De-Fossilizing the ICE Vehicle Fleet with Sustainable Liquid Fuels – A Vital Net-Zero Pathway

Dr. Richard Osborne
Global Technical Expert – Sustainable Fuels

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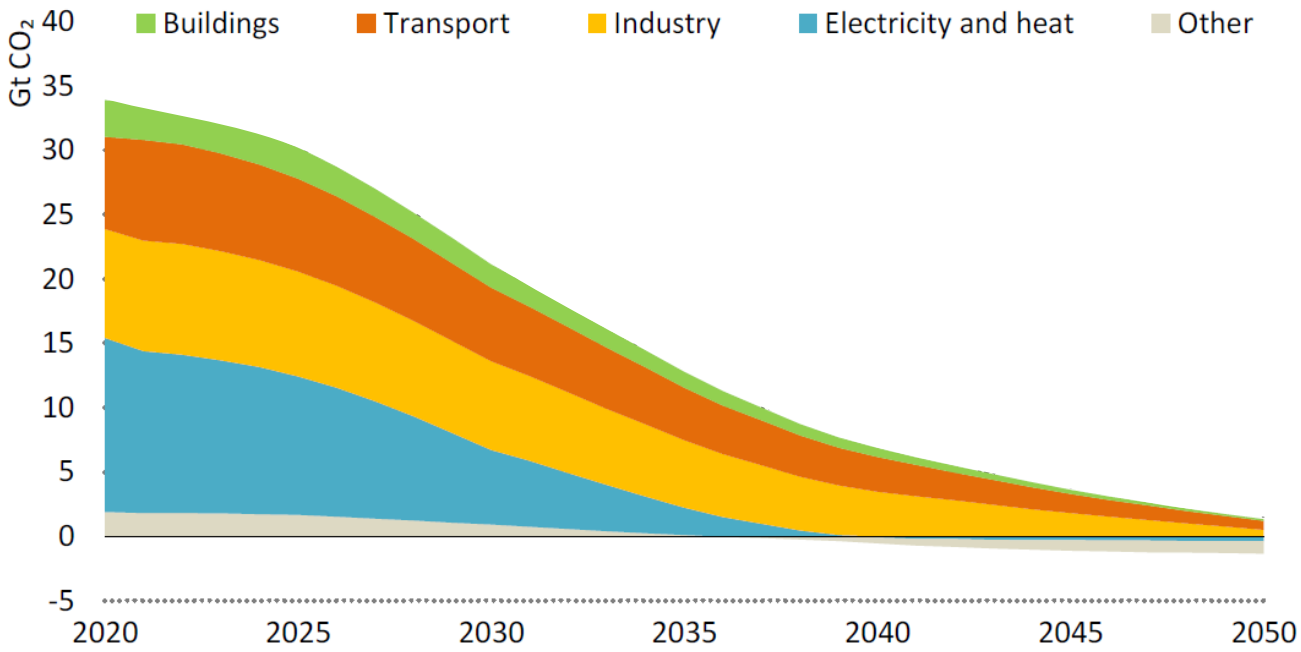
There is an urgent requirement to de-fossilize road transport

- To limit the long-term increase in global temperatures to 1.5 °C, we must reduce greenhouse gas emissions to **net zero by 2050**
  - Transport is one of few sectors where emissions have stayed level or **continued to grow**
- In Europe according to the 'Fit for 55' plan GHG emissions from passenger cars must reduce by **55% by 2030**
  - New cars must be zero emission at the tailpipe by 2035

