The Role of Bioethanol in Sustainable Mobility, Social and Economic Development

FUNDAÇÃO TOYOTA DO BRASIL

Factsheet by Glaucia Mendes Souza (University of São Paulo), Luiz Augusto Horta Nogueira (Federal University of Itajubá), Raffaella Rossetto (Agronomical Institute of Campinas)

Bioethanol is not simply a transition fuel but a cornerstone of net-zero transport systems

Ethanol's century-long history and global leadership in countries like Brazil, the USA, and India prove it is ready, reliable, and resilient - an essential part of the global decarbonization pathway.

Bioethanol global role and strategic potential

Ethanol at the Core of Transport Decarbonization

The global transport sector is one of the most challenging arenas for decarbonization. Despite rapid growth in electric mobility, over 95% of road transport energy demand still relies on internal combustion engines (ICEs). Bioethanol, derived from renewable feedstocks such as sugarcane and corn, is a mature, scalable, and affordable solution that immediately reduces GHG emissions and petroleum dependence.

Proven Reductions

Brazilian sugarcane and corn ethanol cut GHG emissions by **75–85%** compared with gasoline.

Global Deployment

Bioethanol production reached **117 billion liters** (GL) in 2024. More than 57 countries have implemented blending mandates, typically ranging from **5% to 30%.**

Future Demand

To meet the IEA Net Zero scenario, global biofuel consumption must increase **2.5 times** by 2030, offsetting approximately **800 Mt of CO_2** - around **10%** of transport sector emissions.

Enormous Potential

Biofuel production in the Global South has the potential for significant expansion. Estimates indicate that biofuels production increase could displace **>300 MtCO2.**

Land Use, Food Security, and Socio-Economic Impacts

Efficient Land Use in Brazil and Beyond

Brazil's ethanol uses **<1% of national land area.**

98% of sugarcane expansion since 2000 occurred on degraded pastures.

Yield increases since 1975: **+85% sugarcane, +265% corn, +101% soybeans.**

Intensified pasture use and crop rotation (soy, peanuts, second-crop corn) free land while improving soils and enhancing carbon sequestration.

Expansion Without Deforestation (Brazilian perspective)

Conservative scenarios show **+20 GL** of ethanol achievable using spare land, plus **+10 GL** from yield gains.
Converting just **6% of pastures** to energy crops could yield **+8 GL.**
Using all second-crop corn for ethanol (currently **~15% utilized**) could yield an additional **+6 GL** of ethanol.
(GL = 1 billion litres)

The Food vs. Fuel non-Dilemma

A review of **224 studies** found that two-thirds reported neutral or positive impacts of biofuels on food availability and security.
Negative effects are mostly from modeled projections, while real-world data show far **fewer negative impacts.**
In low-SDI countries, biofuels often **improve food production and access** by strengthening infrastructure and increasing farmers' purchasing power.

Socio-Economic Benefits of Production in Brazil

2.2 million jobs in 2023
Despite the widespread adoption of mechanized harvesting, now responsible for 92% of sugarcane harvested in recent seasons.

Involvement of 70,000 small farmers
Access to modern technology for sugarcane production.

Formal employment & wages
Sugarcane jobs offer 87% formal employment and wages are 46% higher than the agricultural average.

Local growth
New mills raise municipal GDP per capita by ~$1,000/ year for at least a decade.

Rural electrification
Sugarcane bioelectricity contributes to increased energy access and higher Human Development Index values.

Best Practices and Innovation in Ethanol Production

Residue recycling
Vinasse and filter cake are used as fertilizers; or with biodigestion turned into biomethane.

Bioinputs
Hormones, amino acids, and microbial interactions improve sugarcane yields and reduce fertilizer needs.

New varieties
Breeding for locally adapted, climate-resilient cultivars, biotechnological tools for improved yields and disease resistance.

Digital agriculture
AI, IoT, and precision sensors improve machinery efficiency, cut fuel use, and reduce soil compaction.

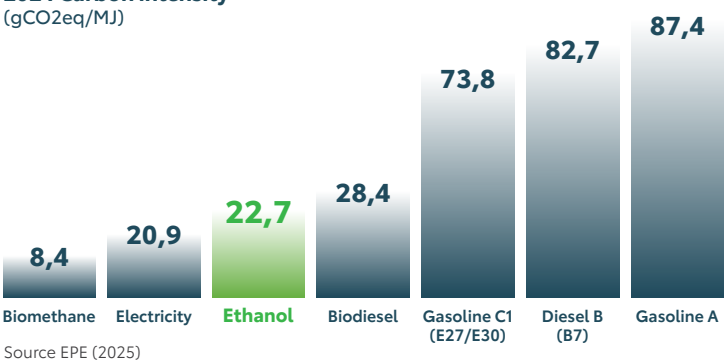
Ethanol: Sustainable and Already in-use Solution

Ethanol: Lower Carbon Intensity

Ethanol is a renewable energy source that stands out for its lower carbon intensity compared to fossil fuels. Produced mainly from sugarcane and corn, its life cycle results in significantly reduced greenhouse gas emissions.This is because the CO_2 released when ethanol is burned is partially offset by carbon absorption during plant growth, making it a cleaner and more environmentally responsible option.

