

# Assessing the role of biomass-based diesel in U.S. rail decarbonization strategy

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## BACKGROUND

Consumption of biodiesel and drop-in renewable diesel by the U.S. rail sector could grow as the industry responds to external pressures to decarbonize. Rail in the United States consumed roughly 3.8 billion gallons of diesel fuel equivalent (DGE) in 2022 and nearly all of that came from fossil diesel.<sup>1</sup> In the National Blueprint for Transport Decarbonization, the U.S. Department of Energy (DOE) identified liquid biofuels as a long-term decarbonization strategy for rail, long-haul trucks, and the maritime and aviation sectors.<sup>2</sup> Indeed, the DOE's Bioenergy Technologies Office (BETO) is exploring blending both biodiesel and renewable diesel into locomotive engines.<sup>3</sup>

An estimated 1% of U.S. rail is electrified.<sup>4</sup> This is in sharp contrast with many other countries. The International Energy Agency (IEA) estimated that, worldwide, locomotives consumed diesel and electricity in near equal shares in 2022.<sup>5</sup> Regions with major rail networks in Europe and Asia have widely adopted overhead catenary wire networks to electrify their rail systems, but catenary systems are comparatively rare in the United States. While Europe has electrified nearly 70,000 miles of its rail

- 1 U.S. Energy Information Administration, "Annual Energy Outlook 2023," March 16, 2023, [https://www.eia.gov/outlooks/aeo/tables\\_ref.php](https://www.eia.gov/outlooks/aeo/tables_ref.php).
- 2 U.S. Department of Energy, U.S. Department of Transportation, U.S. Environmental Protection Agency, U.S. Department of Housing and Urban Development, *The U.S. National Blueprint for Transportation Decarbonization* (Washington, DC: U.S. Department of Energy, 2023), <https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf>
- 3 Jim Spaeth, "Systems Development & Integration Overview," (presentation, 2023 Bioenergy Technology Office Peer Review, Denver, CO, April 3, 2023), <https://www.energy.gov/sites/default/files/2023-06/beto-05-project-peer-review-plenary-apr-2023-spaeth.pdf>
- 4 Richard Nunno, "Electrification of U.S. Railways: Pie in the Sky, or Realistic Goal?," Environmental and Energy Study Institute, May 30, 2018, <https://www.eesi.org/articles/view/electrification-of-u.s.-railways-pie-in-the-sky-or-realistic-goal>.
- 5 International Energy Agency, "Energy Consumption for Rail by Fuel in the Net Zero Scenario, 2010-2030," chart, June 19, 2023, <https://www.iea.org/data-and-statistics/charts/energy-consumption-for-rail-by-fuel-in-the-net-zero-scenario-2010-2030>.

**Acknowledgments:** This work was generously supported by the Norwegian Agency for Development Cooperation. Thanks to Zhenying Shao and Chelsea Baldino for helpful reviews.

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network, for example, the United States has electrified only 800 miles along the Northeast and Keystone corridors.<sup>6</sup>

The U.S. rail sector lacks a clear path to decarbonization. It lags behind many peer countries partly because of certain structural conditions. Much of the U.S. rail network is owned by private companies that have historically invested in diesel infrastructure and avoided the high upfront costs of electrification. Meanwhile, governments in other countries subsidized the transition from diesel to electricity.<sup>7</sup> Low population density and long distances between urban centers in the United States also lessen public demand and political pressure for cleaner and more abundant rail networks.

Because liquid biofuels are compatible with existing diesel engines and infrastructure, they can be easily adopted in the near term. However, such blending could increase demand for biomass-based diesel (BBD) fuels in the United States and thus increase cross-sectoral competition for biomass resources. It is projected that demand for BBD in the rail sector could reach a maximum of 3.91 billion gallons in 2050, assuming freight lines do not electrify or pursue alternative solutions such as hydrogen.<sup>8</sup>

This brief draws upon various studies by the ICCT to consider the greenhouse gas (GHG) emissions and broader sustainability impacts that could result if the U.S. rail sector transitions to BBD fuel. After comparing the life-cycle carbon intensity (CI) of various renewable diesel pathways with the standard CI for electricity and fossil diesel produced in California, we estimate the available biomass feedstocks in the United States in 2030. We then compare our projections for sustainable biomass availability in 2030 with DOE's availability estimates. Concluding remarks discuss the role of non-liquid fuel alternatives—such as battery electric locomotives, catenary systems, and hydrogen fuel cell locomotives—as decarbonization strategies along with the policy levers that could be used to support the growth of these alternatives, including many already implemented by the State of California.

