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Opportunities and risks for continued biofuel expansion in Brazil

SUMMARY

Brazil is one of the world's leading biofuel markets, producing nearly 40 billion liters of biofuels in 2018. Brazil's biodiesel industry has expanded in recent years as a result of increases in mandated blend levels for diesel fuel. The introduction of the RenovaBio program to expand ethanol production, accompanied by further increases in the biodiesel blending mandate, is expected to lead to even higher biofuel consumption in the next decade. This paper provides an overview of Brazil's biofuel policy framework, highlights the risks of continued biofuel expansion, and presents several opportunities to improve the climate performance of Brazil's fuel policies.

The continued growth of Brazil's biofuel industry over the next decade could have profound impacts on the climate. Biofuel policy in Brazil is of special importance because of the country's substantial forestland and high biodiversity. Although Brazil has implemented some policies to discourage deforestation, as well as some sustainability safeguards within its biofuel framework, these measures may do little to discourage the indirect pressures of biofuel demand on deforestation and grassland, which may result in the conversion of high-carbon stock land. Recent political changes affecting Brazil's forestry and agricultural policy, in conjunction with the continued expansion of Brazil's biofuel industry, may pose further risks to biodiversity. Additionally, further increases to Brazil's biodiesel blending mandate could create compatibility issues for the country's vehicle fleet, degrading equipment and emitting greater amounts of local air pollutants.

This briefing provides an overview of the potential negative impacts of Brazil's biofuel policies on the environment and vehicle fleet. It also offers the following recommendations on how these policies could support more sustainable alternative fuels:

» **Maintain or scale back the current biodiesel mandate:** Continued rapid increases in Brazil's biodiesel mandate have increased the blend rate of biodiesel far beyond levels in most other countries in the world, without a concurrent change

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in the composition of Brazil's vehicle fleet. Soy biodiesel blend levels in excess of 10% not only increase emissions of nitrogen oxides (NO_x) but also contribute to compatibility issues for most vehicles, resulting in damage and increased maintenance costs. Capping the biodiesel mandate at 10% beyond 2019 would mitigate the harmful effects of higher-level blends of biodiesel on vehicle compatibility as well as the risk of additional soybean demand driving deforestation.

» **Introduce subtargets or ILUC factors within RenovaBio to facilitate greater deployment of advanced biofuels:** RenovaBio, as currently implemented, provides a weak incentive for non-food fuels and is likely insufficient to support the production of more sustainable but costly advanced fuels. Introducing indirect land-use change (ILUC) emission factors would aid the transition to advanced biofuels by allowing producers to generate more tradeable decarbonization (CBIO) credits relative to first-generation fuels. Alternatively, a subtarget for advanced fuels—defined as those produced from wastes, residues, or lignocellulosic feedstocks—would provide a separate incentive for advanced biofuels within RenovaBio without substantial changes to its life-cycle analysis methodology.

» **Incorporate sustainability criteria to mitigate indirect land conversion within RenovaBio:** Existing land protections in Brazil are insufficient to prevent the indirect, market-mediated land conversion that may occur in response to biofuel demand. Existing proposals for sustainability protections rely heavily on the efficacy of these land protections and only prevent direct land conversion for biofuel production. Additional criteria, such as eligibility requirements for land conversion for a given feedstock to fall below a threshold for deforestation, could eliminate risky feedstocks such as oilseeds from being able to generate CBIO credits, thus directing the program support toward feedstocks with better greenhouse gas performance.

OVERVIEW OF BRAZIL'S BIOFUEL POLICY FRAMEWORK

Historically, mandates have driven biofuel consumption in Brazil. Ethanol blending started in 1975 with the National Alcohol Program (Programa Nacional do Alcool; Proálcool) to promote domestic ethanol production. Proálcool progressively ramped up mandated ethanol blend rates from fuel suppliers to 27% by 2015.[1] This was accompanied by an increasing set of biodiesel blending mandates, beginning in 2003 to 11% in 2019. Taken together, nearly 40 billion liters of biofuels were consumed in Brazil in 2018, primarily derived from food crops. Further expansion is expected over the next decade, as the newly introduced RenovaBio policy introduces carbon pricing into Brazil's fuel policy and could lead to further expansion.[2] Figure 1 illustrates the growth of Brazil's ethanol and biodiesel consumption and blend rates over the past decade.

1 Tim Dallmann and Cristiano Façanha, *International Comparison of Brazilian Regulatory Standards for Light-Duty Vehicle Emissions* (ICCT: Washington, DC, 2017), www.theicct.org/publications/international-comparison-brazilian-regulatory-standards-light-duty-vehicle-emissions.

2 Lei Ordinária 13.576, de 26.12.2017; www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/lei/L13576.htm.

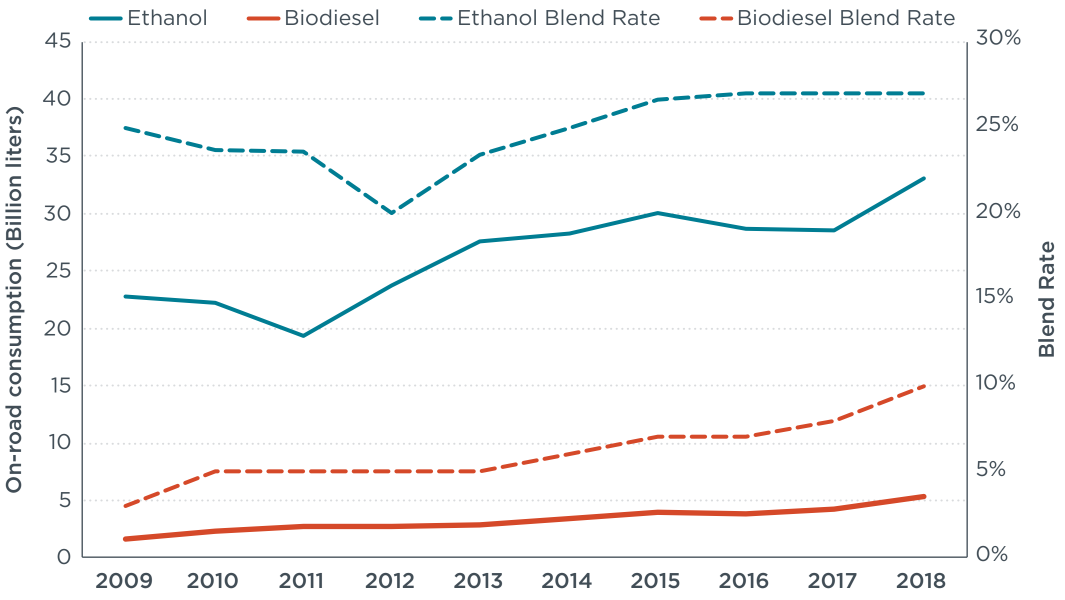

Figure 1. Ethanol and biodiesel consumption and blending in Brazil, 2009–2018.
Source: Agência Nacional do Petróleo, Gás Natural e Biocombustíveis [National Agency of Petroleum, Natural Gas and Biofuels]. Dados estatísticos: Produção de biocombustíveis [Statistical Data: Production of Biofuels].

