



# Magic green fuels

Why synthetic fuels in cars will not solve Europe's pollution problems

## Transport & Environment

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## Executive Summary

Plug-in cars are in the midst of a boom, accounting for almost every fifth car bought across the EU in 2021. As their sales soar and performance improves, more and more carmakers are now committing to go 100% electric from 2030 onwards. But despite the most optimal zero emission technology to decarbonise cars - batteries - now clear, some in the oil and automotive industry including Bosch[1], Porsche[2] and Europe's oil lobby FuelsEurope[3] are pushing for synthetic petrol and diesel, or “e(lectro)” fuels instead. These are made by an expensive process which turns electricity into hydrogen, which in turn is combined with CO<sub>2</sub> to produce liquid fuel that can be similar to petrol or diesel used in conventional engines (as well as kerosene used in aviation). Its proponents claim that if renewable electricity is used and CO<sub>2</sub> is captured from the air, then the e-petrol and e-diesel are climate neutral fuels that will also reduce pollution. So the argument goes: instead of decarbonising engines, why don't we decarbonise the fuel itself.

T&E decided to put these clean fuel claims to test and commissioned IFP Energies Nouvelles to run a series of lab based tests simulating real-world driving (WLTC and RDE) to measure the emissions of different e-petrol blends in an A-class (A180) Mercedes. Despite much publicity from some auto suppliers and the oil industry, the e-petrol to perform the tests could not be purchased due to lack of commercial production, IFPEN had to blend three e-fuel blends representative of potential future fuel that are compatible with petrol cars. Two different 100% e-petrol blends and one blending 2nd generation ethanol (10%) and e-fuel were made. The emissions were compared to the standard E10 EU petrol.

### **Beyond particles, other emissions are stable or higher with e-petrol**

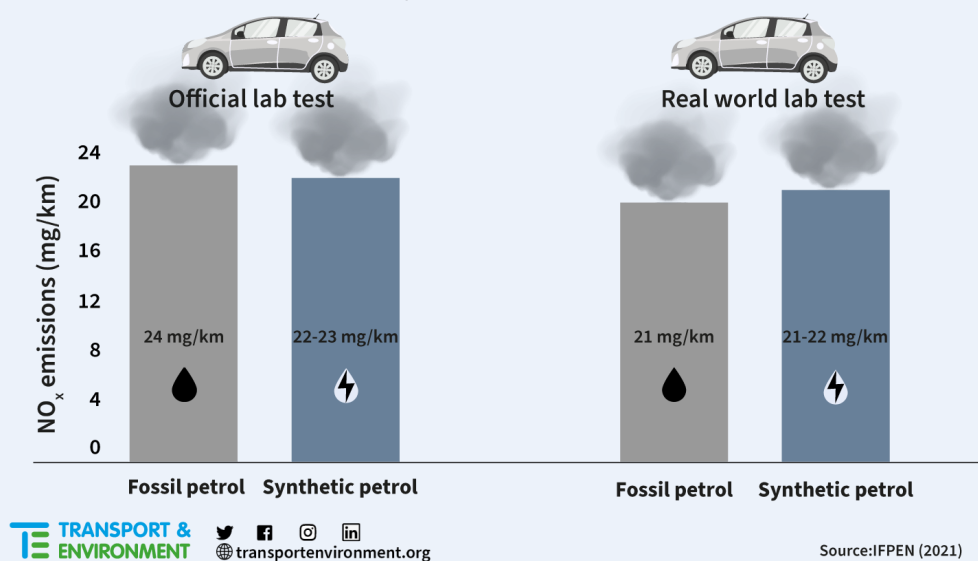
The results of pollutant emissions show that:

- **No difference in NOx emissions** were observed for any of the e-fuels tested either on the lab or on road tests compared to today's petrol fuel. This means that e-fuels emit the same amount of NOx pollution as fossil fuels today, so the use of e-petrol in cars will have little impact on NOx emissions which are at the heart of toxic NO2 pollution across Europe's cities.
- **A substantial decrease in particle emissions was observed on all tests.** The number of particle emissions (PN) larger than 10 nm decreased by 97% on the lab test, and by 81-86% on the RDE test cycle. While this was a significant improvement compared to the fossil fuel tested - and is many times below the legal limit - the very large number of particles emitted out of the exhaust in the first place meant that particle pollution was far from eliminated. Even with the use of 100% e-petrol blends, at least 2.2 billion particles were still released for every kilometer driven. There was no difference observed in particle mass (PM) emissions.

- **Toxic carbon monoxide emissions were much higher** with the e-petrol blends tested. Emissions were up to almost 3 times higher on the lab WLTC test and 1.2-1.5 times higher on the RDE test compared to fossil fuel. The largest increase in emissions occurred when the engine was first switched on, which happens often in towns and cities.
- **Hydrocarbon emissions**, i.e harmful chemical compounds made of hydrogen and carbon, **decreased by 23-40% on the WLTC test but no difference was observed on the RDE test due to low emissions for all fuels**. Emissions of dangerous but not yet regulated aldehydes - acetaldehyde and formaldehyde - decreased with the use of e-fuels when the engine was first switched on, but no significant difference was seen on the test overall.
- **Ammonia emissions of two e-petrol blends roughly doubled on the RDE test**, with emissions particularly increasing after the engine is first switched on (cold start) which frequently occurs in towns and cities. These results indicate that some e-petrol blends may cause an increase in ammonia emissions which is a precursor to PM2.5 pollution.

## Synthetic petrol emits as much poisonous NO<sub>x</sub> as petrol

Tests compare car powered by 3 e-petrol blends to fossil petrol



Overall, the testing shows that e-petrol is not a clean fuel and, beyond particles, will do little to reduce toxic pollutant emissions of both regulated and unregulated pollutants compared to petrol fuel used today. The previous testing conducted by CONCAWE[4] - the oil industry association - showed that, similarly, e-diesel has little impact on improving pollutant emissions. At a time when over 400 thousand Europeans die prematurely from air pollution[5] and 2 out of 3 citizens of the EU's biggest cities demand

cleaner air,<sup>1</sup> Europe needs a credible plan to slash toxic pollution from cars, one of the biggest sources of air pollution. Unlike emissions-free electric cars, e-petrol and e-diesel will not help as they will not eliminate or significantly reduce pollution. As long as fuel -synthetic or not- is burnt, or combusted in engines rather than being replaced by electricity, toxic air pollution in cities and beyond will persist.

### **Using e-fuels in cars is not climate neutral**

It is assumed that the use of renewable e-petrol or e-diesel in cars is climate neutral as the CO<sub>2</sub> emitted from burning e-fuels in an engine is equal to the CO<sub>2</sub> captured for the production of the fuel itself. This is already a big assumption as it requires huge amounts of renewables to produce 100% green hydrogen and power the process, as well as direct capture of CO<sub>2</sub> from the air - a technology that is not yet widely available - to compensate for the CO<sub>2</sub> that is released when e-fuels are burnt in engines. But T&E's tests show that there are additional climate damaging emissions beyond CO<sub>2</sub>. Burning e-petrol in a combustion engine produces two more potent greenhouse gases: methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). (Similarly, these gases were also found to be emitted by e-diesel in tests performed by CONCAWE[4].) These are not taken into account in the above "climate neutrality" claims.

T&E measured the emissions of these GHG and calculated that the Mercedes running on e-petrol and driving the EU average of 12,000km, would emit the equivalent of an additional 7-9kg of CO<sub>2</sub> a year. While relatively small per car, T&E calculates that if all new diesel and petrol cars sold in 2020 ran on e-petrol or e-diesel, the additional CO<sub>2</sub> (from methane and nitrous oxides) would be equivalent to around 50,000 extra fossil fuel cars on the EU's roads in just one year. As the real world emissions of the two gases vary depending on driving conditions such as temperature, length of trip etc. it is doubtful whether the emissions of these gases from cars running on e-fuels could ever be effectively counted and offset through initiatives such as carbon capture and storage. These unaccounted for climate warming emissions, while in small amounts, put nonetheless into doubt the notion that e-fuel burnt in cars is fully climate neutral.

### **E-fuels are not a solution EU drivers can afford**

T&E[6] has already shown that even under the most optimistic assumptions for the price of e-fuel in 2030, a driver with a petrol car running on e-fuel would be €10,000 worse off than a BEV owner on a 5-year usage basis. T&E estimates that getting CO<sub>2</sub> credits for e-petrol or e-diesel - as pushed for by the oil & gas and auto suppliers industries - would also be expensive for car makers, costing them three times more than producing battery electric cars in 2030.

E-fuels are also more expensive for second hand cars, which over 5 years is still almost €10,000 more expensive than owning a second hand BEV. Even buying a new BEV will be cheaper. The high e-fuel prices mean that running an older car on e-fuels is not a realistic choice for EU consumers, and would particularly hurt drivers in Central, Southern and Eastern Europe. Blending e-fuels into traditional fuels

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<sup>1</sup> A pan European by YouGov of 21 of Europe's largest cities shows that 2 out of 3 do not want to go back to the levels of pollution experienced before the lockdown. Source:T&E. No going back: [European public opinion on air pollution in the Covid-19 era](#).

may also be more difficult than the industry suggests: when T&E first added ethanol to e-petrol, it would not blend so IPFEN had to add fusel oil to ensure miscibility. The added complexity might make e-fuels more expensive. What European consumers need is not expensive e-petrol but affordable mass market electric models - via the ever stricter CO<sub>2</sub> standards on EU carmakers - as well as cheap second hand BEVs alongside better public transport and shared mobility.

### **Making enough e-fuels for Europe's existing car fleet is not feasible**

Alongside the pollution from burning e-petrol or e-diesel in a conventional car, using e-fuels is also a lot less efficient than direct electrification. It takes almost five times more renewable electricity to drive a conventional car running on e-fuels the same distance as a battery electric car. While we need to replace fossil fuels with synthetic kerosene in planes or with synthetic ammonia in shipping because no other zero emission technology is yet available for those sectors, using e-petrol and e-diesel in road transport is simply a waste of green electrons that are needed elsewhere.

While production of electric cars is already in millions and ready to replace fossil fuels, the availability of e-petrol and e-diesel in the EU is close to zero. When T&E tried to obtain less than 100l of e-fuel for testing either directly or through IPFEN, there was none available to buy. Given its inefficiency, a huge amount of e-fuels would be needed to decarbonise even a fraction of new car sales in 2030, yet alone the 252 million ICE cars which would be on the road in 2030 .

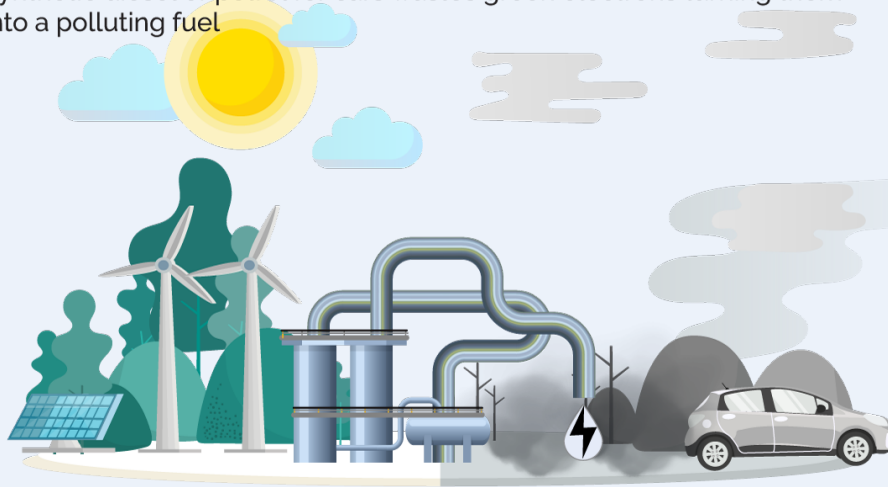
T&E estimates that the newly proposed 2030 car CO<sub>2</sub> target of -55% would require an additional 3.7 million BEVs on the road compared to current policies. If these BEVs were replaced with fossil cars running on e-fuels, 23 billion litres of e-fuel would be needed in 2030 alone. That is equivalent to 189 e-fuel plants with 240 million litre capacity each (similar to an e-fuel plant in Austria which may reach such capacity in 2030)<sup>2</sup>. Such scale up is not feasible based on what has so far been announced and - crucially - this would divert production of synthetic fuels or green hydrogen from the sectors such as aviation or steel where they are most needed. On the contrary, a boom in battery investments in Europe means that there will be sufficient battery cell supply to power most EU cars by 2030.

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<sup>2</sup> Based on the assumption that 50% of capacity is dedicated to aviation and 50% to road, an optimistic assumption.

## Oil's Trojan horse: synthetic diesel and petrol

Synthetic diesel or petrol for cars wastes green electrons turning them into a polluting fuel



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Source: T&E 2021

### Conclusion & recommendations

This testing programme shows that e-petrol used in cars will perpetuate Europe's air pollution problems and, given some unaccounted for greenhouse gas emissions, cannot be considered fully climate neutral. The very complexity of producing e-fuels might sound like green magic to non-experts - capable of making engines zero emission, which was previously impossible. But a closer look shows that taking all that renewable electricity to make green hydrogen (both clean technologies) and adding CO<sub>2</sub> captured from air (thus reducing atmospheric CO<sub>2</sub>) results in a fuel that once again emits toxic pollution. No amount of magic can overcome the basic laws of thermodynamics.

The urgency with which we have to decarbonise all sectors of our economy does not allow us to bet on a not yet commercially available technology in a sector where a superior zero emission alternative - battery electric cars - already exists and is sold in millions. Losing focus away from electrification of road transport risks diverting resources and delaying scaling up of battery electric vehicles. Betting on e-petrol and e-diesel, either for new or existing fleet, will undermine Europe's zero emissions ambitions as we risk arriving in 2030 with no "green magic" fuels available, only extra emissions. To avoid this scenario, T&E recommends:

- 1) **Car, van and truck CO<sub>2</sub> standards for engines should not allow any, even voluntary, CO<sub>2</sub> credits for e-fuels**, but should instead be regulated via EU's fuel legislation such as the Renewable Energy Directive. Instead, the post-2020 EU car CO<sub>2</sub> standards should lead to a mass

market of electric cars by requiring carmakers to achieve a 30% CO<sub>2</sub> cut by 2025, at least 45% by 2027 and 80% by 2030, coupled with a 100% zero emission vehicles sales goal by 2035 latest.