## LIFE-CYCLE CARBON INTENSITY OF RENEWABLE DIESEL

BBD is often considered to have zero carbon dioxide emissions from fuel combustion because of an accounting convention used by the United Nations' Intergovernmental Panel on Climate Change (IPCC) and major regulatory agencies. This convention assumes that carbon emissions generated during biogenic fuel combustion are offset by carbon sequestration during plant growth. While this assumption significantly reduces the life-cycle carbon intensity (CI) of BBD relative to fossil fuel, most biofuels generate GHG emissions at various points in their supply chain that are upstream of combustion, and these include direct emissions from feedstock cultivation (e.g., fertilizer use) and fuel production (e.g., process inputs). Researchers estimate the life-cycle CI of a given fuel supply chain by summing all the emission sources together, measured in grams of carbon dioxide-equivalent (CO<sub>2</sub>e) per megajoule of fuel.

In addition to direct, supply chain emissions, some biofuels also generate indirect emissions associated with how markets respond to biofuel demand. These can be high enough in some cases to offset all the life-cycle GHG savings associated with

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6 Wyatt Gordon, "Electrified Rail Is the Future. Is Virginia All Aboard?," commentary, *Virginia Mercury*, January 9, 2023, <https://viriniamercury.com/2023/01/09/electrified-rail-is-the-future-is-virginia-all-aboard/>.

7 Nunno, "Electrification of U.S. Railways."

8 U.S. Energy Information Administration, "Annual Energy Outlook 2023."

some biofuels.<sup>9</sup> Demand for biofuel feedstocks such as soybeans and corn directly competes with demand for these feedstocks as food and animal feed. As a result, farmers must either clear a new parcel of land to support additional biofuel production, improve their yields, or divert feedstocks from their existing uses. Some portion of additional demand can be expected to be met with yield improvements and increased cropping intensity. Most often, however, some new land will need to be cleared to allow production to meet growing demand for a given crop. This can generate indirect land-use change (ILUC) emissions, which are the GHG emissions that result from shifting agricultural activity from existing farmland to land with high carbon stocks such as grasslands, wetlands, and forests.

Though estimates of the amount of ILUC emissions vary significantly across the scientific literature and across different regulatory assessments, there are several trends. For one, ILUC emissions tend to be the highest for oilseeds such as soy and palm, which are linked to the vegetable oil markets and to land conversion involving carbon-rich soils such as peatland and primary forestland.<sup>10</sup> In some cases, economic modeling has shown that ILUC emissions may drive the life-cycle CI of BBD fuel above that of fossil diesel.<sup>11</sup> Another trend is that most analyses consider ILUC emissions to be zero or negligible for waste and residue feedstocks such as distillers corn oil, as these do not compete with food and feed markets.<sup>12</sup> Cellulosic energy crops such as switchgrass and *Miscanthus* also have a low CI when they are grown on marginal land that does not compete with food and feed crop production.<sup>13</sup>

To illustrate the differences, we estimated the life-cycle CI of various renewable diesel pathways with the standard CI for electricity and fossil diesel produced in California; results are in Figure 1. Although fatty acid methyl ester (FAME) biodiesel can also be blended into diesel locomotive engines, we did not assess it because FAME has performance constraints above 20% by volume blend rates.<sup>14</sup> We included the CI of Fischer-Tropsch (FT) diesel produced from the gasification of lignocellulosic materials such as agricultural and forestry residues. FT-diesel production is costly and less likely to be commercially available than renewable diesel in the near term. However, it remains a viable technology pathway being explored by BETO and could scale up as other transport modes pursue their own decarbonization strategies.<sup>15</sup> The locomotive industry is also exploring dimethyl ether and methanol as emerging fuel pathways for biomass materials.<sup>16</sup>

9 Hugo Valin et al., *The Land Use Change Impact of Biofuels Consumed in the EU: Quantification of Area and Greenhouse Gas Impacts* (Utrecht, Netherlands: Ecofys, 2015) [https://pure.iiasa.ac.at/id/eprint/12310/1/Final%20Report\\_GLOBIOM\\_publication.pdf](https://pure.iiasa.ac.at/id/eprint/12310/1/Final%20Report_GLOBIOM_publication.pdf); Jane O'Malley, Stephanie Searle, and Nikita Pavlenko, *Indirect Emissions from Waste and Residue Feedstocks: 10 Case Studies from the United States* (Washington, D.C.: International Council on Clean Transportation, 2021), <https://theicct.org/publication/indirect-emissions-from-waste-and-residue-feedstocks-10-case-studies-from-the-united-states/>.

