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An industrial blueprint for batteries in Europe

How Europe can successfully build a sustainable battery value chain

Transport & Environment

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Acronyms

CAM - cathode active materials
Capex - capital expenditure
CO_2e - carbon dioxide equivalent
Co - cobalt
CRMA - Critical Raw Materials Act
DLE - direct lithium extraction
ESS - energy storage systems
EV - electric vehicle
GHG - Greenhouse gas emissions
GWh - gigawatt-hour
HPAL - high pressure acid leach
IRMA - The Initiative for Responsible Mining Assurance
kt - kilotonnes
kWh - kilowatt-hour
LCA - Life Cycle Assessment
LCE - lithium carbonate equivalent
LFP - lithium iron phosphate
Li - lithium
LiOH - lithium hydroxide
Li-ion batteries - lithium-ion batteries
LMFP - lithium manganese iron phosphate
LMR-NMC - lithium-manganese rich nickel manganese cobalt oxide
LNMO - lithium nickel manganese oxide
MHP - mixed hydroxide precipitate
Mn - manganese
Mt - million tonnes
Na-ion batteries - sodium-ion batteries
NCA - lithium nickel cobalt aluminium oxide
Ni - nickel
NMC - lithium nickel manganese cobalt oxide
NZIA - Net-Zero Industrial Act
Opex - operating expenses
pCAM - precursor cathode active materials
t - tonne
US IRA - The USA Inflation Reduction Act

Executive summary

As Europe is decarbonising its economy, it is facing a monumental challenge to rebuild the fossil-based system into a carbon free one. Batteries and the materials that go into making them are central to our effort to clean up cars, trucks and buses as well as to expand renewable energy networks. A year ago, as T&E estimated that two-thirds of Europe's announced battery plans are at risk, the EU announced a raft of measures in response to the US Inflation Reduction Act. So one year on, what does the progress in building battery supply chains look like? This report analyses the progress, as well as challenges associated with onshoring this supply chain, providing an industrial footprint for governments to build a local, resilient and sustainable battery supply chain.

Key findings include:

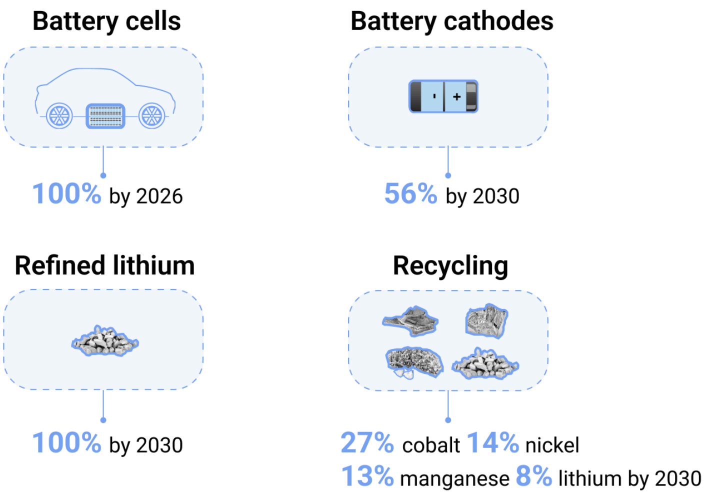
- Europe can become self-sufficient in battery cells by 2026, and manufacture most of its demand for key components (cathodes) and materials such as lithium by 2030. But over half of gigafactory plans in Europe remain at risk of either being delayed or cancelled, down from close to two-thirds a year ago.
- Onshoring the battery supply chain offers significant climate benefits: 37% reduction in carbon emission when using the EU grid, or 133 Mt of CO2 by 2030 compared to China. When relying on predominantly renewable energy sources, the reductions double to 62%.
- However, many of the announced projects remain uncertain and, given the nascent nature of this industry in Europe, would not happen without stronger government action.
- The industrial policy blueprint should include maintaining the investment certainty (via the 2035 clean car goal), providing EU-level investment support and stronger made in EU provisions for best-in-class projects.

Significant local potential exists

Europe is not starting from scratch. Years of ambitious policy to secure a local electric vehicle market, as well as the efforts of the European Battery Alliance, have resulted in dozens of battery investments and announcements throughout the supply chain. Based on the latest announcements, Europe can:

- Become self-sufficient in local battery cell supply from as early as 2026
- Supply over half (56%) of battery's most valuable components - cathodes - by 2030, into which critical minerals such as nickel and lithium are processed
- Supply all of its processed lithium needs by 2030, and
- Secure between 8% and 27% of battery minerals supply from locally recycled sources by 2030.

The potential for Made in Europe EV battery value chain



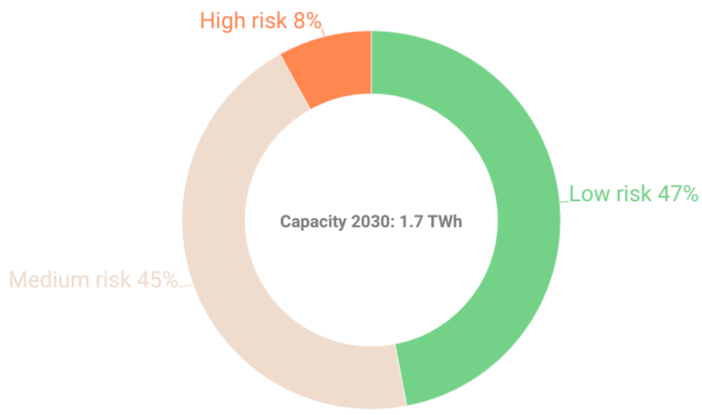
Source: Transport & Environment, 2024. The analysis includes EU, UK, Switzerland and Norway.

But these plans are all at different stages of maturity and require long-term political vision and targeted industrial strategy to materialise. On top, Europe is not operating in a vacuum: a fierce "battery arms race" is happening across the world, from China's overcapacity resulting in imports of cheap EVs and batteries into Europe to growing resource nationalism across the Global South. The risks to Europe's onshoring ambition are many-fold.

A year since T&E started assessing the viability of battery plans, over half of gigafactory plans in Europe remain at risk of either being delayed or cancelled, down from close to two-thirds a year ago. This is an improvement of 15%. ACC in France kicked off production in the last year, while Northvolt's second gigafactory in Germany was saved thanks to the German state's generous subsidy to counter the US IRA. Thanks to a similar support package in France, Verkor is about to start commercial production in France. On the other hand, some companies - notably Freyr and VW's PowerCo - have downgraded their plans. Overall, the capacities at low risk amount to around 815 GWh, sufficient to power 13.6 million electric cars.[1]

[1] Assuming a battery capacity of 60 kWh.

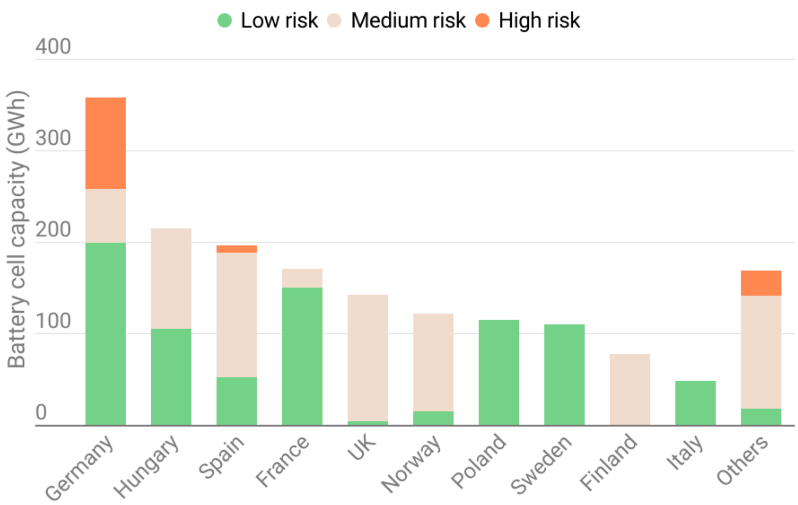
More than half the announced battery cell capacities in Europe are at risk of being delayed, scaled down or cancelled



Source: T&E analysis of publicly announced battery production projects planned up to 2030

Across Europe, Finland, the UK, Norway and Spain, with projects by the Finnish Minerals Group, West Midlands Gigafactory, Freyr and Inobat, have the highest shares of capacity at high or medium risk. On the other hand, France, Germany and Hungary have made the most progress in securing capacity compared to last year.

Risk assessment of battery cell capacities across Europe

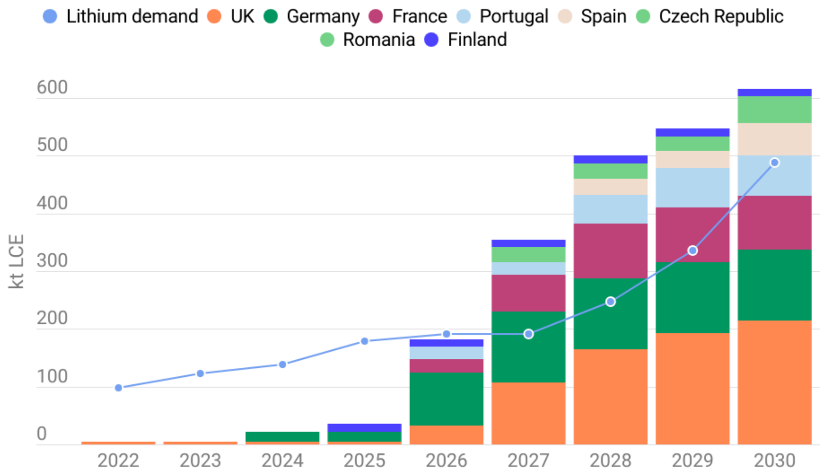


Source: T&E analysis of publicly announced battery production projects planned up to 2030

Going further mid- and up-stream reveals more risks. While plans to build cathode active material facilities across Europe exist, these have experienced less development than cells, with the region facing critical gaps in terms of project development. These represent over half of the battery's value with their production almost exclusively concentrated in China today. This highlights the urgency of establishing domestic capabilities to allow Europe to capture the full value chain. But only Umicore in Poland and BASF in Germany have started commercial operations so far, with Northvolt piloting a small batch manufacturing in Sweden. However, in the last 12 months a number of companies, predominantly Chinese, have announced plans to set up cathode facilities on the continent.

