21 October 2021

Technology Collaboration Programme on Advanced Motor Fuels

IEA AMF Task 57 HDV Performance Evaluation

IEA AMF Webinar 21.10.201






Petri Söderena
Nils-Olof Nylund
VTT Technical Research Centre of Finland Ltd

Debbie Rosenblatt
Jonathan Stokes
Environment and Climate Change Canada

Nuncio Lama
Alfonso Cádiz
Ministry of Energy and Ministry of Transport & Telecommunications of Chile

Yutaka Takada
Masayuki Kobayashi
Organization for the Promotion of Low Emission Vehicles (LEVO), Japan

Chun-Beom Lee
KATECH
Korea Automotive Technology Institute
Korea

Magnus Lindgren
Swedish Transport Administration
Sweden

IEA AMF Task Main Info

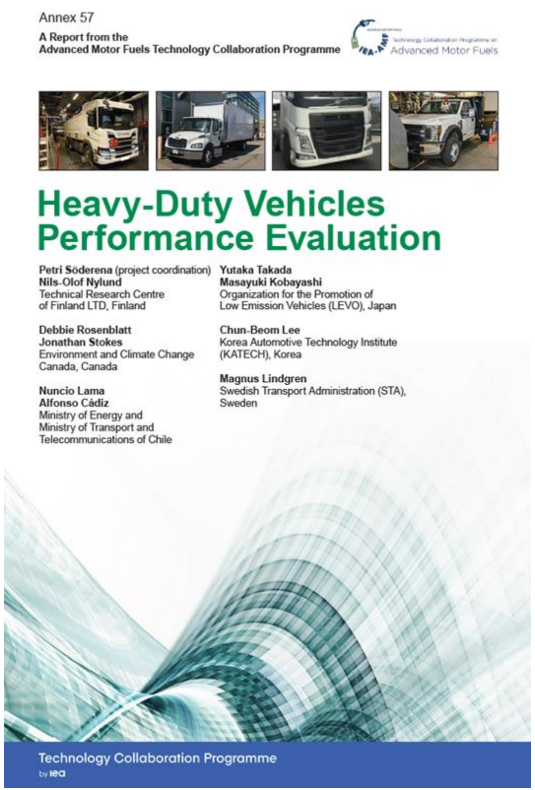
Task **Number and Title**	**Task 57** **HDV Performance Evaluation**
Operating Agent (institution)	VTT LTD Finland
Start and End Date	October 2018 - May 2021
Participants	Canada, Chile, Finland, Japan, Republic of Korea, Sweden
Task Sharing	Canada, Chile, Finland, Republic of Korea, Sweden
Cost Sharing	Japan and Sweden
Total Budget	~€610,000 (~$671,000 US)
Project Leader **(name and email)**	Petri Söderena VTT Technical Research Centre of Finland petri.soderena@vtt.fi

Technology Collaboration Programme on Advanced Motor Fuels

IEA AMF Task 57 HDV Performance Evaluation

Objective and key questions

- Provide information for political decision making, OEM's, transport sector and NOG's by investigating the current performance of HDV's on laboratory and on-road and future pathways (fuels and technology) for ICE powered vehicles to achieve ever more stringent climate and air quality targets
- The overall activity covers three time dimensions:
  - Legacy vehicles and a reference backwards through completed AMF Annexes (Annex 37: buses and 49: HDV's)
  - Current performance of the best-available-technology HDVs using conventional and alternative fuels
  - Joint activity with Hybrid Electric Vehicle (HEV) TCP to bring an insight how different HDV's powertrain and fuel (fossil and renewable) options perform against the CO_2 emission regulations in 2025 and 2030 perspective


Annex 57

A Report from the Advanced Motor Fuels Technology Collaboration Programme

Heavy-Duty Vehicles Performance Evaluation

Petri Söderena (project coordination)
Nils-Olof Nylund
Technical Research Centre of Finland LTD, Finland

Debbie Rosenblatt
Jonathan Stokes
Environment and Climate Change Canada, Canada

Nuncio Lama
Alfonso Cádiz
Ministry of Energy and Ministry of Transport and Telecommunications of Chile

Yutaka Takada
Masayuki Kobayashi
Organization for the Promotion of Low Emission Vehicles (LEVO), Japan

Chun-Beom Lee
Korea Automotive Technology Institute (KATECH), Korea

Magnus Lindgren
Swedish Transport Administration (STA), Sweden

Technology Collaboration Programme by iea

IEA AMF Task 57 HDV Performance Evaluation

Project content

- Testing on chassis dynamometer
  - Canada, Chile, Finland and Sweden
- Testing with PEMS in on-road conditions
  - Canada, Finland and Sweden
- One year continuous on-road NOx concentration monitoring
  - Finland
- HD vehicle simulation
  - Description of Heavy-duty vehicle Emission Simulator (HES) in Korea
  - Modelling and simulation of High Capacity Transport vehicles in Finland
- Future projection with HEV TCP for energy consumption and CO2 emission analysis in WTW and WTT basis for typical long-haul operation