Brazil has been a world leader in ethanol production from sugarcane. The ethanol mandate has increased from a 4.5% blend in 1977 to 27% in 2015, resulting in more than 33 billion liters of ethanol produced in 2018.[3] Of that total, roughly 23 billion liters were hydrous ethanol, which can be consumed by flex-fuel vehicles. Table 1 compares Brazil's blend rates to those of other countries and jurisdictions with substantial biofuel policies.

Table 1. Biofuel blend rates in selected jurisdictions.

Country/region	Ethanol blend rate	Biodiesel blend rate
United States	10%	5%
EU-28	5.7%	7.2%
Brazil	27%	11%
Indonesia	0%	20%

Brazil's ethanol use mandate, Proálcool, primarily supports its production through a series of federal and regional tax incentives. At the federal level, Brazil levies a tax on gasoline through the Contribution for Intervention in Economic Domain (CIDE) and Social Integration Program/Contribution for Financing Social Security (PIS/COFINS) policies; in early 2019, these policies have totaled R$ 0.8925 per liter.[4] Although ethanol is not taxed under CIDE, ethanol producers are taxed under the PIS/COFINS policy at a rate of R$ 0.1309 per liter in March, 2019.[5] The difference between the total tax rates for gasoline and ethanol increases the competitive advantage of ethanol, even after accounting for the difference in energy density between the two fuels. Depending on the regional tax rates and fluctuations in the price of crude oil, ethanol may have a competitive advantage relative to gasoline and vice versa.

3 Agência Nacional do Petróleo, Gás Natural e Biocombustíveis [National Agency of Petroleum, Natural Gas and Biofuels], "Dados estatísticos: Produção de biocombustíveis" [Statistical Data: Production of Biofuels] (2019), www.anp.gov.br/dados-estatisticos.

4 Federação Nacional do Comércio de Combustíveis e de Lubrificantes [National Federation of Fuel and Lubricants Trade], *Tributação* [Taxation]; www.fecombustiveis.org.br/revendedor/tributacao/.

5 Ibid.

The wide-scale deployment of flex-fuel vehicles capable of using higher ethanol blends in Brazil's vehicle fleet ensures a large market for high-ethanol blends. The Inovar-Auto fiscal incentive program has promoted increased vehicle efficiency through a vehicle energy consumption target (with penalties for noncompliance) in conjunction with credit multipliers and tax breaks for manufacturers of vehicles with advanced propulsion systems. Through the program, both ethanol and flex-fuel vehicles produced in Brazil have qualified for a tax break on the industrialized products tax and can qualify for off-cycle credits to meet the energy consumption target.[6] The Rota 2030 program, set to replace Inovar-Auto, will continue to provide tax credits to flex-fuel and ethanol vehicles through 2032.[7] As a result of strong policy support, flex-fuel vehicles constituted approximately 98% of all passenger cars in 2018 and approximately two-thirds of the light-duty vehicle fleet; 100% ethanol (E100)–powered vehicles are estimated to constitute 0.7% of the total vehicle fleet.[8]

The biodiesel industry has seen a rapid expansion over the past decade. Beginning in 2003, the National Program of Biodiesel Production and Use (NPBP) has implemented a biodiesel mandate that has ramped up quickly from 2% in 2008 to 10% in 2018.[9] Brazil's National Council for Energy Policies (CNPE) has proposed a 1% annual increase to reach B15 (15% biodiesel) blending rates by 2023 as long as certain technical requirements are met.[10] The National Agency of Petroleum, Natural Gas and Biofuels (ANP) has already established specifications for biofuel blends up to 30% and has even established criteria for the use of B100 blends on an experimental basis.[11]

Government support for biodiesel is ensured through a price floor established through an auction system. The federal government, via ANP, operates regular public reverse auctions where biodiesel producers competitively bid to sell lots of biodiesel to buyers. Obligated parties for the blending mandate, such as blenders of fossil diesel, are then required to pay the prices set by the auction for their biodiesel lots.

The rapid expansion of Brazil's biodiesel industry corresponds with the growth and expansion of its soy industry, which provides more than two-thirds of its biodiesel. Roughly 12.5% comes from tallow.[12] Although biodiesel blend rates have increased in recent years, there has not been a corresponding increase in compatible vehicles. The biodiesel mandate stands at 11% in 2019, with even higher allowed blend rates for rail, agricultural, and industrial uses. Local-level initiatives could increase sales of vehicles designed for high-biodiesel blends, such as the São Paulo Climate Committee's goal of transitioning to a fossil-free bus fleet.[13] In addition, the city of São Paulo revised its

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6 Cristiano Façanha, *Brazil's Inovar-Auto Fiscal Incentive Program Updates,* (ICCT: Washington, DC, 2015) www.theicct.org/publications/brazils-inovar-auto-fiscal-incentive-program-updates.

7 Ministério da Indústria, Comércio Exterior e Serviços [Ministry of Industry, Foreign Trade and Service], "Governo sanciona lei que institui o Programa Rota 2030" [Government enacts law establishing the Rota 2030 Program], December 11, 2018; www.mdic.gov.br/index.php/ultimas-noticias/3726-governo-sanciona-lei-que-institui-o-programa-rota-2030.

8 Sindicato Nacional da Indústria de Componentes para Veículos Automotores [National Union of the Components Industry for Automotive Vehicles] e Associação Brasileira da Indústria de Autopeças [Brazilian Association of the Autoparts Industry], "Relatório da Frota Circulante 2018" [Current Fleet Report 2018], www.sindipecas.org.br/sindinews/Economia/2018/R_Frota_Circulante_2018.pdf.

9 Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, 2019.

10 Lei Ordinária 13.263, de 23.3.2016; www.planalto.gov.br/ccivil_03/_ato2015-2018/2016/lei/L13263.htm.

11 Resolução ANP 30, de 23.6.2016 - dou 24.6.2016 - RET. dou de 13.1.2017, http://legislacao.anp.gov.br/?path=legislacao-anp/resol-anp/2016/junho&item=ranp-30-2016; Resolução ANP 34, de 28.7.2016 - DOU 29.7.2016, http://legislacao.anp.gov.br/?path=legislacao-anp/resol-anp/2016/julho&item=ranp-34--2016&export=pdf.