- 2) Given similar levels of air pollution from synthetic and fossil fuels, a new **ambitious Euro 7 standard**, that cuts pollutant emissions from **all fuels regardless of vehicle type**, is required for new cars, vans, trucks and buses from 2025 onwards.
- 3) **No EU or national targets, nor specific financial support should be provided for the use of e-fuels in road transport.** Instead, renewable and sustainable e-fuels should be supported in sectors where no better alternatives exist. This includes setting renewable e-fuel targets for aviation and shipping in RefueEU and FueEU Maritime.

The use of e-fuels in road transport is not innovative or new, it is a technology which takes green electrons from renewable electricity and transforms them into a toxic hydrocarbon - an outdated fuel of the 20th century. As such, it is a Trojan Horse to continue oil's business as usual and delay the transition to true zero emission technologies.



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## Preamble

Many carmakers are already committed to a zero emission, electric future to allow the EU to meet its climate targets. Yet some carmakers, suppliers and the wider oil and gas industry are proponents of an alternative decarbonisation pathway and are heavily advocating for the use of so-called synthetic fuels/ e-fuels instead of fossil fuels in internal combustion engine cars. Rather than decarbonising the engine - their line of argument goes - why not decarbonise the fuel itself?

However little is known about the air pollution impact of using e-fuels in road transport. Therefore, in 2021 T&E Commissioned IFPEN (IFP Energies Nouvelles), based in France to investigate the emissions of both regulated and unregulated pollutants emitted from the combustion of e-petrol in a Mercedes A180.

The results of the testing are presented in **Part 1** of this report which includes chapters 2-4. **Part 2** (chapter 5) of the report covers broader considerations of using e-fuels in road transport already explored in other T&E reports with updated modelling based on newly proposed car CO2 reduction targets proposed by the European Commission. Both parts of the report can be read standalone.

# **PART 1**

## **1. Introduction**

### **Cars cause two main environmental problems in Europe.**

The first major problem from cars are greenhouse gas (GHG) emissions, including carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) drive global warming. In Europe, cars alone are responsible for 12% of all GHG emissions[7]. Increased car mileage, the rise of the SUV and a failure to reproduce lab based CO<sub>2</sub> savings on the road have resulted in car's CO<sub>2</sub> emissions growing since 1990 culminating in 481 million tonnes of CO<sub>2</sub> emissions in 2019 alone[8]. Until last year, average new car CO<sub>2</sub> emissions were on an upwards trajectory[9]. Only due to an introduction of manufacturer fleet average CO<sub>2</sub> targets for new cars of 95g/km last year, which forced carmakers to increase sales of electric vehicles (EVs), did new car CO<sub>2</sub> emissions fall by 12%[10].

However, this is still a minor reduction compared to the decarbonisation challenge that the EU faces to achieve its Green Deal net zero greenhouse gas emission target by 2050, which requires a rapid reduction in emissions from road transport. To facilitate this transition the European Commission has, in the summer of 2021, proposed new, more stringent CO<sub>2</sub> targets for cars than the already agreed 37.5 % fleet average reduction required in 2030. If the Commission proposal is adopted, new car fleet average CO<sub>2</sub> emissions will need to decrease by 55% in 2030 and 100% in 2035[11]. The evidence suggests this needs to be even higher if new cars are to be on track to become zero emission by 2035 and contribute their fair share to Europe's climate goals[12].

The second problem is air pollution. Polluted air caused by road transport exacerbates a wide range of illnesses including respiratory diseases such as asthma, cardiovascular disease, diabetes and cancer resulting in tens of thousands of premature deaths[13] and tens of billions in healthcare costs annually[14]. Road transport is the largest source of nitrogen oxide (NO<sub>x</sub>) emissions[5] - the pollutant at the heart of the dieselgate scandal. In Europe's big cities where high traffic volumes result in poor air quality, cars contribute to between 33-54% of transport NO<sub>2</sub> emissions- the toxic fraction of NO<sub>x</sub>[15]. In addition to NO<sub>2</sub>, cars emit a wide range of other toxic pollutants including particles-with road transport being the third largest source of PM<sub>2.5</sub>[5], carbon monoxide (CO) and hydrocarbons (HC). Many cities still fail to meet EU Air Quality limits and new World Health Organisation (WHO) guidelines published in 2021 recommend significant reductions in pollutant air concentrations of key transport air pollutants compared to current EU limits: a 75% reduction in NO<sub>2</sub> and an 80% reduction in PM<sub>2.5</sub>, while warning that there is no safe level of air pollution[16]. Reduction of air pollution and improvement of air quality is a key deliverable of the European Green Deal, detailed in the EU's Zero Pollution Action Plan[17]. As one of the

largest sources of air pollution in Europe, road transport emissions will have to decrease rapidly to meet these targets.

### **Carmakers plan to sell EVs to meet CO<sub>2</sub> targets, yet some industries push e-fuels**

Many carmakers such as VW are committed to reaching the upcoming fleet average CO<sub>2</sub> targets through the rapid expansion of battery electric vehicle (BEV) sales, the most optimal zero emission technology to decarbonise cars today. VW expects 60% of group wide sales to be BEV by 2030[18], Volvo and Ford have set even more ambitious targets of 100%[19]. This strategy makes sense both for carmakers and the environment. The rapid uptake of BEVs by consumers keen to switch from conventional models (ICE) vehicles to greener alternatives has seen sales of BEVs skyrocket from just 1.9% in 2019 to 5.4% in 2020[20]. This year sales are expected to reach 8.5%[20]; in the third quarter of 2021, 1 in every 10 cars sold was a BEV[21]. Higher CO<sub>2</sub> targets in 2025 (-15%) and 2030, purchase price parity between BEV and ICE expected in 2025-2027 as well as a reduction in price thereafter (the average medium electric car is expected to be 18% cheaper than a petrol equivalent by 2030) is further predicted to boost sales. Mass market penetration coupled with the high energy efficiency of direct electrification, expansion of the charging network and the expected low availability of zero emission alternatives such as hydrogen fuel cell cars means that BEVs are forecast to be the cheapest and most efficient pathway to decarbonising cars.

Alongside the climate benefits and the reduction in vehicle noise, the added benefit of switching away from ICE to BEVs is the complete elimination of toxic tailpipe pollution which contributes to poor air quality, especially in towns and cities where traffic volumes are high. Switching to zero emission vehicles is expected to significantly improve air quality in European cities by eliminating one of the biggest sources of air pollution[22].

However, while many carmakers are already committed to a zero emission, electric future, some carmakers, suppliers and the wider oil and gas industry are proponents of an alternative decarbonisation pathway. Porsche[2], Mazda[23], Bosch[1], CLEPA (European Association of Automotive Suppliers)[24], Fuels Europe[3] and others are heavily advocating for the use of so called e-fuels instead of fossil fuels in internal combustion engine cars as a route to eliminating greenhouse gas emissions from new cars, as well as the existing fleet of cars already on the EU's roads. Instead of decarbonising the engine - their line of argument goes - why not decarbonise the fuel itself? T&E has tested a number of potential e-fuel combinations to show what effect this would have on pollutant and greenhouse gas emissions from cars in the future.

## **1.1 What are e-fuels?**

E-fuels are synthetic hydrocarbons refined from a power-to-liquid (PtL) process. The process combines hydrogen and carbon monoxide or CO<sub>2</sub> through a complex chemical reaction, or the Fischer-Tropsch process. The resulting synthetic e-fuel produced is not a single fuel, but a mix of different hydrocarbons i.e. the same type of chemicals that make up fossil fuels. As with fossil fuel oil, a refinery process is used

to split the crude e-fuel into specific fuel fractions for specific uses such as e-kerosene (for aviation) or e-diesel and e-petrol for use in road transport. The e-fuel industry states that the e-diesel or e-petrol can then be used both in new cars and within the existing fleet of cars either as a drop-in fuel i.e blended into fossil petrol or diesel or used as a stand alone fuel[25].

## 1.2 What impact do e-fuels have on pollutant emissions?

When it comes to climate impacts, the origin of the hydrogen and CO<sub>2</sub> determines if the e-fuel can be considered as carbon neutral. Only when e-fuel is produced using green hydrogen (i.e. electrolysis from water from additional renewable electricity such as solar or wind) and the CO<sub>2</sub> captured directly from air (direct-air capture, DAC) and not from industrial emissions, can the e-fuel be considered to be carbon neutral. This is because the net amount of CO<sub>2</sub> emitted through combustion of the e-fuel should be the same as the amount of CO<sub>2</sub> captured for its production. The *additional* renewable electricity ensures that the renewables are not diverted from other sectors that would then require non-renewable electricity sources.

When it comes to air pollutants, there is little test data available on the impact of car pollutants emissions associated with switching from fossil fuels to e-fuels - likely due to the lack of availability of e-fuels on the market. Nevertheless, the E-fuels Alliance insists that 'e-fuels emit significantly less nitrogen oxide and particulate matter than conventional fuels'[24]. The German Mechanical Engineering Industry Association (VDMA) states that 'the combustion of e-fuels is very clean and can be brought down to a level close to zero with exhaust gas aftertreatment technology available'[26].

A recent study by the CONCAWE[4] investigated pollutant emissions from a diesel Euro 6d-temp car running on e-diesel and found little difference in the emissions of the e-fuel compared to fossil diesel. There was a slight reduction in NO<sub>x</sub> emissions however particle emissions increased.

Due to limited data on the pollution impact of switching from fossil fuels to e-fuels, in 2021 T&E decided to investigate this issue further commissioning IFPEN (IFP Energies Nouvelles), based in France to investigate the emissions of both regulated and unregulated pollutants emitted from the combustion of e-fuels. The focus of the study was directed towards potential future e-petrol blends due to the lack of evidence available on pollutant emissions from e-petrol as well as the higher sales of petrol vs. diesel cars in the EU. Due to the lack of e-fuels available in the market at the time of testing, IFPEN blended potential future e-fuel candidates which are representative of future e-petrol blends that could be sold in the EU and would be compatible with new vehicles as well as the existing fleet. The emissions of a Mercedes A class Euro 6d-temp car were measured on the chassis dyno over the World Harmonised Light Vehicles Test Cycle (WLTC) and a Real Driving Emissions (RDE) type cycle more representative of the different driving conditions encountered on EU roads. The emissions with three different e-fuels were measured and compared to the emissions when running on standard EU E10 petrol.

## 2. Methodology

In 2021, T&E commissioned IFP Energies nouvelles (IFPEN) based in France to undertake the emissions testing of a petrol car running on different e-fuels on laboratory based chassis dyno tests representing both type-approval and real world driving conditions. As no e-fuels were available for purchase due to their limited production in pilot plants only, IFPEN developed custom e-fuel blends to test, representing e-fuels that could be brought to the EU market in the future. The emissions measured from the fuels were benchmarked against standard E10 fuel used in official type-approval tests in the EU.

### 2.1. The Fuels

T&E chose to focus this study on the pollutant emissions impact of switching from petrol fossil fuel to petrol e-fuel as a diesel e-fuel has already recently been tested by CONCAWE[4]. Additionally, petrol cars now make up most new car passenger car sales at 48% in 2020 compared to 28% for diesel[27] and within the next decade diesels share is expected to decline further. This can be seen from future EU car production data which shows that while petrol cars' share is expected to remain broadly constant up to 2030, diesel's share is expected to fall from 30% at the start of the decade to just 5% in 2030[28]. By focusing on petrol the study ensures that the results will be applicable to most new cars sold within the next decade.

As e-fuel production is currently at pilot scale, producing only small batches of fuel, it was impossible to obtain e-fuel produced directly from renewable energy and water electrolysis to use in this testing programme (T&E needed less than 100l for the testing). Therefore, as part of the project IFPEN were tasked with blending three e-fuels which are representative of potential future e-fuels that could be brought to the EU market, from the relevant chemical components made from non-renewable sources. These included light aromatics (< C<sub>8</sub>) and C<sub>5</sub>-C<sub>8</sub> hydrocarbons including linear and branched alkanes such as isopentane, isooctane and alkenes such as diisobutylene. The e-fuel blends were prepared with the objective of producing fuel blends which are representative of potential future EU e-petrol blends which are compatible with the EU EN228 fuel specification and have good combustion properties in order to ensure existing fleet capability.

Three different e-fuel blends were prepared:

**E-fuel 1: 100% paraffinic e-fuel** i.e a blend with 100% hydrocarbon chains and no ring shaped hydrocarbon with delocalised electrons such as benzene (i.e. aromatics). Future e-fuels are likely to be mostly paraffinic blends as these are the chemicals produced during the Fischer-Tropsch process. This is an e-petrol blend which ensures efficient combustion and is representative of a basic e-fuel blend that could be brought to the EU market.

**E-fuel 2: 90% paraffinic e-fuel, 10% aromatic e-fuel,** some aromatics may be added to e-fuels in the future to improve the combustion properties of the fuel. Therefore, in this blend 10% aromatics are included to check the effect that this could have on pollutant emissions.

**E-fuel 3: 90% paraffinic e-fuel, 10% 2nd generation ethanol.** Fuel manufacturers may consider future use of e-fuel and 2nd generation ethanol blends to reduce the fuel cost and increase total volume of renewable fuel available in the market. A 10% blend was chosen due to existing fleet and EN228 standard compatibility. Adding ethanol to the paraffinic e-fuel blend did not work due to miscibility issues. The ethanol and e-fuel would separate out similarly to oil and water. This could not be solved with addition of up to 20% aromatics into the blend. Finally, 1% fusel oil had to be added to the blend for the ethanol not to separate out.

The baseline fuel (representative of current market fuel) used to compare the effect of e-fuels on emissions during this testing was an **E10** homologation grade fuel blend compatible with the EN228 standard and EU Regulation 2008/692/EC. Analysis results of the four fuels tested are included in Annex 1.

