



Energy Transition & Future Powertrains Status Update

Image credit: [gyanchakra.co.in](https://www.gyanchakra.co.in)

W. Addy Majewski

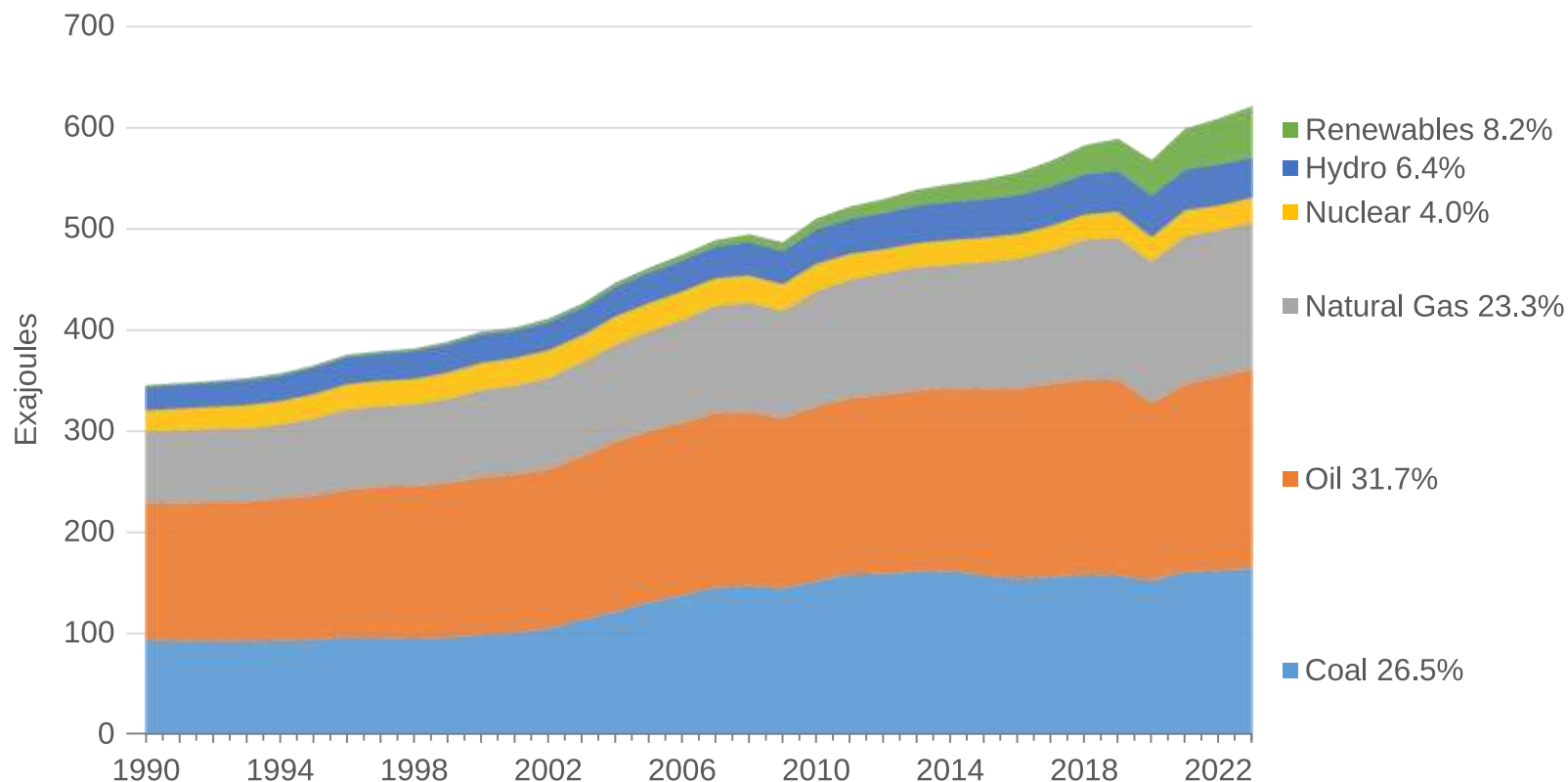
[DieselNet.com](https://dieselnet.com)

MDEC MVPC Conference | Sudbury | October 23, 2024

DieselNet

World's primary energy consumption, 1990-2023

Fossil fuels provided 81.5% of global primary energy in 2023



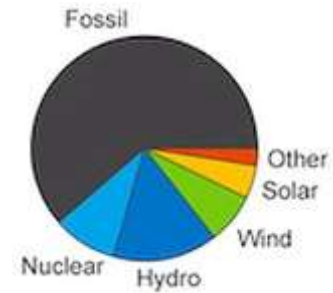
Renewables = wind + solar + geothermal + wave power.

Electrical energy (renewables, hydro, and nuclear) is converted into EJ on an 'input-equivalent' basis, assuming about 38% conversion efficiency in a thermal power station.

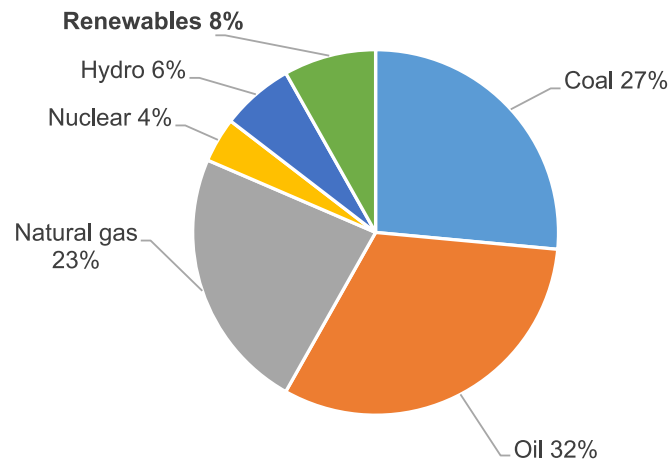
Data: Energy Institute Statistical Review of World Energy 2024

Renewables and global energy supply

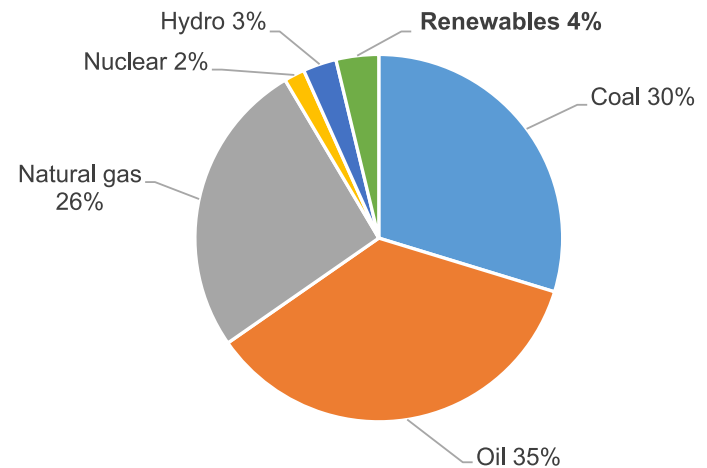
- Contribution of renewables to **global electricity** production (2023)
 - Renewables excl. hydro: 15.9%
 - Renewables incl. hydro: 30.0%
 - Renewables met 74% of net electricity demand growth in 2023
- Contribution of renewables to **global primary energy** supply



