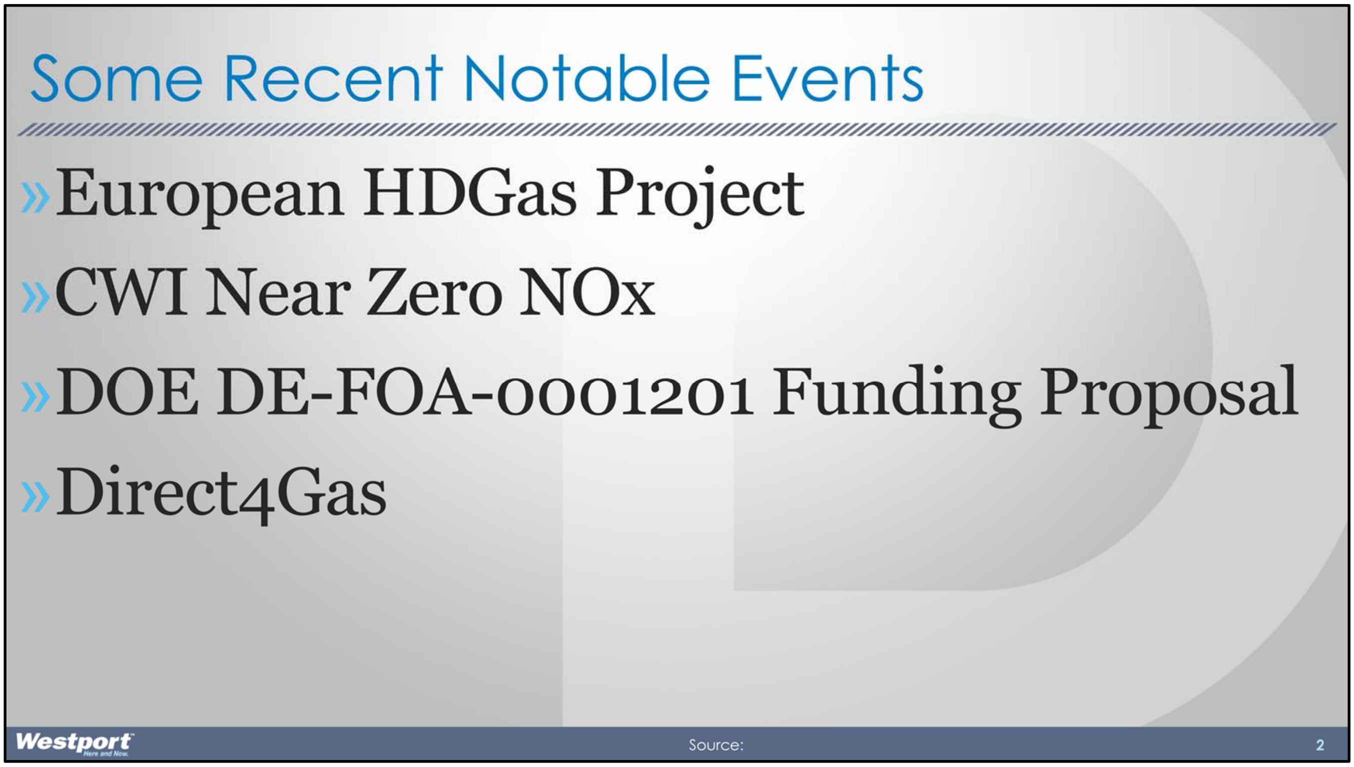
There has been a number of interesting news pertaining to efficiency improvements of Natural Gas Engines

European HDGAS

- Objective is to provide breakthroughs in LNG long haul HD vehicles
- ~30M€ project, ~20M€ EC funding
- 19 Partners: including AVL, BorgWarner, Bosch, Daimler, Ecocat, FPT, Iveco, MAN, Ricardo, SAG, TNO, TUGraz, Volvo, and others
- Euro VI emission regulations; meet at minimum 10% CO2 reduction compared to state of the art technology; show a range before fueling of at least 800 km on natural gas;
- 3 Concepts
    - A low pressure direct injection spark ignited engine with a highly efficient EGR system;
    - A low pressure port injected dual fuel engine;
    - A high pressure gas direct injection diesel pilot ignition gas engine.

