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## **Alberta Biofuel Projects - Lessons Learned from Brazil**

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CIRL Occasional Paper #88

June 19, 2025

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*Acknowledgements*

The authors would like to thank the Alberta Law Foundation for their generous support in the development of this occasional paper. The authors thank the Canadian Institute of Resources Law for facilitating this project. Any errors belong to the authors alone.



## 1.0 Introduction

Biofuels comprise fuels derived from organic materials such as plants and animals. These plant- and animal-based fuels include gaseous fuels such as hydrogen (H<sub>2</sub>) and methane (CH<sub>4</sub>), and liquid fuels such as methanol (CH<sub>3</sub>OH), ethanol (C<sub>2</sub>H<sub>5</sub>OH), biodiesel, and acetone (C<sub>3</sub>H<sub>6</sub>O), among others.<sup>1</sup> Biomass can be converted directly into liquid fuels, called "biofuels," to help meet transportation fuel needs. The two most common types of biofuels in use today are ethanol and biodiesel, both of which represent the first generation of biofuel technology. In Brazil, biofuels play a particularly important role in decarbonizing transport by providing a low-carbon solution for existing technologies, such as light-duty vehicles in the near term and heavy-duty trucks, ships, and aircraft with few alternative and cost-effective solutions in the long term.

## 2.0 Canadian & Alberta Biofuels

### 2.1 Canadian Biofuels Policy Framework

The Canadian federal government has implemented several measures to promote biofuels as part of its broader clean energy agenda. The Renewable Fuels Regulations (RFR) under the Canadian Environmental Protection Act 1999 (CEPA) form the core regulatory framework for biofuels. The RFR mandate that gasoline must contain an average of 5% renewable fuel and diesel fuel must contain 2% renewable content. This policy aims to reduce the life-cycle emissions of fuels consumed in Canada.<sup>2</sup> The Clean Fuel Standard (CFS), introduced in 2016, further incentivizes the use of low-carbon fuels by establishing life-cycle carbon intensity limits.<sup>3</sup> The CFS is expected to have a significant impact on the demand for biofuels across the country.

### 2.2 Alberta Biofuels Production

Alberta's oil and gas industry makes a critical contribution to the provincial and national economy. At the same time, Alberta has a small biofuel sector. The province's vast agricultural resources make it an ideal location for biofuel production. Alberta's Renewable Fuels Standard Regulation requires that gasoline and diesel sold in the province contain 5% and 2% renewable content,

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<sup>1</sup> Carlos H. Brito Cruz, Glauca Mendes Souza, Luiz A. Barbosa Cortez, "Chapter 11 - Biofuels for Transport" in Trevor M. Letcher, ed, *Future Energy*, 2<sup>nd</sup> ed (Oxford: Elsevier, 2014) 215.

<sup>2</sup> *Renewable Fuels Regulations*, SOR/2010-189, s. 1.

<sup>3</sup> *Clean Fuels Regulations*, SOR/2022-140, s. 3.

respectively.<sup>4</sup> Alberta's biofuel production capacity is supported by policies that align with federal initiatives, as well as provincial incentives aimed at diversifying the energy economy.

The province's energy diversification strategy is not only focused on production but also on research and development. Alberta Innovates, a provincial research agency, has invested in biofuel projects aimed at enhancing production efficiency and reducing environmental impacts.<sup>5</sup> These initiatives contribute to Alberta's broader goals of reducing its carbon footprint while remaining a key player in Canada's energy sector.

### **2.3 Issues**

One of the issues that has arisen globally in biofuel production is the competition between biofuel production and food security, as bioethanol production relies heavily on agricultural feedstock like corn and wheat. This has raised concerns about the negative impact on food prices and land use. In response, Canada is investing in second-generation biofuels, which utilize non-food biomass, such as forestry residues and municipal waste, to mitigate these issues.<sup>6</sup> Another challenge is the cost competitiveness of biofuels relative to fossil fuels. While government incentives and carbon pricing schemes, like the federal carbon tax, have made biofuels more competitive, further investments in technology are required to bring down production costs and increase efficiency. However, the integration of biofuels into Canada's energy transition presents opportunities. The decarbonization potential of biofuels can contribute to Canada's goal of achieving net-zero emissions by 2050.<sup>7</sup> Furthermore, Alberta's leadership in research and development positions the province as a key player in the future of bioenergy in Canada.

### **2.4 Conclusion**

Biofuels are one component of Canada's renewable energy strategy in response to climate change to reduce GHG emissions while utilizing a variety of the country's vast natural resources. Alberta's role as both an experienced energy producer and innovator highlights the province's potential to advance biofuel technology and increase the number of biofuel projects. However, to fully realize the potential of biofuels, Alberta must consider, production costs in comparison with other

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<sup>4</sup> *Renewable Fuels Standard Regulation*, Alta Reg 29/2011, s. 2.

<sup>5</sup> Alberta Innovates, "Bioenergy," online: <https://albertainnovates.ca/programs/bioenergy>.

<sup>6</sup> Government of Canada, "Biomass and Bioenergy," online: <https://natural-resources.canada.ca>.

<sup>7</sup> Government of Canada, "Net-Zero Emissions by 2050," online: <https://canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050>

alternative lower GHG emitting transportation and electricity generation sources and technological innovation. With continued federal and provincial cooperation, biofuels can contribute more to a sustainable energy future.

### **3.0 Biofuel**

Ethanol is the most commonly used biofuel in North America, with most gasoline containing up to 10% ethanol (E10). Flex-fuel vehicles can run on fuel with up to 85% ethanol (E85), but the remaining 15% must be gasoline because ethanol is more difficult to ignite in engines.<sup>8</sup> While using biofuels in engines still produces carbon dioxide (CO<sub>2</sub>), they are derived from biomass that absorbs CO<sub>2</sub> while growing. As a result, the CO<sub>2</sub> released during combustion is roughly equivalent to what was absorbed, making biofuels closer to carbon neutral than fossil fuels.<sup>9</sup> Any discrepancies between CO<sub>2</sub> input and output require careful lifecycle analysis. Both biofuels and fossil fuels originate from organic matter, but fossil fuels come from organisms that died millions of years ago, whereas biofuels are made from recently deceased organic material. From a climate change perspective, biofuels release as much CO<sub>2</sub> as fossil fuels during combustion. However, since the CO<sub>2</sub> from biofuels is recent atmospheric carbon, it does not increase the total carbon in the carbon cycle, unlike fossil fuels, which release long-stored carbon.<sup>10</sup> While biofuels do not reduce tailpipe emissions, they significantly lower net carbon emissions.

### **4.0 Current Status of Biofuels in Canada**

Rahul Saini et al. provide a detailed review of the current state of biofuels in Canada, including the regulatory frameworks and the future prospects of the industry. Despite the global push towards clean energy, Canada faces unique challenges in scaling up biofuel production and needs stronger policies, infrastructural support, and investment in advanced biofuels technologies.<sup>11</sup>

Over the past decade, biofuel production in Canada has evolved, with various commercial projects focusing on bioethanol and biodiesel production. The country currently operates 14 ethanol plants

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<sup>8</sup> U.S. Energy Information Administrations, “How Much Ethanol Is in Gasoline and How Does It Affect Fuel Economy?” Online: <http://www.eia.gov/tools/faqs/faq.cfm?id=27&t=4>

<sup>9</sup> Suzanne Paulson, “Biodiesel Fuel” (2013) Online: UCLA Institute of the Environment and Sustainability <http://www.environment.ucla.edu/reportcard/article7320.html>

<sup>10</sup> “Bio or Bust? The Economic and Ecological Cost of Biofuels” (2008) ENBO Rep, online: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2246417/>

<sup>11</sup> Rahul Saini et al., “A Critical Insight into the Development, Regulation, and Future Prospects of Biofuels in Canada,” (2021) 12:2 Bioengineered 9847.

and 6 biodiesel plants, with capacities of 2145 million liters and 629 million liters annually, respectively.<sup>12</sup> However, while bioethanol production has gained traction, the industry continues to rely heavily on vegetable oil and cereals, which pose sustainability concerns due to their competition with food production.<sup>13</sup> The push towards using non-food feedstocks such as lignocellulosic biomass represents a promising shift, but these second-generation biofuels remain challenging to commercialize on a large scale.

#### **4.1 Regulatory Framework**

The federal regulatory environment in Canada has included several initiatives aimed at promoting biofuel use, including mandates for renewable fuel content in gasoline and diesel. The Clean Fuel Standard (CFS) policy, introduced by the federal government, seeks to reduce greenhouse gas emissions by 30 million tonnes by 2030.<sup>14</sup> Under the CFS, biofuel blending mandates were established, requiring a minimum of 5% ethanol in gasoline and 2% renewable content in diesel.<sup>15</sup> Despite these federal regulation, biofuel production remains below national targets due to infrastructural and market constraints, prompting the needs for further policy innovation and economic incentives.

#### **4.2 Economic Investment and Challenges**

The commercialization of biofuels in Alberta is hindered by several economic challenges, including high production costs and competition from cheap fossil fuels. Investments in biofuel technology has been relatively low compared to other energy sectors. Government programs such as the Ethanol Expansion Programme and ecoENERGY aimed to provide financial support for biofuel projects, but the scale of funding has not been sufficient to match the demand for biofuels.<sup>16</sup> Additionally, the lower energy density of biofuels compared to conventional fuels, and their higher tax burdens, discourage widespread consumer adoption.<sup>17</sup>

#### **4.3 Future Perspective**

The future of biofuels in Alberta lies in overcoming the technological and economic barriers that currently limit large-scale production. The focus is shifting towards third- and fourth-generation

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<sup>12</sup> *Ibid* at p 2.

