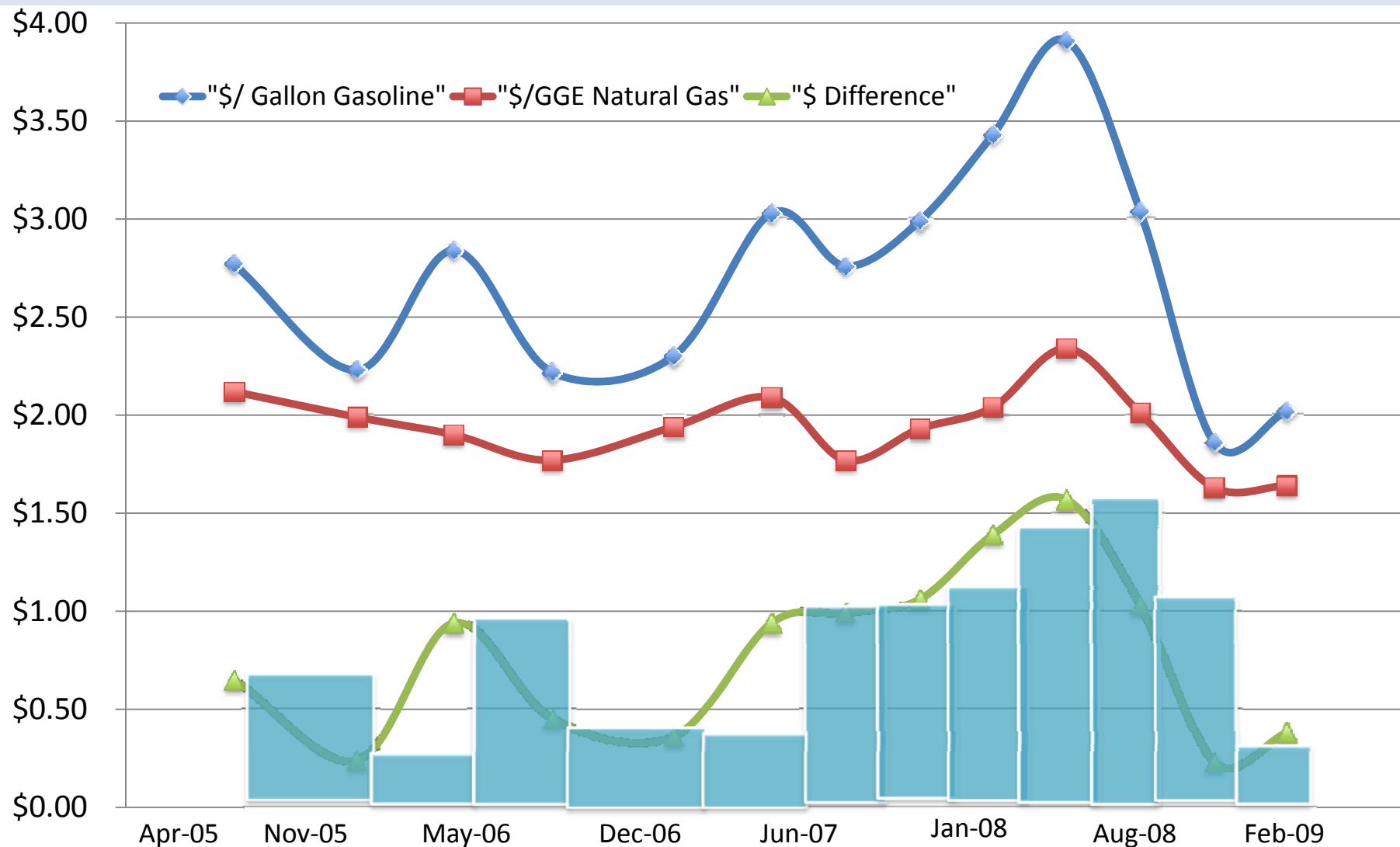
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Overall Average Fuel Price in the US on an Energy Equivalent Basis (Source: DOE EIA)



Financial Saving from Using Natural Gas (12K miles/year) (25miles/gallon)

- Over entire time period analyzed (3.6 years): ~\$1350 or ~\$370/year
- From April 2008 to October 2008 (.5 years): ~360 or ~\$715/year

