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ZEV TRANSITION COUNCIL

Decarbonizing road transport by 2050

Zero-emission pathways for passenger vehicles

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The Zero Emission Vehicles Transition Council is an international forum focused on enhancing political cooperation on the transition to zero emission vehicles (ZEVs).

It brings together Ministers that represent over 50% of the global car market. Council members have agreed to collectively address some of the key challenges in the transition to ZEVs, enabling the transition to be faster, cheaper, and easier for all.

The Council will convene on a regular basis to discuss how to accelerate the pace of the global transition to ZEVs, to reduce emissions and help the global economy meet our goals under the Paris Agreement.

Acknowledgments

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Significantly decarbonizing road transport by 2050, in line with Paris Agreement objectives and the current research from the Intergovernmental Panel on Climate Change,[1] will require (a) identifying and supporting the technology pathways capable of delivering deep greenhouse gas (GHG) emissions reductions on a life-cycle basis and (b) understanding the related policy challenge of time. The ICCT has conducted a comprehensive life-cycle assessment of GHG emissions from a variety of alternative passenger car powertrains and fuels, and this briefing presents an overview of the findings and the implications for policy.

The evidence shows there is no realistic pathway to full decarbonization of internal combustion engine vehicles. Natural gas does not offer climate benefits compared to gasoline and diesel, and many biofuel pathways do not, either. There will not be sufficient supply of very low-GHG biofuels, biogas, and e-fuels to decarbonize internal combustion engine vehicles. E-fuels, also known as electrofuels and power-to-liquids, are produced from carbon dioxide (CO_2) and electricity. Drivers of plug-in hybrid electric vehicles rely too much on the gasoline engine for this pathway to be a long-term climate solution. Only full battery electric vehicles (EVs) and hydrogen fuel-cell EVs have the potential to be very low-GHG pathways, and the emissions from manufacturing batteries, solar panels, and wind turbines are small when compared to the GHG savings from the greater efficiency and cleaner energy supply of EVs compared to conventional vehicles.

Importantly, battery EVs can be expected to operate with progressively fewer upstream emissions over their lifetimes as electricity grids “green.” The average useful lifetime of a passenger car is between 15 and 18 years (for trucks and buses, it is often even longer),[2] and this study finds the bulk of a vehicle’s life-cycle GHG emissions come from fuel and electricity production and consumption. Thus, decarbonization policies will be most impactful if they reflect passenger cars transitioning to all EVs for new sales by the early 2030s, in order to achieve deep decarbonization of the transport sector by 2050.

Life-cycle emissions from vehicles

Vehicle life-cycle GHG emissions refers to those emissions produced in the manufacture, maintenance, and disposal of a vehicle, and in the production and combustion of the fuel that powers it. This briefing summarizes results of a comprehensive assessment of the life-cycle GHG emissions from conventional and alternative vehicle and fuel pathways, based on a detailed analysis of vehicles and fuels in China, Europe, India, and the United States (U.S.).[3] Here, we present “global” results as the sales-weighted average of these four regions. The study considers battery and hydrogen fuel-cell EVs, plug-in hybrid EVs, natural gas, biofuels, and e-fuels.

Figure 1 shows the results of this assessment for global typical medium-size cars registered in the year 2021 and used for the next 15 to 18 years, with GHG emissions

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[1] IAMC 1.5°C Scenario Explorer and Data (Retrieved from the Integrated Assessment Modeling Consortium & International Institute for Applied Systems Analysis, version 1.x), https://doi.org/10.22022/SR15/08-2018.15429

[2] Georg Mehlhart, Alexandra Möck, Daniel Goldmann, *Effects on ELV waste management as a consequence of the decisions from the Stockholm Convention*, (Oeko-Institut: Darmstadt, Germany, 2018), https://www.oeko.de/fileadmin/oekodoc/ACEA-DecaBDE-final-report.pdf

[3] Georg Bieker, *A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars*, (ICCT: Berlin, Germany, 2021), https://theicct.org/publications/global-LCA-passenger-cars-Jul2021

in grams $CO_{2\ eq.}$ per kilometer driven for every stage of vehicle and fuel production and use. Although this briefing focuses on passenger cars, which account for 40% of oil consumption in transportation, the most of any transport sector,[4] the underlying analysis extends to heavy-duty vehicles, as well.