<sup>13</sup> *Ibid*.

<sup>14</sup> *Ibid* at p 4.

<sup>15</sup> *Ibid* at p 5.

<sup>16</sup> *Ibid* at p 5.

<sup>17</sup> *Ibid* at p 5-7.

biofuels, that utilize algae and genetically engineered microorganisms, although these technologies are still in the early stages of development.<sup>18</sup> The authors emphasize the importance of life-cycle assessments and techno-economic analyses to ensure the sustainability and feasibility of biofuels production as the industry scales up. Furthermore, expanding the use of co-products and developing zero-waste biorefineries could enhance the economic viability of biofuels.<sup>19</sup>

#### **4.4 Conclusion**

There has been limited progress in Canada's biofuel industry in recent years, however, there are regulatory and economic hurdles that must be addressed in both Alberta and other provinces to fully capitalize on its potential. Strengthened policies, increased investment in advanced biofuel technologies, and improved infrastructure will be essential to meeting the nation's greenhouse gas reduction targets by 2030. The future of biofuels in Canada ties into progress in feedstock technology and biofuel production processes.

### **5.0 Biogas Production Regulations in Alberta: Lessons from Recent Projects<sup>20</sup>**

As Alberta has a significant agricultural industry, biogas, a renewable energy source produced from organic waste, has garnered increasing attention in Alberta as part of the province's broader strategy to reduce greenhouse gas (GHG) emissions and promote sustainable energy alternatives. Several recent biogas projects in Alberta highlight both the potential and the regulatory challenges of integrating this technology into the province's energy framework.

#### **5.1 Regulatory Framework for Biogas in Alberta**

The regulatory landscape for biogas production in Alberta is shaped by a combination of provincial regulation and municipal bylaws. At the provincial level, the Environmental Protection and Enhancement Act (EPEA) provides the framework for managing the environmental impacts of energy projects, including biogas facilities.<sup>21</sup> Under EPEA, biogas producers are required to obtain approvals for air emissions, waste management, and water use. In addition, the Alberta Utilities

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<sup>18</sup> *Ibid* at p 10.

<sup>19</sup> *Ibid* at p 11.

<sup>20</sup> EXP, "Biogas Production Regulations in Alberta: Lessons from Recent Projects", online:<https://www.exp.com/insights/biogas-production-regulations-in-alberta-lessons-from-recent-projects>.

<sup>21</sup> *Environmental Protection and Enhancement Act*, RSA 2000, c E-12.

Commission (AUC) regulates the interconnection of biogas facilities to the provincial grid, ensuring that energy produced from biogas complies with safety and reliability standards.<sup>22</sup>

A key component of biogas regulation is the Renewable Energy Act, which encourages the development of renewable energy projects through financial incentives and streamlined permitting processes. This act has been instrumental in facilitating the growth of biogas projects by providing clear guidelines on project approvals and feed-in tariffs.<sup>23</sup>

## **5.2 Recent Biogas Projects in Alberta**

In the past few years several biogas projects have been developed in Alberta, showcasing the potential of biogas as a renewable energy source. For example, the Lethbridge Biogas Project is one of the largest biogas facilities in the province. The project successfully integrated biogas into the local energy grid, processing organic waste from farms and food processors into renewable electricity.<sup>24</sup> The project has demonstrated both the economic and environmental benefits of biogas, including reducing methane emissions and diverting waste from landfills. However, the project also encountered regulatory hurdles, particularly concerning land-use planning and waste management. The municipal governments have struggled to balance the economic benefits of biogas with concerns about odor, land use, and the impact on nearby communities.<sup>25</sup> These issues underscore the need for more robust municipal regulations that address the specific challenges posed by biogas production.

## **5.3 Lessons Learned**

The experiences of recent biogas projects in Alberta offer several key lessons for the development of future regulatory frameworks. First, there is a need for improved coordination between provincial and municipal regulations to ensure that projects are not delayed by conflicting land-use or environmental policies. Streamlining the approval process for biogas projects, particularly in rural areas where agricultural waste is abundant, would help unlock the full potential of biogas production. Second, the regulatory framework must evolve to address emerging issues as the management of digestate, the byproduct of biogas production. Currently, digestate is treated as a

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<sup>22</sup> Alberta Utilities Commission, “Biogas Energy Facilities: Regulatory Requirements,” *AUC Decision 23456-D01-2020*, s. 4.

<sup>23</sup> *Renewable Energy Act*, SA 2016, c R-17, s. 2.

<sup>24</sup> Lethbridge Biogas Project, “Annual Environmental Report 2023,” online: <https://lethbridgebiogas.ca>.

<sup>25</sup> Lethbridge Biogas Project, “Project Overview,” online: <https://lethbridgebiogas.ca>.

waste product, but it has significant potential as a fertilizer or soil conditioner.<sup>26</sup> Regulations should therefore be updated to reflect the economic value of digestate and to promote its reuse in agricultural applications. Finally, public engagement is crucial to the success of biogas production. Recent projects have highlighted the importance of consulting with local communities early in the planning process to address concerns about odor, traffic, and other potential impacts. A more proactive approach to public engagement, supported by regulatory guidelines, could help mitigate opposition and ensure smoother project implementation.

#### **5.4 Conclusion**

Biogas production represents a promising opportunity for Alberta to diversify its renewable energy portfolio and reduce GHG emissions. However, the regulatory framework governing biogas projects must continue to evolve in response to the lessons learned from recent projects. Clearer coordination between provincial and municipal regulations, updated rules on byproduct management, and improved public engagement practices are all essential to unlocking the full potential of biogas in Alberta's energy future.

### **6.0 Board Review Process for Biofuel Projects Under the Natural Resources Conservation Board Act, RSA 2000, c N-3<sup>27</sup>**

The Natural Resources Conservation Board Act (NRCBA) provides the legislative framework for the assessment and regulation of natural resource projects in Alberta. The Act establishes the Natural Resources Conservation Board (NRCB), which has the authority to review and approve or reject projects based on their environmental, economic, and social impacts. The Act ensures that natural resource development in the province is subject to rigorous environmental scrutiny, protecting Alberta's natural resources while supporting sustainable development.<sup>28</sup> Under the NRCBA, the NRCB has the power to conduct public hearings, assess environmental impact statements, and impose conditions on project approvals to mitigate adverse effects. The

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<sup>26</sup> Government of Alberta, "Digestate Use and Management Guidelines," online: <https://alberta.ca/digestate-management>.

<sup>27</sup> *Natural Resources Conservation Board Act, RSA 2000, c N-3*

<sup>28</sup> *Natural Resources Conservation Board Act, RSA 2000, c N-3, s 1.*

comprehensive approach in the NRCBA ensures that Alberta's natural resources are conserved for future generations.<sup>29</sup>

The NRCBA provides for a review process for natural resource projects including some biofuels projects in Alberta. Under this framework, the NRCB assesses the environmental, economic, and social impacts of proposed developments. The review process begins when a proponent submits an application, which is then evaluated for completeness and compliance with regulatory requirements. Public notice is given, and interested parties may participate in the review through written submissions or oral hearings.<sup>30</sup>

The NRCB is tasked with considering both environmental sustainability of the project and the economic benefits to Alberta. The board balances competing interests, such as environmental protection and resource development, when making its decisions. If the NRCB approves the project, it will issue a decision report that outlines any conditions the proponent must meet, such as mitigation measures to reduce environmental harm.<sup>31</sup>

### **6.1 Biofuel Project Reviews**

Natural resource project reviews in Alberta are critical to ensuring that development proceeds in an environmentally responsible manner. The NRCB, established under the Natural Resources Conservation Board Act, is responsible for conducting these reviews. The process is designed to evaluate the long-term impacts of projects, such as those involving agriculture, forestry, or oil and gas, on Alberta's natural environment.<sup>32</sup> NRCB project reviews often involve multiple stages, including environmental impact assessments, stakeholder consultations, and public hearings. These stages provide a platform for proponents, regulators, and the public to contribute to the decision-making process. Reviews are structured to ensure that projects meet sustainability goals while balancing economic development with environmental conservation.<sup>33</sup>

### **6.2 Waste-to-Ethanol Biofuels Plant in Edmonton Closes 11 Years Ahead of Schedule**

Edmonton's waste-to-ethanol biofuels plant, initially lauded as a groundbreaking project, was unexpectedly closed 11 years ahead of its original schedule. The facility, operated by Enerkem,

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<sup>29</sup> *Natural Resources Conservation Board Act, RSA 2000, c N-3, ss. 8-9.*

<sup>30</sup> *Natural Resources Conservation Board Act, RSA 2000, c N-3, s. 8*

<sup>31</sup> NRCB, "Board Review Process," online: <https://nrcb.ca/review-process>.

