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Assessing the potential advanced alternative fuel volumes in Germany in 2030

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Introduction

As part of its overall decarbonization strategy, the European Union (EU) updated its Renewable Energy Directive (RED) to increase the share of renewable and low-carbon energy consumed by its member states by 2030. The updated Directive (RED II), establishes a 27% renewable energy target for 2030 along with a 14% sub-target for renewable energy consumption in road and rail transport to be met by fuel suppliers.[1] The sub-target of 0.5% advanced biofuels by 2020 established by RED was expanded in RED II to a 3.5% target by 2030. The RED limits on the contribution of feedstocks made from food crops to the overall transport target will be extended to 2030, and stricter limits are imposed on the contribution of high indirect land-use change (ILUC)-risk feedstocks.

The recast RED II includes specific requirements for crediting fuels towards the transport target. Advanced biofuels double-count towards the 3.5% sub-target but can only come from a list of approved feedstocks listed in Annex IX of the Directive. Contributions from list A of the Annex are uncapped, and include a mix of lignocellulosic energy crops, wastes, and residues. The contribution from List B is capped to 1.7% of the overall target and includes advanced biofuel feedstocks that can be converted using commercial technology, including used cooking oil and animal fats. Renewable electricity supplied to the road and rail sectors can also count towards the 14% target, and receive credit multipliers of 4 and 1.5, respectively.

As a Directive, these targets must be transposed into national legislation by member states, though each member state has some discretion on how to design its policies and incentive structures so that the broad requirements of the Directive are met. Germany may utilize a number of possible policy structures to meet the targets and requirements in the RED II. Germany has already implemented a carbon pricing mechanism within its fuels policy to facilitate the deployment of lower-carbon transport fuels and transition away from the highest-pollutant-emitting fuels. Germany also currently has in place a greenhouse gas (GHG) quota, requiring a reduction in the GHG intensity of the road fuel mix by 6% by 2025. There is a non-compliance penalty of €470 per tonne of CO_2e of GHG savings not achieved, which implies fuel suppliers should be willing to pay up to €470 per tonne of CO_2e reduction for alternative fuels in order to avoid paying the penalty price. In addition, Germany's sub-target for advanced biofuels will increase to 0.5% of the transport fuel mix by 2025.[2] In order to meet the new targets in RED II, it is possible that Germany will reconsider its current set of biofuel policies, potentially extending and increasing its targets to 2030 or introducing new policy measures.

This working paper aims to estimate the volumes of advanced, non-food-based fuels that could potentially be produced in Germany over the 2021-2030 period in order to inform policymaking. We evaluate the production cost, feedstock availability, and potential facility deployment

1 Directive (EU) 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast), Official Journal of the European Union, L 328/82, December 11, 2018 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

2 Achtunddreißigste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung zur Festlegung weiterer Bestimmungen zur Treibhausgasminderung bei Kraftstoffen - 38. BImSchV). [Thirty-eighth Ordinance on the Implementation of the Federal Pollution Control Act (Ordinance laying down further provisions on the reduction of greenhouse gases in the case of fuels - 38th BImSchV)), Bundesministerium der Justiz und für Verbraucherschutz, December 8, 2017, https://www.gesetze-iminternet.de/bimschv_38_2017/BJNR389200017.html.

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for a variety of advanced, non-food-based fuel pathways with varying levels of policy support. In addition, we project the possible advanced fuel volumes that could be delivered by the implied value of the non-compliance penalty in Germany's existing GHG quota.

Table 1. Summary of Fuel Conversion Pathways & RED II Crediting for this Analysis

Technology	Feedstock	Sub-target	Multiple counting
Cellulosic Ethanol	Agricultural residues	Annex IX, List A	2x
	Energy crops and wood		
Biodiesel and hydrotreated renewable diesel	Used cooking oil	Annex IX, List B	
	Tall oil	Annex IX, List A	
Synthetic diesel (gasification and Fischer-Tropsch)	Agricultural residues		
	Energy crops and wood		
	Forestry residues		
	Black liquor		
	Municipal solid waste		
Electrolysis and fuel synthesis	Renewable electricity	N/A	N/A
Flue gas fermentation	Industrial flue gas	N/A	N/A
Electricity in road sector	Renewable electricity	N/A	4x
Electricity in rail	Renewable electricity	N/A	1.5x
Biomethane	Livestock manure and Sewage Sludge	Annex IX, List A	2x

Note: N/A = not applicable

Methodology

PATHWAYS AND SCENARIOS

This analysis only includes alternative fuels that could be produced from feedstocks available within Germany. Apart from used cooking oil, Germany is producing very low volumes of advanced biofuels. The alternative fuel pathways included in this assessment are based on the list of eligible fuels and feedstocks in the RED II, and are those we believe are most likely to deliver significant volumes of fuel in the EU in the 2030 timeframe. Table 1 lists the pathways and technologies studied, as well as the crediting that each fuel pathway receives relative to the targets in the RED II.

This study estimates potential fuel volumes in three general policy scenarios, as well as the implied financial value from avoiding penalties in Germany's current GHG quota:

- Low policy support (€0.50 per diesel-equivalent liter)
- Medium policy support (€1.00 per diesel-equivalent liter)
- High policy support (€2.00 per diesel-equivalent liter)
- The non-compliance penalty of €470 per tonne of CO_2e of GHG savings not achieved in Germany's current GHG quota

The analysis implicitly assumes that the policy support is provided in a stable, long-term, predictable manner that allows investors to reasonably assume support will be provided over the entire period 2021-2030. For example, the high policy support scenario reflects a simple €2.00 per liter subsidy for the entire 2021-2030 timeframe without any need for re-authorization by policymakers. In reality, most policy measures are not as stable and predictable as this example and tend to be discounted by investors in alternative fuel facilities.[3] In addition, the incentive provided by Germany's GHG quota non-compliance penalty is likely substantially weakened by the eligibility of first-generation fuels for the same policy target. This is discussed in more detail below.

OVERALL METHODOLOGICAL APPROACH

This analysis utilizes feedstock availability, blending constraints, and technology readiness as the primary constraining factors on advanced alternative fuel production in the 2030 timeframe. We evaluate the impact of each factor on the overall production of each of the fuel pathways listed in Table 3, estimating the total 2030 production based on these constraints.

The potential production volumes and GHG performance for electrofuels, such as power-to-liquids and power-to-gas, and biomethane are taken from Searle and Christensen[4] and Baldino et al.[5], which use a similar cost-constrained production methodology.

VEHICLE ELECTRIFICATION

To assess the contribution of electric vehicles (EVs) towards the RED II targets, we utilize the light-duty vehicle fleet turnover model developed by

3 Nikita Pavlenko, Stephanie Searle, Chris Malins, and Sammy El Takriti, *Development and Analysis of a Durable Low-Carbon Fuel Investment Policy for California,* (ICCT: Washington, DC, 2016), https://www.theicct.org/sites/default/files/publications/California%20Contracts%20for%20Difference_white-paper_ICCT_102016.pdf

4 Stephanie Searle and Adam Christensen, *Decarbonization Potential of Electrofuels in the European Union,* (ICCT: Washington, DC. 2018), https://theicct.org/sites/default/files/publications/Electrofuels_Decarbonization_EU_20180920.pdf

5 Chelsea Baldino, Nikita Pavlenko, Stephanie Searle, and Adam Christensen, *The Potential for Low-Carbon Renewable Methane in Heating, Power and Transportation in the European Union,* (ICCT: Washington, DC 2018), https://theicct.org/sites/default/files/publications/Renewable_Gas_EU-28_20181016.pdf

Lutsey in conjunction with Germany's proposed EV sales targets for 2030.[6] The turnover model assumes a steady increase to 6 million cumulative sales in Germany by 2030, using separate efficiency and vehicle-kilometers-travelled assumptions for each model year.[7] We project that the passenger EV electricity consumption will total 14.1 billion kWh in 2030. Because only energy from renewable sources is counted towards the RED II targets, we use Germany's political intension of 65% renewable electricity target for the renewable share of EV charging.[8] The uncertainty around the government's ability to achieve this level of renewable deployment, in conjunction with the quadruple counting of electric vehicle charging under the RED II, may greatly impact Germany's compliance with the overall 14% transport target.

To estimate the potential contribution of renewable electricity to the rail sector, we utilize the EU reference scenario to project the total rail energy demand from 2020 to 2030.[9] From there, we estimate the share of rail energy demand to be supplied by electricity based on the International Energy Agency's base case scenario for the EU in its *Future of Rail* report.[10] Under these assumptions, the share of rail sector energy supplied by electricity increases to 81% by 2030. Germany's stated 65% renewable electricity target and the 1.5x multiplier is utilized to estimate the share of electricity to be met with renewables which count towards the RED II's 14% transport energy target.