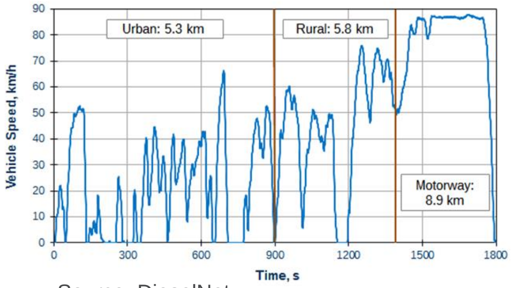
The original project plan constituted of nine work packed listed below:

- WP 0: Collection and consolidation of existing data
- WP 1: Agreement on common test procedures and protocols
- WP 2: Vehicle chassis dynamometer testing
  - Contemporary diesel vehicles as well as alternative fuel vehicles in different vehicle categories
- WP 3: Vehicle on-road testing with PEMS
  - Contemporary diesel vehicles as well as alternative fuel vehicles in different vehicle categories
- WP 4: Vehicle on-road NO_x concentration monitoring
  - Contemporary diesel vehicles as well as alternative fuel vehicles
  - NO_x concentration monitoring during normal operation
- WP 5: HD vehicle simulation
  - Description of a simulation model developed in Korea
  - Simulation model for high capacity transport vehicles fue consumption analysis
- WP 7: Aggregated test results
  - Analysis and comparison of chassis dynamometer and on-road test results generated within the Annex
- WP 8: Future projections of heavy-duty vehicle performance
  - Aggregating available data from similar studies such as U Super Truck programs and European counterparts
  - Cooperation with HEV TCP for future projection of heavy-duty vehicle CO_2 emissions and energy consumption
  - Mirroring of performance against legislative targets
- WP 9: Co-ordination of the project, synthesis and reporting
  - Administrative co -ordination, communication with the IEA AMF ExCo, synthesis of data, compilation of the Final Report and dissemination of the results

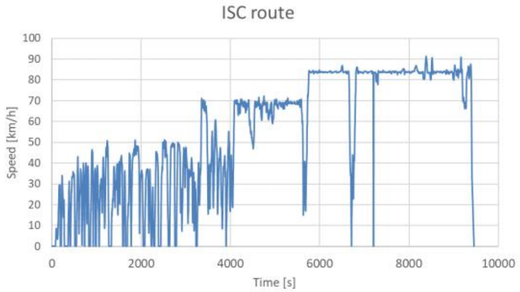
IEA AMF Task 57 HDV Performance Evaluation

Project methods

- Common testing procedure and protocol
  - On chassis dynamometer: WHVC* imitating WHTC** testing procedure i.e. cold start cycle following hot start cycle
  - On-road PEMS testing: Following Euro VI ISC*** requirement
  - Targeting half-of the maximum payload
  - Typical regional fuels i.e. EN590 diesel, ULSD and Chile diesel
- Additional testing based on participants
  - Chassis dynamometer testing
  - On-road PEMS testing
  - For example: different fuel blends and test cycles



Source: DieselNet
https://dieselnet.com/standards/cycles/whvc.php



Example of ISC route

*World Harmonized Vehicle Cycle, **World Harmonized Transient Cycle used in Euro VI engines type approval, *** Euro VI HDV's In-service conformity