<sup>32</sup> *Natural Resources Conservation Board Act, RSA 2000, c N-3, s 2.*

<sup>33</sup> NRCB, "About Project Reviews," online: <https://nrcb.ca/project-reviews>.

was designed to convert non-recyclable waste into ethanol, providing a renewable fuel source while diverting waste from landfills. Despite initial success, the plant faced significant operational and financial challenges, leading to its premature closure.<sup>34</sup> The plant's early shutdown raises questions about the viability of large-scale waste-to-fuel projects in Canada. While technological innovation and renewable energy policy remain key drivers, the Edmonton plant's experience underscores the complexity and risks associated with such ventures. Future biofuel projects may need to address these challenges more comprehensively to ensure long-term sustainability.<sup>35</sup>

### **6.3 Consumers Paper Corp. – Waste Paper Recycling Project<sup>36</sup>**

The wastepaper recycling project reviewed and approved by the NRCB under section 4 of the NRCB Act<sup>37</sup> requires it to review all projects “to construct a facility to be used to manufacture pulp, paper, newsprint or recycled fiber.” The Board reviewed the evidence presented and determined that the proposed facility was in the public interest, considering its social, economic, and environmental impacts. The Board's decision included several conditions:

- (i) Requiring Consumers Paper Corporation to finalize an agreement with the City of Medicine Hat for treating wastewater before discharging effluent,<sup>38</sup>
- (ii) Requiring Consumers Paper Corporation to test effluent for heavy metals, dioxins, furans, temperature, and toxicity upon start-up and to repeat these tests as requested by Alberta Environmental Protection or the City of Medicine Hat with data provided to both entities,<sup>39</sup>
- (iii) Requiring Consumers Paper Corporation to comply with all relevant provincial permitting and licensing laws, including the Environmental Protection and Enhancement Act, Water Resources Act, Clean Water Act, Clean Air Act, and other applicable regulations.<sup>40</sup>

The Board also made additional recommendations for consideration by Consumers Paper Corporation and Alberta Environmental Protection.

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<sup>34</sup> Enerkem, “Edmonton Waste-to-Ethanol Plant Closure,” online: <https://enerkem.com/closure>.

<sup>35</sup> Government of Alberta, “Biofuel Projects in Alberta,” online: <https://alberta.ca/biofuels>.

<sup>36</sup> NRCB, “Consumers Paper Corp Waste Paper Recycling Project,” online: <https://www.nrcb.ca/natural-resource-projects/natural-resource-projects-listing/137/consumers-paper-corp-waste-paper-recycling-project>

<sup>37</sup> *Natural Resources Conservation Board Act*, RSA 2000, c N-3, s. 4 – CanLII.

<sup>38</sup> *Ibid.*

<sup>39</sup> *Ibid.*

<sup>40</sup> *Ibid.*

Brazil's Proálcool policy and program launched in 1975, has made it the world's largest ethanol producer and exporter with sugarcane as the feedstock.<sup>41</sup> The program has reduced national dependence on imported energy, increased employment opportunities, and diversified the country's renewable energy portfolio. The government provides subsidies, incentives, and tax breaks to boost competitiveness. Ethanol production contributes to the economy, with investments reaching \$4.7 billion between 2010 and 2011, creating 4.5 million jobs and contributing to exports.<sup>42</sup> The program also focuses on partnerships with private and research sectors. In the second phase of the program, Brazil transitioned from anhydrous ethanol to hydroethanol for direct use in vehicles. By 1986, 700,000 ethanol-powered vehicles were licensed, and ethanol production surged to 12.3 billion liters, a threefold increase from 1976.<sup>43</sup> Many Asian and African countries are considering similar steps to cultivate fuel crops.<sup>44</sup> The motivation behind Proálcool was energy insecurity in the 1970s. Until the 1980s Brazil found itself in a challenging energy security position, with approximately 80% of oil consumed in the country imported from other nations.<sup>45</sup> In response to the 1973 oil crisis, the nation committed to creating an ambitious biofuel initiative that not only enhanced energy security and bolstered the economy but also had the added advantage of lowering greenhouse gas emissions (GHG). Furthermore, a significant benefit of ethanol lies in its compatibility with current technology, allowing it to be stored, distributed, and utilized much like gasoline.

Globally, more than 80 countries have policies that support biofuel demand. Collectively, biofuel consumption reduced oil use for transportation vehicles by 4% of global road transport oil use (2 million barrels of oil) on an energy basis in 2022<sup>46</sup>. Brazil remains one of the dominant markets, the second largest biofuel producer in the world, accounting for 85% of total demand. Biofuel

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<sup>41</sup> Decree number 76,593 of 14th November 1975 (Brazil).

<sup>42</sup> “The Story of Brazil’s Ethanol Programme”, online (pdf): UK Government [https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806\\_ENV\\_BraEthPro\\_GUIDE](https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806_ENV_BraEthPro_GUIDE).

<sup>43</sup> Biodieselbr, “PróAlcool – Programa Brasileiro de Álcool ( The Brazilian Ethanol Programme)” (2011), online: Biodieselbr.

<sup>44</sup> “The Story of Brazil’s Ethanol Programme”, online (pdf): UK Government [https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806\\_ENV\\_BraEthPro\\_GUIDE](https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806_ENV_BraEthPro_GUIDE).

<sup>45</sup> Brazilian Energy Research Company (Empresa de Pesquisa Energética – EPE) *Brazil Energy Balance 2012*, (Rio de Janeiro: EPE 2011).

<sup>46</sup> International Energy Agency, “Biofuels - Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>. (Retrieved May 5, 2025).

demand was expected to increase by 11% in 2024, with two-thirds of growth occurring in emerging economies. In 2009, a total of 23 % of the energy for road transportation came from biofuels.<sup>47</sup> While biofuels offered energy security benefits, their prices climbed more quickly than those of gasoline and diesel in many countries.

Unlike in Brazil, as of 2021, biofuel consumption in Alberta's transportation sector is minimal. Data from Natural Resources Canada indicates that biodiesel usage in Alberta's road transportation was effectively 0%, with no significant consumption recorded.<sup>48</sup>

In recent years, biofuel adoption has gained significant momentum globally, supported by policies and initiatives to reduce greenhouse gas (GHG) emissions and mitigate climate change.<sup>49</sup> In 2022, biofuel demand reached a record high of 4.3 EJ (170,000 million liters), surpassing pre-pandemic levels seen in 2019.<sup>50</sup> Biofuels accounted for over 3.5% of global transport energy demand, primarily driven by road transport.<sup>51</sup> The use of biofuels has expanded at nearly 6% annually over the past five years, except 2020, when the COVID-19 pandemic caused a temporary decline in demand.<sup>52</sup>

Several countries have emerged as leaders in biofuel adoption through ambitious policies and blending mandates. For instance, India achieved 10% ethanol blending in 2022, ahead of its initial schedule, and is now targeting a 20% blending rate by 2025.<sup>53</sup> Similarly, Brazil has committed to increasing biodiesel blending from 10% in 2022 to 15% by 2026, further solidifying its role as a global biofuel pioneer.<sup>54</sup> In North America, the United States Inflation Reduction Act (IRA) is set to provide an estimated USD 9.4 billion in production and investment support for biofuels through

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<sup>47</sup> Carlos H. Brito Cruz, Glauca Mendes Souza, Luiz A. Barbosa Cortez, “Chapter 11 - Biofuels for Transport” in Trevor M. Letcher, ed, *Future Energy*, 2<sup>nd</sup> ed (Oxford: Elsevier, 2014) 215.

<sup>48</sup>Natural Resources Canada , “Transportation Energy Use in Alberta”, online: <https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?juris=ab&page=1&rn=2&sector=tran&type=C&year=2021> (Retrieved May 5, 2025).

<sup>49</sup> International Energy Agency, “Biofuels - Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>. (Retrieved May 5, 2025).

<sup>50</sup> *Ibid.*

<sup>51</sup> *Ibid.*

<sup>52</sup> *Ibid.*

<sup>53</sup> Press Information Bureau India , “Press Note”, online:<https://pib.gov.in/PressNoteDetails.aspx?NoteId=153363&ModuleId=3&reg=3&lang=1>

<sup>54</sup>Global Agricultural Information Network, “Report Name: Biofuels Annual”, online (pdf): [https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels+Annual\\_Brasilia\\_Brazil\\_BR2023-0018](https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels+Annual_Brasilia_Brazil_BR2023-0018)

2031.<sup>55</sup> Canada started implementing its Clean Fuel Regulations in 2023, which aim to achieve a 13% reduction in GHG emissions intensity for transport fuels by 2030.<sup>56</sup>

The European Union is also taking significant strides to promote biofuels. The forthcoming Renewable Energy Directive (RED III) seeks to double the renewable content requirements in transportation fuels compared to current targets.<sup>57</sup> These efforts underscore the global recognition of biofuels as a critical tool for achieving climate goals, reducing reliance on fossil fuels, and supporting energy security.