Cummins Westport Near Zero NOx

- Near Zero NOx Emissions ISL G Natural Gas Engine ~Proprietary technology capable of reducing NOx emissions by 90%~
- Will be released with Closed Crank Case Ventilation
- Fueled with biomethane / RNG could provide deep reduction in GHG emissions



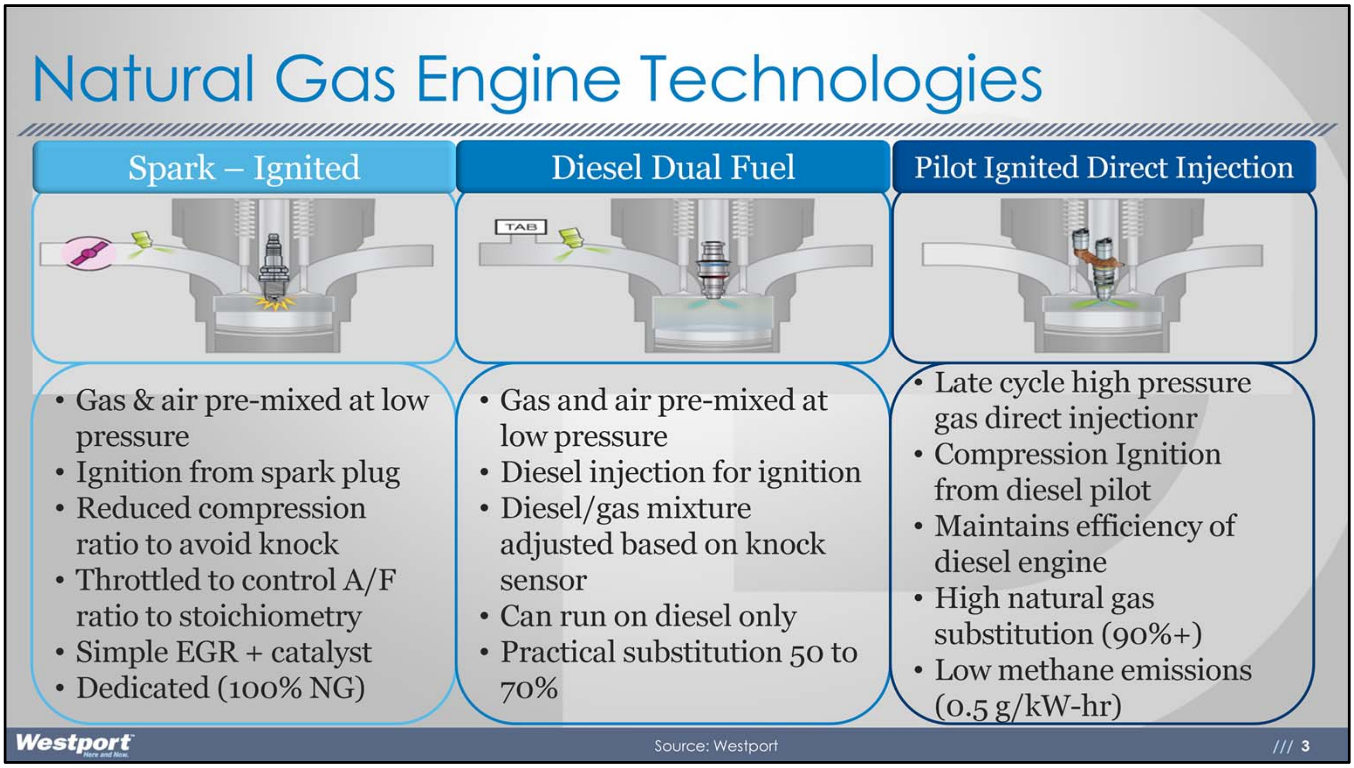
DOE FA1201: Bosch

- This project will develop and demonstrate a high-efficiency spark-ignited natural gas engine and develop a hybrid three-way catalyst (TWC)-selective catalytic reduction (SCR) exhaust aftertreatment system to maximize engine efficiency at a significantly lower cost than competing, diesel-based, dual-fuel approaches.

Direct4Gas

- German government-funded project to develop a direct injection system for monovalent natural gas engines—i.e., engines that run exclusively on CNG. Compared with present systems that use manifold gas injection, a direct injection system for natural gas could deliver as much as 60% more torque at low rpm, and offer the prospect of an even more dynamic driving experience in the CNG cars of the future. The very high octane rating and resulting high resistance to knock is promising for small, supercharged, downsized SI engines. Additional advantages include lower heat losses due to lower combustion temperature, no need for enrichment, no problems with soot, high EGR tolerance and good prospects for stratified combustion. A direct injection stratified natural gas engine could reduce CO_2emissions by 35% compared to a contemporary port injection gasoline engine, the team said.