- Input-equivalent (substitution) method: **8.2%**

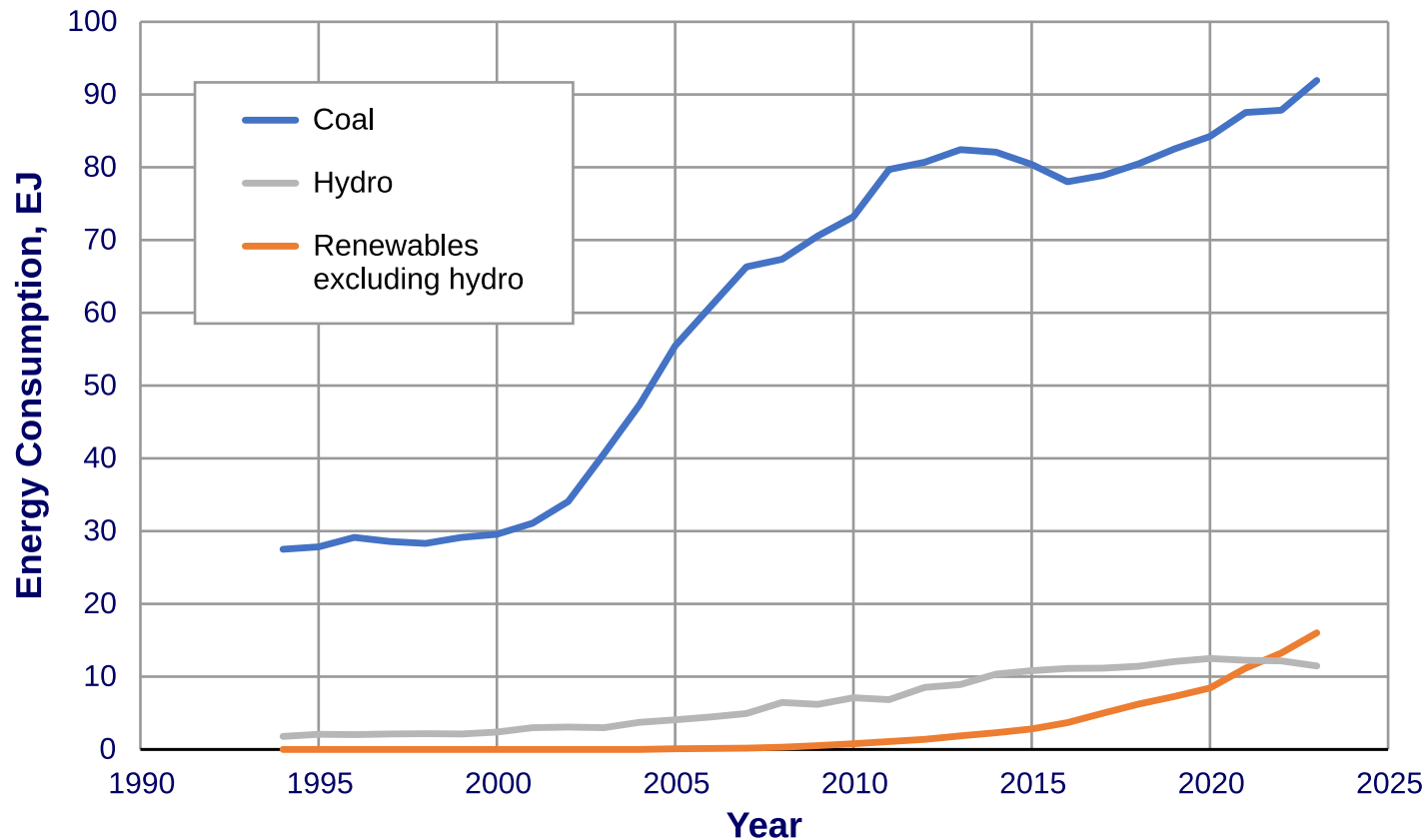


- Heating value method: **3.7%**



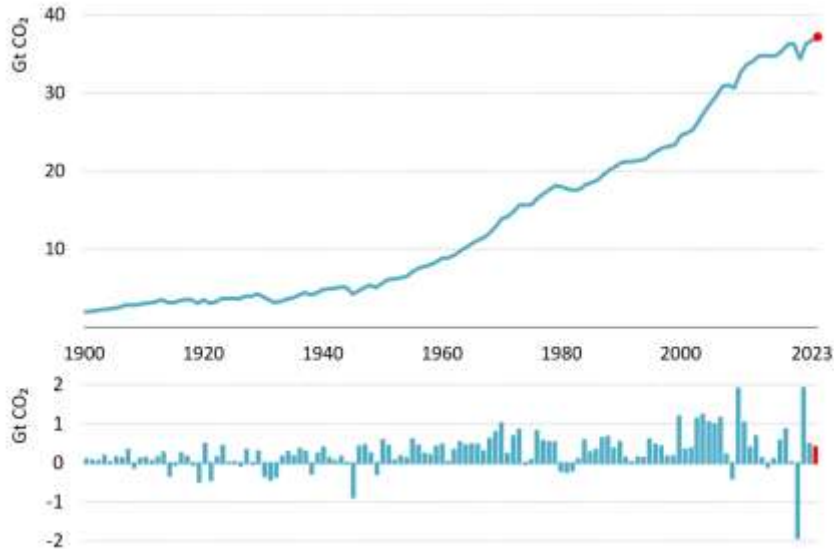
“Energy Transition” or “Energy Addition”?

- Renewables are being added on top of growing fossil energy demand
- Electricity consumption is accelerating faster than renewable sources can provide for it



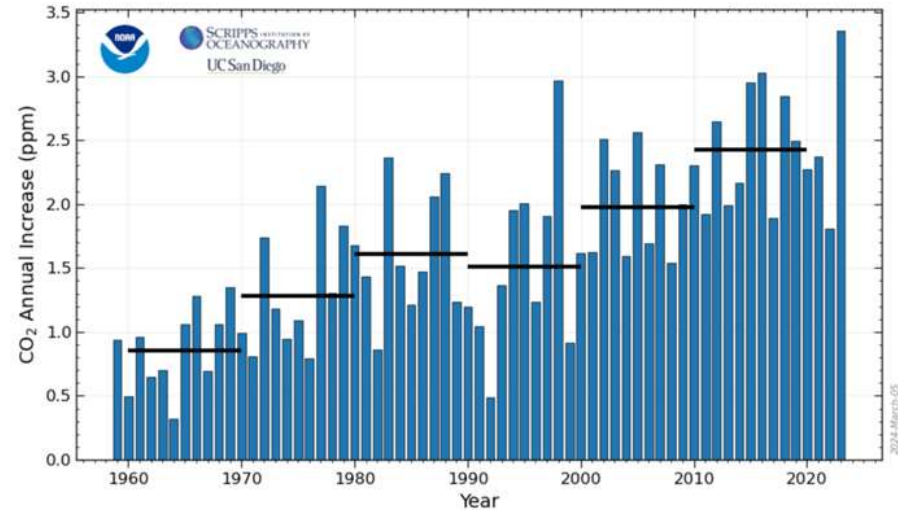
Consumption of coal & renewable energy in China