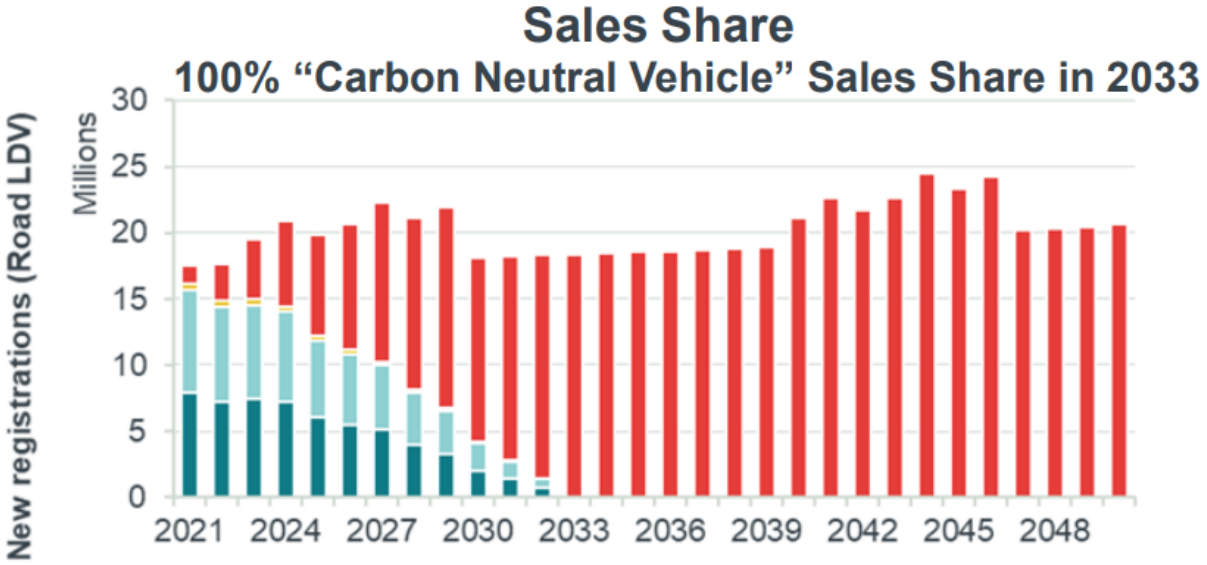


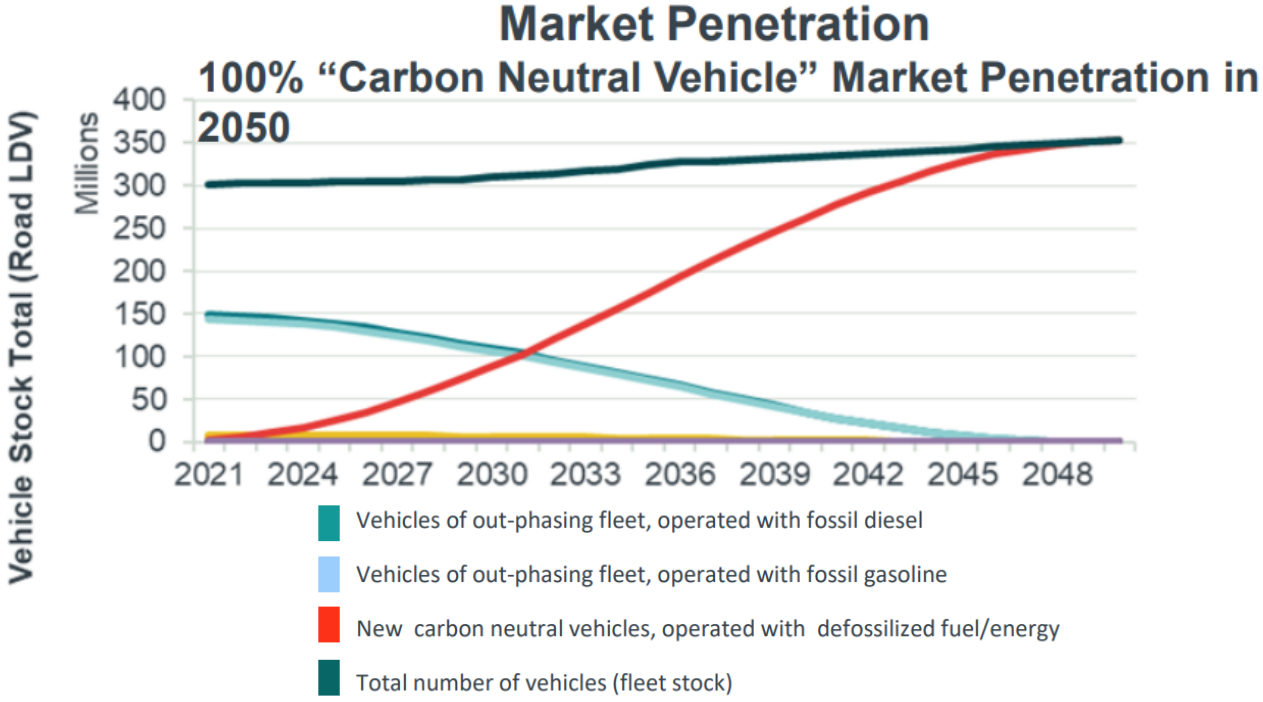
The remaining global CO_2e budget (2020 – 2050) is ***500 Gt***

