SUSTAINABLE ENERGY CARRIERS & ENERGY CONVERTERS FOR THE MOBILITY SECTOR

Technology diversity is an outcome, not a compromise

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Mobility is an energy system question

"The future of mobility will not only depend on how we develop and manufacture vehicles, but also on how we generate, convert, transport, store and use the energy needed to operate them."

Renewable generation → Conversion (electrolysis, synthesis, biomass) → Transport & storage → Distribution (charging, refuelling) → Vehicle-side converter

Guiding question: Which energy carriers and converters can provide sustainable, competitive and reliable solutions for different mobility applications?

Energy trilemma – three goals that have to be balanced at the same time [I]

Sustainability
climate and environmental performance

Competitiveness
affordable energy for households and industry

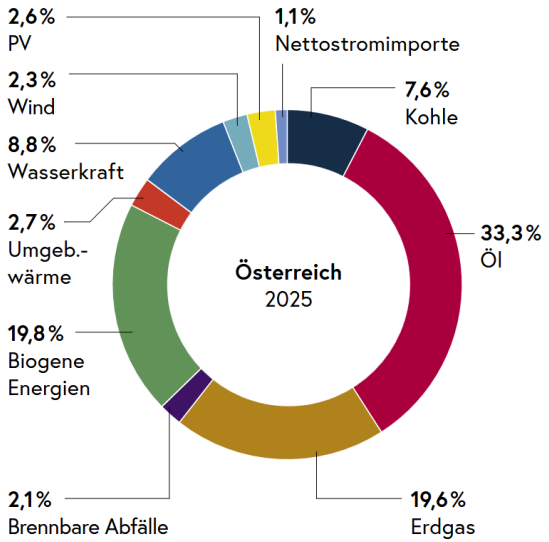
Security of supply
reliable, resilient energy system

Thesis: Technology diversity is an outcome, not a compromise.

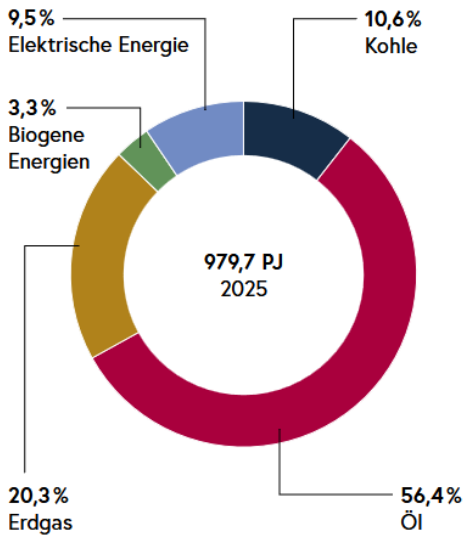
Evidence labels: [E] evidence · [A] assumption · [I] interpretation. Energy trilemma: framing anchor [I].

Austria: where does our energy come from – and what do we import?

Gross inland consumption in Austria by energy source, 2025 (share in %)



Structure of energy imports in Austria, 2025 (share in %)



≈ 36 % of our gross inland consumption is renewable

≈ 64 % is still oil, gas, coal and other non-renewable sources

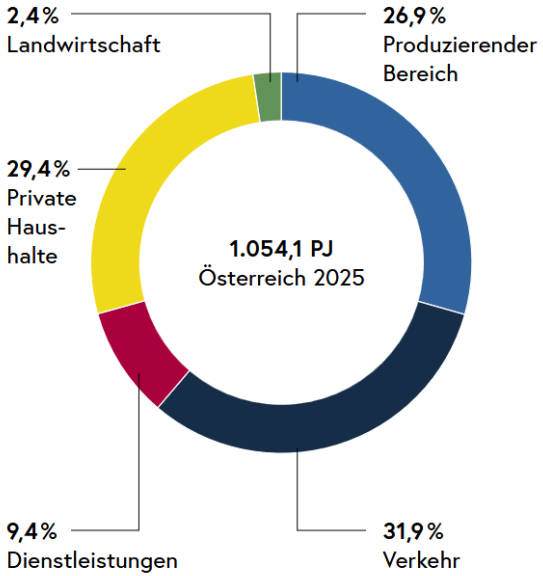
≈ 4 × more energy is imported than exported (980 vs. 232 PJ)

So what [I]: Climate neutrality by 2040 (government programme) means addressing the remaining ≈ 64 %: efficiency, electrification and changes in demand alter the energy quantities needed, and what remains must be supplied renewably. Austria cannot supply all its energy itself: imports will remain necessary – but they must shift to renewable carriers, e.g. renewable hydrogen. Resilience and security of supply matter, so that we do not fall back into strong dependencies – as today's world-market energy prices show.

