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The Next Generation Near-Zero Emission Natural Gas Vehicles

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Context

- Natural gas is
  - Clean
  - Cost effective
  - Domestic
- However – emission standards are getting tighter and tighter
- Key question – how close can natural gas get to zero emissions and at what cost?

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NGV Technology Advances will be Key

Opportunity Area	Comments
Engine Technology and Drive Trains	• Improvements of 35% to 60%+ in fuel economy predicted by some experts • Both engine technology and hybridization can help • Aerodynamics, light-weight materials and peripherals can help as well • Fuel efficiency eliminates all tailpipe emissions -- #1 in the "loading order"
Advanced After-treatment	• Catalyst systems similar to those in use today • Has technical potential to reduce NOx to "near zero" levels (90% less than 2010 standards)
Carbon – the elephant in the room	• Biogas • Solar methane synthesis
"Supporting " advances -- On-board tanks -- Fueling infrastructure	• Helps reduce lifecycle emissions by reducing required compression energy • Low –cost, efficient fueling infrastructure is a key enabler • Efficiency improvements reduce lifecycle emissions

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Example -- Next Generation Refuse/Transit

Objective

Develop dedicated natural gas engine with near zero emissions without sacrificing performance or efficiency compared to 2010 diesel engine

Demonstration Elements

- Modify 11L 340hp Doosan engine (conversion from lean burn SCR)
- Stoichiometric operation
- Cooled Exhaust Gas Recirculation for mixture dilution
- Three way Catalyst
- Advanced ignition system for highly dilute mixtures
- Optimized in-cylinder turbulence
- High efficiency turbo matching
- Advanced control for knock and misfire detection

Expected Benefits:

- 80% reduction in NOx emissions
- Replace SCR with 3-way catalyst
- Similar efficiency and cost to diesel alternatives

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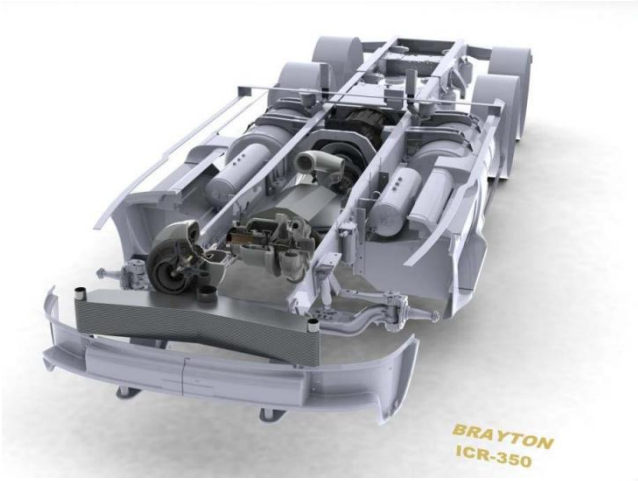
Example -- Hybrid Heavy Duty Vehicles

Objective

Develop a near zero emissions dual liquid / natural gas combustor for the existing 350 kW gas turbine engine designed for Class-8 trucks.

Benefits

- Near-zero emissions (90% NOx improvement)
- Fuel flexibility
- Improved efficiency through hybridization



