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ENERGY RESEARCH

From Brazil to Europe: The Renewable Hydrogen Opportunity

Public Report 2024

Agenda

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I. Introduction

II. Overview of Brazil's hydrogen policy

III. Business models to scale up Brazilian exports to Europe

IV. Key takeaways

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Aurora provides market-leading forecasts & data-driven intelligence for the global energy transition

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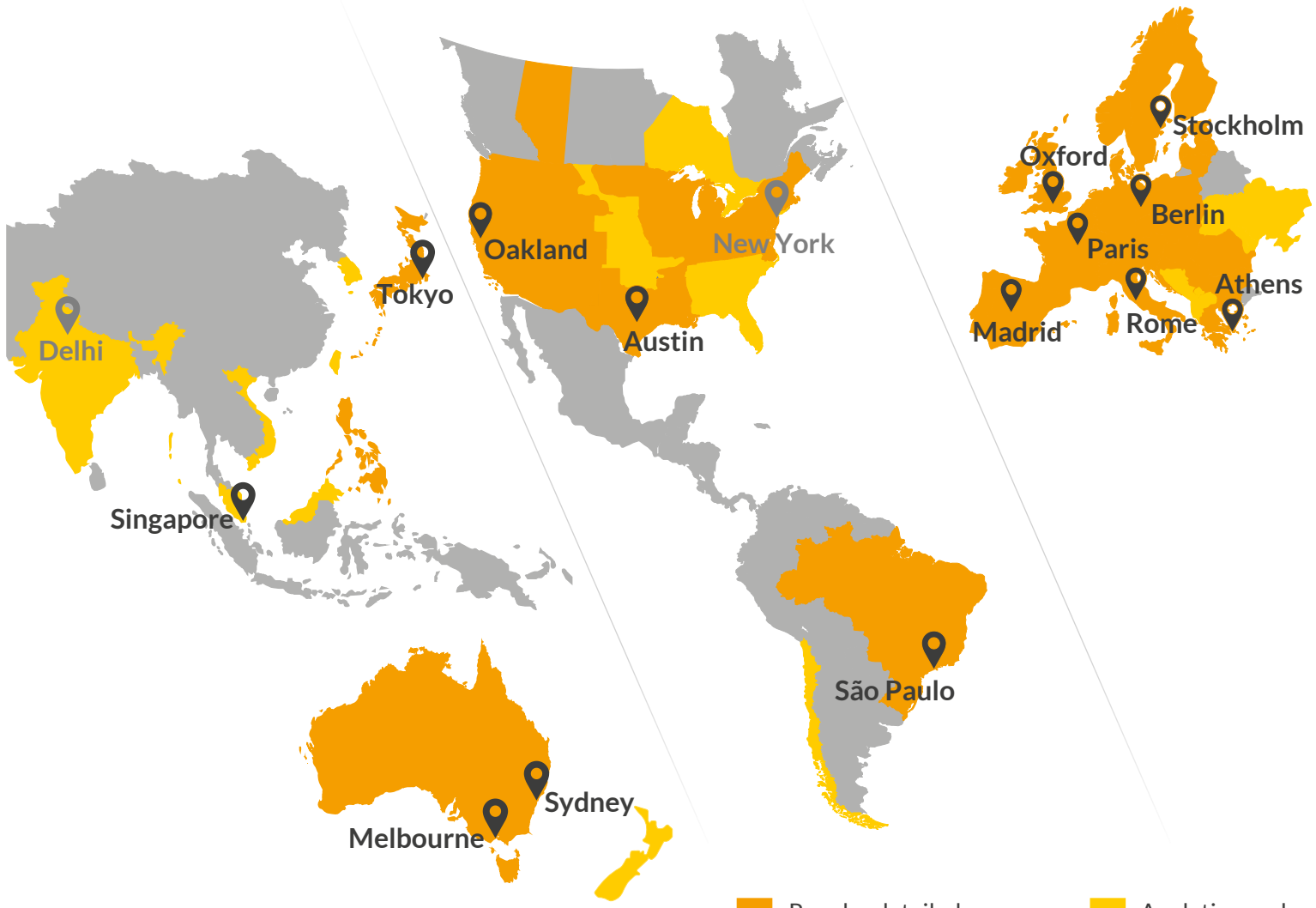
- Power markets
- Renewables & PPAs
- Storage
- Grid & Congestion
- Electric vehicles
- Hydrogen H_2
- Carbon CO_2
- Natural gas