Energy sources

2024 Carbon intensity
(gCO2eq/MJ)



Source EPE (2025)

A Fuel as Old as the Automobile Itself

Nikolaus Otto (1860) tested ethanol in the first internal-combustion engines; Henry Ford's Model T (1908) was designed to run on ethanol, gasoline, or any blend.

Early 20th-century cars in the U.S., Europe, and Brazil already used ethanol.

Countries Perspectives

USA

Produces annually ~ **70 GL ethanol** (first global producer), with nationwide E10 baseline, E15 expansion, and E85 for FFVs. U.S. ethanol exports increased **37% in 2024.**

Brazil

Currently, a mandatory **30% ethanol** blend (E30) is in effect, the fleet includes **37 million** flex-fuel vehicles (FFVs), and production reached **36.8 GL** of ethanol in 2024 (7.7 GL corn-based).

India

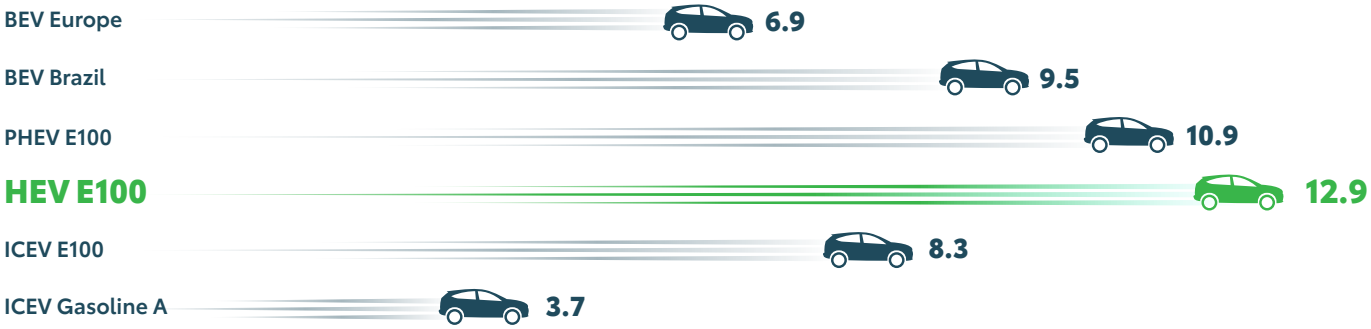
Ethanol blending started in 2014 and reached **12% in 2023**, E20 by 2025 for more than **330M vehicles.**

Emerging Economies: In regions with large existing vehicle fleets, limited charging infrastructure, and long distances (e.g., Latin America, Africa, Asia), ethanol offers a cost-effective, immediately deployable decarbonization pathway.

Bioelectric Hybrids on Ethanol: Effective Contribution

By uniting ethanol, a low-carbon renewable fuel already produced and used in dozens of countries, for example the **Toyota Hybrid System (THS)** - a powertrain refined over five generations since 1997 - it delivers one of the lowest life-cycle CO2 emissions on the market: ≈ **77.5 g CO_2e/km.**
An HEV100 can drive **12.9 km before emitting 1 kg CO_2e**, while a conventional ICE vehicle emits the same amount after just **3.7 km.**

Kilometres driven for each category of vehicles to emit 1 kg of CO_2e



Results from a Worldwide Harmonized Light Vehicles Test Procedure, for 160.000 km Life Cycle, by Gauto et al. (2023). *Hybrid vigor: Why hybrids with sustainable biofuels are better than pure electric vehicles*. **Energy for Sustainable Development.** Vol.76.101261. Elsevier.

The result is a sustainable, affordable, and practical solution

No external charging required

Fast refueling at any fuel station

Proven reliability and global scalability

Since 2019, **more than 100,000 hybrid flex-fuel vehicles (HEV FFVs),** have been sold in Brazil, already avoiding 314 million tonnes of CO_2. This showcases a model of low-carbon mobility that can inspire other Global South nations with similar climate and agricultural strengths.

HEV