Climate change: Energy-related CO₂ emissions



Global energy-related CO₂ emissions and their annual change

<https://www.iea.org/reports/co2-emissions-in-2023/>



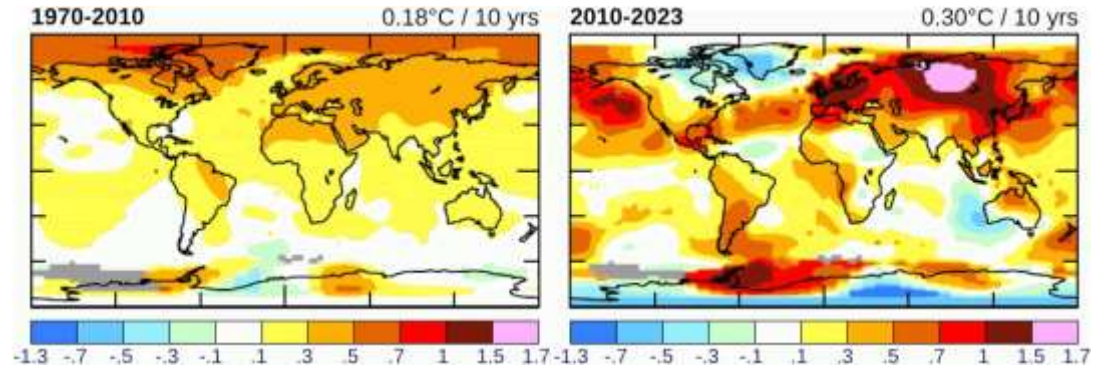
Annual increase of CO₂ concentration
at NOAA Mauna Loa observatory
Black lines represent 10-year averages

<https://gml.noaa.gov/ccgg/trends/gr.html>

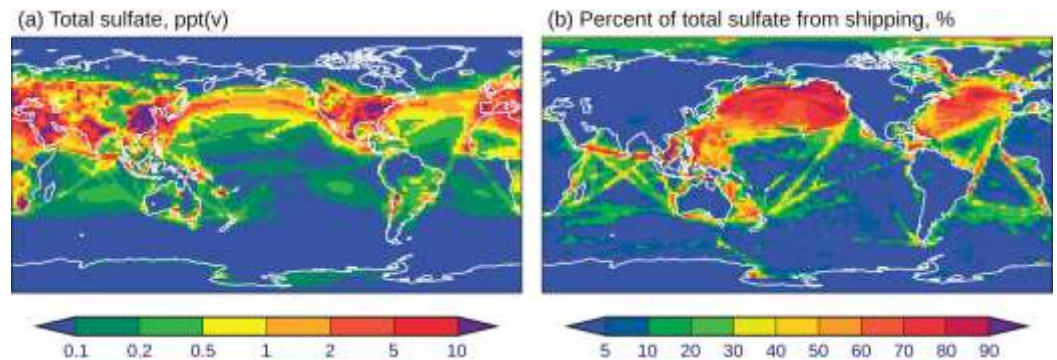
- CO₂ emissions from fossil fuels increased by 1.1% in 2023
- CO₂ emissions decrease during periods of decreased economic activity (Covid-19 lockdowns, 2008 GFC, recession in the 1980s)
- Ambient CO₂ concentrations increased by a record high 3.3 ppm in 2023
- CO₂ reached 425 ppm in March 2024

Decreasing aerosols accelerate global warming

- Decreasing human-made aerosols—such as due to the reduction of sulfur content in marine fuels—accelerated global warming in the past decade
- Global warming in 2010-2023 is $0.30^{\circ}\text{C}/\text{decade}$, 67% faster than $0.18^{\circ}\text{C}/\text{decade}$ in 1970-2010
- The large warming over the North Pacific and North Atlantic coincides with regions where ship emissions dominated sulfate aerosol production prior to IMO fuel sulfur regulations
- According to some climate models, the impacts of aerosols *may outweigh* the effects of greenhouse gases



Local and global temperature trends ($^{\circ}\text{C}$) in two periods



Total sulfate (parts per trillion by volume) and percentage of total sulfate provided by shipping prior to IMO regulations on sulfur content of fuels

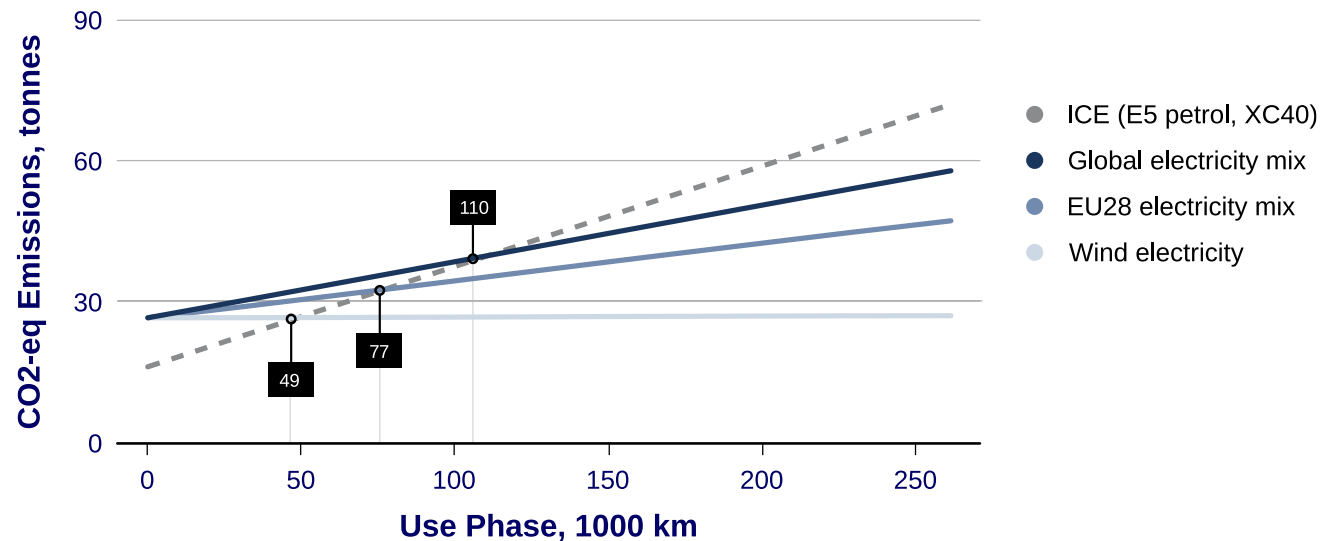
Electric vehicles: Life cycle emissions from BEVs

Carbon footprint
for Volvo XC40 ICE
and C40 Recharge
(tonnes of CO₂eq; total
distance 200,000 km)

Vehicle	Materials Production & Refining	Li-ion Battery Modules	Volvo Cars Manufacturing	Use Phase Emissions	End-of-Life	Total
XC40 ICE (E5 petrol)	14	-	1.7	43	0.6	59
C40 Recharge (global electricity mix)	18	7	1.4	24	0.5	50
C40 Recharge (EU-28 electricity mix)	18	7	1.4	16	0.5	42
C40 Recharge (wind electricity)	18	7	1.4	0.4	0.5	27

