INTERNATIONAL ALUMINIUM

Aluminium, shaping a better tomorrow

DECARBONISATION PATHWAYS: ALUMINIUM VS. COMPETING MATERIALS

This factsheet, based on Eunomia's study, *Decarbonisation Pathways in Aluminium Vs. Competing Materials*, evaluates emissions reduction strategies for aluminium, steel, copper, container glass and PVC on the path to Net Zero.

Using a consistent methodology, the study focuses on process emissions and emissions from energy and electricity use across material value chains, from mining to semis production, while excluding activities such as transportation. The full study is available on the IAI website.

12 years

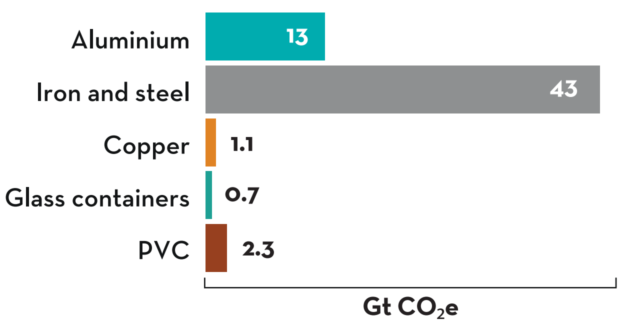
At 2020 GHG emission levels, the carbon budget for each material will be exceeded in about 12 years.

CARBON BUDGETS AND ENERGY NEEDS

Carbon budget refers to the maximum amount of greenhouse gases (GHGs) that can be emitted cumulatively into the atmosphere while staying within a specific global temperature limit, acting as a cap on cumulative emissions and an accountability tool to guide industries towards emissions reductions. The Eunomia study is based on a 66% probability of staying within 1.5°C.

The Eunomia study concludes that all material industries will be required to take significant action within the next five years to manifest a downward trend in global CO2 emissions, otherwise it is unlikely that their carbon budgets will be met. If no reductions are undertaken, the 1.5°C budgets will be consumed approximately within the next 12 years.

1.5°C GLOBAL CARBON BUDGETS (CUMULATIVE EMISSIONS BETWEEN 2020 AND 2050)



Aluminium: Primary aluminium is 65% electricity-dependent; needs 1,160–1,700TWh by 2050.

Steel: Relies on coking coal; shifting to Electric Arc Furnace required.

Copper: Primary copper is 60% electricity-dependent; requires 369 TWh

Glass: Transitioning to electric furnaces, needs 68TWh.

PVC: Technology shift from calcium carbide- based production to ethylene in China.

For **aluminium** and **copper**, the decarbonisation of electricity is critical, as 65% and 60% of their emissions for producing primary aluminium and copper come from electricity in 2020 respectively.

For **steel**, the full adoption of the DRI (Direct Reduction of Iron) process is likely to be the primary driver in decarbonising primary steel, especially when combined with an Electric Arc Furnace, offering the potential for Net Zero production.

For **container glass**, the key technological leap required for swift progress towards Net Zero is furnace electrification, likely to be in the form of the hybrid furnace. The pathway for primary **PVC** is less clear with techology shifts, electrification, recycling and alternative fuels.

GLOSSARY

TWh (Terawatt-Hour): A unit of energy equal to one trillion watt-hours, used to measure large-scale electricity consumption or generation.

Gt CO_2e = Gigatonnes of Carbon Dioxide Equivalent, a unit measuring the combined warming potential of greenhouse gases, equal to one billion tonnes of CO_2.

THE RELIANCE AND MATURITY OF ALUMINIUM VS OTHER MATERIALS

The data in this table below shows that decarbonisation potential varies significantly across materials.

Aluminium relies heavily on a green grid transition and recycling, yielding reductions between 43-67%. **Steel** shows greater dependency on technology adoption (64%). The transition for **copper** depends highly on electricity decarbonisation (45%), similar to aluminium, but facing uncertainty in the use of alternative fuels. **Container glass** also shows strong reliance on green electricity but needs to replace furnaces first, while **PVC** exhibits a reliance on low carbon electricity, new technology and recycling. Recycling is highly relevant for all materials in this study, especially for aluminium, where recycling is already well integrated into the production value chain.