BLEND LIMITS

To estimate the total availability of advanced alternative fuels in Germany, we assume that advanced biofuel pathways, such as cellulosic ethanol, take precedence over other biofuel pathways (e.g. grain ethanol) when considering biofuel blend limits, although this may not necessarily be true in practice. We also do not factor in the blending of food-based fuels on blending constraints. To estimate the baseline sectoral energy demand, we draw upon the projections for total road fuel demand, gasoline blend demand, and diesel blend demand from the 2016 EU Reference Scenario.[11]

We assume a blend limit of 7% biodiesel in diesel; however, the two eligible feedstocks in this analysis that might commonly be used to produce fatty acid methyl ester (FAME) biodiesel—used cooking oil and animal fats—can instead be processed into hydrotreated renewable diesel, a drop-in fuel that effectively has no blending limit. Therefore, we do not anticipate that diesel blending limits will pose a constraint for advanced alternative fuels.

Ethanol can be supplied and consumed either at low blends in most conventional fueling stations and vehicles, or at higher blends (E85) in compatible fueling equipment and vehicles. We assume that 2% of the total amount of gasoline blend supplied is E85,[12] and that E85 is 75% ethanol content on average. We assume that the remainder of gasoline blends supplied contain up to 10% ethanol. The overall potential blend rate of ethanol in gasoline is thus approximately 11%.

COST ASSESSMENT

We assume that alternative fuels will be supplied only if they can be produced at a comparable levelized cost to the untaxed price of conventional, petroleum-derived fuels after taking into account the four levels of fiscal incentives. Feedstocks that can be converted into fuel using existing commercial scale technologies, such as transesterification to produce biodiesel or hydrotreating to produce renewable diesel, are assumed to be viable at the lowest incentive level, as they are supported today through existing incentives. For advanced fuel pathways with few, or no, existing commercial-scale facilities, we utilize a techno-economic assessment approach to estimate the costs for producing those fuels on a diesel liter-equivalent basis. The cost modeling for this assessment is performed

6 Nic Lutsey, *Global Climate Change Mitigation Potential from a Transition to Electric Vehicles,* (ICCT: Washington, DC, 2015), http://theicct.org/global-ev-2050-ghg-mitigation-potential

7 Bundesministerium für umwelt, naturschutz, Bau und reaktorsicherheit (BMuB) [Federal Minister for the Environment, Nature Conservation, and Nuclear Safety], The German government's climate action Programme 2020, (2014), http://www.bmub.bund. de/fileadmin/Daten_BMu/Pools/Broschueren/aktionsprogramm_klimaschutz_2020_ broschuere_en_bf.pdf

8 Christlich Demokratische Union Deutschlands (CDU), Christlich-Soziale Union in Bayern (CSU), and Sozialdemokratische Partei Deutschlands (SPD), *Ergebnisse der Sondierungsgespräche: Finale Fassung* [Results of the exploratory talks: Final Version], (2018), Retrieved from the CDU: https://www.cdu.de/artikel/ergebnisse-der-sondierungsgespraeche-von-cdu-csu-und-spd

9 Capros P, De Vita A, Tasios N, Siskos P, Kannavou M, Petropoulos A, Evangelopoulou S, Zampara M, et al., *EU Reference Scenario 2016 - Energy, transport and GHG emissions Trends to 2050.* (European Commission Directorate - General for Energy, Directorate - General for Climate Action and Directorate - General for Mobility and Transport: Luxembourg, 2016).

10 International Energy Agency, Future of Rail, (2019), https://www.iea.org/futureofrail/

11 Capros P, De Vita A, Tasios N, Siskos P, Kannavou M, Petropoulos A, Evangelopoulou S, Zampara M, et al. *EU Reference Scenario 2016 - Energy, transport and GHG emissions Trends to 2050.* (European Commission Directorate - General for Energy, Directorate - General for Climate Action and Directorate - General for Mobility and Transport: Luxembourg, 2016).

12 We use the US as an example, where approximately 2% of fueling stations offer E85; U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Alternative Fuels Data Center (AFDC), Alternative Fueling Station Locator, (2019), https://afdc.energy.gov/stations/#/analyze?fuel=E85

Table 2. Per-liter prices for select advanced biofuel pathways developed via the cashflow model (€ per diesel-equivalent liter)

Feedstock	Synthetic diesel cost	Conventional diesel price[a]	Difference (necessary support)	Cellulosic ethanol	Conventional petrol price[a]	Difference (necessary support)
Cellulosic energy crops	€ 2.28	€ 0.58	**€ 1.70**	€ 1.62	€ 0.62	**€ 1.01**
Agricultural residues	€ 2.37		**€ 1.79**	€ 1.56		**€ 0.94**
Forest residues	€ 1.82		**€ 1.25**	N/A	N/A	N/A
Black liquor	€ 1.82		**€ 1.25**	N/A	N/A	N/A
Municipal solid waste	€ 1.43		**€ 0.85**	N/A	N/A	N/A

[a] Conventional diesel and petrol prices are taken from European Environment Agency (EEA), "Oil Bulletin Prices History," https://www.eea.europa.eu/data-and-maps/data/external/oil-bulletin

using data on the capital costs of second-generation biofuel production facilities from Peters et al.[13] and Yao et al.[14] in conjunction with the cashflow modeling approach developed by Pavlenko et al.[15] The prices are compared to the untaxed retail price of diesel and petrol in Germany, averaged over the last 2 years, to estimate the additional financial incentive necessary to achieve cost parity.[16]

Due to the relatively early state of commercial development and high expected costs, we do not include fast pyrolysis facilities in this assessment.[17] Fuel prices are estimated for several different feedstocks ranging in value from agricultural residues to municipal solid waste (MSW). To estimate the level of policy support necessary for a given fuel-feedstock pathway, we subtract the baseline diesel or petrol price from the minimum viable per-liter price estimated via the cashflow model. The feedstock costs reference weighted average EU values developed by JRC,[18] supplemented by Searle et al.[19]

The cost analysis presented in Table 1 is only performed for second-generation fuels produced in either gasification or cellulosic ethanol conversion facilities that are not yet widely produced at commercial scales. For fuel conversion pathways using existing commercialized technologies such as hydrotreating for renewable diesel production, we assume that this is possible under low policy support levels. Likewise, the expansion of electric vehicle charging is assumed to be driven by factors and policies other than the RED II. Based on the results of the cost analysis, we find that the following types of advanced alternative fuel can be supported in each policy scenario:

- **Low Policy Support (€0.50 per diesel-equivalent liter):** biodiesel and renewable diesel from used cooking oil; tall oil renewable diesel; and renewable electricity in vehicles and rail.
- **Medium Policy Support (€1.00 per diesel-equivalent liter):** each of the pathways listed in the low policy support scenario; commercial-scale cellulosic ethanol facilities processing agricultural residues; commercial-scale gasification and Fischer Tropsch facilities processing municipal solid waste; ethanol using flue gas fermentation; and biomethane from sewage sludge.
- **High Policy Support (€2.00 per diesel-equivalent liter):** each of the pathways listed in the low and medium policy support scenario; cellulosic ethanol facilities processing energy crops; and commercial-scale gasification Fischer Tropsch facilities processing agricultural residues, forestry residues, black liquor, and energy crops. In addition, higher volumes of fuels manufactured by using most of the pathways listed in the medium

13 Daan Peters, Sacha Alberici, Jeff Passmore, and Chris Malins, *How to Advance Cellulosic Biofuels: Assessment of Costs, Investment Options & Required Policy Support,* (ICCT: Washington, DC, 2015), https://theicct.org/sites/default/files/publications/Ecofys-Passmore%20Group_How-to-advance-cellulosic-biofuels_rev201602.pdf

14 Guolin Yao, Mark D. Staples, Robert Malina, and Wallace E. Tyner, "Stochastic Techno-Economic Analysis of Alcohol-to-Jet Fuel Production" (2017) 10:18

15 Nikita Pavlenko, Stephanie Searle, and Adam Christensen, *The Cost of Supporting Alternative Jet Fuels in the European Union,* (ICCT: Washington, DC, 2019), https://theicct.org/publications/cost-supporting-alternative-jet-fuels-european-union

16 European Environment Agency (EEA), Oil Bulletin Prices History [data set], https://www.eea.europa.eu/data-and-maps/data/external/oil-bulletin