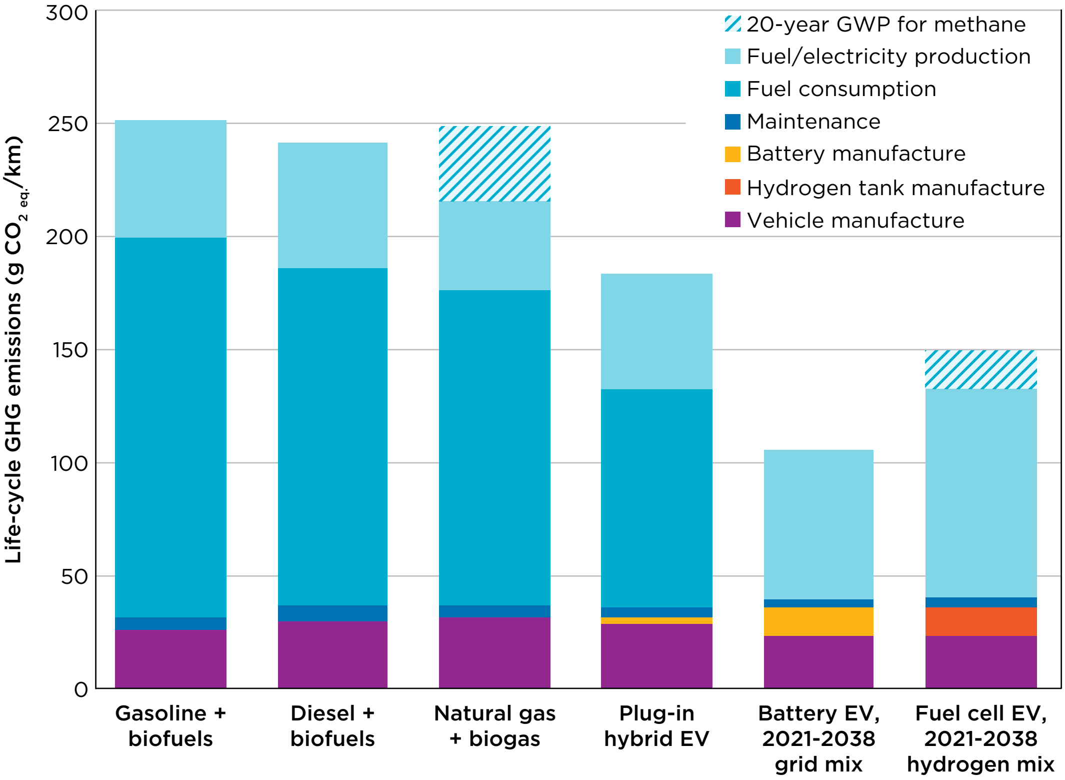

Figure 1. Life-cycle GHG emissions for global typical medium-size passenger cars registered in 2021.

There are clear differences in the GHG performance of different types of cars and fuels when we account for all life-cycle GHG emissions. Diesel, gasoline, and natural gas cars, which we assume use the average mix of fossil fuels, biofuels, and biogas across the key regions, have the highest GHG emissions. In their average real-world usage, plug-in hybrid EVs only reduce GHG emissions slightly. Hydrogen fuel-cell EVs have lower GHG emissions, and battery EVs have the lowest climate impact of any of these pathways. In all cases, the bulk of GHG emissions comes from fuel and electricity production and consumption, with a smaller share from manufacturing vehicles, batteries, and hydrogen tanks, and vehicle maintenance.

The combustion of natural gas releases less CO_2 per unit of energy delivered compared to gasoline and diesel. However, as Figure 1 illustrates, the CO_2 savings from fuel combustion are more than offset by increased methane emissions in the natural gas life cycle, in other words, in production, transportation, storage, and combustion.

The chart incorporates life-cycle emissions of climate pollutants in addition to CO_2, most importantly methane, by converting them to CO_2 equivalents using their 100-year global warming potential (GWP)—that is, the impact of each type of molecule on the greenhouse effect, averaged over a 100-year time frame. This is a standard approach

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[4] International Energy Agency, “World Energy Outlook,” (October 2020), https://www.iea.org/reports/world-energy-outlook-2020

in life-cycle analysis. But it significantly understates the impact of methane and other short-lived climate pollutants, a group of compounds that persist in the atmosphere for much less time than CO_2 (11–14 years, compared to 200 years for CO_2[5], and hence "short-lived") but that molecule-for-molecule exert a much greater warming effect than CO_2 when they are present. Averaged over 100 years, methane's climate impact is 30 times greater than that of CO_2. Averaged over 20 years—another standard metric, termed 20-year GWP—it is 85 times worse than CO_2.[6]

For most types of cars, the amount of methane emitted over their life-cycle is very low, and so the difference between converting methane emissions to CO_2-equivalent using 100-year GWP and 20-year GWP is not significant. But for natural-gas vehicles and fuel-cell vehicles using gas-derived hydrogen the difference is extremely significant.

The hashed areas of the bars representing life-cycle emissions of those vehicles in Figure 1 represent the additional global warming impact of methane when GWP-20 is considered instead of GWP-100, for upstream methane leakage specifically. It is clear that in the near term, natural gas vehicles do not perform any better in climate terms than diesel and gasoline cars. Upstream methane leakage emissions for hydrogen are shown because most hydrogen produced today is made from natural gas.[7]

Battery and fuel-cell electric vehicles

Both battery EVs and hydrogen fuel-cell EVs use electric motors instead of internal combustion engines. Battery EVs power their motors using electricity from batteries, and fuel-cell EVs store hydrogen in a tank and then consume it in fuel-cells to produce electricity. Manufacturing EV batteries and generating electricity to charge them produces some amount of GHGs, but real-world evidence shows that these emissions are not high enough to eliminate the benefit of switching to EVs. Similarly, manufacturing hydrogen tanks for fuel-cell EVs causes GHG emissions, but not enough to offset the climate benefits of this pathway. This is in part due to the fact that battery EV powertrains are 3 times and hydrogen fuel-cell EV powertrains 2 times more efficient than those of internal combustion engine cars.