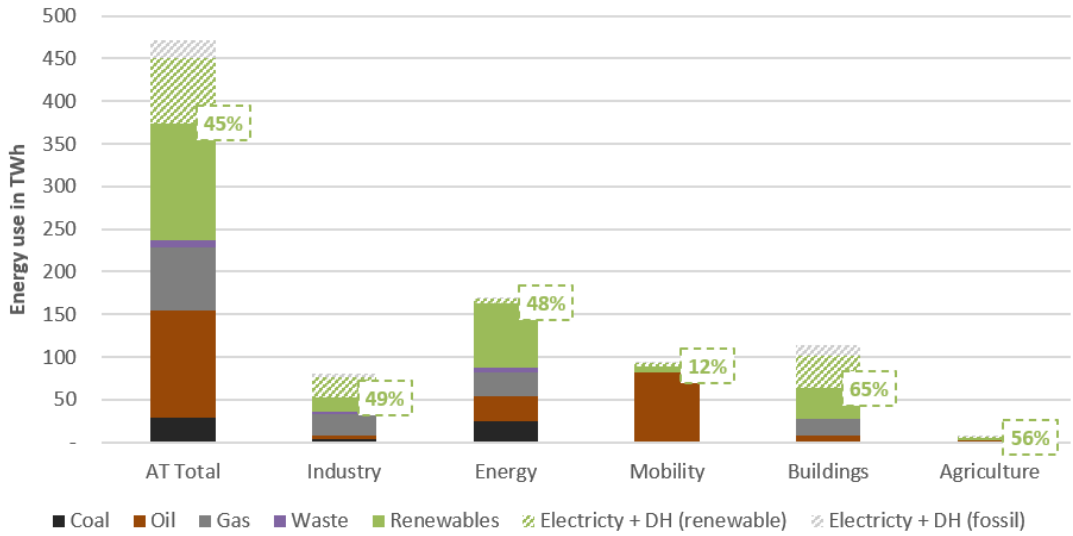
Source: BMWET (2026), Energie in Österreich – Zahlen, Daten, Fakten, Abb. 5, 8 and 12; gross inland consumption and imports 2025; EU-27 value for 2024. Non-renewable share = 100 % − 36.2 % (derived).

Austria: mobility is the largest energy demand sector – and still fossil

Final energy consumption in Austria by economic sector, 2025 (share in %)



Energy demand in Austria per sector and energy carrier (TWh); renewable share in %



31.9 %

of final energy (≈ 336 PJ) is used in transport – the largest demand sector

≈ 12 %

renewable share in mobility (biofuels, renewable electricity); buildings: 65 %, energy: 48 %

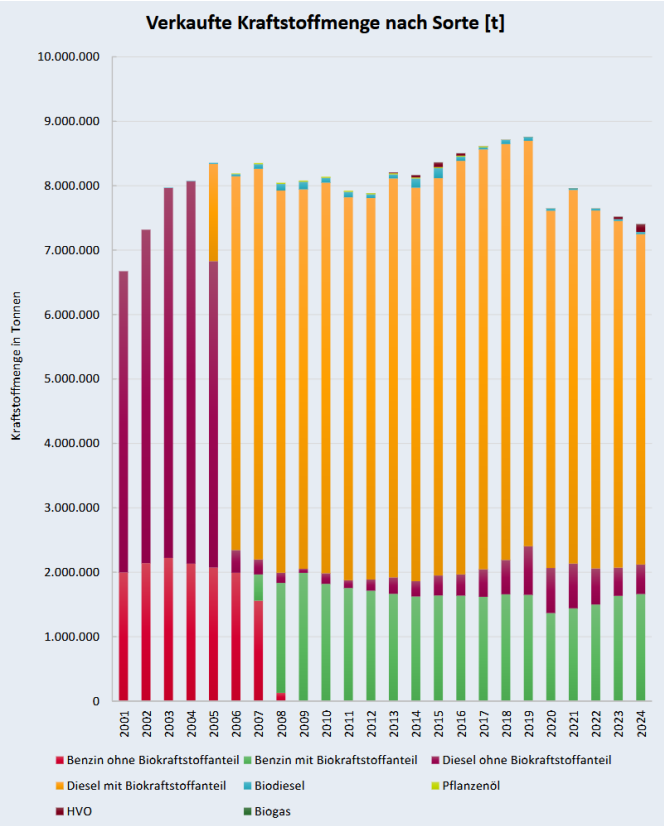
Action needed [I]

but with which carriers and converters?