## 2.2 The car

A Mercedes A180 was chosen by T&E for the tests and sourced independently of T&E by IFPEN. The car obtained was a Euro 6d-temp, 4 cylinder, 1.3L, 6-speed manual car, fitted with a gasoline particulate filter (GPF) and registered in 2019 with a full service history. The mileage at the start of testing was 17,000 km. Prior to the start of testing the vehicle underwent a visual inspection as well as an OBD fault code check to ensure that the vehicle was not damaged and suitable for testing.





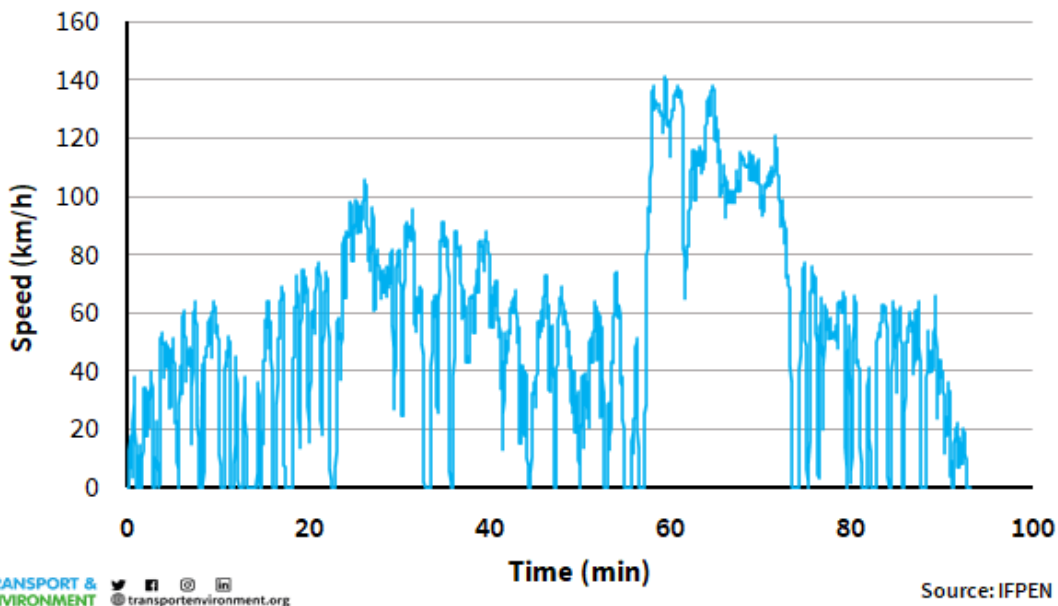
**Figure 1. The Mercedes A180 used for the testing programme.**

### 2.3. The tests

Ahead of testing with each new fuel the following fuel change protocol, as described in CONCAWE's latest study on emissions effects of fuels[4], was used:

1. The vehicle fuel tank was completely drained.
2. Five litres of the new fuel were added to the tank and the vehicle was run at idle for 10 minutes to flush the old fuel from the fuel system.
3. The tank was drained again and the tank filled with the new fuel ready to test.

After the fuel change procedure was complete, the vehicle was soaked at 23 °C overnight. Chassis dynamometer parameters for all tests were set in accordance with the car's Certificate of Conformity (CoC). Start & Stop was deactivated during testing to reduce test to test variability as it could not be guaranteed that stop-start would always function the same on each test. Soaking was followed by the 23 °C cold start WLTC used for type-approval of cars in the EU. After the completion of the WLTC a hot start 23 °C RDE based test cycle followed. The RDE cycle used for the testing was identical to that used by IFPEN to test the performance of Euro 6d-temp cars in a study commissioned by the French government[29] and is representative of the typical driving urban, rural and motorway driving that occurs in the EU. The details of the RDE test cycle and the speed trace are presented in Annex 1 and figure 2 below. Each test cycle was repeated twice for each fuel including the overnight soaking.



**Figure 2. RDE test cycle driven on the chassis dynamo.**

## 2.4. Pollutant measurements

Both the raw emissions coming out of the engine and the tailpipe pollutant emissions were measured on all tests. Engine out emissions were sampled ahead (upstream) of the close coupled three way catalyst.

Tailpipe emissions were diluted through a constant volume sampling (CVS) tunnel prior to sampling aside from formaldehyde and acetaldehyde which were measured by AVL SESAM FTIR from the raw exhaust emissions. Nitrogen oxides (NO, NO<sub>2</sub> and NO<sub>x</sub>), methane (CH<sub>4</sub>), hydrocarbons (HC), non-methane hydrocarbons (NMHC) carbon monoxide (CO) as well as CO<sub>2</sub> were measured by Horiba MEXA-ONE analysers. The unregulated pollutants nitrous oxide (N<sub>2</sub>O) and ammonia (NH<sub>3</sub>) were measured by quantum cascade laser (QCL). PN larger than 23 nm was measured using a condensation particle counter (CPC) 100 and PN larger than 10 nm was counted using an SPCS 2020. All emissions were measured at 1 Hz aside from Particulate Matter (PM) which was measured using the gravimetric filter method.

Engine out pollutant emissions measurement included all regulated gas pollutants. Nitrogen oxides (NO and NO<sub>2</sub>, components of NO<sub>x</sub>), methane (CH<sub>4</sub>), hydrocarbons (HC), non-methane hydrocarbons (NMHC) carbon monoxide (CO) as well as CO<sub>2</sub> were measured continuously at 1 Hz using a raw emissions sampling system combined with the Horiba MEXA-ONE analyser. In addition, particle number (PN) emissions of all particles larger than 10 nm were measured by a Horiba MEXA 2110 Solid Particle Counting System (SPCS).

## 3. Test Results

This section presents the pollutant emission results of the Euro 6d-temp petrol car running on European E10 petrol and on 3 petrol e-fuel blends on the WLTC and RDE test cycles. Results are presented as the average of the two WLTC or RDE test cycles.

### 3.1 Nitrogen oxide (NO<sub>x</sub>)

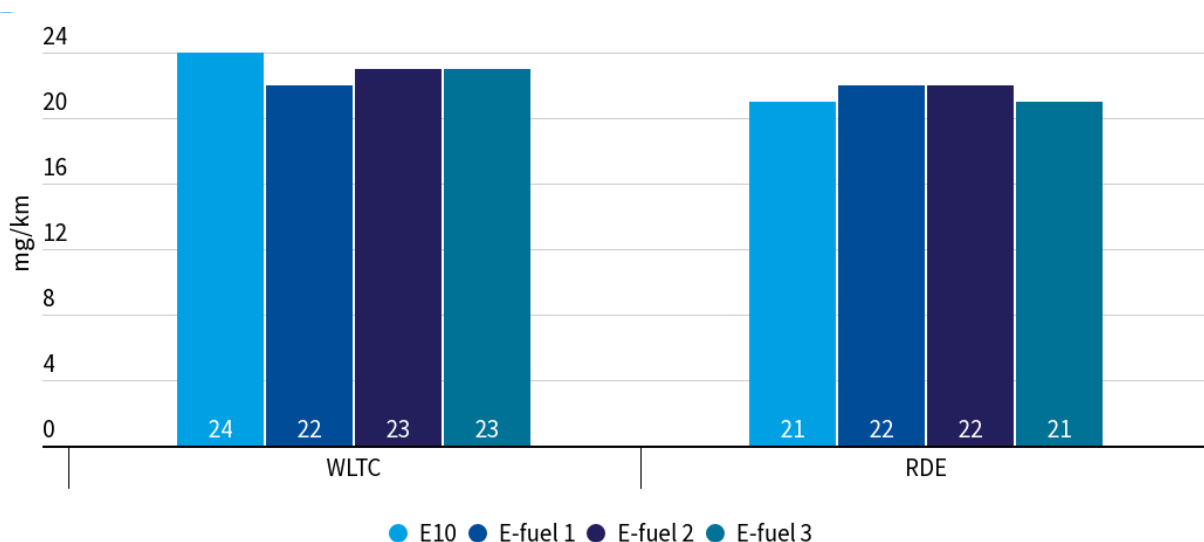
Both nitrogen oxide (NO) and nitrogen dioxide (NO<sub>2</sub>) are emitted from internal combustion engines (ICE)'s regardless of the fuel used due to the combustion (i.e. burning of fuel) process. While NO<sub>2</sub> is the toxic component of NO<sub>x</sub>, NO is converted to NO<sub>2</sub> in ambient air. As such the regulation of the tailpipe emissions of both is necessary, and for petrol cars the Euro 6 regulation stipulates a combined nitrogen oxide (NO<sub>x</sub>) emission limit of 60 mg/km, CLOVE (the consortium working on behalf of the Commission to help develop new car emission standard) proposes reducing the limit to 20mg or 30 mg/km[30] for the future Euro 7 standard which is currently under development by the European Commission[31].

NO<sub>2</sub> causes a wide range of serious negative health effects including inflammation of the airways, reduced lung function and increased asthma attacks[32]. In the EU, in 2018 54,000 people died prematurely due to NO<sub>2</sub> pollution and EU citizens living in urban areas continue to be exposed to illegal levels of<sub>2</sub>[5]. In 2021, the World Health Organisation (WHO) published new air quality guidelines which require further

reductions in NO<sub>2</sub> pollution of 75% compared to current EU limits[16]. As road transport remains the largest source of NO<sub>x</sub> emissions[5], significant reductions in road transport emissions will be required to meet the new WHO guidelines.

### 3.1.1 NO<sub>x</sub> emission results

Overall, tailpipe NO<sub>x</sub> emissions remained within Euro 6 limit on all tests and virtually unchanged between the four different fuels and test cycles (figure. 3) with average WLTC lab E10 emissions of 24 mg/km and average e-fuel 1-3 emissions of 22-23 mg/km. E10 on-road RDE emissions were 21 mg/km compared to 21-22mg/km for the e-fuel blends. Variability in average NO<sub>x</sub> emissions between the different fuels were within the variability witnessed between tests thereby **indicating that the petrol e-fuels tested have no impact on tailpipe NO<sub>x</sub> emissions and remain at the same levels as with traditional fuels. Based on this, we calculate that this car driving 12,000 km a year would emit at least 250g of NO<sub>x</sub> a year<sup>3</sup>. However, annual emissions in the real-world are expected to be higher as the vehicle was tested at the optimum type-approval temperature of 23 °C. More demanding driving conditions such as many short trips, wind, colder or hotter weather are likely to result in higher annual emissions.**



Source: IPFEN (2021).

**Figure 3. Average nitrogen oxide (NO<sub>x</sub>) emissions of E10 and the three e-fuels on lab WLTC and RDE test cycles.**

### 3.2 Particles

Particle pollution is increasingly seen across Europe as the biggest problem for air quality, with the latest report by the European Environmental Agency indicating that PM<sub>2.5</sub> (particulate matter smaller than 2.5

<sup>3</sup>Based on whole test RDE results.

micrometer) pollution was responsible for 379,000 premature deaths in the EU in 2018[5]. Particle pollution is also a contributing cause for a wide range of diseases including Alzheimer's[33], cancer as well as cardiovascular and respiratory illnesses[16].

The WHO stresses that for particles there is no safe level of pollution[16]. Road transport remains the third biggest source of PM<sub>2.5</sub> pollution in the EU and progress in the reduction of PM<sub>2.5</sub> pollution in Europe has effectively stalled at a point where 7 out of 10 residents of European cities breathe air above the previously recommended 10 µg/m<sup>3</sup> WHO limit[5]. New WHO guidelines published in 2021, further reduce the recommended limit for PM<sub>2.5</sub> exposure by 50% (to 5 µg/m<sup>3</sup>).

Tailpipe particle emissions from petrol cars are regulated through two different tailpipe emission limits:

- 1) Particulate mass (PM) which regulates the total mass of particles emitted out of the exhaust and for Euro 6 is set at 4.5 mg/km.
- 2) Particle number (PN) which regulates the total number of particles emitted out of the exhaust which are larger than 23 nm. For Euro 6 the limit is set at 6x10<sup>11</sup>/km.

Both PM and PN emissions are regulated at the tailpipe as it is not just the total mass of particles in the air that determines particle pollution's negative health effects. It is also the size and number of particles that is important. Very small particles, especially ultrafine particles which are less than 100 nanometers in size, are increasingly considered as potentially the most dangerous for health. Medical studies have shown that these particles are able to deposit in the lungs and airways with very high efficiency and, unlike larger particles, can evade the body's immune defences. This means that they are not readily removed and can accumulate within the body[34]. Once deposited in the lungs, they can also travel to other areas of the body such as the brain[35] and the placenta[36]. Medical studies show that even short exposure to these particles can cause changes in heart function[16] and these particles have been linked to an increased risk of heart disease[37] and brain cancer[38].

However due to their small size, often smaller than a typical virus, they contribute little to the total mass of particles emitted. For example, for ambient air, the previous WHO air quality guideline for PM<sub>2.5</sub> was 10 µg/m<sup>3</sup>. One large 2500 nm particle per cm<sup>3</sup> of air will reach this threshold but for ultrafine particles of 20 nanometers in size, 2.4 million particles are needed per cm<sup>3</sup>[39]. Therefore to effectively limit the emissions of these small particles a tailpipe particle number emission limit is necessary.