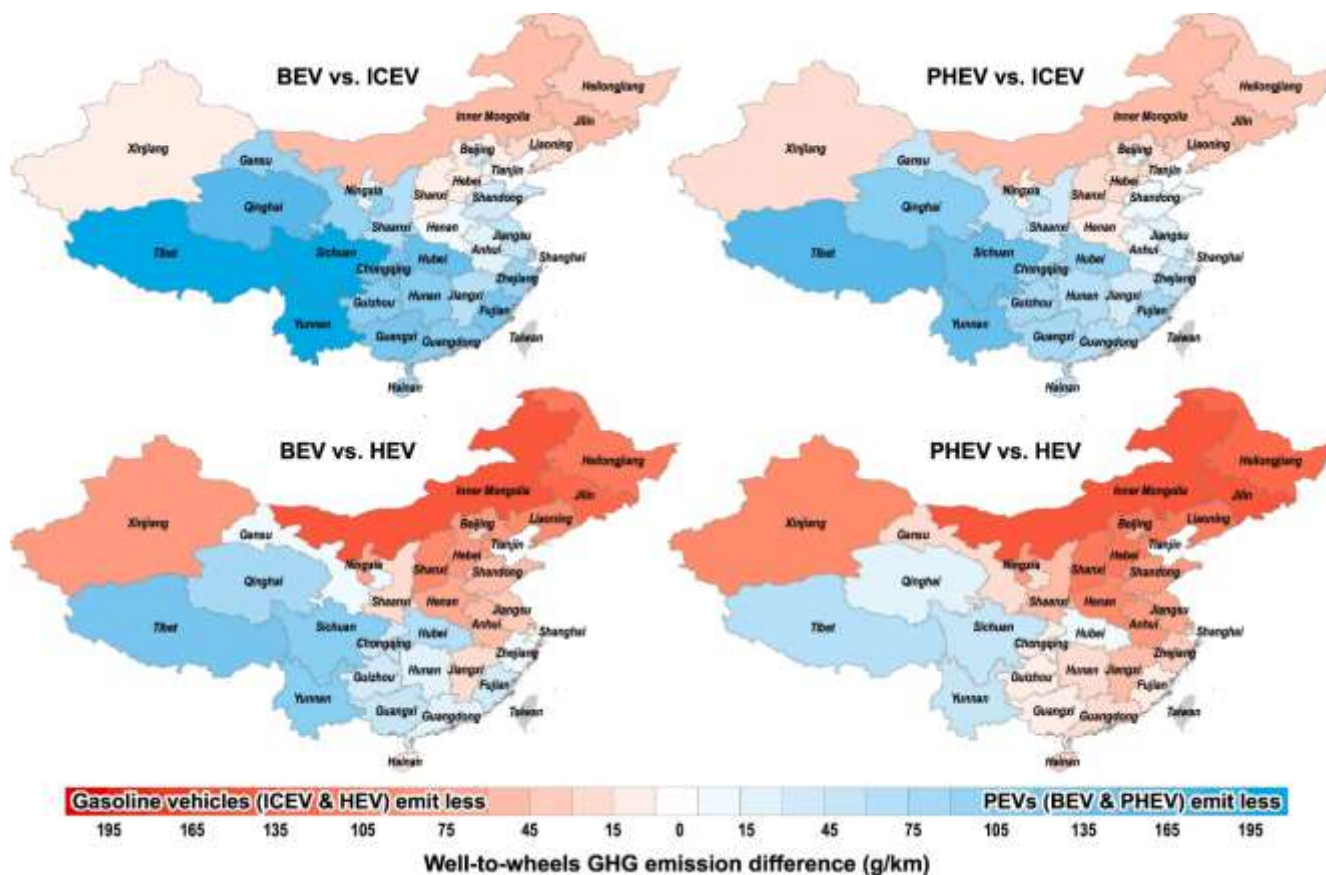
Emissions break-even
diagram for Volvo
C40 Recharge BEV

75 kWh battery
360 km (225 mi) range

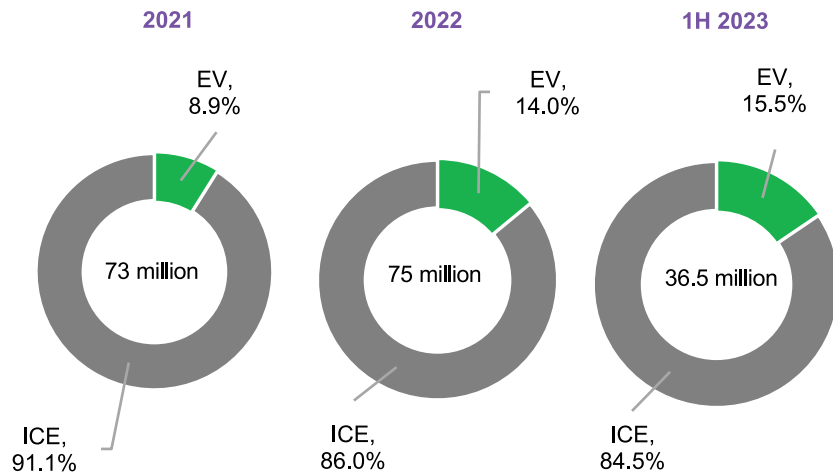


WTW emissions from ICEVs, HEVs, PHEVs, and EVs

Comparison of WTW GHG emissions between gasoline vehicles (rows) and PEVs (columns) at the provincial level in China—the impact of grid electricity mix and climate



































Electric vehicle markets: Global EV sales



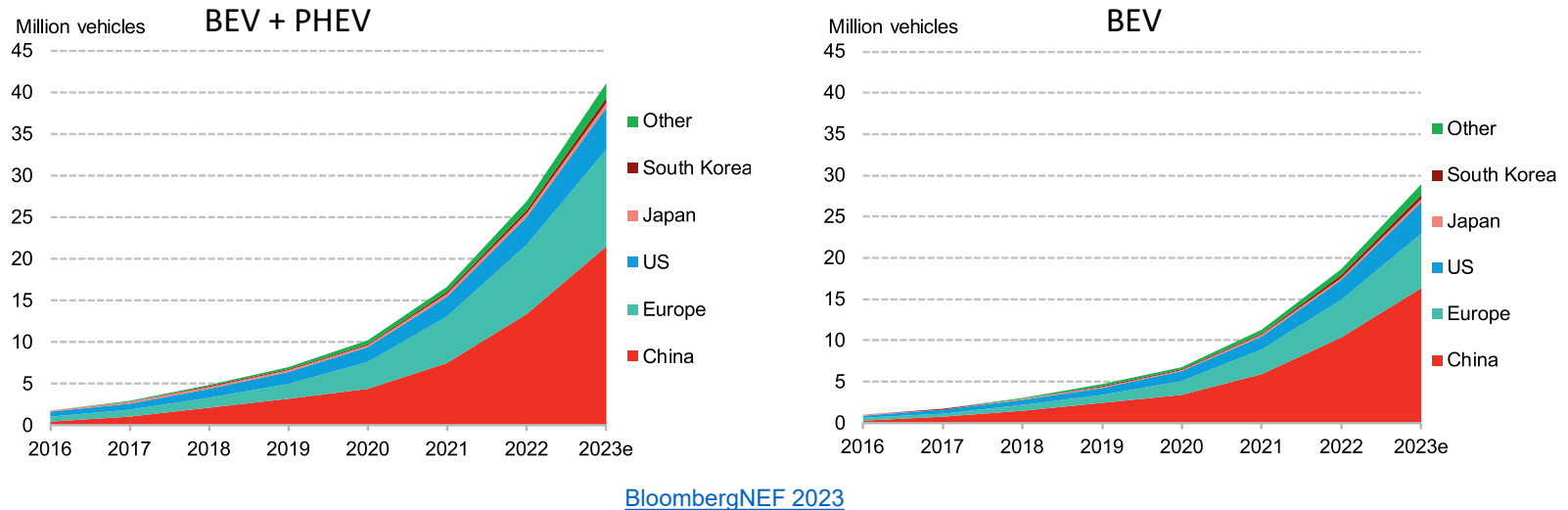
- EVs include BEVs and PHEVs
- Sales driven by EV policies