Sources: IEA, 'Net Zero by 2050: A Roadmap for the Global Energy Sector' May 2021;
IPCC 'Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development', 2018

Almost all road transport policy is based on BEV substitution

- The ICEV fleet comprises more than 1.4 bn vehicles worldwide; more than 300 m in Europe
- The FVV Future Fuels study has analyzed scenarios for the European transport system in detail
- The average lifetime of a European vehicle is 17 years – to achieve a ‘carbon neutral’ fleet in 2050, only carbon neutral vehicles are sold from **2033 onwards**

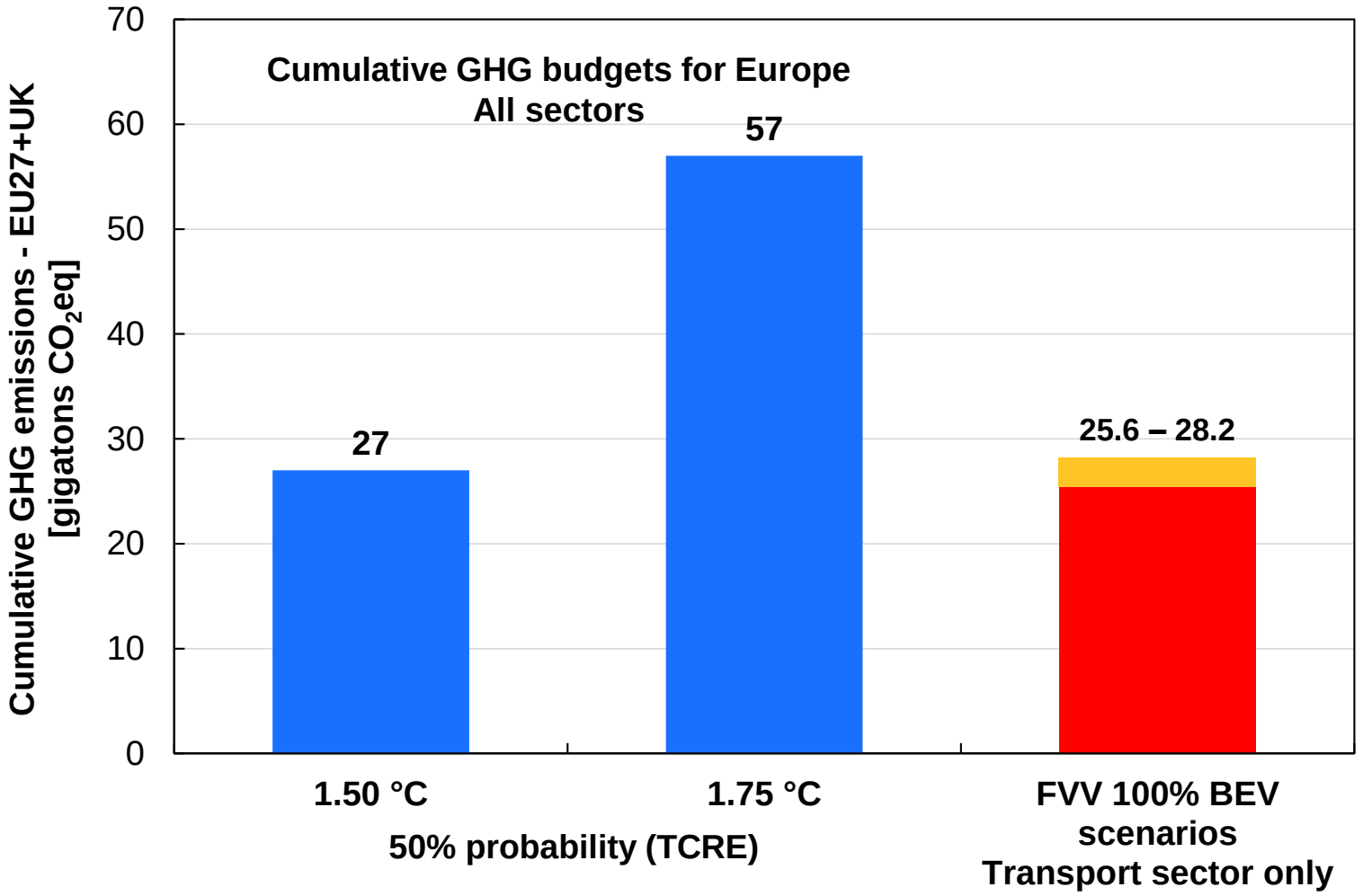




Source: FVV, ‘Future Fuels: FVV Fuels Study IV, Final Report’ 2021

Will we meet climate goals with this approach?