The results illustrated in Figure 1 reflect the full life-cycle GHG emissions of battery and fuel-cell EVs. For battery EVs, the GHG emissions for "fuel/electricity" production are dominated by the coal and natural gas used in electricity generation; but the total also accounts for the GHG emissions from manufacturing solar panels and wind turbines that produce renewable electrical power to fuel battery EVs, as well as energy losses in electricity transmission and EV charging.

Renewable electricity generates far lower GHG emissions than fossil fuels, and electric grids will become lower carbon as renewable generating capacity grows. A similar

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[5] Gunnar Muyhre et al., "Anthropogenic and Natural Radiative Forcing: Supplementary Material," Intergovernmental Panel on Climate Change, (2013), https://www.ipcc.ch/site/assets/uploads/2018/07/WGI_AR5.Chap_.8_SM.pdf

[6] Intergovernmental Panel on Climate Change, "Climate Change 2013: The Physical Science Basis," Working group I contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change (2013), https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf

[7] Myles R. Allen et al., "Summary for Policymakers" in *An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, eds. Valérie Masson-Delmotte et al., (Intergovernmental Panel on Climate Change, 2018), https://www.ipcc.ch/sr15/.

trend can be seen for hydrogen. Most hydrogen is currently made from natural gas,[8] and this production process emits essentially the same amount of CO_2 as if the natural gas were combusted directly in the car. Hydrogen fuel-cell EVs will only deliver climate benefits compared to gasoline and diesel if produced from cleaner energy sources. GHG emissions from hydrogen production will likely decline as policies promote the pairing of carbon capture and storage (CCS) with hydrogen production from natural gas, and the use of renewable electricity directly for hydrogen generation through electrolysis. Our analysis accounts for these shifts, assuming the ambitious renewable energy policies that would be necessary to meet the goals of the Paris Agreement.[9] Still, fuel-cell vehicles powered by electricity use 3 times more electricity per kilometer driven than battery EVs. This presents an important consideration in the short-to-medium term while renewable electricity supply remains scarce. For battery and hydrogen fuel-cell EVs registered in the year 2021, Figure 1 includes the effect of the gradual "greening" of global electricity and hydrogen production over the period 2021–2038 on the GHG emissions of battery and fuel-cell EVs over their lifetime. While both battery EVs and hydrogen fuel-cell EVs have much lower life-cycle GHG emissions than conventional cars, battery EVs have the best climate performance. Our findings support and add to a growing body of literature on the climate benefits of EVs compared to gasoline, diesel, and natural gas cars.[10]

Future performance

The effect of rising renewable energy penetration becomes more pronounced in the lifetime climate performance of cars registered in the year 2030, reflecting kilometers driven from 2030–2047. As shown in Figure 2, the life-cycle GHG emissions of both battery and hydrogen fuel-cell EVs are much lower for 2030 cars than 2021 cars. The GHG emissions of gasoline, diesel, and natural gas cars, on the other hand, are almost identical. The relative benefit of driving EVs compared to gasoline, diesel, and natural gas cars grows over time.

When 100% renewable electricity is used to power battery EVs and create the hydrogen for fuel-cell EVs, the climate benefits of these powertrains increase further. Figure 2 shows that the GHG emissions from the cleanest battery and hydrogen fuel-cell EV pathways, using only renewable energy, are only 18%–22% that of gasoline and diesel cars. This scenario represents the energy system we will need in 2050 to avoid the worst impacts of the climate crisis. Because passenger car lifetimes are generally 15–18 years, a transition to fully or heavily electric car sales will be necessary by around 2030 in order to significantly decarbonize cars by 2050. *While long vehicle lifetimes mean that EVs sold over the coming decade can benefit from a "greening" grid, it also translates to urgency for the EV transition in new vehicle sales*.

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[8] International Energy Agency, "The Future of Hydrogen," (June 2019), https://www.iea.org/reports/the-future-of-hydrogen

[9] International Energy Agency, "World Energy Outlook 2020," (2020), https://www.iea.org/reports/world-energy-outlook-2020

[10] For example: Nikolas Hill et al., *Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA*, (European Commission: Brussels, Belgium, July 2020), https://op.europa.eu/en/publication-detail/-/publication/1f494180-bc0e-11ea-811c-01aa75ed71a1; Transport and Environment, *How clean are electric cars? T&E's analysis of electric car lifecycle CO_2 emissions*, (April 2020), https://www.transportenvironment.org/sites/te/files/downloads/T%26E%E2%80%99s%20EV%20life%20cycle%20analysis%20LCA.pdf