10 Valin et al., *Land Use Change Impact*.

11 Valin et al., *Land Use Change Impact*.

12 California Air Resources Board, *Detailed Analysis for Indirect Land Use Change* (Sacramento, CA, 2014), [https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/iluc\\_assessment/iluc\\_analysis.pdf](https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/iluc_assessment/iluc_analysis.pdf); U.S. Environmental Protection Agency, *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis* (Washington, DC, 2010), <https://19january2017snapshot.epa.gov/sites/production/files/2015-08/documents/420r10006.pdf>.

13 Stephanie Searle, *Sustainability Challenges of Lignocellulosic Bioenergy Crops* (Washington, DC: International Council on Clean Transportation, 2018), <https://theicct.org/publication/sustainability-challenges-of-lignocellulosic-bioenergy-crops/>.

14 U.S. Department of Energy, *Alternative Fuels Data Center: Biodiesel Blends*, accessed January 20, 2024, [https://afdc.energy.gov/fuels/biodiesel\\_blends.html](https://afdc.energy.gov/fuels/biodiesel_blends.html).

15 U.S. Department of Energy Bioenergy Technologies Office, "The U.S. Department of Energy Announces \$16.7 Million in Project Selections to Advance Production of Affordable Biofuels and Biochemicals," news release, September 29, 2023, <https://www.energy.gov/eere/bioenergy/articles/us-department-energy-announces-167-million-project-selections-advance>.

16 DCC plc, "DCC Energy Announces Partnership with Oberon Fuels to Boost Renewable Dimethyl Ether Production," news release, March 29, 2023, <https://www.dcc.ie/news/press-releases/2023/dcc-energy-announces-partnership-with-oberon-fuels-to-boost-renewable-dimethyl-ether-production>.

The direct supply chain GHG emissions in Figure 1 are the U.S. default values from the Greenhouse gases, Regulated Emissions, and Energy Use in Transportation (GREET) model. The ILUC emissions are from the California Air Resources Board's (CARB) Low-Carbon Fuel Standard (LCFS) regulation. We assumed a fossil comparator value of 94.47 g CO<sub>2e</sub>/MJ—based on the California LCFS baseline diesel emission factor—and an electricity comparator value of 69.1 g CO<sub>2e</sub>/MJ, based on the average electricity emissions factor for the California subregion (CAMX) from the Emissions & Generation Resource Integrated Database (eGRID). We adjusted the electricity CI by a factor of 4.6 to account for the high powertrain efficiency of heavy-rail electric locomotives.<sup>17</sup> Light rail and trolley car locomotives powered by electricity have an efficiency factor between 3.1 and 3.3. For hydrogen fuel cell and combustion locomotives, we adopted an energy economy ratio (EER) of 1.9. We note that the electricity EERs adopted under the California LCFS apply to fixed guideway systems and are based on their efficiency in units of energy per passenger miles.<sup>18</sup> For freight trains, a more appropriate equivalence unit would be tonne-kilometers, because it better reflects the vehicle's primary mode of operation. If California updates the EER for heavy-rail freight locomotives in the future, a more appropriate EER may be approximately 4.0, as demonstrated in a Fraunhofer ISI study.<sup>19</sup>

In Figure 1, the dashed line indicates a 50% CI reduction from the fossil diesel baseline. We also include the range of possible emissions from electricity- and hydrogen-based pathways. Electricity pathways include results for grid-average electricity (shown in hatched bars) and a fully decarbonized electricity grid. For the hydrogen pathway that uses fossil gas with carbon capture and sequestration (CCS), we assumed the real-world average CO<sub>2</sub> capture rate (55%) as a minimum bound. We assumed the capture rate used in the default 2022 GREET model (96.2%) as a maximum bound.<sup>20</sup>