IEA AMF Task 57 HDV Performance Evaluation

Technology Collaboration Programme on Advanced Motor Fuels

Project testing activities

Country	Tested vehicles	Emission class	Chassis	Engine	Tested fuels	CD	PEMS	Other testing	On-road
Canada	Truck 1 Truck 2	EPA 2010	Rigid 4x2	6.7L CI 7.7L CI	ULSD B20	WHVC	ISC		
Chile	Truck 1 Truck 2 Truck 3	Chile 2015	Rigid 4x2	3.0L CI 3.0L CI 4.0L CI	Diesel Chile*	WHVC			
Finland	Truck 1 Truck 2 Truck 3 Truck 4 Truck 5 Truck 6 Truck 7 Truck 8	Euro VI C Euro VI C Euro VI D Euro VI D Euro VI C Euro VI D Euro VI D Euro VI C	Tractor 4x2 Tractor 6x2 Tractor 4x2 Tractor 4x2 Rigid 6x2 Tractor 4x2 Rigid 6x2 Rigid 6x2	13L SI 13L SI 13L CI 13L CI HPDI 13L CI 11L CI 13L CI 13L CI HPDI	CNG, CNG** LNG EN590, HVO*** LNG&EN590 ED95 EN590, HVO*** EN590 LNG&EN590	All trucks WHVC HDVPerE	All trucks ISC HDVPerE	All trucks WHVC HDVPerE 44 ton	NOx monitoring NOx monitoring NOx monitoring
Sweden	Truck 1 Truck 2 Truck 3 Truck 4 Truck 5 Truck 6	Euro VI C Euro VI C Euro VI C Euro VI C Euro VI D Euro VI D	Rigid 4x2 Rigid 4x2 Tractor 4x2 Tractor 4x2 Tractor 4x2 Tractor 4x2	9.0L CI 9.0L SI 13L CI 13L CI HPDI 13L CI 13L CI HPDI	EN590 CNG EN590 LNG&EN590 EN590 LNG&EN590	All trucks WHVC	All trucks ISC		

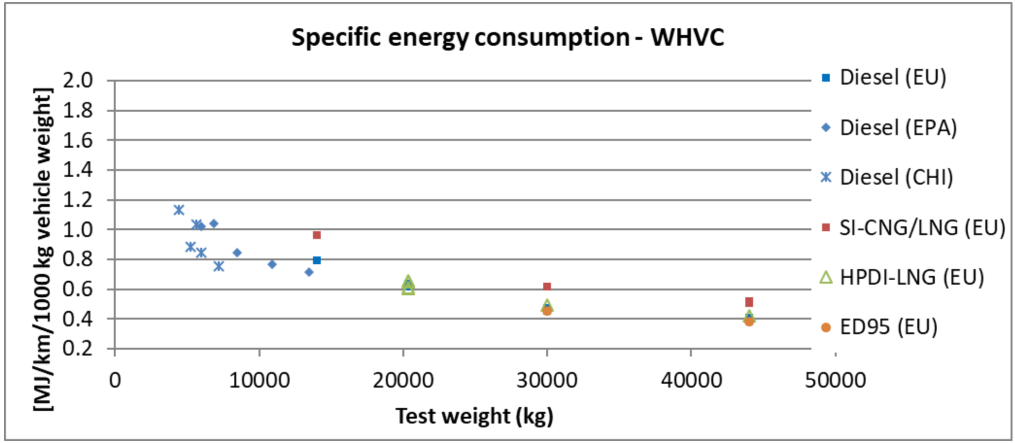
*Commercial diesel in Chile, **Low methane number gas (MN approx. 77), ***EN15940 HVO

Aggregated results

Aggregated results - WHVC

Energy consumption

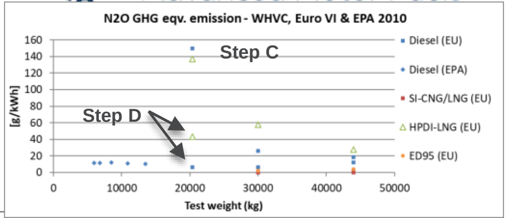
- In energy consumption (EC) wise vehicle GVW is the most effective factor – increased GVW reduces specific EC
- For the EC the combustion process has second highest effect
  - Compression ignition engines in general have lower energy consumption
    - Diesel and ED95 engines have similar efficiency
    - HDPI-LNG engine has slightly lower efficiency compared to diesel, roughly 4 to 7 % higher
  - SI-LNG/CNG engines have some 15 to 30 % higher EC compared to diesel