Major EV policies in three key EV markets

Policy	China	US	Europe
Supply side			
Fuel economy targets	 		  
EV quotas	 	 	
ICE phase out			  
Manufacturing subsidies	 	  	
Demand side			
Purchase incentives	  	  	  
Company car benefit			 

[BloombergNEF 2023](#)

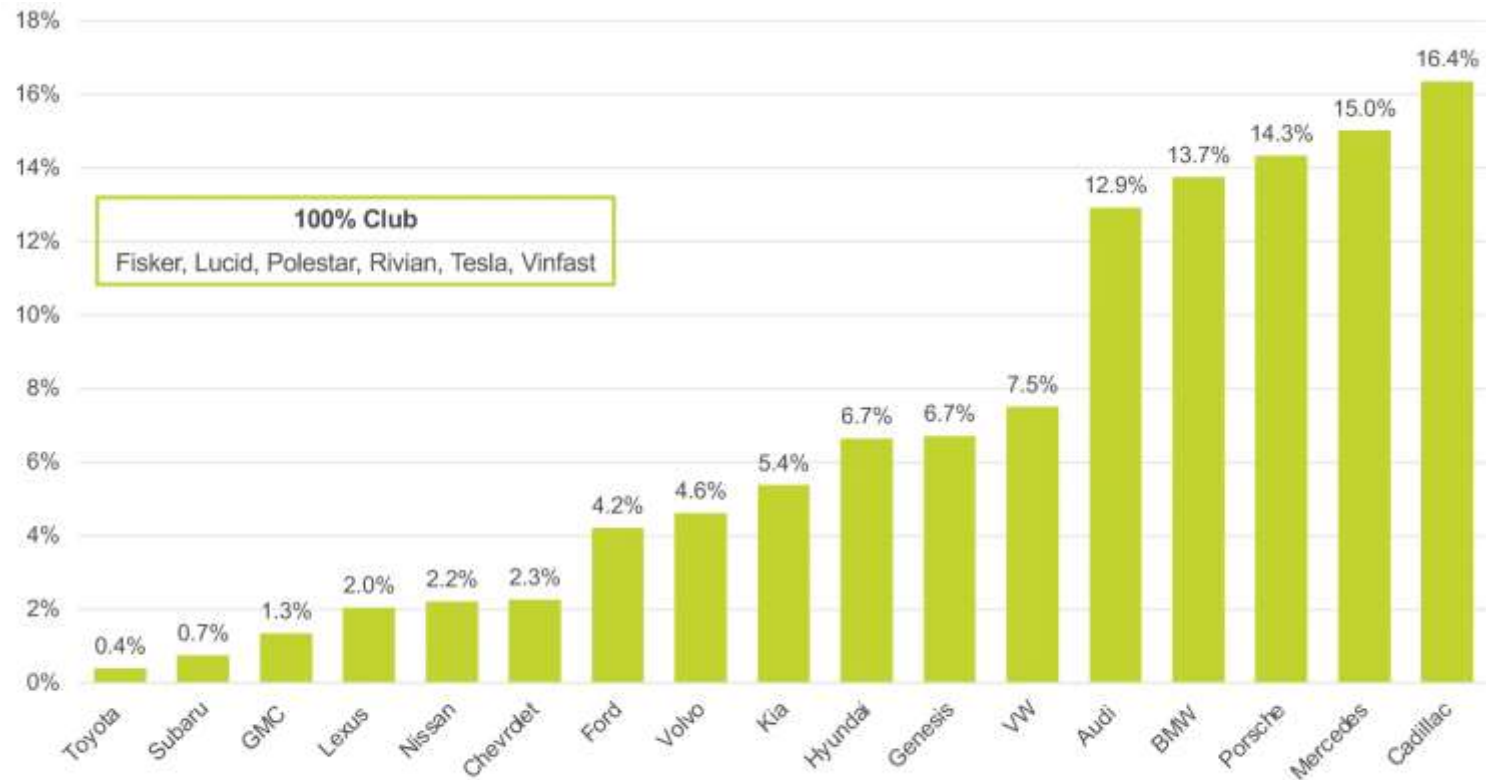
Global EV vehicle fleet



- A cumulative total of 41 million EVs—including 29 million BEVs—were sold by the end of 2023, up from just 10 million at the end of 2020.
- Most of these vehicles are still on the road, which means that EVs now make up about 3% of the global fleet of passenger vehicles.
- China and Europe are home to 80% of that EV fleet.

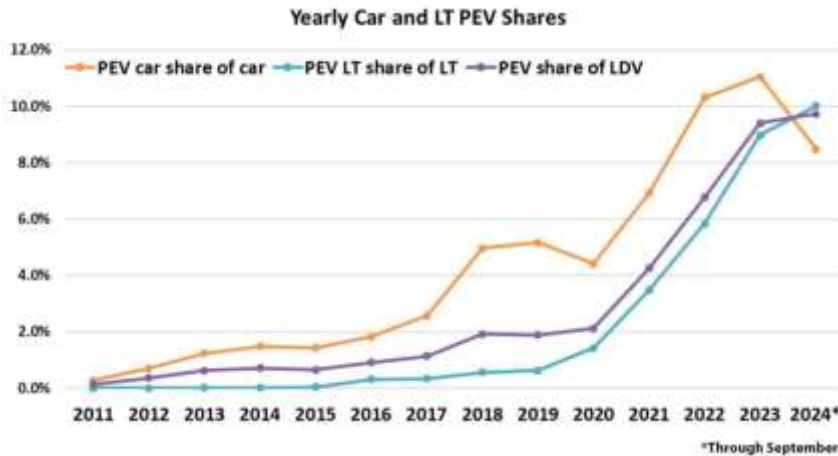
EV sales share by brand, Q1 2024

EV market continues to be luxury-driven



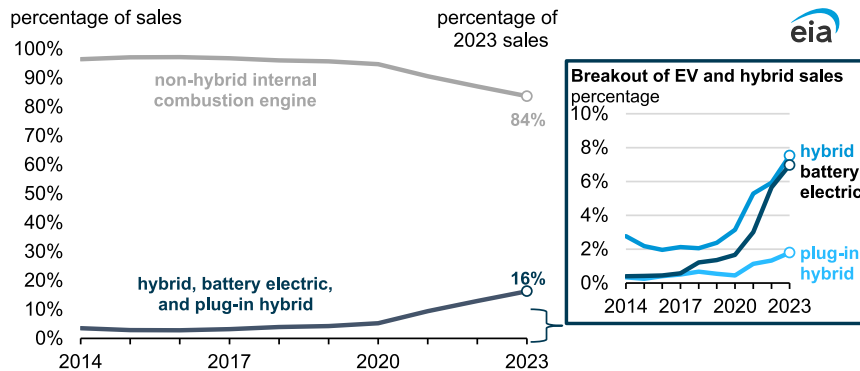
Source: Kelley Blue Book

EV market trends: BEVs stabilize, PHEV & HEVs increase share



US yearly car and light truck (LT) PEV shares

[Argonne](#)