### **7.0 Advances and Challenges in the Production of Biofuel**

The vast majority of biofuel production currently uses so-called conventional feedstocks, such as sugar cane, corn, and soybeans.<sup>58</sup> However, expanding biofuel production to advanced feedstocks is critical to ensuring minimal impact on land use, food and feed prices and other environmental factors. Used cooking oil and waste animal fats provide most non-food crop feedstocks for biofuel production today. Given that these feedstocks are limited, new technologies will need to be commercialized to expand non-food crop biofuel production. For instance, cellulosic ethanol and biomass-based Fischer-Tropsch (bio-FT) technologies can use non-food feedstocks to produce low-carbon biofuels for use in the transport sector. While the average production cost of such biofuels is still double to triple that of fossil fuel equivalents, it could decline by as much as 27% over the next decade, with any remaining cost gap covered by policy measures to spur production and demand.<sup>59</sup>

Many other biofuel production pathways have achieved commercial status, including ethanol production from corn and sugarcane, fatty acid methyl esters (FAME) biodiesel, hydrotreated vegetable and waste oil (HVO) renewable diesel, and hydrotreated esters and fatty acids (HEFA)

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<sup>55</sup> United States Department of Energy, “DOE and EPA Announce \$9.4 Million to Spur Development of Advanced Biofuels”, online: <https://www.energy.gov/eere/bioenergy/articles/doe-and-epa-announce-94-million-spur-development-advanced-biofuels-part>

<sup>56</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>

<sup>57</sup> Council of the European Union, “Renewable Energy: Council Adopts New Rules”, online: <https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/renewable-energy-council-adopts-new-rules>

<sup>58</sup> Caterpillar, “Biofuel for CAT® Generators”, online: [https://www.cat.com/en\\_US/by-industry/electric-power/electric-power-industries/renewable-liquid-fuels.html](https://www.cat.com/en_US/by-industry/electric-power/electric-power-industries/renewable-liquid-fuels.html)

<sup>59</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

biojet kerosene from vegetable oils and waste oils. Others are on the cusp of commercialization: the alcohol-to-jet (ATJ) route from ethanol production was expected to become commercial at the end of 2023, while other companies are exploring novel oilseed crops that avoid competition with arable land.<sup>60</sup>

Using biofuels has many benefits. Although HVO and biodiesel do not significantly reduce CO2 emissions at the tailpipe, switching to biofuels will reduce lifecycle greenhouse gas emissions compared to diesel. One notable advantage of biofuels over traditional fossil fuels is their ability to reduce visible smoke emissions. This reduction is especially essential in cities and industrial areas where air quality is a major problem. Biofuels contribute to cleaner air and better public health by reducing particulate matter in exhaust emissions, making them a viable option for combating environmental pollution. Biofuels additionally pose as an easy alternative. HVO fuel is a drop-in replacement for diesel. Running generators on biofuels provides similar performance to diesel. Biofuels are available now and are easy to switch to. Running on biofuel provides similar rated power output, transient response, start up time, and NOx emissions to running on diesel.<sup>61</sup>

Leading producers like Brazil, supply global markets with biofuels made from sugarcane, corn, and other crops, helping to reduce greenhouse gas emissions and achieve net zero carbon (emission minus absorption) by 2050. At the same time, this will be a substantial source of income and can contribute to a reduction in the world’s significant economic asymmetries.<sup>62</sup>

<b>Environmental Gains</b>	Carbon sequestration -  Lower emission levels in consumption
<b>Renewability</b>	Short production cycle -  man-controlled process

<sup>60</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>61</sup> Caterpillar, “Biofuel for CAT® Generators”, online: [https://www.cat.com/en\\_US/by-industry/electric-power/electric-power-industries/renewable-liquid-fuels.html](https://www.cat.com/en_US/by-industry/electric-power/electric-power-industries/renewable-liquid-fuels.html)

<sup>62</sup> Agencia Fapesp, “Biofuels Are Crucial to the Energy Transition, but Misinformation Must Be Overcome” (19 July 2023), online: <https://agencia.fapesp.br/biofuels-are-crucial-to-the-energy-transition-but-misinformation-must-be-overcome/41919>

<b>Economic Aspects</b>	New demand component - impacts on trade balance
<b>Social Aspects</b>	Job Creation  Income Distribution
<b>Energy Security</b>	Diversification  Reduction of Imports <sup>63</sup>

In 2023, in Brazil, which is the second largest biofuel producer in the world, a total of 21 % of the energy for road transportation came from biofuels.<sup>64</sup> Overall, more than 80 countries have policies that support biofuel demand. Collectively, biofuels avoided 4% of global road transport oil use (2 million barrels of oil) on an energy basis in 2022.<sup>65</sup> Brazil remains one of the dominant markets, accounting for 85% of total demand. Biofuel demand is expected to increase by 13% over the next five years, with growth in emerging economies offsetting declines in advanced ones.<sup>66</sup> While biofuels offered energy security benefits, their prices climbed more quickly than those of gasoline and diesel in many countries. To mitigate increases in transport fuel costs, Brazil, Sweden, and Finland delayed planned increases to biofuel blending obligations in 2022.<sup>67</sup> Brazil is expanding biodiesel blending to 15% by 2026 from 12% in 2023.<sup>68</sup>

<sup>63</sup> Convention on Biological Diversity, online: <https://www.cbd.int/doc/meetings/agr/rwspubio-01/other/rwspubio-01-biofuel-brazil-en.pdf>

<sup>64</sup> “Transportation fuel demand and biofuel share in Brazil” (Statista), online: <https://www.statista.com/statistics/1550253/transportation-fuel-demand-and-biofuel-share-brazil/>

<sup>65</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>66</sup> Minnesota Bio-Fuels Association, “IEA Predicts Increased Biofuel Demand Through 2028”, online: <https://www.mnbiofuels.org/iea-predicts-increased-biofuel-demand-through-2028>

<sup>67</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>68</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

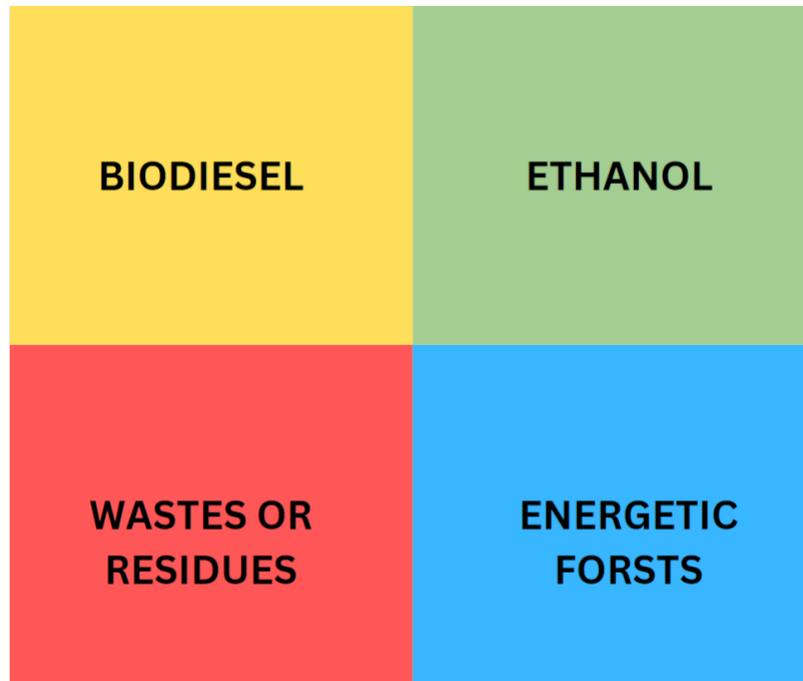


Figure: Brazil's Agroenergy Plan

### **8.0 Historical Milestones and Biofuel Policy Evolution in Brazil**

In 1975, Brazil inaugurated its ethanol program called Proálcool, which has made the country the world's largest producer and exporter of sugarcane ethanol.<sup>69</sup> The program has not only significantly reduced national dependence on imported energy but also it has also boosted employment opportunities, bolstered the economy, and diversified the country's renewable energy portfolio. Many Asian and African countries are considering the same steps of cultivating fuel crops.<sup>70</sup>

This program enabled Brazil to reduce its dependence on petroleum for a portion of its national transportation fuel supply. Additionally, Proálcool revitalized the sugarcane industry by repurposing idle mills and distilleries for ethanol production. The program also played a pivotal role in advancing technology in sugarcane cultivation and processing. One of its significant achievements was fostering collaboration between major industries, research institutions, and

<sup>69</sup> Decree number 76,593 of 14th November 1975 (Brasil)

<sup>70</sup> "The Story of Brazil's Ethanol Programme", online (pdf): UK Government, [https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806\\_ENV\\_BraEthPro\\_GUIDE](https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806_ENV_BraEthPro_GUIDE).

government agencies in areas like technology, industrial policy, energy planning, and agriculture to create sectoral synergies.

Proálcool has helped reduce greenhouse gas (GHG) emissions and create countless job opportunities in Brazil. The program aimed to increase ethanol production from sugarcane, primarily to blend it with gasoline as a sustainable alternative to petroleum. Government regulations and incentives were critical in driving and maintaining competitive ethanol production.

Key efforts included mandatory blending rules, financial incentives to boost ethanol competitiveness, and collaborations with the business and research sectors, all of which helped Brazil become the world's largest sugarcane ethanol market. To help fund the program, the government provided subsidies, tax exemptions, and other incentives to reduce production costs and increase ethanol's market viability. However, addressing the environmental and social consequences of ethanol production necessitated novel planning methods and stringent enforcement mechanisms. Aside from environmental benefits, ethanol production has made a considerable contribution to Brazil's economy, strengthening sectors like mill equipment manufacturing, research and development investments, and the full agro-industrial value chain.

According to the Brazilian Sugarcane Journal (*Jornal da Cana*), sugarcane output for sugar ethanol and bioelectricity was worth around US\$60 billion between 2010 and 2011, accounting for 1.6% of national GDP. During the same time period, investments in sugarcane production totaled US\$4.7 billion, supporting 4.5 million direct and indirect jobs. The sugarcane business also employed 72,000 independent producers, contributed US\$12.5 million in exports, and collected US\$7.5 million in taxes. Furthermore, second-generation ethanol has the potential to greatly boost production without expanding cultivation, making it a more sustainable fuel source in the future.<sup>71</sup>

The motivation behind Proálcool was energy insecurity in the 1970s. Until the 1980s, Brazil found itself in a sticky position, with approximately 80% of oil consumed in the country coming from abroad.<sup>72</sup> In response to the 1973 oil crisis, the nation committed to creating an ambitious biofuel initiative that not only enhanced energy security and bolstered the economy but also had the added

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<sup>71</sup> “The Story of Brazil’s Ethanol Programme”, online (pdf): UK Government, [https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806\\_ENV\\_BraEthPro\\_GUIDE](https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806_ENV_BraEthPro_GUIDE).