17 Chelsea Baldino, Rosalie Berg, Nikita Pavlenko and Stephanie Searle, *Advanced Alternative Fuel Pathways: Technology Overview and Status,* (ICCT: Washington, DC, 2019), https://theicct.org/publications/advanced-alternative-fuel-pathways

18 Pablo Ruiz, Alessandra Sgobbi, Wouiter Nijs, Christian Tiel, Francesco Dalla Longa, Tom Kober, Berien Elbersen, Geerten Hengeveld. "The JRC-EU-TIMES Mode: Bioenergy Potentials for EU and Neighboring Countries". (JRC Science for Policy Report, European Commission Joint Research Centre: Luxembourg, 2015), https://setis.ec.europa.eu/sites/default/files/reports/biomass_potentials_in_europe.pdf

19 Stephanie Searle, Nikita Pavlenko, Sammy El Takriti and Kristine Bitnere, *Potential Greenhouse Gas Savings from a 2030 Greenhouse Gas Reduction Target with Indirect Emissions Accounting for the European Union,* (ICCT: Washington, DC, 2017), https://www.theicct.org/sites/default/files/publications/RED-II-Analysis_ICCT_Working-Paper_05052017_vF.pdf

policy support scenario would be produced.

- **Non-compliance penalty price in Germany's GHG quota:** the implied financial incentive from the penalty price ranges from €1.45 to 1.79 per diesel-equivalent liter for the various pathways, except for dairy manure biomethane, for which it is €6.90 per diesel-equivalent liter.[20] This makes all of the pathways from the medium policy support scenario cost-viable, as well as cellulosic ethanol facilities processing energy crops, gasification and Fischer Tropsch facilities processing forestry residues and black liquor, and greater volumes of waste biomethane.

This working paper also draws upon two previously-conducted analyses to estimate the levelized costs for producing electrofuels from renewable electricity and biomethane from sewage sludge and livestock manure. Searle and Christensen utilizes a discounted cashflow rate of return analysis in conjunction with projections of future renewable electricity costs through 2050 to estimate the cost of producing electrofuels in the EU-28. The authors estimate that by 2030, electrofuels are not viable at policy support levels below €4 per liter. Baldino et al. uses a similar discounted cashflow rate of return analysis in conjunction with anaerobic digester capital costs and grid interconnection costs to assess the costs of supplying biomethane. The authors find that the majority of livestock manure biomethane resources in Germany may be cost-prohibitive to develop, largely due to the small average size of German dairy farms and the anticipated costs of linking distant farms to the gas grid.[21]

FEEDSTOCK AVAILABILITY

This analysis makes the following assumptions about the availability of various waste and residue feedstocks:

- **Agricultural and forestry residues and wastes:** This category includes stalks and leaves from major crops produced in the EU, treetops and small branches from forestry harvesting, and the biological fraction of municipal and industrial waste. Country-specific residue and waste availability for 2030 was taken from Searle and Malins.[22]
- **Used cooking oil and animal fats:** We project the potetial contribution of used cooking oil in Germany in 2020 using 2015 data for commercial and household used cooking oil collection—approximately 141,000 tonnes.[23] We assume this quantity stays constant through 2030, but may increase in the medium and high policy support scenarios due to an increased incentive for household collection. In Germany, the domestic supply of used cooking oil is much lower than the total quantity of used cooking oil biodiesel production. For example, in 2018, the production of used cooking oil biodiesel is estimated to be roughly 864,000 tonnes due to imports.[24] Animal fats comprised approximately 2% of Germany's 2018 biodiesel production in 2018. Animal fats are not credited towards Germany's biofuel mandate due to concerns about existing uses for the feedstock; therefore, we exclude them from this analysis.[25]
- **Black liquor:** Black liquor is a by-product of the production of pulp used in paper making. Black liquor is a liquid mixture containing primarily lignin and hemicellulose. Total availability is based on a 5-year average of black liquor production from Eurostat.[26]
- **Crude tall oil:** Crude tall oil (CTO) is produced from the acidulation of crude sulfite soap which is separated from black liquor. Some crude sulphite soap is combusted for energy without refinement into crude tall oil. Crude tall oil is often refined into a slate of products, including distilled tall oil and tall oil pitch, and other materials. We assume that CTO consumption for biofuel in 2020 is zero in Germany. In the absence of other data, we project that Germany's CTO production will be proportional to its share of the EU's overall pulp and paper

20 The high cost of manure-derived biomethane is largely a factor of the high carbon savings associated with capturing and combusting methane in some analyses, which is a high-GWP gas

21 Chelsea Baldino, Nikita Pavlenko, Stephanie Searle, and Adam Christensen, *The Potential for Low-Carbon Renewable Methane in Heating, Power and Transportation in the European Union,* (ICCT: Washington, DC 2018), https://theicct.org/sites/default/files/publications/Renewable_Gas_EU-28_20181016.pdf

22 Stephanie Searle and Chris Malins. "Waste and Residue Availability for Advanced Biofuel Production in EU Member States". Biomass and Bioenergy. no. 89, (June 2016): 2-10

23 Greenea, *Analysis of the Current Development of Household UCO Collection Systems in the EU*, (ICCT: Washington, DC, 2016), https://www.theicct.org/sites/default/files/publications/Greenea%20Report%20Household%20UCO%20Collection%20in%20the%20EU_ICCT_20160629.pdf

24 "Rohstoffe für Biodiesel: 2018 mehr Raps und Altspeisefette, deutlich weniger Palm [Raw materials for biodiesel: 2018 more rapeseed and used cooking oil, significantly less palm]," Verbandes der Deutschen Biokraftstoffindustrie (VDB) [German Association of the German Biofuel Industry], Accessed August 22, 2019 http://www.biokraftstoffverband.de/index.php/detail/items/rohstoffe-fuer-biodiesel-2018-mehr-raps-und-altspeisefette-deutlich-weniger-palm.html

25 US Department of Agriculture, Foreign Agricultural Service, *EU-28 Biofuels Annual*, (2019), https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_7-15-2019.pdf

26 Eurostat, Supply, transformation and consumption of renewables and wastes—Black liquor [data set], http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_108a&lang=en

industry.[27] By 2030, we assume that CTO volumes will increase due to increased acidulation of crude sulphite soap in the low policy support scenario and approximately 16% of tall oil used for other uses would be diverted in the medium and high policy support scenarios, following expected sources of additional tall oil supply from Malins.[28]

- **Ethanol from flue gas:** Ethanol can be produced from flue gas, which is the waste gas that is emitted during the steel making process. Flue gas contains energy-carrying gases, including carbon monoxide (CO) and hydrogen (H_2). The quantity of steel mill flue gases was derived from the World Steel Association's estimate of Germany's overall steel production in 2015.[29] We use separate emission factors for conventional blast oxygen furnace steelmaking and electric arc furnace methods, as each method generates different quantities of CO and H_2 per tonne of steel produced.[30] Lastly, we assume that 70% of flue gases are utilized for onsite energy recovery.[31]
- **Energy crops and wood:** taken from Searle et al.[32]
- **Waste-derived biomethane:** Estimated based on Germany's share of the total EU production of manure and wastewater treatment biomethane identified in Baldino et al.[33]

TECHNOLOGICAL READINESS AND FACILITY DEPLOYMENT

The fuel conversion technologies included in this assessment are presented in Table 3. Our assessment of technological readiness comes from a review of advanced alternative fuel conversion technologies, current industry status, and barriers to commercialization.[34] For this analysis we assume that each of these conversion pathways is technologically ready to launch a commercial-scale facility by 2020, but some have greater barriers to deployment than others. This assumption affects the overall quantity of fuel production viable from each pathway relative to feedstock supply.

We assume that existing technologies that already operate at commercial scales, such as biodiesel and hydrotreated vegetable oil (HVO), do not have any kind of deployment constraints. The EU currently has multiple large biodiesel or HVO facilities producing tens of millions of liters of fuel annually; HVO production in particular is projected to surge over the next five years.[35, 36] These technologies tend to use relatively simple technologies with relatively short construction and ramp-up times; therefore, it is conceivable that they will grow to utilize the full supply of available feedstocks.