Looking at battery metals, lithium refining projects hold high potential for Europe's self-sufficiency. From a very limited lithium chemicals production today, the announced capacities could cover the region's needs by 2030. The largest capacities are located in the UK (e.g. Tees Valley Lithium and Green Lithium), Germany (e.g. Vulcan Energy Resources and Livista Energy) and France (e.g. Lithium de France and Imerys). But many of these projects are still in early stages of development. In the nickel space, the existing nickel sulphate plans can potentially cover a fifth of future demand from electric vehicle and energy storage batteries.[2]

Announced lithium refining capacities could potentially meet the future European battery demand from EVs & ESS



Note: LCE denotes lithium carbonate equivalent. The currently operating plant mainly caters to non-battery applications.

Sources: T&E analysis, company reports, publicly available information on lithium projects

The benefits of onshoring are significant

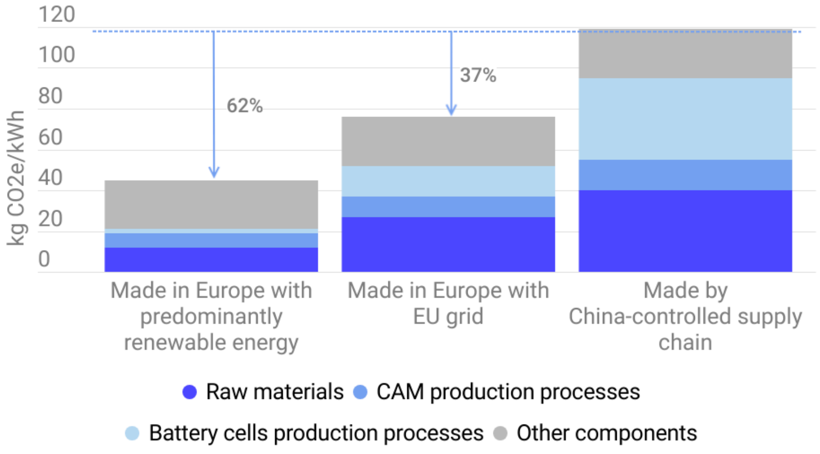
Onshoring the battery supply chain offers more control over how things are done. Local manufacturing means Europe can set and enforce environmental and social standards, as well as stipulate the effective and meaningful engagement of local communities. Localising the battery value chain can also lead to shorter supply chains and reduced transportation-related emissions, on top of Europe's relatively high share of renewables to benefit cleaner processes.

From a pure climate perspective, manufacturing some of the more energy intensive and valuable components in Europe will also reduce carbon emissions. Producing battery cells locally compared to China on average saves 20-40% of carbon emissions, while onshoring cathode production would save up to a fifth additionally. Local sources of nickel would be 85-95% lower in emissions than the current supply from Indonesia, while lithium will come with an up to 50% improvement to Australian ore processed in China. Overall, the carbon benefits of onshoring into Europe are in the order of 37% carbon emission reduction based on the EU grid,

[2] Capacities compared to demand in the Regulatory scenario, which follows the EU regulations on CO2 emissions standards for light and heavy duty vehicles.

rising to over 60% when predominantly renewable energy sources are used. Compared to a fully imported supply chain, producing Europe's demand for battery cells and components locally would save an estimated 133 Mt of CO2 by 2030, comparable to the emissions produced by entire Chile or the Czech Republic in 2022 [1].

The climate benefits of onshoring the battery supply chain to Europe



Note: Emissions from precursor production are included in cathode active materials (CAM) production emissions. For other components, which are beyond the current study's scope, average industry emissions were considered.

Sources: T&E analysis, Eunji Yoo et al. (Argonne National Laboratory), Minviro

But it won't be easy

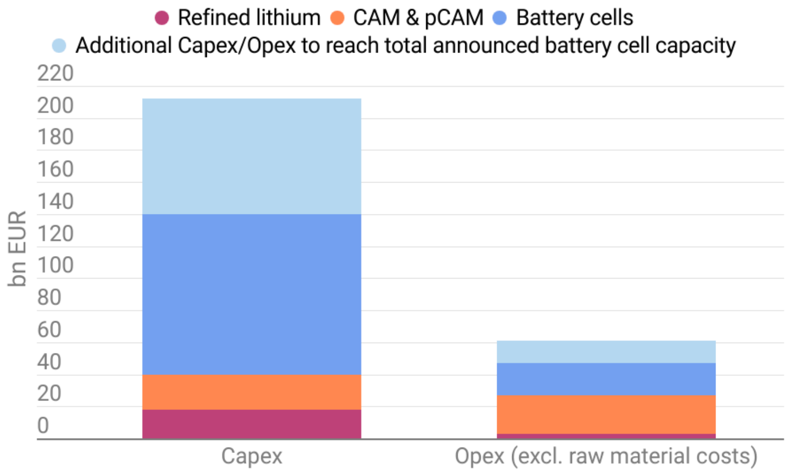
But reaping these climate and industrial benefits will not be easy. Significant challenges in scaling the European battery value chain exist. First, securing the battery raw materials themselves. T&E estimates that the available domestic supply from primary mined and secondary sources can on average cover 35%-70% of end use battery demand (or 45%-100% of cathode processing demand) by 2030, but many mining projects remain uncertain and face local opposition. Ultimately, a global raw materials strategy and sharp diplomacy will be needed to secure the materials for Europe's ambition with both Europe's interests and local development goals in mind.

One of the key questions asked is if Europe can develop the expertise and skills necessary to build up this capacity. While some progress has been made on cell making (with over half of Europe's needs already produced locally by European and Asian companies), the midstream value chain is less certain. However, T&E analysis shows that a lot of innovation and skills are available locally. E.g. much progress is happening in the area of lithium processing, with Europe being one of the leading continents in developing the clean direct lithium extraction technologies (15% of all lithium projects plan to use that), and the first continent that aims to commercialise the cleaner bioheap leaching route for nickel refining (in Finland).

While China undoubtedly has a lead in cathode making, European companies do have the necessary expertise in chemicals and hydrometallurgy necessary to scale this sector. The current efforts are targeting efficiency and process step reduction, as well as using cleaner processes, to cement a European edge. On skills, T&E finds that while there is a shortage of direct metallurgical workers, the adjacent skills can be drawn from the petrochemicals, pharmaceuticals and material science sector among others. Some of these adjacent industries - notably oil and automotive catalysts - are expected to decline in the coming years, so offer a great reskilling opportunity.

At the same time, both capital expenditure (CAPEX) and running, or operational (OPEX) costs, of building and running battery cell, component and material facilities are some of the highest in Europe. This is due to less expertise building these facilities, as well as due to higher energy and labour costs (at least compared to China). T&E estimates that developing all the announced plans for battery cell manufacturing, cathode and precursor facilities and lithium refining in Europe (including non-EU countries) will require EUR 215 billion in CAPEX and EUR 61 billion in annual OPEX, coming primarily from private investment. If Europe aimed, for example, to match the operational support provided under the US IRA, it would need to provide around EUR 2.6 bn in OPEX support on an annual basis alone.

Building a European battery value chain will require significant investments



Note: Capex and Opex of companies across Europe. Opex excludes raw materials costs.

Sources: T&E analysis, BloombergNEF, McKinsey

Key recommendations

In a nutshell, while the significant potential to build a local and clean battery supply chain exists, the risks are manifold. Without political leadership and strong policies Europe will struggle to create the business case amidst the fierce global competition. T&E presents its own industrial blueprint for the governments across Europe, including:

1	Clear policy and long-term vision are paramount to secure investment into battery supply chains. This includes the 2025-2035 car CO2 ambition that must remain unchanged, as well as additional ambition to electrify fleets and create a European compact BEV industry.

2	Robust policies to secure local manufacturing, away from overreliance on imports. This includes strong sustainability requirements to reward local clean manufacturing (such as the upcoming battery carbon footprint rules), faster implementation of projects under CRMA and NZIA and a revamped trade policy. Crucially, comprehensive investment support will be critical to build the supply chain across Europe, including better instruments under the European Investment Bank and a quickly operationalised EU Battery Fund.
3	All of this must be done sustainably, breaking with the past practices in metal supply chains across the world. This means building the global raw material partnerships on high standards and supporting local value add in resource-rich countries. Europe should also commit to bring its own mining practices in line with global best practice, notably on tailings management.

Batteries, and metals that go into them, are the new oil. European leaders will need laser sharp focus, strong and joint up thinking and, above all, stepping out of the comfort zone to succeed. The costs of failing are high and can result in Europe losing out on entire industrial sectors. Some progress has been made in the last year, but the next European Commission and Parliament have a monumental task of finishing the job.

1. Introduction

The European Green Deal, among the most ambitious climate policies worldwide, aims to transition the European Union to a net-zero economy by 2050. Achieving this goal will require a significant scale-up of clean technologies, ranging from wind turbines and solar panels to electric vehicle batteries.

Today, Europe finds itself in a global race to lead the production of cleantech and the minerals that go into them, with China having a longstanding advantage fuelled by decades long subsidies and the US offering generous tax credits to investors. One year later, the USA Inflation Reduction Act (US IRA) has reshaped the battery landscape in the US, drawing substantial investments in battery factories and raw material processing plants.

In keeping up with competition, Europe must continue developing a robust industrial strategy to build a local battery value chain, ensuring security of supply, job creation and economic resilience.

Following its first analysis of Europe's battery value chain development vis-a-vis the US Inflation Reduction Act in 2023 [2], the report provides an update on the progress made, including an in-depth industry analysis, along with a toolbox of industrial policies for Europe to secure a resilient and sustainable battery supply chain domestically.