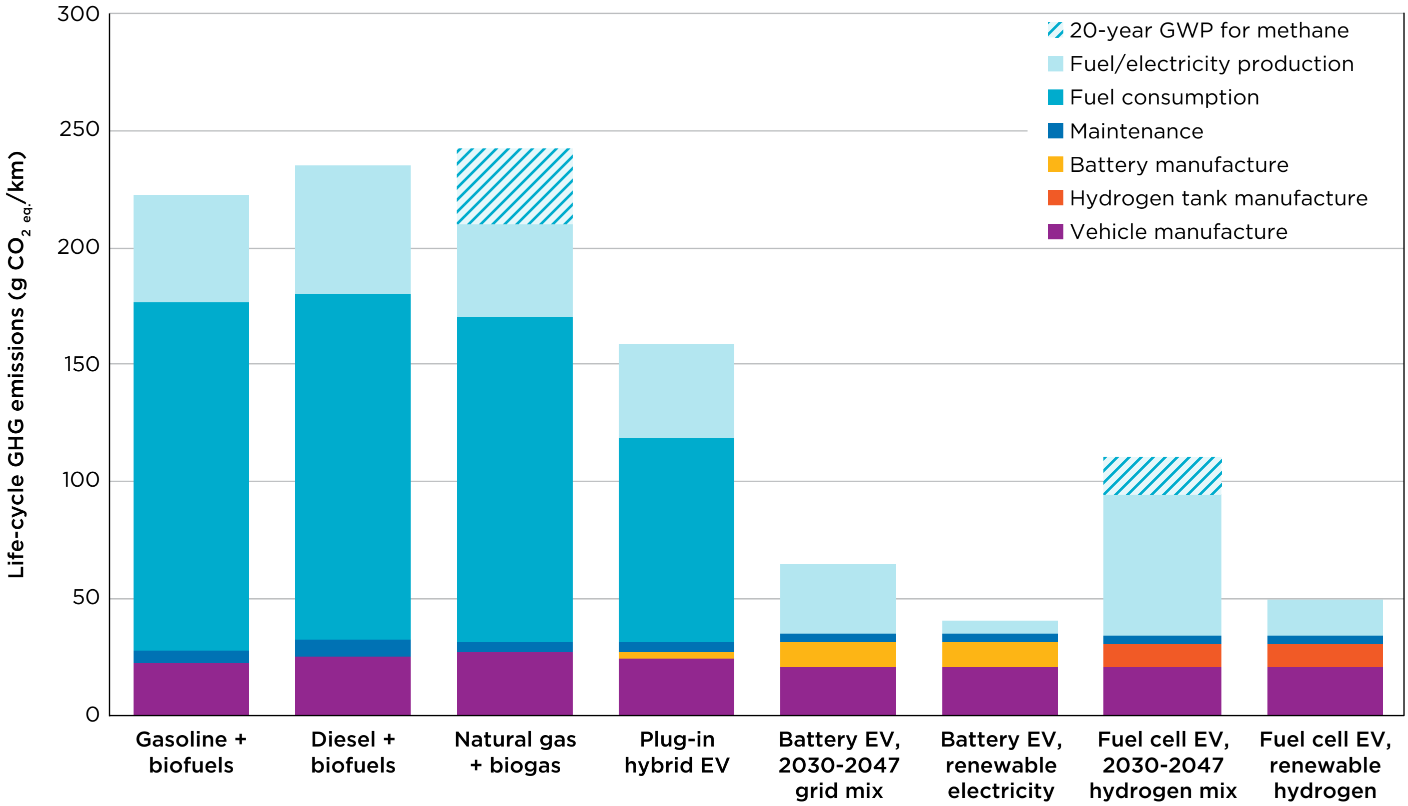

Figure 2. Life-cycle GHG emissions for global typical medium-size passenger cars registered in 2030.

Regional comparison

The GHG performance of vehicles varies geographically. Figure 3 shows the life-cycle GHG emissions of gasoline and battery-electric cars in the 4 key regions in our analysis: China, Europe (the European Union and United Kingdom), India, and the United States. For each region, the dark bars show GHG emissions of cars registered in 2030 and the lighter colors show the higher GHG emissions of cars sold in 2021. In the EU and U.S., which have relatively low-GHG electricity grids, the climate benefit of battery EVs compared to gasoline cars is large. China and India rely more heavily on coal in electricity generation, but even in these countries, battery EVs offer a clear climate benefit compared to gasoline cars. In all regions, the GHG emission benefits of battery EVs increase over time.