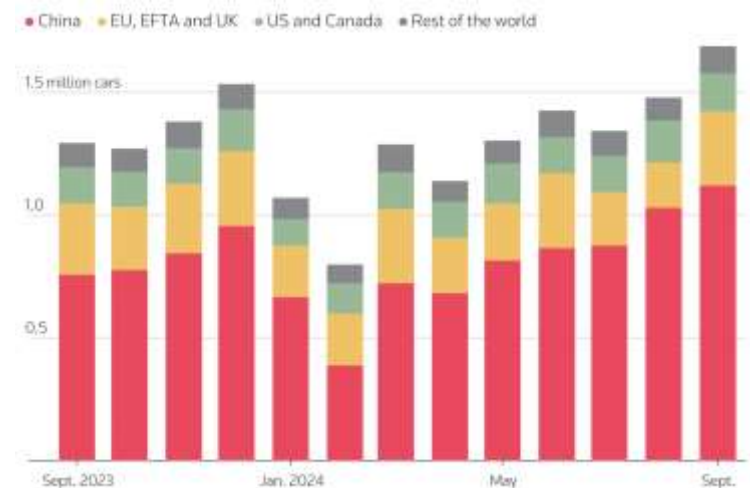
US annual light-duty vehicle sales by powertrain

[US EIA](#)



New BEV market share in Europe-28

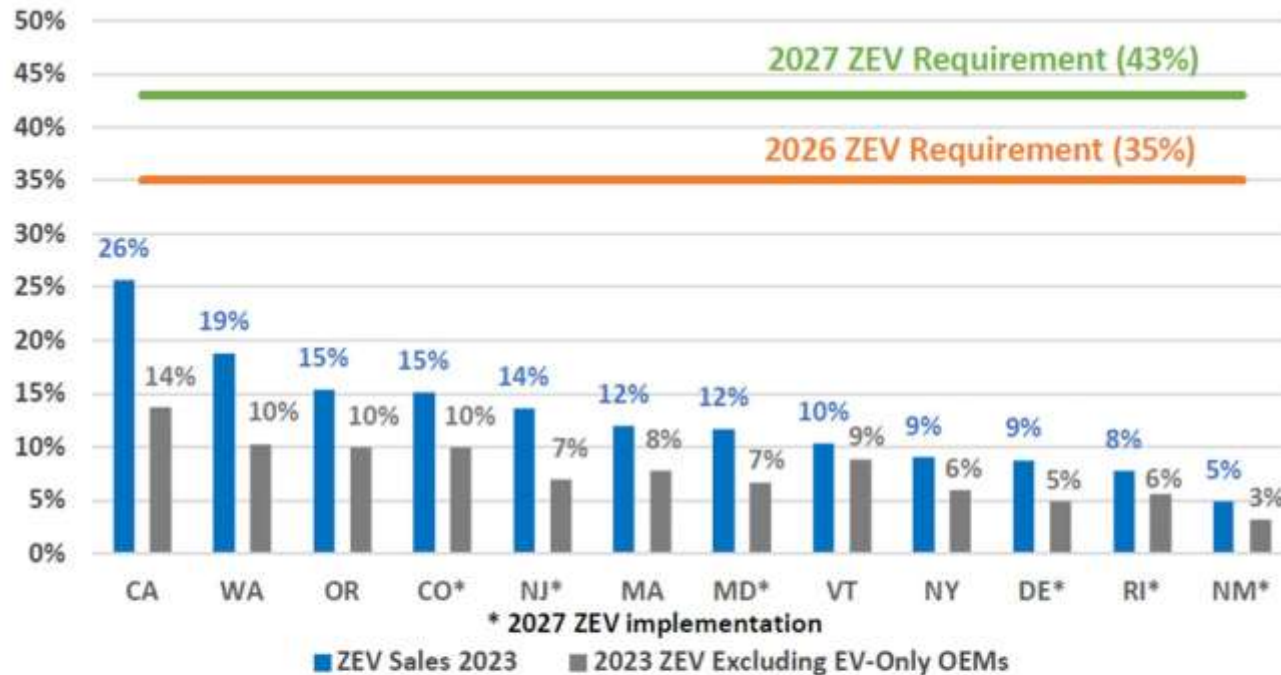
[Jato Dynamics](#)



China dominates global PEV sales

[Rho Motion via Reuters](#)

EV sales by state (Section 177) vs 2026-27 ZEV sales mandates



2023 Calendar Year ZEV Sales Rates in California and Section 177 States Compared to ACC II Requirement in MY2026 and MY2027. Note: ZEV sales requirements increase to 50% in 2029, 76% in 2031 and 100% in 2035 leaving little time to make up sales deficits.

Source: Automotive Alliance

Decarbonization of heavy-duty engines & vehicles

- No clear decarbonization pathway for heavy-duty engines
 - Electrification mostly limited to some medium-duty vehicles
 - A mix of biofuels, H2 fuel cell engines and H2-ICE under discussion
 - US EPA Phase 3 GHG emission standards will require that about 1 in 10 new trucks be electric by 2027, and about 4 in 10 by 2032
 - *Customer acceptance* is heavily weighted toward diesel, as diesel vehicles have a superior payload, range, and cost

“Long haul trucking, off-highway, rail, marine (...) are all in a similar state of **fuel confusion, indecision and paralysis**”

Chris Atkinson, Ohio State / US DOT, @ COMVEC 24

- Biofuel availability is limited by the limited biomass resources
 - Most biofuel resources will be consumed by the aviation sector
- Other low-carbon, synthetic fuels—hydrogen, ammonia—face too many challenges to succeed

Battery-electric mining trucks

- Several ongoing demonstration projects in mining, including large trucks in open pit mines
- EPCA (AU) “Green Machine”—an electrified CAT 777 truck
 - A total of 1,740 kWh battery capacity
 - Increased power from 1,000 hp to 1,120 hp and improved torque from 4,700 Nm to 5,200 Nm



- Challenges include charging time, operating time for operation, capacity to haul heavy loads uphill, battery heat management, cost
- Energy density—Cat 777 with a 300 gal (1136 L) diesel tank carries 11,436 kWh of energy

