JEC WTW v5

Well-to-Wheels analysis of future automotive fuels and powertrains in the European context

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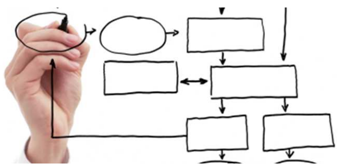
a JRC - Unit C.2 – Ispra

b EUCAR

c Concawe

Methodological approach

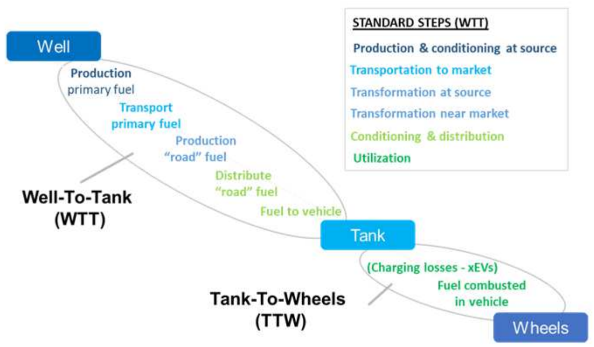
Nicolae **Scarlat**



JRC *– Directorate C - Energy, Transport and Climate Energy Efficiency and Renewables - Unit C.2*

European Commission

JEC WTW - Goals



Establish

in a **transparent** and **objective** manner
a consensual **Well-to-Wheels assessment** of:
- energy use
and
- GHG emissions

for a **wide range** of **automotive fuels** and **powertrains**, relevant to Europe in 2025+

Analysis updated as technologies evolve
Common methodology and data-set

JEC WTW


JRC SCIENCE FOR POLICY REPORT

JEC Well-to-Tank report v5

Well-to-Wheels analysis of future automotive fuels and powertrains in the European context

Concawe
eucar

Data from JEC WtW are normally used and cited by numerous scientists world-wide and elements of it directly feed into EU policies. Currently, **JEC WTW has been used as source** for:

- DG-MOVE report "**State of the art on alternative fuels transport systems in the European Union - 2020 update**",
- DG-CLIMA study "**Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA**", performed by a consortium led by RICARDO.
- Data have been supplied for work of the **IPCC WG3 LCA data (**call for data on climate footprints and costs of mitigation options within the transport sector**)**.

Attributional vs Consequential

To complement the analysis, a detailed **section comparing attributional and consequential CO_2 allocation methods** to refining products (focus on gasoline and diesel) is included (**NEW!**).

The **JEC use** a **consequential approach** as it **aims to guide judgements** on the potential benefits **of substituting conventional fuels/vehicles** by alternatives **and for future fuels**, to **understand where the additional energy** resource **would come from** (if demand for a new fuel were to increase).

We invite JEC readers and LCA practitioner not to directly apply JEC results without taking into consideration the methodological approach chosen.

Comparison between attributional (A-LCA) and consequential (C-LCA) approaches

	A-LCA	C-LCA
Goal and scope	Assessment of goods and services	Assessment of a change (e.g. policy implementation)
Technical system	Energy and material flow physically linked to the product system	Energy and material flows affected by marginal changes
Dealing with Multi-functionality	Mass, energy or economic allocation, substitution	System expansion
Data requirements	Average data	Marginal data (Site-, process-, product-specific)

Summary. Refinery allocation results based on extended literature review

	Consequential "Marginal" (g CO_{2eq}/MJ)			**Attributional "Average" (g CO_{2eq}/MJ)**			
	JEC (Concawe)		JRC paper (2017)	Aramco paper (4)		JRC paper	Sphera (2020)
	JEC v4 (1)	**JEC v5 (3)**	JRC (2)	Standard Mass allocation	Customized allocation (4)*	EN (2)	Mass & Energy
Gasoline	7	**5.5**	5.8	10.2	7.6	5.7 - 5.8	9.6
Diesel	8.6	**7.2**	7.2	5.4	6.8	5.8 - 6	3.4

Methodology: Co-product emissions JEC vs REDII

A given (fuel) production process may produce multiple products*

* Co-products
Different routes can have very different implications in terms of energy, GHG, or cost
…and it must be realised that economics – rather than energy use or GHG balance – are likely to dictate which routes are the most popular in real life.

Co-products in RED and RED Recast

- **RED and RED Recast allocate GHG emissions to biofuels and co-products by energy content** (LHV), i.e.:
  - Emissions are allocated to the main product and on co-products on the basis of their respective energy contents

☑ **Allocation methods have the attraction of being simpler to implement**
☒ Any benefit from a co-product depends on what the by-product substitutes: allocation methods take no account of this

Co-products in JEC WTW Methodology

- **JEC methodology uses a substitution method**, i.e.:
  - All energy and emissions generated by the process are allocated to the main or desired product;
  - The co-product generates an energy and emission credit equal to the energy and emissions saved by not producing what the co-product is most likely to displace.

☑ **Closer representation of "real-life": economic choices of stakeholders**
☒ Uncertainty: outcomes dependent on fate of co-products

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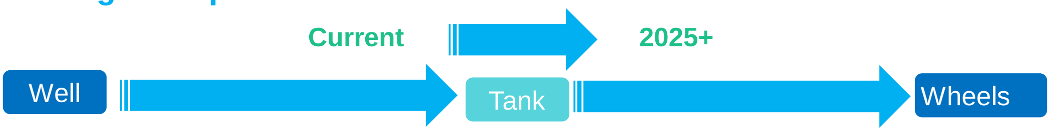
JEC WTW v5. What's new?

Changes respect to version 4



174 **Major update of JEC v4 pathways**

+

78 **New pathways**
New technologies, new fuels and new feedstocks.

+

WTT Cost Analysis
on selected biofuel routes

HDV **NEW!**
Heavy Duty section!
Class 4 and 5

PC **NEDC & WLTP cycles**
Modelling work!

European Commission

Disclaimer

The JEC Well-to-Wheels study is a technical analysis of the energy use and GHG emissions of possible road fuel and powertrain configurations in the European context for a time horizon of 2025+.

This study is not intended to commit the JEC partners to deliver any particular technology or conclusion included in the study.

***

For a **full description of the study** including assumptions, calculations and results, please consult the full set of reports and appendices available at:

https://ec.europa.eu/jrc/en/jec

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JEC Well-to-Tank (WTT)

Environmental impact of traditional and alternative fuels production

- Marta **Yugo**

Concawe – Environmental Science for European Refinery

European Commission

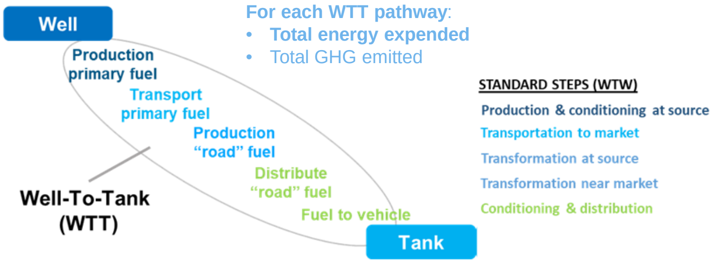
JEC WTT v5 - Scope

- **Scope**

Well-to-Wheels analysis of future automotive fuels and powertrains in the European context

JEC Well-to-Tank report v5

Concawe
eucar
European Commission



Link to JEC WTT v5 report + Appendixes

https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-tank-report-v5

WTT Appendixes

Complementing the main text, different detailed Appendixes have been created:

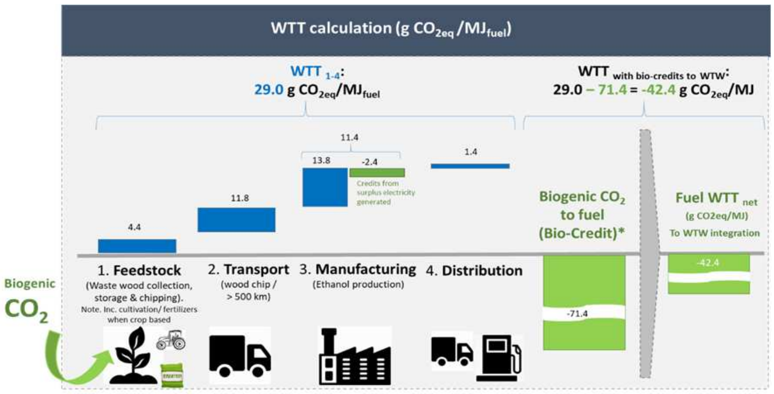
- Appendix 1. WTT individual workbooks (ZIP).
- Appendix 2. Conversion factors, fuel properties and input data.
- Appendix 3. Comparison versus JEC WTT v4.
- Appendix 4. Heat & Power. Inputs and Energy / GHG results.
- Appendix 5. ILUC/DLUC.
- Appendix 6. Contribution of construction materials.
- Appendix 7. Cost analysis on liquid biofuel pathways.

JEC WTT v5 - Pathways analysed

JEC WTT v5 IN NUMBERS

Schematic representation of JEC WTT GHG intensity calculation for fuel pathways and its use in the JEC WTW integration

Example. Waste wood based pathway (Ethanol – WWET1b)



(*) CO_2 released back to the atmosphere when 1 MJ of the fuel is totally combusted. Equivalent to the amount of CO_2 initially captured by the tree during the photosynthesis process (zero net effect)

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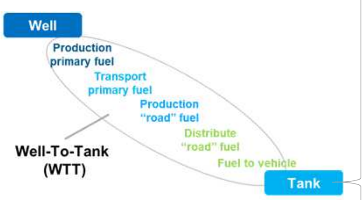
JEC WTT v5 – Pathways analysed

- Scope



Major updated versus JEC WTT v4

For each WTT pathway indication of Technology & Commercial readiness levels **(TRL & CRL)** (NEW!)

JEC WTT v5 IN NUMBERS

- 252 — **Total WTT pathways**
- 78 — **New pathways**
- 54 — **Synthetic fuel** pathways investigated
- 7 — **Resource categories**

From Resource to fuel: production routes (*Pathways*)

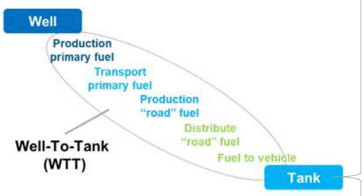
- Crude oil
- Natural gas
- Coal
- Electricity production
- Biomass / Waste
  - ✓ Crop based
  - ✓ Waste
  - ✓ Wood
- Hydrogen
- Power-to-fuels (e-fuels)

Role of CCS

European Commission

JEC WTT v5 – Pathways analysed

- Scope



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- 10 – **Final fuels** ("families")
- ~40 – **Experts involved**

Thanks to the members of the JEC expert group assisted by LBST!