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and two more coming soon

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market experts

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subscribing companies

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Agenda

AURORA

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IV. Key takeaways

The National Low Carbon Emission Hydrogen Policy establishes several guidelines regarding certification, subsidies and incentives

PL 2308/2023, approved by the Senate on the 19th of June, institutes the National Low Carbon Emission Hydrogen Policy, including several guidelines regarding certification, audit management, market and infrastructure development, financial subsidies and tax incentives. However, precise definitions are still pending. The approved draft, along with the accepted amendments, must be reassessed in Congress and approved by Brazil's president before it becomes an official law.

Guidelines	Details
National Hydrogen Program (PNH2)	▪ Regulated by the CNPE's[1] Steering Committee of the National Hydrogen Program (Coges-PNH2), created to oversee the implementation of the Low Carbon Hydrogen Development Program (PHBC) - regarding incentives, policies and applications of the low carbon hydrogen. ▪ Assigns ANP[2] as responsible for the authorization of the production, import, transport, export and storage of hydrogen.
Brazilian Hydrogen Certification System (SBCH2)	▪ National certification program responsible for the classification of the nature of the hydrogen, using its life cycle emissions as a guideline. The extension of the stages that will be accounted for the lifecycle emissions calculation still needs to be specified by the committees.
Special Incentive Regime to Produce Low-Carbon Emission Hydrogen (Rehidro)	▪ Establishes minimum quotas regarding the use of national assets and services in the production, investments in R&D and a maximum production for export for eligibility. ▪ Participating projects can also be qualified for the Incentivized Debentures and Reidi[3] programs, allowing even more financial incentives. Main incentives include the suspension of PIS/Pasep and Cofins incidence on imports, purchase of raw materials, intermediate products, packaging, stocks and construction materials. ▪ Rehidro's eligible sectors include: 1. Conditioning, storage, transportation, distribution or commercialization of low carbon hydrogen. 2. Renewable energy generation destined to low carbon hydrogen production. 3. Production of biogas or biomethane destined to low carbon hydrogen production.

1) National Council of Energy Policy. 2) National Petroleum, Natural Gas and Biofuels Agency. 3) Special Incentive Regime for Infrastructure Development.

Sources: Aurora Energy Research, Brazilian Congress

On June 19, Brazil's hydrogen law was approved by the Senate, although precise definitions are still pending

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After Congress approval in November 2023, the Draft Law received numerous amendments by the Senate, with EU's RED II act as a basis. The act outlines the definitions for low-carbon and renewable hydrogen, along with the criteria that must be met for certification eligibility. The draft, approved by the Senate and yet to be re-discussed in Congress approved only a handful of amendments, distancing the Brazilian framework from its European counterpart both in definitions and lack of criteria specificity.

Definition	EU	Brazil
Emissions Threshold	▪ Requires a 70% GHG reduction compared to grey hydrogen (3.4 $kgCO_{2eq}/kgH_2$).	▪ Requires emissions to be less or equal to 7[3] $kgCO_{2eq}/kgH_2$.
Lifecycle GHG emissions	▪ Emissions from the supply of inputs, electricity, processing, transport and distribution, and combusting the fuel in its end use minus any emissions savings from CCS.	▪ The specific stages of the lifecycle to be considered weren't yet set by SBCH2.
Renewable Hydrogen	▪ Wind, hydro and solar power technologies. ▪ Must meet additionality, geographical, and temporal correlation criteria. However, **EU's Delegated Act also set out scenarios when certain criteria may be exempt.**	▪ Wind, hydro and solar power, but also biomass, biogas, biomethane, geothermal, ethanol and tidal-based technologies. ▪ Geographical and temporal correlation criteria were not specifically outlined. Additionality criteria wasn't accepted[1].