- Even with this aggressive transition to BEVs, climate goals are not met
  - FVV 100% BEV scenarios show that the total GHG budget for Europe will be consumed by transport
- The problem is emissions from the remaining **ICEV fleet** using fossil fuels
  - These account for up to 74% of the cumulative GHG emissions



Source: FVV, 'Future Fuels: FVV Fuels Study IV, Final Report' 2021

Sustainable fuels are a complement to electrification

The landscape for sustainable liquid fuels

Crop

Advanced/ waste

Sustainable biomass

Renewable electricity

Water

Bio Energy with Carbon Capture & Storage (**BECCS**)

Captured carbon dioxide

Direct Air Carbon Capture (**DACC**)

Electrolysis

Broadly mechanical and organic chemistry processes. E.g.
- Pressing
- Fermentation
- Digestion
- Esterification
- Rendering
- Distillation
- Hydrotreating

Gasification / Steam reforming

Synthesis gas

More intensively chemical processes with catalysis e.g.
– Fischer-Tropsch
– Methanol synthesis
– OME / DME synthesis

Hydrogen

Nitrogen

Haber-Bosch Synthesis

Synthesis e.g.
– Sabatier (methane)
– RWGS + Fischer-Tropsch
– Methanol Synthesis
– Methanol dehydration

Biofuels
- Ethanol
- Biodiesel
- Biogas
- Hydrotreated vegetable oils (HVO)
- Fatty acid methyl esters (FAME)

Synthetic Biofuels
- Fischer Tropsch Liquids
- Bio-methanol
- Dimethyl ether (DME)
- Oxymethylene ethers (OME)