BEV 1,740 kWh ↔ Diesel 11,436 kWh

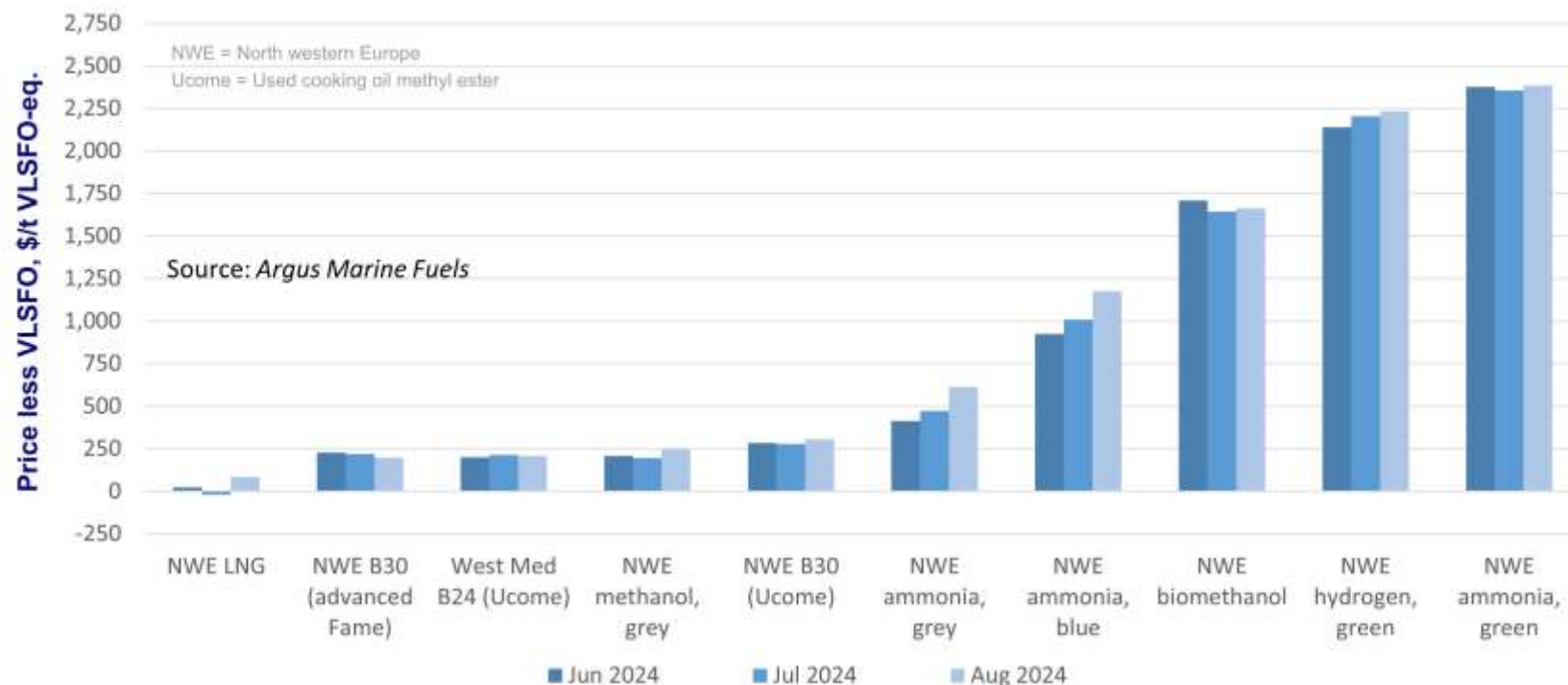
Hydrogen-powered mining equipment

- Liebherr L566 H wheel loader
- Liebherr H₂ combustion engine
- Field tests began at a STRABAG quarry in Austria



- “Green” or “blue” hydrogen required to reduce GHG emissions
- Nearly all hydrogen produced today is fossil fuel hydrogen, primarily from steam methane reforming (i.e., from natural gas)
- High pump price of hydrogen is already a barrier for wider adoption of H₂ powertrains. E-fuels are likely to be even more costly.

Low carbon fuels: Prices



Low carbon marine fuels: Price premium over VLSFO

Avg. VLSFO price = \$624 per tonne (Oct 2024)

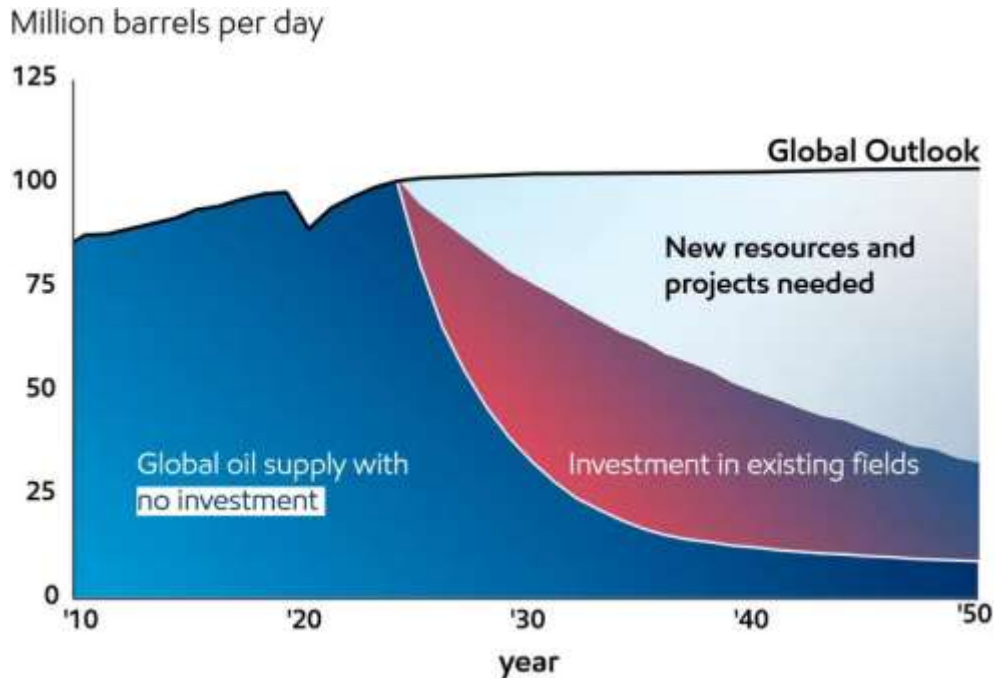
Resources: Global oil output remains below 2018 levels



[US EIA](#)

Oil & natural gas decline—New projects require more investment

ExxonMobil: If every new car sold in the world in 2035 were electric, oil demand in 2050 would still be 85 million b/d, the same as it was in 2010.



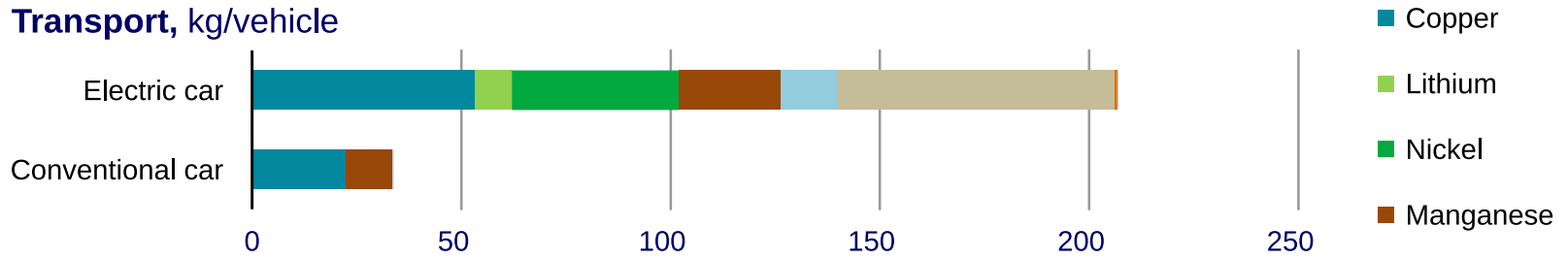
Global oil supply, 2010-2050

[ExxonMobil Global Outlook](#)