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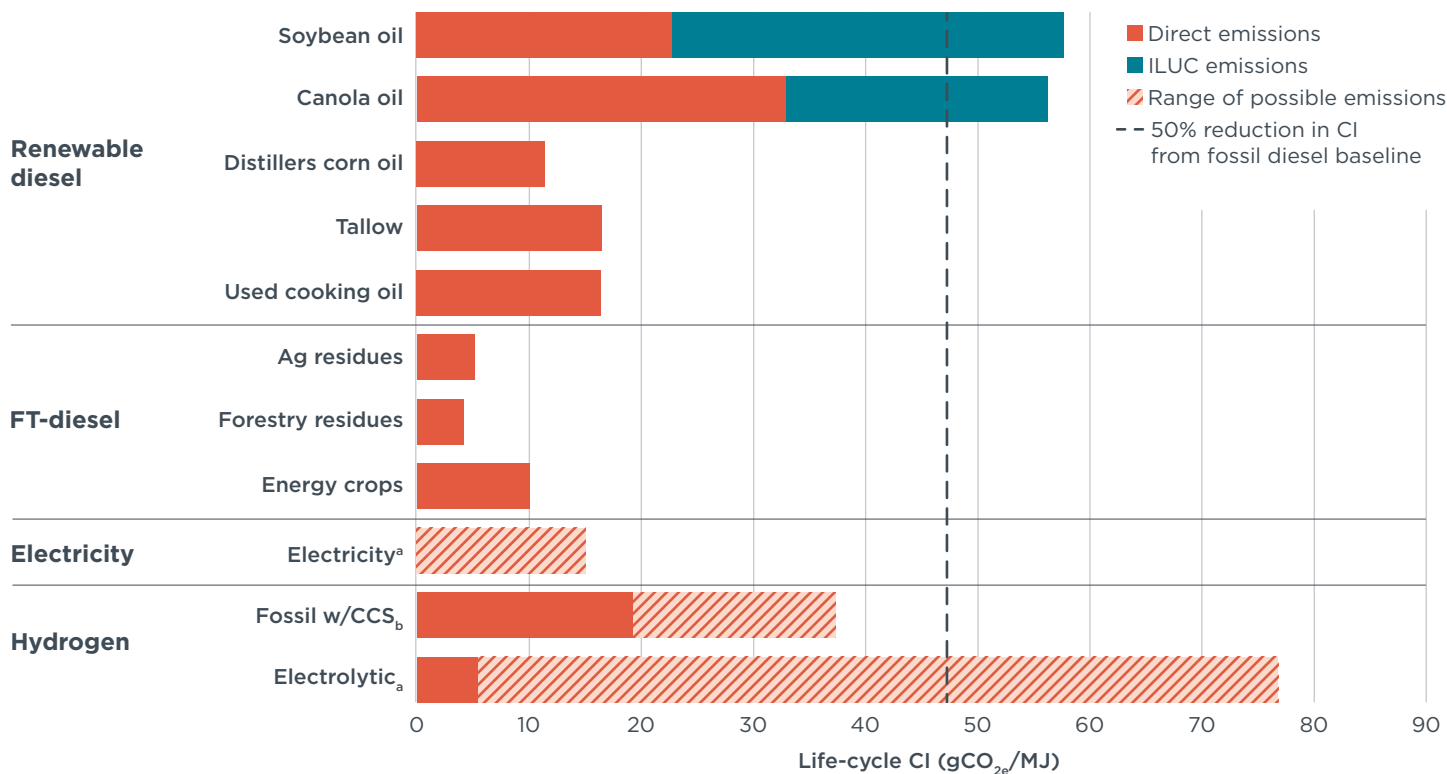
17 California Air Resources Board, "Low Carbon Fuel Standard (LCFS) Guidance 20-04: Requesting EER-Adjusted Carbon Intensity Using a Tier 2 Pathway Application," April, 2020, [https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance\\_20-04.pdf](https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_20-04.pdf).

18 California Air Resources Board, "Unofficial ELECTRONIC VERSION of the Low Carbon Fuel Standard Regulation," 2020, [https://ww2.arb.ca.gov/sites/default/files/2020-07/2020\\_lcfs\\_fro\\_oal-approved\\_unofficial\\_06302020.pdf](https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf).

19 Claus Doll et al., *Methodology for GHG Efficiency of Transport Modes* (Karlsruhe, Germany: Fraunhofer Institute for Systems and Innovation Research ISI, 2020), <https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccn/2021/Methodology%20for%20GHG%20Efficiency%20of%20Transport%20Modes.pdf>

20 Yuanrong Zhou et al., *Life-Cycle Greenhouse Gas Emissions of Biomethane and Hydrogen Pathways in the European Union* (Washington, DC: International Council on Clean Transportation, 2021), <https://theicct.org/publication/life-cycle-greenhouse-gas-emissions-of-biomethane-and-hydrogen-pathways-in-the-european-union/>.