2. Europe's battery value chain one year after the US IRA

2.1 Battery gigafactories

Lithium-ion batteries are at the epicentre of the global efforts to decarbonise the economy: they are indispensable to decarbonise road transport [3], the single largest source of carbon emissions for many countries, as well as to shift to a renewable energy system backed by robust storage. Battery is the most valuable component of electric vehicles, the sales of which are expected to reach 10 million[3] in Europe by 2030. So the race to dominate this technology and its supply chain is unfolding in Europe.

While China dominates the global battery cell manufacturing with 80% market share in 2023 [4], Europe has been catching up thanks to its large domestic market for electric vehicles spurred by the EU vehicle CO2 standards, as well as targeted initiatives such as the European Battery Alliance. The demand for lithium-ion batteries is expected to reach around 1,000 GWh (or 1 TWh) by 2030 in Europe driven by transport electrification and energy storage systems.[4] All of this has spurred a flurry of announcements for setting up large lithium-ion battery cell production plants, or gigafactories. On the latest count, around 54 gigafactories have been

[3] Sales of electric vehicles in the Regulatory scenario. More details in the Methodology section of the report.
[4] In the Regulatory scenario developed by T&E which follows the EU regulations on CO2 emissions standards for light and heavy duty vehicles.

announced across Europe by 2030, resulting in an estimated 1,725 GWh (or 1.7 TWh) of theoretical capacity.

A number of new projects have been announced in 2023, including by Prologium in France (planning to produce solid state batteries)[5], TATA Group in the UK [6], Finnish Minerals Group as well as Svolt in Finland [7] [8], Inobat in Spain [9], Inobat together with Gotion in Slovakia [10] and Romvolt in Romania [11] with future combined capacities of over 230 GWh.

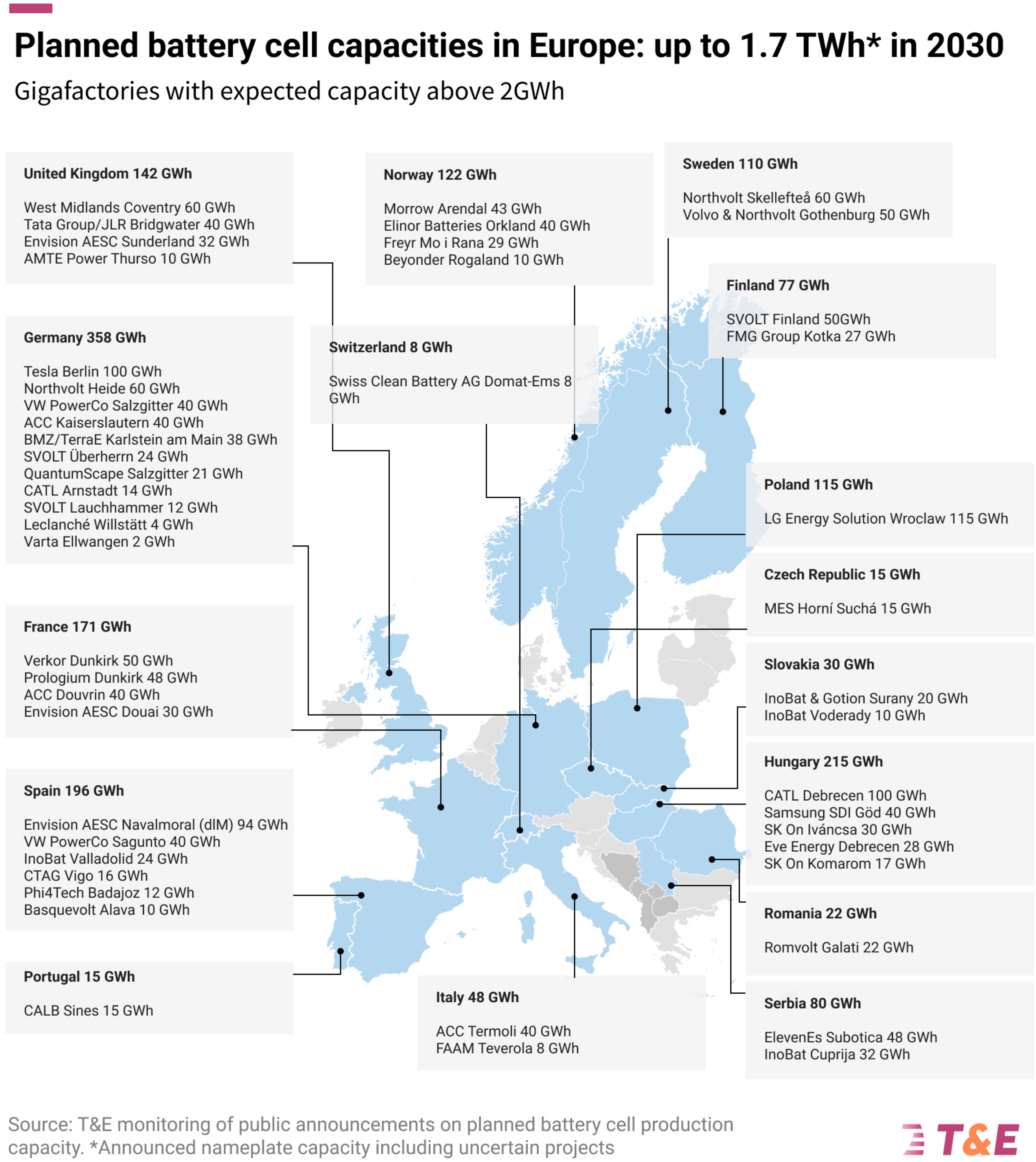


Figure 1: Announced battery cell capacities in Europe by 2030

In terms of the country of origin, the majority of the announcements, or 55%, is led by European companies, followed by Chinese companies at 23%, with the remainder coming from a mix of South Korean, Taiwanese and American players.

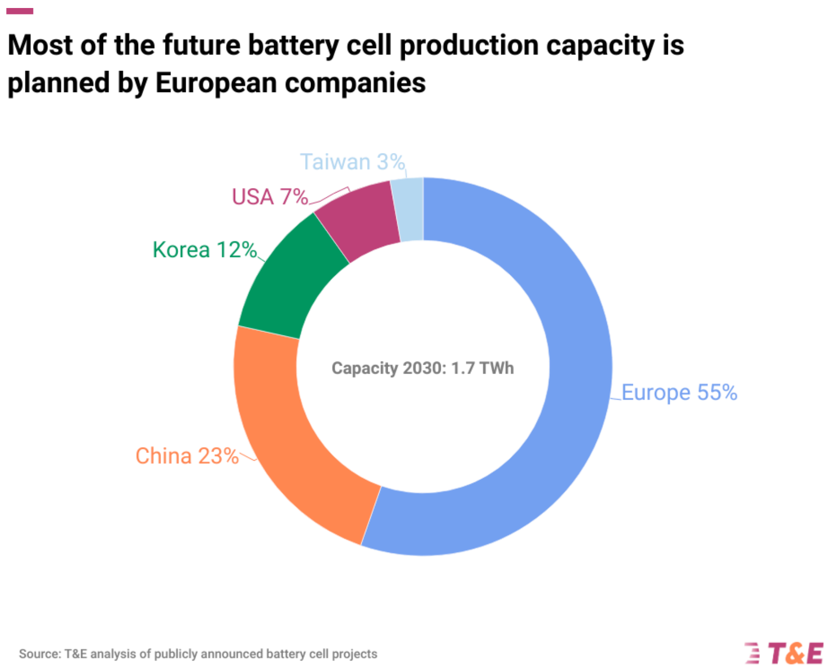


Figure 2: Announced gigafactory capacities in Europe by country of origin

T&E estimates that in 2023 the local battery cell capacity in Europe grew to around 225 GWh and the production output to nearly 100 GWh (on net basis, excluding scrap), led by LG Energy Solution in Poland with an estimated output between 34 and 55 GWh[5], Samsung SDI (about 21-24 GWh) and SK On in Hungary (about 10-12 GWh), Northvolt in Sweden (up to about 6 GWh), BMZ (up to about 10 GWh) and CATL (5-8 GWh) in Germany.[6] This compares to around 210 GWh of end use battery demand from electric vehicles and energy storage systems, with the European-based production covering almost half of the demand.

Moving forward, the domestic supply[7] has the potential of around 72% of Europe's demand for lithium-ion batteries in 2025 and 100% from 2026 on (if all projects materialise on volume and schedule as planned).

[5] Actual production volumes are uncertain as production data is not publicly available. We provide a range between T&E's own estimates (see annex for methodology) and some estimates derived from GlobalData's Hybrid & EV Sales Forecast (Q3 2023).
[6] The production output was calculated factoring in varying capacity utilisation and scrap rates, depending on the maturity of each plant. More details in the Methodology section of the report.
[7] Supply from all announced projects, on a net basis, excluding scrap.

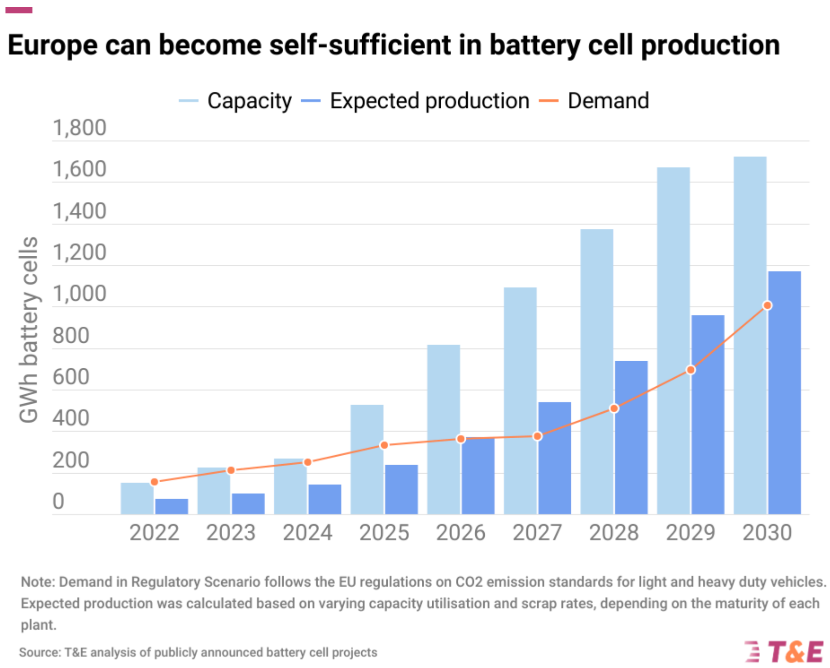


Figure 3: Announced battery cell capacities, expected production and demand in Europe by 2030

2.1.1 Battery plans maturity one year on

However, these blanket numbers hide a lot of variability as to the maturity of the different projects. For example, some like Northvolt's first gigafactory in Sweden, Northvolt Ett, are already producing battery cells for European carmakers, while others such as Finnish Minerals Group in Finland have just been announced. Crucially, a lot of risks stay in the way of Europe building out its battery capacity. On the one hand, sourcing the raw materials alone will be an important hurdle as these factories will need around 490 kt LCE (lithium carbonate equivalent) per year by 2030 to meet Europe's demand. Beyond raw materials, capacity and expertise to process them into high quality battery grade compounds is even more critical (and where most value is), as covered in sections 2.2-2.4 of this report.