Sources: BMWET (2026), Abb. 16 (1,054.1 PJ ≈ 293 TWh; transport 335.8 PJ); chart: Energieinstitut an der JKU Linz, based on Statistik Austria. Right chart: different system boundaries (incl. sector Energy; electricity and district heat hatched), not comparable with final energy or the 36 % on slide 3.

Fuels in transport today: low share of sustainable carriers

Sales of fossil fuels by type, with and without biofuel content, and of pure biofuels, 2001–2024



Transport final energy by carrier group, Austria 2024

Carrier group	Energy [PJ]	Share
Fossil fuels	308	≈ 89 %
Biofuels (blended and pure)	≈ 25	≈ 7 %
Electricity and other (remainder)	≈ 13	≈ 4 %
Total transport final energy	346.5	100 %

Message [I]: fossil fuels still cover ≈ 89 % of transport final energy; biofuels (≈ 7 %) are the largest sustainable carrier, electricity adds ≈ 4 %.

- Diesel and petrol dominate; biofuels are mainly blended [E]
- No renewable hydrogen reported; alternative fossil fuels (LPG, CNG, LNG) ≈ 0.07 % [E]

Sources: Statistik Austria (energy balance 2024: fossil fuels in transport 308 PJ); BMWET (2026) (transport final energy 2024: 346.5 PJ); BMIMI (2026), data 2024, Abb. 6, Tab. 2–3 (biofuels 25.4 PJ; alternative fossil fuels 0.23 PJ). Electricity and other = remainder (own calculation) [A].

One assessment frame: six dimensions linked by a causal chain

Every pathway is assessed along six dimensions – and the dimensions are linked.

Dimension	Guiding question
Technical	Is it suitable and efficient?
Economic	Is it competitive over its lifetime?
Ecological	What are its life-cycle emissions and resource impacts?
Infrastructure & system	Can energy and infrastructure be provided?
Regulatory	Are market conditions supportive?
Socio-economic	What does it mean for value creation, employment and acceptance?



Causal chain [I]; raw material availability enters as a cross-cutting constraint.

Four pathways – each defined by conversion, carrier and converter

Whether electricity, hydrogen, e-fuels or biofuels: every pathway is a chain from renewable energy to the vehicle – what differs is the number of conversion steps and the infrastructure behind them.

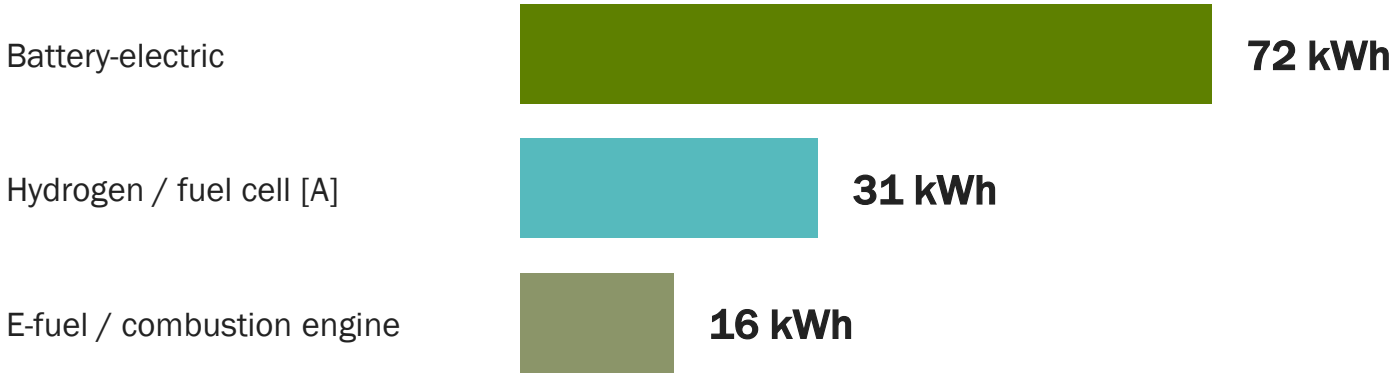
Pathway	Supply-side conversion	Energy carrier	Vehicle-side converter
Direct electrification	Grid, charging	Electricity	Battery + electric motor
Hydrogen	Electrolysis (compression / liquefaction)	Hydrogen	Fuel cell / H_2 engine
Power-to-X	Electrolysis + synthesis (CO_2 / N_2 source)	E-fuels, e-methanol, e-ammonia	ICE / turbine (partly fuel cell)
Bioenergy	Biomass conversion	Biofuels, biomethane	ICE / turbine