Final fuels ("families")
(Pathways)

- Gasoline/diesel fuels (& ED95 & AdBlue components)
- Synthetic Fischer-Tropsch diesel (GLT, BTI, CTL, PtD)
- Pyrolysis / HTL diesel/gasoline
- CNG/LNG, CBM/LBM, SNG/LNG, LPG
- Ethanol
- FAME, FAEE and HVO
- Methanol
- Ethers (MTBE, ETBE/ DME, OME)
- Electricity
- Hydrogen

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JEC WTT v5 – Resource to fuels

252

Conversion pathways based on:

STATE-OF-THE-ART

- Updated / New pathways based on recent literature review and/or empirical data to reflect new technologies, fuels and feedstocks.
  - Data from other Associations (e.g. NGVA), Technology Providers included.
- Stakeholders / experts are invited to contribute!

STANDARD STEPS (WTW)

Production & conditioning at source
Transportation to market
Transformation at source
Transformation near market
Conditioning & distribution

New fuels: e.g. ED95. Ethanol with ignition improver fulfilling SS 155437. ED95 can be used in dedicated compression ignition engines.

Resources To "fuels" (Resource)		Gasoline, Diesel (2017 quality)	Gasoline E10 / Gasoline High octane	Synthetic gasoline (Pyrolysis-based Naptha)	Diesel B7 (2017 market blend)	Synthetic gasoline	Synthetic diesel	Synthetic diesel (Pyrolisis-based diesel)	DME	OME	Ethanol	Methanol	MTBE/ETBE	ED95	Pure vegetable oil	FAME / FAEE	HVO	CNG	CBG	SNG	LNG	LPG	Hydrogen (Comp., liquid)	Electricity	Heat
Crude Oil		X (1)	X (1)																					X (5)	X (6)
Coal							X		X			X											X	X	
Natural gas	Piped						X		X	X		X						X					X (1)	X	
	Remote						X (1)		X (1)			X						X (1)			X (1)		X	X	
Shale gas																		X							
LPG	Remote (3)												X									X			
Biomass / waste	Sugar beet										X		X (10)												
	Wheat										X		X	X											
	Barley/rye										X														
	Maize (Corn)										X (4)								X (2)		X (2)			X (2)	
	Wheat straw										X			X											
	Sugar cane										X														
	Rapeseed															X	X								
	Sunflower															X	X								
	Soy beans															X	X								
	Palm fruit															X	X								
	Double crooping																		X (2)		X (2)				
	Wood waste (8)			X			X (9)	X (1)	X (9)	X	X	X (9)								X (7)	X (7)		X (9)	X (9)	X
	Farmed wood (poplar)			X			X	X (1)	X	X	X	X								X (7)	X (7)		X	X	X
	Waste veg oils															X	X								
	Tallow															X	X								
	Palm oil mill effluent																X								
	Municipal organic waste																		X (2)					X	X
	Manure																		X (2)		X (2)			X	X
	Sewage sludge																		X (2)		X (2)				
Renewable electricity (Wind)							X			X										X	X		X	X	
Nuclear																							X	X	
Electricity mix																							X	X	

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JEC WTT v5 – Technology to fuels

252

Conversion pathways based on:

STATE-OF-THE-ART

- Updated / New pathways based on recent literature review and/or empirical data to reflect new technologies, fuels and feedstocks.
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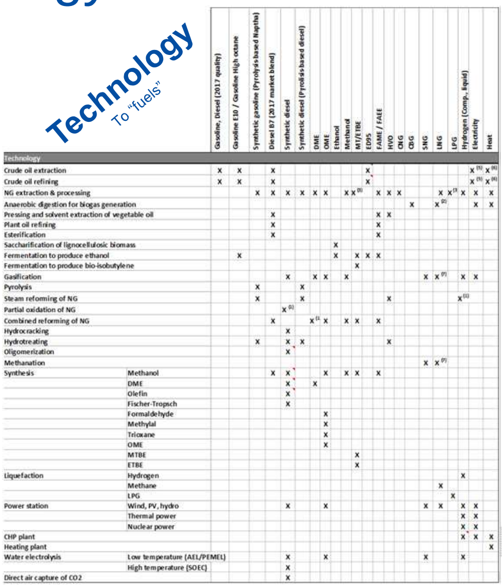

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JEC WTT v5 – Updated Pathways

252

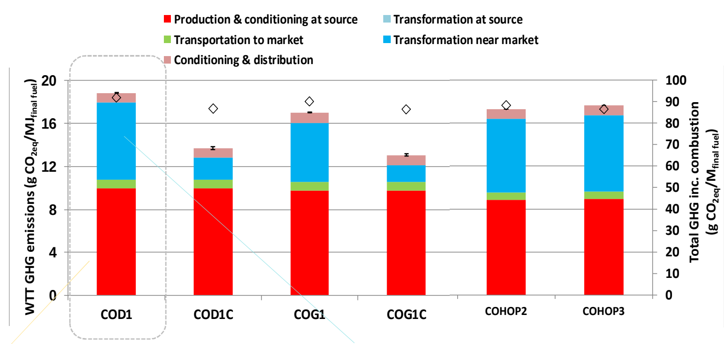
Conversion pathways based on:

Recent Studies
STATE-OF-THE-ART

INPUTS updated (examples):

- Electricity mix (LV including upstream losses)
  - ❑ Current EU mix (2016 - JRC / EEA): 110 g CO_{2eq}/MJ (~29% RES)
  - ❑ EU mix (2030 - IEA NPS + En. Eff improve. for combustion power plants): 75 g CO_{2eq}/MJ (45% RES)
- Crude oil extraction from Exergia et al.
- Refining products from latest Concawe's analysis
- Biofuel pathways → inputs for forestry residue collection, transport & distribution, etc. aligned to RED II
- CNG / LNG pathways → distances and quality per location updated; EU mix included as indication.

Example. Crude oil based fuels
WTT GHG emissions (w/o and with combustion) (g CO_{2eq}/MJ_{fuel})



Crude oil production/transport

JEC WTT v5: 10 g CO_{2eq}/MJ_{prod}

(WTT v4: 4.7 g CO_{2eq}/MJ_{prod})

Transformation (Refining – Marginal Diesel)

JEC WTT v5: 7.2 g CO_{2eq}/MJ_{prod}

(WTT v4: 8.6 g CO2/MJ marginal diesel)

JEC WTT v5 – New Pathways

78

Conversion pathways based on:

New technologies, new feedstocks, new fuels

Examples:

- Gasoline / Diesel + CCS
- Biofuel + CCS (BECCS / Negative emissions)
- High octane gasoline (HOP)
- Pyrolysis / HTL based gasoline & diesel
- H2 from methane cracking

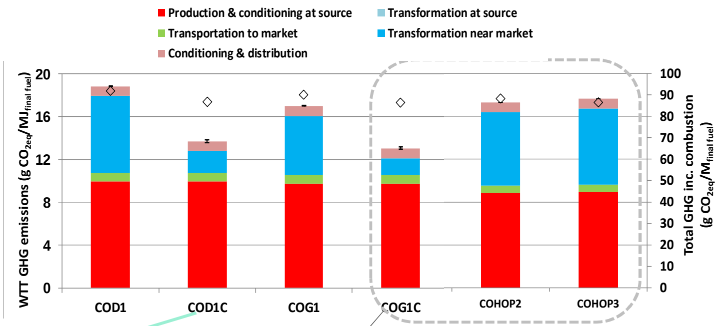
- Power-to-fuels (Carbon Capture and Usage)

- POME (Palm Oil Mill Effluent)
- 100% Bio-based ETBE (Global Bio-energy)
- CNG/CBG from sludge
- SNG from RES

- ED95
- adBlue
- …

Example. Crude oil based fuels

WTT GHG emissions (w/o and with combustion) (g CO_{2eq}/MJ_{fuel})



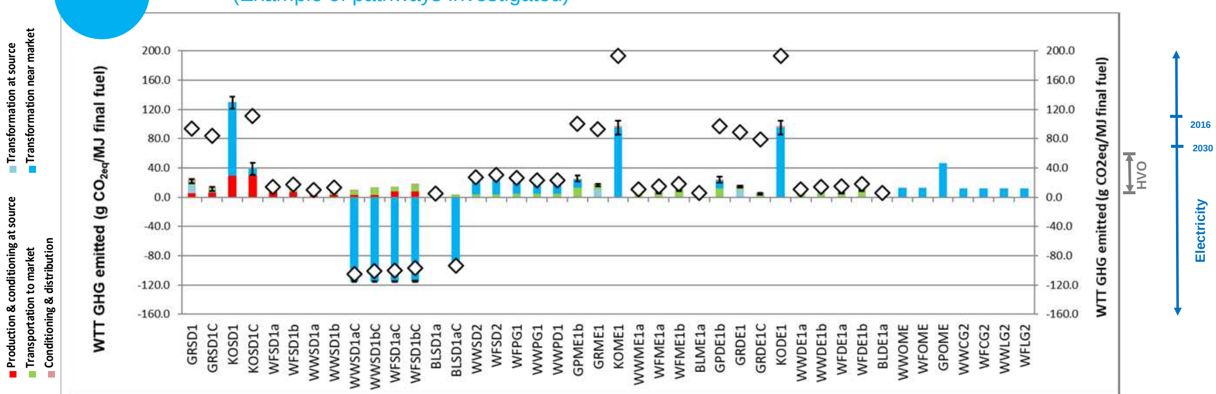
Diesel + Carbon Capture and Storage (CCS)
CCS schemes added to a number of selected pathways to assess the potential impact (WTT)

New HOP (High Octane Gasoline)
Oil based gasoline, Ethanol and Ethers
100 RON and 102 RON (E5eq and E10eq)
(Source: Concawe)

JEC WTT v5 - WTT – Synthetic fuels

54

- **Synthetic fuel (Part I. Biomass, waste, organic material)**
  (Example of pathways investigated)



Syn-diesel (XTL)
Fischer-Tropsch with/wo CCS) from gas, coal, wood

Pyrolysis / HTL

Methanol

DME

OME

Bio-SNG

Code:
WW: wood residue
WF: farmed wood
BL: Black liquor
xC: With CCS
SD: synthetic diesel
GPx: natural gas

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JEC WTT v5 - WTT – Synthetic fuels (Power-to-X)

54

- Power-to-fuels **(NEW!!)**

Green H_2 electrolysis (Renewable) + CO_2 (waste)

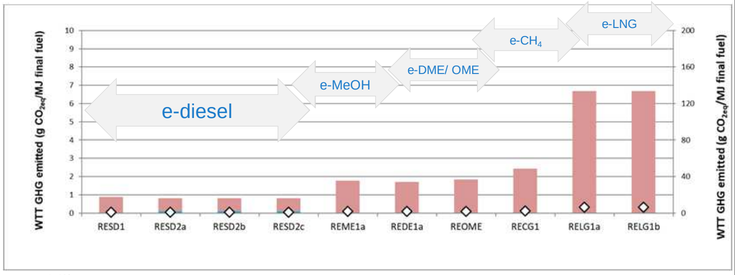
Renewable electricity

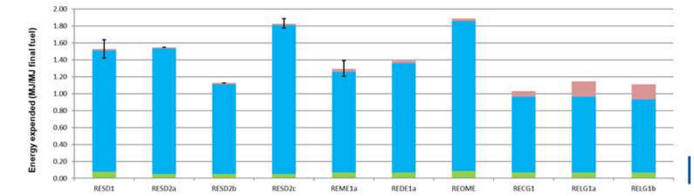
e-fuels (Power-to-X)

TRL ~ 6 - 9

CRL ~ 1 - 3

Deep GHG Reduction savings.
Highly energy intensive production process vs conventional diesel (e.g)!