But the other major industrial risk in the way of Europe's ambitions is the global battery arms race, as coined by Benchmark Minerals Intelligence [12]. Europe is not alone in wanting to onshore the valuable battery cell production; we are competing with China that has a two-decade lead, and, more recently, with the US following the launch of the US Inflation Reduction Act in mid-2022.

Given this, back in March 2023 T&E estimated that 68% of potential battery production capacity, or 1.2 TWh, in Europe is at risk of being delayed, scaled down or not realised if further action is not taken [13]. That risk was well understood by the European governments, with funding (mostly relaxation of state aid to enable national subsidies) and new policy frameworks (the Net Zero Industry Act and the Critical Raw Materials Act) put in place.

The tone and sense of urgency to secure local battery manufacturing has certainly changed over the course of 2023, but has these made the battery plans more viable?

Since early 2023, when media headlines were full of stories of European companies swapping EU plans for the US in pursuit of generous US IRA subsidies, several battery companies kicked off the production of battery cells in Europe. These include ACC in France [14] and Inobat in Slovakia [15].

Moreover, some of the projects on T&E's risky list have been supported and are now moving forward, including Northvolt, which began construction of their second battery cell production plant in Europe (Northvolt Drei) [16] after receiving state aid funding approval from the European Commission, and Verkor, which also started construction of the plant in France [17], aided by an ambitious package of industrial policy measures announced by the government and plans on kicking off production in early 2025.

On the other hand, there have been some less positive developments as the sector continues to consolidate. Notably, the Italvolt project in Italy was cancelled in favour of a new gigafactory in the UAE [18]; the fourth battery plant of PowerCo, Volkswagen's battery subsidiary, initially slated for Eastern Europe, has been indefinitely put on hold [19]. Additionally, the Norwegian company Freyr decided to redomicile to the US and reduce its footprint in Europe, minimising spending in its Giga Arctic project in Norway (implying a halt of GigaVaasa expansion in Finland) and instead focusing on scaling up Giga America in the US [20] [21];

Lastly, the capacities of several projects have been revised downwards, including among others: CATL in Germany (from 80 GWh to 14 GWh), CALB in Portugal (from 45 GWh to 15 GWh), Inobat and Gotion joint venture in Slovakia (from 40 GWh to 20 GWh by 2030), Farasis in Germany (16 GWh, cancelled). Lastly, certain projects were removed from the list in light of information revealing their focus on cell assembly rather than cell production such as Gotion and Microvast in Germany.

Change	Company	Country	Affected capacity (GWh)
Started production	ACC	France	13
	InoBat	Slovakia	10
	ElevenES	Serbia	0,5
	Total starting production		***23***
Risk category improvement (from medium to low risk or from high risk to medium risk)	Northvolt	Germany	60
	CATL	Hungary	30
	EVE Energy	Hungary	28
	Envision AESC	Spain	10
	Phi4Tech	Spain	10
	InoBat	Serbia	4
	Total improvement		***142***
Risk category downgrade (from medium to high risk)	Tesla	Germany	25
	Total downgrade		***25***

Change	Company	Country	Affected capacity (GWh)
New announcements	Svolt	Finland	50
	Prologium	France	48
	Tata Group/JLR	UK	40
	Finnish Minerals Group	Finland	27
	InoBat	Spain	24
	Romvolt	Romania	22
	InoBat & Gotion	Slovakia	20
	Total new		***231***
Cancelled	Italvolt	Italy	45
	Freyr (Vaasa)	Finland	40
	Freyr Nordic Battery Belt	Nordics	40
	Volkswagen PowerCo	Eastern Europe	40
	Farasis	Germany	16
	Freyr (Mo I Rana)	Norway	14
	Blackstone Resources	Germany	10
	Eurocell	Netherlands	3
	Total cancelled		***208***

Table 1: Recent developments of battery projects in Europe

Following these policy and market developments, T&E has updated its risk assessment of battery plans in Europe. Around 53% of the announced capacities by 2030 are now considered at risk of being delayed, scaled down or cancelled, compared to 68% last year. This is an improvement of 15% compared to a year ago.

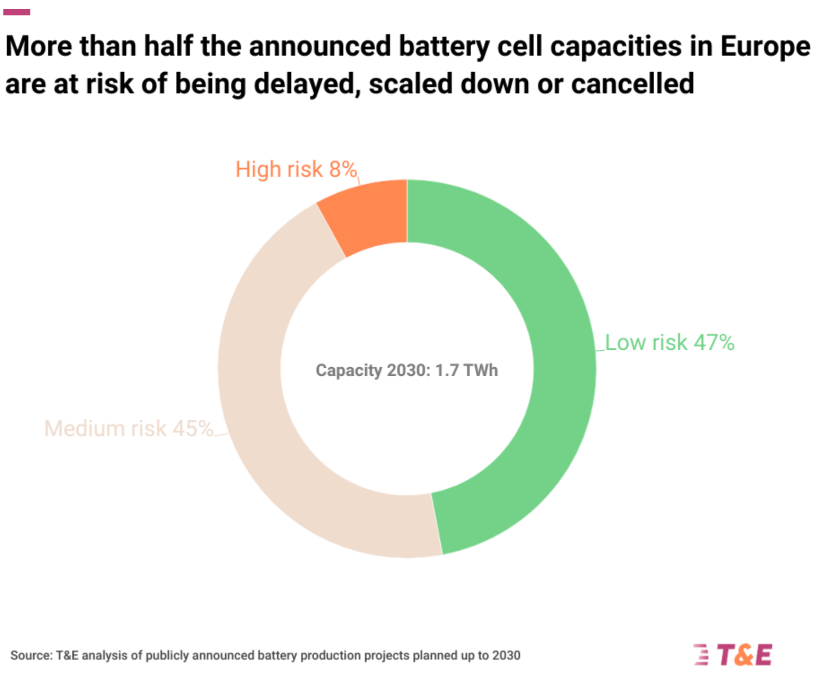


Figure 4: Risk assessment of European gigafactory capacities in 2030

The projects at high risk account for 8% of capacities (versus 16% in the 2023 assessment) and include Tesla's plans in Germany. Meanwhile, those at medium risk make up for 45% (versus 52% a year ago) and include West Midlands Gigafactory in the UK and Romvolt in Romania, as well as the expansion plans of a number of gigafactories slated for the end of the decade and thus holding some degree of uncertainty.

Overall, Finland, the UK, Norway and Spain, hosting projects like those led by the Finnish Minerals Group, West Midlands Gigafactory, Freyr and Inobat, among others, have the highest shares of capacity at high or medium risk. On the other hand, France, Germany and Hungary have made the most progress in securing capacity compared to last year.

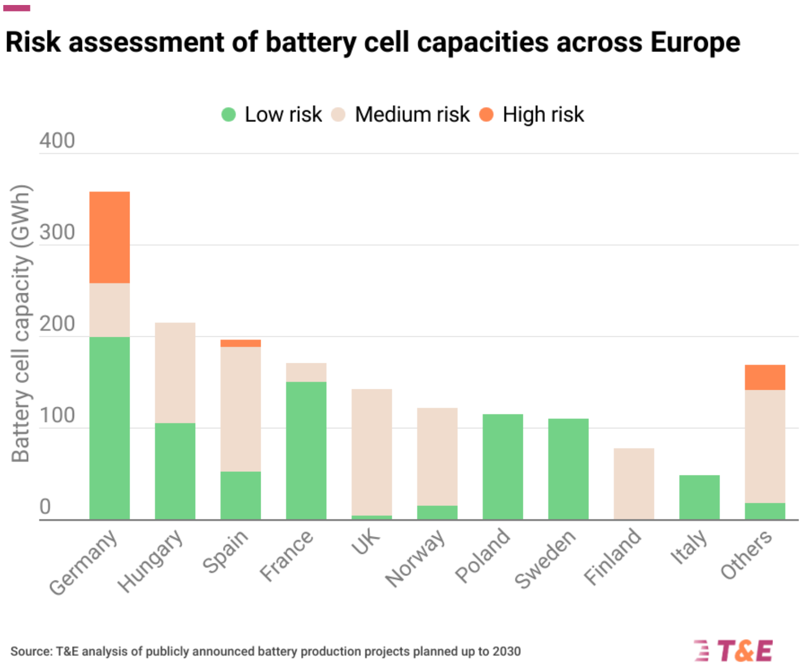


Figure 5: Risk assessment of battery cell capacities in Europe by country

2.2 Cathode active materials & precursors

While the gigafactory landscape in Europe has undergone significant evolution in recent years, the midstream stage of the battery value chain - connecting battery producers with mineral processors and where cathodes, anodes and their precursors are manufactured - has experienced less development, with the region facing critical gaps in terms of project development.