Renewable hydrogen criteria-exempt scenarios:

Brazil can explore these scenarios to produce renewable hydrogen eligible for EU's certification.

Power sourcing	Description	⊕	🌐	⏱	*
Off-grid	▪ Electrolyser directly connected to a RES asset	✗	✓	✓	A
Grid Connected	▪ Electrolyser located in a bidding zone where average RES share in electricity mix >90%	✓	✗	✓	
Grid Connected (PPAs required)	▪ Electrolyser using power that would have been curtailed otherwise	✓	✗	✗	B
	▪ Electrolyser located in zone with average grid carbon intensity < 64.8 gCO_2/kWh	✓	✗	✗	C

⊕ Additionality ⏱ Temporal correlation 🌐 Geographical correlation ✓ Criterion already fulfilled ✗ Criterion needs to be met * Deep Dive

1) Additionality criteria would arguably prevent the use of the country's already highly renewable matrix . 2) If the condition is met in the previous calendar year, it is considered to be reached in the following 5 calendar years. 3) Value accepted in the final draft that will be reassessed by the Congress before presidential approval.

Sources: Aurora Energy Research, Brazilian Senate Energy Transition and Hydrogen Committee, European Commission.

Agenda

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I. Introduction to today's session

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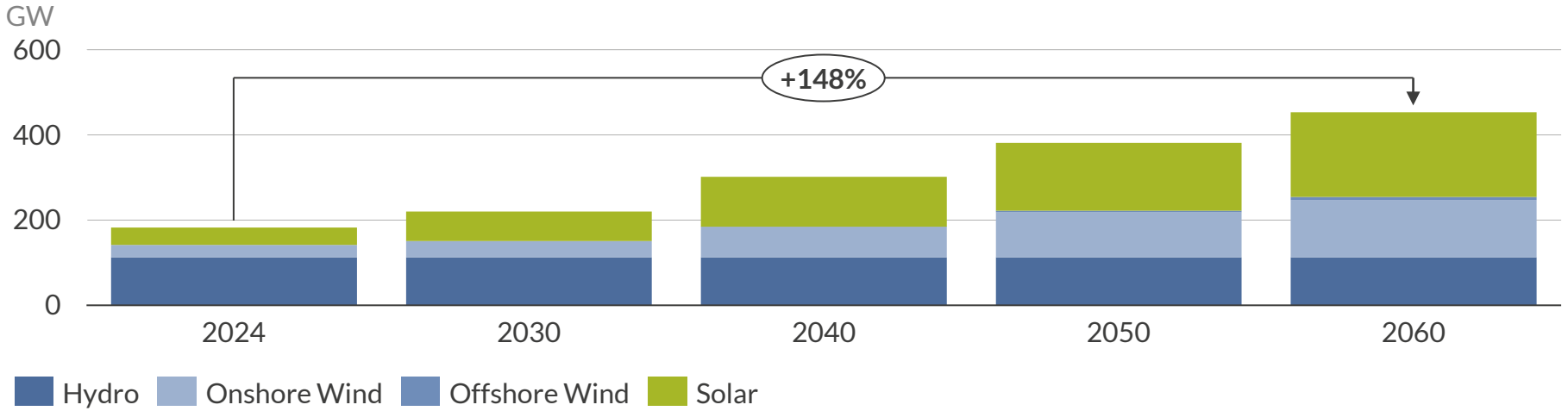
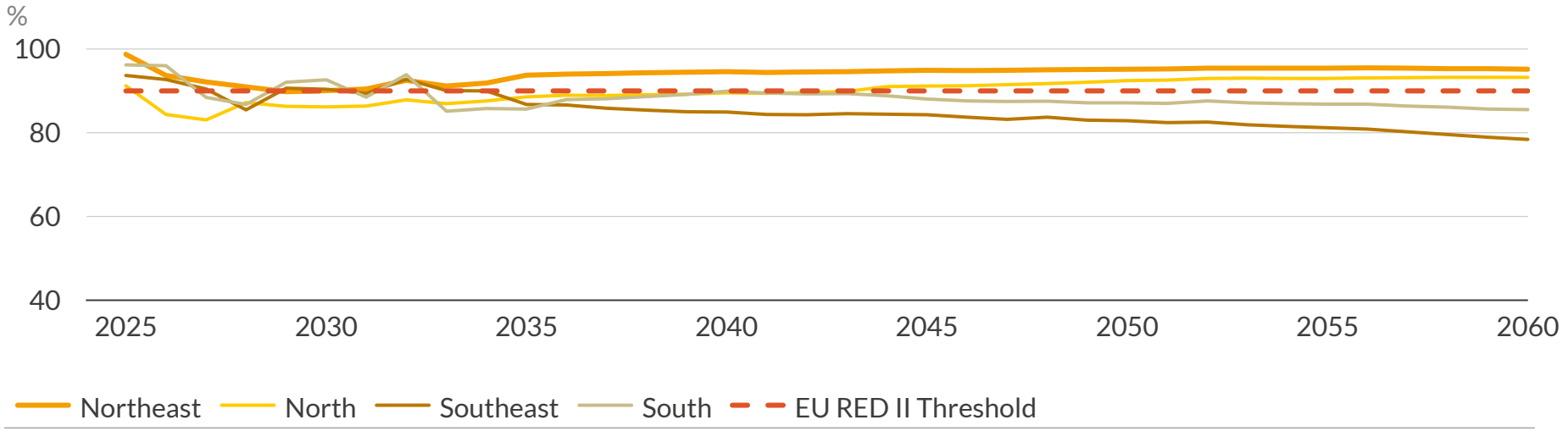
A Brazil has the potential to explore various production business that ensure eligibility for EU's renewable hydrogen certification

