Review of Low Carbon Technologies for Heavy Goods Vehicles

Summary for Low Carbon Vehicle Partnership

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The low carbon technologies reviewed for application to HGVs are grouped into vehicle, powertrain and fuel themes

Technology Areas

Vehicle

- Low carbon technologies that affect the vehicle body, including wheels, chassis, trailer and cab, affecting how much energy is consumed in moving the vehicle

Powertrain

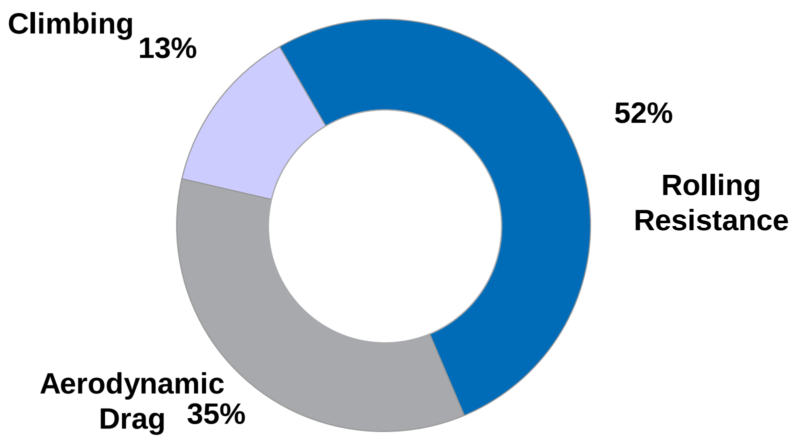
- Includes engine, transmission and driveline low carbon technologies
- Technologies include individual components and whole systems
- Technologies affect how efficiently energy is transformed

Fuel

- Alternative fuels used to propel the vehicle
- Affects the overall CO2 impact of running the vehicle

Rolling resistance and aerodynamic drag represent the largest areas of energy consumption and are the areas targeted for improvement

Energy Distribution for HGV, 44t GVW



- This energy distribution is based on 1,528 km test route over 3 days across the UK involving a mix of cross country roads and motorway

Source: Ricardo Analysis of Commercial Motor information

Key Insights

- Ricardo conducted analysis on a “typical” HGV route – the route used by Commercial Motor magazine to test drive trucks
- Over half, 52%, of energy for the vehicle is used to overcome rolling resistance and a third, 35%, to overcome aerodynamic drag
- Vehicle technologies aimed at reducing rolling resistance and aerodynamic drag can therefore have a large impact on the vehicle fuel consumption
- For example, using the energy distribution previously given:
  - A 10% reduction in rolling resistance would result in a 5.5% reduction in fuel consumption
  - Likewise a 22% reduction in aerodynamic drag would result in an 8.7% improvement in fuel consumption
- For fuel consumption benefits to be noticeable to fleet owners, benefits need to be in excess of 2% to be out of the usual variations in fuel consumption

For the vehicle theme, technologies lie in the fields of improving aerodynamics, reducing rolling resistance and driver behaviour

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Aerodynamics

- A number of technologies are being developed which aim to improve the ... of ... to ...nd fuel consumption

6-10% benefit depending on speed

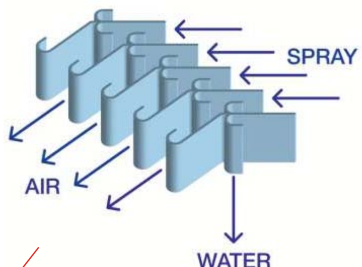
Aerodynamically Shaped Trailers

Tapering of the trailer to produce lower drag

Aerodynamic Fairings

Addition of ... fairings to ... vehicle a...

Surprising benefit even when dry



Trailer Spray Suppressers

Spray suppressing mudflaps, which help reduce both spray and aerodynamic drag

Rolling Resistance

5-10% benefit depending on speed, applicability, baseline. Reduced lifespan?

Low Rolling Resistance Tyres

Incorporation of silica into tyre design to reduce rolling resistance but maintain grip

Single Wi...

Replacing sta... thinner wheels w... base ...

Automatic Ty... Adjust...