Cathode active materials (CAM) in particular are key components that determine the capacity and voltage of lithium-ion batteries and contain valuable raw materials such as lithium, nickel and cobalt. These account for up to 55% of the battery cell cost, depending on the chemistry, raw material prices and plant location [22].[8] This highlights the urgency of establishing domestic capacities to allow Europe to capture the value derived from battery manufacturing. In addition to value creation, cathode capacity building would also provide incentives for the

[8] Based on data retrieved from BloombergNEF's bottom-up battery cost model (BattMan).

development of upstream projects as well as offer climate benefits by reducing the carbon footprint of batteries as shown in section 3.

Currently, the main CAM producers operating in Europe are:

- Umicore in Poland, which started the commercial production in 2022 [23];
- BASF in Germany, which inaugurated its first CAM plant in June 2023 [24];
- Northvolt in Sweden, which is just ramping up production;
- IBU-tech in Germany, producing LFP cathodes at relatively small scale.

Since the analysis of the European CAM market by T&E in January 2023 [2], several CAM projects have been announced including by:

- Orano (French nuclear fuel cycle company) and XTC New Energy Materials Xiamen (Chinese cathode materials manufacturer) in France [25];
- Umicore and Volkswagen's battery subsidiary PowerCo joint venture, Ionway, which will build a plant in Poland next to Umicore's existing cathode plant [26];
- The Chinese cobalt and battery materials company Huayou Cobalt in Hungary [27].

At the same time, many projects face an uncertain future, including the one led by the Norwegian battery company Freyr in Finland, given its decision to limit investments in Europe [28] as well as expansion plans by various companies slated for later in the decade.

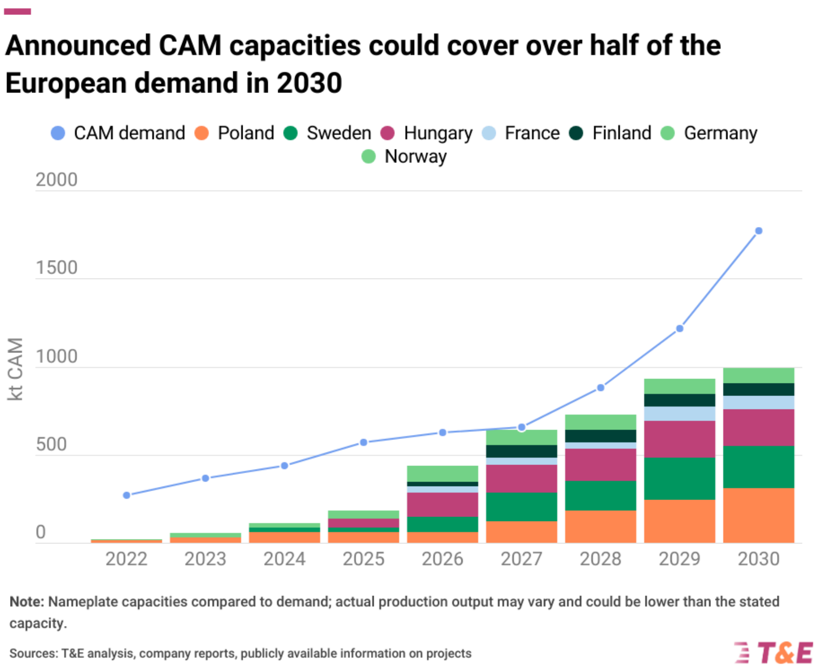


Figure 6: Announced CAM capacities and demand in Europe by 2030

Overall, the announced CAM capacities could theoretically amount to almost 1 million tonnes of CAM by 2030, covering 56% of Europe's demand from vehicles and energy storage systems,[9] which is above the Net-Zero Industrial Act (NZIA) local manufacturing benchmark. However,

[9] Since the closure of the report, a new project has been announced in Spain by Hunan Yuneng, which would increase the total capacity in Europe to around 1,045 kt CAM by 2030.

around half of these capacities are in very early stages of development and thus subject to uncertainty.

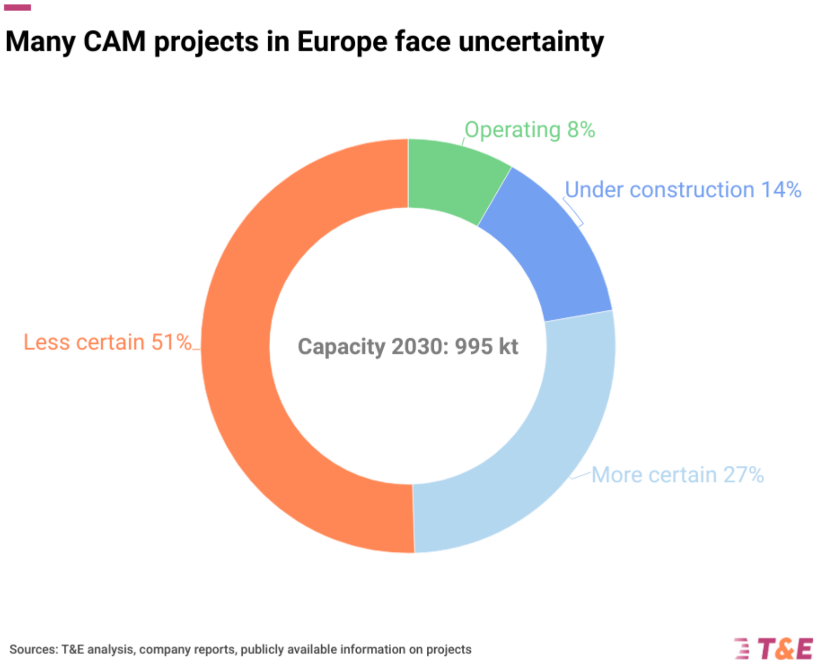


Figure 7: Announced CAM projects in Europe by project status

In terms of regional distribution, Poland, Sweden and Hungary are leading in planned capacity expansions, hosting projects by companies such as Umicore, Northvolt and EcoPro.

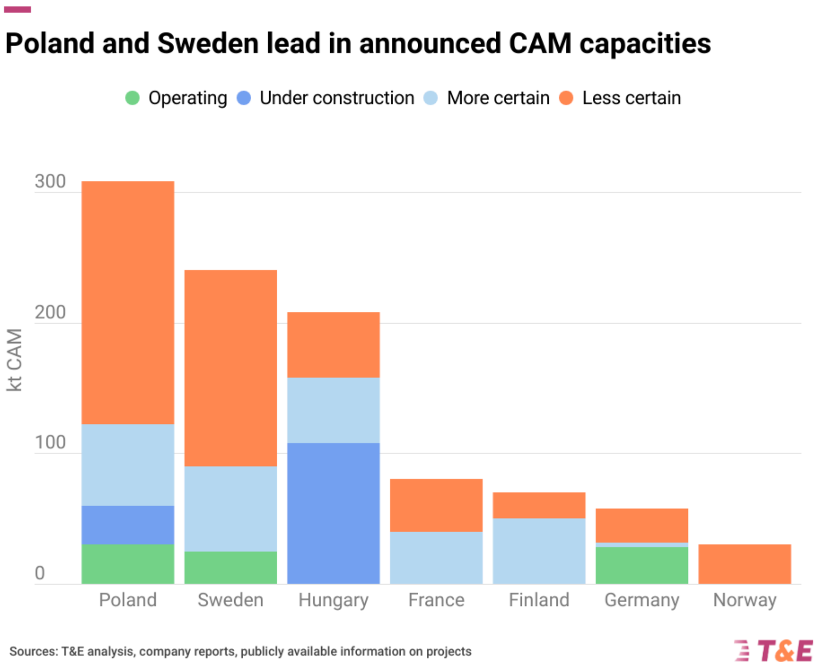


Figure 8: Announced CAM projects in Europe by country and project status

2.2.1 Precursors

Higher up in the value chain, the pipeline for precursor cathode active material (pCAM) projects in Europe is more limited than that of CAM projects.

Precursors are intermediate products from which cathodes are formed, making up for up to 70% of the cathode material costs [29]. For example, in the case of NMC cathode synthesis, the precursor consists of a mix of nickel, manganese and cobalt sulphates. Lithium is added later during the cathode forming stage, via lithiation, to create the final cathode material, i.e. lithium nickel cobalt manganese oxide.

In addition, precursors represent an important value chain stage in relation to the recycling sector as these represent similar expertise as recovering battery grade materials during the recycling process and are the key market for metal recyclers. Without precursor capacities, the materials recovered from black mass would not find a domestic market or worse, the material recovery of battery waste would not happen in Europe and thus potentially impede the building of recycling capacities in the region.

Based on the identified project pipeline, pCAM capacities in 2030 could reach nearly 580 kt PCAM, equivalent to 34% of the European demand, but two-thirds of these are uncertain. These capacities are slightly below the NZIA 40% local manufacturing benchmark.

Today, the only operating precursor plant in Europe is Umicore in Finland, where it also produces cobalt chemicals. But multiple projects have been announced across Europe including by:

- Northvolt in Sweden, in addition to its battery and CAM operations as well as battery recycling and lithium refining plans (the latter in Portugal) [30];
- Orano and XTC joint venture in France (to be integrated with CAM and battery recycling) [25];
- Umicore and Volkswagen joint venture in Poland (to be integrated with CAM) [31];
- Finnish Minerals Group and China-based CNGR joint venture in Finland [32];
- Australia-based Pure Battery Technologies in Germany, aiming to produce precursors from mixed hydroxide precipitate (MHP) and black mass [33];
- Turkey-based EGE Kimya in Poland, which is also a manufacturer of cobalt-based dyes [34];

Many of these projects were announced in the past few years, with the plans of Orano and XTC as well as those of Umicore and Volkswagen being revealed in 2023.

On the downside, BASF's high profile project in Finland has recently been put indefinitely on hold due to prolonged permitting challenges related to its sodium sulphate wastewater management plans [35] [36]. Considering the limited pipeline of pCAM projects in Europe, such suspensions can have repercussions on the region's autonomy. It is important to kick such projects off without delay, to enable Europe to get experience, while gradually integrating stricter sustainability practices as they move forward.