In contrast to HVO production, conversion pathways utilizing cellulosic feedstocks, such as agricultural residues and energy crops, still suffer from uncertain commercialization prospects. Technological barriers to increasing production, particularly concerning pre-treatment, remain and supply chains for many cellulosic feedstocks must be still developed to ensure a consistent supply of suitable feedstock.[37]

With so few existing cellulosic biofuel production facilities in existence, it

27 Confederation of European Paper Industries (CEPI), *Key Statistics 2017—European Pulp and Paper Industry*, (2017), Retrieved from http://www.cepi.org/system/files/public/documents/publications/statistics/2018/210X140_CEPI_Brochure_KeyStatistics2017_WEB.pdf

28 Chris Malins, *Waste Not, Want Not: Understanding the greenhouse gas implications of diverting waste and residual materials to biofuel production*, (ICCT: Washington, DC, 2017), https://theicct.org/sites/default/files/publications/Waste-not-want-not_Cerulogy-Consultant-Report_August2017_vF.pdf

29 World Steel Association, (*World Steel in Figures 2016*," (2016), Retrieved from https://www.worldsteel.org/en/dam/jcr:1568363d-f735-4c2c-a1da-e5172d8341dd/World+Steel+in+Figures+2016.pdf

30 Alexis M. Bazzanella and Florian Ausfelder, *Low Carbon Energy and Feedstock for the European Chemical Industry*, (Gesellschaft für Chemische Technik und Biotechnologie e.V. (DECHEMA) [Society for Chemical Engineering and Biotechnology e.V.]: Frankfurt am Main, 2017), https://dechema.de/dechema_media/Downloads/Positionspapiere/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry-p-20002750.pdf

31 Stephanie Searle, Nikita Pavlenko, Sammy El Takriti and Kristine Bitnere, *Potential Greenhouse Gas Savings from a 2030 Greenhouse Gas Reduction Target with Indirect Emissions Accounting for the European Union*, (ICCT: Washington, DC, 2017), https://www.theicct.org/sites/default/files/publications/RED-II-Analysis_ICCT_Working-Paper_05052017_vF.pdf

32 Ibid.

33 Chelsea Baldino, Nikita Pavlenko, Stephanie Searle, and Adam Christensen, *The Potential for Low-Carbon Renewable Methane in Heating, Power and Transportation in the European Union,* (ICCT: Washington, DC 2018), https://theicct.org/sites/default/files/publications/Renewable_Gas_EU-28_20181016.pdf

34 Chelsea Baldino, Rosalie Berg, Nikita Pavlenko and Stephanie Searle, *Advanced Alternative Fuel Pathways: Technology Overview and Status,* (ICCT: Washington, DC, 2019), https://theicct.org/publications/advanced-alternative-fuel-pathways

35 U.S. Department of Agriculture, Foreign Agricultural Service, "EU-28 Biofuels Annual," (2019), https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_7-15-2019.pdf

36 "Festive Commissioning of the HVO Production Plant in Rotterdam." Union zur Förderung von Oel- und Proteinpflanzen (UFOP) [Union for the promotion of oil and protein plants]. Accessed August 2nd, 2019. https://www.ufop.de/english/news/festive-commissioning-of-the-hvo-production-plant-in-rotterdam/

37 Chelsea Baldino, Nikita Pavlenko, Stephanie Searle, and Adam Christensen, *The Potential for Low-Carbon Renewable Methane in Heating, Power and Transportation in the European Union,* (ICCT: Washington, DC 2018), https://theicct.org/sites/default/files/publications/Renewable_Gas_EU-28_20181016.pdf

is difficult to estimate the necessary time to construct a project and begin producing fuel at its full capacity. Many of the existing cellulosic ethanol projects in the EU and U.S. have suffered from lengthy delays and have yet to produce fuels at their full, listed capacity.[38] For this analysis, we utilize a simple assumption about the rate of facility deployment that factors construction, ramp-up, and the gradual expansion of the industry through a learning curve, as listed in Table 2.

If a feedstock and conversion pathway is considered cost-viable at a given incentive level, we assume a single large-scale cellulosic facility for that feedstock category would begin design and construction in 2021. No other facilities of that type are established until the first wave of projects has begun production at full capacity. At that point, a second wave of two facilities begins design and construction. In the High Policy Support scenario, we assume that the construction and design times are shortened by one year, allowing for a third wave of cellulosic ethanol facilities to begin production by 2030. The total number of facilities is capped according to the biomass availability for that resource as estimated by Searle & Malins.[39]

The assumed deployment rate for cellulosic feedstocks is comparable to that utilized by E4Tech in a 2017 analysis of cellulosic ethanol potential in 2030 for the EU. In that assessment, the authors projected that the growth of the cellulosic ethanol industry initially would resemble the growth rate of the first-generation ethanol industry in the United States in the 1980s in that study's central scenario, and the growth rate in the 1990's in its ambitious policy support scenario.[40] Depending on the scenario, the authors assume that a first-of-a-kind facility takes 7-9 years to reach production capacity, and a period of 4.5-6 years for subsequent facilities towards 2030. Over 10 years, EU-wide production increases from roughly zero to 2.75 billion liters in the central scenario, and 3.8 billion liters in the ambitious scenario. There is a concurrent increase to over 45 facilities in the central case and over 60 in the ambitious scenario. Assuming Germany's biofuel deployment would be proportional to its share of EU transport energy demand of approximately 15% in 2030, that would equate to approximately 413 million liters in the central scenario and 570 million liters in the ambitious scenario.

Table 3. Assumed design and construction times and ramp-up times for large-scale cellulosic ethanol and gasification-Fischer Tropsch facilities

	Design and construction time for first facility (years)	Design and construction time for follow-on facilities (years)	Ramp-up time to full capacity (years)
Cellulosic ethanol, medium policy support	5	4	1
Cellulosic ethanol, high policy support	4	3	1
Gasification and Fischer Tropsch	5	3	1

We acknowledge that these assumptions of facility deployment are somewhat arbitrary and simplistic; however, we include these constraints in order to reflect the existing limits on facility financing and production ramp-up. These constraints also reflect the observed historical timeline of deployment of demonstration-scale and commercial-scale cellulosic biofuel facilities in the United States and European Union, which has been much slower than many economic models predict.[41] While the first several facilities have a lag time of several years, this deployment model assumes that deployment will accelerate over time as new entrants take on best practices from previous projects.

GREENHOUSE GAS ANALYSIS

To estimate the emissions reductions achievable from each policy support scenario, we assign each fuel pathway combination a different carbon intensity, including both direct and indirect emissions attributable to that pathway. Direct and full lifecycle GHG intensities for bio-based feedstocks and flue gas ethanol are taken from Searle et al. and presented in Table 3.[42] The estimated indirect emissions reflect the increased production emissions for materials substituting for these feedstocks if they are diverted away from non-fuel existing uses. For example, the diversion of tall oil from its existing material uses may require

38 Nikita Pavlenko, "Failure to Launch: Why Advanced Biorefineries Are So Slow to Ramp Up Production [blog post]," (November 13, 2018), Retrieved from the International Council on Clean Transportation https://theicct.org/blog/staff/failure-to-launch-biorefineries-slow-ramp-up

39 Stephanie Searle and Chris Malins. "Waste and Residue Availability for Advanced Biofuel Production in EU Member States". Biomass and Bioenergy. No. 89, June 2016, 2-10

40 Claire Chudziak, Genevieve Alberts, and Ausilio Bauen. *Ramp up of Lignocellulosic Ethanol in Europe to 2030.* (E4Tech (UK) Ltd: London, UK, 2017), http://www.e4tech.com/wp-content/uploads/2017/10/E4tech_ICLE_Final_Report_Dec17.pdf

41 Nathan Miller, Adam Christensen, Ji Eut Park, Anil Baral, Chris Malins, and Stephanie Searle, *Measuring and Addressing Investment Risk in the Second-Generation Biofuels Industry,* (ICCT: Washington, DC, 2013), https://www.theicct.org/sites/default/files/publications/ICCT_AdvancedBiofuelsInvestmentRisk_Dec2013.pdf

42 Stephanie Searle, Nikita Pavlenko, Sammy El Takriti and Kristine Bitnere, *Potential Greenhouse Gas Savings from a 2030 Greenhouse Gas Reduction Target with Indirect Emissions Accounting for the European Union,* (ICCT: Washington, DC, 2017), https://www.theicct.org/sites/default/files/publications/RED-II-Analysis_ICCT_Working-Paper_05052017_vF.pdf

the additional production of virgin vegetable oil. Indirect emissions for renewable electricity used for electrofuel production take into account the upstream infrastructure emissions attributable to new, dedicated renewable electricity generation.[43] For the baseline GHG intensity of fossil fuels, we utilize the fossil fuel comparator of 94.1 gCO2e/MJ in the Fuel Quality Directive, as amended in 2015.[44] We assume the GHG intensity of renewable electricity used in vehicles to be 1 gCO2e/MJ.[45]

Results

CONSTRAINING FACTORS BY PATHWAY

Alternative fuel production in each assessed pathway is constrained by cost, feedstock availability, or the rate of deployment for certain conversion pathways, depending on the level of policy support available in each scenario. We find that in some cases the constraints for a given fuel pathway changes if more policy support is provided. Table 2 summarizes these constraining factors for all pathways in each policy scenario.