Schematic overview [I]. Pathways differ in efficiency, conversion effort, storability, infrastructure and use cases.

Efficiency sets the renewable-electricity demand

How much of the renewable electricity we feed in actually reaches the wheels? This determines how much generation, grid and capital we need.

Useful traction energy at the wheels from 100 kWh renewable electricity (passenger car)



4.5 ×

BEV vs. e-fuel ICE in a car

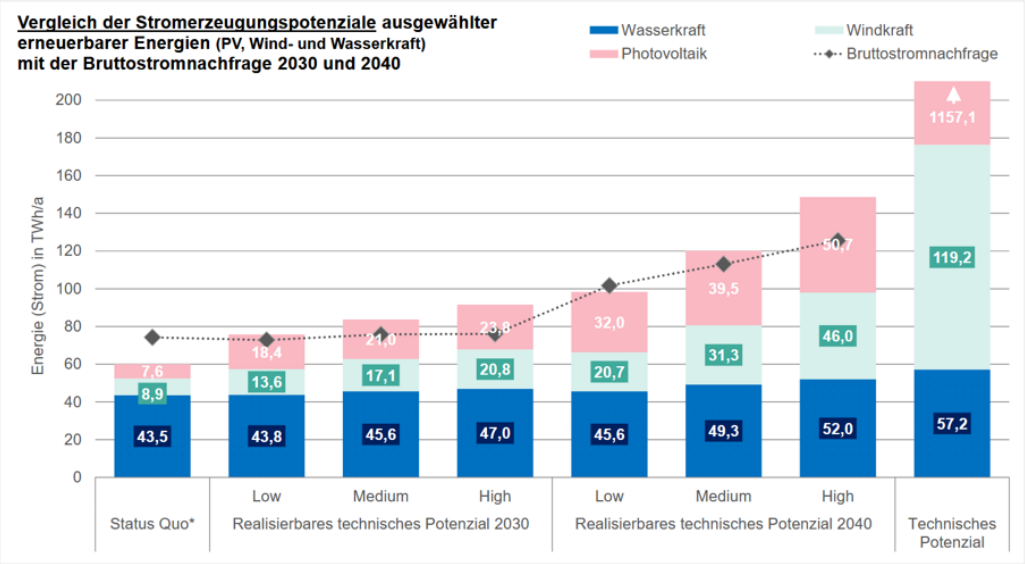
Message [I]: every conversion step loses energy. A battery-electric car needs about 4.5 times less renewable electricity per kilometre than a car running on e-fuel – and renewable electricity is limited. So: use electricity directly wherever possible, and use hydrogen and e-fuels where direct electrification is hard (e.g. aviation, shipping).

Illustrative values; efficiency is a key criterion, but not the only one. Grid-to-wheel ≠ life-cycle assessment.