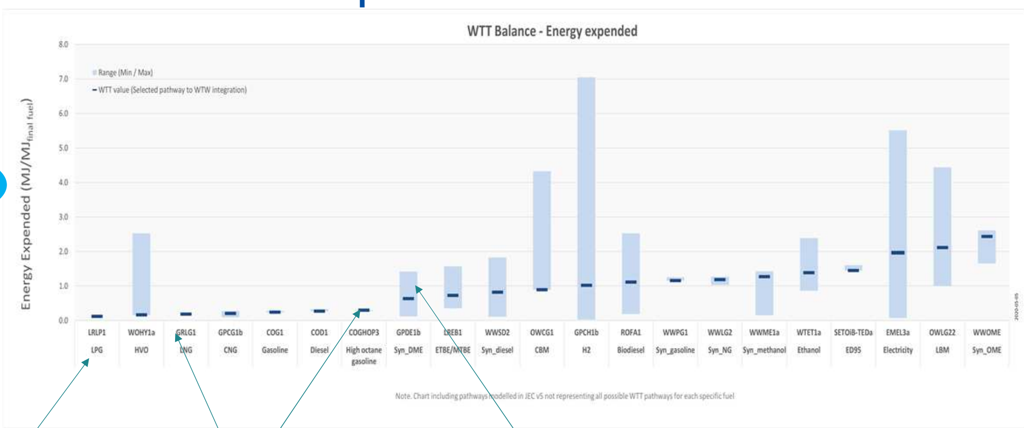


- Production & conditioning at source
- Transportation to market
- Conditioning & distribution
- Transformation at source
- Transformation near market
- ◇ Total GHG inc. combustion

JEC WTT v5 – Comparative

Fuel comparison

(Range presented around a selected representative pathway)



Fuel

Representative WTW pathway (Code + Volume)

RANGE (WTT) Min/Max from pathways modelled in JEC v5

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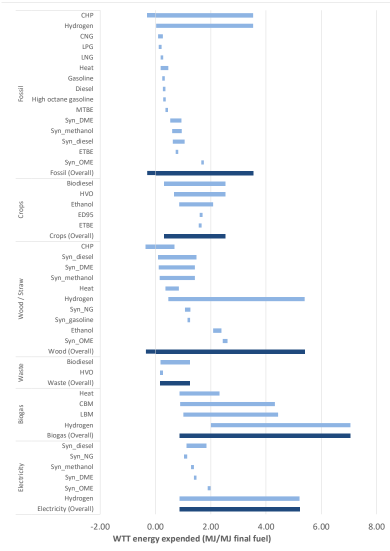
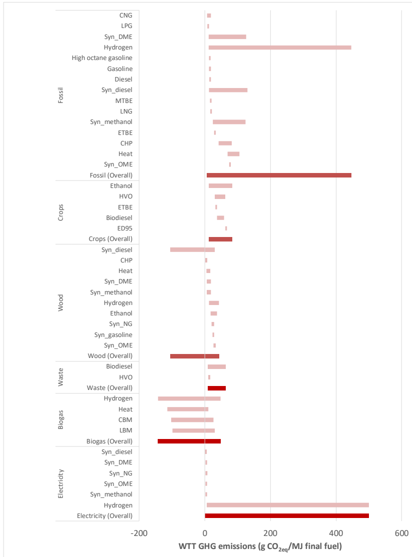
JEC WTT v5 – Comparative

RESOURCE COMPARISON

Ranges per type of feedstock/resource into final fuels

(Only for pathways included in JEC v5)





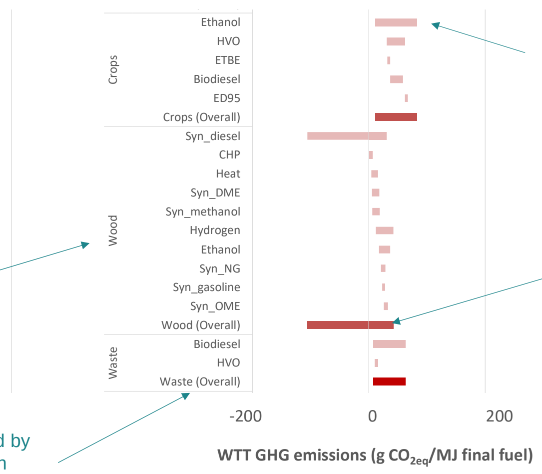
JEC WTT v5 – Comparative

RESOURCE COMPARISON

Ranges per type of feedstock/resource into final fuels

(Only for pathways included in JEC v5)

RESOURCE

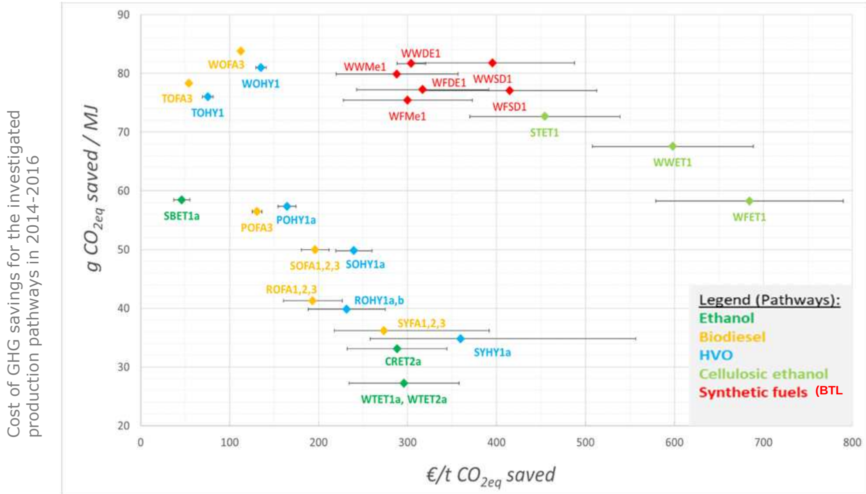


Range for a specific resource (Min / max from the pathways modelled in JEC WTTv5)

Range for a specific fuel (Min / max from the pathways modelled in JEC WTTv5)

Final fuels produced by means of a certain resource/feedstock

JEC WTT v5 – Cost analysis



Note.

Total production costs

= CAPEX

(Investment)

+

OPEX

(cost of feedstocks and operational costs).

12% capital charge rate <> ~ 8% return on investment wo taxes.

20% uncertainty range on CAPEX

European Commission

JEC Tank-to-Wheels (**TTW**)

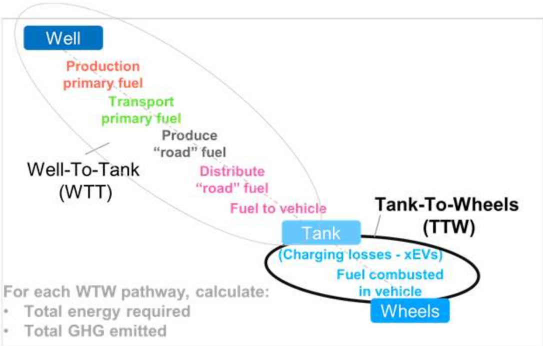
Version 5 for passenger cars and heavy-duty vehicles

- Luis de **Prada**

  EUCAR – Research programme manager

European Commission

Introduction



The Tank-to-Wheels (TTW) study aims to provide technology-neutral comparison of powertrain and energy carrier combinations by estimating GHG emissions or energy efficiency.

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Passenger Cars (**PC**)

MAIN RESULTS

European Commission

Introduction

TTW passenger cars (PC):

- Representative of EU market,
- Generic C-segment passenger car (2015 and 2025+),
- TTW simulations to reflect changes in test cycles from NEDC (New European Drive Cycle) to WLTP (Worldwide Harmonized Light duty Test Procedure).
- PC simulations have been performed by AVL List GmbH using Cruise software (as in Version4).