**Figure 1**  
**Life-cycle carbon intensity (CI) for heavy-rail fuel pathways in California**



<sup>a</sup> Hatched bars for electricity and electrolytic hydrogen indicate possible CI based on the level of decarbonization in the electricity grid, with the highest CI based on the current California grid average. The solid orange bar indicates CI with a fully decarbonized grid.  
<sup>b</sup> Hatched bar for fossil hydrogen indicates possible CI based on the level of carbon capture and sequestration (CCS) during hydrogen production, with the highest CI based on the current real-world average carbon capture rate of 55%. The solid orange bar indicates CI with a 96.2% capture rate.

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The CIs for the potential renewable diesel pathways range between 11g and 58 g CO<sub>2e</sub>/MJ while the CIs for FT-diesel produced from lignocellulosic residues are between 5 g and 10 g CO<sub>2e</sub>/MJ. Vegetable oil pathways have the highest direct emissions across all pathways and ILUC makes up the largest share of emissions in most cases. Electric locomotives provide some of the largest reductions in GHG emissions and have an efficiency-adjusted CI of 15.0 g CO<sub>2e</sub>/MJ when assuming the current grid mix in California. As the electricity grid continues to decarbonize, the electricity CI will drop even lower. Electrolytic hydrogen has the potential to deliver significant emission reductions if it is produced from 100% renewable electricity; if not, its upstream emission impacts are amplified due to the low conversion efficiency of the electrolysis process.

The existing pool of renewable diesel consumed in the United States comes mainly from waste oil feedstocks; approximately 18% by volume is soybean oil.<sup>21</sup> As the United States does not release national-level data on renewable diesel consumption by feedstock, we infer these trends from California, which consumes nearly all the renewable diesel produced in the country.<sup>22</sup> The mix of renewable diesel feedstocks consumed today has a relatively low CI, but expanding the use of renewable diesel to other sectors is likely to create more demand. This demand might be met using more abundant but higher-CI feedstocks, posing sustainability and climate risks. We next

21 California Air Resources Board, “Low Carbon Fuel Standard Reporting Tool Quarterly Summaries,” accessed January 28, 2023, <https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries>.  
 22 U.S. Energy Information Administration, “Almost All U.S. Renewable Diesel Is Consumed in California; Most Isn’t Made There,” July 20, 2023, <https://www.eia.gov/todayinenergy/detail.php?id=57180>.

explore the availability of biomass in the United States that does not currently have competing uses in other sectors and thus could be diverted to the rail sector to align with BETO's liquid fuels decarbonization strategy.

## AVAILABILITY OF RENEWABLE DIESEL FOR THE RAIL SECTOR

Here we draw upon previous work by the ICCT for the road and aviation sectors that assessed the availability of vegetable and waste oils to produce biofuels. We also draw from DOE's Billion-Ton Report for our estimates of the availability of lignocellulosic feedstocks such as agricultural residues and dedicated energy crops.<sup>23</sup> Because we consider feedstocks to be sustainably available if they do not lead to additional market-mediated impacts, the feedstock quantities consumed in non-transport applications such as food and consumer products were excluded. For lignocellulosic feedstocks, we also excluded the shares of biomass from whole trees due to their high sustainability risks.<sup>24</sup>

In estimating the production potential of renewable diesel and FT-diesel for use in rail applications, we updated process yield conversions from a previous assessment for the aviation sector. We also updated our adjustment factors at biorefineries to account for a road- or rail-optimized product slate rather than a jet-optimized product slate.<sup>25</sup> Our availability assessments for vegetable oils, waste oils, and lignocellulosic feedstocks and their corresponding fuel production volumes are summarized in Table 1.