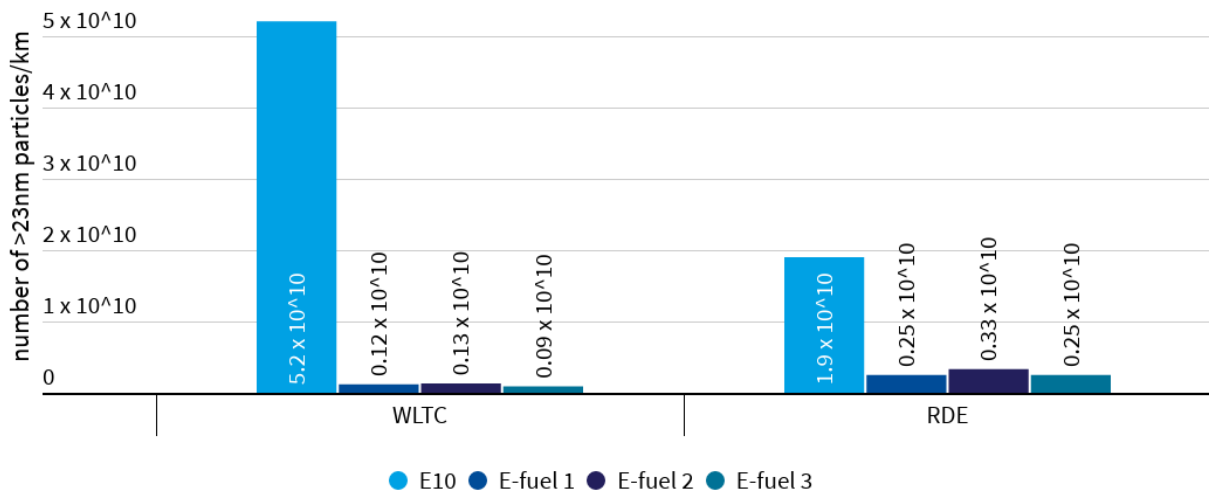
CLOVE proposes to reduce the particle number emission limit, for cars for Euro 7, from 6x10<sup>11</sup>/km to 1x10<sup>11</sup>/km[30], a significant reduction. However, no amount of particle pollution is safe, so ideally we should get to as close to zero as possible. IFPEN measured PM, regulated >23 nm PN (PN23) emissions and currently unregulated 10-23 nm PN by measuring all particles larger than 10 nm with an additional

analyzer. 10 nm particle emissions are also likely to be regulated as part of the new Euro 7 emission standard.

### 3.2.1 Regulated particle emissions results

Both PM and PN23 emissions were measured on all tests. PM emissions for all fuels, on all tests were low <0.1 mg/km. As the uncertainty of the measurement is higher than the emissions measured, no fuel impact on emissions could be deduced.

Emissions of PN23 were below the Euro 6 limit of  $6 \times 10^{11}/\text{km}$  for all tests as well as the proposed future Euro 7  $1 \times 10^{11}/\text{km}$  limit. A large decrease in emissions was observed for all three e-fuels compared to E10 throughout the entire test. On the WLTC tests average PN23 emissions of the three e-fuels were 97-98% lower than E10 emissions. On the RDE tests the reduction was smaller of between 82-87% (figure 4).



Source: IPFEN (2021).

**Figure 4. Larger than 23 particle number (PN) emissions of E10 and the three e-fuels on lab WLTC and RDE test cycles.**

The decrease in particle emissions observed for the e-fuels is likely mainly related to the low aromatic content of the e-fuel blends, <0.1% for e-fuel 1 and 3 and 10% for e-fuel 2 compared to E10 (26%) as detailed in the fuel analysis results in Annex 1. It is likely that future e-fuels will have low aromatic content as non-aromatics are produced by the Fischer-Tropsch process. Increasing aromatic content in petrol blends has been shown to increase particle number emissions[40] with the effect likely due to large (heavy) aromatics[41] and their incomplete combustion. Aromatics have a lower hydrogen to carbon ratio compared to aliphatic hydrocarbons and require higher air to fuel ratios for efficient combustion. Aromatics are therefore more likely to result in incomplete combustion and particle/soot formation than aliphatic hydrocarbons. No significant difference was observed in the PN emissions of e-fuel 2 compared to e-fuel 1 or 3 likely because the blend did not contain any heavy aromatics despite the 10% aromatic

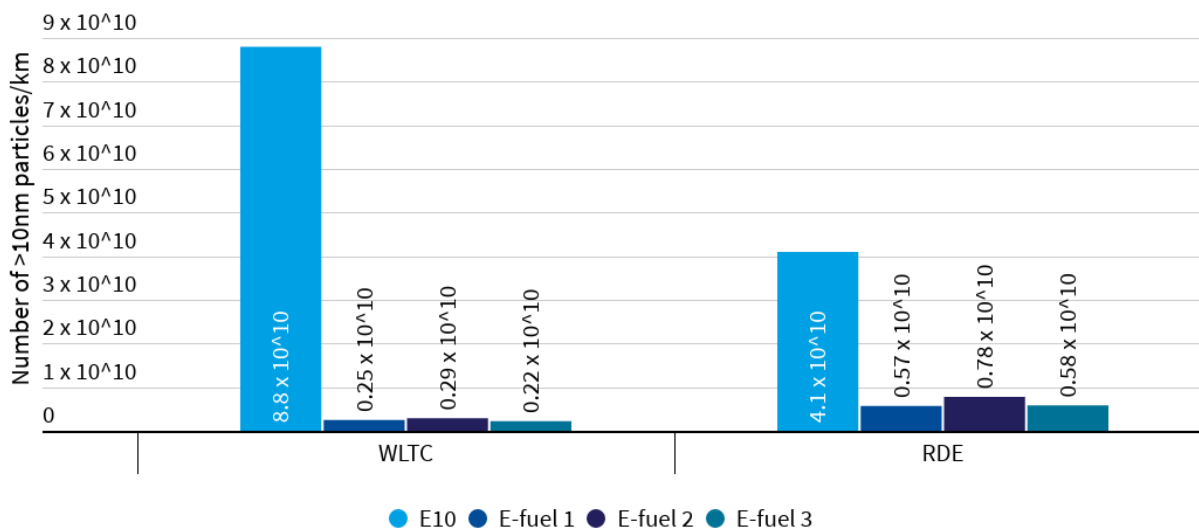
content. **These findings highlight that e-petrol may significantly reduce emissions of regulated, larger than 23nm particles.**

### **3.2.2 Unregulated particle emission results**

Particle emissions measured during most emissions' tests, such as the ones discussed above, do not actually include all of the particles contained in vehicle exhausts. This is because the current method for measuring PN emissions only includes solid particles larger than 23 nanometers. Particles smaller than this are not included in the measurement. However, tests show that for petrol engines the emissions of these very small particles can be substantial and in some cases exceed the emissions of regulated particles[42].

This means that for many vehicles the majority of particles emitted out of the exhaust are neither measured nor regulated. This is problematic as it means that the full particle pollution impact of vehicles is not considered. Additionally, the very smallest particles may be the worst for human health as they deposit in the lungs with greater efficiency than larger particles[43].

During this testing programme IPFEN measured emissions of particles down to 10 nm (PN10). When PN10 particles were measured total particle emissions remained below the Euro 6 threshold. Nevertheless, there was a large increase in the total number of particles. On the WLTC test the number of particles increased 1.7 times for the E10 fuel and 2.1 to 2.3 times for the e-fuel blends with the largest proportional increase observed for e-fuel 3. On the RDE test the magnitude of the increase was similar for all fuels; 2.2 times for E10 and 2.3-2.4 times for the e-fuel blends. The results indicate that a larger number of currently unregulated 10-23 nm particles are emitted out of the tailpipe than regulated >23 nm particles for all fuel types on the RDE test and all e-fuels on the WLTC. The measurement of particle emissions just down to 23nm also ignores a large share of particle pollution.



Source: IPFEN (2021).

**Figure 5. Average particle number emissions of all solid particles larger than 10nm of E10 and the three e-fuels on lab WLTC and RDE test cycles.**

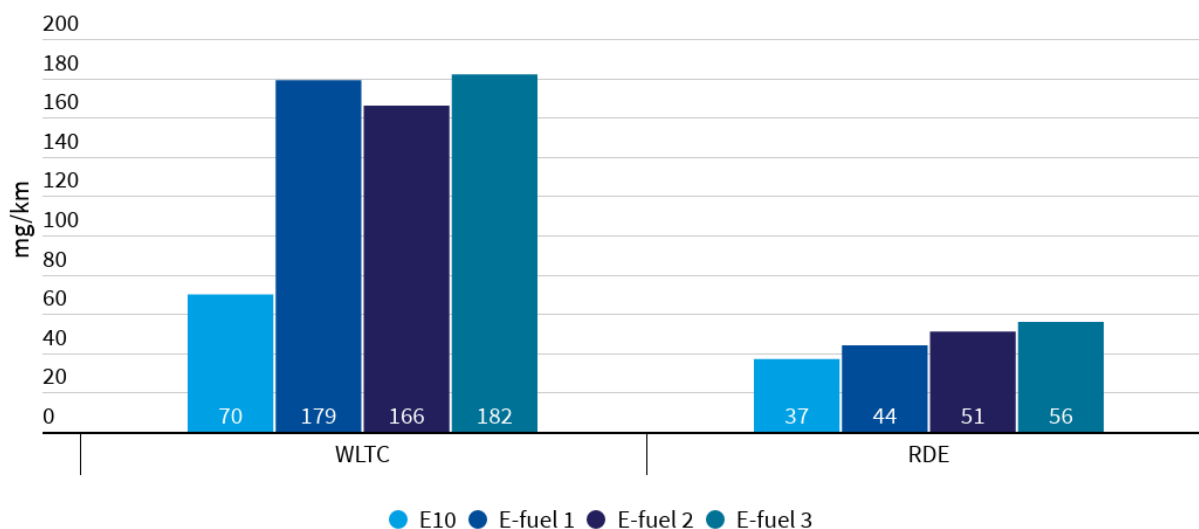
The share of 10-23 nm particles vs. PN23 is higher for e-fuels than E10. For E10 on the WLTC test, 41% of particles were 10-23 nm in size vs. 53-57% for the e-fuels. On the RDE test the difference is somewhat smaller: 55% (E10) vs. 56-58% (e-fuels) on the RDE test. However, total particle emissions were still significantly lower for the e-fuel blends than E10, with a reduction in emissions of 97% on the WLTC test and 81-86% on the RDE test (figure. 5). **These findings highlight that the e-petrol tested significantly reduced emissions of particles even when currently unregulated particle emissions down to 10 nanometers were included in the measurement. However, despite the reduction, e-fuels do not eliminate particle emissions altogether with at least 2.2 billion particles emitted per km driven on RDE tests. The data highlights that not measuring particles between 10-23 nm in size, which is already technically feasible and for which the UN Particle Measurement Programme has developed a measurement procedure, ignores the majority of particles emitted out of the exhaust on most tests.**

### 3.3 Carbon Monoxide

Carbon monoxide (CO) is a colourless and odourless highly toxic gas emitted from ICE's, produced during the incomplete combustion of fuel. The Euro VI limit for petrol cars is 1000 mg/km. CLOVE proposes reducing the limit to 400mg/km for Euro 7[30].

All three e-fuel blends resulted in a large increase in tailpipe CO emissions (figure. 6) on the WLTC cycle of around 2.5 times the E10 emissions. The increase in CO was largely driven by an increase in emissions

during the cold start and city driving phase (low phase) of the test where emissions from the three tested e-fuels were around 3 times higher than the E10 fuel. E-fuel emissions during this period were 1,123-1232 mg/km and exceeded the Euro 6 emission limit by up to 23%. Such a large increase was not observed for engine out emissions, with CO emissions increasing by around 10% compared to E10, suggesting that the large increase in CO emissions is due to the emission control system located in the exhaust. However, from the data available, it is not possible to determine with certainty the reason for this.



Source: IPFEN (2021).

**Figure 6. Average carbon monoxide emissions of E10 and the three e-fuels on lab WLTC and RDE test cycles.**

The increase in tailpipe CO emissions for the e-fuels tested was more moderate on the RDE test with overall e-fuel test emissions 1.2-1.5 times greater than E10. The smaller increase in total CO emissions is largely due to the longer length of the test (83 km) compared to the WLTC test (23 km) resulting in a smaller contribution of the cold start period to total test emissions. E-fuel CO emissions measured during the first 2 km of the RDE test which includes cold start emissions increased by 2-2.5 times compared to the E10 fuel, show a similar increase as observed on the WLTC test.

**The carbon monoxide emissions measured during the tests indicate that carbon monoxide emissions could increase markedly with the use of e-petrol**, especially within the existing fleet where the engine calibration and the exhaust emissions control system is not optimised for the use of e-fuels. It is potentially possible that new cars could be optimised for the use of e-fuels and therefore the increase in CO might not be observed for those cars. However, this could be difficult if varying percentages of drop in e-fuels are used or e-fuels and fossil fuels are used interchangeably. Based on an annual mileage of

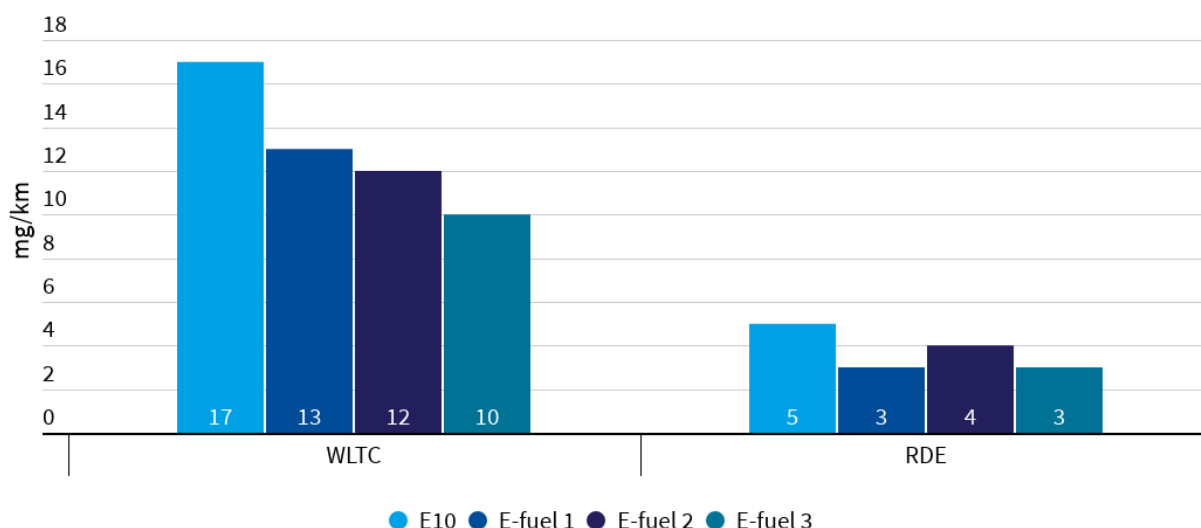


12,000 km this car running on e-fuels would emit between 528-672 g of CO compared to 444 g running on E10<sup>4</sup>.