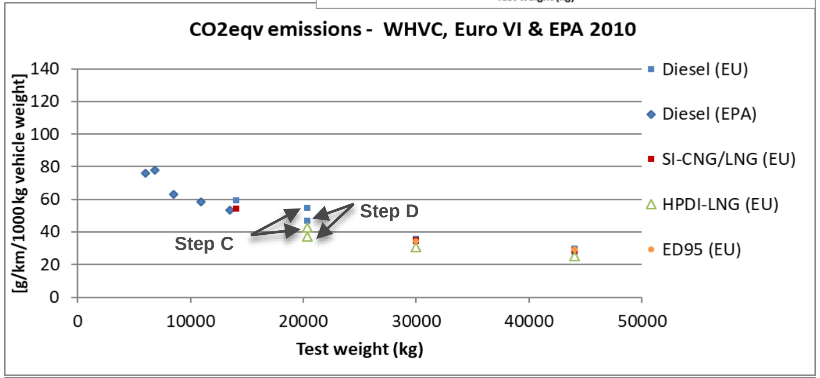


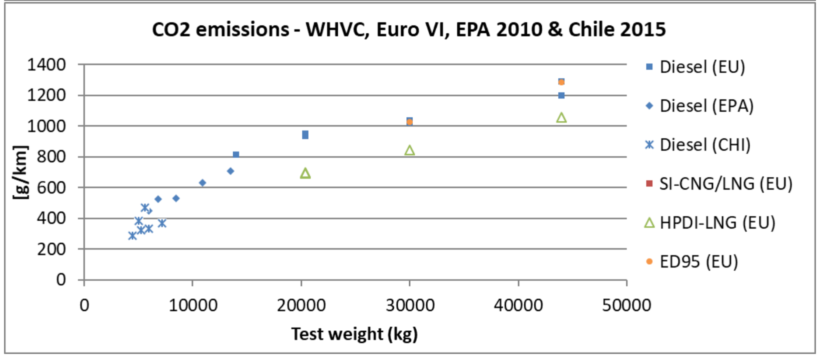
Aggregated results - WHVC

CO2 emissions

- Similarly as with EC the most dominant factor in CO_2 emissions is the vehicle GVW – increase in GVW reduces CO_2 emissions
- New methane fueled engines utilize the favorable carbon intensity of methane. Advantage over diesel in CO_2 emissions
  - HPDI-LNG engines offer in the best case around 20 % lower CO_2 emissions
  - SI-LNG/CNG engines deliver a reduction from -6% to +3% compared to diesel, depending on the vehicle, driving cycle and load
- ED95 engine produces roughly similar CO_2 emissions as diesel
- High CO_2,eqv emissions are observed with some SRC technologies due to high N_2O emissions



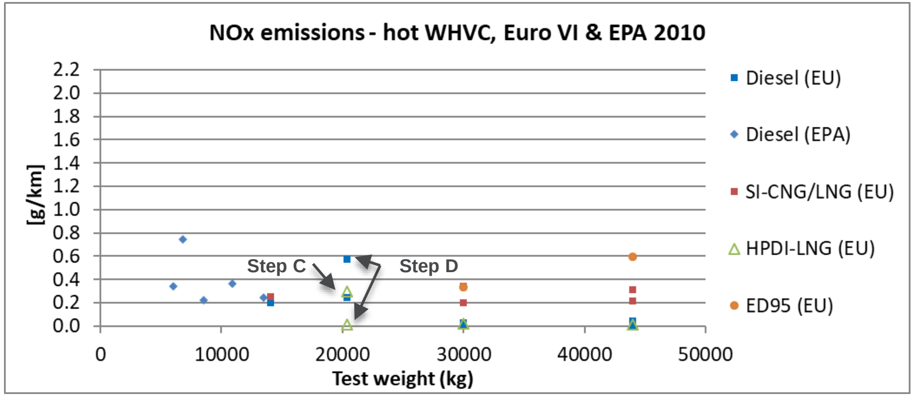


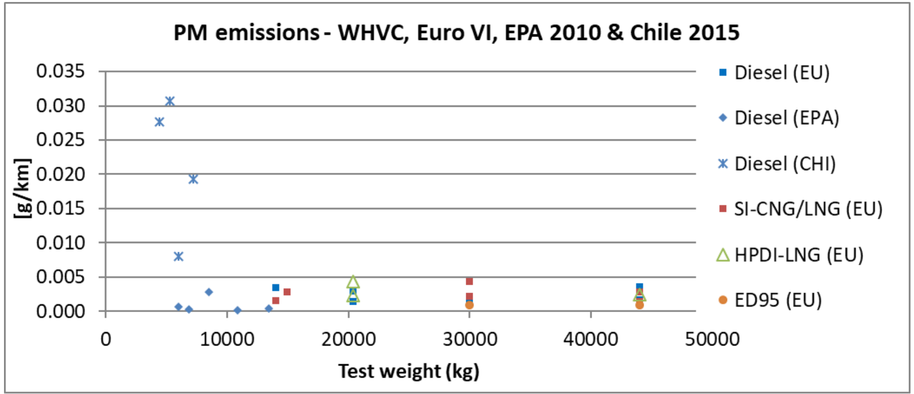


Aggregated results - WHVC

NOx and PM emissions

- NOx emissions depend on the specific technology in each vehicle
  - However, new compression ignition engines (diesel and HPDI-LNG) with SRC are capable close to zero NOx emissions (around 1 mg/kWh)
- PM emissions are low with all Euro VI and EPA 2010 vehicles
  - Euro VI SI-methane, HPDI-LNG, ED95 and diesel
  - EPA 2010 diesel
- Chile 2015 emission regulation based on Euro V