Fuels and powertrain configurations considered

EUCAR V5: 2015 Investigation Matrix	2015 Powertrain Variants										
	DISI	DICI	Hybrid DISI	Hybrid DICI	PHEV50 DISI	REEV100 SI	PHEV50 DICI	BEV150	FCEV	PHEV50 FC	REEV100 FC
Gasoline (E5)	■		■		■	■					
Gasoline E10 market blend	■		■		■	■					
Gasoline high RON (var. 1)	■		■		■	■					
Gasoline high RON (var. 2)	■		■		■	■					
Diesel (B0)		■		■			■				
Diesel B7 market blend		■		■			■				
LPG	■										
CNG	■										
E100	■		■		■	■					
FAME (B100)		■		■			■				
DME		■		■			■				
FT-Diesel*		■		■			■				
HVO*		■		■			■				
Electricity					■	■	■	■		■	■
Hydrogen (CGH2)									■	■	■

EUCAR V5: 2025+ Investigation Matrix	2025+ Powertrain Variants														
	DISI	DISI MHEV	DICI	DICI MHEV	Hybrid DISI	Hybrid DICI	PHEV100 DISI	REEV200 SI	PHEV100 DICI	REEV200 DICI	BEV200	BEV400	FCEV	PHEV100 FC	REEV200 FC
Gasoline (E5)	■	■			■		■	■							
Gasoline E10 market blend	■	■			■		■	■							
Gasoline high RON (var. 1)	■	■			■		■	■							
Gasoline high RON (var.2)	■	■			■		■	■							
Diesel (B0)			■	■		■			■	■					
Diesel B7 market blend			■	■		■			■	■					
LPG	■	■													
CNG	■	■													
E100	■	■			■		■	■							
FAME (B100)			■	■		■			■	■					
DME			■	■		■			■	■					
FT-Diesel*			■	■		■			■	■					
HVO*			■	■		■			■	■					
Electricity							■	■	■	■	■	■		■	■
Hydrogen (CGH2)													■	■	■

* EN15940 synthetic diesel standard to allow optimized engines

Fuels and powertrain configurations considered

Ranges:

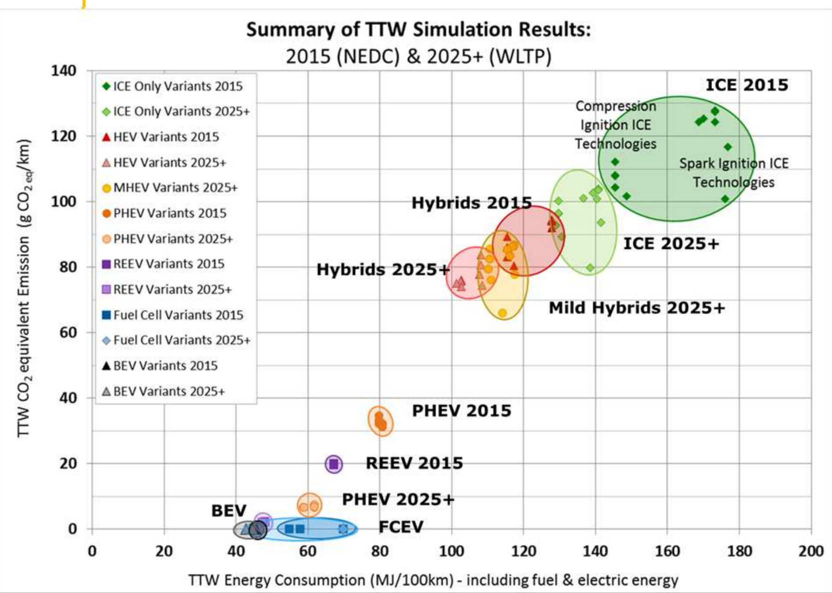
- BEV range: 150km (2015), 2 variants (2025+) 200km and 400km
- PHEV EV range: 50km (2015), 100km (2025+)
- REEV EV range: 100km (2015), 200km (2025+)

Terminology:

- DISI: Direct Injection Spark Ignition
- DICI: Direct Injection Compression Ignition
- HEV: Hybrid Electric Vehicle
- MHEV: Mild Hybrid Electric Vehicle (48v)
- PHEV: Plug-In Hybrid Electric Vehicle
- REEV: Range Extender Electric Vehicle
- BEV: Battery Electric Vehicle
- FCEV: Fuel Cell driven Electric Vehicle
- LPG: Liquefied Petroleum Gas
- CNG: Compressed Natural Gas
- FAME: Biodiesel (B100)
- DME: Di-Methyl-Ether
- FT-Diesel: Paraffinic diesel (EN15940)
- HVO: Hydro-treated Vegetable Oil

European Commission

Results



CO2 equivalent emission and energy consumption for 2015 and 2025+ variants

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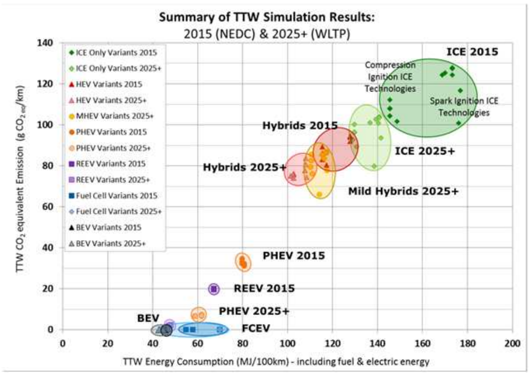
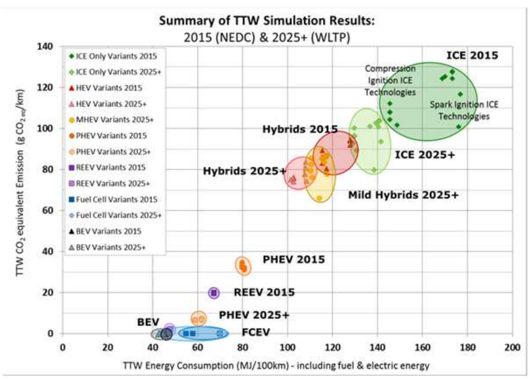
Results



- Due to improvements in future powertrain technology, as well as with the support of fuel quality, ICE powered vehicles will continue to deliver TTW GHG emission reductions and energy savings compared to the 2015 baseline. Future Diesel-type engines will keep energy efficiency benefit.
- Hybridisation (Mild (48v) and Full-Hybrids) will deliver additional reductions in both domains (gasoline and diesel).
- Additional GHG and energy consumption reductions can be achieved with deeper electrification, i.e. PHEV, REEV as well as FCEV and BEV powertrains. However, main differentiator between PHEV and REEV is battery size rather than ICE integration.

Results



- Alternative Fuels in ICE vehicles (e.g. CNG, HVO…) have a GHG emissions reduction effect compared to their fossil equivalents on TTW perspective, however not reflected in current legislation.
- Future legislation will concentrate on reducing real driving emissions – the contribution of sustainable renewable and efficiency-aiding fuels will therefore become more important.

HEAVY DUTY VEHICLES (HDV)

MAIN RESULTS

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Introduction

TTW heavy-duty vehicles (HD):

- New in version 5;
- Representative of EU market,
- Generic long-haul vehicles and specific fuels leveraging VECTO tool (2016 and 2025+), ➔ TTW simulations to reflect groups 4 and 5

- HD simulations have been performed by FVT from Graz University of Technology using VECTO software.

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Introduction

- Baseline year for vehicle simulations 2016 and the outlook 2025+
- Powertrain: Diesel (CI Compression Injection), Dual fuel (PI Port Injection + gas), Hybrid, Battery electric, Fuel cell electric, Electric road (Catenary Electric Vehicle)
- Fuels: Conventional (Diesel), alternatives diesel fuels (Biodiesel (B100), Paraffinic diesel (HVO hydrotreated vegetable oil, paraffinic diesel, eFuel) and ED95, Gaseous fuels (DME Di-Methyl-Ether), OME (Oxy-methylene-ethers), LNG (liquefied natural gas)/LBG (liquefied biogas), CNG (compressed natural gas)/CBG (compressed biogas), Electricity, Hydrogen
- Two applications using VECTO test cycle:
  - Long haul 325kW (VECTO group 5)
  - Regional haul 220kW (VECTO group 4)

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Specifications reference models 2016 & 2025+

	Group 4	Group 5
Curb mass (90% Fuel + driver) [kg]*	5800	7550
Curb mass body/trailer [kg]	2100	7500
Engine power [kW]	220	325
Displacement [ccm]	7700	12700
Max. Torque [Nm]	1295 (1100 -1600 rpm)	2134 (1000-1400 rpm)
Rated speed [rpm]	2200	1800
Idling speed [rpm]	600	600
Engine peak BTE (%)	44.3	45.8
RRC [N/kN] (Steer/Drive/Trailer)	5.5/6.1/---	5.0/5.5/5.0
CdxA [m2]/vehicle height [m]	5.6/4	5.57/4
Transmission type	AMT	AMT
Efficiency indirect gear	96%	96%
Efficiency direct gear	98%	98%
Axle Ratio	4.11	2.64
Axle Efficiency	96%	96%
Advanced Driver Assistance Systems (ADAS)	---	Predictive Cruise Control (PCC)** + Eco-roll***

* This definition refers to the mass as specified under the 'actual mass of the vehicle' in accordance with Commission Regulation (EC) No 1230/2012 (1) but without any superstructure
** Predictive cruise control manages and optimises the usage of the potential energy during a driving cycle
*** Eco-roll reduce the engine drag losses by disengaging the engine from the wheels during certain downhill conditions

	Group 4	Group 5
Curb mass (90% Fuel + driver) [kg]*	5665	7485
Curb mass body/trailer [kg]	2035	7365
Engine power [kW]	220	325
Displacement [ccm]	7700	12700
Max. Torque [Nm]	1295 (1100 -1600 rpm)	2134 (1000-1400 rpm)
Rated speed [rpm]	2200	1800
Idling speed [rpm]	600	600
Engine peak BTE (%)	45.6	47.2
RRC [N/kN] (Steer/Drive/Trailer)	5.02/5.57/---	4.57/5.02/4.57
CdxA [m2]/vehicle height [m]	5.39/4	4.96/4
Transmission type	AMT	AMT
Efficiency indirect gear	96%	96%
Efficiency direct gear	98%	98%
Axle Ratio	4.11	2.64
Axle Efficiency	96%	96%
ADAS	PCC** + Eco-roll***	PCC + Eco-roll

* This definition refers to the mass as specified under the 'actual mass of the vehicle' in accordance with Commission Regulation (EC) No 1230/2012 (1) but without any superstructure
** Predictive cruise control manages and optimises the usage of the potential energy during a driving cycle
*** Eco-roll reduce the engine drag losses by disengaging the engine from the wheels during certain downhill conditions

Fuel and powertrain configurations considered

Powertrain / Fuel	ICE CI (Diesel)	ICE PI (Gasoline)	ICE CI + HEV	ICE PI + HEV	BEV	FCEV	CEV (electric road)
Diesel B0	Both						
Diesel B7 market blend	Both		Both				
DME	Both						
ED95	Both						
Electricity					Both		Both
Biodiesel (B100)	Both						
Paraffinic Diesel	Both						
CNG		Both		Group 4			
Hydrogen						Both	
LNG (EU mix.)	Both	Both		Group 5			
OME	Both						