Two US Vehicle Options: Civic GX or Certified Conversion



Honda GX: ~\$7,000 > Civic LX
Dedicated NGV = Only runs on NGV

	2009 Honda Civic GX NGV	2009 Honda Civic Sedan
Engine Displacement (cc)	1799	1799
Horsepower @ 6300 rpm	113	140
Torque (lb-ft @4300 rpm)	109	128
Compression Ratio	12.5:1	10.5:1
Cargo Volume (ft3)	6	12
Fuel (gallon)	8 GGE @ 3600 PSI	13.2
Fuel Economy (City/Highway/Combined)	24/36/28	25/36/29
Vehicle Range	224	382.8

EPA or CARB Certified Conversions (~\$10K >Original Vehicle)

E.g. Ford Focus = \$16,000 and Ford Focus Converted to NGV \$26,000

US Requires that all Conversion Kits are Certified

- Based on the Clean Air Act's prohibition against tampering with motor vehicle emission
- Certifications are vehicle model and engine type specific (2009 Ford Focus)
- Certification is expensive >\$200,000 - cost is amortized over small volume of conversions

Compare to \$2,500 Conversion Cost from German Company Operating in Singapore

European Bi-Fuel Vehicle Options



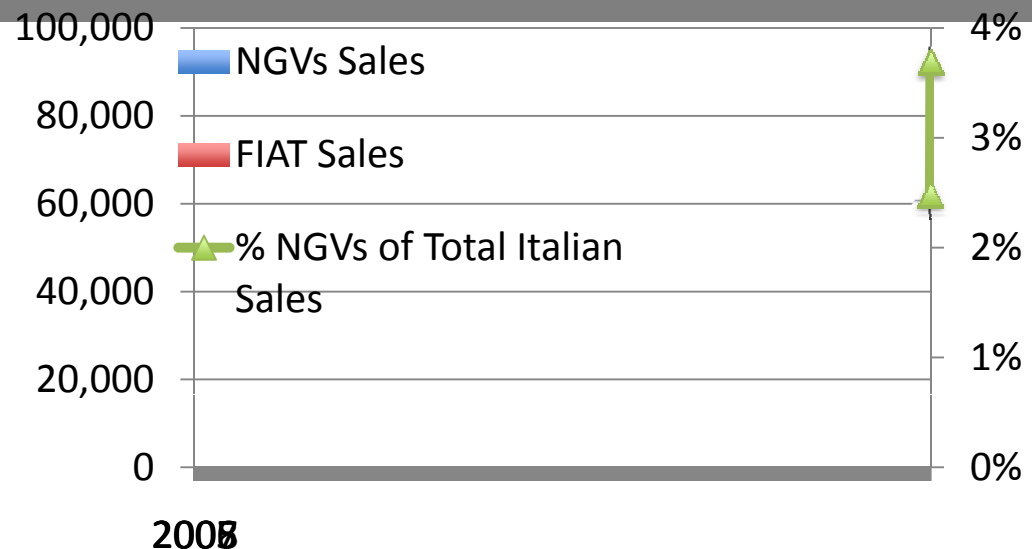
Passat TSI EcoFuel: ~\$3,600
Bi-Fuel (CNG and Gasoline)

VW Passat	TSI EcoFuel	TSI 160
Engine Displacement (cc)	1390	1798
Horsepower	150 at 5,550 rpm	160 at 5,000 rpm
Torque (lb-ft @4300 rpm)	162 at 1500-4500	184 at 1500
Acceleration (0-62 m/hr)	9.8	9.9
Top Speed m/hr	132	137
Cargo Volume (ft3)	17	17
Range (Total/NG/ Petrol) m	572/292/280	577/NA/577
CO2 emissions (g/km)	119	172

- Named the Most Environmental Friendly Car in Europe (ADAC)
 - The second place went to the Toyota Prius
- www.jazzcalculator.com (Marketing) - 20g CO2/km (Biomethane)

