HYDROGEN AND BIOMASS

ILLUSTRATIVE SUMMARY

MINISTÉRIO DE MINAS E ENERGIA
GOVERNO FEDERAL BRASIL UNIÃO E RECONSTRUÇÃO
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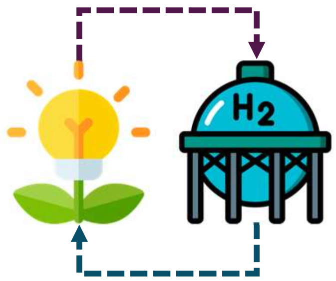


Low-carbon hydrogen and **bioenergy systems** represent decarbonization pathways that align with Brazil's potential.

This summary outlines the main findings of the publication *"Hydrogen and Biomass: Opportunities for Hydrogen Production and Use in Bioenergy Systems"*, which highlights the **mutually reinforcing relationship between the two sectors.**

The modernization and development of bioenergy chains diversify **hydrogen applications** while enabling **H_2 production routes with unique advantages.** Business models that leverage this synergy can accelerate an energy transition that enhances Brazil's competitiveness.

HYDROGEN ENHANCES BIOENERGY...

Traditional hydrogen applications are already essential to bioenergy and could be further redirected toward it in a low-carbon future. These applications are among the key sectors for hydrogen (H_2), for which no direct substitutes exist. Currently [1], the global hydrogen market is divided into:

Use in Refining: 45%
Used in oil refining, hydrogen is also essential for biorefining, a process capable of producing new biofuels such as Sustainable Aviation Fuels (SAF), Renewable Diesel (e.g., HVO), among others;

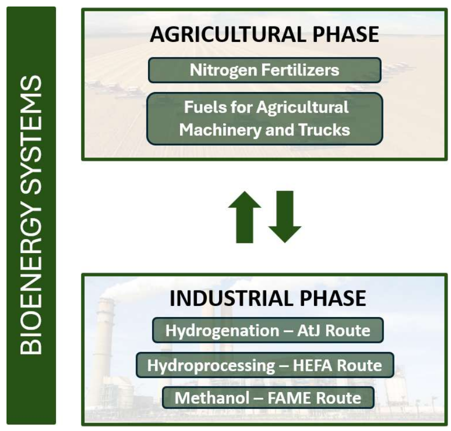
Ammonia Production: 33%
Hydrogen is one of the inputs of the Haber-Bosch process, the primary method used for ammonia production. **Ammonia is the basis of nitrogen fertilizers used in the agricultural phase** of bioenergy systems;

Methanol production: 17%
Methanol synthesis essentially involves reacting hydrogen with gases such as CO or CO_2. Methanol **is a primary input for the transesterification of vegetable oils used in biodiesel production**, and it is also a potential new biofuel;

Other uses: 5%
Additional hydrogen applications associated with bioenergy systems include its direct use as **fuel** for trucks and agricultural machinery, as well as its role as a **feedstock** in other processes such as the methanation of biogas.

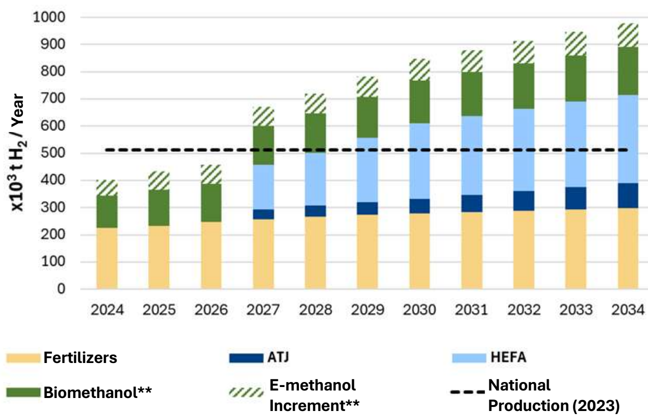
[1]: IEA, Global Hydrogen Review 2024.