Table 4. Assumptions on GHG intensities in analysis

Technology	Feedstock	Direct emissions (gCO_2E/MJ)	Indirect emissions (gCO_2E/MJ)	Total emissions (gCO_2E/MJ)
Cellulosic ethanol	Agricultural residues	14.0	16.0	22.0
	Energy crops and wood	17.0	33.8	50.8
Biodiesel and hydrotreated renewable diesel	Used cooking oil and animal fats	16.9	5.0	21.9
	Tall oil	13.0	89.0	102.0
Synthetic diesel (gasification and Fischer-Tropsch)	Agricultural residues	14.0	16.0	22.0
	Energy crops and wood	17.0	33.8	50.8
	Forestry residues	14.0	17.0	31.0
	Black liquor	10.0	29.0	39.0
	Municipal solid waste	19.0	-45.0	-26.0
Electrolysis and fuel synthesis	Renewable electricity	12.0	14.0	26.0
Flue gas fermentation	Industrial flue gas	12.0	14.0	26.0
Electric vehicles	Renewable electricity	1.0	0.0	1.0
Biomethane	Sewage sludge and livestock manure	19.0 (Sewage sludge) -264.0 (Dairy manure)	0	19.0 (Sewage sludge) -264.0 (Dairy manure)

While cellulosic ethanol is not expected to become a major contributor to Germany's fuel supply, we estimate that with high policy support and in the absence of blending constraints, ethanol would supply roughly 13.6% of gasoline blend demand due to a large potential supply of ethanol from steel mill flue gas. We project that this pathway will deploy more quickly than cellulosic ethanol due to the low cost and consistent supply of the feedstock, whereas cellulosic ethanol requires the development of new supply chains and pre-treatment processes. Therefore, we assume that blending constrains the production of ethanol from steel mill flue gases, the largest source of ethanol in the analysis.

For technologies that are already commercialized, such as waste oil biodiesel or HVO, we find that feedstock availability is the primary limiting factor in all policy scenarios. For synthetic diesel produced from cellulosic feedstocks, we find that cost is a limiting factor in the low and medium policy support scenarios, whereas in the high policy support scenario, the pathways assessed can be economically viable but are constrained by the rate of facility deployment. Municipal solid waste (MSW)-derived fuel is

43 Stephanie Searle and Adam Christensen, *Decarbonization Potential of Electrofuels in the European Union, (ICCT: Washington, DC. 2018),* https://theicct.org/sites/default/files/publications/Electrofuels_Decarbonization_EU_20180920.pdf

44 Council Directive (EU) 2015/652 laying down calculation methods and reporting requirements pursuant to Directive 98/60/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels, Official Journal of the European Union, L107/26, April 20, 2015 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L0652

45 Robert Edwards, Heinz Hass, Jean-Francois Larive, Heiko Maas, and David Rickeard, *Well-to-Wheels Report Version 4.a: JEF Well-to-Wheels Analysis*, (European Commission Joint Research Centre, EUCAR and CONCAWE: Ispra, Italy, 2014), https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/well-wheels-report-version-4a-jec-well-wheels-analysis

Table 5. Constraining factors for production by pathway in each policy scenario

Technology	Feedstock	Low policy support (€0.50 / diesel liter eq.)	Medium policy support (€1.00 / diesel liter eq.)	High policy support (€2.00 / diesel liter eq.)	GHG reduction penalty (€470/tCO_2e)
Cellulosic ethanol	Agricultural residues	Cost	Facility deployment	Facility deployment	Facility deployment
	Energy crops and wood	Cost	Cost	Facility deployment	Facility deployment
Biodiesel and hydrotreated renewable diesel	Used cooking oil	Cost	Feedstock availability	Feedstock availability	Feedstock availability
	Tall oil	Cost	Feedstock availability	Feedstock availability	Feedstock availability
Synthetic diesel (gasification and Fischer-Tropsch)	Agricultural residues	Cost	Cost	Facility deployment	Cost
	Energy crops and wood	Cost	Cost	Facility deployment	Cost
	Forestry residues	Cost	Cost	Facility deployment	Facility deployment
	Black liquor	Cost	Cost	Facility deployment	Facility deployment
	Municipal solid waste	Cost	Facility deployment	Facility deployment	Facility deployment
Electrolysis and fuel synthesis	Renewable electricity	Cost	Cost	Cost	Cost
Flue gas fermentation	Industrial flue gas	Cost	Cost	Ethanol Blending	Ethanol Blending
Electric vehicles	Renewable electricity	Other factors outside this analysis	Other factors outside this analysis	Other factors outside this analysis	Other factors outside this analysis
Biomethane	Livestock manure and sewage sludge	Cost	Cost	Cost	Cost

available at medium levels of policy support due to the assumption that the feedstock costs €0 per tonne.

We find that cost constraints eliminate electrofuels from deployment at all policy support levels. Further, we find that cost largely limits waste biomethane at all policy support levels. The deployment of electric vehicles, which count towards the overall transport energy target, occurs independently of the incentive levels estimated here and is instead proportional to the share of stationary renewable energy projected for 2030 in conjunction with the effects of electric vehicle mandates and a slight growth in rail electrification.

TOTAL POTENTIAL ADVANCED ALTERNATIVE FUEL VOLUMES IN 2030

The total amount of advanced alternative fuel that could be deployed in Germany varies substantially depending on the quantity of policy support. Figure 1, Figure 2, and Figure 3 illustrate the projected volumes of advanced alternative fuels in each of the policy scenarios. Figure 4 illustrates the projected production volumes that could be incentivized with a non-compliance penalty of €470 per tonne of CO_2e of GHG savings not achieved under the GHG quota across the entire fuel pool. In all four charts, the left-hand axis shows the total quantity of fuel production in million tonnes of oil-equivalents (mtoe), whereas the right-hand axis presents the total share of transport sector energy. Multiple counting for the RED II targets is not shown in these figures. Table 4 summarizes the total production volumes from each pathway across all four scenarios.

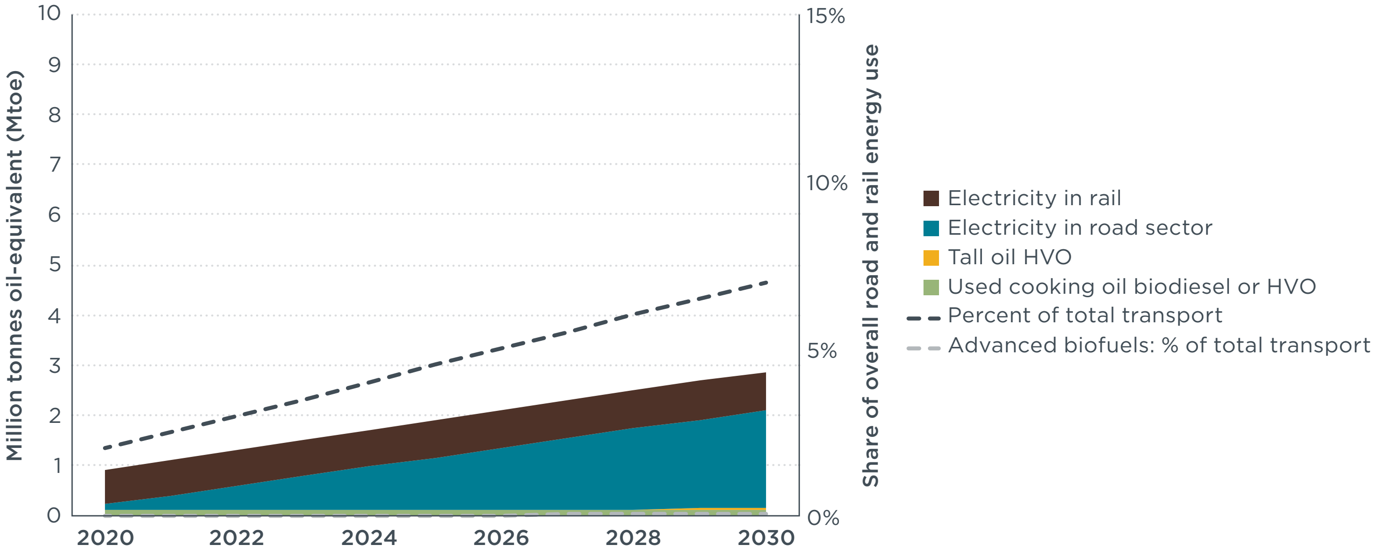

Figure 1. Projected advanced alternative fuel volumes to 2030 in the low policy support scenario (€0.50 per liter)