12 Agência Nacional do Petróleo, Gás Natural e Biocombustíveis [National Agency of Petroleum, Natural Gas and Biofuels], "Informações de Mercado" [Market Information] (2019); www.anp.gov.br/producao-de-biocombustiveis/biodiesel/informacoes-de-mercado.

13 Tim Dallmann, *Climate and Air Pollutant Emissions Benefits of Bus Technology Options in São Paulo,* (ICCT: Washington, DC, 2019), https://www.theicct.org/sites/default/files/publications/Emissions_benefits_bus_sao%20paulo_201902014.pdf.

Climate Change Law in January 2018 that sets 10-year and 20-year targets for fleetwide reductions in tailpipe emissions of fossil carbon dioxide (CO_2) and the air pollutants particulate matter (PM) and nitrogen oxides (NO_x).

The RenovaBio policy builds on Brazil's existing ethanol blending mandate to include a 10% carbon intensity (CI) reduction target for the transport fuel mix, relative to its 2017 baseline of 74.25 gCO_2e per MJ of fuel by 2028.[14] The policy would establish tradeable decarbonization (CBIO) credits generated by the production of biofuels and then redeemed by fuel blenders, increasing the cost of fossil fuels while reducing the relative costs of biofuels. Over the past decade, the low price of oil, in conjunction with climate and economic instability, has resulted in some stagnation within Brazil's domestic ethanol industry. The introduction of the RenovaBio program in 2018 was intended to both support the expansion of ethanol production and improve the cost proposition for ethanol relative to gasoline. The Ministry of Mines and Energy estimates that with the added incentives, the overall demand for Brazilian ethanol will increase to 45 billion liters by 2027.[15]

The RenovaBio policy uses life-cycle greenhouse gas (GHG) accounting to evaluate the climate impacts of fuels but does not account for any emissions from indirect land-use change (ILUC). ILUC emissions are those attributable to market-mediated land expansion caused by biofuel demand for crop-derived feedstocks. Because these emissions may undermine the carbon savings associated with biofuel use, policies such as the U.S. Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS) assign crop-derived fuels an ILUC emission factor estimated through economic modeling. RenovaBio incorporates sustainability criteria to avoid the use of biofuels directly grown either on high–carbon stock land or in areas tied to deforestation. Although those land protections may discourage direct deforestation for biofuel production, they may do little to prevent indirect cropland expansion caused by greater demand for food crops.

RISKS OF BIOFUEL EXPANSION

LAND-USE CHANGE EMISSIONS

ILUC occurs in response to the increased demand for cropland, often stemming from demand for crops for biofuel production. Even if biofuel feedstocks are grown on existing cropland, the additional demand for crops caused by biofuel policies increases the overall price of those commodities, incentivizing cropland expansion in other regions and generating ILUC emissions attributable to that biofuel demand. The magnitude of these ILUC emissions can vary substantially according to the feedstock in question and the source of that biofuel demand. As these emissions cannot be directly measured, they are instead estimated through the use of economic models. ILUC emissions have been estimated and factored into the design of various biofuel policies, including the United States' federal RFS, Europe's recast Renewable Energy Directive for 2030 (RED II), and California's LCFS.

The literature suggests that crops with the lowest ILUC emissions tend to be lignocellulosic energy crops, which can be grown on marginal or degraded lands unsuitable for traditional agriculture; generally, these crops aren't valuable enough

14 Lei Ordinária 13.576, 2017.

15 Ministério de Minas e Energia [Ministry of Mines and Energy], "Plano Decenal de Expansão de Energia" [Ten Year Energy Expansion Plan] (2018), www.mme.gov.br/documents/10584/1432059/Plano+Decenal+de+Expansão%C3%A3o+de+Energia+2027+%28PDE+2027%29/66498aa7-5e33-47ea-b586-2a6b1b994f7f?version=1.1.

to displace food production.[16] Depending on the assumptions and the land use protections in place, some studies suggest that energy crops may even emit zero or negative ILUC emissions as a consequence of their potential to generate long-term carbon sequestration in marginal lands. By-products and residues from first-generation feedstocks, such as corn stover or sugarcane bagasse, can also be converted into biofuels with relatively low climate impacts; however, like energy crops, these lignocellulosic feedstocks are generally more challenging to convert into fuels than conventional sugars, starches, and vegetable oils.

Starchy and sugary crops tend to have moderate ILUC emissions. The International Institute for Applied Systems Analysis (IIASA) uses the GLOBIOM model to assess the ILUC emissions of Brazilian sugarcane ethanol imported into the European Union (EU), estimating emissions of roughly 11.3 gCO_2e/MJ.[17] This estimate is fairly consistent with other assessments in the literature. For example, California's Air Resources Board (ARB) estimates that sugarcane ethanol produced in Brazil generates ILUC emissions of 11.8 gCO_2e per MJ of fuel, the lowest of any food crop–derived fuels certified by ARB.[18] Using a set of assumptions and modeling tools comparable to those used by California ARB, a Brazilian modeling team assessed ILUC emissions from sugarcane-derived jet fuel at 12 gCO_2e/MJ.[19] Sugarcane's low ILUC emissions are partly attributable to its high yields, resulting in less overall land conversion in response to a given level of biofuel demand relative to other biofuel feedstocks.[20]

Figure 2 presents a comparison of the well-to-wheel emissions for a selection of ethanol pathways, including both first-generation and second-generation pathways. Well-to-wheel emissions include direct emissions from manufacturing each fuel (brown bars) and the additional ILUC emissions attributable to biofuel demand (blue bars). For comparison, gasoline emissions are illustrated by the dashed line. Even after accounting for ILUC, sugarcane ethanol may still generate approximately a 52.3% GHG reduction relative to gasoline, whereas domestic and imported corn have slightly higher emissions. The difference between the direct emissions of direct versus imported corn is primarily attributable to the higher electricity grid emissions in the United States, as well as additional transport emissions associated with importing the ethanol over long distances. Bagasse ethanol, a second-generation fuel manufactured from sugarcane residue, provides an 83% GHG reduction relative to fossil gasoline.

16 Nikita Pavlenko and Stephanie Searle, *A Comparison of Induced Land-Use Change Emissions Estimates from Energy Crops* (ICCT: Washington, DC, 2018), www.theicct.org/publications/comparison-ILUC-emissions-estimates-energy-crops.