MATERIAL	The reliance on electrical green grid transition and expansion of capacity	The need for new technology and manufacturing infrastructure replacement	Technical maturity of replacement technologies[1]	The maturity and availability of recycling processes[2]	Remaining Emissions[3]
Aluminium	●●●● Smelting is electricity-driven and dominates the impact.	●● Anode replacement will be required to fully decarbonise.	●●● Inert anode and refinery calciner not yet fully commercialised.	●●●● Recycling is common due to the high value, and expanded capacity is all that is needed.	**5%**
	10%-34% reduction	**29%-53% reduction**, incl. 24% smelting electricity (CCUS)		**33% reduction**	
Steel	●●● Relatively low electricity use currently, but will need to grow with new tech.	●●●● Most current blast furnaces will need to be replaced.	●● A broad technology mix with varying readiness levels will be required.	●●●● Scrap steel is very commonly recycled, and expanded capacity is all that is needed.	**5%**
	6% reduction	**71% reduction** (large share electrification, then green grid transition)		**18% reduction**	
Copper	●●●● The process is heavily dependent on electricity.	● The core process will remain unchanged.	●●● It is unclear which alternative fuels will be used in machinery.	●●● High value and easy to integrate, but centred on few geographic locations.	**4%**
	45% reduction	**44% reduction**, incl. 17% alternative fuels		**7% reduction**	
Glass containers	●●●● The shift to electric furnaces will increase electricity demand.	●●● All furnaces will need to be replaced with hybrid or fully electric.	●● Furnaces are only just beginning to be tested at the scales required.	●●● Glass recycling rates vary significantly by region and not all collected goes to remelt.	**3%**
	70% reduction, incl. 47% furnace electrification			**27% reduction**	
PVC	●● The move to electric steam crackers will require more capacity.	●●●● A switch to electricity driven steam crackers for ethylene and bio-based feedstocks will be required.	●● Ethylene production is common, but electric steam crackers and bio-based are not.	● Recycling is not well established and challenging to integrate. Legacy chemicals are problematic.	**7%**
	24% reduction	**42% reduction**, incl. 11% alternative fuels		**27% reduction**	

KEY

● Low
●●●● High

[1]**Material efficiency** is included under technologies.
[2]Numbers might not add up to 100% due to rounding and category overlap.
[3]**Reduction percentage**: The difference in greenhouse gas emissions between the Business-as-Usual scenario and the Remaining Emissions after succesful implementation of all decarbonisation interventions in the year 2050.

KEY FINDINGS

Aluminium has a high maturity and availability of recycling processes.

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Steel has a high need for new technology and manufacturing infrastructure replacement.

●●●●

Copper has a high reliance on electrical green grid transition.

●●●●

Container glass has a medium technical maturity of replacement technologies.

●●

PVC has a low maturity and availability of recycling processes.

●

TECHNOLOGY READINESS

TIMELINE OF KEY INTERVENTIONS FOR DECARBONISATION

2025

Aluminium
Energy transition begins to reduce reliance on fossil fuels in production.

Glass
Move from fossil fuel-fired furnaces to fully electric or 'hybrid' furnaces – 80% electric, 20% natural gas with a further transition to biomass and hydrogen.

2030

PVC
Bio-based feedstocks adoption begins, reducing fossil fuel dependence.

Preparations for ethylene production shift and low-carbon technologies start.

Aluminium
Carbon Capture, Utilisation and Storage (CCUS) begins implementation to reduce emissions.

Anode replacement deployment begins – critical for low-carbon smelting.

Steel
DRI (Direct Reduction of Iron) and EAF (Electric Arc Furnace) ramp-up – key for decarbonising production.

Transition to hydrogen-based methods starts for replacing coal in production.

2032

Copper
Electrification of mining and equipment begins to replace fossil fuel use.