E-Fuels

Zero TTW Carbon Fuels

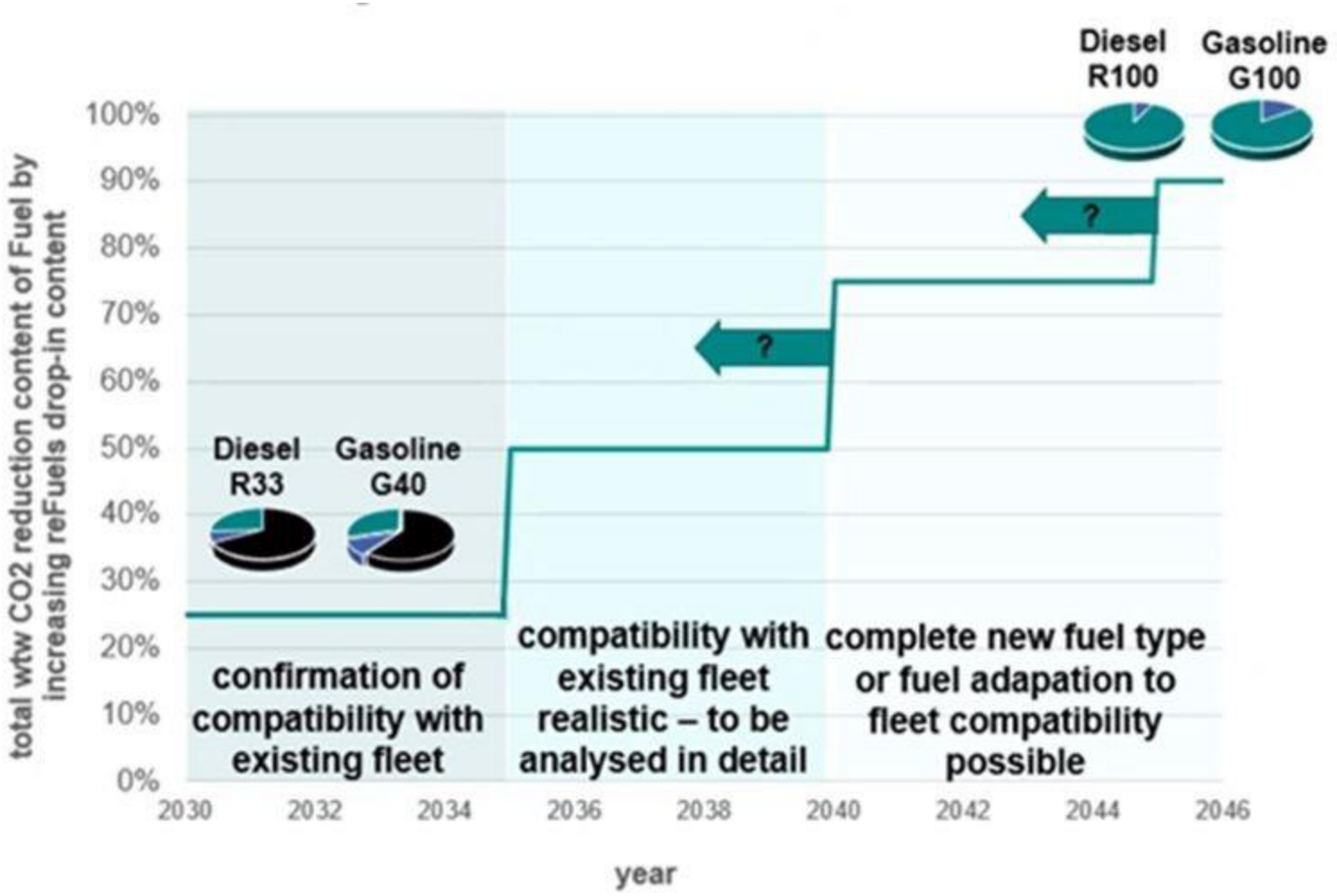
Hydrogen

Ammonia

Reduced TTW Carbon Fuels
- Fischer-Tropsch Liquids
- Methane
- Methanol
- Dimethyl ether (DME)
- Oxymethylene ethers (OME)

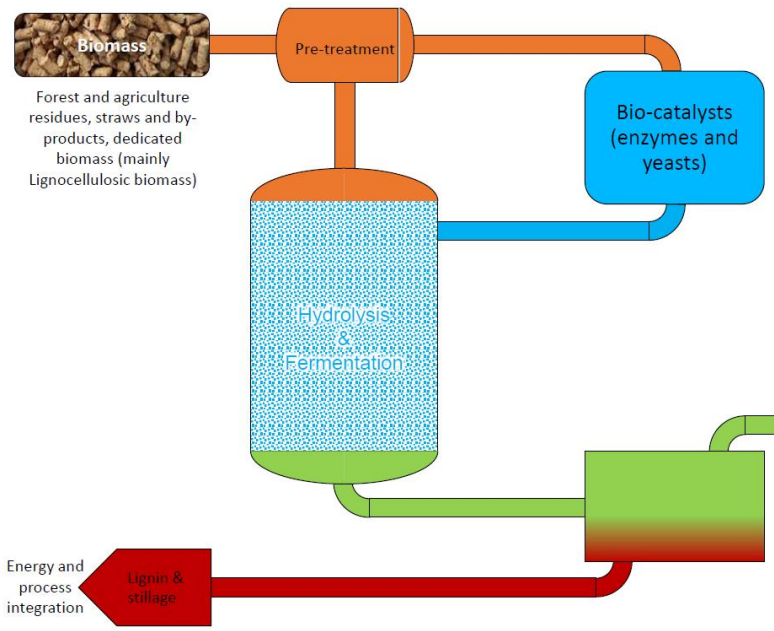
Scenarios for the introduction of sustainable liquid fuels

- To address the ICEV fleet, we need **drop-in fuels –** those that meet EN228 and EN590
- These should comprise both **e-fuels** and **advanced biofuels**
  - Advanced biofuels can make a major contribution before e-fuels **capacity is available**
- One scenario for phased introduction has been developed on the **reFuels project**