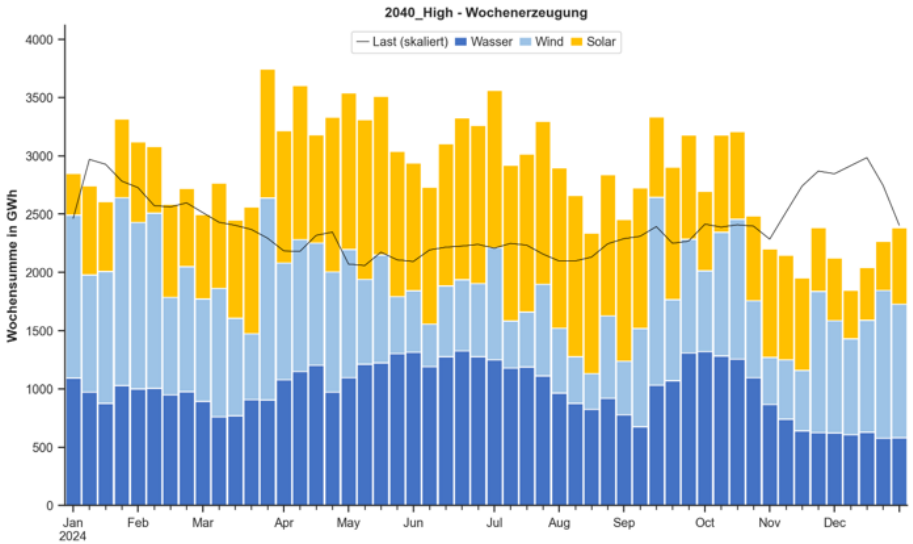
Sources: ICCT (2024) vehicle-stock report, Fig. 8; Ueckerdt et al. (2021) Nat. Clim. Change, DOI 10.1038/s41558-021-01032-7. H_2 value: EI-JKU illustration 0.70 × 0.80 × 0.55 ≈ 31 % [A]. Grid-to-wheel, passenger car.

How much renewable electricity can Austria generate – and when?

Renewable generation potentials (hydro, wind, PV) vs. gross electricity demand, Austria 2030 and 2040



Weekly renewable generation vs. load, Austria 2040, scenario High



Scenario 2040 “High” [A]

- Upper bound, above EABG targets: 148.7 TWh (hydro 52.0, wind 46.0, PV 50.7) vs. ≈ 125 TWh demand
- Structural surplus ≈ 28 TWh/a after ≤ 24 h smoothing

Volatility and load profile [I]

- Generation fluctuates daily and seasonally; load follows its own profile (e.g. EV charging peaks) – no automatic balance
- Needs: storage, load shifting, storable carriers – and imports (winter)

Left: AIT, AEE, Energiewerkstatt, TU Wien, Umweltbundesamt (2026), Erneuerbare Energiepotenziale in Österreich 2030 und 2040, for Klima- und Energiefonds. Right: Energieinstitut an der JKU Linz (scenario High, base year 2024). High = upper bound, above EABG targets [A].

Application profiles define requirements – matching pathways and applications

The same carrier is not equally suitable everywhere: the requirements of the application decide which pathway fits.

Selection criteria

- Energy density (mass / volume)
- Range, energy per day
- Payload and weight limits
- Operating hours, utilisation
- Refuelling / charging time
- Infrastructure requirements
- Readiness and costs

Project: AdvancedPTL (FFG)

Sustainable aviation fuel: high-efficiency co-SOEC (eSyngas) combined with load-flexible Fischer–Tropsch synthesis

Application	Direct electric	Hydrogen	Molecules (e-fuels, bio)
Passenger cars	●●●	○	●
Light commercial vehicles	●●●	●	●
Buses	●●●	●●	●
Heavy-duty road	●●	●●	●
Non-road	●●	●●	●●
Rail	●●●	●●	●
Inland waterway	●●	●●	●●
Maritime	●	●	●●●
Aviation	●	●	●●●

●●● preferred long-term ●● relevant / niche ● case-dependent ○ limited

Message [I]: there is no single best pathway – direct electrification leads in short-cycle road transport and rail; molecules remain essential where energy density and global fuelling count (aviation: ReFuelEU 6 % SAF in 2030, 70 % in 2050 [E]).

[I] EI-JKU assessment, horizon ≈ 2035; not a forecast. AdvancedPTL: FFG project database.

Market development today: global and Europe – uneven and slower than announced

≈ 25 %

of new cars worldwide were electric (BEV + PHEV) in 2025; strong regional differences. Austria, Oct 2026: BEV 34.9 %, BEV + PHEV 49 %.

9 / 25 / 3 %

electric share of new medium and heavy trucks 2025: world / China / Europe. > 90 % of electric trucks are sold in China.

0.8 %

SAF share of global jet fuel 2026e (1.9 Mt in 2025 → 2.4 Mt). ReFuelEU mandates 6 % in 2030.