Pretty indicative that there is a strong belief in the long term role of NGVs



SI Engines have

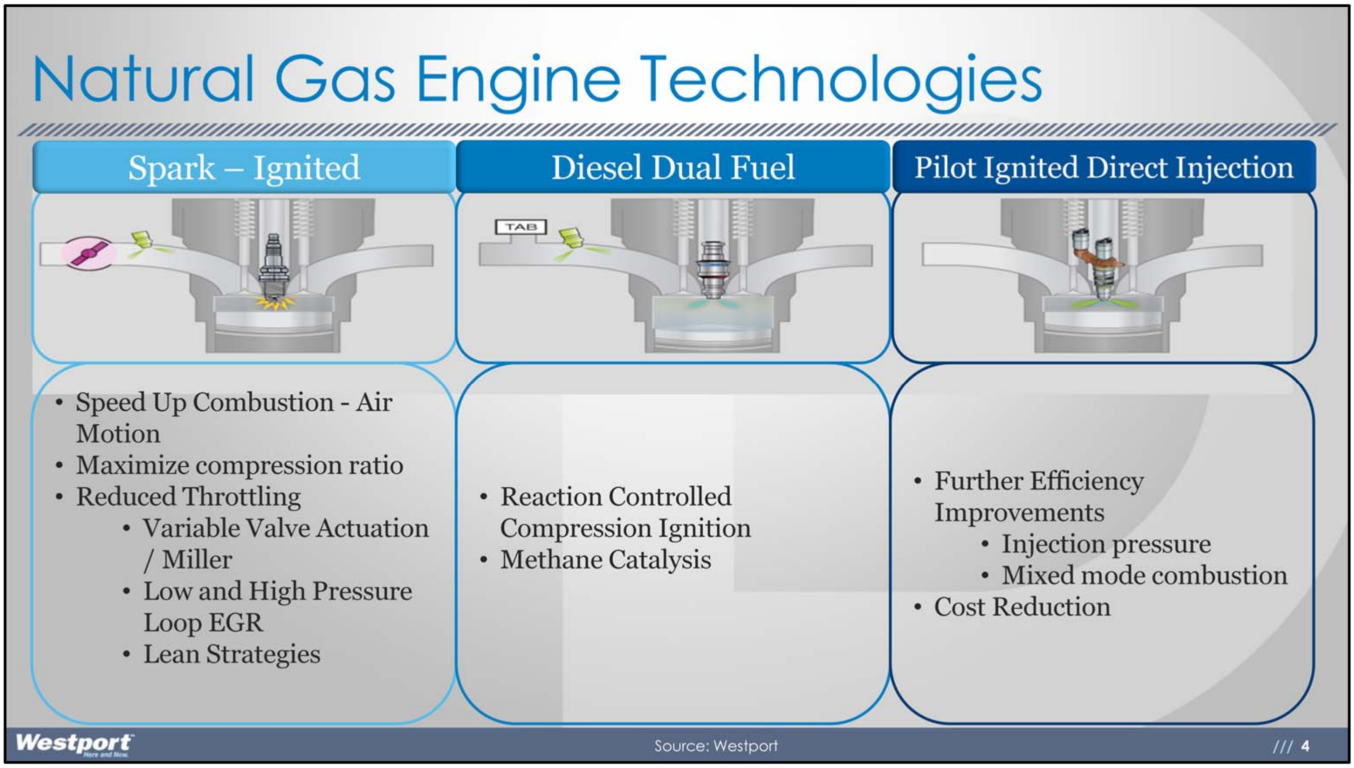
- Reduced Noise
- Compatible with LNG and CNG
- Can now meet Near Zero NOx
- Today 10-15% Thermal Efficiency Loss

Dual Fuel

- Exhaust methane emissions are a significant hurdle
- Compatible with CNG and LNG

HPDI

- Requires LNG and cryo pump



Each Technology is the focus of on-going improvements

On the SI front, as highlighted in the EU HDGas, there are some efforts to explore Lean Strategies. These could include early and late direct injection, and NOx catalysis.

On the DF front, there are efforts to examine whether RCCI could lead to some significant improvements in methane emissions. RCCI relies on diffused diesel within a lean gas charge leading to a fast, low NOx and lower methane combustion.

On the HPDI front, there has been some cost reduction efforts.

All technologies can also be fitted to some of the energy saving measures being considered to meet the EPA Phase II regulations.

