

# US Light Duty Natural Gas Vehicles – Role of NGV's and Implications for Regional Manufacturing



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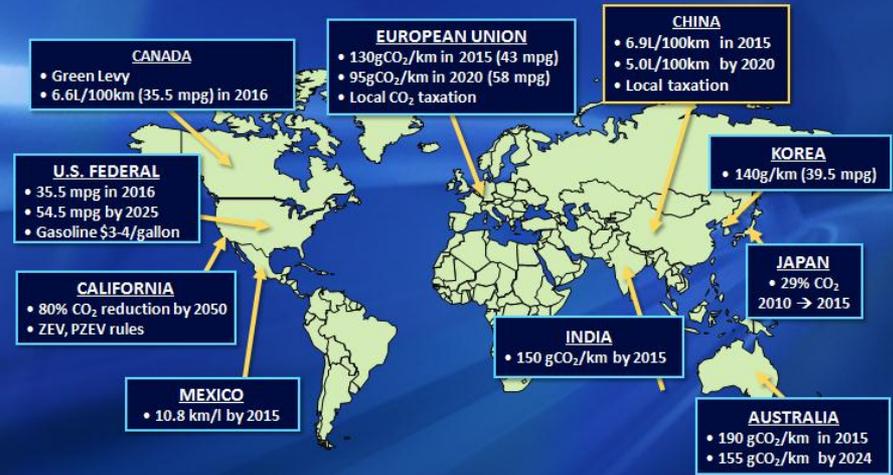
Shale Gas: Implications for America's Regional Manufacturing Economies  
National Academy of Engineering, Carnegie Mellon University



# WIDE RANGE OF TECHNOLOGY DRIVERS



# OUTLOOK FOR GLOBAL FUEL ECONOMY AND GREEN HOUSE GAS REQUIREMENTS



# Advanced Propulsion Technology Strategy

It is all about energy diversity



# IMPROVING GASOLINE & DIESEL ENGINES

Increasing Fuel Economy While Reducing Emissions



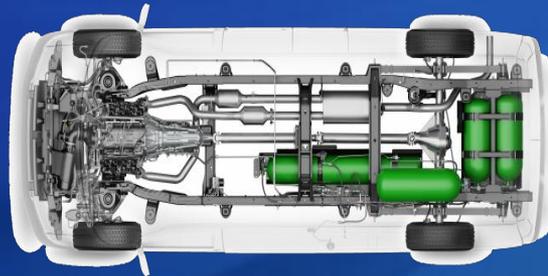
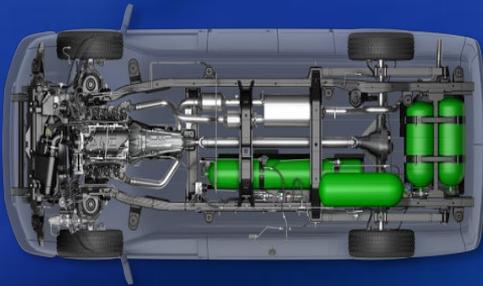


# 2500 HD / 3500 HD Full Size Van Dedicated CNG Van Offerings – 6.0L

¾ Ton and 1 Ton 135” and 155” Wheelbase Cargo



**100,000  
MILE  
WARRANTY**  
5-YEAR POWERTRAIN



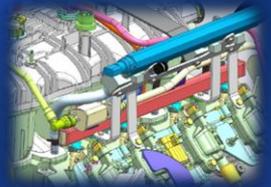
16 gge 3 tank or  
23 gge 4 tank  
configurations



Shipment of our Chevrolet Express and GMC Savana CNG Cargo Vans began in late January 2011 with over 2400 units produced

# 2500HD Extended Cab Pick-up Truck Bi-fuel CNG – 6.0L (LC8)

Chevrolet Silverado and GMC Sierra  
Available with long or short bed  
Available in both 2WD and 4WD



2013 Model Year introduction with over 1300 orders

# Hurdles for LIGHT DUTY Natural Gas Vehicles

■ Priority For R&D or Deployment Investment   
 ■ Minimal/No Barriers   
 ■ Will take investment and time, but pathway for success has been identified   
 ■ Significant Barrier-or-High Risk-or-High Uncertainty -or- Requires "Breakthrough or Invention"