17 Hugo Valin, Daan Peters, Maarten van den Berg, Stefan Frank, Petr Havlik, Nicklas Forsell, and Carlo Hamelinck, *The Land Use Change Impact of Biofuels Consumed in the EU: Quantification of Area and Greenhouse Gas Impacts* (Ecofys: Utrecht, 2015); https://ec.europa.eu/energy/sites/ener/files/documents/Final Report_GLOBIOM_publication.pdf. This emissions estimate has been linearly converted into a 30-year time horizon for consistency with ILUC estimates from California's ARB.

18 California Air Resources Board (ARB), "Detailed Analysis for Indirect Land Use Change" (2015), www.arb.ca.gov/fuels/lcfs/iluc_assessment/iluc_analysis.pdf.

19 Marcelo Moreira, Angelo C. Gurgel, and Joaquim E. A. Seabra, Life cycle greenhouse gas emissions of sugar cane renewable jet fuel. *Environmental Science & Technology, 48,* 14756–14763 (2014); doi: 10.1021/es503217g.

20 Andre Meloni Nassar and Marcelo Moreira, "Evidences on Sugarcane Expansion and Agricultural Land Use Changes in Brazil." Institute for International Trade Negotiations (ICONE) (2013), www.iconebrasil.com.br/datafiles/publicacoes/estudos/2013/evidences_on_sugarcane_expansion_and_agricultural_land_use_changes_in_brazil_1206_2.pdf.

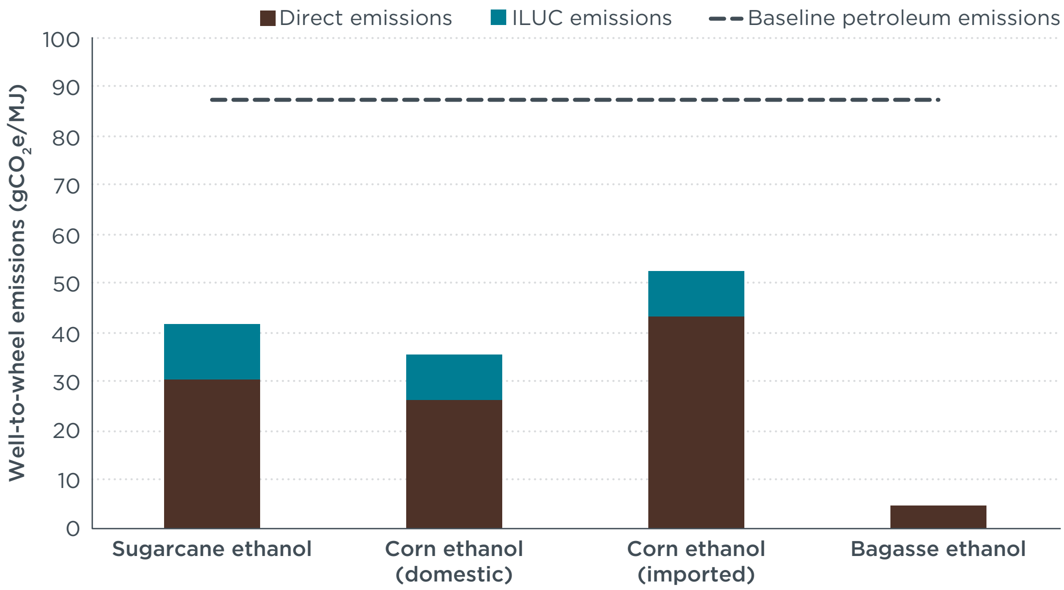

Figure 2. Comparison of life-cycle GHG emissions of selected ethanol fuel pathways relative to conventional fossil gasoline.
Source: Direct emissions values taken from the Renovacalc tool; ILUC emissions values taken from Valin et al. (2015) for corn and sugarcane. These values are all provided in terms of a 30-year time horizon.

Figure 3 shows that direct production emissions for biodiesel and hydrotreated vegetable oil (HVO) are comparable, and the largest differences among oilseed pathways are attributable to ILUC. Relative to sugarcane, the ILUC emissions attributable to oilseed production are typically much higher.[21] There is not a publicly available ILUC assessment for soy-derived biofuel production in Brazil; however, there have been several assessments of ILUC for soy produced in the United States and soy demand originating in the EU. Because ILUC assessments rely strongly on observed trade patterns between countries, EU-specific ILUC assessments may provide a greater insight on the ILUC emissions of soy in Brazil due to existing trade relationships with both North and South America in the modeling frameworks, whereas U.S. assessments generally assume that soybean demand is met domestically.[22]

21 Valin et al., 2015.

22 Chris Malins, Stephanie Searle, and Anil Baral, *A Guide for the Perplexed to the Indirect Effects of Biofuels Production* (ICCT: Washington, DC, 2014), https://theicct.org/publications/guide-perplexed-indirect-effects-biofuels-production.

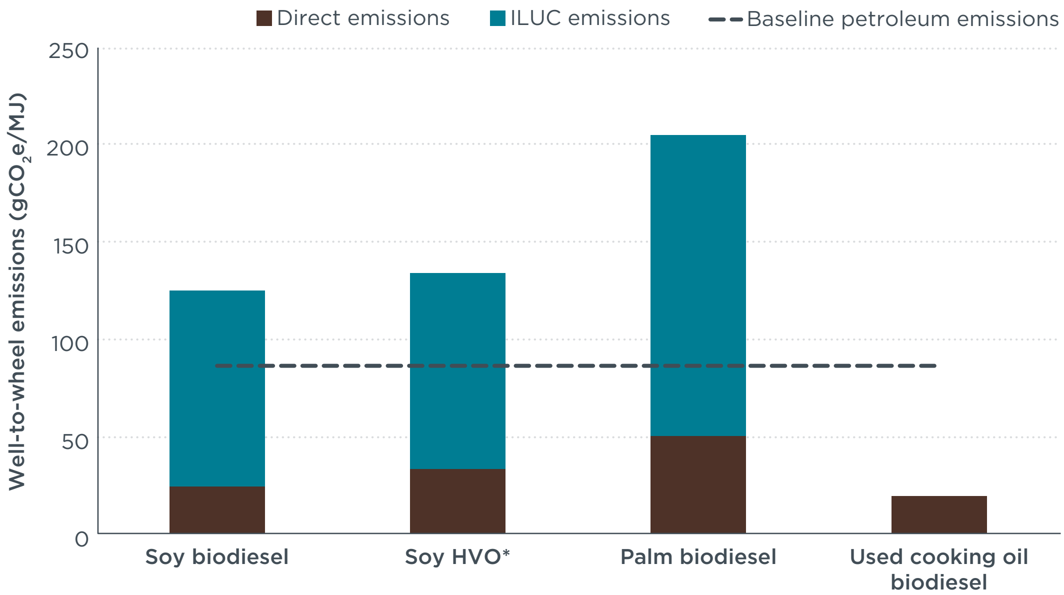

Figure 3. Comparison of life-cycle GHG emissions of selected biodiesel and hydrotreated vegetable oil (HVO) pathways relative to conventional fossil diesel.
Source: Direct emissions values are taken from the Renovacalc tool; palm and used cooking oil biodiesel values are taken from the GREET model; ILUC emissions are taken from Valin et al. (2015).
*HEFA value from Renovacalc is used as a proxy for soy HVO fuel.