Wind, hydro and solar installed capacity in Brazil forecast[1]



Renewables share of generation per subsystem



1) For Aurora's April 2024 Central scenario. 2) We assume that only 105 TWh of electricity demand for baseload electrolysers will enter in the Northeast between 2027-2060. Higher electrolyser electricity demand would result in an increase in renewable capacity addition . 3) EU RED II Threshold includes all emissions, from production to end use.

Sources: Aurora Energy Research

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Off-grid production

- Brazil's solar and wind installed capacity is set to grow almost five-fold[2] from 2024 to 2060.
- This growth presents an opportunity for off-grid hydrogen production, respecting the criteria demanded by EU's RED II act.

Grid-connected production

RES Share > 90%

- The Northeast subsystem maintains its renewables share of generation above the 90% threshold[2] determined by the EU for qualifying as renewable hydrogen.

To learn more about the various available business models reach out to **Priscila Vellano**: priscila.vellano@auroraer.com.

B An estimated 12 million tonnes of Brazilian renewable hydrogen could be produced from 2030 – 2060, utilizing exclusively curtailed renewables

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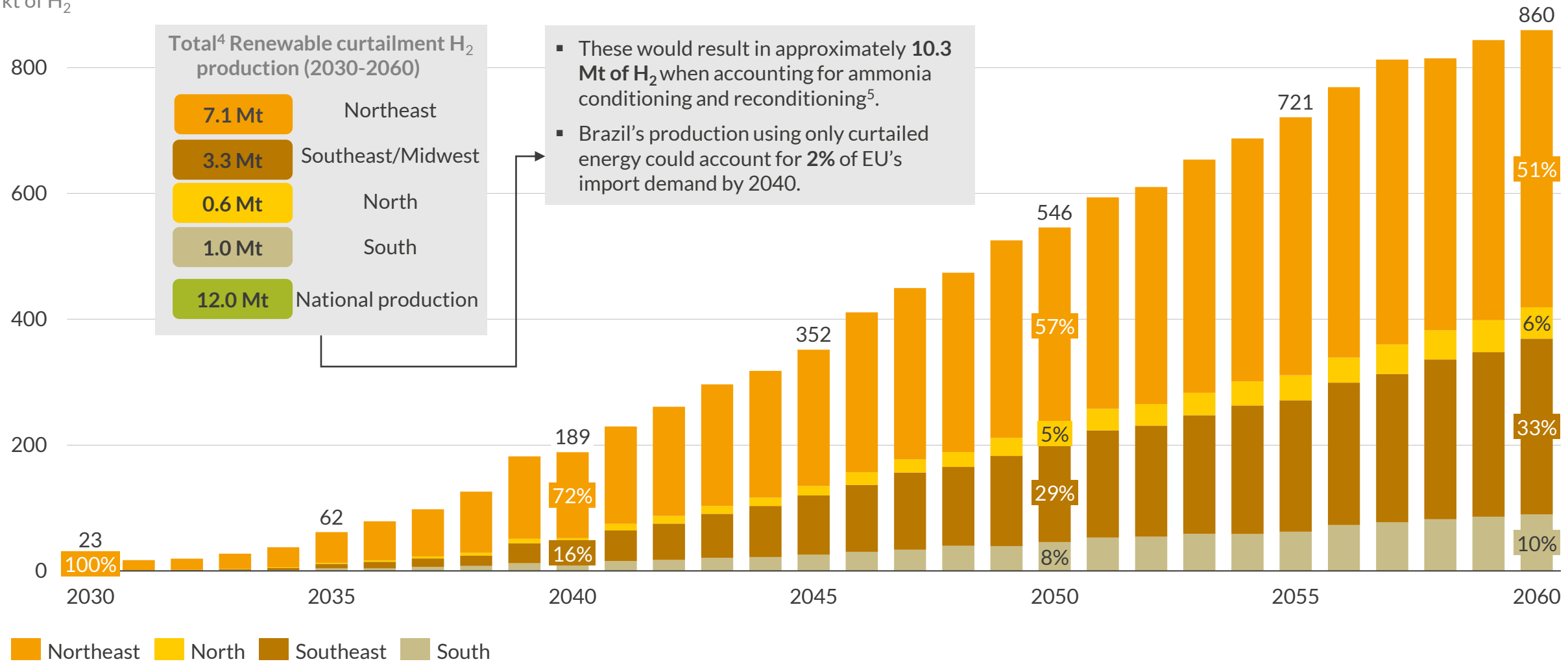
Hydrogen production using economically curtailed renewable energy[1,2,3] - PPA required

kt of H_2



1) Electrolyser with a 66% - 77% efficiency range across the timeline. 2) 1kg H2 = 39.4 kWh. 3) No curtailment profiles were evaluated, only the total sum of renewable curtailment volume due to oversupply (economical curtailment). Does not include grid curtailment. 4) Sum of potential hydrogen produced throughout the period. 5) Considering a 95% efficiency in ammonia conditioning and 90% efficiency in ammonia cracking. No transportation losses were accounted for.