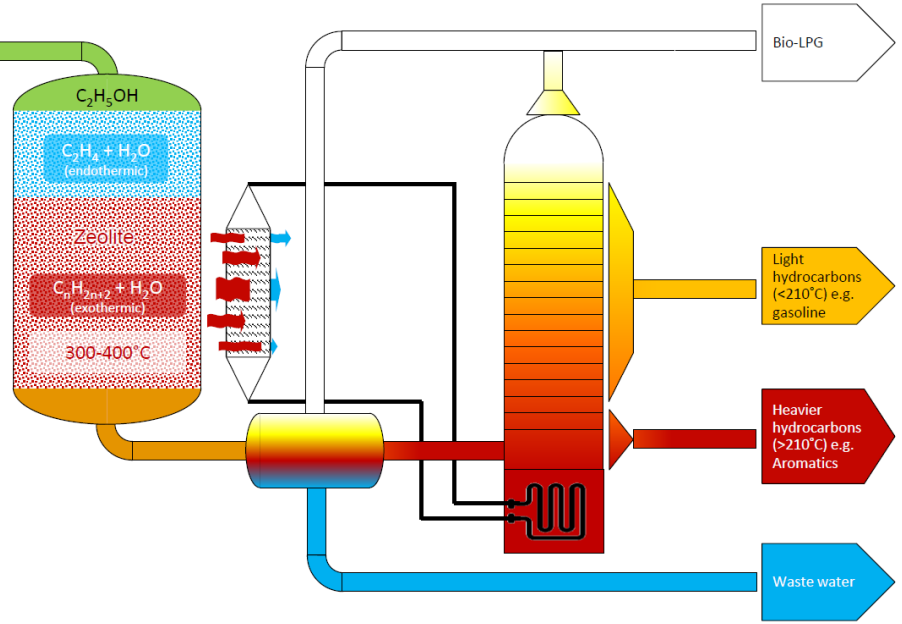


Source: KIT

Bio-gasoline tested with Ricardo Magma xEV pre-chamber engine



Parameter	Euro 6 E10 Gasoline	Bio-Gasoline
Lower (Nett) Calorific Value [MJ/kg]	41.70	40.76
Analysed RON	97.0	96.1
FBP [°C]	181.4	207.4
Aromatics [%v/v]	26.3	38.8
GHG savings (RED II) [%]	0	**80**



CORYTON
FOR A CLEANER FUTURE

This fuel provides a greenhouse gas saving of over 80% using REDII definitions

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Current vehicle CO_2 regulation is not fit for purpose

*Renewable Energy Directive (**RED**)*
*Emissions Trading System (**ETS**)*
*Energy Taxation Directive (**ETD**)*
Renewable fuels crediting system

Current CO_2 regulation (TTW)

WTW CO_2

Fuel Production

Producing the energy vector(s) from primary energy source to distribution

Vehicle Production

Producing the vehicle from raw materials to complete product

Use

Tailpipe CO_2 from driving

Disposal

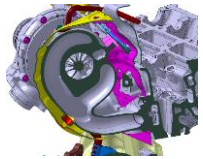
Environmental impact of 'end of life': re-using components, recycling materials, and landfill

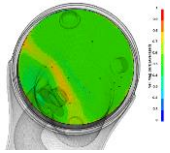
Life-cycle CO_2

Source: Ricardo

Euro 7 will continue the reduction of pollutant emissions

Platform	Status and Timing	Objectives	Toolsets	Output and Next Steps
Ricardo Euro 7 Demonstrator Vehicle **VEP Gen3 HP 48V MHEV Volvo XC60** 48V EHC SULEV TWC EU GPF Aurobay	*Project Started Feb 2021* *Phase 1 completion expected Apr 2022*	• **Physical and virtual twin** validated at Euro 7 levels – EHC with aux air, SAI • Development of **software toolsets** to simulate and optimise SAI operation • Demonstration of **hybrid control** potential to improve emissions • **Test platform** to assess Euro 7 applicable technologies	IMBD IGNITE • Integrated Model Based Development (IMBD) with IGNITE • SAI combustion modelled in VECTIS 3-D and WAVE 1-D WAVE VECTIS	• Physical and virtual emission results at Euro 7 level • Further development of ATS towards **zero impact** • Assessment of OBM sensors • Assessment of e-fuels • Evaluation of Euro 7 technologies – Exhaust air pumps and control – 3rd generation GPF systems – Ammonia aftertreatment – Next-gen O_2 sensors • Calibration development to optimise fitted technologies





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Conclusions

- We must pursue all pathways to road transport de-fossilization in order to meet climate goals
- The ICEV fleet alone – using fossil fuels – will consume remaining carbon budgets
- Sustainable liquid fuels are required to de-fossilize new and existing ICE vehicles
- Life-cycle analysis of different vehicle types is required to drive technology development
- Euro 7 will reduce pollutant emissions to close to zero-impact levels