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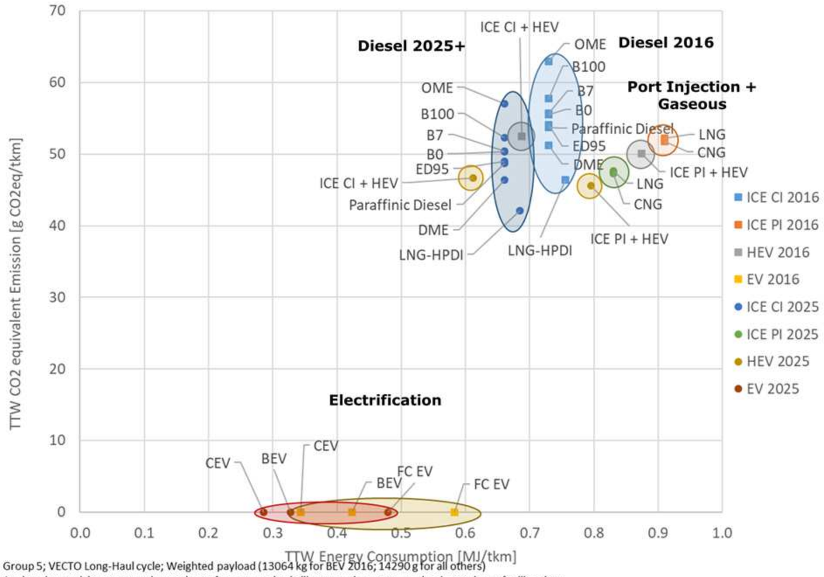
Fuel and powertrain configurations considered

Fuel Type	Description
Diesel B0	Diesel fulfilling EN590, with no FAME addition.
Diesel B7 market blend	Diesel fulfilling EN590, with up to 7% FAME addition.
FAME (B100)	Fatty Acid Methyl Esters biodiesel (B100) specified in EN14214.
ED95	Ethanol with ignition improver fulfilling SS 155437. ED95 can be used in dedicated compression ignition engines.
Paraffinic Diesel	Paraffinic Diesel fulfilling EN 15940. Gas to liquid (GtL or XtL) or Hydrogenated Vegetable oils (HVO).
DME	DiMethyl Ether, CH_3OCH_3, fulfilling base fuel standard ISO 16861. It can be used in dedicated compression ignition engines.
OME	Oxymethylene Ether, $CH_3O(CH_2O)nCH_3$, n=3,4,5. OME can be used in dedicated compression ignition engines.
H-CNG (2016)	Compressed Natural Gas, EU mix of H-Gas,specified in EN 16723-2.
H-CNG (2030)	Compressed Natural Gas, projected EU mix of H-Gas for 2030.
Hydrogen (CGH2)	Compressed hydrogen at 700 bar.
LNG (EU mix. 2016/2030)	Liquified Natural Gas, specified in EN 16723-2.

Results



Group 5; VECTO Long-Haul cycle; Weighted payload (13064 kg for BEV 2016; 14290 g for all others)
Analysed propulsion systems do vary in performance criteria like operating range, payload capacity or fuelling time

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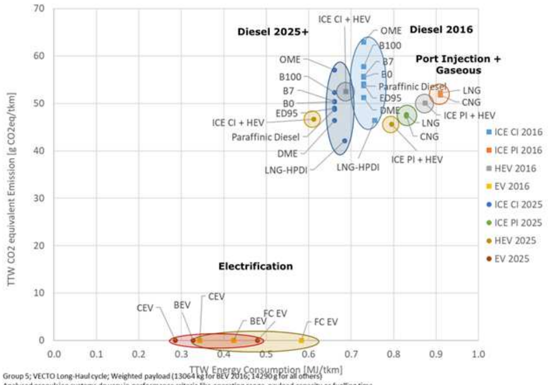
Results



Group 5; VECTO Long-Haul cycle; Weighted payload (13064 kg for BEV 2016; 14290 g for all others)
Analysed propulsion systems do vary in performance criteria like operating range, payload capacity or fuelling time

- Future ICE technologies and alternative fuels will continue to deliver GHG & energy savings.
- Diesel CI engines have about 20% lower fuel consumption than the PI gasoline engine.
- Hybrids provide significant energy and GHG reduction.

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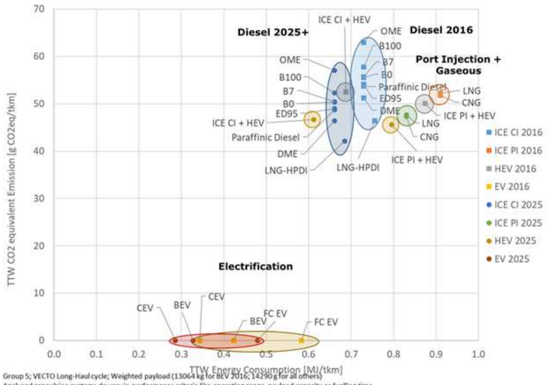
Results



Group 5; VECTO Long-Haul cycle; Weighted payload (13064 kg for BEV 2016; 14290g for all others)
Analysed propulsion systems do vary in performance criteria like operating range, payload capacity or fuelling time

- Fully electric and fuel cell alternatives offer zero TTW GHG emissions and significantly higher energy efficiency, up to 2.5 times for catenary electric vehicle (CEV, electric road).
- Alternative fuels (e.g. CNG/LNG, DME…) could provide a decrease in GHG emissions even considering only a TTW perspective as in current legislation.
- Future legislation will move towards real driving conditions and the contribution of fuels is expected to become more important.

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Conclusions

JEC TTW V5 – Passenger cars & Heavy-duty vehicles

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Takeaways

- Due to improvements in future powertrain technology, as well as with the support of fuel quality, ICE powered vehicles will continue to deliver TTW GHG emission reductions and energy savings compared to the baselines.
- Hybridisation will deliver additional energy and GHG reduction.
- Alternative Fuels in ICE vehicles offer GHG emissions reduction effect compared to their fossil equivalents on TTW perspective.
- The contribution of fuels to achieve energy and GHG reductions will become more important.

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JEC Well-to-Wheels (**WTW**)

Version 5

Matteo **Prussi**

JRC *– Directorate C - Energy, Transport and Climate Energy Efficiency and Renewables - Unit C.2*

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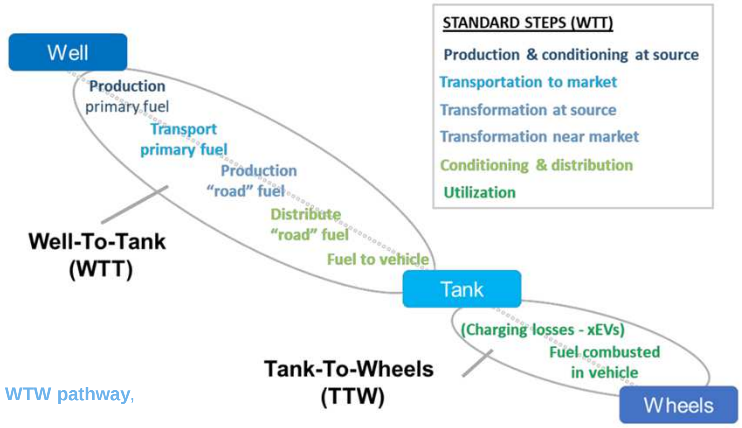
JEC WTW v5. Scheme



For each WTW pathway, calculate:

- Total energy required
- Total GHG emitted

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Integration

WTT
fuel
gCO2 / MJ

TTW
Powertrain efficiency
MJ / km

FLEET

Penetration of alternative powertrains

> 250 Resource to fuel pathways

>60 powertrains combinations

> 1500 possible combinations!

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Pathways selection criteria

For **each fuel group** (i.e. ethanol, biodiesel, etc.) we selected a maximum of **5 WTT pathways** for WTW integration

Criteria to select pathways		**Icon**
Reference fuel for comparison	Conventional fuel: the alternative can be compared against (e.g. regular diesel).	●
GHG emissions - Max **(Maximum value - gCO_{2eq}/MJ)**	Value close to the maximum allowed GHG Emissions, according to RED recast. As a general rule, WTT pathways with significantly higher GHG Emissions are not included in the comparison[5].	★
GHG emissions - Min **(Minimum value - gCO2eq/MJ)**	The route offering the minimum WTT GHG emissions. This value, along with the maximum route mentioned above, determine the WTT range of the production routes explored towards a final fuel.	★
Representative pathway	Selected pathway for the final fuel. Chosen by consensus within the JEC as example of one of the commercially available routes depending on the case (e.g. most frequent in Europe, higher share in the current mix, etc.).	△
Special interest	Selected examples of interesting new pathways/ feedstock.	◆
Technology Readiness Level	TRL > 6 (*)	(no icon)

Note. (*) In this WTW report we have focused on WTT feedstock/conversion routes at or close to be ready for commercialization. Therefore, WTT pathways with Technology Readiness Level (TRL) <6 have been excluded for the present WTW comparison (For additional comparisons, we would suggest the reader to refer back to the individual WTT and TTW reports where all the results for individual pathways/powertrain modelled are detailed).

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WTW integration

FUELS

- Biodiesel
- HVO
- Ethanol
- Compressed Biomethane
- Electricity
- …

SELECTED PATHWAY

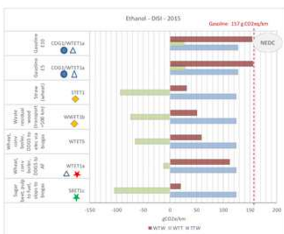
COG1	Conventional gasoline
OWCG1	Municipal waste (closed digestate)
OWCG21	Manure (closed digestate)
OWCG22	Manure (open digestate)
OWCG4	Maize, whole plant (closed digestate)
WWCG2	Syn-methane from Waste wood
RECG1	Syn-methane from renewable electricity

SELECTED POWERTRAIN

- PC: Class-C, single configuration.
- HDV: Class V, single configuration.