<sup>72</sup> Brazilian Energy Research Company (Empresa de Pesquisa Energética – EPE) *Brazil Energy Balance 2012*, (Rio de Janeiro: EPE 2011).

advantage of lowering greenhouse gas emissions. Furthermore, a significant benefit of ethanol lies in its compatibility with current technology, allowing it to be stored, distributed, and utilized much like gasoline. On a different line, the program was also intended to reduce income disparities within the country, expand the production of capital goods, and create jobs.

In due course, the Brazilian government opted to change the focus of the second phase of its Proálcool program. This shift involved transitioning from the production of ethanol as an additive (anhydrous ethanol) to producing it as a complete fuel (hydrous ethanol) for direct use in vehicles equipped with suitable engines. In 1979, Brazil introduced its first commercially available car designed to run solely on ethanol. Throughout the 1980s, a majority of the vehicles sold in the country were powered by ethanol. By 1986, a remarkable 700,000 ethanol-powered vehicles had been licensed, and ethanol production had surged to 12.3 billion liters, a threefold increase compared to 1976.<sup>73</sup>

Despite the success of the program, a decrease in global oil prices and a surge in international sugar prices in the late 1980s prompted producers to shift their focus away from ethanol production. This resulted in a severe shortage of ethanol supply between 1989 and 1990, leaving many unable to purchase fuel for their vehicles. The crisis adversely impacted the reputation of Proálcool. Additionally, subsequent reductions in government incentives for ethanol production further elevated prices, leading to a notable decline in demand and, consequently, a drop in sales of ethanol-powered cars. Ultimately, the Proálcool program was discontinued in 1990.

The National Program for the Production and Use of Biodiesel (PNPB) was therefore launched in 2005 and incorporates the footsteps of Proálcool focusing on biodiesel supply, also with a strong focus on social aspects and regional development.<sup>74</sup> Notably, both programs were created to increase the transportation fuel supply and enhance energy security as the primary goals, while the environmental benefits from biofuels were recognized later.<sup>75</sup>

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<sup>73</sup> Biodieselbr, “PróAlcool – Programa Brasileiro de Álcool ( The Brazilian Ethanol Programme)” (2011), online: Biodieselbr.

<sup>74</sup> L.L. Benites-Lazaro, N.A. Mello-Thery, & M. Lahsen, “Business storytelling about energy and climate change: the case of Brazil's ethanol industry Energy” (2017) 31 Energy Research & Social Science 77

<sup>75</sup> S.L. Stattman, O. Hospes, & A.P.J Mol “Governing biofuels in Brazil: a comparison of ethanol and biodiesel policies”

However, as of January 1, 2025, Alberta's population reached approximately 4.96 million, reflecting a remarkable growth of over 168,000 people in just one year.<sup>76</sup> This growth has important implications for energy planning, particularly in the transportation sector, as more people translate into greater demand for mobility and fuel.

Currently, Alberta's transportation fuel landscape is dominated by an ample and steady supply of gasoline and diesel. This abundance sharply contrasts with countries like Brazil, where limited oil reserves and different resource configurations have encouraged the development and mainstream use of biofuels. In Alberta, however, the availability of conventional fuels has historically slowed momentum toward large-scale biofuel adoption.

This status quo is reinforced by Alberta's record oil and gas production. In 2023 alone, the province was responsible for over 60% of Canada's natural gas and nearly 85% of its oil equivalent output, including bitumen and these figures are supported by significant investments and infrastructure advancements, most notably, the completion of the Trans Mountain Pipeline Expansion.<sup>77</sup>

Adding to its dominance in fossil energy, Alberta sits atop one of the world's largest hydrocarbon repositories, the Western Canada Sedimentary Basin.<sup>78</sup> The Alberta Energy Regulator ensures that these vast resources are managed with regulatory rigor and long-term sustainability in mind.

Still, Alberta is not resting on its fossil laurels. To meet climate obligations and address rising greenhouse gas emissions, the province is increasingly investing in carbon capture, utilization, and storage (CCUS) technologies.<sup>79</sup> A prime example is Strathcona Resources' recent partnership with the Canada Growth Fund, an ambitious plan to invest up to C\$1 billion in infrastructure that will capture and store 2 million tonnes of CO<sub>2</sub> annually.<sup>80</sup>

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<sup>76</sup> Government of Alberta, "Alberta's population grew by over 168,000 in 2024", online: <https://rdnewsnow.com/2025/03/19/albertas-population-grew-by-over-168000-in-2024>

<sup>77</sup> Alberta Energy Regulator, "News Release – 2024-06-24", online: <https://www.aer.ca/about-aer/media-centre/news-releases/news-release-2024-06-24>

<sup>78</sup> Wikipedia, "Western Canada Sedimentary Basin", online: [https://en.wikipedia.org/wiki/Western\\_Canada\\_Sedimentary\\_Basin](https://en.wikipedia.org/wiki/Western_Canada_Sedimentary_Basin)

<sup>79</sup> Government of Alberta, "Clean Hydrogen Markets", online: <https://www.alberta.ca/clean-hydrogen-markets>

<sup>80</sup> Rod Nickel, "Oil producer Strathcona partners with Canada Growth Fund for carbon capture" (10 July 2024), online: Reuters <https://www.reuters.com/business/energy/oil-producer-strathcona-partners-with-canada-growth-fund-carbon-capture-2024-07-10>

At the same time, Alberta is charting a low-carbon future through its Hydrogen Roadmap, which positions hydrogen as a cornerstone of its clean energy transition. This initiative builds on Alberta's status as Canada's largest hydrogen producer, currently generating 2.5 million tonnes per year for industrial uses.<sup>81</sup>

The Hydrogen Roadmap identifies five key end-use markets: industrial processes, residential and commercial heating, power generation and storage, exports, and importantly, transportation. Within the transport sector, Alberta is advancing pilot projects such as the Alberta Zero Emissions Truck Electrification Collaboration (AZETEC) and the Alberta Zero Emission Hydrogen Transit (AZEHT). These projects aim to test and deploy hydrogen fuel cell vehicles for heavy-duty and municipal transit, demonstrating their potential to drastically reduce GHG emissions compared to conventional diesel engines.

In essence, Alberta's energy story is at a crossroads. While the province continues to benefit from its abundant fossil resources, it is also strategically investing in technologies like CCUS and hydrogen that align with both climate commitments and future energy competitiveness. The Hydrogen Roadmap is not just a policy, it's a vision that seeks to future-proof Alberta's economy, build new energy markets, and ensure that its transportation systems are as sustainable as they are strong.

## **9.0 Lessons and Innovations from Brazil's Biofuel Journey**

Many European countries asserted that there was not enough land and biofuel production would compete with food production as well as contributing to forest degradation, but this has been entirely refuted by Brazil's experience.<sup>82</sup> They claim that there is not enough biomass. However, when considering well-established biofuels such as ethanol from sugarcane and corn and biodiesel from soybeans and palm oil, it was concluded that the reduction in emissions was significant in every case, reaching 86%, that the biofuels in question were competitive in price with fossil fuels, that they created jobs, and that these countries had sufficient amounts of pastureland to double

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<sup>81</sup> Government of Alberta, "Clean Hydrogen Markets", online: <https://www.alberta.ca/clean-hydrogen-markets>

<sup>82</sup> Agencia Fapesp, "Biofuels Are Crucial to the Energy Transition, but Misinformation Must Be Overcome" (19 July 2023), online: <https://agencia.fapesp.br/biofuels-are-crucial-to-the-energy-transition-but-misinformation-must-be-overcome/41919>

biofuel production by converting 5% on average into cropland for this purpose. The conversion rate for Brazil was only 3%. The projection that Brazil's biofuel production could double is actually conservative, as studies show that production could be increased by a factor of 6 merely by reusing degraded pastureland, without falling a single tree in the Amazon or Cerrado.<sup>83</sup> The problem it seems is, enormous poor understanding of realities which once again is being leveraged to construct narratives aligned with economic interests that oppose an effective energy transition.

There is some reluctance to shift entirely to electric vehicles because of economic interest, especially the desire to maintain market share. Europe rushed into EVs because they didn't want to be prisoners of the oil sheikhs, but now they're prisoners of the Chinese battery makers. Instead, there is a possibility that Brazil might focus on hybrids with a small battery and an internal combustion engine running on low-carbon fuel such as ethanol. It is faster, and does not require all the infrastructure. It is cheaper as it will use a less expensive battery and it can be entirely made in Brazil. If all vehicles were 100% electric, demand would be low because of their cost, the fleet would age, and the huge gap between social classes in Brazil would widen.<sup>84</sup>

Brazil is also skeptical about sourcing electricity. Reactivating coal mines to fuel electric power plants does not seem prudent.<sup>85</sup> Despite Brazil's advances in biofuel manufacturing, various barriers prevent widespread adoption. One key challenge is a lack of environmental awareness among customers, which limits their comprehension of biofuels' role in mitigating climate change and lowering greenhouse gas emissions. Furthermore, the country's price regulations provide a hurdle, as many individuals value cost over the environmental benefits of greener energy sources. This emphasis on affordability frequently overshadows the long-term advantages of using biofuels. Furthermore, there is a longstanding misperception that ethanol causes pollution, undermining its credibility as a sustainable fuel source. Compounding these difficulties is the lack of strong governmental initiatives targeted at educating customers about the benefits of sustainable energy.