	Hurdle	Required State for Reaching Wide-scale Commercialization	Rating	Comments
Engine	Power & Torque	Match equivalent gasoline engine ratings.	●	When properly optimised for CNG, no impact on power or torque, particularly in dedicated configuration.
	Fuel Economy	Minimal or no penalty relative to gasoline.	●	Dedicated CNG engines can exceed gasoline efficiency via higher compression ratio.
	Hot/Cold Weather Performance	Comparable performance to ICE's.	●	Utilise similar engine control strategies to gasoline.
	Advanced Fuel Economy Potential	Long term viable roadmap for continued improvement.	●	Compatible with boosting, downsizing, hybridization, lightweighting, etc.
	Direct Injection	Technical pathway for Direct Injection CNG.	●	Non-critical as market can persist as PFI, but value in R&D needed to identify solution for dedicated CNG DI. Reliance of PFI only may incur FE limit.
	Emissions Compliance	Emissions compliance with no incremental aftertreatment over gasoline.	●	May require custom catalyst formulations to meet future CH4 standards.
	OBD Compliance	Fully compliant with all OBD requirements.	●	Requires tailored Electronics and Software architecture to capture full range of CNG system states.
	NG Optimised Designs	Engine systems designed specifically for NG operation.	●	Piston, valvetrain, air handling optimisation. Can be justified when sufficient market volume is achieved.
	Durability	No penalty relative to gasoline.	●	No impact with shared architecture, ratings and OEM support.
	OEM Production	Factory built, first fit engines to provide build capacity and diversity of product options.	●	Limited range of engine options available. Some plant investment required to adapt assembly lines.
Onboard Fuel Storage	CNG Storage Capacity	No impact on required vehicle operating range compared to gasoline.	●	Increased tank volume (and weight) due to low energy density of CNG. Sufficient fuel can be stored for 300 mile range. Near term cost issues.
	Increase Energy Density	Not specifically required but would be beneficial.	●	Not market critical, but R&D into nano-structure or adsorbent materials could provide step change in fuel energy storage, range extension or reduced packaging.
	Fuel Venting	No unintentional venting of fuel.	●	No issue for CNG systems.

- Direct Injection – Technical Pathway
- Increase Energy Density - Storage Systems
- Vehicle Price Premium