MAIN RESULTS

(for a specific reference year)



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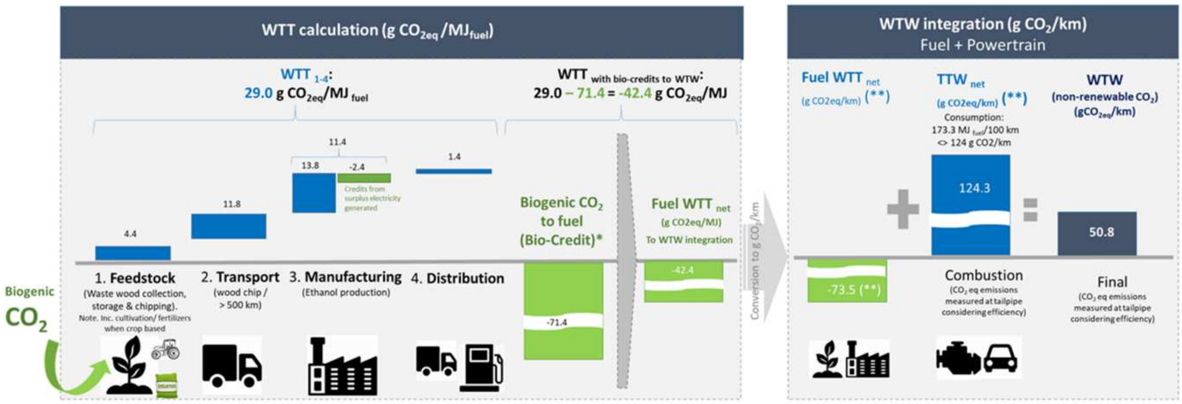
WTW integration



(*) CO_2 released back to the atmosphere when 1 MJ of the fuel is totally combusted. Equivalent to the amount of CO_2 initially captured by the tree during the photosynthesis process (zero net effect)

(**) WTT fraction related to the amount of fuel consumed in a specific powertrain: $WTT_{net\ to\ WTW}$ = -42.4 (g CO_{2eq}/MJ) x 173.3 MJ $_{fuel}$/100 km <> - 73.5 g CO_{2eq}/km

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Passenger Cars (**PC**)

MAIN RESULTS

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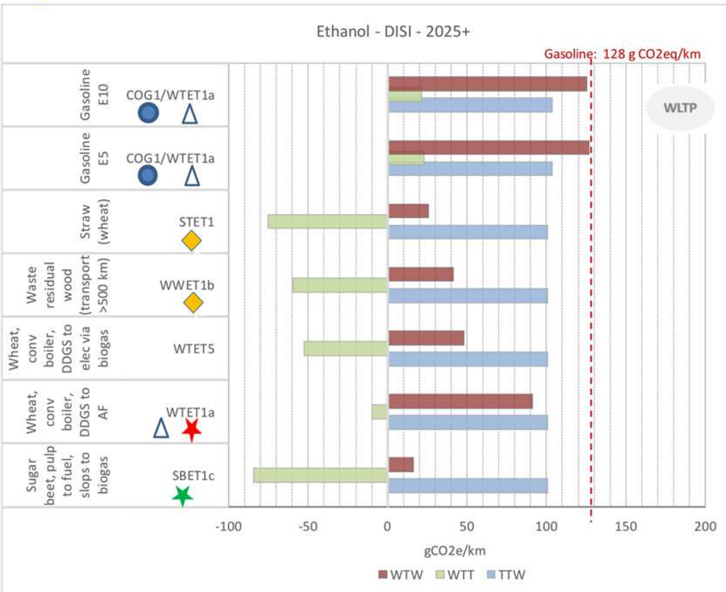
Example of integration: Biodiesel

The potential **GHG saving offered** by the use of **biodiesel** are strongly **related** to the **feedstock** used.

They vary **from ~50%,** versus **equivalent fossil diesel DISI** in the case of rape seed oil, **up to ~90%** when **waste oil routes are explored** .

Example of integration: Ethanol



Currently, gasoline with different ethanol blends is available in the European Market. **E5** (5%v ethanol) and **E10** (10%v) ethanol **are included as a reference**.

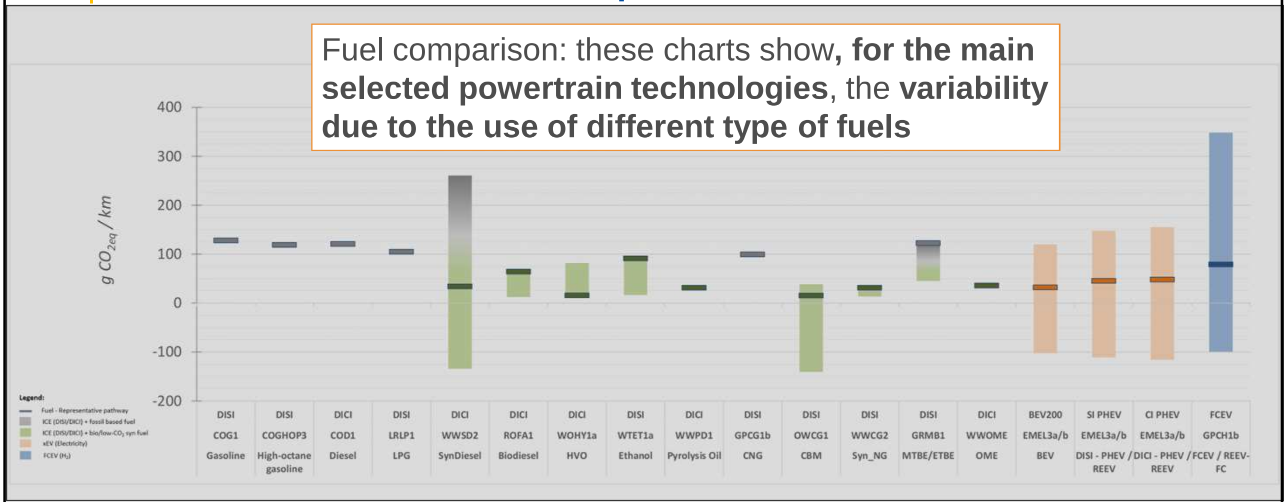
WTW GHG emission savings varying from 30 up to ~90%, versus conventional gasoline (100% fossil).

The best GHG performance for pathways where process by-products are valorised in the production cycle, to reduce energy demand.

Interesting GHG savings can be achieved using residues and wastes, as residual wood and straw:

- waste wood based pathways could perform ~70% better WTW than a conventional gasoline engine.

PC WTW – Fuel comparison



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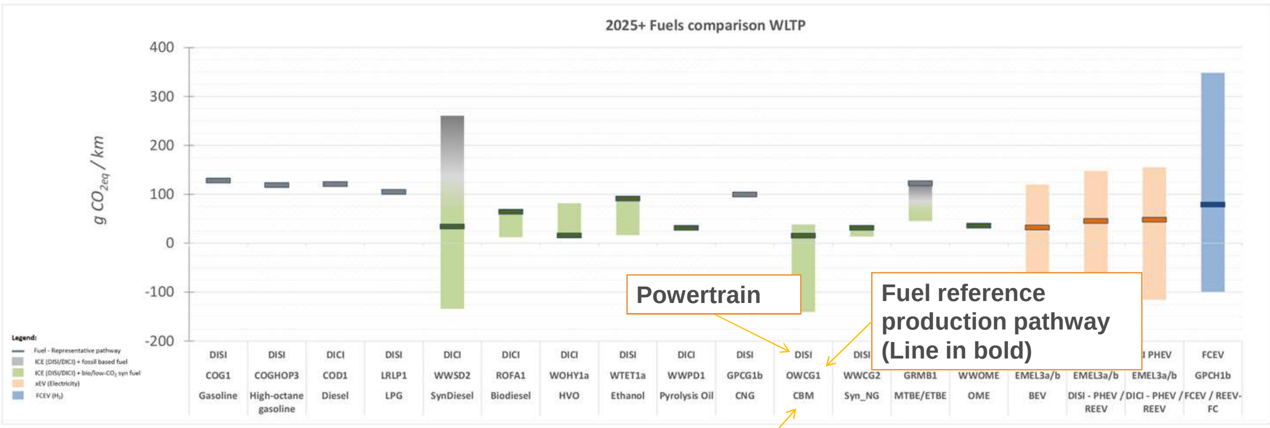
PC WTW – Fuel comparison



Alternative fuel type

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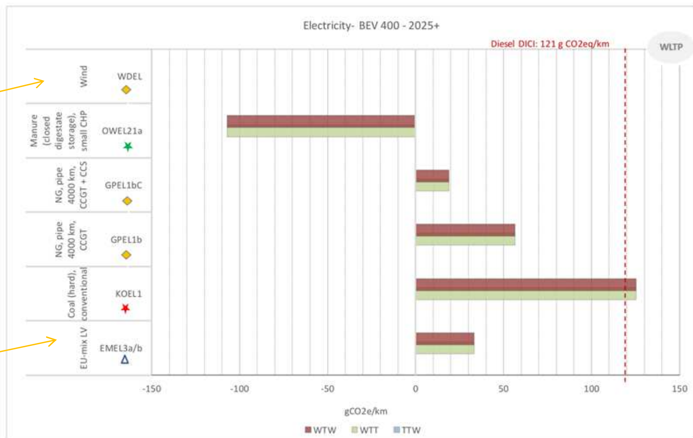
Main outcomes – fuel comparison

1. Almost all the **alternative fuels analysed** offer a **better WTW performance** than **conventional oil based gasoline/diesel** when used in Internal Combustion Engines (DISI/DICI).
2. Pathways, such as **alternative fuels based on waste** cooking oil (WOHY1a) **offer significant WTW performance improvements.**
3. **Electricity** and **Hydrogen** are energy vectors, so their WTW potential to lower **CO_2 emissions depend on the primary source of energy used** for the production.
4. The use of **renewable electricity** for **xEVs** and H2 production for **FCEV** offer **one of the lowest WTW intensive combinations**.

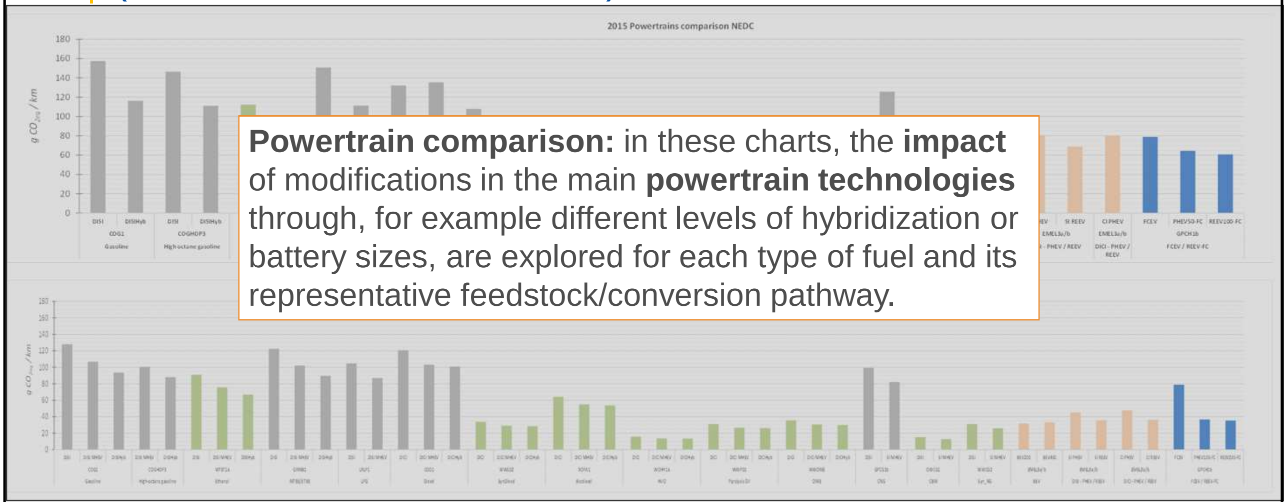
Electricity in Battery Vechicles

Renewable energies production is **crucial** to get **GHG saving from BEV.**

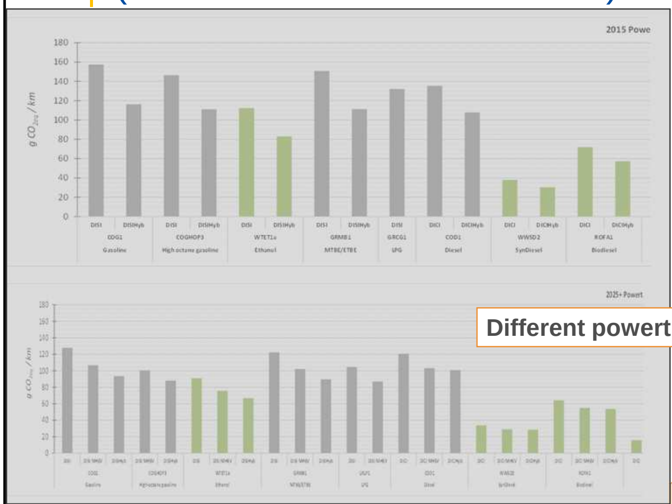
EU-ETS and **European Green Deal** are expected to push for **reducing GHG intensity** of EU **energy mix**, **far beyond** what modeled on the base of the current status of knowledge