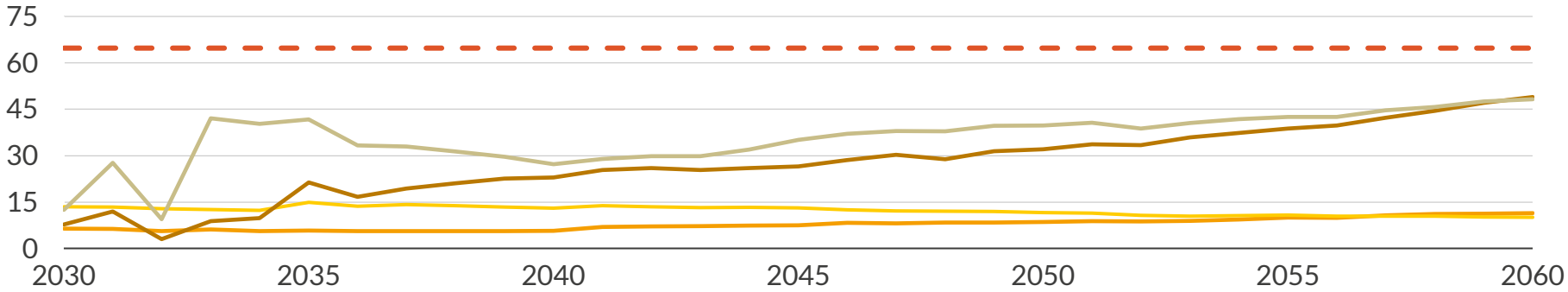
Sources: Aurora Energy Research

C Despite rising CO_2 intensity in southern subsystems, grid-connected H_2 production ranges from 0.4 to 2.5 $kgCO_2/kgH_2$

In Brazil, direct carbon emissions from the generation stage of a grid-connected electrolyser operating at baseload would remain below Europe's threshold by 2060, ranging between 0.4-2.5 $kgCO_2/kgH_2$. This allows for a margin of up to 3 kg of CO_{2eq} for other emissions across the value chain, competitively positioning Brazilian hydrogen.

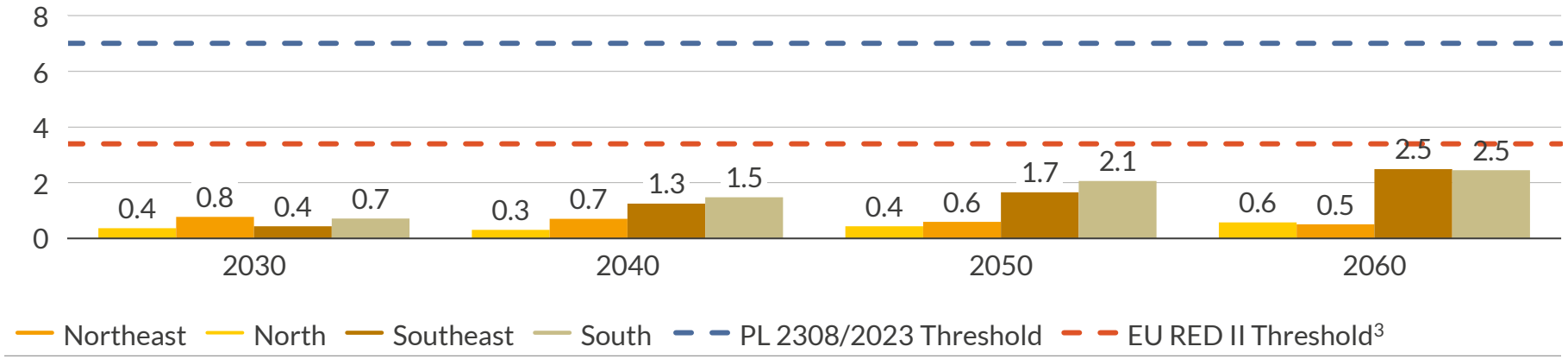
Power sector carbon intensity[1]

gCO_2/kWh



Hydrogen production carbon intensity: grid-connected electrolyser[2]

$kgCO_2$[1]$/kgH_2$



1) Only direct generation carbon emission (not equivalent) are considered. 2) Electrolyser with a 66% - 77% efficiency range across the timeline. 3) EU RED II Threshold includes all emissions, from production to end use.