Maintains c... pressure for safety and to reduce fuel consumption

3-10% benefit depending on baseline. Platooning hugely challenging but potential benefits large

Driver Behaviour

Predictive Cruise Control

Using knowledge of the road ahead to control vehicle speed for lowest fuel consumption

Vehicle Platooning

Allowing vehicles to follow safely at speed a close ...istance to the vehicle in front to reduce fuel consumption

Driver Behaviour

Driver training aimed at improving understanding of fuel efficient and safe driving

For the powertrain theme, engine efficiency is a main area for low carbon technologies grouped into 4 themes

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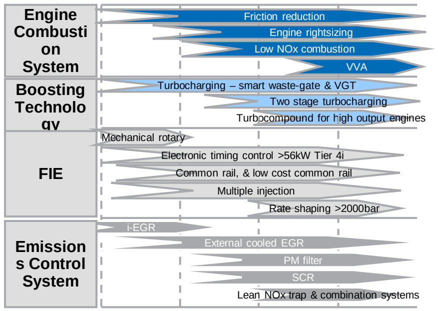
Engine Efficiency



Combustion Systems

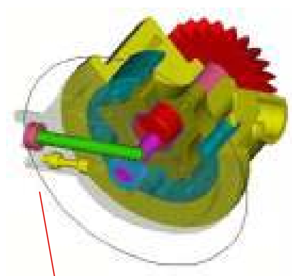
- Methods for reducing CO_2 emissions include:
  - *Injection Timing opti...*
  - *High... Sys...*
  - *Opt... ...rl*
  - *Earl... Con...*
  - *Low... Pre...*
  - *Boo... Mat...*
  - *Inlet Manifold Temperature Control*

Used to maintain neutral efficiency penalty as air quality emissions get tighter

Friction Reduction

- Friction reduction can be achieved through a number of measures:
  - *Lubricant Viscosity Specification*
  - *Pisto...*
    - *F...*
    - *F... I...*
  - *Plasi... cylin...*
  - *Piston skirt ... design and coating*
  - *Crank/cylinder axis offset*
  - *Bearing design*

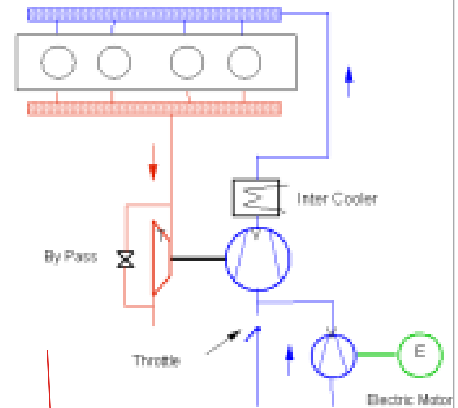
Ongoing background development yields 0.5-1.5% gain



Engine Accessories

- Reduction in parasitic losses of engine accessories
- Example...
  - *Air c... optim... electr...*
  - *Oil pu... flow ...*
  - *Water pump - electric*

0.5-4% gain depending on duty cycle



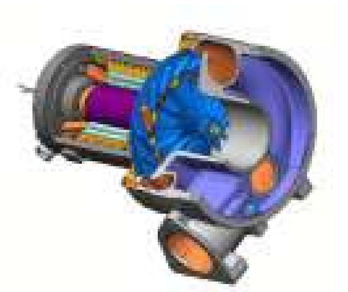
Gas Exchange

- CO_2 reduction can be achieved through improvements in gas exchange handling including:

up to 2% gain but strong interaction with emissions control system

Waste heat recovery, alternative powertrains and transmissions are the other 3 main areas of low carbon technologies for powertrain

Waste Heat Recovery



- A number of different exhaust heat recovery systems are being developed:
  - Turl Mec
  - Turl turb
  - Bra
  - Ran
  - The gen

Some maturity in market, 3-6% benefit depending on duty cycle. Cost?