Fuel Storage Technology

Liquefied Natural Gas (LNG)

- Stored under cryogenic conditions
- ~-160°C, 3 to 10 bar
- Stainless Steel, double walls, vacuum insulation
- 5 day hold-time
- Pressure relief valve to prevent over-pressure if fuel not used or for accidents
- Fast filling time, takes about twice the space of diesel for equivalent range

Compressed Natural Gas (CNG)

- Stored under high pressure conditions
- 250bar, ambient temperature
- Mostly Type IV tanks, plastic liners with carbon fiber wrapping
- Pressure and temperature relief valve to prevent over-pressure in case of accident
- Slower or over night fills, takes about 4 times the space of diesel for equivalent range

Westport

Source: Westport

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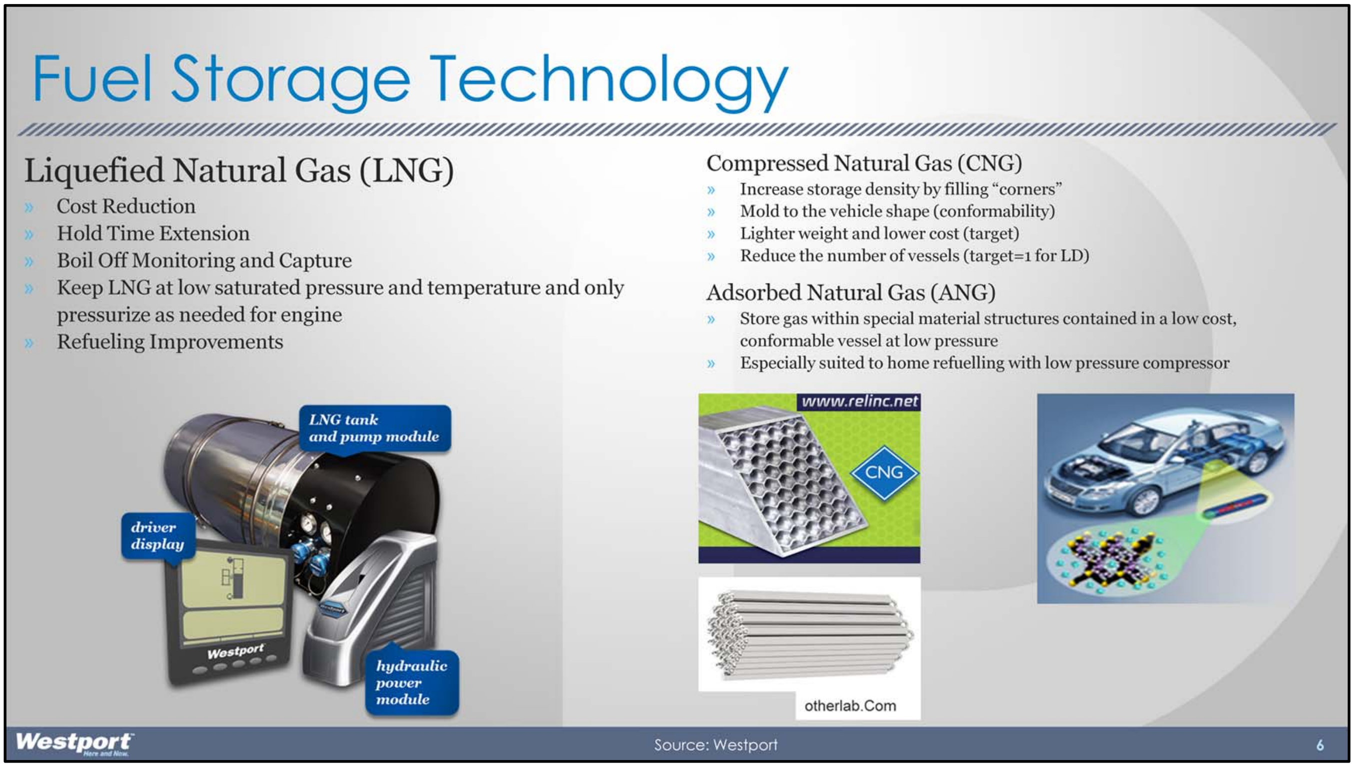
Storage is really important because it represents between 50 and 80% of the incremental cost of the vehicles.



The Arpa-E program has sponsored much work in CNG and ANG for passenger cars.