Sources: Aurora Energy Research

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Grid-connected – PPA required

Grid carbon intensity

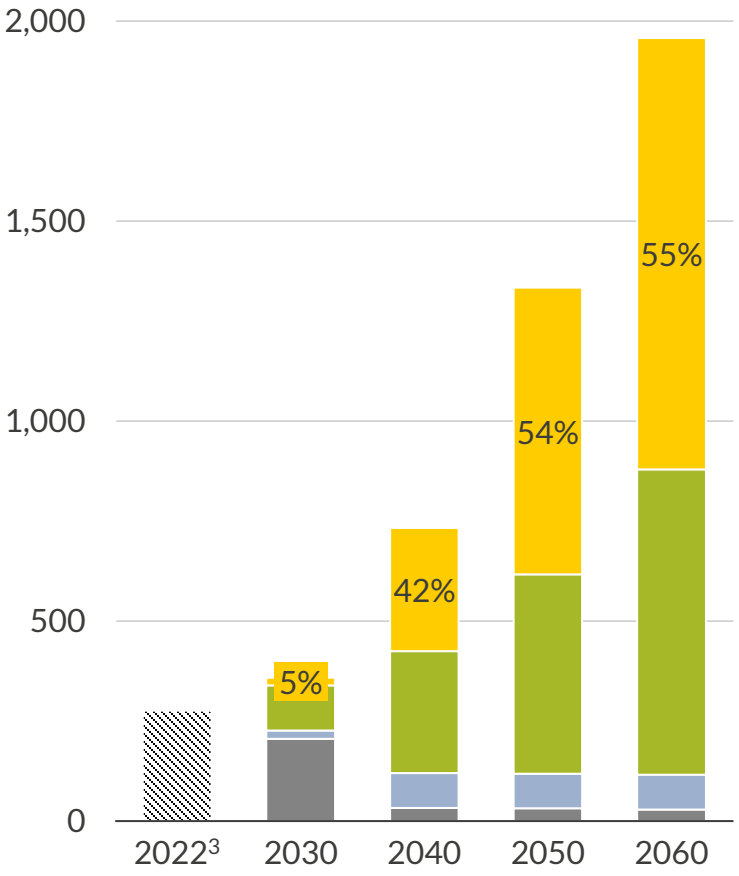
- Brazil's power sector direct emissions respect EU's Delegated Act threshold of a maximum grid carbon intensity of 64.8 gCO_2/kWh, allowing for renewable hydrogen production connected to the grid through the timeline, while being exempted from additionality requirements.

Hydrogen production CO_2 intensity

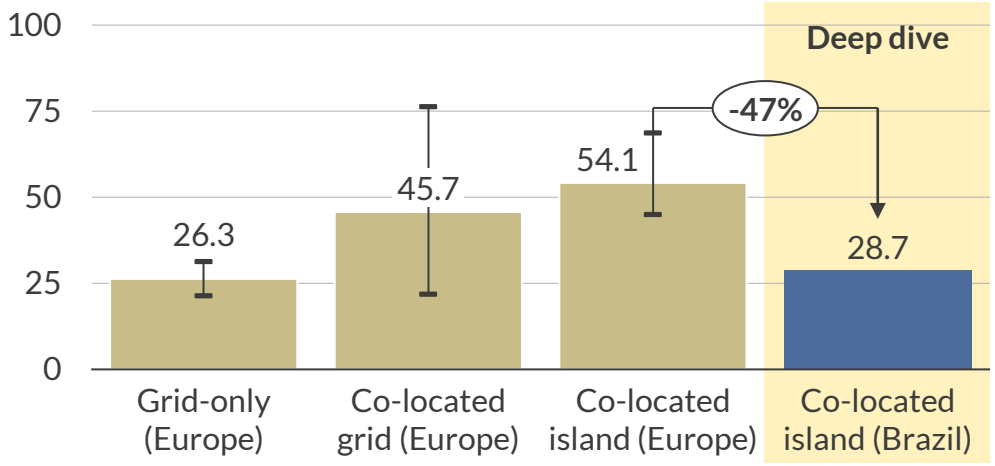
- Brazil's PL 2308/2023 sets a 7 $kgCO_{2eq}/kgH_2$ threshold, but doesn't specify the lifecycle stages accounted for calculations
- Under EU's RED II directive, exports eligible for renewable certification must be below the 3.4 $kgCO_{2eq}/kgH_2$ threshold[3].