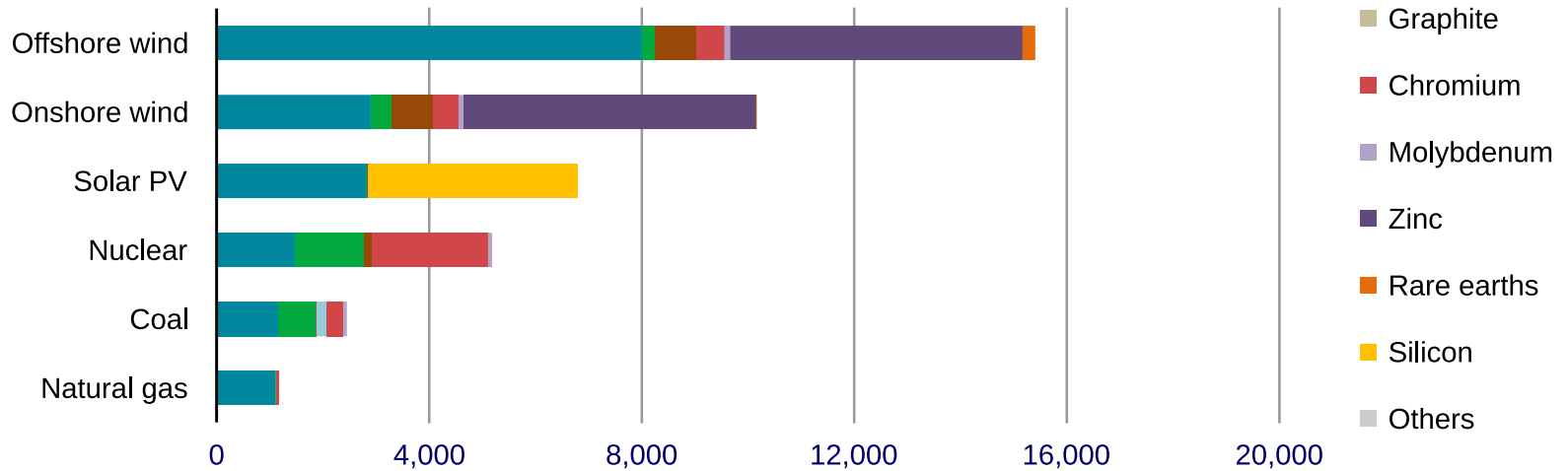
- *Global oil demand* will reach a plateau beyond 2030, remaining above 100 million b/d through 2050—making up >50% of the world's energy mix.
- Oil production declines naturally at a rate of ~15% per year—nearly double the IEA's prior estimates of about 8%.
- This increase is the result of the world's shifting energy mix toward “unconventional” sources of oil and natural gas.
- Unconventional oil resources require higher CapEx, OpEx—they provide less benefit to the economy than conventional oil.

Clean energy & mineral resources

Transport, kg/vehicle



Power generation, kg/MW

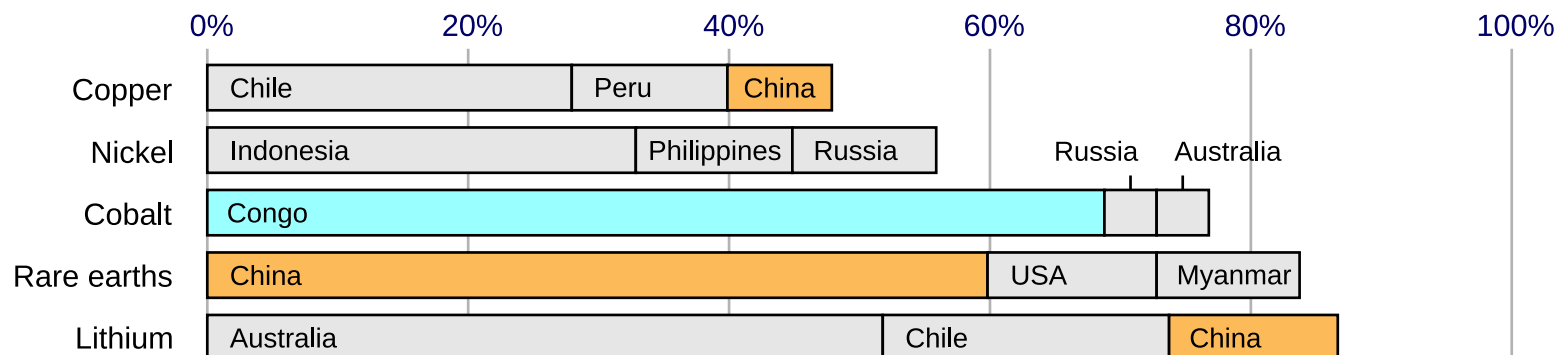


Minerals used in selected clean energy technologies
Steel and aluminum not included

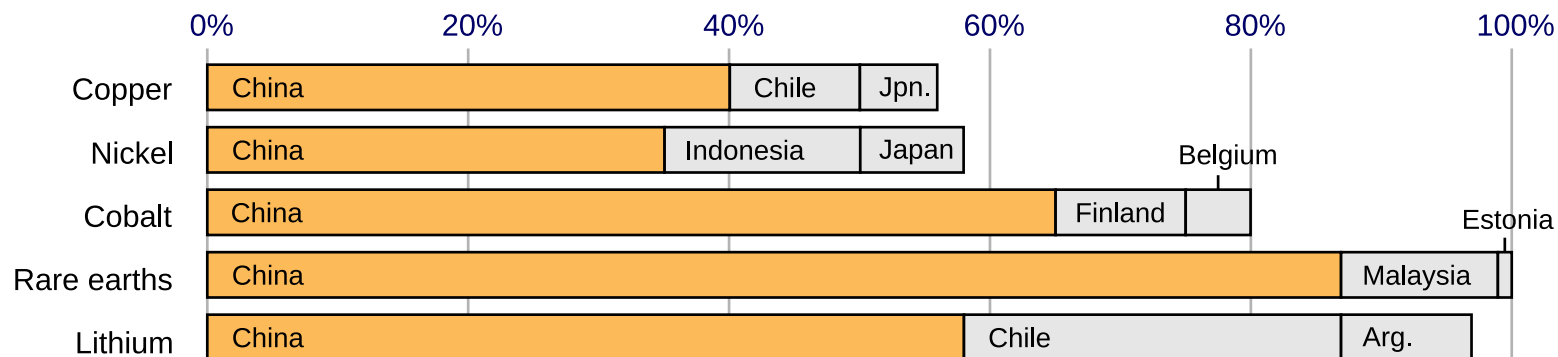
[IEA: The Role of Critical Minerals in Clean Energy Transitions](#)

Mining and refining of key clean energy minerals

Metal resource mining



Metal refining and processing



Mining and refining of key clean energy minerals—top three producers in 2020

Data: IEA after the [New York Times](#)

Concluding remarks

- World's energy consumption and its ecological footprint continues to increase. Renewable energy is added on top of growing fossil fuel energy. CO₂ emissions, ambient CO₂ concentrations, and the rate of warming have all been increasing.
- The approach to decarbonization of transportation varies greatly between geographical regions and sectors of the industry.
- Electrification of light-duty vehicles—after a few years of rapid expansion—seems to stabilize at about 10-15% of new vehicle sales (US & EU), with increasing market share of hybrid vehicles. Remaining issues include EV affordability, charging infrastructure, grid capacity, mineral resources, and availability of renewable electricity.
- There is no clear pathway to decarbonization of “hard-to-electrify” sectors, including long-haul trucking, nonroad, mining, rail, marine and aviation sectors
 - These heavy-duty sectors will compete for limited supply of biofuels and other low carbon fuel sources.
 - Hydrogen and e-fuels face several challenges and are unlikely to see wide-scale commercialization.
- EVs and renewable electricity are metal and mineral resource-intensive. Access to resources (minerals & energy) will reflect on the future geopolitical and economic status quo.

Thank you!

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1901: Spindletop Gusher—0 psi technology



\$5.7 billion

2024: Chevron Anchor—20,000 psi technology