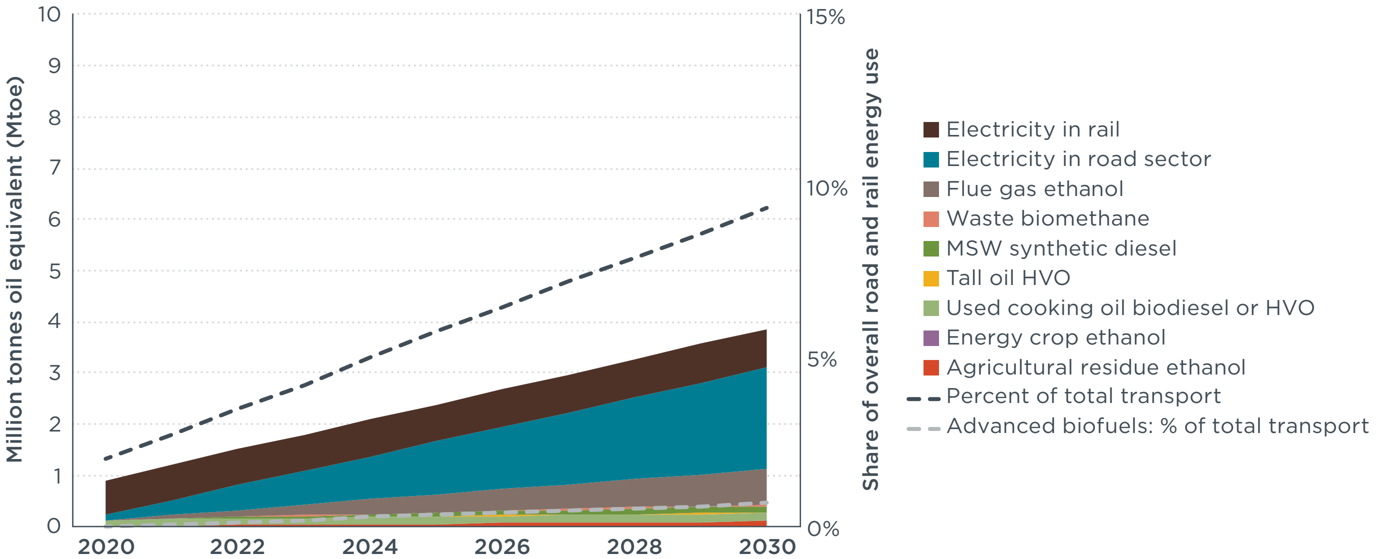

Figure 2. Projected advanced alternative fuel volumes to 2030 in the moderate policy support scenario (€1.00 per liter)

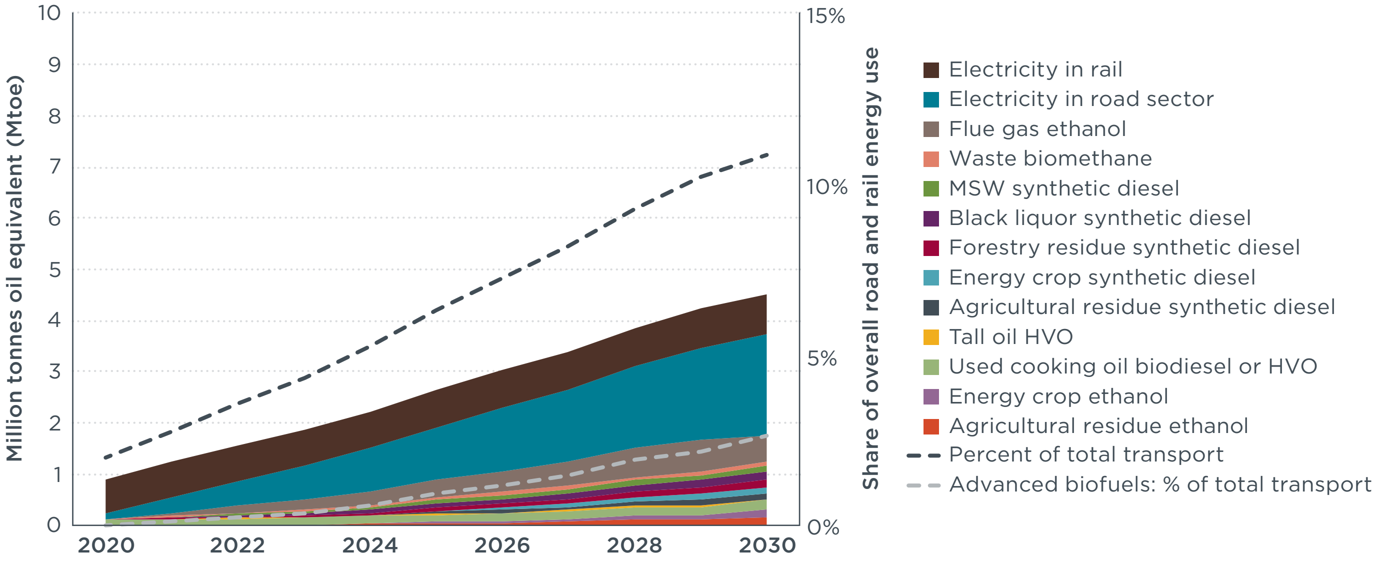

Figure 3. Projected advanced alternative fuel volumes to 2030 in the high policy support scenario (€2.00 per liter)

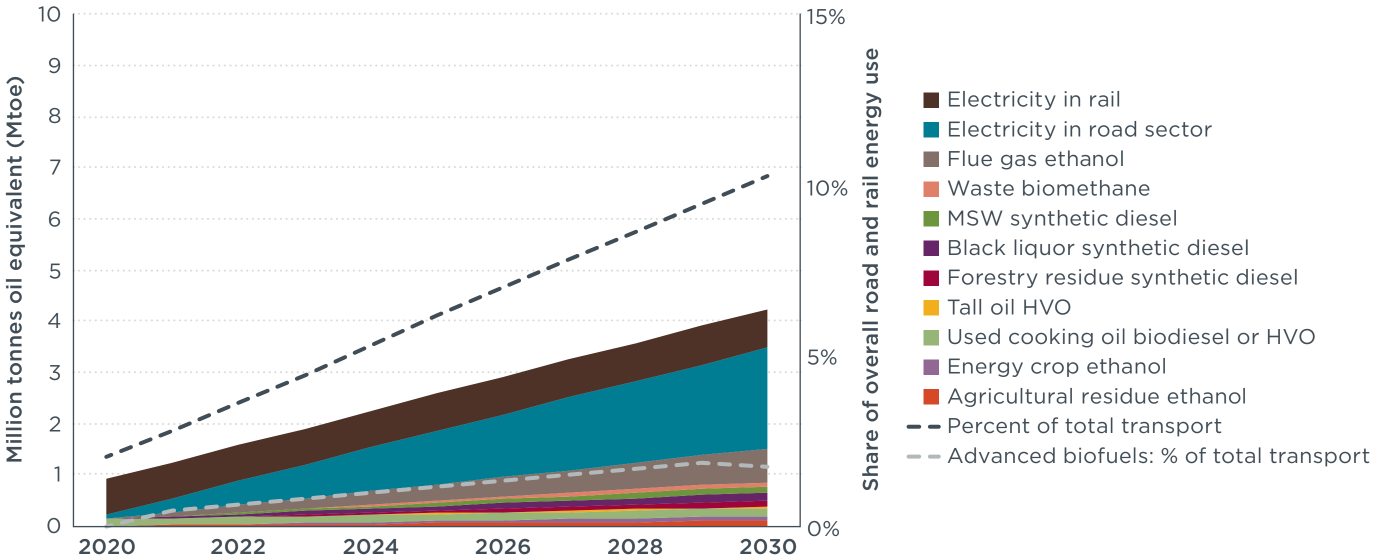

Figure 4. Projected advanced alternative fuel volumes to 2030 in the GHG reduction penalty scenario

The scenario summary presented in Table 4 suggests that the obligation on fuel suppliers to blend 3.5% advanced biofuels from Annex IX list A is unlikely to be met without high policy support in place, even after factoring in the double counting of advanced biofuels. In the low and medium policy support scenarios, the total contribution of advanced biofuels is only 0.2% and 1.3%, respectively, after including the 2x multiplier. In particular, we find that the production of abundant biofuel from cellulosic resources remains largely price-constrained until policy support reaches approximately €1 per liter.