More than half of Europe's hydrogen is expected to be imported; to capitalize on it, Brazil needs to adhere to EU's standardized protocols

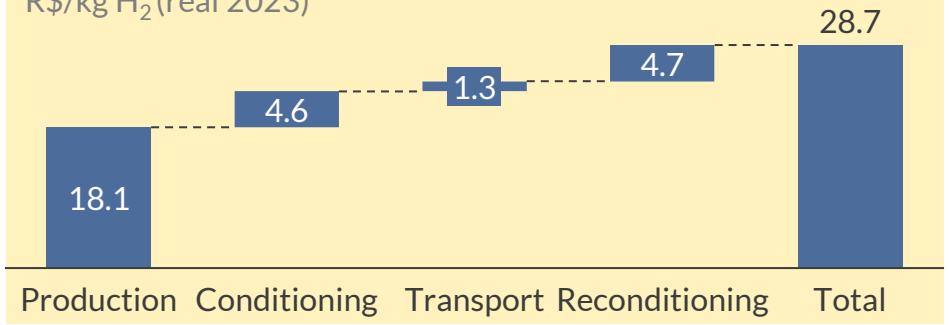
Supply mix of hydrogen and derivatives in Europe
TWh_{HHV}, final energy consumption



Levelised cost of hydrogen (LCOH) by 2030[1]
$R\$/kg\ H_2$ (real 2023)



LCOH for a co-located island asset in Northeast Brazil[2] - 2030
$R\$/kg\ H_2$ (real 2023)



Historical | Grey and by-product | Blue | Electrolytic | Imports | Europe LCOH | Brazil LCOH

- Europe's dependence on imported hydrogen is set to increase rapidly, comprising more then 50% of the total demand in 2050.
- Brazil's estimated LCOH for a co-located island asset is almost half as its average European counterpart[1], even when considering ammonia conditioning, transport and reconditioning costs.
- If the production and audit protocols detailed in EU's Delegated Act were to be followed, Brazil's LCOH can become even more competitive, once it will allow for grid-only and co-located grid, due to the Brazil's RES potential[3] and its low carbon grid.

1) Average of 15 European countries' LCOH for European values, with country-specific RES capacity and load factors and a 10.5% WACC. For Europe, a 100 MW PEM electrolyser with 90% load factor was considered. For Brazil, a 1GW PEM electrolyser was considered. 2) Ammonia as energy vector for transportation. 3) Due to high load factors and technology complementarity.
Sources: Aurora Energy Research

Agenda

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Key Takeaways: Routes to scale up Brazilian renewable hydrogen exports to Europe

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1. Even considering the most expensive hydrogen business model and exporting costs, Brazil emerges as a strong contender for success in the European renewable hydrogen market due to Europe's reliance on imports and Brazil's low Levelised Cost of Hydrogen (LCOH)

2. The Northeast presents the greatest potential for grid-connected renewable hydrogen business models, once it maintains its >90% renewable generation share across the timeline, without requiring additionality, geographical and temporal criteria

3. For grid-connected business models in other regions, renewable PPAs that prove the compliance with EU's RED II criteria[1] will be fundamental to unlock Brazil's full potential as a leading exporter of renewable hydrogen

1) Additionality, geographical and temporal correlation criteria.

Source: Aurora Energy Research

Upcoming developments for subscribers of the Aurora's Brazilian services

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Quarterly update of the Power and Renewables Market Forecast
- Updated to reflect near-term commodity price changes

2024 — July — September — October — December — 2025 — January

10/09 Second subscriber Group Meeting 2024
- Capacity markets and storage

Quarterly update of the Power and Renewables Market Forecast
- Bi-annual update

03/12 Third subscriber Group Meeting 2024
- Topic to be confirmed based on market and subscriber interest

Quarterly update of the Power and Renewables Market Forecast
- Updated to reflect near-term commodity price changes

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Source: Aurora Energy Research

Brazilian Power & Renewables Service:

Dive into key market analysis and forecasts for the Brazil power and renewables markets

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