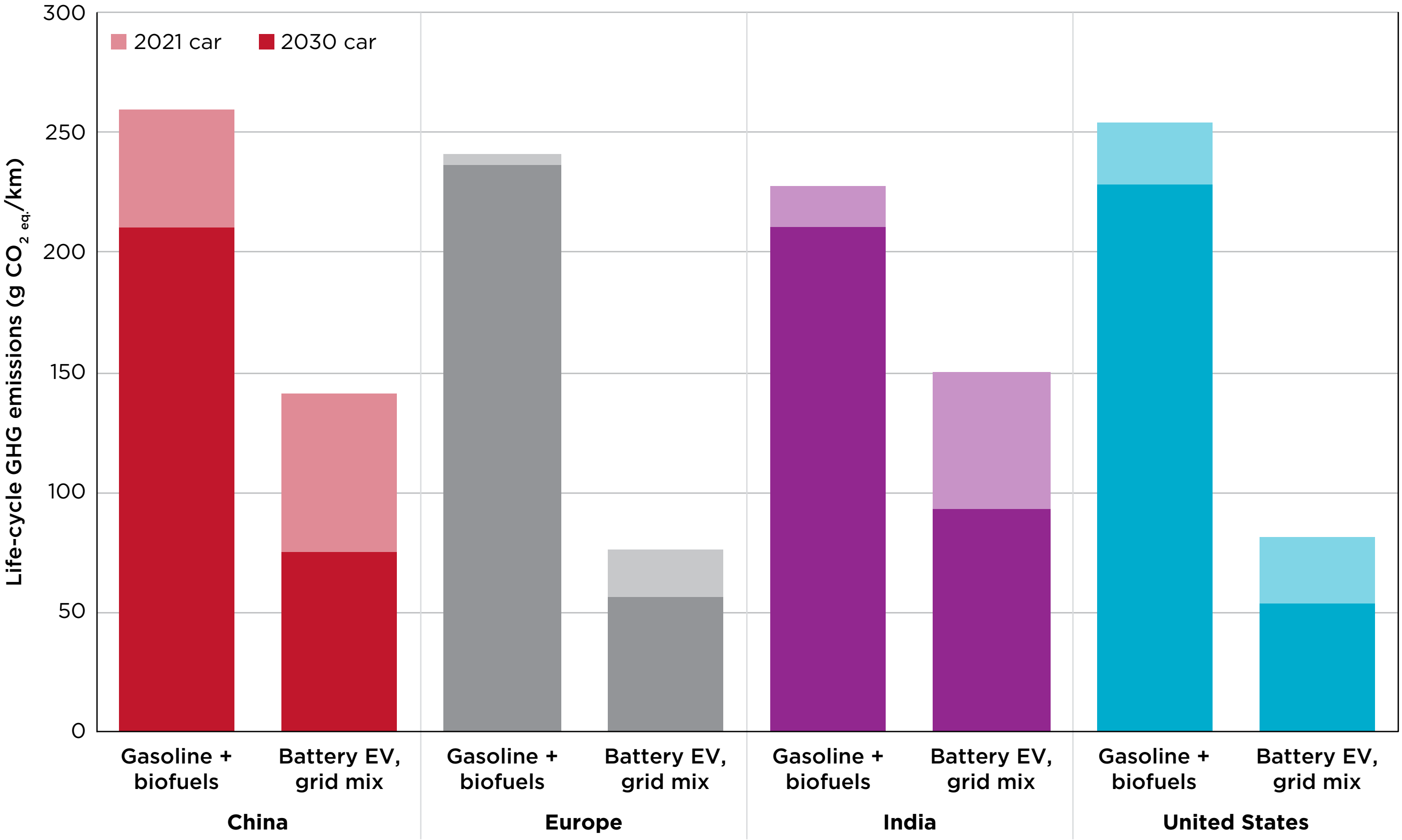

Figure 3. Life-cycle GHG emissions for medium-size gasoline and battery-electric passenger cars registered in 2021 and 2030 in China, Europe, India, and the United States.

Plug-in hybrids

Battery EVs deliver large GHG reductions compared to gasoline and diesel cars. Plug-in hybrid EVs do not. Plug-in hybrids are cars with both electric motors (powered by a battery and electric charging) and internal combustion engines (fueled by gasoline). Plug-in hybrids have the ability to operate in a mostly, although usually not entirely, electric drive mode. However, in practice drivers tend not to operate plug-in hybrids on electricity nearly as much as they could feasibly do, but instead use the gasoline engine for around half the vehicle miles traveled.[11] Plug-in hybrids are better for the climate than conventional gasoline cars, but given current driving behavior, they are not a very low-GHG solution.

Biofuels

The role of biofuels in transport decarbonization is complicated. Biofuels are any kind of fuel made from plant or animal material. Examples include corn ethanol and palm biodiesel. Biofuels can reduce life-cycle GHG emissions compared to petroleum because the carbon that is emitted from their combustion was previously sequestered from the atmosphere in the plants from which the biofuel was made. There are, however, other sources of GHG emissions along the life cycle of biofuels. These come from cultivating, harvesting, and transporting the feedstock and producing and transporting the biofuel. Much of that activity relies in practice on fossil fuels.

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[11] Patrick Plötz et al., *Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving, and CO_2 emissions*, (Fraunhofer ISI and ICCT: Berlin, Germany, 2020), https://theicct.org/publications/phev-real-world-usage-sept2020

Most biofuels today are produced from crops such as corn, soybeans, and palm oil, and using these crops for biofuels also causes significant GHG emissions from land use change. The diversion of crops from agricultural markets to produce biofuel leaves a mismatch between supply and demand for food and other uses, and this inevitably leads to agricultural expansion on to forest and other natural lands. When the GHG emissions from deforestation and other land use impacts are taken into account, it is not clear that food-based biofuels are any better for the climate than petroleum.

Figure 4 shows the range of life-cycle GHG intensity estimates for major biofuel pathways according to regulatory analyses in the European Union and United States. The bottom of each floating column represents the lowest regulatory estimate for total life-cycle GHG emissions for each biofuel pathway, and the top of the column represents the highest estimate. The dotted line represents the life-cycle GHG emissions for a global typical gasoline or diesel fuel for comparison. Some regulatory analyses have found that soy and palm biodiesel increase GHG emissions compared to fossil fuels, and at least one analysis concluded that corn ethanol has about the same GHG intensity as conventional gasoline. The very large ranges in GHG intensity estimates for these feedstocks derive in part from regional differences in crop and biofuel production, but are mostly due to the unavoidable uncertainty in predicting global land use responses to biofuel demand. At best, food-based biofuels can reduce GHG emissions by around half compared to fossil fuels. At worst they can double or triple fossil-fuel emissions.