### 3.4 Hydrocarbons

Like carbon monoxide, hydrocarbons (HC) are emitted from ICE's due to the incomplete combustion of fuel. HC contribute to ground-level ozone formation (another harmful pollutant which can inflame and damage airways[44]) and smog. Many hydrocarbons are also toxic[45]. For petrol cars the total hydrocarbon limit is 100 mg/km, CLOVE proposes a 25-45mg/km non-methane organic gas (NMOG) standard which would cover a wider range of chemicals[30].

HC emissions were low on both tests. Average WLTC hydrocarbon emissions (figure. 7) decreased by 23-40% with the e-fuel blends tested compared to the E10 fuel with all emissions below Euro 6 limits. The largest decrease was observed during the motorway (extra-high speed) phase of the WLTC of between 54-77%. Due to the lower HC emissions on the RDE test for all fuels <5mg/km the difference between the fuel blends on this test is not discernable. **Overall, the results indicate that there may be a decrease in hydrocarbon emissions with the use of petrol e-fuels.**



Source: IPFEN (2021).

**Figure 7. Average hydrocarbon (HC) emissions of E10 and the three e-fuels tested on lab WLTC and RDE cycles.**

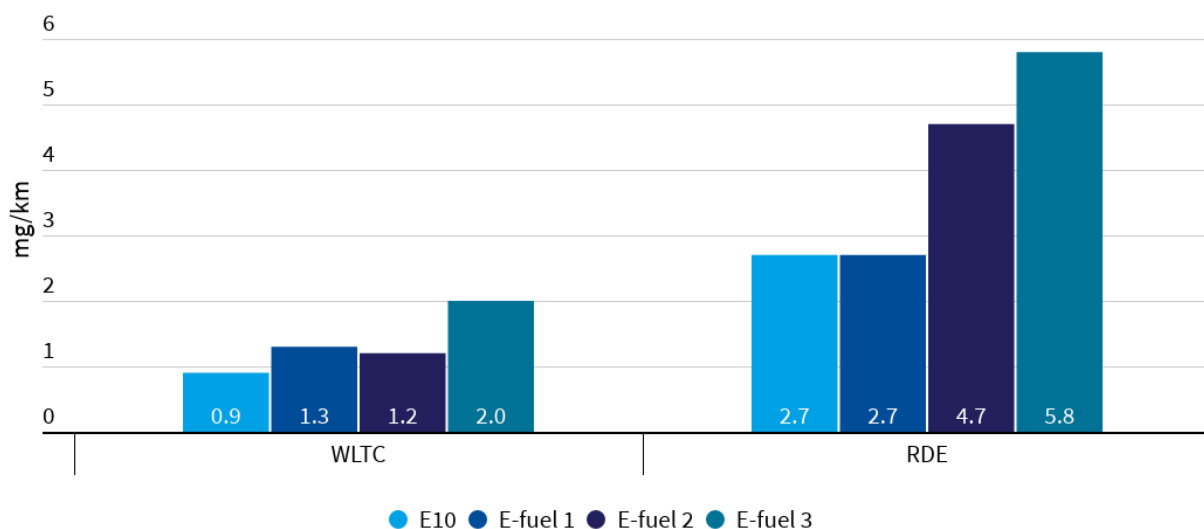
### 3.5 Ammonia

Ammonia emissions (NH<sub>3</sub>) contribute to poor air quality as they are a precursor to secondary particle formation, contributing to PM<sub>2.5</sub> (particles smaller than 2.5 micron) pollution. In towns and cities the

<sup>4</sup> Based on emissions measured on the RDE test.

dominant source of ammonia emissions is road transport[46]. Ammonia emissions from cars are not regulated under the current Euro 6 standard, however a limit of 10mg/km has been proposed by CLOVE for inclusion in the future Euro 7 standard[30]. For petrol cars ammonia is generated within the three-way catalyst through a combination of NO<sub>x</sub> and hydrogen. Hydrogen is typically produced in the engine during rich operation such as during cold start when the air/ fuel ratio is lower to quickly increase the exhaust temperature in order to get the three-way catalyst to a sufficient temperature for efficient operation as quickly as possible.

Overall, on the WLTC test (figure 8) emissions for all fuels were generally low at around 1 mg/km, except for e-fuel 3 which had higher emissions at 2mg/km. However, a marked increase in emissions of the e-fuels compared to e10 was observed during the cold start and city driving phase (low phase) of the test, during this period average emissions of three fuel blends were between 3.5-7 times higher than the E10 blend. But due to the high variability in NH<sub>3</sub> emissions between the two tests run with each e-fuel it is impossible to determine if the increase in NH<sub>3</sub> emissions on the WLTC test is due to the e-fuel blend or variable behaviour of the emission control system.



Source: IPFEN (2021).

**Figure 8. Average ammonia (NH<sub>3</sub>) emissions of E10 and the three e-fuels tested on WLTC and RDE cycles.**

On the RDE test however, there was a clear increase in NH<sub>3</sub> emissions with e-fuel 2 and 3 of 1.7 and 2.2 times respectively. The main increase in e-fuel emissions compared to E10 was observed during cold start and city driving in the first 2 km of the test. During this period emissions were 2 times higher for e-fuel 2 and 2.5 times higher for e-fuel 3 compared to the E10 fuel. **These results suggest that there could be an increase in on-road ammonia emissions with the use of petrol e-fuel blends particularly during shorter trips typical of driving in towns and cities. This car driving 12,000km a year and running on**

**e-fuel 2 would emit around 56 g of ammonia a year and 70 g on e-fuel 3. This is almost double the emissions of E10 today (32 g).**

### **3.6. Aldehydes**

Of the aldehydes emitted from petrol cars, formaldehyde and acetaldehyde are the dominant species. Emissions of these compounds are a significant risk to health as acetaldehyde and formaldehyde are both considered as probable human carcinogens[47],[48].

#### **3.6.1 Formaldehyde emissions**

Tailpipe formaldehyde emissions are not regulated as part of the Euro 6 emission standard, however an emission limit of 5 mg/km has been proposed for inclusion in the upcoming Euro 7 standard by CLOVE[30].

Overall emissions of Formaldehyde were very low for all fuels of less than 0.3 mg/km on the WLTC test and 0.2 mg/km on the RDE test. Aside from the cold start period at the beginning of the WLTC and RDE test when there is a spike in formaldehyde emissions, emissions were 0.3-1.2 mg/km -most likely due to the catalyst being below the temperature for optimal conversion- over the rest of the test cycles emissions were below the measurement equipment minimum detection limit<sup>5</sup>. During the first 3 km of the WLTC test there was a 39-62% decrease in formaldehyde emissions, with the largest effect seen for e-fuel 3. A similar decrease is observed over the first 2 km of the RDE test of 32-67%. **These results indicate that e-fuel use may result in some decrease in formaldehyde emissions during the cold start period.**

#### **3.6.2 Acetaldehyde emission**

Acetaldehyde emissions are also not regulated as part of the Euro 6 standard. No direct emission limit has been proposed for acetaldehyde emission as part of Euro 7, however emissions of this pollutant could be regulated for Euro 7 as part of the CLOVE proposed non-methane organic gas limit (NMOG) of 25-45 mg/km[30].

As for formaldehyde emissions, acetaldehyde emissions were below the detection threshold for the majority of both the WLTC and RDE test cycles apart from during the cold start period. Emissions were 3.0 mg/km for E10 and 0.6-1.9 mg/km for the e-fuel blends on the low phase (1st 3km) of the WLTC test and 4.2mg/km for E10 and 0.9-1.9 mg/km for the e-fuel blends on the RDE test. E-fuels 1 and 2 reduced cold start emissions by 81% on the WLTC cycle. E-fuel 3 had the highest emissions of the three e-fuels tested only reducing emissions by 37% compared to E10. On the RDE test the reduction was slightly smaller compared to E10 with 79% for e-fuel 1, 72% for e-fuel 2 and 54% for e-fuel 3. **These results suggest that e-fuel use may result in some decrease in acetaldehyde emissions during the cold start period.**

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<sup>5</sup> For the equipment used this is less than 2.5ppm.

### 3.7 Greenhouse gas emissions

Three greenhouse gases (GHG) were measured during this testing programme: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). Aside from carbon dioxide emissions which are regulated through a per manufacturer fleet average limit, the other GHG are currently unregulated. This is despite them both having a much higher global warming potential (GWP)- a measure of how powerful a climate warming agent is compared to CO<sub>2</sub>. The GWP of both pollutants are listed in the table 1 below, for methane the GWP potential for methane of non-fossil origin was used in all subsequent calculations on the assumption that the CO<sub>2</sub> used to make e-fuels in the future will be sourced from DAC. Methane also has a negative impact on air quality as it is a precursor for the formation of ground level ozone[49].

**Table 1. Global warming potential of methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) over twenty and one hundred years[50].**

Greenhouse gas	Carbon dioxide equivalent (CO <sub>2</sub> e)	
	20-year GWP	100-year GWP
CO <sub>2</sub>	1	1
CH <sub>4</sub> fossil origin	82.5	29.8
CH <sub>4</sub> non fossil origin	80.8	27.2
N <sub>2</sub> O	273	273

#### 3.7.1 Carbon dioxide emissions results

Tailpipe carbon dioxide emissions were reduced by between 3-4% for all three e-fuels, likely due to the higher hydrogen to carbon ratio of the hydrocarbons which make up e-fuel blends compared to E10 due to the presence of less aromatic compounds. This results in a proportionally lower carbon content per volume of fuel compared to E10 resulting in lower CO<sub>2</sub> emissions. The higher energy content of e-fuel 1 and 2 (indicated by a higher lower heating value, Annex 1) likely also contributed to lower fuel consumption and therefore lower CO<sub>2</sub> emissions.

#### 3.7.2. Methane emissions and nitrous oxide emissions results

Emissions of the two GHG were largely similar for all fuels. Methane emissions for all fuels on both tests were low at 1mg/km. Emissions were below the uncertainty level for the measurement outside of the cold start period during which emissions increased to around 10mg/km.

Emissions of nitrous oxide (N<sub>2</sub>O) were similar at 1 mg/km on the WLTC test with the highest emissions measured during the cold start period of around 7 mg/km. Emissions were slightly higher on the RDE test. E10, e-fuel 2 and 3 emitted 2 mg/km and higher emissions of 3mg/km were measured for e-fuel 1. As for

the WLTC test the highest emissions were measured during cold start, particularly for e-fuel 1 with emissions of 16 mg/km. E10, e-fuel 2 and 3 emissions were lower at around 11-12 mg/km.

The results indicate that for longer trips, for example equivalent to the length of the RDE test undertaken as part of this testing campaign, the contribution of methane and nitrous oxide to total trip GHG emissions is relatively small of 0.6-0.8 gCO<sub>2</sub>e/km based on a 20 year GWP, and 0.5-0.7 gCO<sub>2</sub>e/km based on 100 year GWP. However, on very short trips -such as the first 2 km of the RDE test- emissions would be higher due to higher N<sub>2</sub>O and CH<sub>4</sub> emissions at cold start. Emissions during the first 2km of the RDE test were 4.1-5.1 gCO<sub>2</sub>e/km based on a 20 year GWP and 3.4-4.6 gCO<sub>2</sub> e/km based on a 100 year GWP. This means that for those drivers who frequently drive shorter trips, which often occur in towns and cities, emissions would be higher.

## 4. Discussion

### 4.1 E-fuels impact on air pollution

The results of this testing programme which tested three potential e-petrol blends show that e-fuels are not a credible solution for consistently reducing all pollutant emissions from road transport, and do not deliver the NO<sub>x</sub> reductions that the industry claims[51]. Substituting fossil petrol with e-petrol will do little to reduce emissions of key pollutants which are harmful to human health or the environment at a time when the EU needs to drastically cut air pollution to meet new World Health Organisation (WHO) air quality recommendations.

The tests show that emissions from all fuels stayed below legal limits but switching from fossil to e-petrol delivers mixed results depending on the pollutant measured. Switching could potentially result in a large decrease in particle number (PN) emission on the road, there was a 81-86%<sup>6</sup> reduction in PN on the RDE test along with some decrease in formaldehyde and acetaldehyde emissions. However, emissions of these pollutants are far from eliminated. For example for PN, at least 2.2 billion particles are emitted from the exhaust for every kilometer driven. The e-petrol blends tested also appear to have no impact on nitrogen oxide (NO<sub>x</sub>) emission or hydrocarbon (HC) emissions during RDE testing, meaning continuous emissions of these pollutants equivalent today's levels from future e-fuel driven cars

Worryingly, RDE carbon monoxide emissions (CO) are substantially increased (by 1.2-1.5 times) for all e-fuels, and ammonia emissions increased by 1.7-2.2 times for two of the e-fuels tested. For ammonia (2-2.5 times) and carbon monoxide (2-2.5 times), the majority of the increase in emissions was predominantly observed during the cold start period, i.e. those emissions which occur when the engine is first switched on. This suggests that the increase in emissions of these pollutants will largely impact on shorter trips, typically driven in towns and cities. This is supported by the higher variability in emissions

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<sup>6</sup> For all particles larger than 10nm.

between E10 and the three e-petrol blends tested on the WLCT test which is much shorter, and therefore cold start contributes to a higher share of emissions.

Analysis by CONCAWE[4], a European oil industry association which tested a potential future 100% e-diesel blend and a 50:50 e-diesel and conventional B7 diesel blend on a Euro 6d-temp diesel car on WLTC tests also showed that e-fuels will have little impact on key vehicle pollutant emissions. The results found that while NO<sub>x</sub>, CO and HC emissions were slightly reduced, particle emissions were largely unaffected even with particles down to 10 nm measured. A similar trend was observed for the Euro 5 and 6b diesel cars tested, except for the magnitude of emissions, which as expected was highest for the Euro 5 car and lowest for the Real Driving Emissions (RDE) approved 6d-temp car.

While both sets of testing indicate that the change in emissions of cars running on e-fuels compared to fossil fuels is dependent on the type of e-fuel used (e-petrol or e-diesel), they strongly indicate that e-fuels will do little to reduce pollutant emissions from new cars (such as Euro 6d or 6d-temp) or existing vehicles (such as Euro 5 or Euro 6 cars), counteracting claims from the E-fuel Alliance[25]. Therefore, transitioning from fossil fuels to e-fuels for diesel and petrol cars will do little to contribute to the European Commission's Green Deal Zero Pollution[17] ambition to prevent air pollution at source thereby failing to fix the EU's air pollution problems, especially in urban areas. E-fuels are not a credible alternative to a full transition to zero emission mobility which can actually deliver the clean air across Europe which EU citizens overwhelmingly demand.