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<sup>83</sup> Agencia Fapesp, "Biofuels Are Crucial to the Energy Transition, but Misinformation Must Be Overcome" (19 July 2023), online: <https://agencia.fapesp.br/biofuels-are-crucial-to-the-energy-transition-but-misinformation-must-be-overcome/41919>

<sup>84</sup> Agencia Fapesp, "Biofuels Are Crucial to the Energy Transition, but Misinformation Must Be Overcome" (19 July 2023), online: <https://agencia.fapesp.br/biofuels-are-crucial-to-the-energy-transition-but-misinformation-must-be-overcome/41919>

<sup>85</sup> Hugo Cagno Filho, Chair of Brazil's National Bioenergy Union (UDOP), Statement

Without concerted efforts to promote awareness and dispel these myths, biofuels' potential to drive a sustainable energy transition in Brazil goes untapped.

Alternatively, Brazil has been upfront in developing some very interesting bioproducts. For instance, Methionine, an amino acid used quite widely as a chicken feed supplement, can now be made from renewable resources. This is much cheaper than the petrochemicals. Succinic acid, which has many applications, the petrochemical costs ten dollars per kilo, while the product made from renewable biomass costs two.<sup>86</sup>

In addition, Flex-fuel (FFV) technology allows engines to operate on varying combinations of ethanol and gasoline. Embraced by consumers, these vehicles played a pivotal role in increasing ethanol consumption within the domestic market, paving the way for the expansion of Brazil's ethanol industry. Subsequently, the adoption of FFVs experienced a rapid surge. In 2003, FFVs accounted for 4.7% of the total light vehicle market, and by 2011, a substantial 83.1% of new cars sold in Brazil utilized flex-fuel technology. This widespread adoption led to a remarkable growth in ethanol production, rising from 11.5 billion liters in 2003 to its peak of 28 billion liters in 2009.<sup>87</sup>

The ethanol economy in Brazil experienced a revival with the introduction of the innovative "flex engine" technology after 2003. This technology allows vehicles to be powered by 100% ethanol, gasoline, or any combination of the two. After almost two decades of using flex-fuel automobiles, 93% of cars in Brazil now come equipped with flex-fuel engines. Additionally, imported cars can be adapted to run on an E27 blend with minimal engine modifications, often costing as low as \$50.

In addition to significant foreign exchange savings amounting to \$261 billion, Brazil's ethanol program has contributed to avoiding over 1.34 billion tons of CO<sub>2</sub> equivalent emissions. This has resulted in a 50% reduction in air pollution, contributing to improved public health in major cities such as Sao Paulo.

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<sup>86</sup> Luis Fernando Cassinelli, Professor of Polymeric Packaging at Maua Institute of Technology and Member of Steering Committee for BIOEN-FAPESP, Statement

<sup>87</sup> "The Story of Brazil's Ethanol Programme", online (pdf): UK Government  
,[https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806\\_ENV\\_BraEthPro\\_GUIDE](https://assets.publishing.service.gov.uk/media/57a08a08ed915d622c00050b/130806_ENV_BraEthPro_GUIDE).

To strengthen its biofuel business and promote the use of ethanol, Brazil has enacted a number of legislative changes targeted at increasing production efficiency and cost competitiveness. One significant goal is to increase the anhydrous ethanol blend in gasoline from 20% to 25%, resulting in a greater amount of renewable energy in the country's fuel mix. Furthermore, tax relief measures have been implemented, lowering ethanol production expenses by up to US\$0.05 per liter. Financial incentives have also been altered, including a large reduction in the yearly interest rate on sugarcane credits from 9.5% to 5.5%. Similarly, the yearly interest rate on investments in ethanol storage has been reduced from 10% to 7.7%. These policy changes are intended to increase the competitiveness of ethanol in the energy market, assist the sugarcane industry, and stimulate additional investment in renewable energy infrastructure. These policies have not satisfied the purpose. They are considered short-term policies insufficient to reduce ethanol prices at the pumps or stimulate new investments.

Moreover, in Brazil, the implementation of the RenovaBio program has mandated that fuel distributors acquire emissions reduction certificates. This is expected to provide a financial incentive for the production of ethanol, biodiesel, and the advancement of biofuels. The levels of fuel taxation also play a crucial role in determining price competitiveness at the pump, thus influencing consumer choices. This is particularly significant in Brazil, where gasoline and ethanol directly compete for market share. As of March 2018, state and federal taxes accounted for 46% of the final cost of gasoline to the consumer.<sup>88</sup>

Ethanol currently benefits from favorable federal taxation rates and, in some cases, lower state taxes. When taxes on fuels were increased in 2017, that included the tax on gasoline. These changes in fuel taxation, coupled with higher crude oil prices, led to a 25% surge in hydrous ethanol consumption in the latter half of the year. In total, ethanol made up 44% of Brazil's gasoline-pool fuel demand in 2017.<sup>89</sup> Ethanol has significant advantages as a renewable energy source, making it a critical component in the global transition to sustainable fuels.<sup>90</sup> It is quite simple to manufacture on a big scale by utilizing current agricultural infrastructure and technologies. Compared to current oil prices, ethanol production costs are competitive, increasing

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<sup>88</sup> Petrobras, *Annual Report 2018*

<sup>89</sup> UNICA (União da Indústria de Cana-de-Açúcar), *Annual Report (2018)*

<sup>90</sup> Convention on Biological Diversity, online:<https://www.cbd.int/doc/meetings/agr/rwspubio-01/other/rwspubio-01-biofuel-brazil-en>.

its economic appeal. Furthermore, ethanol may be produced from a variety of raw materials, including sugarcane, corn, and biomass, providing flexibility and lowering reliance on a single resource. Its manufacturing helps economic growth, particularly in rural areas, by creating jobs and supporting local enterprises. Ethanol also has bright prospects in the global energy market due to its scalability and demand as a green fuel.

From an environmental standpoint, ethanol is a renewable energy source with a zero-carbon balance, which means that its lifecycle emissions are offset by the carbon absorbed during feedstock production. It is not petroleum-dependent, making it less vulnerable to disruptions in fossil fuel supply. Ethanol's high miscibility with gasoline makes it a suitable substitute for tetraethyl lead, a harmful gasoline additive. Ethanol, as an oxygenated molecule, reduces total emissions such as carbon monoxide and particulates. It is also low in toxicity and free of sulfur, which helps to purify the air and decrease acid rain.

Despite the benefits, increasing ethanol production presents substantial environmental and ecological challenges. One of the most worrying challenges is the permanent conversion of virgin ecosystems to farmed land for ethanol feedstock production. Deforestation can cause species extinction, the loss of crucial habitats, and the disruption of ecosystem services like biomass generation and genetic diversity conservation. Additionally, large-scale forest degradation has an impact on the hydrological cycle and local climate, diminishing regional precipitation and increasing temperatures. Currently, less than 13% of Brazil's natural forests are intact and not subject to rigorous environmental protection legislation. Other negative consequences of ethanol expansion include soil degradation, biodiversity loss, and excessive water consumption, which stresses local water resources. Water contamination, atmospheric emissions, and the production of huge trash all worsen environmental concerns. When Brazil's Próalcool program began, insufficient environmental legislation and ineffective public management failed to ameliorate the negative consequences, causing severe harm.<sup>91</sup>

The conversion of rainforests into sugarcane farms causes soil erosion and biodiversity difficulties, while pre-harvest burning contributes to local air pollution. The burning of sugarcane plants aids manual harvesting, decreases worker injuries and emits pollutants into the environment. These

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<sup>91</sup> SOS Mata Atlântica, “. A Mata Atlântica (The Atlantic Forest)” online publication (no date available).

problems underscore the need for stronger environmental regulations and novel techniques to ensure ethanol's sustainability.

<b>Raw Material</b>	<b>Energy Output/Energy Input</b>
<b>Wheat<sup>92</sup></b>	<b>1.2</b>
<b>Corn<sup>93</sup></b>	<b>1.3-1.8</b>
<b>Sugar Beet <sup>94</sup></b>	<b>1.9</b>
<b>Sugar Cane<sup>95</sup></b>	<b>9.3 (High photosynthesis efficiency C4 crop)</b>

Figure: Energy efficiency of ethanol in Brazil

Multiple factors affect biofuel production cost, pricing, and profitability. The expense of feedstock is critical in determining the overall production costs of biofuels. In the United States, corn serves as the primary feedstock for fuel ethanol, while Brazil predominantly relies on sugar cane. Additionally, both countries predominantly use soybeans for the production of biodiesel. The costs of these agricultural commodities are influenced by factors such as planted area, yields, harvest conditions, and market dynamics, all of which are subject to annual variations. Furthermore, the production costs are impacted by the technical sophistication of the production facility and the prices of fuels utilized to process energy. There are other factors that also determine biofuel pricing. For instance, prices are frequently adjusted based on the current rates of gasoline and diesel to optimize profit margins. In Brazil, the cost of sugar cane ethanol experiences fluctuations with the harvest cycle, with an increase observed during the January-March inter-harvest period.