An IIASA assessment using the GLOBIOM model assesses the ILUC emissions for soy biodiesel used in the EU, estimating emissions of roughly 100 gCO_2e/MJ—pushing soy biodiesel above the baseline emissions for petroleum diesel from ILUC alone.[23] The model estimates that 37% of EU soy biodiesel demand is met through soybeans imported from South America, with another 55% imported from North America. The model finds that the bulk of land expansion would occur in South America on grassland as pastureland expands, in addition to cropland expansion on high-carbon stock land in Southeast Asia caused by increased palm oil demand. The latter phenomenon is predicted to occur because the increased use of soy oil for biofuels diverts it from existing uses and incentivizes the increased use of its lowest-cost substitute, palm oil.[24]

Brazil's government has decided to exclude explicit ILUC emissions accounting from the RenovaBio program because of these emissions' uncertainty and the perception that Brazil's existing land protections are sufficient to mitigate deforestation.[25] Instead, the eligibility of individual fuel pathways within RenovaBio will be determined by criteria established by Brazil's National Petroleum Agency (ANP), which determines the quantity of CBIO credits awarded per unit of fuel. A proposal originally developed by the Brazil Agricultural Research Corporation (Embrapa) and intended to instead mitigate the risk of deforestation by establishing eligibility criteria for feedstock producers without the use of ILUC emission factors was incorporated into the final regulation. The sustainability criteria for biomass include the following:

1. All certified production must come from an area without deforestation after the date of enactment of the RenovaBio law (December 26, 2017);

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23 Valin et al., 2015.

24 Stephanie Searle, *How Rapeseed and Soy Biodiesel Drive Oil Palm Expansion,* (ICCT: Washington, DC, 2017), www.theicct.org/sites/default/files/publications/Oil-palm-expansion_ICCT-Briefing_27072017_vF.pdf.

25 Miguel Ivan Lacerda de Oliveira, Marcelo Augusto Boechat Morandi, Marília Folegatti Matsuura, and Marcelo Ramalho Moreira, "RenovaBio irá vincular CBios a sustentabilidade no uso da terra" [RenovaBio will link CBios to sustainability in land use]. Embrapa (2018); www.embrapa.br/busca-de-noticias/-/noticia/33448696/artigo---renovabio-ira-vincular-cbios-a-sustentabilidade-no-uso-da-terra.

2. The entire area must comply with the Forest Code, through the regularization of the Rural Environmental Registry; and,

3. The sugar cane and palm production areas should comply with the agroecological zoning of sugarcane and oil palm, as defined by Federal Decrees 6961 and 7172, respectively.[26]

Although this proposal would reduce the risk of direct conversion of high–carbon stock lands such as forests and savannah (i.e., the Cerrado region), its impact on indirect land conversion would be more questionable. If soy expansion is merely restricted onto pastureland, as allowed when using the above criteria, this would only reinforce historical patterns of land expansion; both Arima et al. and Barona et al. link soy expansion onto pasture with subsequent pasture expansion onto forestland. In those cases, soy production on pastureland displaces industries that rely on pasture, such as raising livestock, and may incentivize those industries to expand onto higher–carbon stock land.[27]

Existing land protections in Brazil may be ineffective at mitigating market-mediated land conversion. Despite the introduction of the soy moratorium and forest code, some recent analyses suggest that deforestation has continued on smaller plots of land where these land protections are more difficult to enforce.[28] The European Commission's Joint Research Centre estimates that 10.4% of recent soy expansion in Brazil has occurred on high–carbon stock land.[29] Although the literature generally agrees that deforestation has slowed down over the past decade, recent analysis suggests that much soy expansion has instead shifted onto the Cerrado, which is relatively high in carbon stocks; soy expansion onto the Cerrado ranged from 11 to 23% from 2007 to 2013.[30] In contrast, the link between sugarcane expansion and deforestation in Brazil is generally weaker than for soybeans.[31]

The paired policies of increased biodiesel mandates and the new financial incentives provided by RenovaBio will likely create additional demand for crops, increasing pressure on deforestation and land use more generally. Increasing support for alternative feedstocks that create less demand for land could substantially mitigate these risks. For example, the increased use of by-products, wastes, and residues could also serve as a critical component of a biofuel strategy. In 2018, roughly 20% of Brazil's biodiesel came from tallow and less than 1% of Brazil's ethanol came from sugarcane bagasse.

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26 Ibid.

27 Eugenio Y. Arima, Peter D. Richards, Robert Walker, and Marcellus Caldas, Statistical confirmation of indirect land use change in the Brazilian Amazon. *Environmental Research Letters, 6,* 024010 (2011), doi:10.1088/1748-9326/6/2/024010; Elizabeth Barona, Navin Ramankutty, Glenn Hyman, and Oliver T. Coomes, The role of pasture and soybean in deforestation of the Brazilian Amazon. *Environmental Research Letters, 5,* 024002 (2010), doi:10.1088/1748-9326/5/2/024002.

28 Peter Richards, Eugenio Arima, Leah VanWey, Avery Cohn, and Nishan Bhattarai, Are Brazil's deforesters avoiding detection? *Conservation Letters,* 10, 470–476 (2017); doi:10.1111/conl.12310.

29 European Commission, *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of Regions on the Status of Production Expansion of Relevant Food and Feed Crops Worldwide* (March 13, 2019); https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2019:0142:FIN.

30 H. K. Gibbs, L. Rausch, J. Munger, I. Schelly, D. C. Morton, P. Noojipady, B. Soares-Filho, P. Barreto, L. Micol, and N. F. Walker, Brazil's soy moratorium. *Science,* 347, 377–378 (2015), doi:10.1126/science.aaa0181; Arnaldo Carneiro Filho and Karine Costa, "The expansion of soybean production in the Cerrado: Paths to sustainable territorial occupation, land use and production," Iniciativa para o Uso da Terra (INPUT) (2016); www.inputbrasil.org/wp-content/uploads/2016/11/The-expansion-of-soybean-production-in-the-Cerrado_Agroicone_INPUT.pdf.