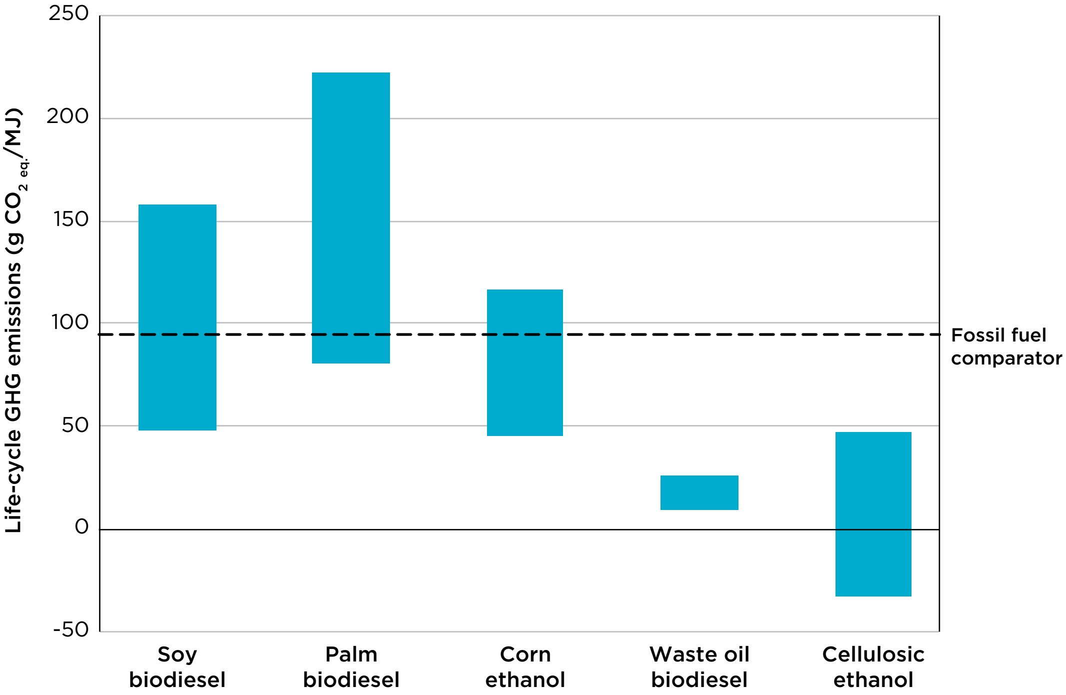

Figure 4. Life-cycle GHG emissions for biofuels. From Jane O'Malley et al. (ICCT: Washington, D.C., forthcoming 2021)

The overall impact of biofuels on transportation GHG emissions is slight because they are typically blended into gasoline and diesel at a rate of 10% or less. Typical blending rates of biofuels are incorporated into the diesel and gasoline car scenarios in Figures 1–3. The comparison of vehicle and fuel technologies in this study thus accounts for the GHG reduction or increase associated with biofuel blending in the diesel and gasoline pathways. We also include a forward projection of how the biofuel mix will change according to stated policies that will increase the share of cellulosic biofuels in particular. Figure 4 shows that cellulosic biofuels have much lower life-cycle GHG emissions than food-based biofuels and can potentially even be negative-carbon, meaning that just the production of these biofuels delivers climate benefits, even before considering avoided petroleum use.

Cellulosic biofuels are promising from a climate perspective, but cannot deliver deep decarbonization for the transport sector on their own because there are limited resources for producing sustainable biomass.[12] Biofuels production from waste oils, another low-GHG pathway, are even more constrained by feedstock supply.[13] The same is true for low-GHG biogas produced from wastes like sewage and manure.[14] In future decades, the demand for low-GHG biofuels and e-fuels from sectors that are harder to decarbonize, particularly aviation, will likely limit the availability of biofuels for road vehicles.[15]

E-fuels

Although e-fuels provide another opportunity for decarbonizing the gasoline and diesel supply for conventional cars, as with biofuels, their supply will likely remain very limited. E-fuels are made by producing hydrogen from electrolysis, ideally using renewable electricity, and combining it with CO_2 from industrial waste streams or direct air capture. This process results in liquid or gaseous fuels that can theoretically be used at blends up to 100% in conventional diesel and gasoline cars.

E-fuels are much more expensive to produce than biofuels. For example, our previous study estimated that they could cost more than 3 euros per liter at the pump in Europe in the 2030 time frame.[16] The main reason is that the production process is inherently inefficient; approximately half of the energy in the input electricity is lost during conversion. Furthermore, in contrast to hydrogen, e-fuels are combusted at very low efficiency in internal combustion engines. The end result is very high overall energy use on this transportation pathway. Combined with the necessary and high capital expenses of the electrolyzers and fuel synthesis equipment needed to produce e-fuels, the high electricity consumption leads to unavoidably high costs.[17] Because of the high cost, we do not include any e-fuel blending in the diesel and gasoline scenarios in our life-cycle analysis. While e-fuels can theoretically be used at up to 100% blends in conventional cars and can be very low-GHG if produced entirely from new renewable electricity, it seems unlikely that they will be a significant part of a global transport decarbonization strategy, given the high costs compared to EVs.