Across all policy support levels, The use of renewable energy in electric vehicle charging and rail electrification together greatly exceed the 14% transport sector target due to the credit multipliers, even without considering the contribution of advanced or food-based biofuels. To better illustrate the effects of multipliers, Figure 5 incorporates them into a projection of transport energy supply in the high policy support scenario, illustrating that renewable energy would supply nearly 30% of transport energy demand by 2030. If Germany meets its targets for electric vehicle deployment, virtually no further policy action is needed in order to meet the 14% transport sector target for renewable energy.

High levels of policy support would be necessary for Germany to be able to exceed its 3.5% advanced biofuels subtarget with 2.6% blending, even with double counting of 5.2% towards the advanced biofuels target

Table 6: Total potential fuel production volumes by pathway in each policy scenario in 2030 (thousand tonnes oil equivalent)

Technology	Feedstock	Low policy support (€0.50 / diesel liter eq.)	Medium policy support (€1.00 /diesel liter eq.)	High policy support (€2.00 / diesel liter eq.)	GHG reduction penalty (€470/tCO_2e)
Cellulosic ethanol	**Agricultural residues**	0	99	165	99
	Energy crops and wood	0	0	153	92
Biodiesel and hydrotreated renewable diesel	**Used cooking oil**	122	153	153	153
	Tall oil	20	24	24	24
Synthetic diesel (gasification and Fischer-Tropsch)	**Agricultural residues**	0	0	124	0
	Energy crops and wood	0	0	115	0
	Forestry residues	0	0	124	124
	Black liquor	0	0	164	164
	Municipal solid waste	0	124	124	124
Electrolysis and fuel synthesis	**Renewable electricity**	0	0	0	0
Flue gas fermentation	**Industrial flue gas**	0	694	521	648
Biomethane	**Sewage sludge and livestock manure**	0	29	81	81
Electricity in the road sector	**Renewable electricity**	1,971	1,971	1,971	1,971
Electricity for rail	**Renewable electricity**	763	763	763	763
Alternative fuels as share of total transport energy (without multipliers)		7.0%	9.3%	10.9%	10.4%
Advanced biofuels (Annex IX list A) as share of total transport energy		0.1%	0.7%	2.6%	1.7%
Used cooking oil as share of total transport energy		0.3%	0.4%	0.4%	0.4%
Advanced biofuels as share of total transport energy (Annex IX list A, including multipliers)		**0.2%**	**1.3%**	**5.2%**	**3.4%**
Total non-food alternative fuels as share of total transport energy (including multipliers)		**22.5%**	**25.6%**	**29.1%**	**26.8%**

(Figure 5)The largest contributors to the advanced biofuels sub-target would be fuels produced from agricultural residues and energy crops. Due to the time-sensitive deployment constraints, we speculate that the potential volumes for cellulosic pathways could increase significantly beyond 2030. We find that the 1.7% cap on biofuels produced from used cooking oil and animal fats is unlikely to be a hindrance unless the Germany substantially increases imports of these feedstocks and changes its current policy to include animal fats.[46]

In the high policy support scenario, the total potential production of advanced ethanol, including flue gas ethanol, is greater than can be accommodated given blending restrictions in petrol. We assume that the production of flue gas ethanol is reduced in this scenario. Under real-world conditions, it is likely that the production of advanced ethanol produced from energy crops and agricultural residues would also be reduced due to blending limits. Furthermore, significant volumes of advanced ethanol can only be achieved if policies place a higher priority on its production compared to first-generation food-based ethanol. As long as there is policy support for food-based ethanol and no requirement that advanced ethanol take precedence in blending, it is likely that the availability of relatively inexpensive food-based ethanol will exert substantial blending constraint on all advanced ethanol pathways in any of the policy scenarios modeled here.

The deployment rate of both cellulosic ethanol and gasification pathways limits their contributions to renewable energy supply in both the medium and high policy support scenarios. We estimate that the annual production of cellulosic ethanol in 2030 would grow to 200 and 600 million liters in the medium and high policy support scenarios, respectively. Gasification contributes an additional 100 million and 1 billion liters of diesel-equivalents in the medium and high policy support scenarios. However, these values are highly uncertain due to the combination of insufficient cost modeling for next-generation fuel production technologies as well as the use of a speculative deployment model. The projected volumes for cellulosic ethanol are similar to the proportional share of cellulosic ethanol estimated by E4Tech, as described above, in its EU-wide cellulosic ethanol deployment estimate.

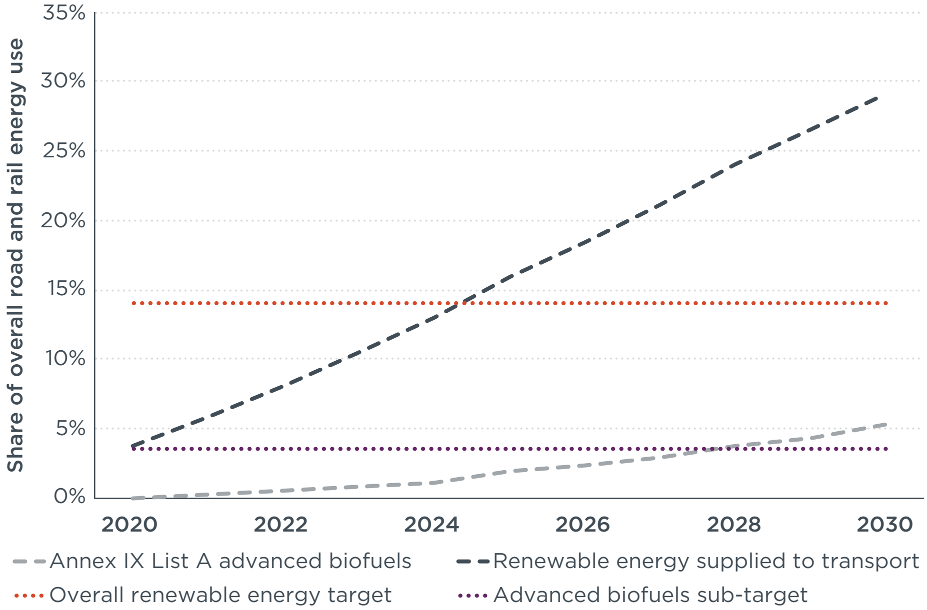

Figure 5. Projected advanced biofuel and total renewable energy deployment as a share of total transport demand, including RED II multipliers, in the high policy support scenario of €2.00 per liter

We also assessed the production volumes of advanced fuels that would be incentivized with the current non-compliance penalty of €470 per tonne CO_2e in GHG savings not achieved in Germany's GHG quota; this is shown in the final column in Table 3. This penalty represents the maximum level of implied policy support to alternative fuel producers because obligated parties would presumably prefer to purchase alternative fuel at a price lower than the penalty than pay the penalty. For most pathways, this implied policy support level falls in between the medium and high policy support levels in our other scenarios, or between €1 and €2 per diesel-equivalent liter. We found that up to 1.7% of the energy demand in Germany's road and rail transport could be met with advanced biofuels in Annex IX list A of the RED II. With double counting, this increases to 3.4%, slightly lower than the 3.5% RED II sub-target for advanced biofuels.