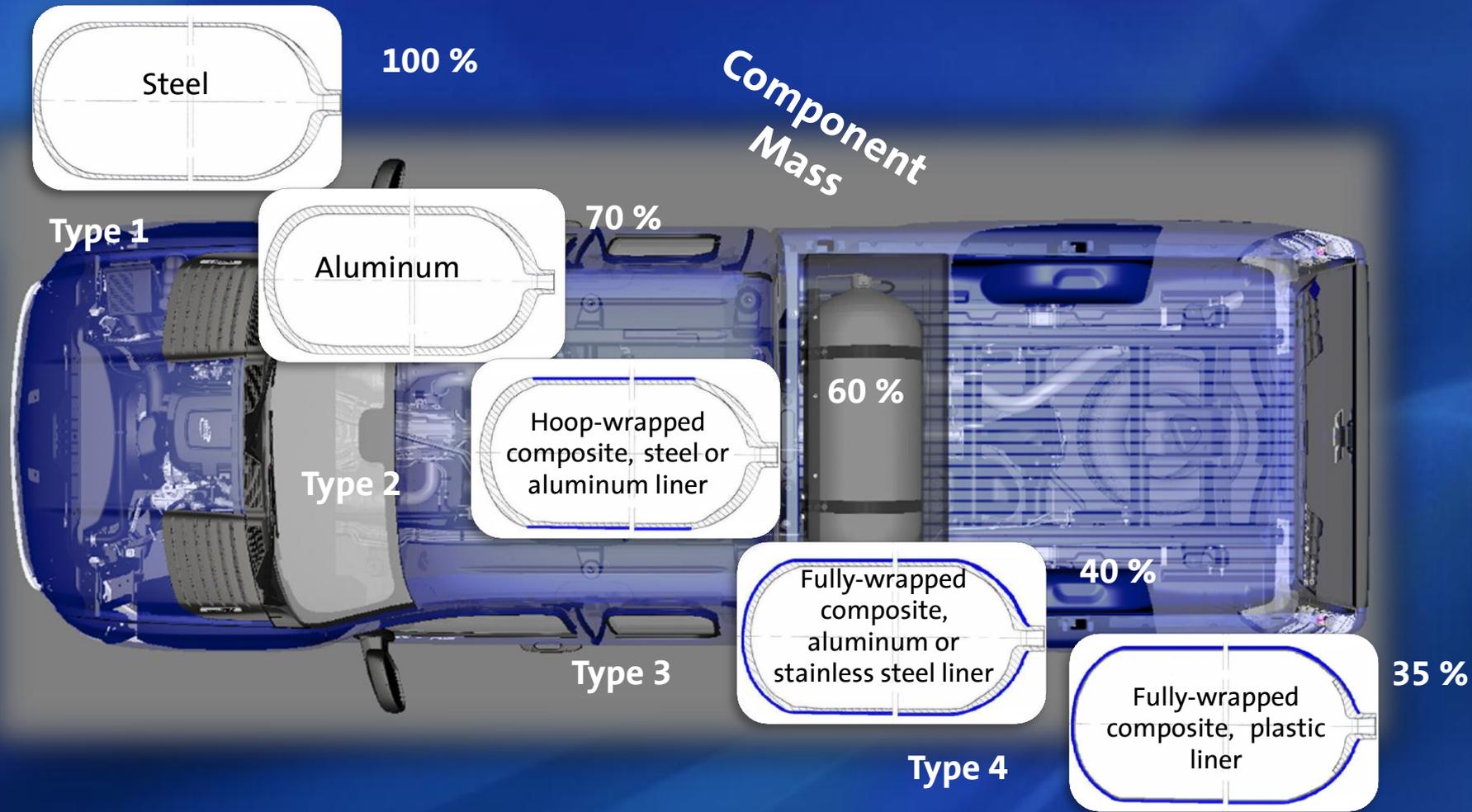
**Time Adjusted Cost of CNG Content in Small Car**  
Assumes fixed fuel economy and fuel storage for 300 mile range



- Low and High bound on incremental costs used to model range of uncertainty in projections.
- With assumptions used, significant reductions in incremental costs are possible.

	Hurdle	Required State for Reaching Wide-scale Commercialization	Rating	Comments
Vehicle	Vehicle Option Availability	Broad range of OEM vehicles tailored for different segments and vocations.	●	Majority of options available only as aftermarket today. More OEM produced "CNG ready platforms" being offered. Not a barrier if market pull is sufficient.
	OEM Integration	Optimised vehicle integration in vehicle platform and factory build.	●	OEM involvement is obsoleting requirement for retrofit NG conversions.
	Operating Range	Minimum 250 to 300 mile range capability.	●	Improved Fuel Economy or Fuel Storage will further improve range.
	Cabin & Luggage Space	No functional impact relative to conventional gasoline & diesel vehicle.	●	Requires OEM consideration for CNG within model architecture definition. Trending to no impact in Europe, with fuel tank/chassis/body integration.
	Weight	Weight increase manageable without operating impact.	●	Manageable. Type 1 CNG tanks can result in a weight increase, offsetting fuel economy. Type 4 carbon tanks significantly lighter, but more costly.
	Safety	No unmanageable safety risks from vehicle operation and maintenance.	●	Appropriate use of design, codes & standards, education and training.
Vehicle Economics	Vehicle Price Premium	Premium relative to conventional vehicles is manageable within equivalent purchase constraints	●	Current high price premium only recovered over very high mileage use, eg fleet operations. Viable pathway to competitive price via OEM integration & scale.
	Increase Energy Density	Equal or less than comparable ICE vehicle.	●	Low cost per mile due to comparable vehicle efficiency and low cost fuel.
	Fuel Venting	Equal or less than comparable ICE vehicle.	●	Long term economics are much more favorable with scaled production and lower price premiums.