<sup>92</sup> F O Licht, *World Ethanol and Biofuels Report* (2004) 2(21)

<sup>93</sup> F O Licht, *World Ethanol and Biofuels Report* (2004) 2(21)

<sup>94</sup> F O Licht, *World Ethanol and Biofuels Report* (2004) 2(21)

<sup>95</sup> I Macedo et al., "Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil" (2008).

To evaluate the profitability of biofuel production, it is essential to consider the value of co-products. For instance, the production of corn-based fuel ethanol results in dried distiller's grains (DDGs) as a co-product, while biodiesel production from soybeans yields soybean meal. Both of these by-products are valuable as animal feed, making them integral to the economic aspects of biofuel production.

In Brazil, bagasse is generated during the sugar cane-crushing process and is utilized as a fuel in sugar mill co-generation plants to meet onsite energy needs. In some cases, surplus electricity is even generated for export. The future production of cellulosic ethanol in Brazil would lead to an increased demand for bagasse as a feedstock for advanced biofuel production, consequently enhancing its value.<sup>96</sup>

## **10.0 Renewable Energy and Environmental Conservation in Brazil**

Brazil's development of sugarcane and ethanol as a sustainable energy source has included several milestones. In 1532, Martim Afonso de Sousa introduced sugarcane to Brazil, laying the groundwork for the country's success in sugarcane farming and ethanol production. By 1925, Brazil had tested its first ethanol-powered car, showcasing pioneering work in alternative fuels. This transportation breakthrough culminated in 1979 with the introduction of the first commercially available vehicle fueled solely by ethanol, thereby integrating biofuels into the transportation industry. The advent of flex-fuel motors in 2003 further transformed Brazil's automotive sector, allowing vehicles to run on ethanol, gasoline, or a combination of the two. This innovation dramatically increased ethanol consumption and solidified its position as a key component of Brazil's energy plan.<sup>97</sup>

During the initial phases of the Brazilian ethanol program, the government extended loans to both sugarcane growers and ethanol producers, often being the same entities, in a bid to promote the cultivation of sugarcane and the production of ethanol. Subsequently, regulations were

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<sup>96</sup> International Energy Agency, "How competitive is biofuel production in Brazil and the United States?", online: IEA <https://www.iea.org/articles/how-competitive-is-biofuel-production-in-brazil-and-the-united-states>

<sup>97</sup> Convention on Biological Diversity, online: <https://www.cbd.int/doc/meetings/agr/rwspubio-01/other/rwspubio-01-biofuel-brazil-en>.

implemented to control ethanol prices, ensuring economic viability for producers and cost advantages for consumers opting for ethanol. Over time, Brazil successfully attained a lower price for ethanol than gasoline, considering energy content. This reduced cost significantly contributes to the widespread preference for ethanol over gasoline among consumers in Brazil.<sup>98</sup>

In comparison to ethanol derived from corn or sugar beets, ethanol produced from sugarcane in Brazil demonstrates significantly more favorable outcomes in terms of energy balance and reductions in greenhouse gas emissions. These advantages are primarily attributed to two key factors: (i) the substantial increase in sugarcane yield in Brazil over the past 25 years, and (ii) the utilization of bagasse, rather than fossil fuels, in ethanol plants to supply the necessary heat for plant operations and generate electricity for export to electric grids. Technological advancements in both sugarcane farming and ethanol production have played a crucial role in realizing the substantial benefits associated with sugarcane ethanol.<sup>99</sup>

Brazil's medium-term energy policy is reflected in the Ten-year energy expansion plans (PDEE), which are updated on a yearly basis. Originally focused on electricity, in 2007 the ten-year plans expanded to cover the energy sector. The National Energy Plan 2030 (PNE), developed in 2006-07, provides a longer-term integrated energy strategy. A National Energy Plan 2050 is in the development stages. Law 9478 of 1997 established the general principles of Brazil's national energy policy, including the use of renewable energy sources as a pillar of the country's energy policy.<sup>100</sup>

Brazil's renewable energy targets are embedded in its Ten-year energy expansion plans (PDEE). The PDEE aims for renewable energy to account for 42.5% of the country's total primary energy supply by 2023 up from 42.1% in 2014 which are the basis for ordinary power capacity auctions (see below). The latest PDEE edition, PDEE 2023, anticipates renewables (including large hydro) to represent 86.1% of the electricity generation matrix by 2023 up from 79.3% in 2013, with wind power accounting for 8.1% and expanding 20 GW. By contrast, in 2007, the PNE projected an additional capacity of 3.3 GW for wind power by 2030. The 2007 Brazil National Climate Change

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<sup>98</sup> Michael Wang, "Fuel Pathways Analysis" (2006) 1 Environmental Research Letters 011002.

<sup>99</sup> Michael Wang, "Fuel Pathways Analysis" (2006) 1 Environmental Research Letters 011002.

<sup>100</sup>IRENA, "Renewable Energy Policy Brief: Brazil", online: <https://www.irena.org>

Plan (Decree 6233 of 2007) set the goals of increasing electricity co-generation, mainly from sugarcane bagasse, to 11.4% of total supply in 2030, and adding 34.5 GW of hydropower capacity as scheduled in the PDEE.

The legal framework for the electric system is the Electricity Law of 2004 (Law 10848 of 2004), which proposes a number of amendments and redesigns the original electricity market launched in 2000, following the 2001-2002 electricity crisis. It creates a regulated market for electric companies providing public service and upholds the market for qualifying consumers, alongside a market for free customers (defined as having a peak load  $\geq 3$  MW). The core of these legal instruments is the creation of an organized procurement process scheme for the regulated utilities (distribution companies) via auctions of power purchase agreements (PPAs). Auctions are organized to offer short-, and long-term PPAs, where in the latter the objective is to ease generation financing. The Brazilian National Council for Energy Policy (CNPE) established a list of renewable energy priorities designed to instruct the Brazilian Electricity Regulatory Agency (ANEEL)'s and the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP)'s decision-making process on Research, Development and Innovation (RDI) investments.

<b>Policy Category</b>	<b>Program Initiative</b>	<b>Year introduced</b>	<b>Key Features</b>	<b>Current Status</b>
<b>National Programs</b>	Proálcool (National Alcohol Program)	1975	<ul style="list-style-type: none"> <li>• Mandatory ethanol blending</li> <li>• Government subsidies</li> <li>• Ethanol vehicle development</li> <li>• Distribution infrastructure</li> </ul>	Transformed into newer programs
	RenovaBio	2017	<ul style="list-style-type: none"> <li>• Carbon Credits (CBios)</li> </ul>	Active

			<ul style="list-style-type: none"> <li>• Producer certification</li> <li>• Emission reduction targets</li> <li>• Market mechanisms</li> </ul>	
<b>Blend Mandates</b>	Ethanol Mandate	Current	<ul style="list-style-type: none"> <li>• 27% ethanol in gasoline</li> <li>• Pure ethanol (E100) availability</li> </ul>	Mandatory
	Biodiesel Mandate	Current	<ul style="list-style-type: none"> <li>• 10% biodiesel (B10)</li> <li>• Planned incremental increases</li> </ul>	Mandatory
<b>Tax Incentives</b>	Federal Incentives	Ongoing	<ul style="list-style-type: none"> <li>• Reduced PIS/COFINS taxes</li> <li>• R&amp;D tax credits</li> <li>• Import duty reductions</li> </ul>	Active
	State Incentives	Varies By State	<ul style="list-style-type: none"> <li>• Variable ICMS Rates</li> <li>• Regional development benefits</li> </ul>	Active

<b>Research support</b>	EMBRAPA Program	Ongoing	<ul style="list-style-type: none"> <li>• Sugarcane research</li> <li>• Advanced biofuel development</li> <li>• Sustainability studies</li> </ul>	Active
<b>Financial Support</b>	BNDES Funding	Ongoing	<ul style="list-style-type: none"> <li>• Low-interest loans</li> <li>• Infrastructure funding</li> <li>• Modernization support</li> </ul>	Active
<b>Environmental controls</b>	ZAE Cana	2009	<ul style="list-style-type: none"> <li>• Sugarcane zoning</li> <li>• Ecosystem protection</li> <li>• Land use guidelines</li> </ul>	Enforced
	Forest Code Requirements	Updated 2012	<ul style="list-style-type: none"> <li>• Preservation areas</li> <li>• Sustainable land use</li> <li>• Environmental monitoring</li> </ul>	Enforced
<b>Social programs</b>	Social Fuel Seal	2004	<ul style="list-style-type: none"> <li>• Family farmer integration</li> </ul>	Active

			<ul style="list-style-type: none"> <li>• Regional development</li> <li>• Social inclusion criteria</li> </ul>	
<b>International Initiatives</b>	Export Promotion	Ongoing	<ul style="list-style-type: none"> <li>• Trade partnerships</li> <li>• Quality certification</li> <li>• Market development</li> </ul>	Active
<b>Future Development</b>	RenovaBio Targets	2022-2030	<ul style="list-style-type: none"> <li>• Production expansion</li> <li>• Emission reductions</li> <li>• Infrastructure development</li> </ul>	In progress

Figure: POLICIES IN DETAIL

The combustion of fossil fuels has been the predominant cause of increased carbon dioxide levels in the atmosphere which has significantly contributed to climate change.<sup>101</sup> The extensive use of fossil fuels has directly impacted the global climate and economy.<sup>102</sup> As a result of the increasing use of fossil fuels and the risks associated with it, there is a growing interest with biofuels obtained from biological sources like ethanol, vegetable oil, and various types of biomasses.