31 European Commission, 2019.

Some analyses have suggested that the increased use of some by-products and wastes may have unintended consequences in cases where those materials had existing uses.[32] For example, the use of tallow or used cooking oil for biofuels in some regions may cause the diversion of those materials from uses in the oleochemical industry or as animal feed in the livestock sector; in response, those sectors may draw upon virgin materials such as vegetable oil instead. However, because only 2.5% of used cooking oil is recovered in Brazil, it is likely that the discarded portion can be collected and used for biofuel production without affecting existing markets and driving demand for substitutes.[33] A displacement analysis for by-products, wastes, and residues in the Brazilian context has not been developed to date, but the implications could be similar if those materials already have existing uses and well-developed markets in Brazil.

FUEL COMPATIBILITY AND LOCAL AIR POLLUTANTS

ETHANOL

Brazil's longtime investment and support for flex-fuel and E100 vehicles has meant that the blend wall is not a major concern for continued ethanol deployment. Flex-fuel vehicles constituted approximately two-thirds of the light-duty vehicle fleet and 98% of passenger vehicle sales in 2018.[34] Because these vehicles are designed to operate with variable ethanol blends between E0 and E100, mandates to increase ethanol blend levels and the continued expansion of the ethanol industry are thus unlikely to pose compatibility problems.

For flex-fuel vehicles capable of using either hydrous ethanol or blended gasoline, the choice of fuel is often dictated by price, as there is some variation in their relative prices depending on regional and seasonal factors. Hydrous ethanol has higher water content and a lower energy density than a comparable volume of blended gasoline. Comparing the performance of the two fuels across one engine, hydrous ethanol achieves slightly higher torque and power, along with higher thermal efficiency.[35] Flex-fuel vehicles incorporate several technologies to accommodate higher ethanol blends, including sensors to detect the blend ratio prior to combustion, a gasoline reservoir to maintain performance for cold starts, and more durable materials for reactive engine components and gaskets.[36]

BIODIESEL

At higher blend levels, biodiesel can create compatibility issues for conventional vehicles and emit higher quantities of local air pollutants. The rapid ramp-up of Brazil's biodiesel blending mandate without a concurrent increase in the deployment of B20- or B100-compatible vehicles suggests that compatibility issues may be occurring across Brazil's diesel fleet. Generally, vehicle manufacturers recommend biodiesel blends of 5% to

32 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), www.theicct.org/publications/potential-greenhouse-gas-savings-2030-greenhouse-gas-reduction-target-indirect.

33 Aldara da Silva César, Dayana Elizabeth Werderits, Gabriela Leal de Oliveira Saraiva, and Ricardo César da Silva Guabiroba, The potential of waste cooking oil as supply for the Brazilian biodiesel chain. *Renewable and Sustainable Energy Reviews, 72,* 246–253 (2017); www.sciencedirect.com/journal/renewable-and-sustainable-energy-reviews/vol/72/suppl/C.

34 Sindicato Nacional da Indústria de Componentes para Veículos Automotores [National Union of the Components Industry for Automotive Vehicles] e Associação Brasileira da Indústria de Autopeças [Brazilian Association of the Autoparts Industry], "Relatório da Frota Circulante 2018" [Current Fleet Report 2018]; www.sindipecas.org.br/sindinews/Economia/2018/R_Frota_Circulante_2018.pdf.

35 Rodrigo C. Costa and José R. Sodré, Hydrous ethanol vs. gasoline-ethanol blend: Engine performance and emissions. *Fuel, 89,* 287–293 (2010); www.sciencedirect.com/science/article/pii/S0016236109002981.

36 Suani Teixeira Coelho, José Goldemberg, Oswaldo Lucon, and Patricia Guardabassi, Brazilian sugarcane ethanol: Lessons learned. *Energy for Sustainable Development, 10*, 26–39 (2006); doi:10.1016/S0973-0826(08)60529-3.

7%,[37] with higher diesel blends voiding customer warranties in some cases.[38] Brazilian automakers have already expressed skepticism about vehicle compatibility for biodiesel blend levels exceeding 10%.[39] Over time, corrosion and deposit formation can degrade vehicle components, affecting reliability and increasing maintenance costs.[40] This also necessitates more frequent filter replacements and maintenance. Biodiesel is less chemically stable than fossil diesel and can absorb water or oxidize over time. Testing suggests that B20 blends can be stored for approximately 1 year and remain within specification, and that biodiesel blends are generally stable within the normal course of use. However, it is good practice that for biodiesel stored longer than 4 months, special measures such as the addition of blending additives are taken to prevent damage from oxidation.[41] At higher blend levels, such as B100, biodiesel may be entirely incompatible with some plastic components and metals.[42] Preliminary analysis from Brazil's Ministry of Mines & Energy incorporates findings both from Brazil's association of vehicle manufacturers (Associação Nacional dos Fabricantes de Veículos Automotores) and local biodiesel associations, but has not yet been conclusive. [43] The report leaves open the possibility for B15 blend approval after further testing and tightening of specifications for biodiesel oxidation stability and water content.

Although biodiesel contains less sulfur than fossil diesel, its use as a fuel may actually increase the emissions of other local air pollutants, particularly NO_x. While there is some variation in NO_x emissions by the feedstock used for producing biodiesel production, the literature suggests a linear relationship between the blend level of biodiesel and the NO_x emissions from the blended fuel relative to conventional diesel; as the blend level of soy biodiesel approaches 100%, the increase in NO_x approaches 20%.[44] This change is thought to be caused by a combination of factors, including higher pressure leading to earlier fuel injection and higher oxygen availability during combustion, which would in turn increase NO_x formation. There is some variation in CO and PM formation depending on the biodiesel feedstock in question, although for soy biodiesel there isn't a strong relationship between blend level and pollutant emissions.[45] All new vehicles should comply with current PROCONVE national emission standards; even so, it will be important that homologation tests use the biodiesel blends that are being commercialized to ensure real-world compliance.

DROP-IN FUELS

Although the climate performance of drop-in fuels is dictated to a large extent by the feedstock used to manufacture them, on an operational basis, drop-in biofuels offer

37 Toyota Europe, "Biofuels: Made responsibly, used efficiently"; www.toyota-europe.com/world-of-toyota/feel/environment/better-air/biofuels.

38 National Biodiesel Board, "OEM warranty statements and use of biodiesel blends over 5% (B5)" (2005), www.biodiesel.org/docs/default-source/ffs-engine_manufacturers/oem-warranty-statement-and-use-of-biodiesel-blends-over-5-(b5).pdf?sfvrsn=6.