Alternative Powertrains

Fuel Cells and Electric Vehicles

- Fully electric vehicles
- Fuel cell vehicles

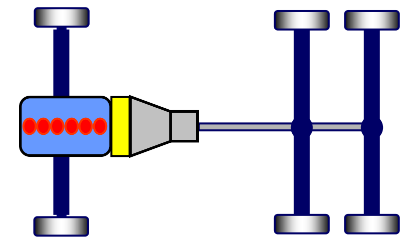
EV limited to 12t GVW. Fuel cell cost. Arguable WTW benefit

Hybrid Vehicles

- Hybrid concepts for medium and heavy duty application
- Level of
  - Sto
  - Full

7-20% gain depending on duty cycle. Cost, weight impact

Transmissions



- Fuel consumption can be reduced through careful matching of rear axle and gear ratios
- Automated transmissions for lower fuel consumption, ensuring optimum shift points:
  - AMT
  -

up to 10% gain but depends on baseline. Many OEMs already offering AMTs

For the fuel theme, biofuels and alternative fuels have been identified for analysis

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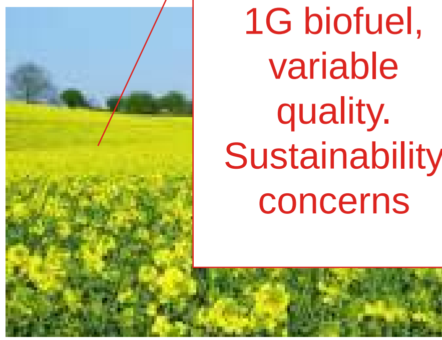
Biofuel

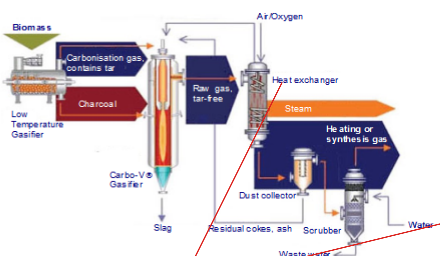
- Under the banner of biofuels a number of different types of fuels can be considered, which each can use a variety of feedstock
- Current engine technology standards can take up to 5% biodiesel, planned to increase to 7%



1G biofuel, variable quality. Sustainability concerns

FAME

Biodiesel made from esterification of vegetable oils



2G biofuel of high quality

BTL

...el created from ...to liquid process

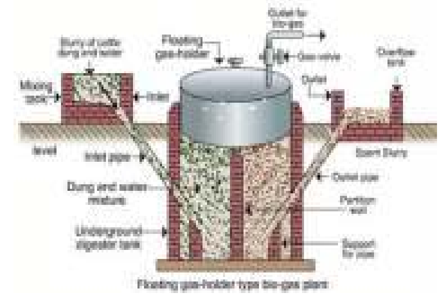
HVO

Biodiesel made from hydrogenation of vegetable oils and animal fats

Alternative Fuels

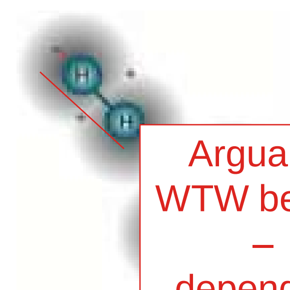
CNG

Compressed Natural Gas



Biogas

Creation of methane from biomass



Hydr...