Yet many countries still fail to meet EU Air quality limits today[52] and new World Health Organisation (WHO) air quality guidelines require 75% less NO<sub>2</sub> and 80% less PM<sub>2.5</sub> than current EU limits with the WHO clearly stating that there is no safe level of air pollution[16]. Since road transport is the 1st (NO<sub>x</sub>) it is imperative that air pollution from cars and other road vehicles is reduced as quickly as possible for the sake of EU citizens' health.

This can only be achieved through a tougher new emission standard for cars and vans (Euro 7) currently under development by the European Commission) for the 95 million cars with conventional engines[53] expected to still be sold in Europe between 2025 - when the new emission standard is expected to enter into force - and 2035 when all new car sales are proposed to be zero emission[54]. Only tougher pollutant emission limits for ICE cars combined with a plan to phase out internal combustion engines and transition to zero emission alternatives by 2035 through the car CO<sub>2</sub> standard is a credible plan for reducing pollution from cars in Europe. Betting on e-fuels to reduce pollution from ICE cars is unrealistic and is not a valid alternative to zero emission BEVs.

## 4.2 E-fuels and greenhouse gas emissions

As already discussed in Section 1.1, e-fuels produced from direct-air capture of CO<sub>2</sub> emissions, an emerging technology with only some pilot plants currently in operation, are generally regarded as carbon neutral as it is assumed that the amount of carbon dioxide emitted out of the tailpipe is equal to the

amount of dioxide captured in the air. However, many e-fuels brought to market within the next decade are likely to not be fully carbon neutral as they will rely on capture of CO<sub>2</sub> emissions from industrial fossil fueled sources -shifting those emissions further down the line- rather than directly removing CO<sub>2</sub> from the air. There are also no EU proposals for ensuring that e-fuels, for any application, are fully carbon neutral from the start so it cannot be automatically assumed that e-fuels are carbon neutral.

In addition, this assumption fails to account for the emissions of other more potent greenhouse gases produced during the combustion process, in particular methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions. The greenhouse gas emissions measured during this testing programme suggests that the use of e-fuels in road transport is not fully greenhouse gas neutral.

Total CO<sub>2</sub> equivalent emissions for the three petrol e-fuels tested by T&E on the RDE test were between 0.6-0.8 gCO<sub>2</sub>e/km (20 year GWP) and 0.5-0.7 gCO<sub>2</sub>e/km (100 year GWP). Multiplied over the typical annual mileage of an EU car<sup>7</sup> this would be equal to between 7.0-9.3 kgCO<sub>2</sub>e per year (20 year GWP) or 6.5-9.0 kgCO<sub>2</sub>e per year (100 year GWP) depending on the e-fuel used to power the vehicle.

Higher methane and nitrous oxide emissions were measured by CONCAWE in their testing of the diesel e-fuel in a Euro 6d-temp car with CO<sub>2</sub> equivalent emissions of 2.0 gCO<sub>2</sub>e/km (20 year GWP) and 1.96 gCO<sub>2</sub>e/km (100 year GWP). For a typical EU vehicle<sup>8</sup> this would be equivalent to 24.5 kgCO<sub>2</sub>e per year (20 year GWP) or 23.6 kgCO<sub>2</sub>e per year (100 year GWP).

Assuming that all new diesel and petrol cars sold in the EU in 2020<sup>9</sup> running on e-petrol or e-diesel had equivalent methane and nitrous oxide emissions as the Euro 6d-temp cars tested by T&E and CONCAWE. Total CO<sub>2</sub> equivalent emissions of the two greenhouse gases in just one year of driving from new cars sold in 2020 would be between 100,000-112,000 tonnes (20 year GWP) and 96,000- 108,000 tonnes (100 GWP). This is equivalent to the CO<sub>2</sub> emissions of around an additional 50,000 average EU cars on the road<sup>10</sup>. This is a conservative estimate of yearly emissions from new car sales due to historically low vehicle sales in 2020 caused by the Covid-19 pandemic and the use of RDE data for the e-petrol fuel blends, where the contribution of high methane emissions at cold start is low due to the much longer length of the test compared to the short city trip which many cars regularly undertake.

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<sup>7</sup> Based on an annual mileage of 12,000km a year, the average EU figure in 2018. Source Odyssee-Mure <https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/distance-travelled-by-car.html>.

<sup>8</sup> Based on an annual mileage of 12,000km a year, the average EU figure in 2018. Source <https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/distance-travelled-by-car.html>.

<sup>9</sup> Sales data from [EEA database on CO2 emissions of passenger cars](#) . EEA without UK used for sales figures.

<sup>10</sup> Based on average yearly CO<sub>2</sub> emissions per car of 1.98 tonnes in 2019. Calculated from total 2019 EU car fleet CO<sub>2</sub> emissions of 481.22Mt obtained from UNFFCC GHG inventories. (2021). EU 2019 car fleet size of 242.7 million obtained from ACEA. (2021-2022) [The Automobile Industry pocket guide](#). 2019 is the latest year for which both sets of data are available.

In addition, there is no EU limit on tailpipe N<sub>2</sub>O emissions for cars and methane emissions are only regulated through a weak total hydrocarbon (THC) limit for petrol or a weak combined hydrocarbon and NO<sub>x</sub> (HC+NO<sub>x</sub>) limit for diesel<sup>11</sup>. Therefore, for other cars, emissions of N<sub>2</sub>O and CH<sub>4</sub> could be higher than those recorded in CONCAWE's and T&E's testing. Indeed for the Euro 5 and 6b cars also tested in CONCAWE's study N<sub>2</sub>O and CH<sub>4</sub> emissions were higher compared to the Euro 6d-temp car suggesting that use of e-fuels in the older existing fleet vehicles may lead to higher carbon leakage than calculated for the 6d-temp cars. Additionally, since compliance with methane limits is only checked on laboratory tests during type-approval, on-road emissions could be higher especially during more challenging driving conditions such as in cold weather[55] when the exhaust emission control system used for methane oxidation (to CO<sub>2</sub> and water) takes longer to heat up.

Even proposed new Euro 7 tailpipe emission limits for cars<sup>12</sup> for both GHGs are not strict enough to reduce emissions compared to levels measured on CONCAWE's and T&E's tests, indicating that even if pollutant emission limits are introduced for these GHGs they are unlikely to reduce emissions significantly compared to emissions measured on these tests. Therefore, even the use of e-fuels in cars certified to a new Euro standard which limits emissions of the two GHG will result in carbon leakage.

While unaccounted for GHG emissions such as methane and N<sub>2</sub>O remain, the use of e-fuels in cars and other road vehicles cannot be considered carbon neutral. Proponents of e-fuels in road transport may suggest additional carbon capture and storage (CCS) to offset any additional GHG produced from the burning of e-fuels in internal combustion engines; however this approach is likely to be ineffective. Unlike CO<sub>2</sub> where vehicle fleet emissions can be calculated from the volume of fuel sold in the EU, an accurate calculator of emissions of the two GHG is likely impossible. This is due to the variability in emissions of N<sub>2</sub>O and CH<sub>4</sub> produced in the engine and emission control system depending on vehicle model, weather conditions, and trip composition as discussed above. In effect, the variability in on-road emissions makes an accurate assumption of fleet emissions, capable of delivering truly net zero emissions through CCS, impossible. Offsetting emissions of N<sub>2</sub>O and methane emitted from ICE vehicles running on e-fuels is not realistic and means that e-fuels in road transport cannot be considered GHG neutral, and the EU should focus on BEVs which are guaranteed to deliver the expected CO<sub>2</sub> and GHG emission savings when running on renewable electricity.

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<sup>11</sup> Compliance with limits is only required on the type-approval WLTC test.

<sup>12</sup> of 10mg/km



# **Part 2**

## **5. Broader considerations of using e-fuels in road transport**

Aside from the air pollution impact of using synthetic petrol or diesel in cars there are other equally important costs, availability and environmental concerns that should be considered. These are outlined in the following section and based on previous analysis undertaken by T&E.

### **5.1. E-fuel efficiency in cars**

E-fuels in road transport are highly inefficient compared to direct electrification i.e. BEVs meaning that the use of e-fuels in road transport would require much larger investments in renewables resulting in an inefficient and expensive transition.

The most effective way to use renewable electricity for road transport is to directly charge electric vehicles resulting in low losses from generation to use (23%). However, for ICE cars running on e-fuels, substantial losses occur due to the energy intensive process of making e-fuels and transportation which results in a loss of 45-48%. The much lower efficiency of the internal combustion engine compared to an electric powertrain (95% vs. 42%) results in additional large losses. Combined this means that BEVs are almost 5 times more efficient than ICE's running on e-fuels. Today, direct electrification is 77% efficient compared to 20% for diesel and 16% for petrol running on e-fuels[56].

The low efficiency of e-fuels means that the amount of renewables which would be needed to meet energy demand from road transport compared to direct electrification is huge. For example if 100% of EU passenger cars were BEVs, charging them would require 417 TWh in 2050 (just 15% more compared to current total electricity demand). Swapping just 10% of those cars to e-fuels and another 10% to hydrogen (which is more efficient than e-fuels by around 50%) would push up electricity demand by 36%. The 181 additional TWh needed[56], would require 23 additional 2 GW off-shore wind farms<sup>13</sup> taking up an area more than 3 times larger than Luxemburg<sup>14</sup>.

Therefore, the use of such an inefficient energy source in cars and road transport more widely when more efficient direct electrification is available, will make the decarbonisation efforts unnecessarily costly and less optimal. The decarbonisation of transport alone will require 2414 TWh of electricity in 2050 equivalent to 305 additional 2 GW off-shore wind farms taking up an area three times the size of

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<sup>13</sup> Based on a generation capacity of 7.9TWh generation capacity per year as detailed in Ricardo. (2020) [Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels.](#)

<sup>14</sup> Assuming that each 2 GW wind farm is 25km x 15km as detailed in Ricardo. (2020) [Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels.](#)

Denmark[56]. To ensure that the clean green transition succeeds and the EU meets its net zero targets in 2050 there is no scope for wasting green electrons and using renewable electricity inefficiently. The use of e-fuels should be reserved for hard to abate sectors such as aviation and shipping where there are simply no better alternatives available and where direct electrification is not currently technically feasible.

## 5.2 E-fuel costs for consumers

The inefficiency of e-fuels mean that they are also an prohibitively expensive technology for decarbonising road transport. In 2030, the energy cost to power an efficient petrol car running on synthetic fuels will be close to four times higher than for a BEV . Depending on the extent to which the production cost of e-fuels drops in the next decades, the energy cost would be in a range of 3.4 and 4.2 times higher (3.8 on average)[6].

The higher energy demand for production along with high capital investments needed translates to high e-fuel prices for consumers. Even with optimistic industry assumptions on electricity generation based in Northern Africa the overall cost of production of e-petrol in 2030 is €1.3/L, rising to a consumer purchase price of €2.30/L when taxes, levies and transport are included. Producing e-fuel in the EU is likely to be much more expensive. The International Council for Clean Transportation (ICCT) calculates that in 2030 significant volumes of e-fuels will not be produced within the EU for less than €3-4/L[57]. For comparison the average consumer petrol price in the EU including duties and taxes over the course of 2021 until the 15th of November was €1.50/L<sup>15</sup> meaning that even under the most favourable cost scenario (imported e-fuels) e-petrol would cost the average consumer 40% more than consumers pay today.

### For new cars

This in effect means much higher costs for consumers over the lifetime of the car. Already today, the total cost of ownership (TCO) of a BEV is lower than the TCO of a comparable conventional ICE car in more than ten European countries<sup>16</sup> without the use of more expensive e-fuel. Over the next decade, the economic case for owning a BEV compared to an ICE will only be strengthened thanks to falling battery prices (-60% between 2020 and 2030), better manufacturing and economies of scale. BEVs are expected to reach upfront purchase price parity with ICEs in the mid 2020s (without subsidies)[12]. On the other hand, even under the most optimistic assumption, e-fuel prices will remain higher than today's conventional fuel price.

Using the most optimistic e-fuel prices, the total cost of ownership of BEV in 2030 would be a third cheaper than an efficient internal combustion engine car running on e-fuels. Over a 5 year ownership period a driver with a petrol car running on e-fuel would spend an additional €10,000 compared to a BEV

<sup>15</sup> European Commission. [Weekly oil bulletin](#). Price based on EU 27 average price of Euro Super 95 petrol.

<sup>16</sup> LeasePlan (2021) [EV Readiness Index 2021](#). Leaseplan calculates a lower TCO for BEVs in 11 countries out of 22 European countries. The 11 countries are: Austria, Belgium, Denmark, France, Germany, Italy, Luxembourg, Netherlands, Norway, Portugal and the UK.

owner, an average of €2,000 a year[6]. This is a large amount for a consumer to pay for a fuel that is not fully greenhouse gas neutral and continues to contribute to air pollution.

### **For the existing fleet**

The e-fuels industry is a big proponent of using e-fuels to decarbonise the existing fleet of ICE cars on the EU's roads[58]. While it is true that the CO<sub>2</sub> emissions of these vehicles would be lower if running on 100% e-fuels or if e-fuel is used as a drop in fuel into existing blends compared to fossil fuels, a second hand petrol car running on e-fuels would still be around €10,000 more expensive compared to a second hand BEV over five years. Even running a second hand car on e-fuels is more expensive than buying a new BEV[6].

The high TCO of ICE cars means that e-fuels are not a realistic option for decarbonising new or existing cars. The high cost would put a great and unnecessary burden on the average European driver essentially making this option economically implausible. This is especially the case for the existing fleet of vehicles; EU consumers who buy second, third or fourth hand cars simply cannot afford the high costs associated with e-fuels.