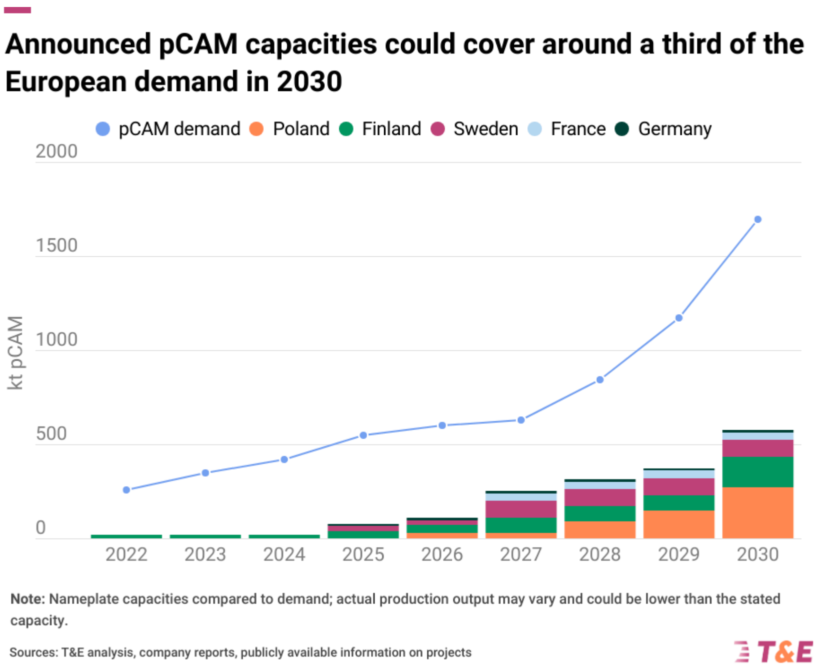


Figure 9: Announced pCAM capacities and demand in Europe by 2030

2.3 Lithium refining

The growing uptake of electric vehicles and energy storage technologies in Europe also means that the demand for critical minerals will increase significantly in the long term. T&E estimates that the end use demand for lithium from these applications will reach nearly 490 kt LCE by the end of the decade from around 100 kt LCE in 2022.[10] On the supply side, a number of lithium projects - especially in the refining stage - have been announced in Europe in the past several years.

Since T&E published the report "A European Response to the US IRA" [2] a year ago, two projects have been added to the lithium refining project pipeline:

- Livista in Germany [37];
- LevertonHELM's expansion in the UK.

Furthermore, the timeline for two projects has been delayed: Vulcan Energy Resources in Germany by one year (current estimated start year 2026 [38]) and Aurora Lithium in Portugal by two years (estimated start year 2028 [39]). Additionally, two projects have been excluded from the list: European Lithium in Austria, planning to export its mined output to Saudi Arabia for further processing [40], and the Rio Tinto project in Serbia, currently on hold due to opposition from local communities.

[10] Demand in 2030 in the Regulatory scenario.

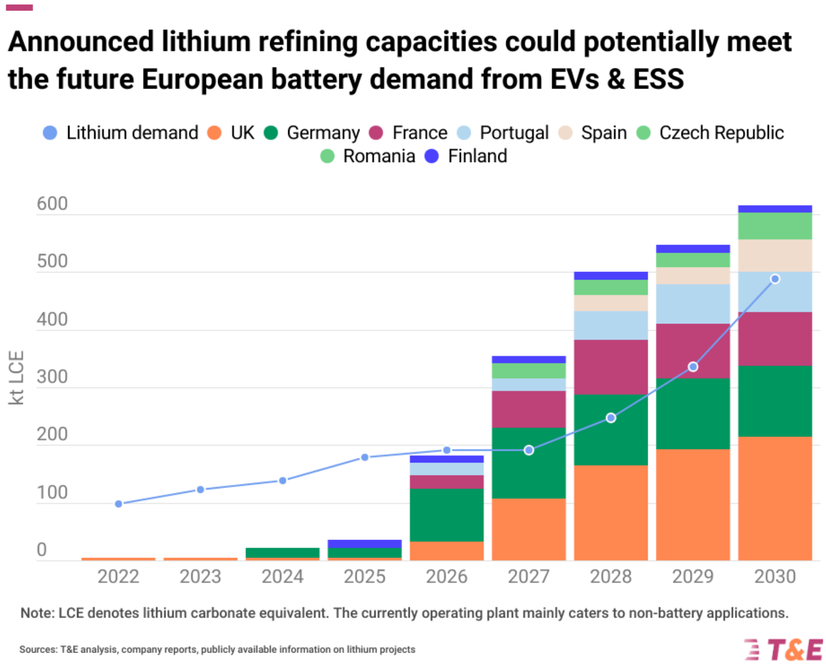


Figure 10: Announced lithium refining capacities and demand in Europe by 2030

Overall, the planned lithium refining plants in Europe could potentially reach a combined capacity of around 615 kt LCE by 2030, theoretically sufficient to cover all of the region's demand by that time.

Nonetheless, many of these projects are still in early stages of development and remain uncertain until the final investment decision is made. Currently, lithium production in Europe is very limited, with one company, LevertonHELM in the UK, producing small volumes of lithium chemicals for various industries (~4 kt LCE). In the next two years, two projects - AMG Lithium in Germany and Keliber in Finland - are expected to come online with a combined capacity of around 31 kt LCE, while all the rest are slated for the second half of the decade.

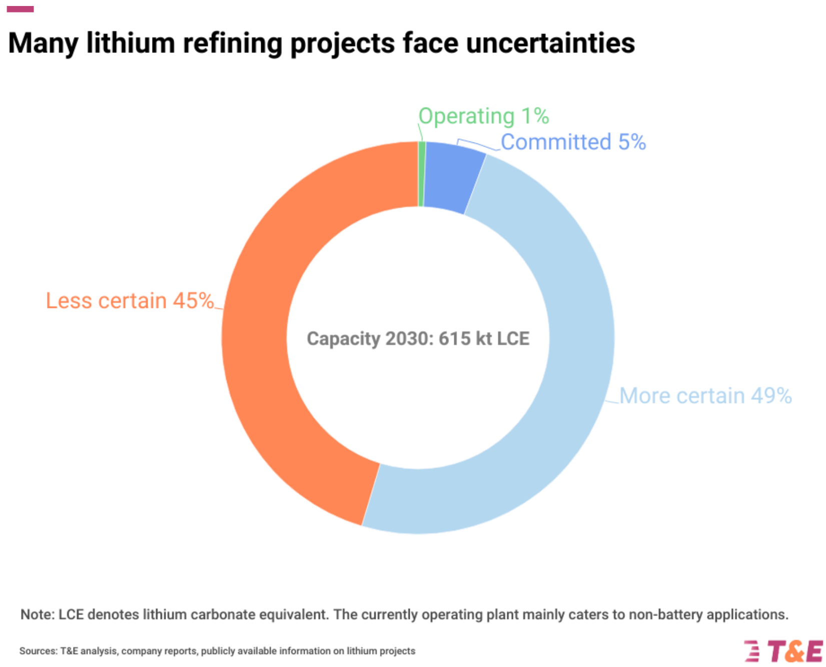


Figure 11: Announced lithium refining projects in Europe by project status

The largest announced capacities are located in the UK (e.g. Tees Valley Lithium and Green Lithium), Germany (e.g. Vulcan Energy Resources and Livista Energy) and France (e.g. Lithium de France and Imerys).

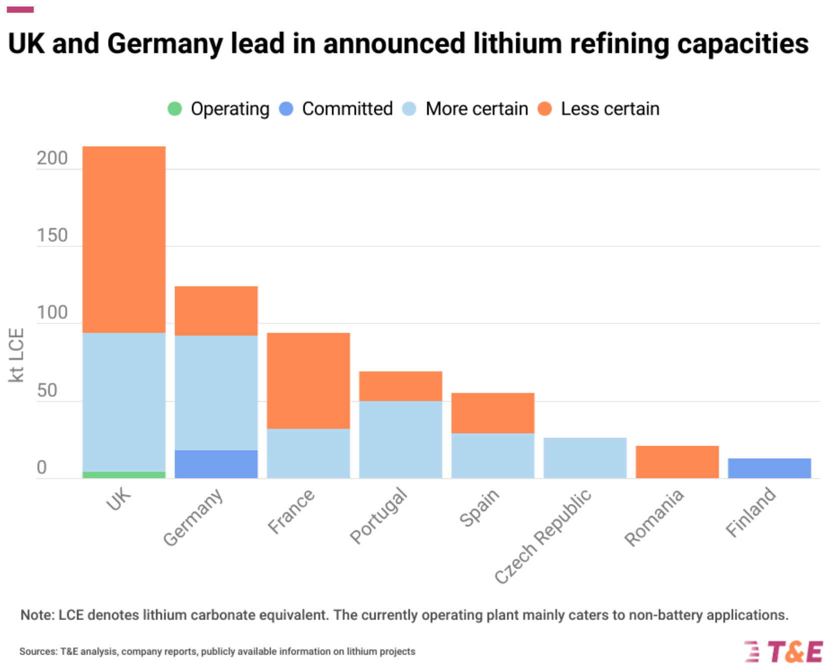


Figure 12: Announced lithium refining projects in Europe by country and project status

2.4 Nickel & cobalt refining

As analysed in the report "Paving the way to cleaner nickel" [41], Europe hosts around 63 kt Ni in nickel sulphate production capacities, the nickel product used in lithium-ion batteries. These capacities are operated by Terrafame in Finland, which commissioned its nickel sulphate facility in 2021 and is still ramping up; Nornickel in Finland; and Hellenic Minerals in Cyprus. Combined, they can cover around a fifth of Europe's needs in 2030.

Apart from nickel sulphate, Europe produces nickel metal and chemicals for other industries such as stainless steel, alloys and electroplating, with capacities of around 200 kt Ni across the EU, the UK and Norway.