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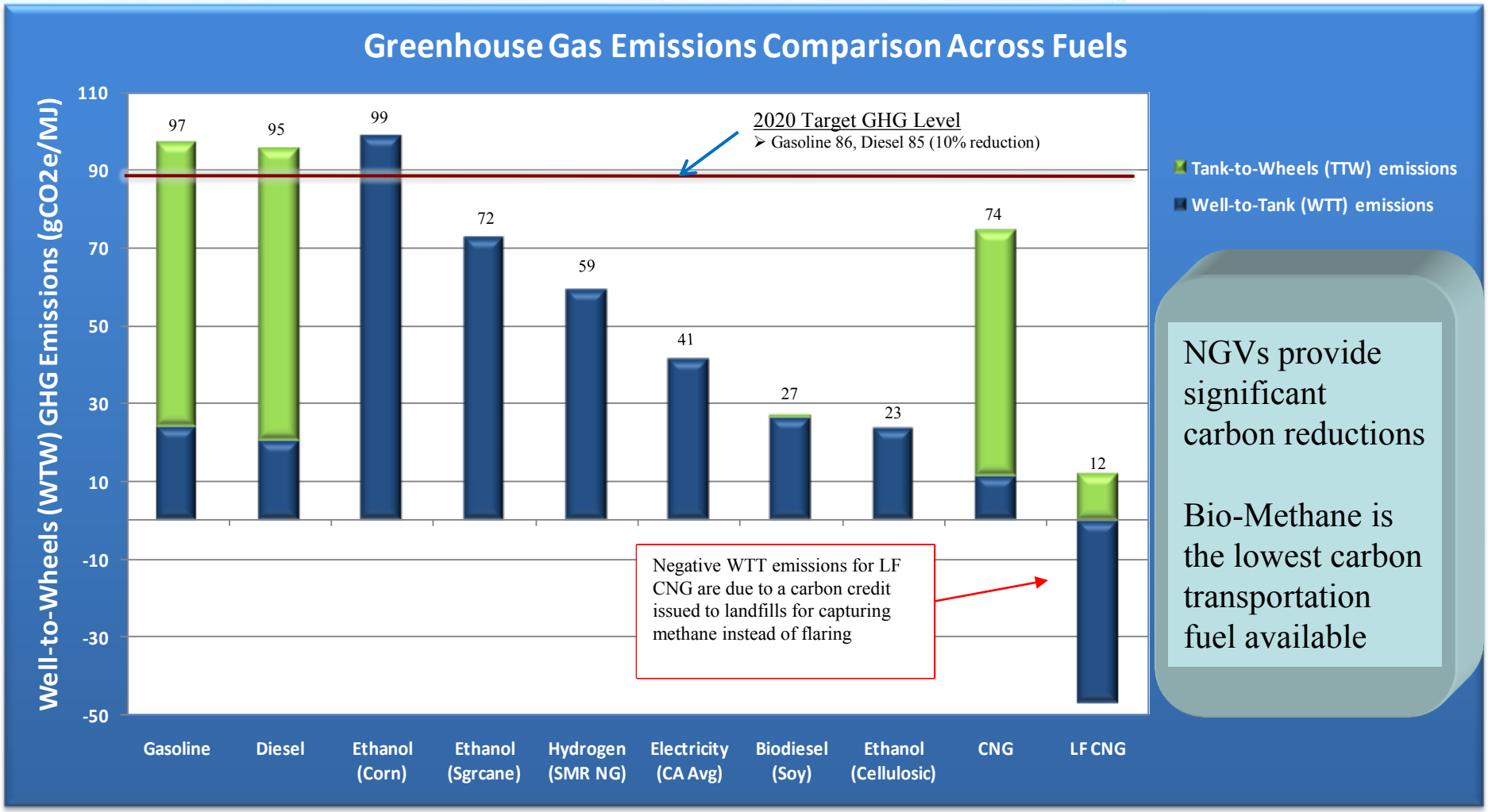
Biogas = Lowest GHG Vehicle Fuel Pathway



NGVs provide significant carbon reductions

Bio-Methane is the lowest carbon transportation fuel available

Source: CARB

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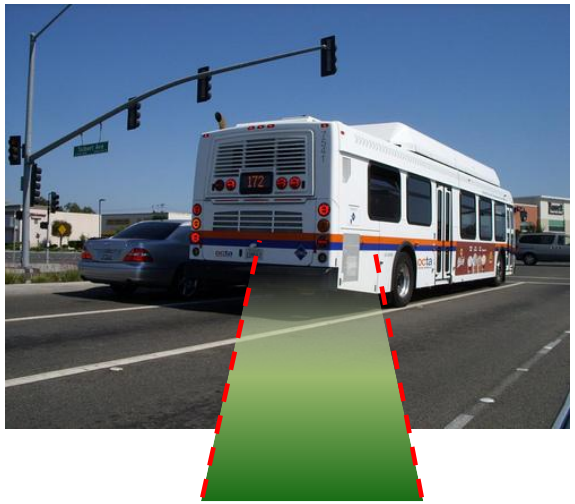
Example – Near Zero Emission Buses

SoCalGas commissioned analysis to assess performance and cost effectiveness of various natural gas solutions for transit buses

- Baseline technologies
  - Model year 2010 diesel or natural gas engines (0.2 g/bhp-hr NOx)
  - Hydrogen hybrid-electric fuel cell
  - Battery electric

- Fuel alternatives for a "zero emission" bus
  - Natural gas with advanced after-treatment
  - Natural gas hybrid-electric
  - Renewable CNG
  - Hydrogen-natural gas blended fuels