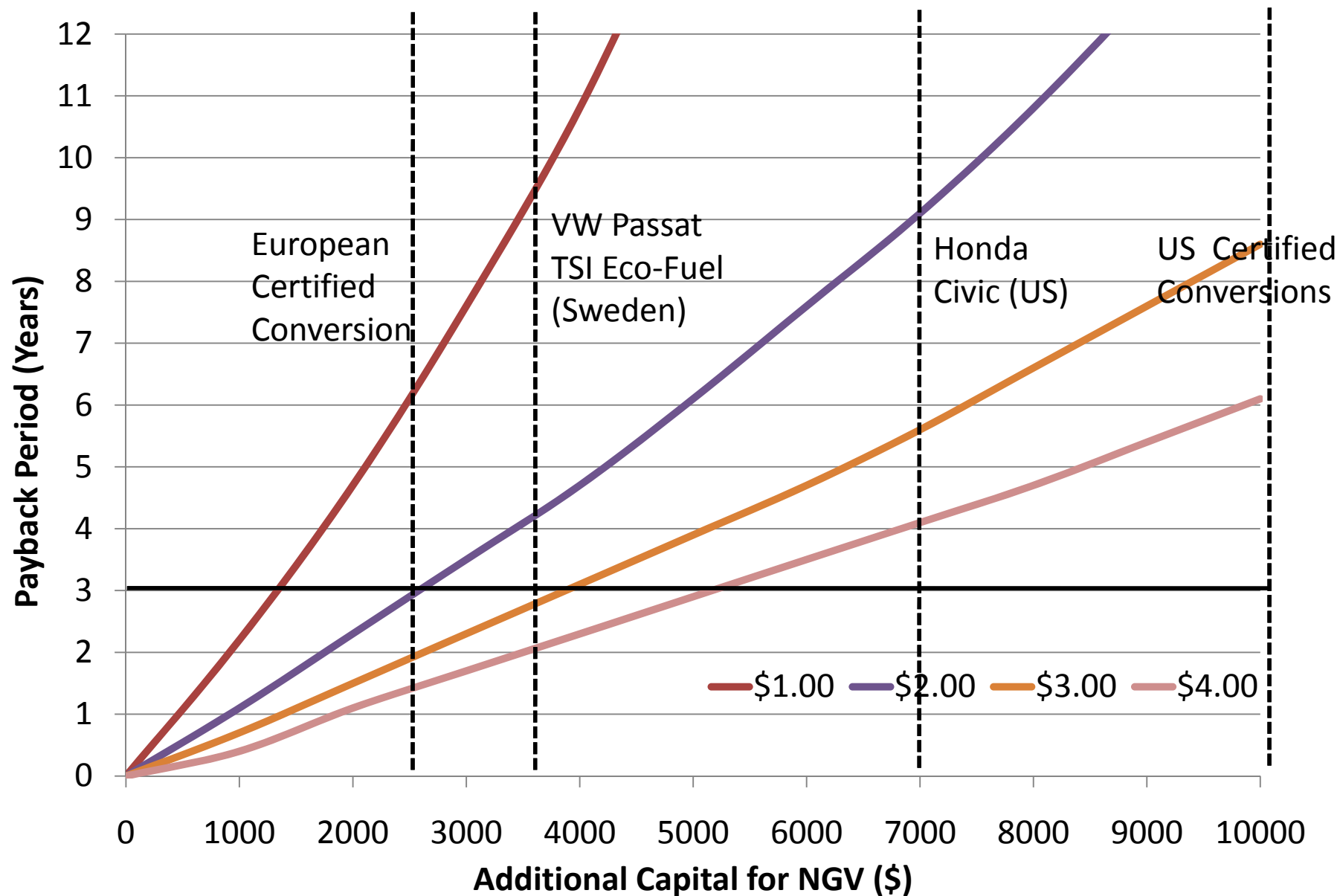


FIAT Punto and Panda: ~\$2,500
Bi-Fuel (CNG and Gasoline)



Effect of Additional Capital for NGV and Fuel Price Spread on Payback Period

Miles/yr: 12,000 Miles/gallon: 25 Discount Rate: 5%



Focus on Market Segments

Fuel Price Spread	Incremental Cost	12,000 miles per year		35,000 miles per year	
		\$3,000	\$7,000	\$3,000	\$7,000
	\$0.50	19.5	>100	4.9	13.9
	\$1.50	4.7	13.3	1.6	3.7
	\$2.50	2.7	7	0.9	2.2

Conclusions from Illustrative Analysis

- High Incremental Cost in the US is a Market Barrier to CNG Vehicle Market Penetration
- Reducing this market barrier may facilitate market penetration and reduce need for public subsidy
- There are niche markets where CNG vehicles make economic sense