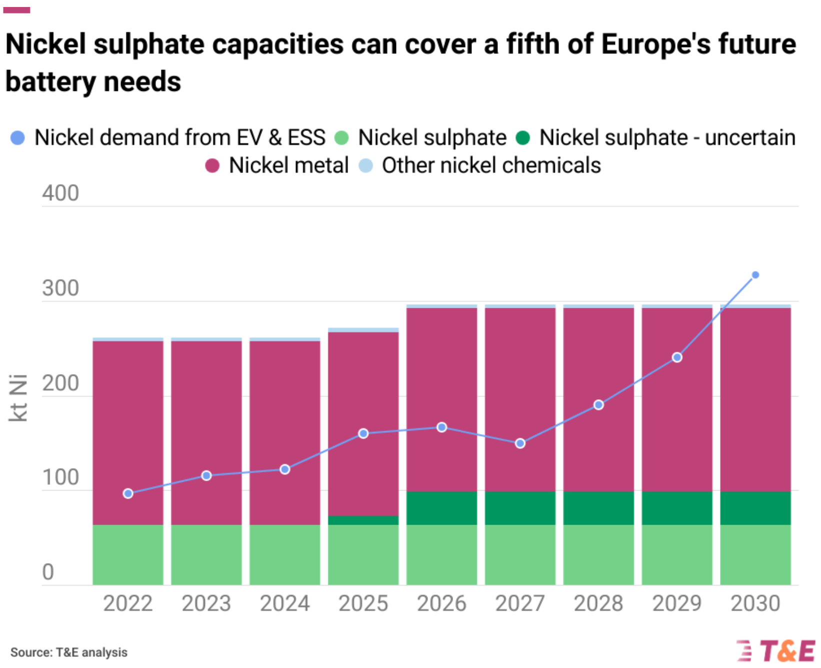


Figure 13: Nickel refining capacities and demand in Europe by 2030

Since T&E's 2023 report, "A European Response to the US IRA" [2], no new projects for refined nickel have been announced in Europe. The only potential expansion, located in Finland and linked to the Russia-based producer Nornickel, remains uncertain.

Russian nickel continues to enter the EU market, with import volumes of nickel metal from Russia totaling 29 kt Ni in 2023, or 21% of nickel metal imports. Although this is 50% lower than in 2022 (59 kt Ni), the risk of potential sanctions remains and could expose European industries to supply chain disruptions.[11]

European nickel sulphate producers such as Terrafame, Nornickel and Hellenic Minerals, also produce cobalt sulphate, with cobalt often being a byproduct of nickel mining operations. Additionally, Umicore produces cobalt sulphate and other chemicals along with cobalt powder in Finland. Their combined cobalt sulphate capacities are estimated at 7 kt Co, meeting a quarter of Europe's demand in 2030.

Moreover, several other plants in Europe specialise in refining cobalt into metal, powder and chemicals other than sulphate. These facilities have combined capacities of 26 kt Co and cater to diverse applications such as superalloys, hard metals and catalysts. As with nickel, no new projects have been announced in Europe in the past year.

[11] According to official EU trade data for the Harmonized System code 75021000 ("Nickel, not alloyed, unwrought", or nickel metal), retrieved from the European Commission platform Access2Markets.

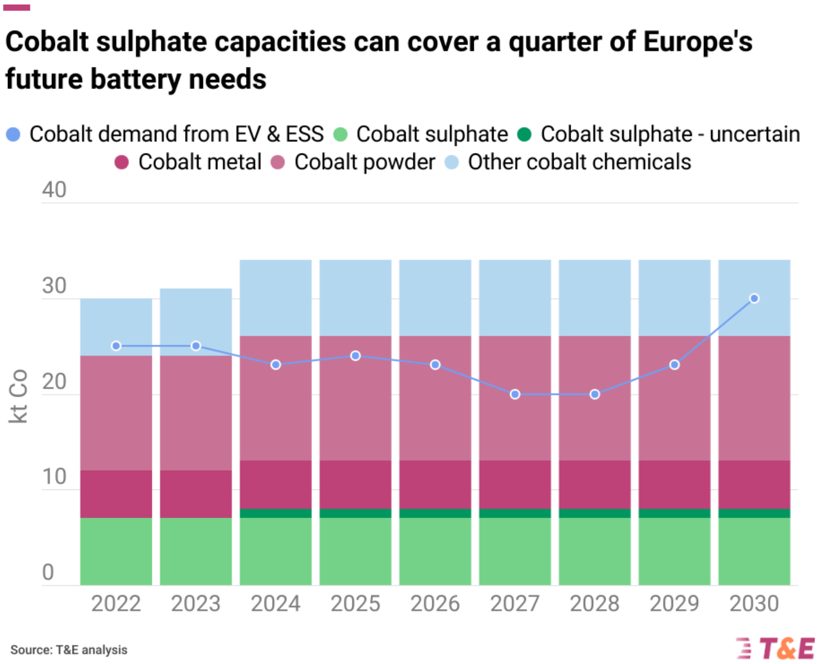


Figure 14: Cobalt refining capacities and demand in Europe by 2030

2.5 Manganese refining

Manganese is increasingly being considered as a potential substitute for cobalt and even nickel in certain cathode chemistries (e.g. LMR-NMC, LNMO, LMFP), thanks to its abundance, cost-effectiveness and capability to provide relatively high energy densities. By 2030, the demand from electric vehicles and energy storage systems in Europe is estimated to reach almost 110 kt Mn.

Today, the only producer of battery-grade manganese sulphate (i.e. high purity manganese sulphate monohydrate, or HPMSM) in Europe, and one of the very few outside China, is the mineral and chemical additives Vibrantz Technologies in Belgium, with a capacity of around 5 kt Mn [42].

In the long run, one notable project is planned by Euro Manganese in the Czech Republic with a capacity of 48 kt Mn (high purity electrolytic manganese metal, or HPEMM, which can be dissolved HPMSM) [43]. The novelty of the project is that it aims to reprocess old manganese deposits in waste from a decommissioned mine, being essentially a re-mining project. Nonetheless, Euro Manganese also plans a dissolution plant in Canada [43], potentially utilising feedstock from its European operations to serve the North American market. This move could represent a missed opportunity for Europe in the absence of a robust CAM and pCAM market.

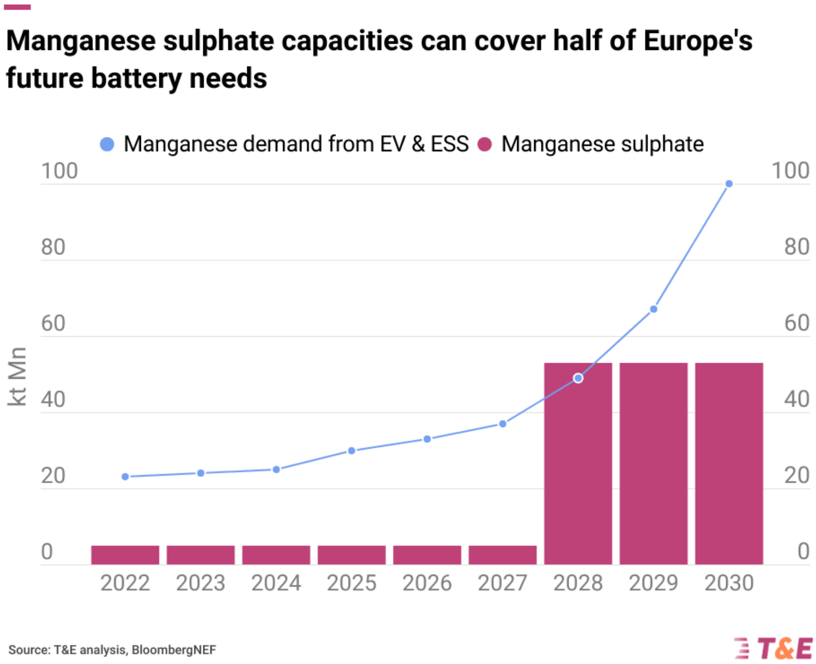


Figure 15: Manganese refining capacities and demand in Europe by 2030

2.6 Battery recycling

In the mid to long term, battery recycling is set to play a crucial role in reducing reliance on virgin materials. In contrast to cars running on fossil fuels in a linear "take-make-dispose" model (where resources are extracted, utilised and burnt), electric vehicle batteries can be recycled with valuable materials recovered and further reused in new batteries.

The EU's Batteries Regulation, which came into effect in August 2023, will pave the way for establishing a circular economy for batteries and their materials. The Regulation mandates, among others, due diligence and sustainability requirements such as carbon footprint declarations for batteries placed on the market, and sets a number of targets, including:

- Recycling efficiencies: 65% by average weight of lithium-ion batteries should be recycled by the end of 2025, rising to 70% by the end of 2030;
- Material recovery efficiencies: 50% for lithium, 90% for nickel, 90% for cobalt should be recovered by end of 2027; rising to 80% for lithium, 95% for nickel and 95% for cobalt by end of 2031;
- Minimum recycled contents: 6% of lithium, 6% of nickel, 16% of cobalt in new batteries should come from recycled metals by 2031, rising to 12% for lithium, 15% for nickel and 26% for cobalt by 2036 [44].

Supported by regulation, the European scrap pool will be expanding in the following years, driven by production ramp-ups at gigafactories in the short term and by the retirement of electric vehicle and energy storage system batteries in the long term.