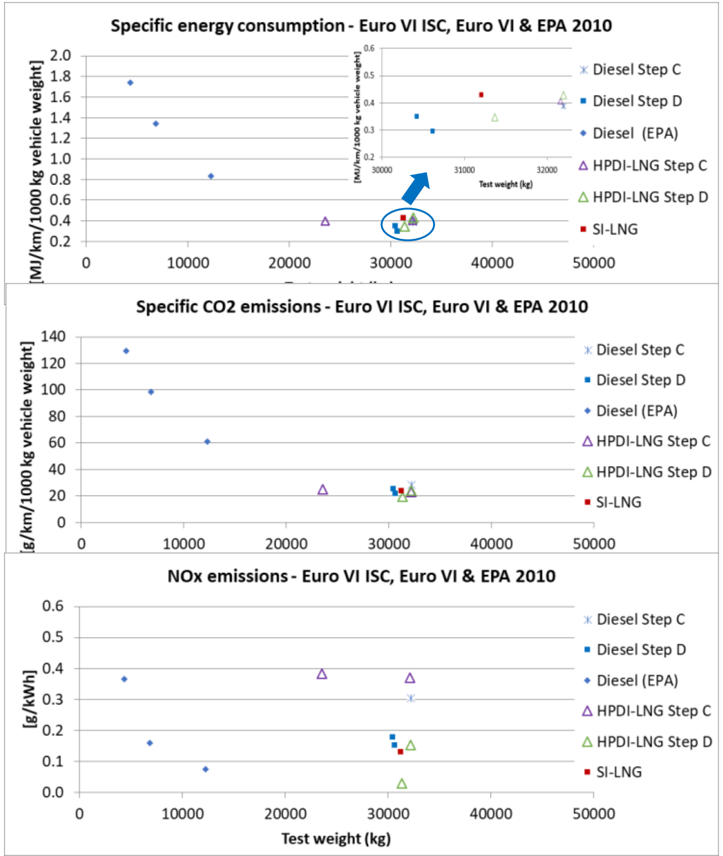




Aggregated results – On-road

Energy consumption, CO2 and NOx emissions

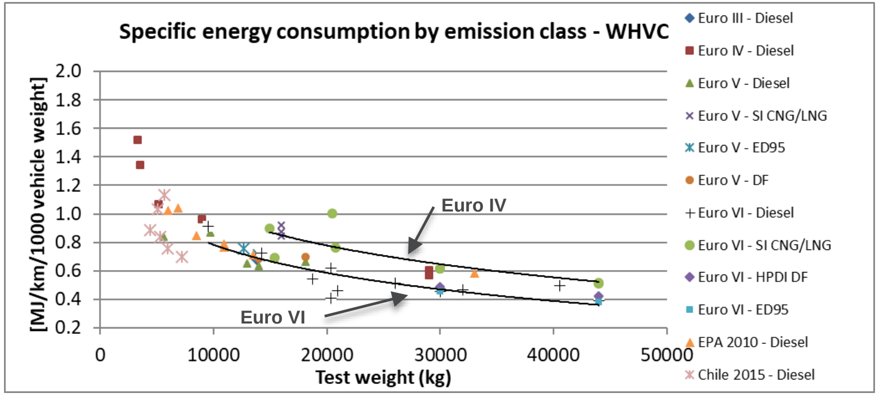
- It should be noted that on-road testing is more pass or fail type testing method and accurate comparison is rather difficult as driving conditions may not be the same (route, traffic, loading, weather)
- In general, energy consumption wise similar trends as in chassis dynamometer
  - Higher GVW has the highest effect on specific EC
  - Trucks with compression ignition engines have lower energy consumption
    - Diesels lower than HPDI-LNG
  - NOx emissions spread over wide spectrum with all powertrains
    - However, emission values below the limit value