The additional estimate for soy oil renewable diesel in Table 1 assumes that whole soybean crush rates are maximized from a current rate of roughly 50%.<sup>26</sup> The soybean crushing process allows producers to separate the soybean oil and soymeal from whole soybeans; uncrushed soybeans are more commonly exported. The EPA projects that domestic soybean crush rates will increase in the coming years due to efforts to expand renewable diesel production capacity and policy incentives that reward the oily fraction of whole soybeans.<sup>27</sup> Higher crush rates in the United States would likely lead to shifts in soybean markets. In some cases, this could prompt producers in the food, feed, and oleochemicals industries to source high-GHG palm oil as a substitute for soybean oil in markets such as China.<sup>28</sup>

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23 Jane O'Malley et al., *Setting a Lipids Fuel Cap under the California Low Carbon Fuel Standard* (Washington, D.C.: International Council on Clean Transportation, 2022), <https://theicct.org/publication/lipids-cap-ca-lcfs-aug22/>; U.S. Department of Energy, *2023 Billion-Ton Report: An Assessment of U.S. Renewable Carbon Resources*, M.H. Langholtz, lead (Oak Ridge, TN: Oak Ridge National Laboratory, 2024), <https://doi.org/10.23720/BT2023/2316165>.

24 Alessandro Agostini, Jacopo Guintoli, and Aikaterini Boulamanti, *Carbon Accounting of Forest Bioenergy: Conclusions and Recommendations from a Critical Literature Review* (Luxembourg: Publications Office of the European Union, 2014), <https://data.europa.eu/doi/10.2788/29442>; O'Malley, Pavlenko, and Kim, "Meeting the SAF Grand Challenge."

25 Nikita Pavlenko, Stephanie Searle, and Adam Christensen, *The Cost of Supporting Alternative Jet Fuels in the European Union* (Washington, DC: International Council on Clean Transportation, 2019), [https://theicct.org/sites/default/files/publications/Alternative\\_jet\\_fuels\\_cost\\_EU\\_2020\\_06\\_v3.pdf](https://theicct.org/sites/default/files/publications/Alternative_jet_fuels_cost_EU_2020_06_v3.pdf).

26 Economic Research Service, U.S. Department of Agriculture, "Oil Crops Yearbook," March 27, 2023, <https://www.ers.usda.gov/data-products/oil-crops-yearbook/oil-crops-yearbook/#Soy%20and%20Soybean%20Products>.

27 U.S. Environmental Protection Agency, *RFS2 Regulatory Impact Analysis*.

28 O'Malley et al., *Setting a Lipids Fuel Cap*.

**Table 1****Estimated feedstock availability and fuel production for biomass-based rail fuel in 2030**

Feedstock	Estimated available quantity (million tonnes)	Fuel pathway	Yield conversion (kg fuel/kg feedstock)	Fuel production (million tonnes)	Fuel production (billion gal)
Canola oil	0.72	Renewable diesel	0.87	0.48	0.16
Soybean oil (at 100% crush rates)	15.3	Renewable diesel	0.87	10.13	3.44
Soybean oil (at current crush rates)	4.2	Renewable diesel	0.87	2.80	0.95
Distillers corn oil	2.1	Renewable diesel	0.87	1.41	0.48
Used cooking oil	2.8	Renewable diesel	0.87	1.83	0.62
Animal fats	2.4	Renewable diesel	0.87	1.59	0.54
Municipal solid waste	111.3	FT-diesel	0.12	7.63	2.53
Agricultural residues	171.5	FT-diesel	0.20	20.00	6.63
Forestry residues	25.4	FT-diesel	0.22	3.31	1.10
Energy crops	89.7	FT-diesel	0.20	10.47	3.47
<b>Total</b>	<b>421</b>			<b>57.3</b>	<b>19.0</b>

In total, we estimate 421 million tonnes (Mt) of available biomass feedstocks in the United States in 2030 that could be converted to 19.0 billion gallons of BBD. This assumes that the sustainable consumption of waste oils in the United States—including distillers corn oil, used cooking oil, and animal fats—is already maximized (we do not consider any increase in imports) and that soybean production could nominally grow over time with yield improvements. The largest sources of available feedstocks in 2030 are from agricultural residues and energy crops that are converted to BBD and soybean oil, assuming maximum crush rates. However, the processes that convert agricultural residues and energy crops to BBD have thus far struggled to commercialize.<sup>29</sup>

If BBD is consumed for rail operations, it will compete with other transport modes, including aviation and maritime shipping. Meeting all the projected fuel demand across all sectors of the economy is likely to run up against supply limitations, and we review the competing sources for BBD feedstocks in the following section.