# Compressed Natural Gas (CNG) Cylinder Types

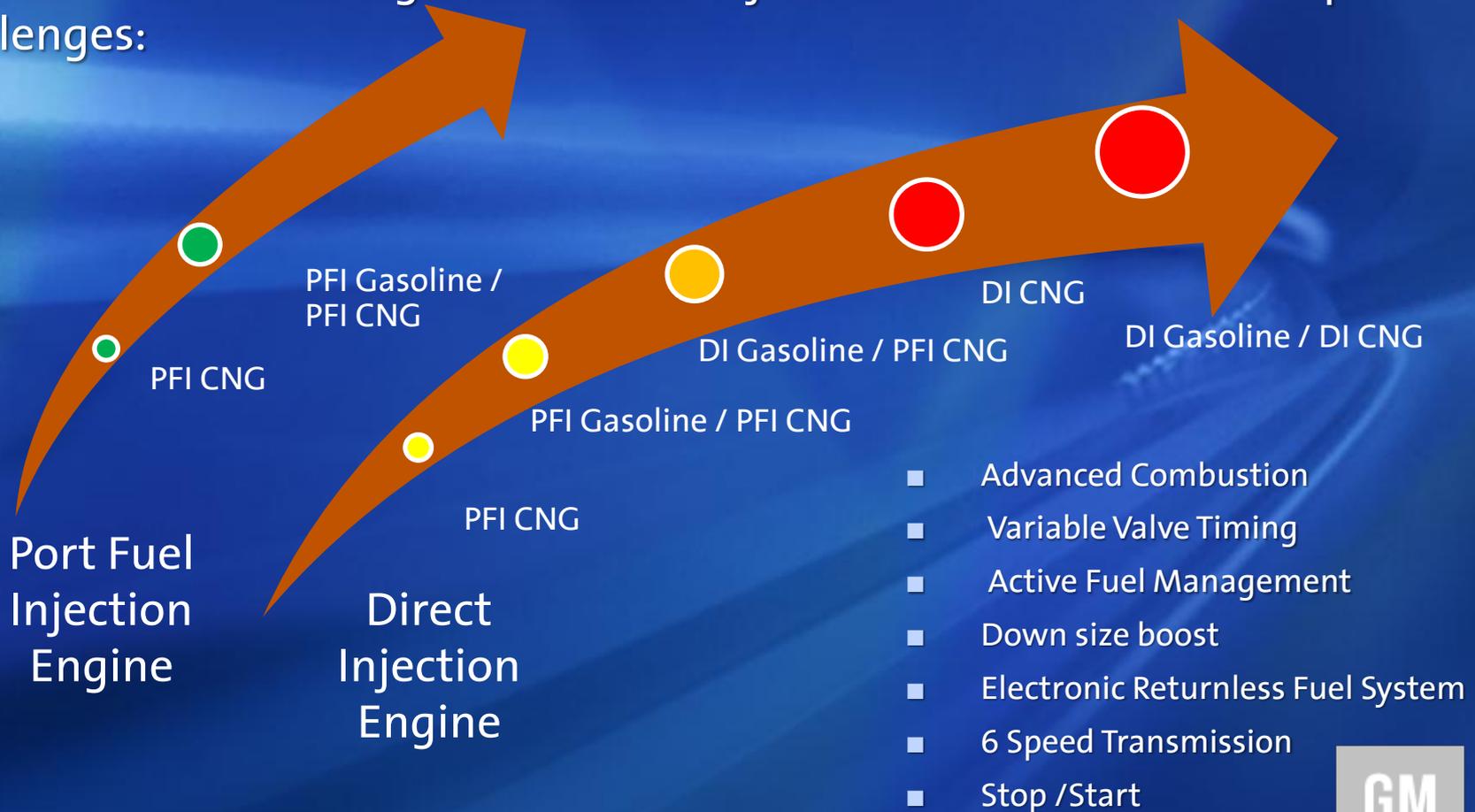


For illustration purposes only



# Powertrain Enhancements / Fuel Variants

Achieving maximum fuel economy potential, while meeting requirements for quality, emissions and performance with advanced engine and transmission fuel saving features in conjunction with CNG variants pose challenges:



# Six Things We Need to Get Right

- Market analysis
- Technical features
- Customer experience
- Public education
- Public policy
- Advanced features and new opportunities



Everything  
**BEGINS & ENDS** with  
**GREAT PRODUCTS**