If an e-fuels policy for road transport is pursued by the EU, the cost burden will be particularly felt by citizens in Eastern Europe, many of whom rely on cheap imports of second hand cars from Western Europe. In 2017 alone Poland imported over 850,000 used cars and Bulgaria 100,000 with the majority of consumers purchasing a vehicle which is over ten years old[59][60] These consumers simply cannot afford the high cost of e-fuels. What they require is cheap, readily available second hand BEVs - alongside better public transport, rail network and, in urban areas, active & shared mobility - all of which offer lower running costs than e-fuels. So the policy focus should instead be on driving the cost of first hand BEVs down - via supply side regulations like Cars CO<sub>2</sub> or via corporate fleets measures - while also investing into car alternatives such as shared mobility.

### **5.3 E-fuel costs for economy**

Aside from the cost to the consumer there is a high cost to the economy associated with pursuing road transport decarbonisation through e-fuels.

Allowing fuel credits within the CO<sub>2</sub> regulation- which would allow carmakers to buy credits from fuel suppliers for synthetic fuels to count towards their CO<sub>2</sub> targets, instead of reducing emissions of ICE vehicles and increasing sales of BEVs - is heavily pushed by the oil and gas industry. However such a route to CO<sub>2</sub> compliance would be very costly for carmakers. T&E estimates that in 2030 it would cost close to €10,000 to purchase sufficient credits for an efficient petrol car placed on the market. In comparison the average cost of a BEV battery is expected to fall to €3000. However, this comparison is somewhat disingenuous as BEVs are expected to reach purchase price parity with petrol ICE in the mid 2020's and likely to be lower in 2030. Therefore, at this stage, it will not cost carmakers more to produce and sell a BEV rather than an ICE and the cost of compliance could even be negative[6].

The higher compliance costs for an efuels pathway will eventually be passed on to the wider society leading to a less cost effective decarbonisation trajectory for our society and our economy. If in line with European Commission proposals carmakers are required to reduce CO<sub>2</sub> emissions by 55% in 2030, this would require carmakers to sell almost an additional 2.0 million BEVs in 2030 and an additional 3.7 million BEVs through the 2020's compared to the 37.5% reduction currently required by adopted CO<sub>2</sub> regulation. If instead of selling BEVs carmakers met the difference between old and new CO<sub>2</sub> targets through e-fuel credits, T&E assumes that instead of the 3.7 million additional BEVs the equivalent amount of petrol cars would be placed on the road. The e-fuels needed for those petrol cars to be counted as zero emission would cost €65 billion up to 2030. On the other hand the additional battery costs to produce the equivalent number of BEVs would be €13 billion[6], or a fifth of the expected e-fuel cost.

To follow the most cost optimal pathway to 100% zero emission cars by 2035 which is needed to achieve a fully zero emission fleet by 2050, a more ambitious reduction in CO<sub>2</sub> emissions is needed in 2030. This requires 67% BEV sales in 2030 equivalent to a -80% CO<sub>2</sub> reduction[61]. Under this more ambitious -80% pathway an additional 4.8 million BEVs would need to be sold in 2030 and 25 million through the 2020's. If the additional CO<sub>2</sub> reduction compared to current adopted policies was met through e-fuels instead of BEVs the additional e-fuel cost through to 2030 is expected to be €441 billion compared to €78 billion for the additional BEV batteries needed, less than a fifth of the e-fuel costs<sup>17</sup>.

This data indicates that pursuing a reduction in new car CO<sub>2</sub> emissions through the use of e-fuels is highly expensive due to the high costs of the e-fuels. This is the case even at optimistic fuel prices which assume that e-fuels will be imported from outside of the EU, a pathway which T&E considers not fully viable. Reaching the targets through sales of BEVs is much cheaper both for consumers and the economy.

## 5.4 Availability of e-petrol and e-diesel in Europe

The current availability of e-fuels for cars within the EU is close to zero . When T&E tried to obtain e-petrol either directly or through IFPEN in the first half of 2021, needing less than 100l for testing, it was not possible to secure even a small amount of e-fuel required for testing. No e-petrol or e-diesel was available for purchase commercially within the EU either as a pure 100% e-fuel or incorporated into existing e-fuels blends.

At present there are only several operating or planned e-fuel pilot or full scale production plants across Europe and globally which aim to produce fuel for road transport. Some examples include a test facility at the Karlsruhe Institute of Technology in Germany[62], the Norsk E-fuel plant in Herøya Norway[63], the AVL plant in Graz[64] and a joint venture in Punta Arenas, Chile which includes the European car

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<sup>17</sup> The modelling of compliance for e-fuels and batteries is based on the methodology detailed in [T&E. \(2021\) E-fuels: why e-fuels in cars make no economic or environmental sense](#). Expected BEV sales are forecast based on T&E modelling of car CO<sub>2</sub> standards.

manufacturer Porsche[2]. However, a huge amount of e-fuels would be required to decarbonise new cars, the existing fleet or both.

To decarbonise an average medium petrol car (C-segment) running on 100% e-petrol and driving 15,000km<sup>18</sup> a year would require 900L of e-fuel just in the first year of use. The Norsk e-fuel plant in Norway has a planned annual production capacity of 10 million litres in 2023 and 100 million by 2026. Even if 50% of the e-fuel produced is e-petrol designated for road use, (this is highly optimistic as up to 70% could be e-kerosene for aviation with around 22% for road fuels[65] likely a mixture of diesel and petrol) the produced fuel would only be enough to decarbonise 5,600 c-class petrol cars in 2023 and 56,000 in 2026<sup>19</sup>. Similarly the Graz plant may produce 240 million litres of e-fuels in 2030[64], based on the same assumptions this would only be enough for 133,000 cars. In comparison before a slowdown in sales in 2019 due to Covid-19, 13 million cars were sold in the EU<sup>20</sup> and T&E forecasts that in 2035 12.5 million<sup>21</sup> will be sold clearly indicating the size of the challenge for the scale up of e-fuels if they were to contribute to the decarbonisation of cars and road transport. This is without even considering how much e-fuel would be needed to decarbonise the EU's existing car fleet which stood at over 242 million cars in 2019 and is continuing to increase, with ownership rates particularly increasing in Eastern and Southern Europe[66].

T&E forecasts that to meet the proposed -55% CO<sub>2</sub> reduction in 2030, and replace the expected 3.7 million extra BEVs that would be sold through to 2030, would require 50 billion litres of e-fuel up to end of 2030, with 23 billion required in 2030 alone. 2030 demand is equivalent to 454 Norsk e-fuels plants or 189 Graz plants<sup>22</sup>. Under the more ambitious -80% reduction in 2030 over 300 billion litres would be required up to the end of 2030, 71 billion litres in 2030 alone equivalent to 1415 Norsk e-fuel plants or 590 Graz e-fuel plants<sup>23</sup>. Even with a larger sized e-fuel plant such as the Haru oni plant in Chile which is expected to produce 550 million litres of e-petrol in 2026[67],[68], 41 plants would be needed to meet the demand in 2030 based on the -55% reduction scenario or 129 based on the -80% scenario if all of the production

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<sup>18</sup> Based on an average annual mileage of 15,000 km for a C-segment car ( compared to 12,000 km for the average EU car fleet). 225,000 km lifetime mileage based on the European Commission study on LCA, as detailed in Ricardo Energy & Environment (2020), [Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA. Final Report for the European Commission](#). On average this is 15,000km per year over 15 years. Fuel consumption is assumed at an optimistic 6L/100km based on the fuel consumption of today's petrol hybrids.

<sup>19</sup> Based on an average annual mileage of 15,000km. 225,000 km lifetime mileage based on the European Commission study on LCA, as detailed in Ricardo Energy & Environment (2020), [Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA. Final Report for the European Commission](#). On average this is 15,000km per year over 15 years.

<sup>20</sup> EU27 without the UK, [EEA database on CO2 emissions of passenger cars](#).

<sup>21</sup> T&E estimates based on production trends and the some level of imports/ exports as in 2019.

<sup>22</sup> Based on Norsk production of 100 million litres per year or Graz production of 240 million litres a year with 50% of production dedicated to e-petrol which is an optimistic assumption.

<sup>23</sup> Fuel volume required in based on the methodology for calculating e-fuel costs outlined in [T&E. \(2021\) E-fuels: why e-fuels in cars make no economic or environmental sense](#). Expected BEV sales are forecast based on T&E modelling of car CO2 standards..

capacity was dedicated to road transport and kept/exported to the EU. Based on what has been announced to date, this is not feasible. This is without even considering the amount of e-fuel that would be required to decarbonise the 252 million ICE cars that would be on the road in 2030<sup>24</sup>.

In contrast there will be sufficient European supply of battery cells. As of May 2021, 17 out of 38 battery cell gigafactories announced in Europe have secured full funding and a further ten projects have secured partial funding. If these projects come online as expected, they will result in 462 GWh of battery capacity produced in Europe by 2025 and 1,144 GWh by 2030. If all these projects are delivered, the planned battery manufacturing capacity would be sufficient to power around 50% electric car sales in Europe in 2025 (32% BEV) and more than 90% in 2030 (75% BEV). This corresponds to a car CO<sub>2</sub> reduction target of 44% in 2025, 62% in 2027 and 91% in 2030 indicating<sup>[69]</sup> that there will be sufficient battery manufacturing capacity in Europe to not only meet the new more ambitious CO<sub>2</sub> targets proposed by the Commission in July of 2021 but to further increase the rate of electrification between 2025 to 2030.

Another suggestion of the e-fuels industry also suggests to use e-fuels as drop-in fuels<sup>[25]</sup> into existing fuel blends, for example a blend of 40% e-petrol and 60% E10 petrol. However, aside from having a much smaller climate benefit than 100% e-fuel and continuing the dependence of fossil fuels this option may be more difficult than the fuel industry suggests. When IFPEN tried to blend paraffinic e-petrol with ethanol the blend separated out like oil and water i.e. the blend was immiscible. Even when up to 20% aromatic content was introduced the blend still separated out at cold temperature. In the end 5% fusel oil had to be added (as a surfactant) to form a stable blend. This suggests that blending paraffinic e-petrol into existing E10 fuel at high concentrations may result in blending issues which the fuel industry would have to solve through the use of additional additives potentially leading to higher costs.

Betting on e-fuels to decarbonise cars and road transport either partially or fully is not credible at a point when serious investment in EU battery cell and BEV manufacturing is taking off. It risks reducing and delaying planned investment in zero emission technology which is already available, can deliver the CO<sub>2</sub> reductions required to meet the EU's 2050 net zero ambitions as well as key intermediate targets (-55% in 2030) and, crucially, wanted by consumers as evidenced by skyrocketing BEV sales. Frustrating EU efforts to get ahead in the zero emission e-mobility race by investing in e-fuels for cars, leaves the door open for Chinese and non-EU manufacturers to grab EV market share, diverting investment away from the EU and risking EU jobs.

It also poses a serious systematic risk to the EU's decarbonisation efforts as there is no guarantee that e-fuels will be scaled rapidly enough over the next 14 years to decarbonise new ICE cars in sufficient volume to allow the EU to meet its 2030 (-55%) and later targets (net zero 2050). All new cars sold in the EU have to be zero emission by 2035 for only zero emission cars to be left on the road by 2050. But if the EU bets on e-fuels, and no e-fuels for road vehicles materialise, the lack of e-fuels combined with stalled

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<sup>24</sup> Based on T&E internal modelling tool (EUTRM) that accounts for BEV sales required by the car CO<sub>2</sub> standards (European Commission proposal targeting a -55% emission reduction in 2030) and the fleet turnover.

BEV investment may mean that the EU ends up in 2030 with no pathway to decarbonise cars. Or the rapid and unnecessarily compressed scale up of BEV may then be necessary to decarbonise cars that will be incredibly expensive for consumers and the economy. This may yet again leave the door open to Chinese and non-EU car manufacturers to grab market share as the EU may end up with no other choice but to import BEVs to meet its climate targets. Rather, the EU's efforts for e-fuels should be focused on the aviation and maritime sectors, sectors which have essentially no other option for clean energy vectors.

## 5.5 Other environmental risks

Inadvertently, if e-fuels are used for road vehicles they will need to be transported from production sites to fuel stations across EU Member States, with widespread coverage necessary for easy consumer access. This will require the movement of liquid hydrocarbons by pipeline, tank truck and even tanker vessel if, as envisaged industry e-fuel is produced and distributed globally[58]. Such operations carry the same risk of leakage or spillages as fossil fuels, which have devastating effects on the environment as well as human health.

While e-petrol and e-diesel is likely to contain less or no aromatic compounds (depending on blend) such as carcinogenic polycyclic aromatic hydrocarbons or benzene, aliphatic hydrocarbons (products of the Fischer-Tropsch reaction used to make e-fuels from direct air capture), the likely dominant building blocks of e-diesel (C10-C19 hydrocarbons i.e hydrocarbons with a chain length of 10-10 carbons) and e-petrol (C4-C12 hydrocarbons)[70] are also harmful to health and the environment. Maximum exposure limits have been determined for humans for these hydrocarbon chemical mixtures due to their possible neurotoxicity[71] and breakdown of these chemicals in the environment can form toxic and carcinogenic compounds [72]. Spillages of e-fuels pose a risk not just to humans but also the environment including fragile ecosystems such as marine life and coral reefs.

Continuing the use of hydrocarbon based fuels for cars and other road transport, even if produced from electricity (e-fuels) continues to pose an unnecessary environmental health risk when less risky direct electrification exists for this transport segment .

## 6. Summary and Policy recommendations

The use of e-fuels in internal combustion engine (ICE) cars will not solve the EU's air pollution problems. Testing of three different e-petrol blends in a Euro 6d-temp car on the chassis dynamometer on WLTC and RDE cycles as detailed in this report have shown that e-fuels are **not a clean burning fuel and, apart from particle number emissions, will do little to reduce toxic pollutant emissions of both regulated and unregulated pollutants** compared to EU E10 fuel. Crucially, the e-fuels had no impact on NOx emissions, the pollutant which many European cities still struggle with illegal levels of, and on RDE type tests no effect was seen for hydrocarbons. Emissions of toxic carbon monoxide were substantially increased, and so were emissions of ammonia which contributes to particle pollution. The only pollutant for which emissions were reduced by a large amount were particle number emissions. However, no such reduction

was observed for particle mass. At a time when 2 out of 3 citizens of the EU's biggest cities demand protection from air pollution<sup>25</sup> and stricter WHO air quality guidelines require large reductions in air pollution concentrations for the protection of EU citizens' health, the EU and Member States need credible and effective plans for slashing toxic pollution from cars. E-fuels will not eliminate or significantly reduce pollution from cars and cannot be considered as part of clean air strategies. The only solution for fully cleaning up pollution from cars are zero emission vehicles.