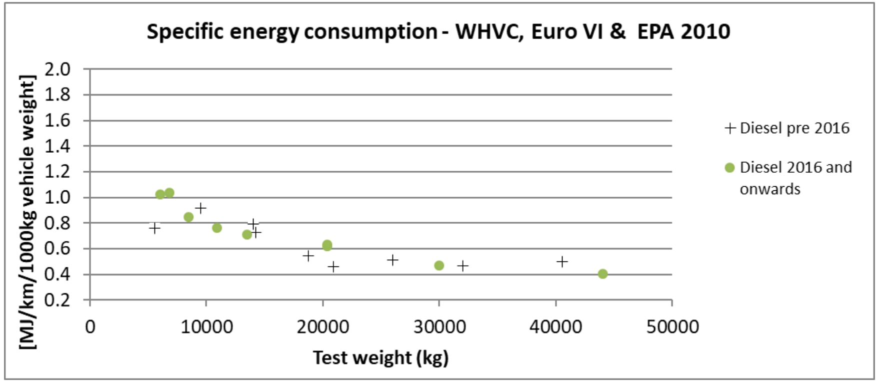


Aggregated results – WHVC

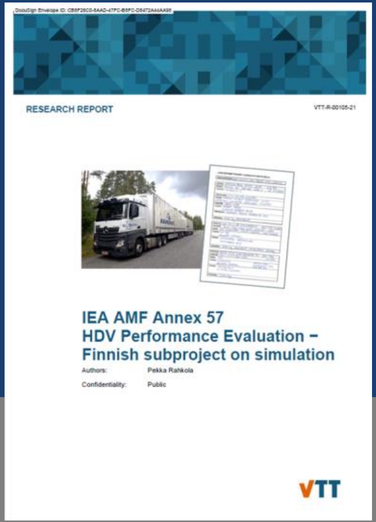
Comparison against the previous study

- In IEA AMF Annex 49 ”COMVEC” performed in 2014-2016 Euro VI and EPA 2010 diesel and Euro VI CNG trucks with various test mass was measured on chassis dyno
- Results of diesel trucks suggest that there has been clear improvement in energy consumption from Euro IV to Euro VI
  - At the same time pollutant emissions are reduced remarkably
- Results within Euro VI class (pre vs. post MY2016 trucks) suggest that there is no noticeable improvement taken place





HCT simulation


RESEARCH REPORT

VTT-R-00105-21

IEA AMF Annex 57
HDV Performance Evaluation – Finnish subproject on simulation

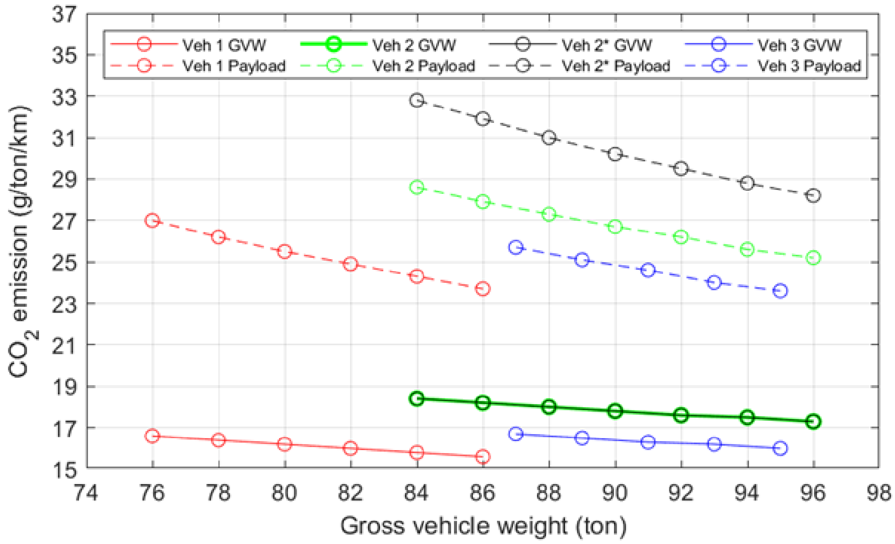
Authors: Pekka Rahkola

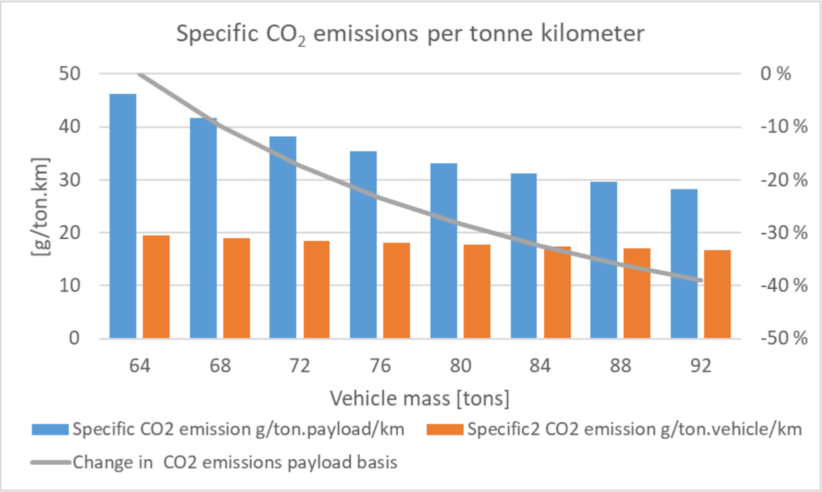
Confidentiality: Public

VTT

HCT simulation

- With each studied vehicle combination increase in GVW reduces the specific CO2 emissions
- The calculated fuel consumption and work data indicate average efficiency of about 46% at the engine level in this specific driving route between Helsinki to Oulu (around 600 km)