Use of hydro... combustion e... alternative fuel

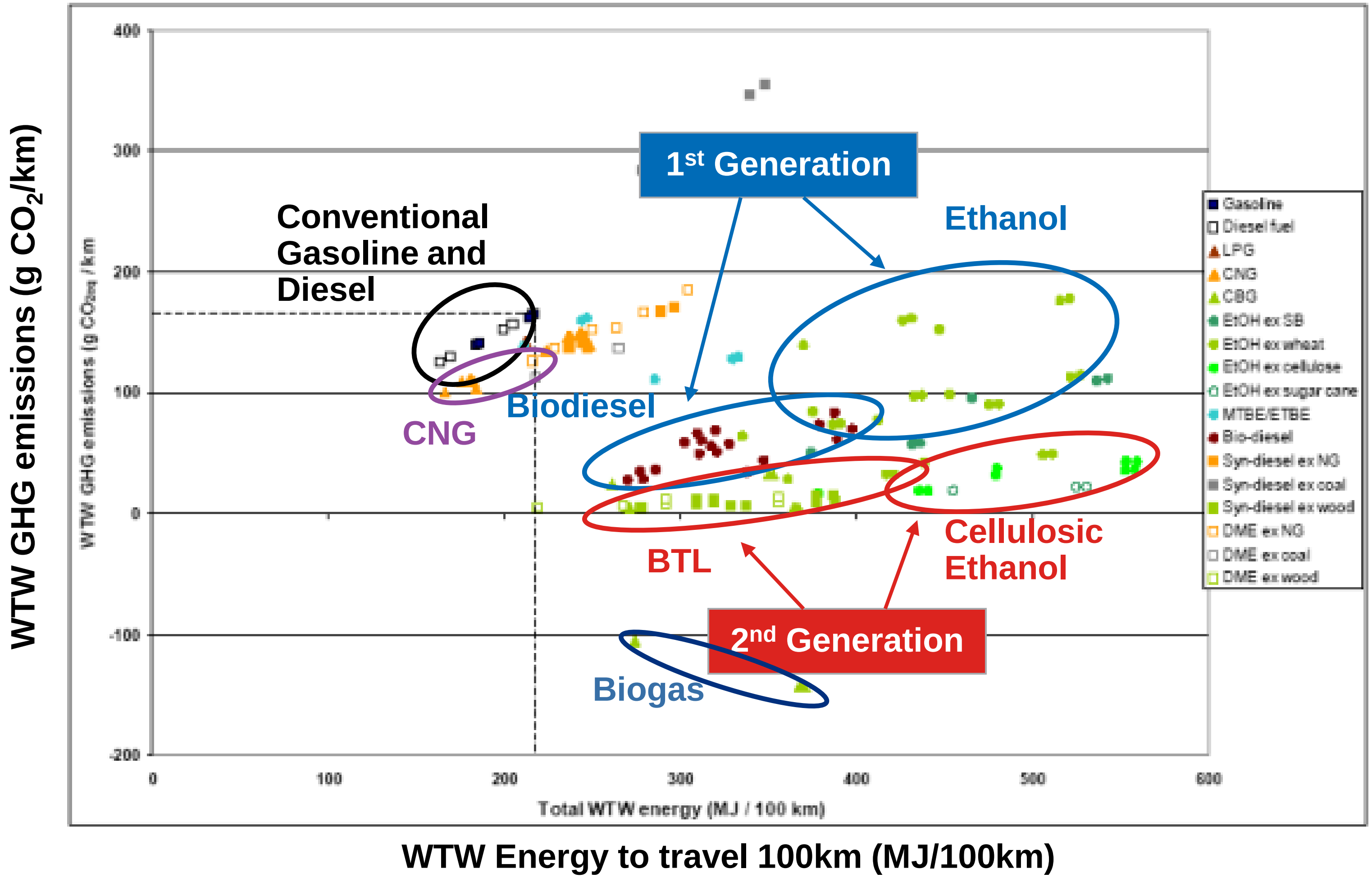
Arguable WTW benefit – dependent on energy used to produce H2

- Note: the fuel that has been focussed on is biodiesel (rather than bio-alcohol) as the prime liquid biofuel for H... (...) i... t...

Low inherent C content, further improved when bio. Limited by infrastructure

Not all biofuels are equal in terms of WTW Energy and GHG emissions savings

WTW Energy Requirement and GHG Emissions



WTW – Well to Wheels
GHG – Greenhouse Gas

Source: Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context - EUCAR, CONCAWE and JRC

Aerodynamic trailers, electric bodies & driver training offer the most promising CO_2 reduction potential for vehicle technologies

- The technologies with the greatest CO_2 reduction potential for the vehicle area are:
  - **Aerodynamic trailers: CO_2 Benefit – 9**
    - Large benefits in CO_2 emissions and fuel consumption reduction for fleets using the teardrop trailers for articulated vehicles in real world situations
    - Technology currently is limited to articulated trailers and greatest benefit will be from fleets with high average speeds and mileage
  - **Electric Bodies: CO_2 Benefit – 9**
    - Electrification of the power requirements of vehicle bodies such as refrigeration and refuse offers significant potential for CO_2 reduction, however this is limited to specific body types which are a small portion of the overall market
  - **SAFED Driver Training: CO_2 Benefit – 8**
    - Good CO_2 potential from initial case studies, but it yet to be seen how long the effects last
    - Benefit varies widely from driver to driver

Powertrain technologies electric vehicles, fuel cells and full hybrids offer greatest tailpipe CO_2 reduction but not without limitations