H_2 is present in several steps of **bioenergy chains**



Hydrogen demand associated with bioenergy systems may exceed national production*

Estimated H_2 demand in bioenergy systems and national production



* National production includes non-bioenergy-related uses. The production value shown in the figure refers to the year 2023.
** Amount of H_2 required to meet methanol demand through low-carbon pathways (biomethanol or e-methanol)

... AND BIOMASS ENHANCES HYDROGEN

Low-carbon hydrogen can be **produced from biomass**. **Thermochemical routes** have greater technological and commercial maturity and can contribute immediately and competitively to the expansion of the hydrogen supply. The separation of gases resulting from these pathways can produce hydrogen with high purity. These include:

- **Gasification**, which converts various types of biomass into synthesis gas (H_2 + CO);
- **Reforming**, which converts resources such as biomethane, bioethanol, and glycerin into synthesis gas (H_2 + CO);
- **Pyrolysis**, which converts various types of biomass into pyrolysis gas (H_2 + CO + CO_2 + CH_4).

Biomass refers to any renewable resource derived from plant or animal organic matter.

Lignocellulosic biomass, such as straw, bagasse, and wood chips, is suitable for **gasification and pyrolysis** routes, presenting the advantage of not competing in the liquid biofuels market.

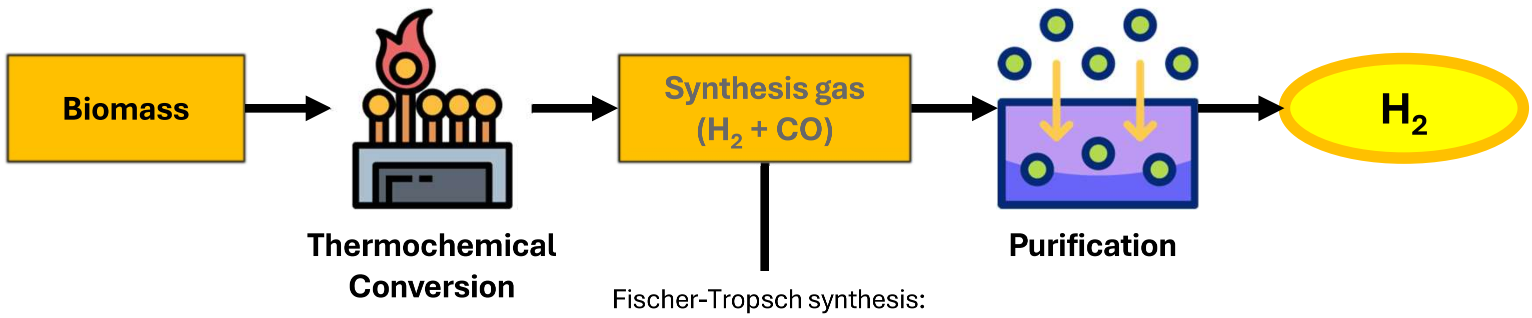
Urban or agro-industrial waste is used to produce biomethane, a resource capable of producing H_2 via **reforming** routes.

Biomass-based H_2 production routes exhibit **low carbon intensity (CI)***, which aligns with **industrial decarbonization** goals.

Associating carbon capture and storage (CCS) with H_2 production can result in products with **negative emissions**.

Route	Estimated CI average**
Steam reforming of biomethane	1,0 – 1,8 kg CO_{2eq}/kg H_2
Steam reforming of ethanol	3,0 – 5,1 kg CO_{2eq}/kg H_2

* Brazilian Law No. 14,948/2024 defines "Low-Carbon Hydrogen" as hydrogen with maximum emissions of 7 kg CO_2eq/kg H_2.
** CI Estimated based on the average feedstock emissions in RenovaBio certifications, considering a range of conversion yields.



Fischer-Tropsch synthesis:

$$nCO + 2nH_2 \rightarrow -(CH_2)_n - + nH_2O$$

Synthetic gasoline | Renewable Diesel | Synthetic aviation fuel | Synthetic marine fuel