27 vs 4.3 Mt

low-emission H_2 for 2030: announced vs. committed investment; ≈ 1 Mt produced in 2025.

Cars electrify – heavy-duty, aviation, shipping and hydrogen ramp up much more slowly than announced.

Mode	Status	Regulatory frame
Cars	Electrification moves	CO_2 standards, AFIR
Heavy-duty road	China leads, Europe 3 %	CO_2 standards, AFIR
Aviation	SAF output far below mandate path	ReFuelEU: 6 % (2030) → 70 % (2050)
Shipping	Rules still open	IMO net-zero framework: adoption pending

Message [I]: where electrification is simple, the market moves; where molecules are needed, announcements are far ahead of realised projects.

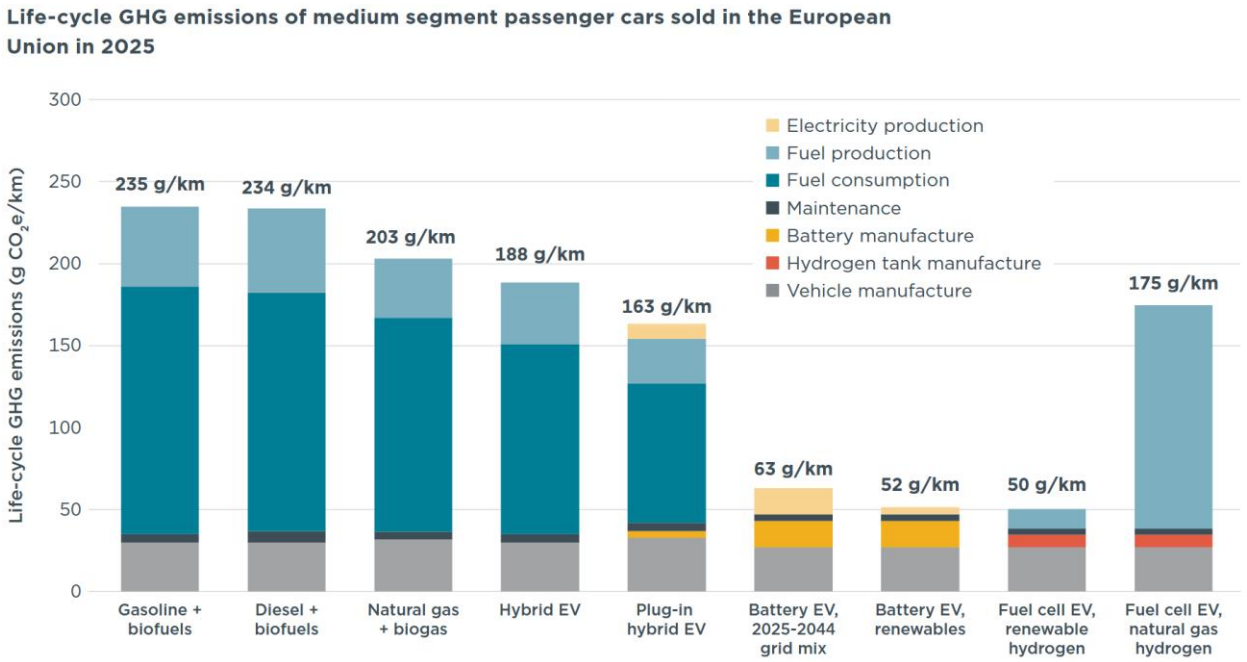
Sources: IEA Global EV Outlook 2026 (2025 data; electric = BEV + PHEV, BEV ≈ 65 % of electric car sales); BMIMI (10 Nov 2026), new registrations Oct 2026 (BEV 8,434, PHEV 3,420 of 24,174); IATA (Dec 2025; 2026 = estimate); IEA Global Hydrogen Review 2026; IMO status Nov 2026; Regulation (EU) 2023/2405.

Think life cycle, not tailpipe

Assess climate performance over the whole life cycle – not only at the tailpipe.