Measurement of greenhouse gas emissions during the testing also suggests that the use of e-fuels in road transport is unlikely to be fully climate neutral. While it is generally assumed that CO<sub>2</sub> emissions of e-fuels produced from direct capture of CO<sub>2</sub> from the atmosphere are carbon neutral, the production of the two more potent greenhouse gases - methane and nitrous oxide - in the engine and exhaust emission control system is not accounted for. T&E estimates that emissions of methane and nitrous oxide in just one year of driving by **new diesel and petrol cars sold in 2020 running on e-fuels would be equivalent to the CO<sub>2</sub> emissions of an extra 50,000 cars on the EU's roads**. Due to the variability in production of those greenhouse gases depending on driving conditions, it is highly doubtful that the emissions of these potent greenhouse gases could ever be effectively offset through initiatives such as carbon capture and storage, meaning that the use of e-fuels in road transport would result in unaccounted for greenhouse gas emissions.

The results of this study highlight that the use of e-fuels in road transport makes no sense where more efficient, cleaner and, when running on renewable electricity, 100% carbon neutral direct electrification technology exists. BEVs are both good for the climate and for air quality as they eliminate tailpipe pollution altogether. E-fuels on the other hand are highly inefficient - they are almost five times less efficient than BEVs - and still produce air pollution. Ironically, making e-fuels for road transport using a lot of renewable energy - turns them into a polluting fuel that is no better than the fossil fuels they replace.

The reality is that e-fuels are just not a credible solution for reducing air pollution, or decarbonising new cars or the existing fleet, due to inefficiency, cost and because they are needed in hard to abate sectors like aviation where no better alternatives exist. Betting on e-fuels to decarbonise cars within the next 14 years, is fraught with risk since there isn't even any e-petrol or e-diesel available for consumers to buy today.

If the 3.7 million additional BEVs which need to be sold up to 2030 to reach -55% CO<sub>2</sub> in 2030 vs. the currently adopted -37.5% were replaced with petrol cars running on e-fuels, 23 billion litres of e-petrol would be required in 2030 alone. There is currently no credible plan available for putting this much e-fuel on the EU market, but gambling that these fuels will materialise within the next nine years will stall planned investment in BEVs. This risks making the EU locked into at least another decade of fossil fuels

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<sup>25</sup> A pan European by YouGov of 21 of Europe's largest cities show and 2 out of 3 do not want to go back to the levels of pollution experienced before the lockdown. Source:T&E. No going back: [European public opinion on air pollution in the Covid-19 era](#).



and the EU missing its climate targets if the promised e-fuels never materialise and insufficient BEVs are available -due to stalled manufacturing investment- to fully decarbonise new car sales by 2035. This is the last date by which all new car sales have to be ZEV to ensure that only zero emission vehicles are left on the road by 2050 in order to meet the EU's 2050 net zero target.

Policymakers need to see e-fuels in road transport for what they really are, - a Trojan Horse for the old industry, i.e. a way for some in the automotive, fuel and gas industry to keep the polluting internal combustion engine alive at a huge cost to consumers and the wider economy and not a credible pathway to decarbonising cars. T&E recommends that:

- 1. Car, van and truck CO<sub>2</sub> vehicle standards cannot allow any credits for e-fuels.** Adding e-fuels to the vehicle CO<sub>2</sub> regulations would greatly weaken its effectiveness for decarbonising vehicles sold in the EU. Carmakers would be able to buy fuel credits for compliance, with no guarantee that consumers would purchase the more expensive e-fuels or that sufficient volumes of such a fuel would be available in the market. The effectiveness would also be watered down when mixing different sectors (downstream transport vs. upstream fuels), already covered in effective sector-specific legislation. Ultimately fuel credits will undermine the credibility and enforceability of vehicle regulations.
  
- 2. More ambition on car CO<sub>2</sub> standards is required to drive the swift uptake of zero emission vehicles for the climate as well as air pollution.**
  - a. EU policymakers must ensure that the EU car CO<sub>2</sub> standards reduce CO<sub>2</sub> emissions from new cars by 30% by 2025, 45% in 2027, 80% by 2030 and by 100% in 2035 at the latest. This will ensure a timely ramp up of battery electric cars including within the wider supply chain, to ensure they are available in time and affordably as Europe needs to transition to mobility en masse in order to meet its climate targets.
  - b. Flexibilities embedded into the car CO<sub>2</sub> regulation will weaken the already inadequate CO<sub>2</sub> standards by allowing carmakers to cut and slow down planned BEV production and/or increase emissions from their conventional models and still remain compliant with the targets. T&E therefore recommends to improve the design of the regulation by:
    - Removing the ZLEV benchmark and corresponding carmaker CO<sub>2</sub> bonus from 2025.
    - Updating the tests to provide realistic CO<sub>2</sub> rating of PHEVs, with the help of real-world data from fuel consumption meters.
    - Stopping the free CO<sub>2</sub> pass for heavier cars by removing the mass adjustment factor as well as limiting the CO<sub>2</sub> savings that can be claimed from eco innovations.
    - Banning the sales of conventional models with CO<sub>2</sub> emissions above 120g/km (mostly SUVs) as of 2030.

- 3. EU target setting for deployment of e-fuels a.k.a renewable fuels of non-biological origins (RFNBOs) must avoid setting targets for the use of these fuels in road transport**, where more efficient alternatives such as direct electrification exist. T&E strongly supports the development of green e-fuels for those transport sectors, such as shipping or aviation, where no better alternatives exist but EU-level target-setting must avoid incentivising use in road transport .

Instead, key pieces of legislation of the ‘fit for 55’-package regarding e-fuels - the upcoming review of the Renewable Energy Directive (RED) and the proposed regulations under the RefuelEU Aviation and FuelEU Maritime initiatives - must require fuel suppliers to deliver the efuels volumes needed to get the decarbonisation of planes and ships underway, after decades of inaction and rising emissions. T&E proposes to introduce **a 2030 target on fuel suppliers to meet 1.6% of transport demand with RFNBOs** (an umbrella term in the RED) for all hydrogen and efuels. The 1.6% target incorporates a subtarget of 0.8% for fuels supplied to the maritime sector[73]. A 2% e-kerosene mandate on fuel suppliers to the aviation sector also contributes to reaching the 1,6% target[74]. This target level promotes an ambitious supply of e-fuels in the aviation and shipping industry, yet also takes into account the challenges involved in deploying the additional renewable electricity capacity needed.

- 4. An ambitious new Euro 7 pollutant emissions standard is required for cars, vans, trucks and buses alongside a clear roadmap to zero emission vehicle sales.** Only an ambitious new emission standard in 2025 applicable to all fuels and powertrains including efuels, coupled with a coherent roadmap to phasing out internal combustion engine cars (via the CO<sub>2</sub> standards) by 2035 at the latest, will bring about the air quality improvements that Europe needs. The new standards must as a priority:

- a) Reduce the outdated Euro 6 limits to the lowest limits globally based on the best available technology.** As a minimum this should be aligned with the most ambitious emissions limits proposed by CLOVE ( the consortium of experts working on behalf of the Commission on Euro 7), such as a 20 mg/km NO<sub>x</sub> limit and a 1x10<sup>11</sup>/km particle number (PN) emission limit. While the tests undertaken during this testing project do not cover all possible driving conditions, NO<sub>x</sub> emissions with standards EU fuel were close to 20mg/km and PN emissions were below the proposed 1x10<sup>11</sup>/km indicating that the proposed ambitious Euro 7 limits can already be met under some driving conditions by cars with today's technology.
- b) Regulate all pollutants harmful to human health or the environment.** This must include all particles larger than 10nm, ammonia, non-methane organic gases and the greenhouse gases methane and nitrous oxide. This testing programme has particularly shown that it is critical to regulate currently unregulated 10-23nm as emissions of just those small particles can be close to the emissions of all currently regulated particles meaning that a large amount of particle pollution is currently ignored by official tests.

- c) **Ensure that all possible EU driving conditions are covered by official tests** so that emission limits have to be met wherever and whenever a car is driven. Any driving conditions which regularly occur within the EU such should be covered by the emission limits without any additional multipliers.
- d) **Ensure that limits are met throughout the entire lifetime of the vehicle** by ensuring that limits and in-service conformity testing requirements apply for a minimum of 240,000km and 20 years with deterioration factors applicable thereafter.

**5. No EU or Member State financial support should be provided for the use of e-fuels in road transport.** Direct electrification should be encouraged in road transport as much as possible, whereas the development and scale-up of renewable e-fuels should be supported for aviation, maritime and other heavy industry. As such, no EU or Member State support should be provided for road transport e-fuels specifically, but rather for their use in the sectors where they are needed for decarbonisation due to lack of better alternatives.

For a successful green transition it is critical that the EU focuses on the most efficient pathway for decarbonising each transport mode. For cars and road transport the best solutions are direct electrification which can both eliminate CO<sub>2</sub> emissions and put an end to toxic tailpipe pollution. E-fuels must be saved for hard to decarbonise sectors such as aviation where simply no better alternative exists.

## Annex 1

**Table 2: Properties of the four tested fuels.**

	Unit	Limit (EN228)*		Method	Results			
		Min	Max		E10	Fuel1	Fuel2	Fuel3
Copper strip corrosion (3h, 50°C)	Rating	Class 1		EN ISO 2160	<b>1b</b>	<b>1</b>	<b>1</b>	<b>1</b>
Oxidation stability	Minutes	360		EN ISO 7536	<b>&gt;480</b>	<b>&gt;960</b>	<b>&gt;960</b>	<b>&gt;960</b>
Existent gum content (solvent washed)	mg/100mL		5	EN ISO 6246	<b>&lt;1</b>	<b>&lt;0.5</b>	<b>&lt;0.5</b>	<b>&lt;0.5</b>
Existent gum content					<b>6</b>	<b>0.5</b>	<b>0.5</b>	<b>0.5</b>
<b>PHYSICAL PROPERTIES</b>								
Density @ 15°C	kg/m <sup>3</sup>	720	775	EN ISO 3675	<b>748.4</b>	<b>763.3</b>	<b>726.0</b>	<b>741.0</b>
DVPE @ 37.8 °C	kPa	45 summer 60 winter	60 summer 90 winter	EN ISO 13016-1	<b>56.4</b>	<b>55.2</b>	<b>60.9</b>	<b>66.2</b>
<b>DISTILLATION</b>								
IBP	°C			EN ISO 3405	<b>35.0</b>	<b>49.7</b>	<b>39.8</b>	<b>44.8</b>
5%Vol	°C				<b>50.9</b>	<b>53.6</b>	<b>49.9</b>	<b>47.3</b>

10%Vol	°C				<b>55.1</b>	<b>54.1</b>	<b>52.6</b>	<b>48.0</b>
20%Vol	°C				<b>60.2</b>	<b>55.1</b>	<b>55.3</b>	<b>49.1</b>
30%Vol	°C				<b>64.8</b>	<b>56.4</b>	<b>58.6</b>	<b>50.3</b>
40%Vol	°C				<b>70.0</b>	<b>57.8</b>	<b>62.9</b>	<b>51.7</b>
50%Vol	°C				<b>94.1</b>	<b>60.0</b>	<b>69.3</b>	<b>53.4</b>
60%Vol	°C				<b>102.6</b>	<b>63.7</b>	<b>78.4</b>	<b>56.8</b>
70%Vol	°C				<b>107.5</b>	<b>70.5</b>	<b>90.3</b>	<b>66.5</b>
80%Vol	°C				<b>114.1</b>	<b>85.7</b>	<b>98.7</b>	<b>80.6</b>
90%Vol	°C				<b>134.2</b>	<b>99.3</b>	<b>101.1</b>	<b>98.5</b>
95%Vol	°C				<b>160.4</b>	<b>100.5</b>	<b>102.2</b>	<b>100.1</b>
FBP	°C			210	<b>176.6</b>	<b>106.0</b>	<b>107.3</b>	<b>106.5</b>
Residue	%Vol			2	<b>1.0</b>	<b>1.0</b>	<b>0.9</b>	<b>0.9</b>
E 70°C	%Vol	22 summer 24 winter	50 summer 52 winter		<b>40.0</b>	<b>69.5</b>	<b>50.9</b>	<b>73.1</b>
E 100°C	%Vol	46	72		<b>56.1</b>	<b>92.9</b>	<b>82.8</b>	<b>93.4</b>
E 150°C	%Vol	75			<b>92.9</b>	<b>&gt;99.0</b>	<b>&gt;99.0</b>	<b>&gt;99.0</b>

<b>COMPOSITION</b>								
Ethanol	%Vol		10	EN ISO 22854	<b>9.3</b>	<b>&lt;0.1</b>	<b>&lt;0.1</b>	<b>9.9</b>
Olefins	%Vol		18		<b>6.8</b>	<b>17.0</b>	<b>17.0</b>	<b>13.9</b>
Aromatics	%Vol		35		<b>26.0</b>	<b>&lt;0.1</b>	<b>10.0</b>	<b>&lt;0.1</b>
Benzene	%Vol		1		<b>&lt;0.1</b>	<b>&lt;0.1</b>	<b>&lt;0.1</b>	<b>&lt;0.1</b>
<b>OCTANE INDEX</b>								
RON	Index	95		EN ISO 5164	<b>97.1</b>	<b>102.3</b>	<b>104</b>	<b>104</b>
MON	Index	85		EN ISO 5163	<b>86.3</b>	<b>87.3</b>	<b>89.3</b>	<b>88.0</b>
<b>COMBUSTION</b>								
Net calorific value in mass	MJ/kg			ASTM D 240-Calculated	<b>41.36</b>	<b>42.80</b>	<b>42.77</b>	<b>40.00</b>
O/C	v/v			Calculated	<b>0.032</b>	-	-	<b>0.051</b>
H/C	v/v				<b>1.937</b>	<b>2.036</b>	<b>2.030</b>	<b>2.135</b>

## Endnotes

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