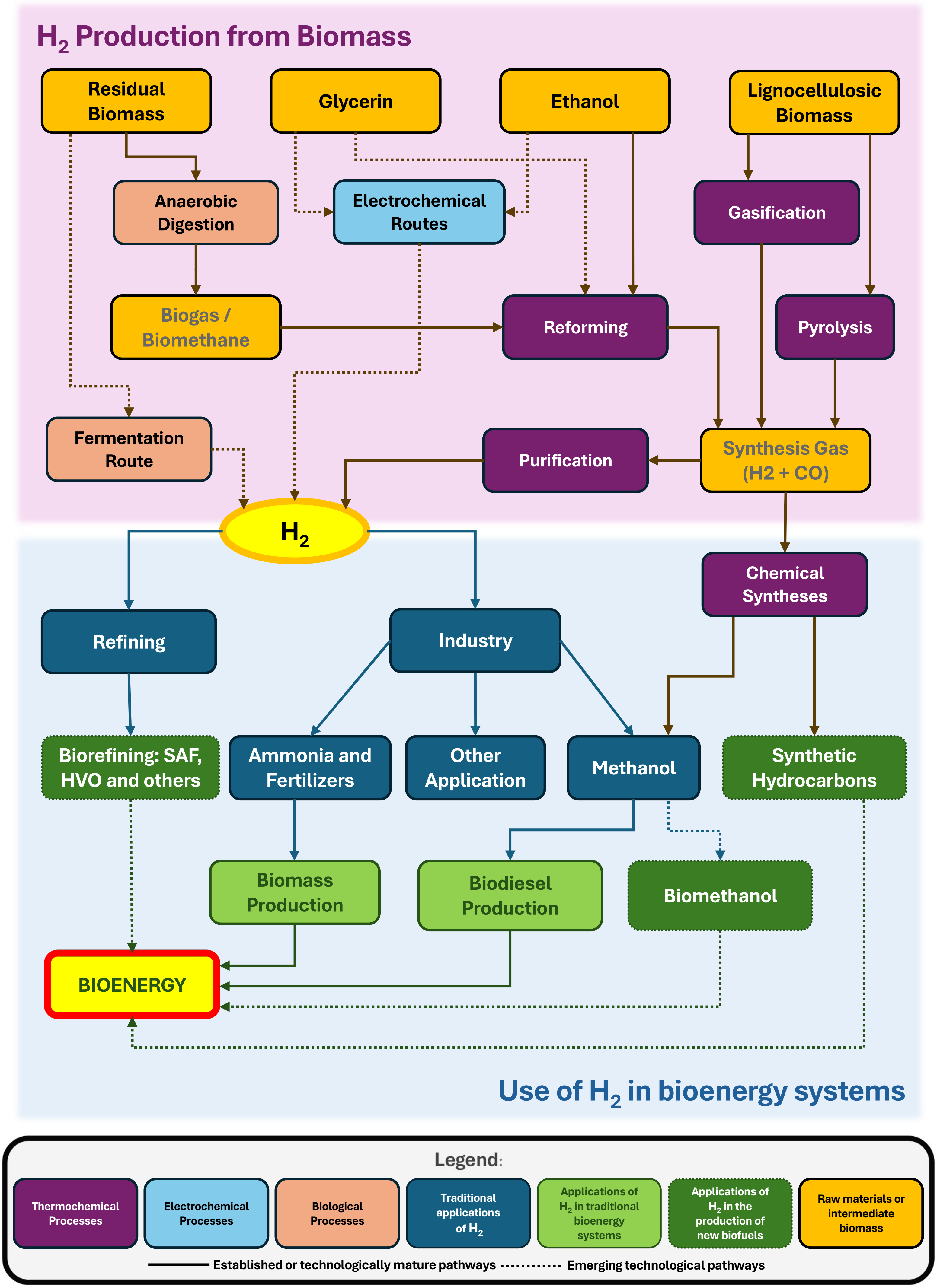
Synthetic biofuels

The synthesis gas produced through thermochemical pathways is a **mixture rich in H_2 and CO**, which are feedstocks for Fischer-Tropsch synthesis. As such, it can be directly used for the ***in situ* production of hydrocarbons within biorefineries**, resulting in the production of a 100% renewable fuel known as **synthetic biofuel**. This approach eliminates the need for hydrogen purification, avoids logistical barriers related to its transport, and expands the product portfolio and the added value of biomass processing.