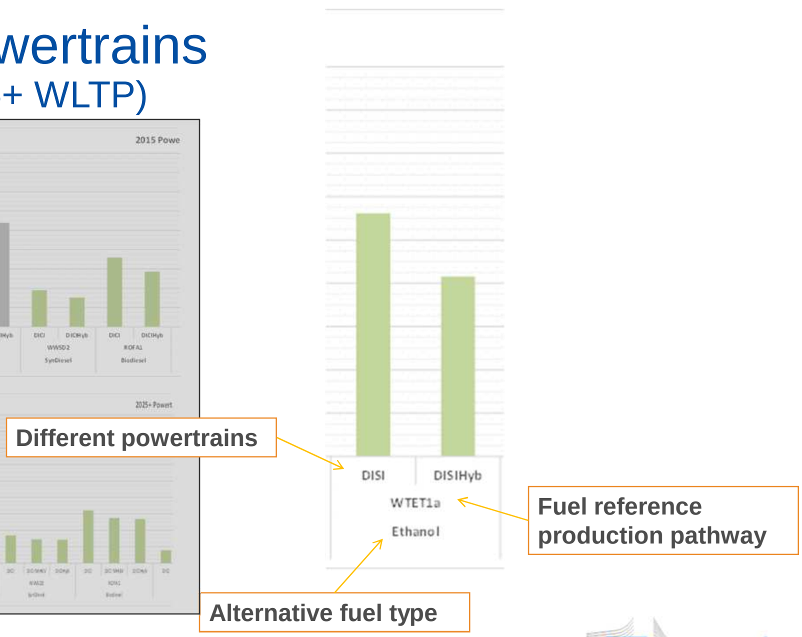


PC WTW – Powertrains
(2015 – NEDC / 2025+ WLTP)



PC WTW – Powertrains
(2015 – NEDC / 2025+ WLTP)





PC WTW – Powertrains
(2015 – NEDC / 2025+ WLTP)

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PC WTW – Powertrains
(2015 – NEDC / 2025+ WLTP)

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Main outcomes – powertrains

1. Generally speaking, the **hybridization of ICEs offers an effective option to reduce fuel consumption**, **up to ~25% .**
2. For **gasoline/DISI type of engines**, the **combination of high compression** with a **high octane gasoline** (102 RON) **offers** a **similar performance than DICI** (diesel) vehicles when **approaching 2025+**.
3. The **xEVs technology is expected to improve significantly towards 2025+** (including battery size increase). In 2015, FCEV and PHEV/REEV offer similar WTW results (~15% better performance of the latter versus FCEV.

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HEAVY DUTY VEHICLES (HDV)

MAIN RESULTS

HDVs first time in JEC study

- This WTW version 5 **concentrates** on the evaluation of energy and GHG balances for the **different combinations of fuel and powertrains**, in **road transport**.
- The **current version 5 investigates**, **for the first time**, the **heavy duty segment**, thus expanding the scope of the previous versions of the study.
- A **complete assessment for two different configurations** have been conducted**: rigid trucks used in regional delivery mission** (**Type 4**) & **tractor semitrailer combination for long haul** (**Type 5**).

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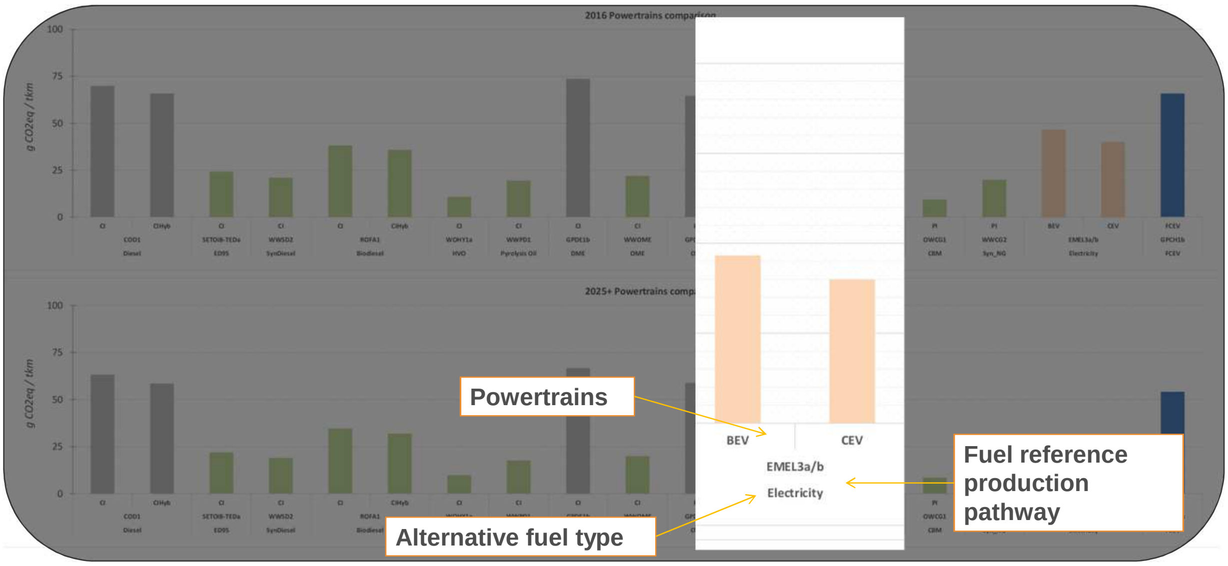
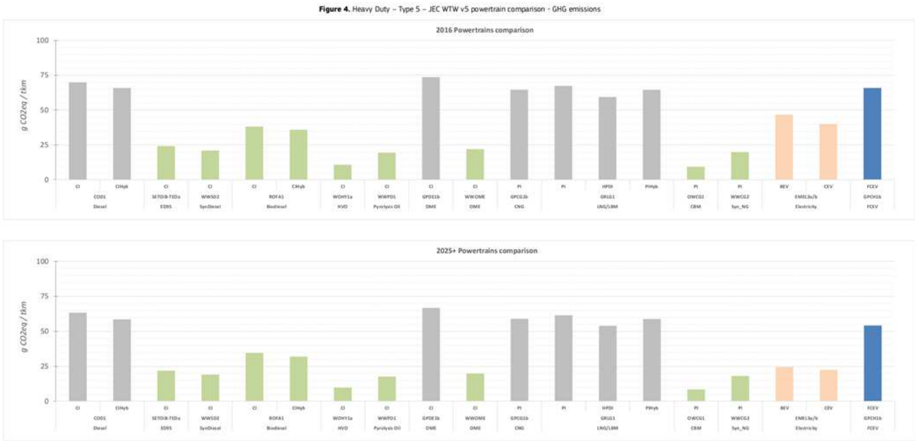
HDVs **WTW** – Powertrains (2016 – NEDC / 2025+ WLTP) - Type 5

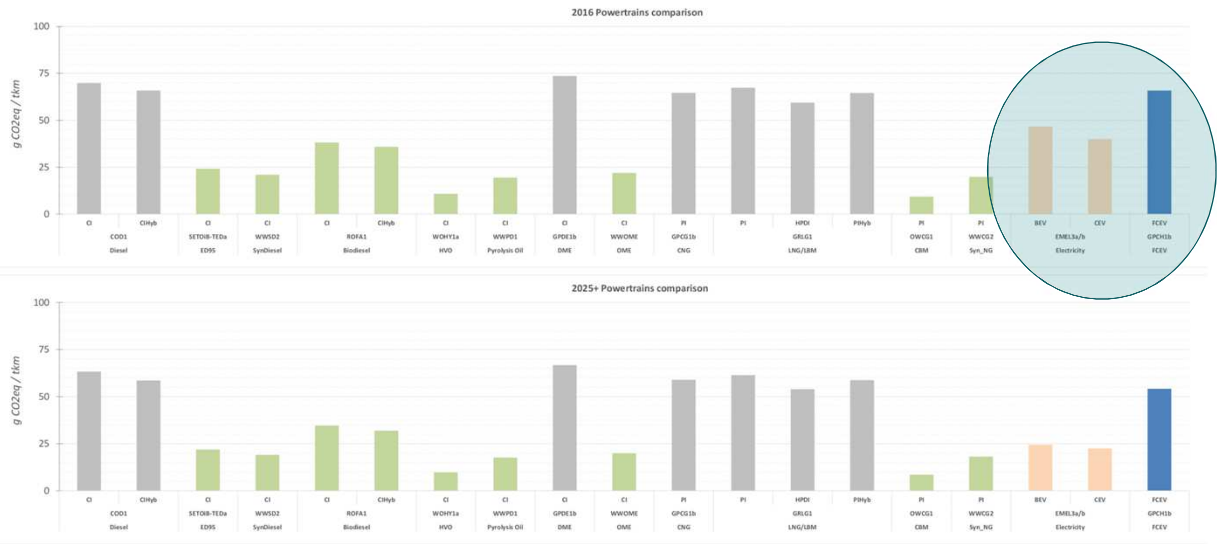


PC WTW – Powertrains (2015 – NEDC / 2025+ WLTP) - Type 5

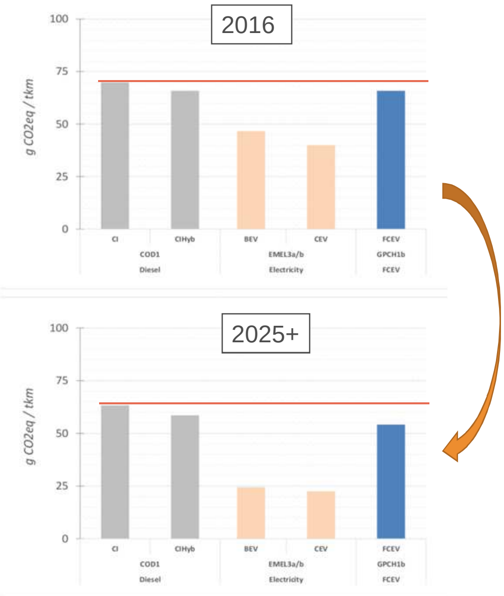


- As for PC, the **hybridisation of ICEs offers an effective option to reduce fuel consumption, up to ~7%.**
- **HPDI offers significant energy savings when compared to SI engines** leading to about up to 12% lower GHG emissions in 2016 and in 2025+ compared to SI engines with the same fuel.