## RESOURCE COMPETITION FOR AVAILABLE BIOMASS

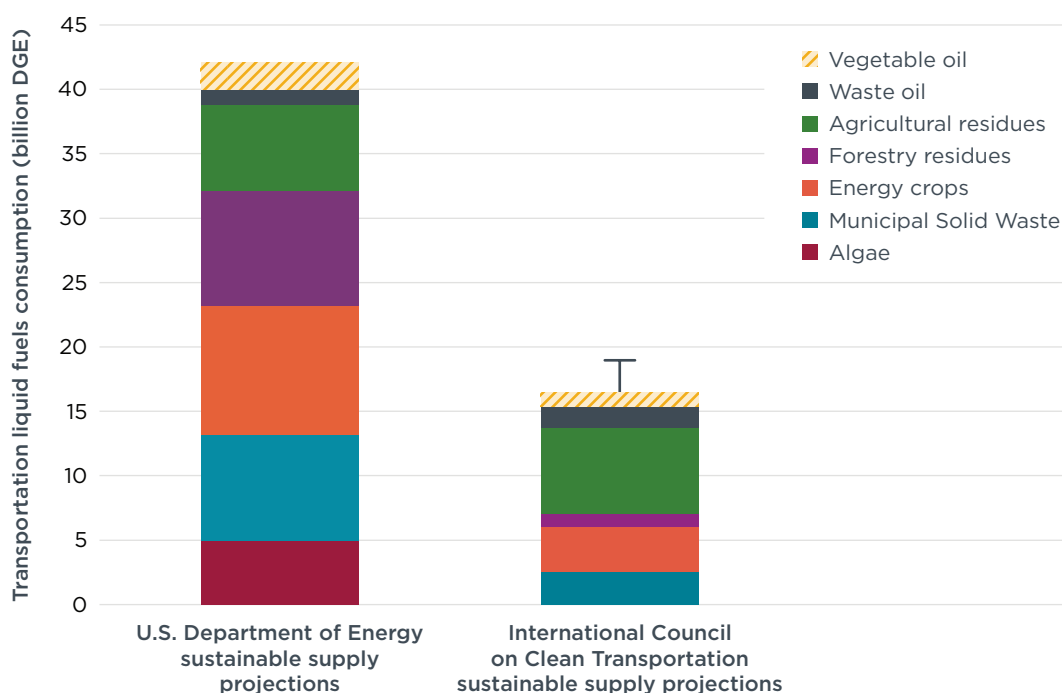
BBD is one of the few options for decarbonizing long-distance maritime and aviation routes because of the need for energy-dense fuel in these applications. The Biden administration and DOE expect biomass to be the primary contributor to the administration’s 35 billion-gallon Sustainable Aviation Fuel (SAF) Grand Challenge

<sup>29</sup> Patricia Anselmi et al., *Future Diesel-like Renewable Fuels - A Literature Review* (Brussels: Concawe, 2022), <https://www.concawe.eu/wp-content/uploads/Rpt-22-18.pdf>.

target.<sup>30</sup> Biomass has also been identified as a promising low-carbon solution for decarbonizing the maritime sector.<sup>31</sup>

The DOE’s projections for sustainable biomass availability fall short of the combined projected fuel demand for the maritime, aviation, rail, and off-road sectors in 2050.<sup>32</sup> In the 2023 National Blueprint for Transport Decarbonization report, the DOE estimated that domestic biomass resources could provide approximately 53 billion DGE of fuel in 2030 and beyond, including fuel made from vegetable oil and starch feedstocks, and pathways that are not yet widely commercialized such as algae and the conversion of lignocellulosic materials. Although BBD derived from vegetable oils does not typically provide substantial GHG savings relative to fossil fuels, we included them in our availability assessment because their volumes are mandated by existing policies such as the federal Renewable Fuel Standard.<sup>33</sup> We exclude starch feedstocks including corn and sugarcane from our Figure 2 comparison because they are not suitable for BBD production.

**Figure 2**  
**Comparison of projections for sustainable biomass supply for rail BBD feedstocks in 2030**



*Note:* Adapted from U.S. Department of Energy et al., U.S. National Blueprint for Transportation Decarbonization. Vegetable oil feedstocks are in hatched bars because we do not consider them to be sustainably available. We adjust DOE feedstock categories by the weighted quantity of unique feedstocks from the 2023 Billion-Ton Report. The error bar represents maximum soybean crush rates.

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<sup>30</sup> Kim Chipman and Tarso Veloso, “Why Green Air Travel Will Be a Lifeline for US Corn Farmers,” *Bloomberg*, September 26, 2023, <https://www.bloomberg.com/news/articles/2023-09-26/sustainable-aviation-fuel-a-lifeline-for-america-s-corn-farmers>.