Vehicle production → Energy provision → Use phase → End of life

Life-cycle GHG emissions, medium-segment passenger cars, EU 2025 (g CO_2e/km)



Reading the result

- Example for medium-segment passenger cars in the EU (2025) – not transferable 1:1 to other vehicle classes
- Petrol / diesel ≈ 235 g/km, mostly from burning the fuel
- BEV: 63 g/km (projected EU power mix) and 52 g/km (renewable power); battery manufacture adds emissions up front
- FCEV: 50 g/km with renewable H_2, but 175 g/km with H_2 from natural gas
- Depends on power mix, H_2 route, feedstock, system boundary [A]
- Clean electricity is the common basis of the electric routes [I]

Source: ICCT (2025), life-cycle GHG emissions of medium-segment passenger cars sold in the European Union in 2025 (original figure).

Resources and supply chains: dependencies shift – they do not disappear

> 55 %

LFP share of global EV battery deployment (2025). LFP = lithium iron phosphate: no nickel or cobalt, but still lithium.

> 80 %

of global lithium-ion cell manufacturing capacity is in China (2025) – concentration in the production step.

72 %

share of the largest refining country in key energy minerals (2025, IEA) – risk lies in processing, not only mining.

≈ 1 %

sodium-ion share of capacity: alternative chemistry without lithium – option for diversification, not yet at scale.

Message [I]: every pathway shifts dependencies – from fuel imports to materials, equipment and energy supply chains – none removes them.

Pathway	Dependency structure
Fossil	Continuous fuel imports
Battery-electric	Upfront material investment; recovery potential (recycling significant from mid-2030s)
Hydrogen	Electrolysers, storage, distribution; partly critical materials
Synthetic fuels	Renewable electricity at scale, CO_2 sources, production plants

Sources: IEA Global EV Outlook 2026 (batteries); IEA Critical Minerals Outlook 2026. Dependency structures: EI-JKU interpretation [I].

Economics, regulation and acceptance decide the pace

Technology is only one side: economics, regulation and acceptance determine how fast pathways scale.

Economics

- Business case: TCO, energy and infrastructure cost, utilisation
- High upfront investment vs. uncertain revenues [I]
- H_2: 27 Mt announced vs. 4.3 Mt committed [E]
- Imports > 4× exports: domestic value creation and employment [I]

Regulation

- EU: CO_2 standards, AFIR, ReFuelEU Aviation
- Austria: climate neutrality 2040, renewable expansion (EABG)
- Stable, predictable, technology-open rules reduce investment risk [I]
- Rule changes change business cases [I]

Acceptance

- Main barriers: purchase cost and range [E]
- 17.1 % hold a negative opinion of EVs [E]
- Charging convenience, reliability, price transparency [I]
- V2G: 42.5 % aware [E] – needs trust and incentives [I]

Challenge [I]: infrastructure, investment and acceptance move more slowly than announcements – planning must be robust across pathways.

Sources: IEA Global Hydrogen Review 2026; BMWET (2026); Regulation (EU) 2023/1804 (AFIR), 2023/2405 (ReFuelEU); Danube Indeet survey (Feb–Mar 2026, n = 5,000, 10 countries). [I] = interpretation.

Outlook

Industry

- Products and business models for application profiles, not one carrier
- Secure raw materials and supply chains early
- Build competence along the full chain

Energy sector

- Expand renewables, grids and storage together with mobility demand
- Plan seasonally: summer surplus, winter deficit
- Build charging, hydrogen and storable-carrier infrastructure

Policy & funding

- Technology-open, outcome-based, stable frameworks
- Resilience and security of supply in import strategies
- Fund demonstration and scale-up

Research

- System-level assessment across six dimensions
- Transparent assumptions; separate evidence from interpretation
- Monitor signals and update

Signals to watch

1 Renewable expansion in Austria (EABG targets)

2 Grid, charging and H_2 infrastructure rollout

3 Import options for renewable carriers

4 H_2 final investment decisions, not announcements

5 Verified flexibility (V2G, load shifting)

6 Battery supply and recycling

7 Certified SAF / marine-fuel volumes

8 Mobility demand (passenger-/tonne-km)

Statements are EI-JKU interpretation [I]. Signals: monitoring framework constructed for A3PS 2026; context IEA 2026.

Four key messages

1

No one-size-fits-all solution – diversity is an outcome

Applications differ – so do the best carriers and converters.

2

Energy efficiency matters

It determines renewable energy demand, infrastructure, cost and regulation.

3

Competitiveness goes beyond technology

Infrastructure, energy cost, raw materials, regulation and acceptance – system and policy decide the pace.

4

A holistic system perspective is essential

Technology, economics and law have to be assessed together.

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