- The technologies with the greatest CO_2 reduction potential for the powertrain area are:
  - **Electric Vehicles: Tailpipe CO_2 Benefit – 10**
    - 100% reduction in tailpipe CO_2 emissions, however lifecycle/WTW CO_2 benefit is likely to be considerably less
    - Limited currently to applications with maximum GVW of 12t
    - Require central depot for overnight charging with current levels of infrastructure for electric vehicle charging
    - Requirement to be run from a central depot may limit resale and hence affect resale value
  - **Fuel Cells: Tailpipe CO_2 Benefit – 9**
    - Replacement of internal combustion engine with a fuel cell results in 100% reduction in tailpipe CO_2 emissions if it is run on hydrogen, but WTW CO2 must be quantified
    - Limitations with the hydrogen infrastructure for refuelling and for storage of the fuel on-board the vehicle without affecting payload and cargo space
  - **Full Hybrid: CO_2 Benefit – 4 – 9**
    - Tailpipe CO_2 emissions reduction can be as high as 30%, but this is very dependent on vehicle duty cycle
    - For applications where the vehicle operates in a frequent stop/start mode hybrids have greatest CO_2 reduction potential. Full hybrids also have the benefit of entering city centres which have restrictions on emissions
    - For long haul applications, CO_2 benefit is lower, but can be around 5%
    - Additional weight of hybrid system is not always off-set by a reduction in engine capacity and can lower vehicle payload

Fuel technologies with greatest lifecycle CO_2 benefit are biogas, biofuels and hydrogen, however tailpipe reductions are lower

- The technologies with the greatest CO_2 reduction potential for the fuel area are:
  - **Biogas: CO_2 Benefit – 10**
    - As a gas used in an internal combustion engine, tailpipe CO_2 reduction is similar to that of CNG
    - However if well to wheel analysis is considered, the overall CO_2 benefit of biogas is considerably higher as use is being made of a waste gas which has greater greenhouse harm potential than CO_2
  - **Biofuel: CO_2 Benefit – 9**
    - Tailpipe CO_2 emissions from biofuels (FAME, BTL and HVO) are similar to that of fossil diesel
    - Well to wheel analysis of CO_2 emissions produces a wide range of values depending on the feedstock used and the process used to manufacture the fuel
    - OEMs do not always warrant the use of fuels with high concentration of biodiesel as it can foul the fuel injection system
  - **Hydrogen: CO_2 Benefit – 9**
    - Tailpipe CO_2 emissions are near zero as hydrogen is a non-carbon fuel so only emissions come from burning of oil
    - Well to wheel CO_2 benefit of hydrogen is also dependent on how the hydrogen is made, with some methods resulting in **higher** lifecycle CO_2 emissions than diesel
    - Storage of the fuel on-board the vehicle is also an issue without reducing vehicle payload and cargo space
    - Further the refuelling infrastructure for hydrogen does not yet exist and as such would only suit vehicle fleets operating from a central depot

Technologies whose CO_2 benefit does not vary greatly for a given application due to external influences can act as potential "indicator technologies"

- While some technologies offer greater potential CO_2 reduction than others, these are not necessarily the best technologies to use as a basis for CO_2 reduction as the benefits they offer can vary significantly based on external influences such as:
  - Driving style
  - Route characteristics
  - Vehicle maintenance and accessories
- An indicative guide means, if a particular technology is applied to a particular vehicle type, the CO_2 benefits are consistent, repeatable and not significantly affected by these variables, such that statistics about take-up of a particular technology can be translated into an estimated fleet CO_2 saving
  - Example:
    - Aerodynamic trailers are a good indicative guide, their CO_2 saving performance is consistent and repeatable when applied to heavy duty articulated vehicles used on a constant high speed duty cycle
    - Full hybrids are a poor indicative guide, as their CO_2 improvement benefit is highly dependent on duty cycle, vehicle architecture, battery size, and environmental impact is strongly dependent on battery technology
- Even the technologies deemed as "good" indicative guides only act as good indicators when applied to specific vehicle applications and duty cycles. Very few technologies can be viewed as "blanket" indicative measures regardless of vehicle implementation

Implementation of many of the low carbon technologies present a certain degree of risk, which can be better understood through trials

Cost vs. Benefit of Low Carbon Technologies