Three-way catalyst system

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Analysis Results

Technologies	NOx (g/mi) (tailpipe)	GHG (g/mi) (WTW)	Cost per ton NOx reduced	Cost per ton GHG reduced	Total cost per mile
2010 CNG	0.8	2,607	n/a	($590)	$1.56
CNG with advanced after-treatment	0.12	2,607	($536K)	($540)	$1.60
H/CNG	0.8	2,688	n/a	($393)	$1.74
Renewable NG	0.8	435	n/a	($52)	$1.80
CNG hybrid	0.6	1,955	($705K)	($106)	$1.85
2010 Diesel - baseline	0.8	3,282	n/a	n/a	$2.00
Diesel hybrid	0.6	2,462	$675K	$164	$2.15
Battery electric	0.0	1,593	$1.1M	$500	$2.93
Fuel cell	0.0	1,793	$4.7M	$2,539	$6.17

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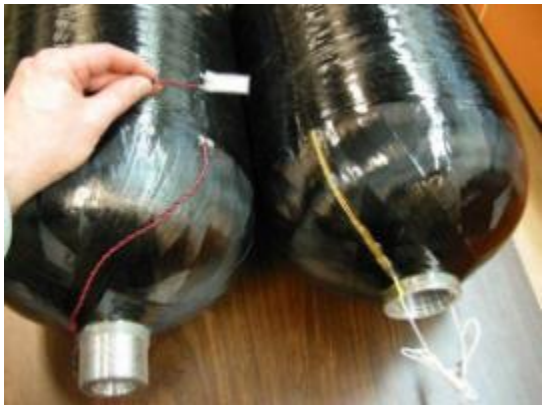
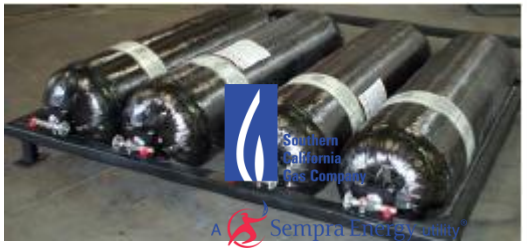
Advanced Storage Systems

- Advanced cost effective CNG and LNG on-board fuel storage systems
  - Adsorbed Natural Gas, new materials
  - Conformable Tank Configurations
  - Extended Cylinder Certification Life
  - Non-destructive Active Monitoring for Damage Detection
  - Nitrogen Blanketed/No Vent Cryogenic Tank Technology



A 120-gallon LNG tank is mounted under the cab.



Example – Low-Pressure Adsorption Storage

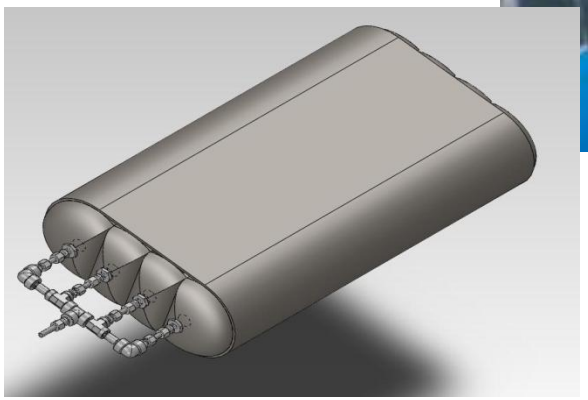
Objective

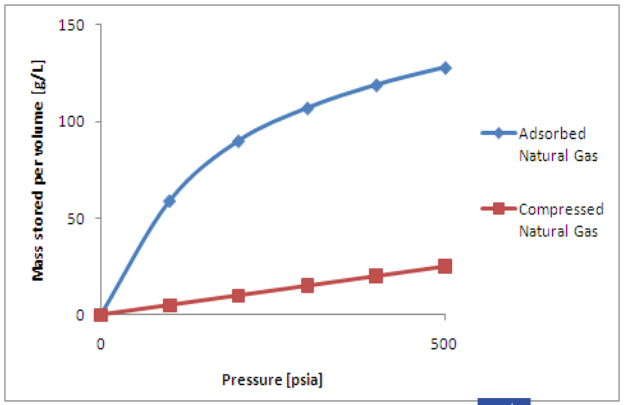
Reduce compression requirement for on-board natural gas fuel storage at comparable energy density (volume requirement

Benefits:

- Less-expensive, thinner-walled pressure vessels
- Conformability
- Less-compression

Adsorption Storage Media





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Example – Next-gen CNG Infrastructure

Objective:
The project is demonstration of three self-contained CNG compressor units manufactured by GNC Galileo S.A., of Argentina for fleet and retail applications

Potential benefits over traditional CNG compressors:

- Compact, self-contained unit suitable for urban setting
- Plug and Play - all components in explosion proof steel enclosure
- Ability to right size a fast-fill product to demand
- Provide solution for small and mid-sized fleets
- Smart software to optimize performance and diagnose problems quickly

Market development objectives:

- Full commercial availability of cost-effective solution for small and mid-sized fleets
- Create customer pull for other competitive products

Microbox – Riverside Base

Nanobox

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Example -- Home Refueling Appliance

- Goal: Facilitate the design and manufacture of 'next generation' CNG fueling appliance(s) approved for residential use.
- Product Targets: Fuel cost adder of $1/gal or less
- Potential Vendors/Manufacturers: over 25 identified to date
- Overall goal is to facilitate introduction of cost-effective products by 2013

Samples of HRA Products/Concepts

NatGasCar

Phill - Impco

Galileo (concept)

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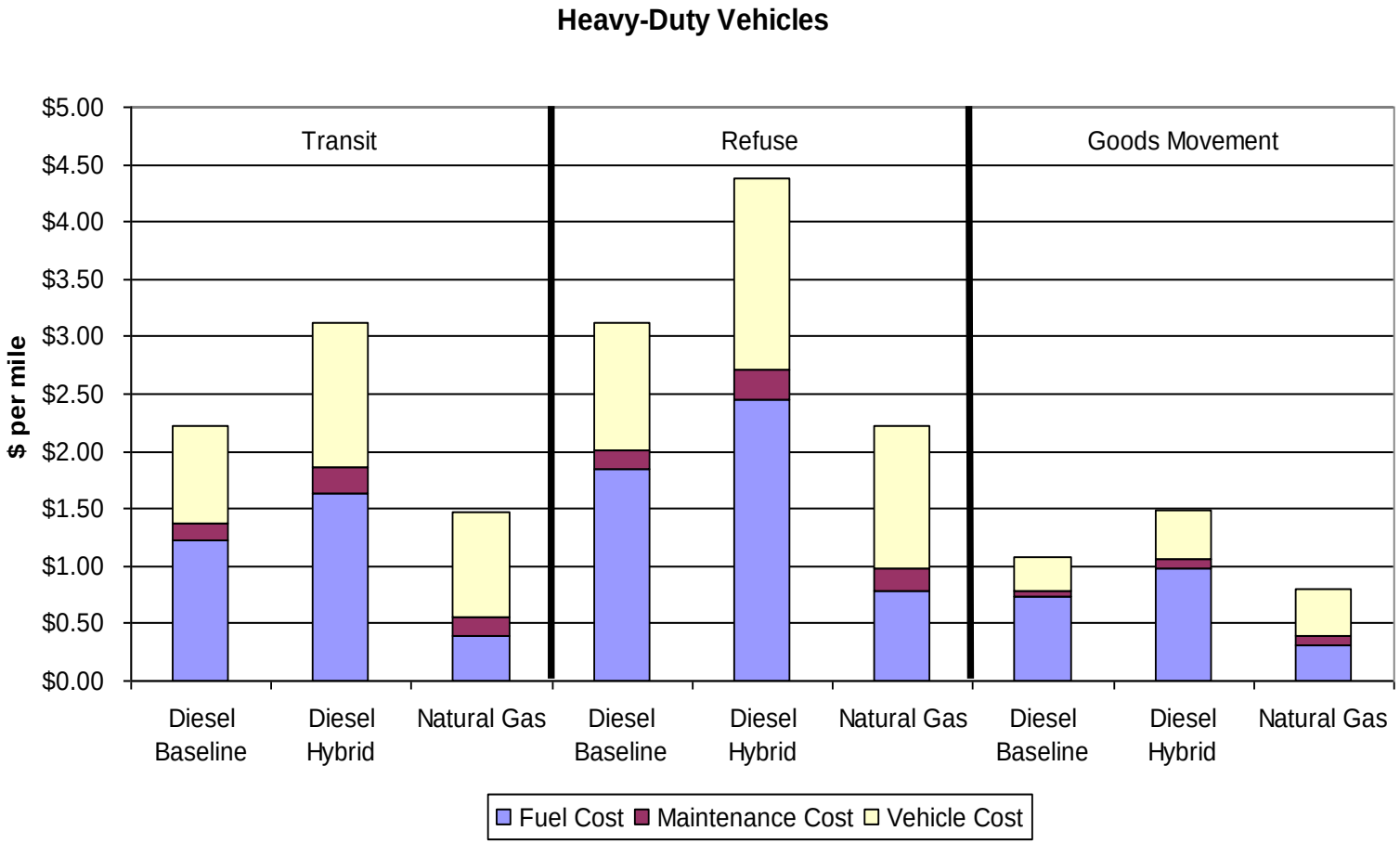
CNG More Economical for Many Segments Today