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[12] Stephanie Searle and Chris Malins, “A Reassessment of Global Bioenergy Potential in 2050.” *Global Change Biology: Bioenergy* 7, no. 2 (March 2015): 328–336. https://doi.org/10.1111/gcbb.12141

[13] Vasu R. Vasuthewan, *Waste-based feedstock for the global biofuel market*, (Eco Oils: Singapore, 2017), https://www.iscc-system.org/wp-content/uploads/2017/04/7.-Vasuthewan_EcoOils_ISCC_PRIMA_Conference_060417.pdf

[14] Stephanie Searle, Chelsea Baldino, Nikita Pavlenko, *What is the role for renewable methane in European decarbonization?*, (ICCT: Berlin, Germany, 2018), https://theicct.org/publications/role-renewable-methane-eu

[15] Energy Transitions Commission, *Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century*, (November 2018), https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-HeavyRoadTransport_final.pdf

[16] Stephanie Searle and Adam Christensen, *Decarbonization potential of electrofuels in the European Union*, (ICCT: Berlin, Germany, 2018), https://theicct.org/publications/decarbonization-potential-electrofuels-eu

[17] Ibid.

With the cost and supply barriers to low-GHG biofuels and e-fuels, it is inevitable that internal combustion engine vehicles will continue to predominantly consume fossil fuels for the foreseeable future.

Implications for heavy-duty vehicles

While this briefing does not directly address heavy-duty vehicles such as trucks and buses, the main conclusions also apply to that sector. First, only battery and fuel-cell electric technologies can substantially decarbonize heavy-duty vehicles. Studies have found that battery and hydrogen fuel-cell electric trucks can dramatically reduce life-cycle GHG emissions compared to conventional or hybrid diesel trucks and natural gas trucks.[18] One key difference between passenger cars and heavy-duty vehicles is that the latter tend to be driven farther over their lifetimes. This means that their lifetime GHG emissions will be weighted more heavily toward the fuel they consume, and the vehicle and battery manufacturing emissions will be spread out over more kilometers. This difference makes it likely that the GHG emission savings of passenger car EVs compared to diesel, gasoline, and natural gas cars will be even greater in trucks and buses.[19] Second, when considering the high methane leakage emissions, liquefied natural gas (LNG)-powered heavy duty vehicles do not offer a GHG emission benefit over diesel vehicles.[20] Third, low-GHG biofuels and e-fuels cannot substantially reduce the life-cycle GHG emissions of diesel and natural gas internal combustion vehicles, as the supply of these low-GHG fuels will likely be limited for heavy-duty vehicles just as for passenger cars. Fourth, as with passenger cars, the climate performance of electric-drive buses and trucks will continue to improve as the electricity grid and hydrogen production grow greener in the coming years. That heavy-duty vehicles tend to have longer lifetimes than passenger cars adds even greater urgency to beginning the transition to electric buses and trucks. Battery and fuel-cell electric heavy-duty vehicle models have already started to enter the global market, and only if heavy-duty vehicles sharply shift to electric in the coming decade will it be possible to fully decarbonize this sector by mid-century.

Conclusions

Decarbonizing the transportation sector is imperative if we are to avoid the worst impacts of the climate crisis. It is also a deeply challenging task that will require rapid adaptation and change. Because of the long lifetime of vehicles, it is urgent to immediately begin the transition to those capable of delivering deep GHG reductions. To that end, this briefing identifies very low-GHG passenger vehicle and fuel pathways. To summarize the key points:

- **Only battery and hydrogen fuel-cell EVs have the potential to be very low-GHG passenger vehicle pathways.** The GHG emissions from manufacturing batteries,

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[18] Burak Sen, Tolga Ercan, Omer Tatari, "Does a Battery-Electric Truck Make a Difference? Life Cycle Emissions, Costs, and Eternality Analysis of Alternative Fuel-Powered Class 8 Heavy-duty Trucks in the United States." *Journal of Cleaner Production* 141 (2017): 110–121. https://doi.org/10.1016/j.jclepro.2016.09.046; Marissa Moutak, Nic Lutsey, Dale Hall, *Transitioning to zero-emission heavy-duty freight vehicles*, (ICCT: Washington, D.C., 2017), https://theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[19] Hill et al., *Determining the environmental impacts*.

[20] Moritz Mottschall, Peter Kasten, Felipe Rodriguez, *Decarbonization of on-road freight transport and the role of LNG from a German perspective*, (ICCT: Berlin, Germany, 2020), https://theicct.org/publications/on-road-freight-lgn-germany

solar panels, and wind turbines are more than outweighed by the GHG savings from the greater efficiency and cleaner energy supply of EVs compared to conventional vehicles. This is likely true for buses and trucks, as well.

- **There is no realistic pathway to full decarbonization of internal combustion engine vehicles.** Biofuels and other alternative fuels for conventional cars do not necessarily reduce GHG emissions compared to gasoline and diesel. Natural gas vehicles do not offer climate benefits over diesel and gasoline, especially when considering the short-term warming impacts of methane. The supply of genuinely low-GHG biofuels, biogas, and e-fuels will not be sufficient to replace liquid fuel demand in the road sector. While plug-in hybrid EVs can partly operate on electricity, in practice drivers still rely heavily on the gasoline engine.
- **The GHG performance of EVs will continue to improve.** The proportion of renewables in the electricity mix is increasing globally, and in many countries the hydrogen supply will become lower-GHG, as well. Battery and hydrogen fuel-cell EVs sold in 2030 will reduce GHG emissions by 70% and 60%, respectively, compared to conventional cars over their lifetime.
- **The transition to EVs is urgent.** Tackling the climate crisis requires significant efforts toward a zero-GHG economy by mid-century. Because of long vehicle lifetimes, new passenger car sales must be heavily electric by 2030 in order to achieve deep decarbonization of the transport sector by 2050. This is even more important for longer-living buses and trucks.