Biomass pathways are unique in offering both hydrogen and renewable carbon within a single **integrated process.**

Synthetic biofuels can be drop-in fuels and take advantage of **existing infrastructure.**

THE SYNERGY IN A SCHEMATIC FORM



POTENTIAL BUSINESS MODELS

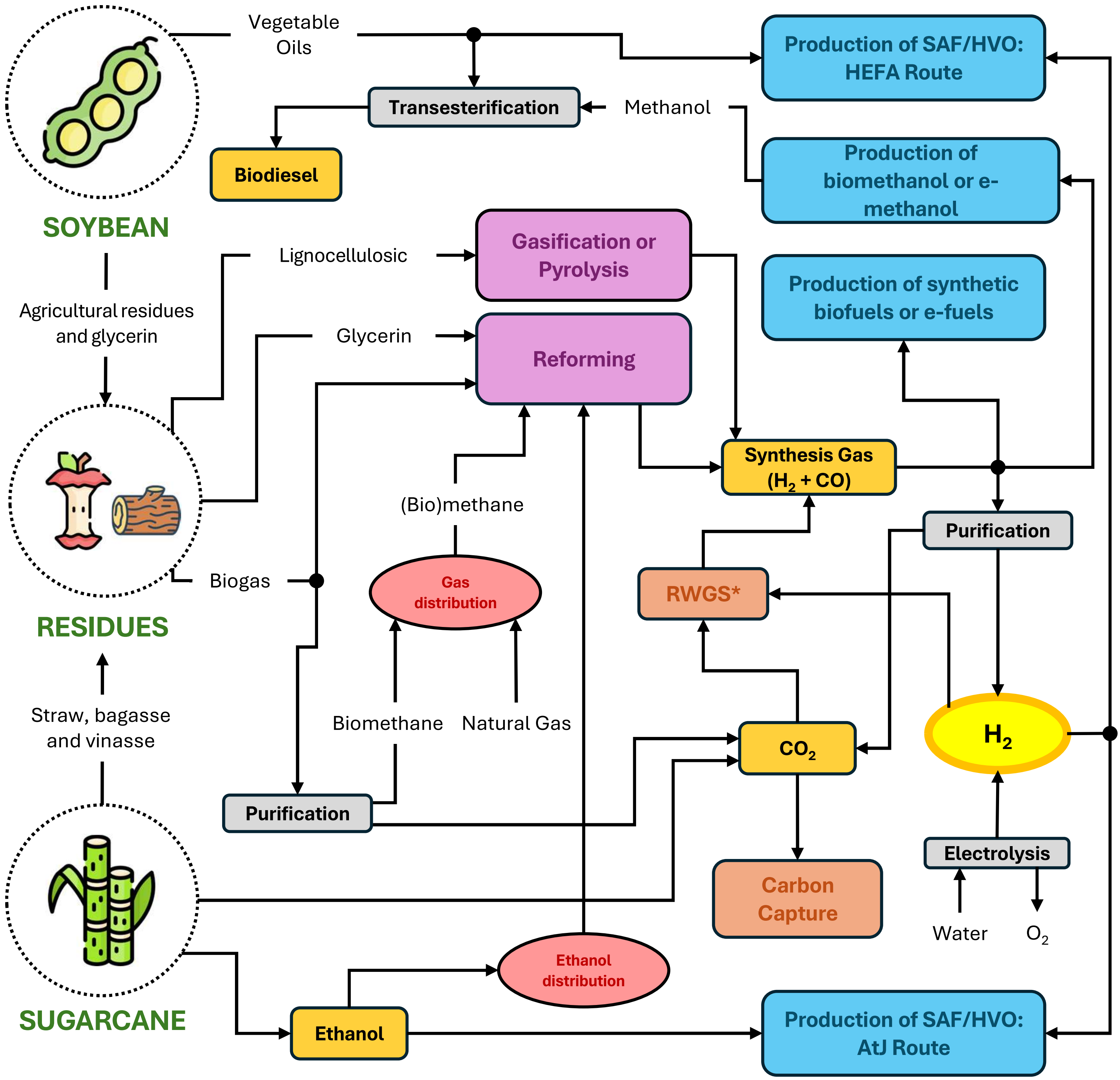
The synergies between bioenergy systems and low-carbon hydrogen enable the **development of several potential business models.** A non-exhaustive set of approaches is exemplified below for three major Brazilian bioenergy systems.