HDVs **WTW** – Powertrains (2016 – NEDC / 2025+ WLTP) - Type 5



PC WTW – Powertrains - Type 5



EU electricity **mix** is used as a **proxy**.

EU-ETS and **European Green Deal** are expected to push for **reducing GHG intensity** of EU **energy mix**, **far beyond** what modeled on the base of the current status of knowledge.

In the **transition**, the **reaction** of the **whole electricity production system** will **define** GHG **emissions**, **related to** a **marginal increase** in electricity demand for **road sector**.

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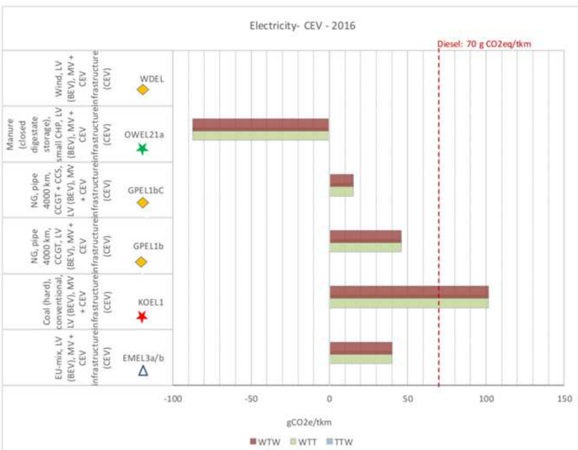
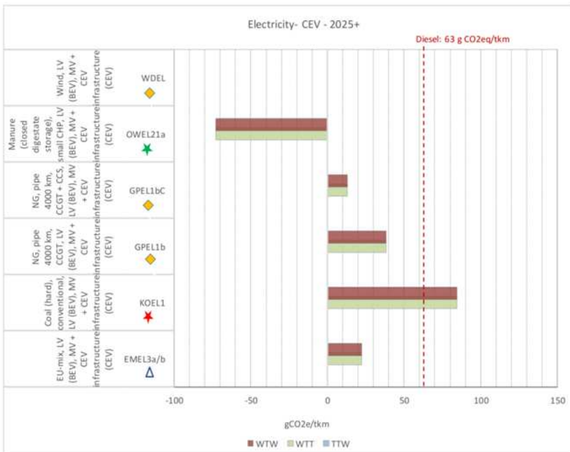
Electricity driven powertrains - Catenary





CEV are **mainly operated** at **catenary** mode and **partly at battery (BEV) mode**

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Electricity in Battery Vechicles

Additional demand from transport, in the **transition** towards a fully green electricity production system**, may lead to displace 1 green kWh from a sector to another** (economic value/4X multip.**). If** the **production generation is limited, system may react consuming fossil resources.**

BEV using **EU mix** are already **able to provide a significant saving against** standard **ICE/diesel.**

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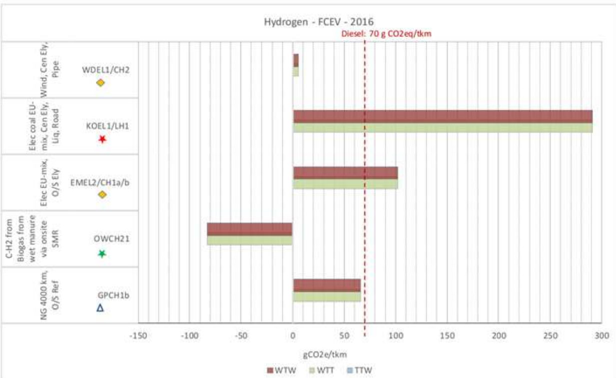
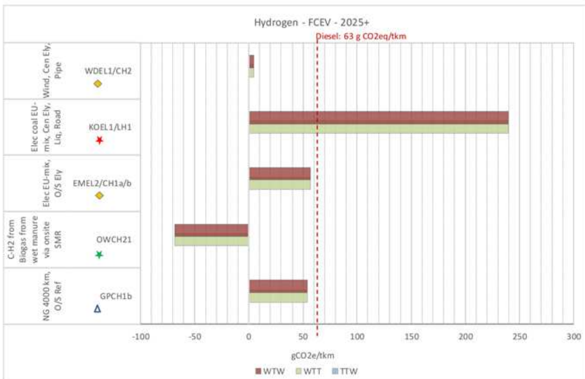
Hydrogen - FCEV **Emissions**





Hydrogen is assumed to be produced from electricity, via electrolysis**. Emissions are then determined by the electricity production pathway.**

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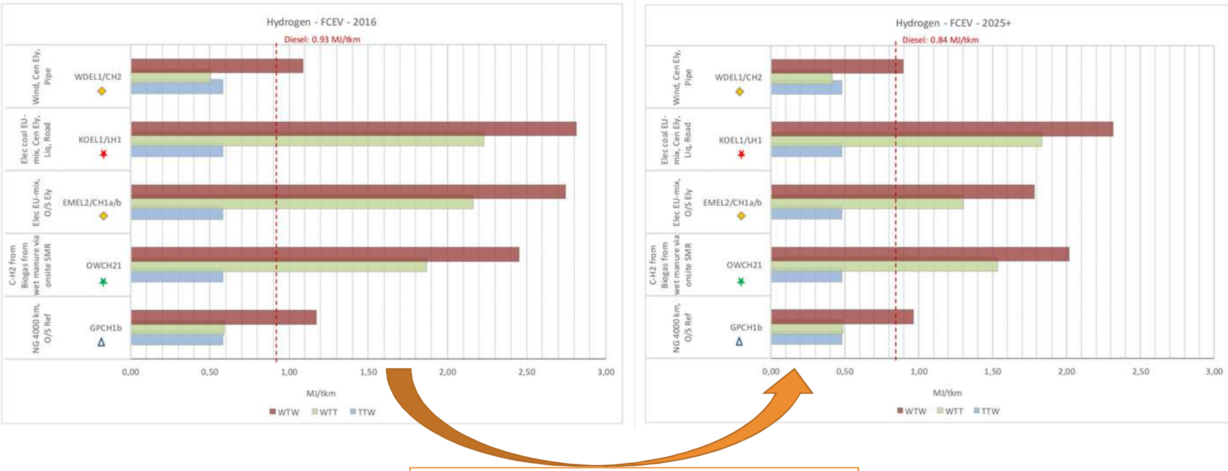
Hydrogen - FCEV **Energy expanded**



Strong **reduction in energy demand** expected for all the analysed pathways.

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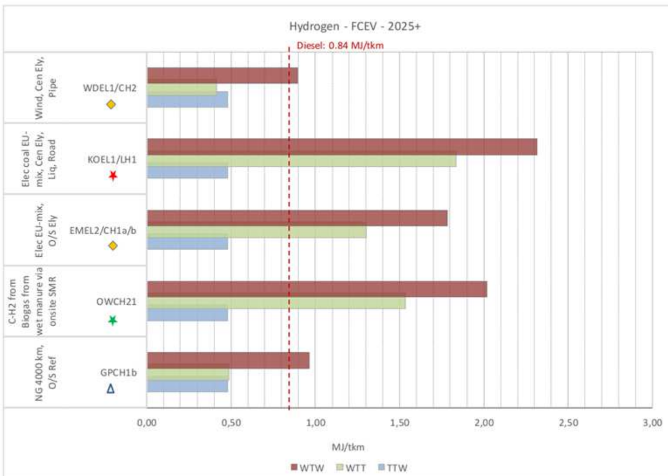
Hydrogen - FCEV **Energy expanded**

The **WTW energy use** for **FCEV** combined with the selected pathways **is higher than that for conventional diesel** used **in CI engines**.

Significant amount of **primary energy required** for **H2 production** using electrolysis => overall **system efficiency issue.**



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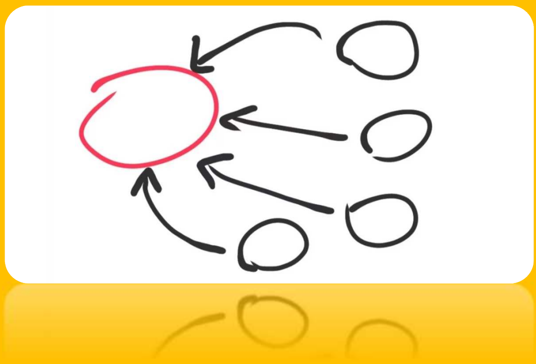
Conclusions



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Conclusions

- When the **WTT** and **TTW results** are **combined**, **factors** such as the **conversion pathways**, the **feedstock/resource** used, together with the **specific powertrain** technology in the 2015/2025+ **timeframe** have a **strong impact** on the final **results**.

- **Electricity** in BEV and PHEV, **e-fuels** in ICE as well as **Hydrogen** in FCEV are **promising options but** their potential for **GHG saving** is **mainly determined** by the pathway of the **electricity production** and/or by the **system reaction** from **displacement** of the **kWh from a sector** (i.e industry) to **another** (i.e. transport).

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FEEDBACK, COMMENTS...

Suggestions and enquiries are welcome, simply **contact us** through the JEC WTW website or, for specific questions to:

- JEC **WTW**: info@concawe.eu
  and JRC-infoJEC@ec.europa.eu
- JEC **WTT**: info@concawe.eu
- JEC **TTW**: eucar@eucar.be

https://ec.europa.eu/jrc/en/jec

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Thank you

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