ADVANCED MOTOR FUELS IEA-AMF Technology Collaboration Programme on Advanced Motor Fuels

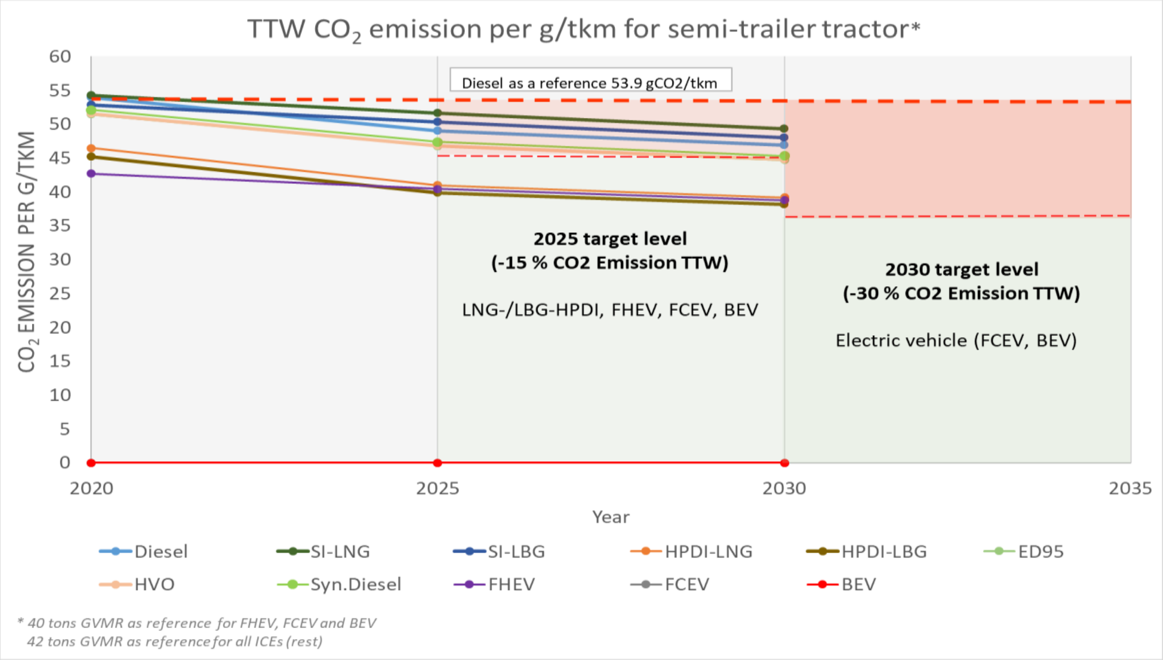
Future projection with HEV TCP for energy consumption and CO2 emission – WTW and WTT analyzes