Use of residual biomass

Opportunity to **add value to organic residues.**

Portfolio expansion

The **production of new biofuels** enables portfolio expansion in biorefineries and creates new demand for hydrogen.



Use of biogenic CO_2

Pursuing **reduced or negative emissions** through the productive use of CO2 can generate complementary direct or indirect revenues, especially when associated with electrolytic H_2.

Use of existing infrastructure

Developed fuel distribution chains enable the use of **ethanol as a hydrogen carrier**. Manufacturing and distribution infrastructure designed for natural gas can **use biomethane without modifications.**

** Reverse water-gas shift*

SYSTEMIC BENEFITS

Opportunities for mutual benefit between H_2 and bioenergy

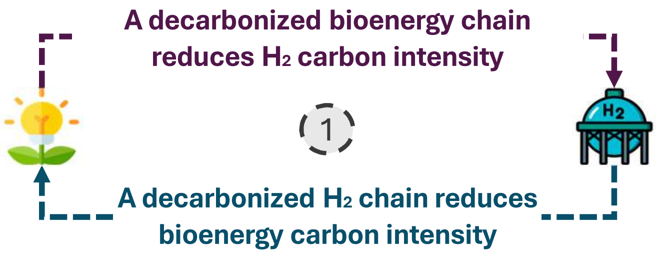
	The supply of H_2 from bioenergy generates:	The use of biogenic CO_2 generates:	The demand for H_2 from bioenergy generates:
For bioenergy systems	✓ Value addition to biomass ✓ Residues valorization	✓ Biofuels with negative emissions ✓ Co-product valorization	✓ Reduction of CI ✓ Increased competitiveness ✓ New biofuels
For the low-carbon hydrogen chain	✓ Diversified and distributed supply ✓ Complementarity	✓ Complementary feedstock to H_2 in chemical applications (e.g., methanol, hydrocarbons)	✓ Consistent and comprehensive demand in the national territory

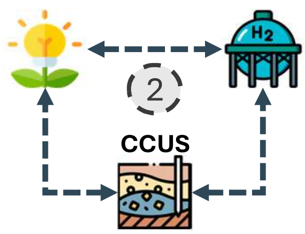
Complementarities between the main low-carbon H_2 production pathways

	Electrolytic H_2	Natural gas reforming with CCUS H_2	Biomass H_2
Ideal locations in Brazil	Abundant and competitive renewable generation. Connection to SIN*. E.g.: Northeast	Access to competitive natural gas and CO_2 storage. E.g.: Northeast and Southeast	High agricultural productivity, structured supply chains, and available residues. E.g.: South, Center-West, Southeast.
Temporal aspects	Intermittent if connected to renewable generation or aiming to reduce costs and emissions.	Firm or flexible supply according to demand characteristics	Seasonality in biomass production as a constraint. Ethanol for flexible supply.
H_2 condition as product	High-purity H_2 (CO_2 supplement is required for chemical uses)	Syngas with fossil CO_2 (CCUS is mandatory if low emissions are desired)	Synthesis gas with biogenic carbon (optional CCS aiming negative emissions)

** National interconnected system*

Synergistic carbon reduction cycles





ⓘ
1. Ammonia, methanol, and low-carbon hydrogen reduce the carbon intensity of bioenergy.
2. CCUS has individual synergies with both bioenergy and H_2, and biohydrogen can maximize CO_2 capture from biomass.

PUBLIC POLICIES

Bioenergy

- Brazilian Law No. 14,993/2024 (Fuel of the Future) promotes biofuel production pathways that require hydrogen.
- Brazilian Law No. 13,576/2017 (RenovaBio) allows carbon intensity gains to be converted into financial revenue.

Hydrogen

- Brazilian Law No. 14,948/2024 recognizes biomass-derived H_2 as renewable and potentially low-carbon, promotes its production, and fosters its technological development through the Special Incentives Regime for Low-Carbon Hydrogen Production (Rehidro), the Low-Carbon Hydrogen Development Program (PHBC), and by strengthening the National Hydrogen Program (PNH2).

The concrete implementation of the opportunities highlighted here requires overcoming several challenges, such as increasing the technological maturity of processes, implementing fair carbon pricing mechanisms (as in RenovaBio and Brazilian Law No. 15,042/2024), and the fostering of industrial innovation.

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