2040

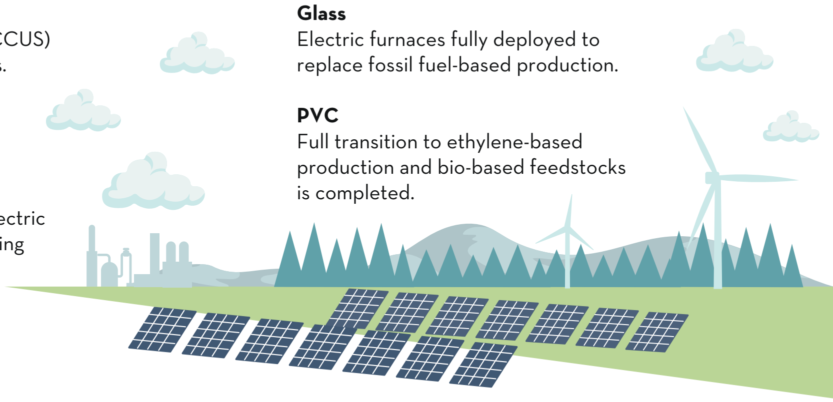
Copper
Electricity is decarbonised with equipment electrification under development.

2045

Aluminium
Energy transition completes, with 50% from renewables and the remaining emissions mitigated through Carbon Capture, Utilisation and Storage (CCUS).

Glass
Electric furnaces fully deployed to replace fossil fuel-based production.

PVC
Full transition to ethylene-based production and bio-based feedstocks is completed.



This timeline highlights the technological maturity of decarbonisation strategies across materials, focusing on advancements needed to achieve Net Zero targets. While aluminium benefits from existing technologies like inert anodes and CCUS, materials like steel and PVC require disruptive innovations, such as hydrogen-based production and bio-based feedstocks, to replace fossil fuels. However, the pace of decarbonisation will depend on industry investment and policy support, meaning progress could accelerate or face delays depending on technological readiness and market conditions.

COMPARING STRENGTHS AND CHALLENGES

Material	Strengths	Challenges
Aluminium	High recyclability, electricity-based production	Reliance on green electricity, high-energy smelting process
Steel	Well-established recycling (EAF), multiple tech pathways	Requires complete transition away from coking coal
Copper	Minimal change needed in core processes	Limited recycling due to long product lifespans
Glass	Integrated recycling potential	Heavy dependence on furnace electrification
PVC	Shared decarbonisation burden with chemicals sector	Reliance on legacy coal-based production in China

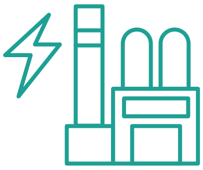
Aluminium benefits from high recyclability, but relies on green electricity for its energy-intensive production.

Steel has established recycling pathways, but must transition away from coking coal. **Copper** requires minimal process changes, though recycling is limited by long product lifespans.

Glass has integrated recycling, but depends on furnace electrification. **PVC** shares decarbonisation efforts with the chemical sector, but relies on coal-based production in China.

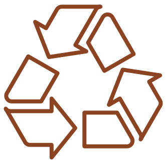
REGIONAL CHALLENGES IN DECARBONISATION

Decarbonisation pathways for materials are heavily influenced by regional production trends, energy sources and technological capabilities. This section explores how different regions shape the progress and challenges for aluminium and other materials.



NORTH AMERICA

Challenge: Limited post-consumer recycling infrastructure for PVC and insufficient green electricity for steel production.
Opportunity: Well-established Electric Arc Furnace (EAF) network can drive low-carbon steel production.



EUROPE

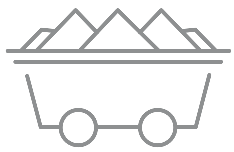
Challenge: Needs to scale electric and hybrid furnaces for glass and steel production to lower carbon footprints.
Opportunity: Strong leadership in recycling aluminium and glass provides a foundation for further decarbonisation.

LATIN AMERICA

Challenge: High emissions from mining operations dominate copper's carbon footprint.
Opportunity: Decarbonising copper mining processes, especially in Chile and Peru, could have a significant global impact.

CHINA

Challenge: Heavily reliant on coal for aluminium smelting, steel production and PVC manufacture, making decarbonisation critical.
Opportunity: Transitioning to green electricity, CCUS and hydrogen technologies can significantly reduce emissions.



ALUMINIUM'S DECARBONISATION OUTLOOK

- **Aluminium stands as a frontrunner in decarbonisation potential**, with mature recycling systems and existing technologies supporting the transition.
- **Scaling these solutions globally is critical**, especially in coal-reliant regions.
- Compared to other materials, **aluminium's energy dependency makes it particularly reliant on the rapid deployment of renewable electricity**.
- **Achieving Net Zero requires collaborative global efforts**, significant investments in technology, and aggressive policy measures.