39 Meghan Sapp, "Brazilian Car Manufacturers Aim to Stop Planned 15% Biodiesel Blend," *Biofuels Digest,* February 18, 2019; www.biofuelsdigest.com/bdigest/2019/02/18/brazilian-car-manufacturers-aim-to-stop-planned-15-biodiesel-blend/.

40 Stephanie Searle and Kristine Bitnere, *Compatibility of Mid-Level Biodiesel Blends in Vehicles in Indonesia,* (ICCT: Washington, DC 2018), https://theicct.org/publications/compatibility-mid-level-biodiesel-blends-vehicles-indonesia.

41 Alternative Fuels Data Center, Biodiesel Handling and Use Guide (Fifth Edition) (November 2016), https://afdc.energy.gov/files/u/publication/biodiesel_handling_use_guide.pdf.

42 Ibid.

43 Ministerio de Minas e Energia [Ministry of Mines and Energy], "Relatório de consolidação dos testes e ensaios para validação da utilização de Biodiesel B15 em motores e veículos" [Consolidation Report of the tests for the validation of the use of biodiesel B15 in engines and vehicles] (February 2019), www.mme.gov.br/documents/1138769/0/MME+Relatorio+B10+30-04-2018+final+v01-+com+Anexos.pdf/6bed5a6b-7d04-41df-a5f3-649f31afd3e9.

44 Searle and Bitnere, 2018.

45 Ibid.

substantially fewer barriers to use than either ethanol or biodiesel. However, their overall life-cycle emissions can still be influenced by upstream factors such as feedstock cultivation and ILUC emissions. Unlike first-generation biofuels, which contain oxygen and possess chemistry different from that of fossil hydrocarbons, drop-in fuels are composed of the same hydrocarbon chains as their fossil counterparts. Examples of drop-in fuels include HVO (also called "renewable diesel" or "green diesel"), renewable gasoline, and alternative jet fuels. These fuels are deoxygenated and treated with a hydrotreatment process to generate synthetic hydrocarbons that can be used interchangeably with conventional, petroleum-derived fuels. Drop-in fuels can be produced from a wide variety of feedstocks, including fats, oils, sugars, and even lignocellulosic feedstocks. Drop-in fuels have roughly the same chemical stability, water content, and energy density as conventional fuels, and therefore do not require special treatment or storage.[46]

Testing by California ARB on various blend levels of renewable diesel (R20, R50, and R100) found that its inclusion in the fuel mix generally decreased emissions of criteria air pollutants relative to conventional diesel.[47] Pure renewable diesel reduces particulate matter and NO_x emissions by 30% and 10%, respectively, and the sulfur content in drop-in fuels is negligible.[48] For these reasons, drop-in fuels are a desirable blendstock to improve the specifications of blended conventional fuels.

OPPORTUNITIES FOR DECARBONIZATION THROUGH BIOFUEL POLICIES

PROMOTING ADVANCED BIOFUELS

Increasing the proportion of advanced biofuels such as cellulosic ethanol in Brazil's fuel mix is a component of its Paris commitments; however, the penetration of these fuels has thus far fallen far short of first-generation fuels. As of 2018, only 139,000 tonnes of bagasse were used for cellulosic production, out of nearly 125 million tonnes produced as a co-product of sugarcane ethanol production; consequently, only 27 million liters of cellulosic ethanol was produced.[49] A primary factor holding back bagasse ethanol conversion is the lack of policy incentives specifically directed toward bagasse ethanol, as cellulosic ethanol conversion is much more expensive than conventional sugarcane ethanol production. Consequently, it is typically much more cost-effective to combust bagasse on-site for electricity.[50] Sugarcane bagasse contributes approximately 15 million MWh, or 4%, to Brazil's annual electricity production, and the potential impact on electricity sector emissions of its diversion for transport fuel production is unclear.[51] Sugarcane straw constitutes approximately one-third of the plant's energetic value and could be used for cellulosic ethanol production, with potentially smaller indirect effects.

46 Neste, *Renewable Diesel Handbook* (May 2016); www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf.

47 California Air Resources Board, "Staff Report: Multimedia Evaluation of Renewable Diesel" (November 2013); www.arb.ca.gov/fuels/multimedia/meetings/RenewableDieselStaffReport_Nov2013.pdf.

48 Neste, 2016.

49 U.S. Department of Agriculture, *Brazil Biofuels Annual 2018* (2018), https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-10-2018.pdf.

50 Marina O. S. Dias, Marcelo P. Cunha, Charles D. F. Jesus, George J. M. Rocha, José Geraldo C. Pradella, Carlos E. V. Rossell, Rubens Maciel Filho, and Antonio Bonomi, Second generation ethanol in Brazil: Can it compete with electricity production? *Bioresource Technology, 102,* 8964–8971 (2011); doi:10.1016/j.biortech.2011.06.098.

51 Leticia Phillips, "Brazilian Sugarcane Sector: Recent Developments and the Path Ahead," Presented at the USDA's 94th Annual Agricultural Outlook Forum, February 23, 2018; www.usda.gov/oce/forum/2018/speeches/Leticia_Phillips.pdf.

Supplementing Brazil's biofuel mandates with carbon credits and a GHG reduction target could support the use of advanced biofuels with lower GHG emissions than those of first-generation biofuels. By excluding ILUC emissions within the GHG calculations in RenovaBio, the crediting system diminishes the substantial differences in life-cycle emissions between first-generation pathways and wastes with low or no ILUC emissions, such as sugarcane- or bagasse-derived ethanol and soy biodiesel. For example, when comparing only direct production emissions, the emissions reductions generated by a given unit of bagasse-derived cellulosic ethanol relative to soy biodiesel differ by only about 7 gCO_2e/MJ.

A possible approach to bring lower-carbon fuels into Brazil's fuel mix would be to create additional compliance subtargets within RenovaBio to support targeted, advanced fuels or low-ILUC risk feedstocks. This approach has already been implemented within the EU's RED II and the U.S. RFS, which contain subtargets for advanced fuels from a selected list of feedstocks and cellulosic ethanol, respectively.[52] Improving incentives for advanced biofuels could improve the commercial prospects for technologies such as cellulosic ethanol, and there is a large potential opportunity to do so. A scenario analysis by the Brazilian National Development Bank (BNDES) estimates a theoretical potential of 6.75 billion liters of cellulosic ethanol available in Brazil by 2025—approximately one-third of its existing anhydrous ethanol production.[53] Furthermore, approximately half of that new cellulosic production could be realized through the retrofitting or expansion of existing sugarcane ethanol mills.