Biofuels play a crucial role in decarbonizing transport by providing a low-carbon solution for existing technologies, such as light-duty vehicles in the near term and heavy-duty trucks, ships, and aircraft with few alternative and cost-effective solutions in the long term. Amidst concerns

<sup>101</sup> Yogeewari Subramaniam & Tajul Ariffin Masron, “The impact of economic globalization on biofuel in developing countries”

<sup>102</sup> Staff R. Developing countries to vastly outpace OECD in carbon emissions: EIA. Retrieved September 2020 from: <https://www.reuters.com/article/us-usa-energy-carbon-idUSBRE96O0KN20130725> (2013).

over the environmental impact of fossil fuels, biofuels are being increasingly highlighted for their potential benefits. Proponents of sustainable fuels underscore the environmental benefits of biofuels, advocating them as a strategy to diminish pollution and mitigate the release of climate-altering greenhouse gases (GHGs) worldwide.<sup>103</sup>

Many countries have taken steps towards biofuel-boosting. Countries like the United States and Canada have implemented acts and regulations with commitments to reduce GHG emissions by using biofuels as an alternative. The European Union also plans to double the requirements for renewable content in transportation fuels through the approaching agreement on its renewable energy directive (RED III).<sup>104</sup> In 2022 biofuels reached a record high of 4.3 EJ (170,000 million liters)<sup>105</sup> representing more than 3.5% of the global transport energy demand, mainly for road transport. The use of biofuels has expanded by nearly 6% a year for the past 5 years, except in 2020 when use declined due to the impacts of the COVID-19 pandemic.<sup>106</sup>

The predominant biofuel production currently relies on conventional feedstocks like sugar cane, corn, and soybeans<sup>107</sup>, but there is a critical need to expand production to advanced feedstocks to minimize impacts on land use, food prices, and the environment. Although the average production cost for these biofuels is currently two to three times that of fossil fuel equivalents, a potential 27% cost reduction is anticipated over the next decade.<sup>108</sup> Policy measures are envisioned to bridge any remaining cost gap and stimulate production and demand. Various biofuel production pathways, including ethanol from corn and sugarcane, fatty acid methyl esters (FAME) biodiesel, hydrotreated vegetable and waste oil (HVO) renewable diesel, and hydrotreated esters and fatty acids (HEFA) bio jet kerosene from vegetable oils and waste oils have achieved commercial status, with others, such as the alcohol-to-jet (ATJ) route expected to commercialize by the end of 2023.

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<sup>103</sup> Benites-Lazaro LL, Mello-Thery NA, Lahsen M. Business storytelling about energy and climate change: the case of Brazil's ethanol industry. *Energy Res Soc Sci* 2017; 31:77e85.

<sup>104</sup> International Energy Agency, "Biofuels – Energy System", online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>105</sup> International Energy Agency, "Biofuels – Energy System", online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>106</sup> International Energy Agency, "Biofuels – Energy System", online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>107</sup> Caterpillar, "Biofuel for CAT® Generators", online: [https://www.cat.com/en\\_US/by-industry/electric-power/electric-power-industries/renewable-liquid-fuels.html](https://www.cat.com/en_US/by-industry/electric-power/electric-power-industries/renewable-liquid-fuels.html).

<sup>108</sup> International Energy Agency, "Biofuels – Energy System", online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

Ongoing exploration of novel oilseed crops aims to avoid competition with arable land.<sup>109</sup> Additionally, this shift to biofuels can serve as a significant source of income and contribute to reducing global economic asymmetries.<sup>110</sup>

Brazil is expanding biodiesel blending to 15% by 2026 from 12% in 2023.<sup>111</sup> Their policy changes include raising the anhydrous ethanol blend in gasoline from 20% to 25%,<sup>112</sup> providing tax relief on ethanol to reduce production costs by up to US\$0.05 per liter, lowering the annual interest rate of credits for sugarcane production from 9.5% to 5.5%, and reducing the annual interest rate for investments in ethanol storage from 10% to 7.7%. Fuel taxation levels are crucial in determining price competitiveness at the pump, and influencing consumer choices, and in Brazil, where gasoline and ethanol compete, state and federal taxes constitute 46% of the final costs of gasoline as of March 2018.<sup>113</sup>

A shift in global oil prices and a surge in international sugar prices in the late 1980s prompted producers to shift their focus away from ethanol production. This resulted in a severe shortage of ethanol supply between 1989 and 1990, leaving many unable to purchase fuel for their vehicles. The crisis adversely impacted the reputation of Proálcool. Additionally, subsequent reductions in government incentives for ethanol production further elevated prices, leading to a notable decline in demand and, consequently, a drop in sales of ethanol-powered cars. Ultimately, the Proálcool program was discontinued in 1990.

Brazil's sugarcane ethanol production is a significant source of energy and reduced greenhouse gas emissions compared to corn or sugar beets.<sup>114</sup> The country's sugarcane yield has increased significantly over the past 25 years, and the use of bagasse instead of fossil fuels in ethanol plants has led to technological advancements. The Brazilian government initially provided loans to

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<sup>109</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>110</sup> Agencia Fapesp, “Biofuels Are Crucial to the Energy Transition, but Misinformation Must Be Overcome” (19 July 2023), online: <https://agencia.fapesp.br/biofuels-are-crucial-to-the-energy-transition-but-misinformation-must-be-overcome/41919>

<sup>111</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>112</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

<sup>113</sup> Petrobras, Annual Report (2018)

<sup>114</sup> International Energy Agency, “Biofuels – Energy System”, online: <https://www.iea.org/energy-system/low-emission-fuels/biofuels>.

sugarcane growers and ethanol producers to promote sugarcane cultivation and production.<sup>115</sup> Regulations later controlled ethanol prices, ensuring economic viability for producers and cost advantages for consumers. Technological advancements in sugarcane farming and production have contributed to these benefits.<sup>116</sup> Ethanol currently benefits from favorable federal taxation rates and lower state taxes. However, increased gasoline taxes in 2017 led to a 25% surge in hydrous ethanol consumption, making up 44% of Brazil's gasoline-pool fuel demand in 2017.<sup>117</sup>

Ethanol expansion poses significant environmental challenges, including irreversible conversion of virgin ecosystems, soil degradation, biodiversity loss, water contamination, atmospheric emissions, and waste generation. The Próalcool program, which began with weak environmental institutions and legislation, failed to prevent significant harm. Ethanol conversion also leads to soil erosion, biodiversity loss, and local air pollution due to burning in plantations before harvest.<sup>118</sup> Pre-harvest burning, which involves burning sugarcane leaves to speed up manual harvesting and reduce injuries, further exacerbates these issues. Today, less than 13% of original forests remain intact.<sup>119</sup> Flex-fuel technology in Brazil has increased ethanol consumption, leading to a significant expansion of the ethanol industry. By 2011, 83.1% of new cars used flex-fuel, with 93% equipped with flex-fuel engines. This has resulted in \$261 billion in foreign exchange savings and a 50% reduction in air pollution.

## 11.0 Conclusion

Decades of experience in Brazil with biofuel production and domestic consumption provide a compelling strategy that incorporates national economic growth, increased transportation fuel domestic security and reduced GHG emission from transportation vehicles. The success of projects like Próalcool demonstrates how government regulations, technology breakthroughs, and public-private collaborations may lead to a robust biofuel economy. Brazil has proved the feasibility of incorporating more renewable fuels into a country's energy mix while lowering

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<sup>115</sup> Michael Wang, "Fuel Pathways Analysis" (2006) 1 *Environmental Research Letters*. 011002

<sup>116</sup> Michael Wang, "Fuel Pathways Analysis" (2006) 1 *Environmental Research Letters*. 011002

<sup>117</sup> UNICA(União da Indústria de Cana-de-Açúcar), *Annual Report* (2018)

<sup>118</sup> Michael Wang, "Fuel Pathways Analysis" (2006) 1 *Environmental Research Letters*. 011002

<sup>119</sup> SOS Mata Atlântica, "A Mata Atlântica (The Atlantic Forest)", online publication (no date available).

greenhouse gas emissions and reducing reliance on fossil fuels by utilizing its agricultural resources and creating flex-fuel technology.

However, Brazil has also experienced constraints on biofuel production, such as land use changes, environmental degradation, and market volatility, that highlight the importance of sustainable practices and strong regulatory frameworks. The lessons from Brazil highlight the significance of investing in advanced biofuel technology and utilizing degraded lands to reduce the environmental imprint. Furthermore, increasing tax policy support for clean energy, can encourage increased biofuel development in Alberta as with the wind energy experience. Unlike Brazil, due to Alberta's solar and wind energy development in recent years along with its substantial natural gas production and reserves, there is not the impetus for a significant increase in biofuel production at the time of writing this paper. However as indicated by the Brazilian biofuel experience, in light of Alberta's strong agricultural and forestry sector, additional biofuel projects have the potential to contribute to reduced GHG emissions in the future as another lower CO<sub>2</sub> emitting energy source.

As the world grapples with climate change and options to reduce GHG emissions, Brazil's decades-old biofuel experience provides insight into the challenges and the accomplishments in one of the world's larger biofuel producing nations. The Brazilian experience reveals that through sound policies and laws, technological innovation, teamwork, and commitment, nations can reduce GHG emissions for a more sustainable energy future. Moving forward, the goal is to replicate the Brazil biofuel development experience results on a larger scale while addressing the complex socioeconomic and environmental challenges to biofuel production.

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