Appendix: Key assumptions

Table A1. Average real-world fuel and electricity consumption of new medium-size passenger cars with different powertrain types registered in China, Europe (EU27+UK), India and the United States in 2021 and in 2030, and a car sales-weighted “global” average of these regions.

		Gasoline car	Diesel car	Natural gas car	Plug-in hybrid EV		Battery EV	Fuel-cell EV
		L/100 km	L/100 km	kg/100 km	L/100 km	kWh/100 km	kWh/100 km	kg/100 km
China	**2021 car**	7.9	—	—	5.8	4.1	20.4	1.0
	2030 car	6.3	—	—	5.2	5.7	14.3	1.0
Europe	**2021 car**	7.2	6.0	5.2	4.1	12.1	20.6	1.0
	2030 car	7.2	6.0	5.2	3.7	13.3	20.6	1.0
India	**2021 car**	6.8	6.0	5.0	—	—	19.2	1.0
	2030 car	6.8	6.0	5.0	—	—	19.2	1.0
United States	**2021 car**	7.8	—	—	2.5	10.6	17.3	0.9
	2030 car	7.0	—	—	2.3	11.7	17.3	0.9
Global average	**2021 car**	7.6	6.0	5.1	4.3	8.5	19.5	1.0
	2030 car	6.8	6.0	5.1	3.9	9.8	17.2	1.0

Table A2. Life-cycle GHG emissions (100-year GWP, in g $CO_{2\,eq.}$/MJ) of the average fossil and biogenic gasoline, diesel, and natural gas blends, grid electricity, and hydrogen mix in China, Europe (EU27+UK), India, and the United States during the 15–18 year lifetime of cars registered in 2021 and in 2030, and a car sales-weighted “global” average of these regions. Values for gasoline, diesel, and natural gas are shown as (production emissions) + (consumption emissions).

g $CO_{2\,eq.}$/ MJ		Gasoline (including biofuels)	Diesel (including biofuels)	Natural gas (including biogas)	Average grid electricity	Hydrogen mix
China	**2021–2035**	21.8 + 70.9	—	—	141.4	107.8
	2030–2044	21.8 + 70.9	—	—	79.1	73.2
Europe	**2021–2038**	21.5 + 70.9	27.4 + 68.4	16.5 + 58.6	45.6	50.4
	2030–2047	21.4 + 70.9	26.7 + 68.4	16.5 + 58.6	26.7	19.7
India	**2021–2038**	20.5 + 69.2	21.8 + 71.8	19.2 + 57.7	155.9	84.4
	2030–2047	20.2 + 65.4	21.7 + 70.1	19.6 + 55.3	72.0	65.7
United States	**2021–2035**	22.2 + 69.7	—	—	66.5	64.3
	2030–2044	22.2 + 69.7	—	—	31.3	49.8
Global average	**2021 car**	21.8 + 70.5	26.6 + 68.9	16.9 + 58.5	93.2	77.8
	2030 car	21.7 + 70.3	26.0 + 68.7	17.0 + 58.1	50.0	50.8

Table A3. GHG emissions (100-year GWP, in t $CO_{2\ eq.}$) of the manufacture of the battery, hydrogen (H_2) tank, and the rest of the vehicle (including recycling) of average new medium-size passenger cars of different powertrain types registered in China, Europe (EU27+UK), India, and the United States in 2021 and in 2030, and a car sales-weighted "global" average of these regions.

t $CO_{2\ eq.}$		Gasoline car	Diesel car	Natural gas car	Plug-in hybrid EV		Battery EV		Fuel-cell EV	
		Vehicle	Vehicle	Vehicle	Vehicle	Battery	Vehicle	Battery	Vehicle	H_2 tank
China	**2021 car**	6.7	—	—	7.3	0.6	6.0	3.6	6.0	3.4
	2030 car	5.7	—	—	6.2	0.6	5.1	3.5	5.1	2.7
Europe	**2021 car**	7.2	7.2	7.6	7.9	0.6	6.5	2.7	6.5	3.4
	2030 car	6.1	6.1	6.5	6.7	0.5	5.5	2.3	5.5	2.7
India	**2021 car**	5.2	5.2	5.5	—	—	4.7	1.6	4.7	3.4
	2030 car	4.4	4.4	4.7	—	—	4.0	2.5	4.0	2.7
United States	**2021 car**	8.3	—	—	9.1	1.0	7.5	4.2	7.5	3.4
	2030 car	7.1	—	—	7.7	0.9	6.4	3.7	6.4	2.7
Global average	**2021 car**	7.2	6.9	7.3	8.0	0.7	6.5	3.4	6.5	3.4
	2030 car	6.2	5.8	6.2	6.8	0.7	5.5	3.2	5.5	2.7

FOR MORE INFORMATION

Find the methodology, more data, and references in Georg Bieker, *A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars*, (ICCT: Berlin, Germany, 2021), https://theicct.org/publications/global-LCA-passenger-cars-Jul2021.