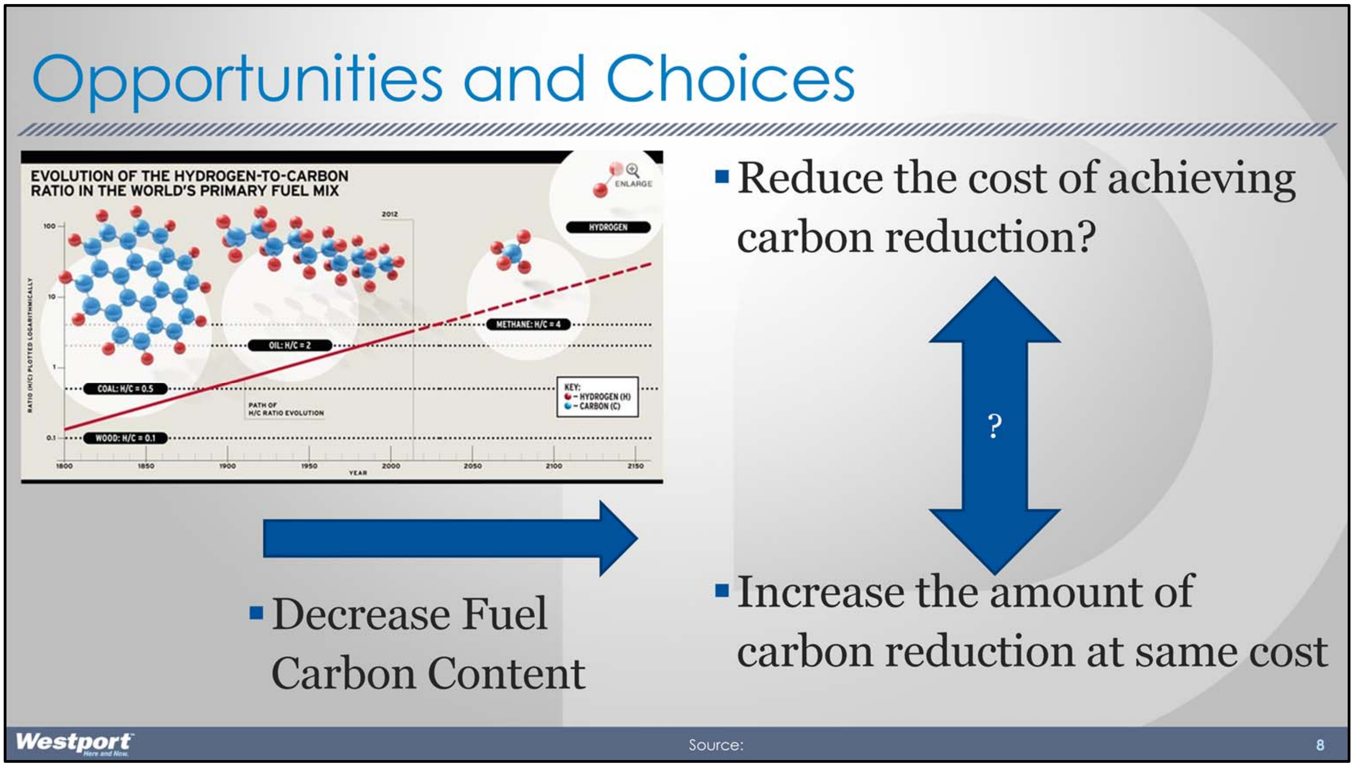
There has been somewhat less efforts on LNG, although it is worth noting the concept of keeping the LNG at low saturation pressure and temperature to reduce the chance of boil off, and to only pressurize the fuel as needed. We have been active in this area.

The EPA has also inquired about the opportunities to extent hold time of LNG tanks, monitor and perhaps capure boil off. Research in this area should be conducted.

Here's the World War 2 "gas car" developed by Thomas Henry Barton (1866-1946), the great oil engine pioneer and founder of Barton Transport Ltd (Chilwell, Nottinghamshire). Mr Barton developed the "gas bag" technology (for using town gas as fuel) in 1916 and it was widely adapted to buses for the rest of World War 1. Barton Transport Ltd was one of the few companies to persist with the "gas bag" bus in World War 2, but the "producer gas trailer" also seen here [I think] was employed by Midland Red and others in 1942-1944. Further information welcome ...

We can make progresses in efficiency, can make progress on cost, and of course reliability and so on. Natural Gas has unique properties and we can continue to built on these .

But where do we go from here?



NGVs are a platform to use a lower carbon content fuel. We have a lot of natural gas and it is at pretty low cost. We could possibly use the platform to lower the cost of achieving the GHG and NOx targets. Or we could use the platform to maximize GHG reductions at similar cost.

Avoiding some of the efficiency improvements expenses might be attractive, but it reduces the financial benefit of using gas as some of the savings are further lost due to the vehicle fuel consumption gap, and, perhaps mostly because the better vehicle efficiency could reduce the cost of storage for a given range, one of the main hurdle of NGVs.

We can also use the platform to increase the content of other low carbon gaseous fuels we may produce: in particular biomethane and hydrogen.

It does seem to make total sense to maximize the biomethane content of the NG. The question is how much biomethane can we count on and at what price?

We did HCNG nearly 10 years ago now – it was quite successful, but we couldn't find a way to make money at it… is is time to reconsider?