While Germany's penalty price of €470 per tonne CO_2e could theoretically incentivize the production volume of advanced biofuels necessary to approach the advanced biofuels sub-target, the current structure of the policy makes that possibility unrealistic in practice. Because the price applies to the biofuels GHG quota as a whole, it incentivizes the production of both advanced fuels and first-generation fuels. Obligated parties may choose to blend either first-generation or advanced alternative fuels to avoid

46 Sammy El Takriti, Stephanie Searle, and Nikita Pavlenko, *Indirect greenhouse gas emissions of molasses ethanol in the European Union*, (ICCT: Washington, DC, 2017), https://www.theicct.org/sites/default/files/publications/EU-molasses-ethanol-emissions_ICCT-working-paper_27092017_%20vF.pdf

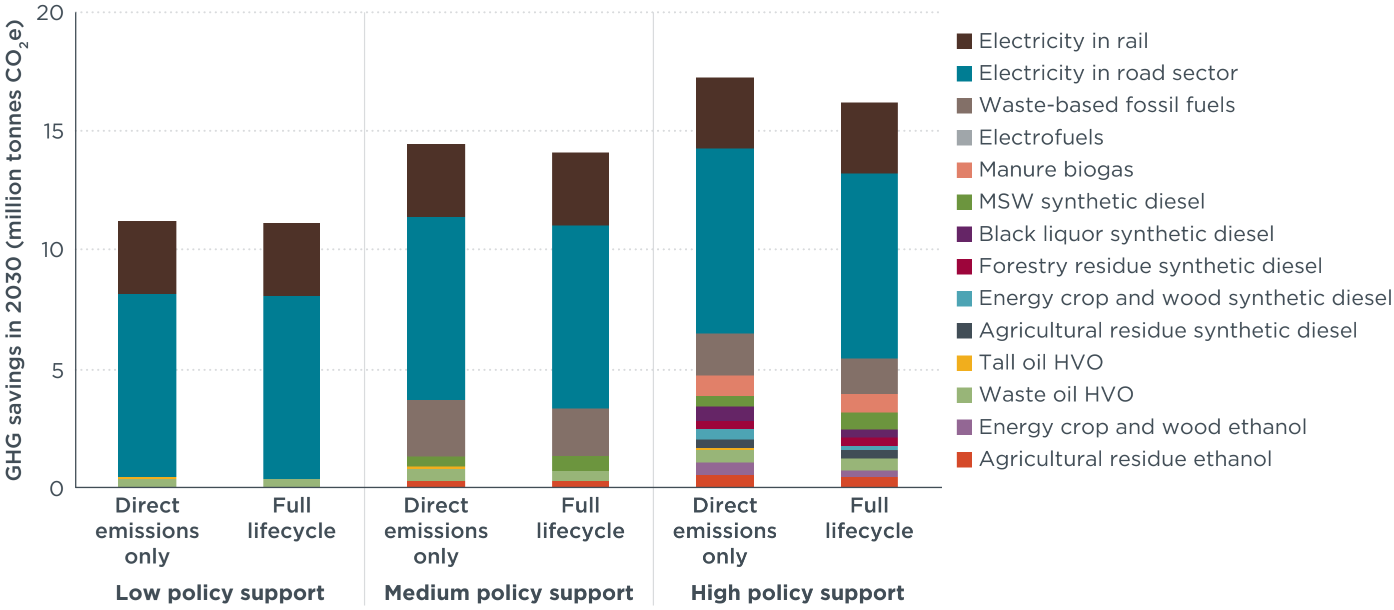

Figure 6. Direct and full lifecycle GHG savings from advanced alternative fuels in 2030 in each policy scenario

paying the penalty. First-generation fuels, including food-based fuels and used cooking oil biodiesel, are generally much less expensive than advanced fuels per tonne CO_2e reduction, especially given that Germany does not account for indirect land use change in its GHG quota. While there is a 0.5% advanced biofuel blending sub-target for 2025, there are not yet any enforcement mechanisms. There is thus a large incentive for fuel suppliers to only blend first-generation fuels to avoid the penalty price, and no incentive to pay higher prices for advanced fuels. Our projection of 1.7% advanced biofuel supply could be achievable if Germany applied an equivalent non-compliance penalty specifically to the advanced biofuel mandate. This penalty price would need to be translated into a per liter or per tonne oil equivalent price in order to be applicable to a volume or energy blending mandate. Our analysis indicates that it is unlikely that advanced biofuel volumes greater than 1.7% could be achievable without a higher penalty price or similar policy.

As Germany evaluates potential policy changes, an important consideration to emphasize is that the implementation of different policy measures can have varying effectiveness. While the cost assessment presented here suggests that a high incentive value is necessary to mobilize investment in advanced biofuel pathways, a high price signal alone does not necessarily ensure that a certain target level is met. In order to achieve the level of deployment for advanced fuel facilities in the penalty price and high policy support scenario, the high incentive would need to be paired with a stable, secure policy environment. Policy uncertainty can undermine the effectiveness of policy measures supporting the deployment of alternative fuel facilities, particularly those using advanced technologies with high capital expenses.[47] In the absence of long-term certainty, investors could perceive the actual value of the incentive as much lower than its nominal value, undermining the value of financial incentives.

47 Kristine Bitnere and Stephanie Searle, *Effective Policy Design for Promoting Investment in Advanced Alternative Fuels*, (ICCT: Washington, DC, 2017), https://www.theicct.org/sites/default/files/publications/Advanced-alternative-fuels_ICCT-white-paper_21092017_vF.pdf

GHG IMPACTS

We also assess the overall GHG performance of the alternative fuel mix in each scenario in Figure 6.The assumed GHG intensities used this analysis are provided in Table 3. Potential GHG emission reductions scale roughly with projected volumes, with greater GHG reductions possible with increasing policy support value. Applying full lifecycle GHG accounting that includes indirect emissions reduces the estimated GHG reductions minimally for this mix of pathways. We find that up to 16 million tonnes CO_2e reduction is possible annually by 2030 in the high policy support scenario, but that only around 11 million tonnes CO_2e reduction would be delivered annually by 2030 in the low policy support scenario. The overall GHG performance of the RED II, as proposed, will thus depend heavily on the effectiveness of Germany's policies to support advanced alternative fuel deployment.

CONCLUSION

This working paper assesses the potential for Germany to meet the transport sector targets set by the EU RED II using advanced, non-food based fuels. The analysis uses a combination of feedstock availability and cost assessment to estimate the volumes of fuels that can be supplied at multiple incentive levels. Policies supporting advanced, non-food based fuels can deliver substantial carbon savings —as much as 16 million tonnes of CO_2-equivalents annually in the high policy support scenario, after taking into account indirect emissions.

We find that the 14% transport sector renewable energy target can largely be met through the increased deployment of electric vehicles and greater rail electrification, likely driven by policies other than the RED II. Based on an assumption of steady growth in electric vehicle penetration and renewable electricity deployment in the power sector through 2030, we estimate that renewable electricity from vehicle charging will supply approximately 4.8% of road and rail sector energy demand—which increases to over 19% after the application of credit multipliers. Continued rail electrification—already high in in Germany—increases renewable electricity's contribution to nearly 23% after taking into account credit multipliers. Germany will be in a strong position to meet its overall, transport sector RED II target, theoretically allowing greater attention to be paid to the more challenging, advanced biofuel sub-target.

The volume of waste and residue-based biofuels necessary to meet the advanced biofuels sub-target are largely constrained by price and are only cost-viable with high levels of policy support. The cost assessment presented here estimates that large, commercial-scale facilities are only cost-viable at policy support levels above €1 per diesel-equivalent liter, at which waste and residue-based biofuels could fulfill 2.6% of Germany's transport energy demand. It will be necessary to implement a strong incentive to overcome the investment risks and high upfront costs of these emerging technologies in order to allow them to expand to the necessary scale of production.

This analysis utilizes a conservative methodology that estimates the potential volumes for advanced fuels in 2030 that are lower than previous studies' estimates, particularly for electrofuels and lignocellulosic feedstocks. Drawing upon a previous techno-economic assessment on electrofuels, we find that the 2030 timeframe is too soon to supply in sufficient volumes at the various incentive costs studied; however, there may be greater potential in the longer term as the price of electricity continues to decline. Likewise, we find that the 2030 timeframe presents a severe constraint for cellulosic ethanol and the gasification of wastes and residues. While lignocellulosic feedstocks such as agricultural residues are an abundant feedstock, the slow pace of deployment for new facilities hinders the market penetration of these fuels. The assumption of a constraint on the pace of new cellulosic ethanol facility deployment provides similar results to an EU-wide assessment of the pace of cellulosic ethanol expansion in the EU conducted by E4tech. While this paper finds that the rate of deployment constrains these fuels within the next decade, a stable policy environment with high incentives could support a larger expansion of these fuels beyond 2030.

The existing GHG quota intended to drive transport sector decarbonization in Germany could be used to meet the RED II targets if it is reconfigured to incentivize the purchase of advanced biofuels. We estimate that at Germany's carbon penalty price of €470 per tonne of CO_2e, enough of the advanced biofuel pathways are cost-viable to meet 3.4% of transport energy demand—which is nearly sufficient to meet the advanced biofuel sub-target. However, it is much easier to comply with the quota by using food-based biofuels. We recommend that Germany adopt a more stringent advanced biofuel sub-target at the national level and levy that non-compliance penalty for advanced fuels specifically.