Technology Collaboration Programme by iea

Future projection with HEV TCP

WTW and WTT analyzes

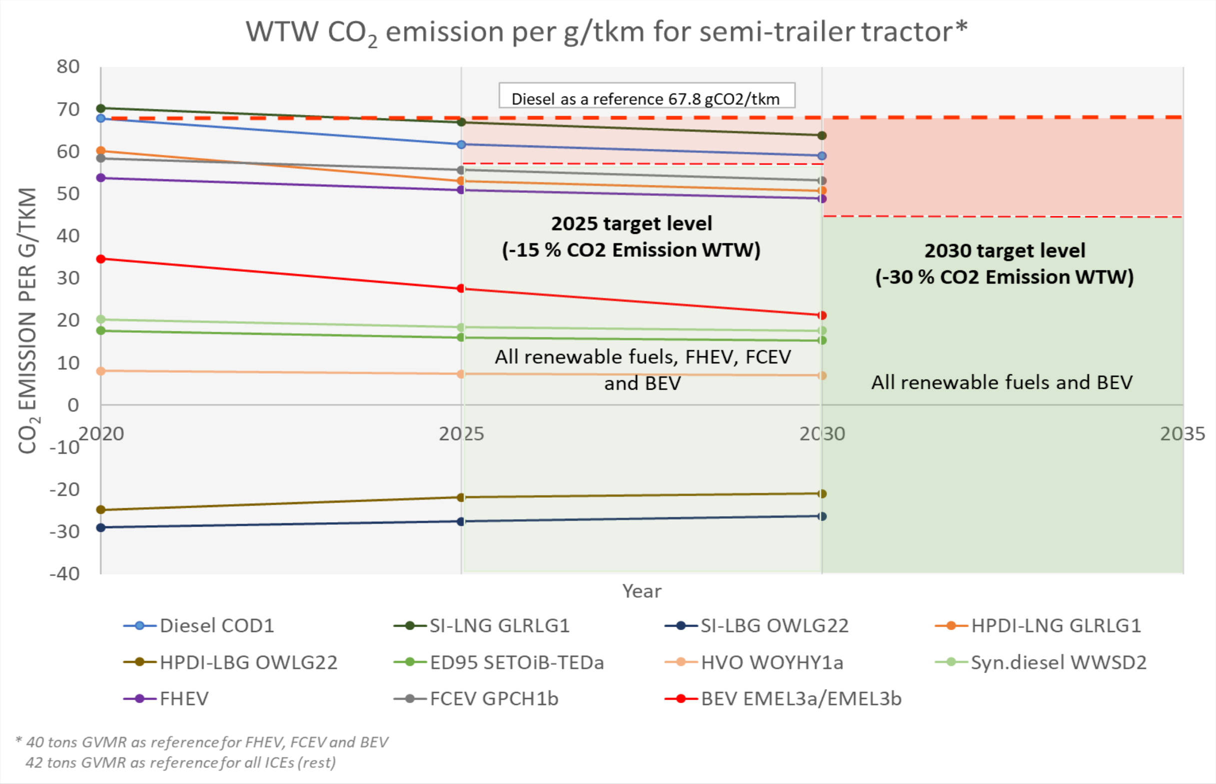
- Based on CD results of AMF Task 57 and simulations of HEV TCP
- Energy consumption and CO2 emissions were analyzed both on TTW (end-use or tailpipe) and WTW (overall impact) basis
  - The WTT data needed for this stems from the newest version of the JEC Well-to-Tank report v5
- Estimations and demonstrations from US Super Truck II* and H2020 LONGRUN** programs were used for estimating the future ICE efficiency



* US Super Truck II
** LONGRUN

Future projection with HEV TCP

WTW and WTT analyzes



Summary and key message

Summary and key message

- Heavy-duty truck engines operating with diesel process (i.e. compression ignition and diffusion combustion) have a clear advantage in efficiency compared to powertrains with spark-ignition engines
  - Up to - 17 % ... - 25 % less consumed energy vs. SI-engines depending on the average loading of the cycle/mission – the higher the loading the lower difference
- New engine options, dual-fuel LNG-diesel and ED95 ethanol, provide interesting options for the future
  - Dual-fuel LNG-diesel powertrain can provides close to 20 % less CO_2 tailpipe emissions compared to diesel
  - ED95 ethanol powertrain provides similar efficiency and CO_2 emissions compared to diesel
- In tailpipe CO_2 emissions SI-methane HDV engines provide slightly lower to slightly higher emissions depending on the engine loading in the specific cycle/mission
  - - 6 %...+3 % vs diesel in chassis dynamometer and even up to 8 % lower emissions in the measured on-road routes

Summary and key message

- Regarding local emissions, all the powertrain options are capable of low emissions
  - Powertrains equipped with SCR are capable of ultra low NO_x emissions in hot operation conditions, even as low as 1 mg/kWh on powertrain basis
  - Engines equipped with particulate filter are capable on PN and PM emissions clearly under the emission limit values
  - In best case, SI-methane engines without particulate filter are also capable on PN and PM emissions under the limit value
    - Other SI-methane truck measured gave PN emissions under and another clearly over the limit value
- N_2O emissions in CO_2 equivalence basis can be relative high in engines equipped with SCR – adding up to 7 % (Euro VI D) compared to CO_2 emissions
  - Not dependent on the fuel, but the chemistry used in the SCR and the exhaust gas temperature
- CH_4 tailpipe emissions are not a problem for the new generation methane powertrains, spark-ignited and direct injection dual-fuel
  - Adds less than 1 % to CO_2 equivalence basis compared to CO_2 emissions

Summary and key message

- HDV CO_2 regulations that focus on tailpipe emissions constitute a barrier for further development of alternative fuelled trucks. This could result in a halt in development of clean and efficient engines for dedicated alternative fuels, resulting in a preference to use drop-in fuel in the legacy fleet and electrification for new trucks entering the market. This type of legislation will have an impact on the prospect to use sustainably produced fuels in the future
    - Moreover, neglecting tools that are already available hinder remarkably successful achievement of the GHG targets
- Based on the simulations within Annex 57 increasing gross vehicle weight rating (GVWR) from some 60 up to 90 tons could reduce CO_2 emissions per ton-kilometre of cargo by up to 40%
    - Thus, HCT offers an effective way for reducing specific energy consumption and CO_2 emissions

Technology Collaboration Programme on Advanced Motor Fuels

Thank you for attention!