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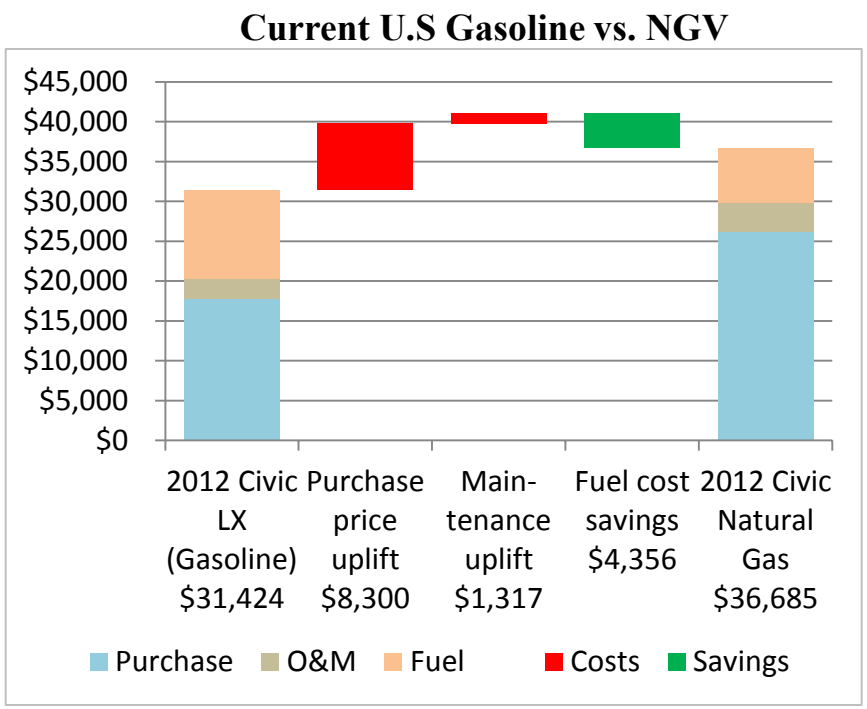
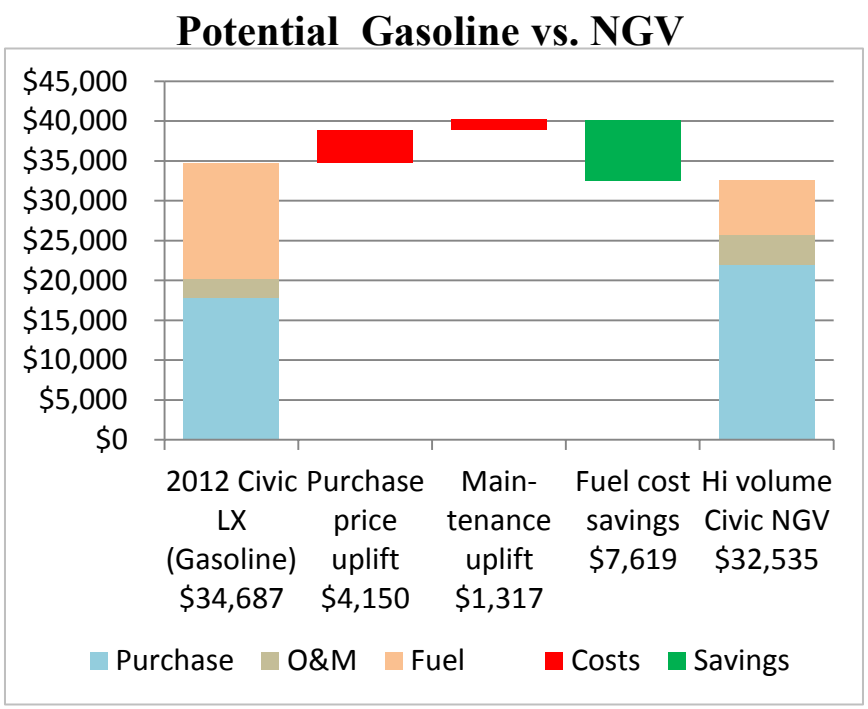
Economics – Passenger NGV can be Cheaper than Conventional





Assumptions:

- Current Honda Civic CNG vehicle price
- Cost difference reduced by 50% with high volume production (similar to current differential in Italy)
- Current fuel price $3.85 per gallon; alternative case gasoline price $5.00
- CNG price $2.30 per gasoline gallon equivalent
- 15,000 miles per year at 29 mpg

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Conclusions

- Natural Gas Vehicle technology is advancing at a fast pace
- Emissions challenges are significant but solutions are in sight to meet long-term goals
- Low-cost, domestic fuel is a major advantage

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