<sup>31</sup> U.S. Department of Energy Bioenergy Technologies Office, “Sustainable Marine Fuels,” accessed January 20, 2024, <https://www.energy.gov/eere/bioenergy/sustainable-marine-fuels>.

<sup>32</sup> U.S. Energy Information Administration, “Annual Energy Outlook 2023.”

<sup>33</sup> We used DOE biomass supply estimates from the 2016 Billion-Ton Report but excluded feedstocks that we consider to be unsustainable. We reallocated secondary crop residues that are classified under municipal solid waste to the agricultural residues category and adjusted energy crop yield estimates based on real-world data.



DOE's sustainable supply assessment is far higher than the ICCT's assessment because we excluded high-risk feedstocks such as whole trees from our analysis and adjusted the expected yields of dedicated energy crops downward to reflect real-world production at scale. We also excluded feedstock pathways that are not likely to become commercially viable for rail applications, including wet wastes (e.g., manure and sewage sludge) and algae. In total, we estimated that sustainable biomass feedstocks could produce approximately 15.5 billion DGE of fuel in 2030, or up to 19.0 billion DGE if we include quantities from high-GHG-risk oilseed pathways. This would not be sufficient to meet the projected fuel demand across multiple transport sectors. Feedstock availability could grow or decrease by 2050, but no projections for later year volumes are made here due to the significant uncertainties involved.

## CONCLUDING REMARKS

Biofuels can fuel long-distance transportation when direct electrification is infeasible, but unlike abundant wind and solar energy, the supply of biomass feedstocks is limited. To conserve limited BBD resources for sectors such as aviation and maritime shipping, other technology options—including catenary systems, electric batteries, and hydrogen fuel cells—can be used to decarbonize rail. These will require substantial funding and investment in new infrastructure so in the near term, as the infrastructure is being built out, rail operators could switch to hybrid diesel-battery-electric systems that comply with EPA's Tier 4 emission standards.

California's In-Use Locomotive Regulation, adopted last year, contains several strategies that could be a model for other states and the federal government. The regulation requires locomotive operators to phase in zero-emission locomotives beginning in 2030 and to transition all switch, industrial, and passenger locomotives to zero-emission by 2050.<sup>34</sup> Additionally, the California LCFS provides a direct incentive for zero-emission rail technologies via fueling credits based on a fuel's life-cycle CI relative to an annually declining CI target. The LCFS also contains a provision that credits eligible parties for infrastructure investments such as light-, medium-, and heavy-duty fast-charging infrastructure. These incentives could be broadened to the rail sector to support infrastructure expansion.

U.S. rail decarbonization strategies could also capitalize on funding streams made available in the 2022 Inflation Reduction Act (IRA) and 2021 Infrastructure Investment and Jobs Act (IIJA). These include the Section 45V tax credit for the production of clean hydrogen and the Surface Transportation Block Grant (STBG) as well as infrastructure programs that make \$250 million in federal funding available between fiscal years 2022 and 2026.<sup>35</sup> At the state level, CARB offers grant funding to locomotive operators to meet requirements set forth under the In-Use Locomotive Regulation.<sup>36</sup> In the near term, it is critical that the U.S. rail sector build upon these policy levers to position itself to meet longer-term GHG reduction goals such as an 80%-100% reduction in transportation sector emissions by 2050.<sup>37</sup> Prioritizing investment in non-liquid fuel alternatives will minimize competition for limited BBD resources that are closely linked with adverse market and environmental impacts.

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34 California Air Resources Board, "CARB Fact Sheet: Class II, Class III, and Industrial Locomotive Operators," June 21, 2022, <https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-class-ii-class-iii-and-industrial-locomotive-operators>.

35 Infrastructure and Investment Jobs Act, Public L. No. 117-58, 135 Stat. 429 (2021), <https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf>.

36 California Air Resources Board, "Incentives for Locomotives: Reducing Rail Emissions in California," accessed January 20, 2024, <https://ww2.arb.ca.gov/our-work/programs/reducing-rail-emissions-california/incentives-locomotives>.

37 U.S. Department of State and the Executive Office of the President, *The Long-Term Strategy of the United States, Pathways to Net-Zero Greenhouse Gas Emissions by 2050* (Washington, DC, 2021), <https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Str>.



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