Transitioning to lower-carbon biodiesel or HVO feedstocks may be possible through the increased use of used cooking oil or tallow. Longer-term, advanced biofuel conversion pathways such as gasification or pyrolysis would be able to convert agricultural residues and wastes into ultralow-carbon synthetic diesel. In the near term, used cooking oil is the most promising feedstock, as it can be converted into either biodiesel or HVO through existing, commercialized technology. The vast majority of cooking oil in Brazil is discarded once it is used—as much as 97.5% in 2017.[54] In 2012, Brazil produced an estimated 330,000 tonnes of used cooking oil, extrapolating from household vegetable oil consumption.[55] Accounting for conversion losses, that quantity could theoretically yield approximately 350 million liters—roughly 8% of Brazil's 2018 on-road biodiesel consumption.[56] However, the bulk of Brazil's used cooking oil generation occurs in households, which may present several complications for its collection. Whereas used cooking oil is collected from centralized sources such as restaurants with relative success in the EU, household collection has struggled outside of Belgium, the Netherlands, and Austria.[57] Implementing regular collection of household used cooking oil requires organization and collaboration among waste companies, local governments, and

52 General Secretariat of the Council of the European Union, Interinstitutional file, "Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources - Analysis of the final compromise text with a view to agreement," 21 June 2018; www. consilium.europa.eu/register/en/content/out?&typ=ENTRY&i=LD&DOC_ID=ST-10308-2018-INIT; U.S. Environmental Protection Agency, "Overview for Renewable Fuel Standard," www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard.

53 Artur Yabe Milanez et al., De promessa a realidade: Como o etanol celulósico pode revolucionar a indústria da cana-de-açúcar: Uma avaliação do potencial competitivo e sugestões de política pública [From promise to reality: How cellulosic ethanol can revolutionize the sugarcane industry: An assessment of competitive potential and public policy suggestions]. *BNDES Setorial, 41,* 237–294 (2015), http://web.bndes.gov.br/bib/jspui/handle/1408/4283.

54 da Silva César et al., 2017.

55 Carlos Daniel Mandolesi de Araújo, Claudia Cristina de Andrade, Erika de Souza e Silva, and Francisco Antonio Dupas, Biodiesel from used cooking oil: A review. *Renewable and Sustainable Energy Reviews, 27,* 445–452 (2013), https://doi.org/10.1016/j.rser.2013.06.014

56 Ibid.

57 Fabien Hillairet, Victor Allemandou, and Katarzyna Golab, "Analysis of the Current Development of Household UCO Collection Systems in the EU," (Greenea, 2016), https://www.theicct.org/sites/default/files/publications/Greenea%20Report%20Household%20UCO%20Collection%20in%20the%20EU_ICCT_20160629.pdf

consumers, as well as promotional activities to build consumer awareness. With these factors in place, perhaps only a small fraction of Brazil's used cooking oil can be considered available for fuel conversion.

LIMITING INDIRECT LAND-USE CHANGE

Another policy option for improving the overall GHG performance of Brazil's biofuel policy is to exclude or limit the contribution of high-ILUC feedstocks. This could be done by establishing a threshold for deforestation for total production of that feedstock in Brazil in order for a producer to generate CBIO credits in the RenovaBio program. If, for example, diesel blenders were unable to generate CBIO credits from fuels with a deforestation threshold above 10%, only biodiesel or HVO producers using tallow, used cooking oil, or other waste feedstocks would be able to generate those credits. For the much larger pool of gasoline substitutes, such as sugarcane ethanol, there are fewer concerns for deforestation. According to the body of research cited above and ILUC modeling, it is therefore likely that sugarcane ethanol would be able to continue to produce CBIO credits with this deforestation threshold in place.

CONCLUSION

Brazil has been able to mobilize one of the world's largest biofuel industries over the past several decades, but its advanced biofuel industry lags far behind the production capacity of its first-generation biofuel industry. Furthermore, Brazil's reliance on crop-derived biofuel feedstocks, in conjunction with its vulnerable forests and savannah, presents unique risks to the climate if biofuel industry expansion continues without implementing adequate sustainability measures.

We find that the largest climate and air quality risks come from continued expansion of biofuels within the diesel pool. In particular, the rapid expansion of soy-derived biodiesel may in fact undermine Brazil's long-term climate goals because of the contribution of ILUC emissions to that fuel's life-cycle emissions impact, negating the emissions savings from displacing diesel. Furthermore, high-biodiesel blends may lead to compatibility issues in a fleet that isn't adapted for its use, leading to higher NO_x emissions as well as higher maintenance costs for vehicles. We recommend that Brazil halt its annual increases to the biodiesel mandate and instead incentivize the use of alternative biodiesel feedstocks without ILUC impacts, such as used cooking oil, which could yield an additional 350 million liters of biodiesel through improved collection practices. In the longer term, the transition to HVO production from used cooking oil and other wastes and residues could provide greater volumes of diesel replacements without compatibility issues.

In contrast to biodiesel, we find that the expansion of sugarcane in Brazil poses fewer risks. The majority of ILUC modeling suggests that although sugarcane ethanol can generate some ILUC emissions, it may still offer some carbon reductions relative to conventional petroleum. Furthermore, the RenovaBio policy will incentivize better-performing sugarcane ethanol producers, allowing the pool of fuels to decarbonize over time, through either increased efficiency or the transition to integrated bio-refineries using greater shares of bagasse residues to produce ethanol. Bagasse ethanol, which generates a 95% carbon savings over fossil gasoline, could be a source of ultralow-carbon fuel in the long term.

The transition to a life-cycle carbon accounting method for incentivizing biofuels through RenovaBio also presents a valuable opportunity to transition toward lower-carbon and advanced biofuels to meet Brazil's long-term climate goals. Introducing ILUC emission factors for crop-derived biofuels could improve the relative credit values for fuels made from wastes and residues. Alternatively, those fuels could be incentivized through the introduction of subtargets within the program. To mitigate the worst potential impacts of land conversion, we recommend that Brazil incorporate sustainability criteria for land conversion within RenovaBio. Existing land protections in Brazil, which protect mostly against direct land conversion of high–carbon stock areas, are insufficient to prevent the indirect, market-mediated land conversion that may occur in response to biofuel demand. Instead, we recommend a more stringent eligibility threshold to ensure that feedstocks linked to deforestation would be ineligible to generate CBIO credits. Together, these changes could ensure that Brazil's continued biofuel expansion would generate greater carbon reductions and place lower pressure on its land resources.