The potential local feedstock availability for recycling is projected to increase to around 100 GWh, or 10% of the battery demand in 2030. Of this, around 75% would come from production scrap at gigafactories as they are scaling up, while the remainder would be sourced from end-of-life batteries. By 2035, the scrap pool is estimated to double to 200 GWh or 11% of the demand, with end-of-life batteries becoming the primary feedstock source as the electric vehicle fleet matures.[12]

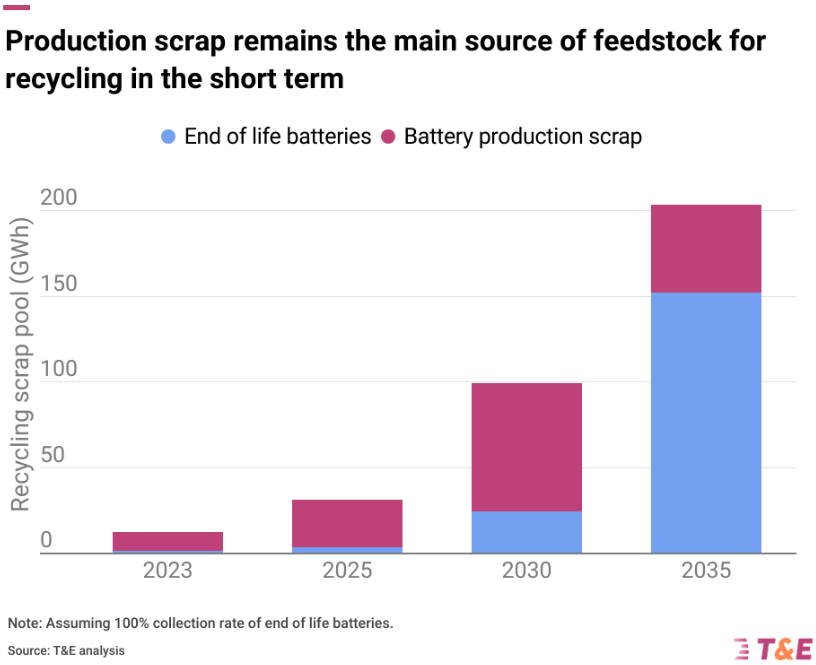


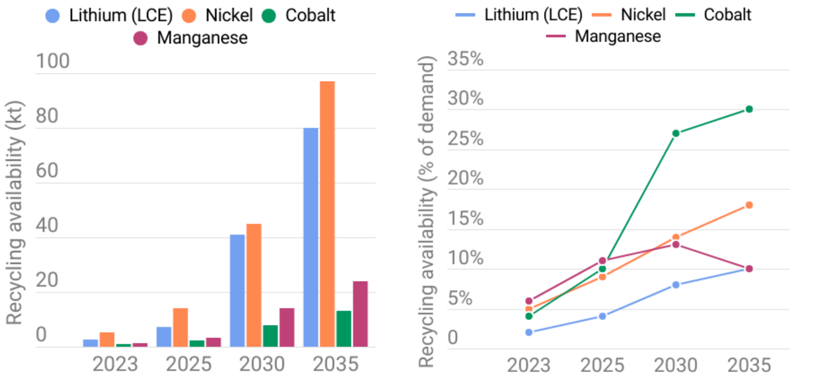
Figure 16: Battery recycling scrap pool by source

Assuming 100% collection rate and various recovery rates for each metal (i.e. 80% for lithium and 95% for nickel, cobalt and manganese in line with the EU Battery Regulation), the estimated volumes of raw materials recycled from these feedstocks are shown below. More details on the assumptions can be found in the Methodology section of the report.

The share of recycled cobalt is expected to make up for 30% of the demand from electric vehicle and energy storage system batteries, as end-of-life batteries produced in early 2020s containing more of the metal would become available for recycling. At the same time, the share of manganese recovered from battery recycling is anticipated to decline in 2035 compared to 2030 due to an accelerated growth in manganese demand driven by the adoption of manganese-rich chemistries.

[12] The figures assume the following: EV batteries would have a lifetime of 20 years with more than half of the electric vehicles being retired between year 10 and 15; 30% of the retired EV batteries would be used in second life applications for another 5 years; 100% end-of-life collection rates; production scrap would account 7% of the battery production in 2030 and 5% in 2035.

Recycling will increasingly contribute to raw materials supply availability over the next decade



	Lithium (LCE)	Nickel	Cobalt	Manganese
2030	41	45	8	14
2035	80	97	13	24

	Lithium (LCE)	Nickel	Cobalt	Manganese
2030	8%	14%	27%	13%
2035	10%	18%	30%	10%

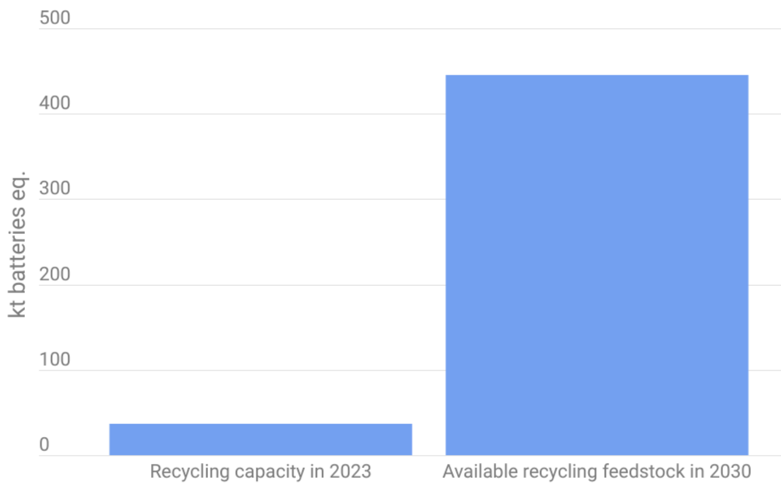
Note: Recycling availability expressed in kt LCE (lithium carbonate equivalent) for lithium and in kt metal content for nickel, cobalt and manganese.

Source: T&E analysis

Figure 17: Battery metals available for recycling by 2035

To meet this demand for recyclable materials, Europe will need to considerably expand its recycling capacities in the next decade. Given that battery recycling typically involves two distinct stages - initial pre-processing including shredding and sieving, followed by a material recovery process such as hydrometallurgy - it will be essential for the sector to build matching capacities in both stages.

Current recycling capacities are insufficient for processing future feedstock



Sources: T&E analysis, Circular Energy Storage

Figure 18: Current material recovery capacities compared to future recycling feedstock

Announced capacities in Europe will be able to process around 830 kt of batteries (or around 195 GWh) in the pre-processing stage and over 880 kt of batteries (or 205 GWh) in the material recovery stage in 2030.[13] According to Circular Energy Storage data, compared to 2022, Europe's pre-processing capacity pipeline increased by around 85 kt batteries, while the material recovery capacities expanded by 65 kt. This shows a worrying trend of material recovery lagging behind pre-processing.

The 5 largest companies active in the pre-processing are expected to account for 40% of the announced capacities in 2030 and include:

- Umicore in Belgium;
- South Korea-based Sungeel Hitech in Hungary, Germany and Spain;
- US-based Li-Cycle in Germany, Norway and France;
- Singapore-based EcoNiLi in Spain;
- Suez in France.

The material recovery market consist of the following top 5 companies that make up almost 70% of the projected capacities in 2030, including:

- Umicore in Belgium;
- Northvolt's recycling project Revolt in Sweden;
- Germany-based copper recycler Aurubis, location yet to be decided;
- UK-based Altilium in Bulgaria and the UK;
- Commodity trader Glencore with North American recycling company Li-Cyle in Italy.

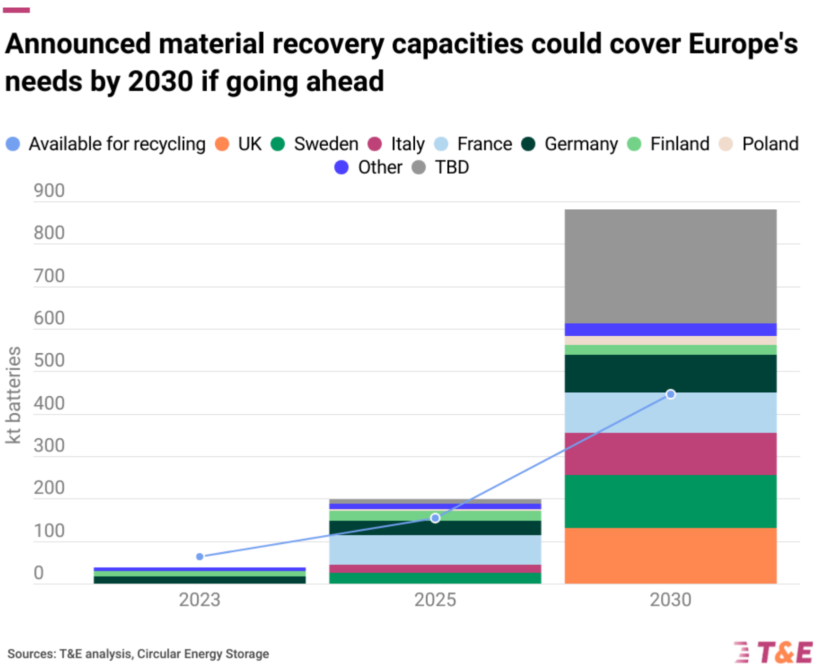


Figure 19: Material recovery capacities and availability of feedstock in Europe by 2030

However, these capacities remain highly uncertain considering that the sector is still in early development. Material recovery capacities, in particular, pose greater complexity requiring higher expertise and technology development. A slowdown in capacity building in this particular

[13] The capacity figures in kt batteries have been sourced from Circular Energy Storage. The equivalent volumes in GWh have been calculated in-house using BloombergNEF data on energy density trends.

stage of recycling could result in intermediate products, such as black mass, being shipped outside of Europe, and thus undermining Europe's goals of achieving raw materials security and circularity. It is therefore important for Europe to support and scale capabilities today so that it can efficiently process the available scrap pool when it becomes accessible.

The present analysis of batteries available for recycling does not account for other applications than electric vehicles and energy storage systems, such as from portables, personal mobility, maritime and industrial sectors, which will also be processed by the same recycling facilities. Including these applications would result in higher utilisation rates of the recycling capacities.

3. Climate benefits of onshoring in Europe

Localising the battery value chain can lead to shorter supply chains and reduced transportation-related emissions. This is particularly significant in the production and transportation of raw materials, components and finished batteries. Moreover, with Europe's stricter environmental regulations and relatively higher share of renewables, onshoring can reduce the overall greenhouse gas emissions (GHG) emissions from the production of batteries and battery materials.

3.1 Batteries

Location matters when it comes to the carbon footprint of battery production. T&E estimates that the most common lithium-ion battery (NMC 811 chemistry) produced with the EU grid in 2023 would have a 75 kg CO2e/kWh carbon footprint. Producing a battery on a lower carbon grid, such as in Sweden, results in a carbon footprint of 62 kg CO2e/kWh, whereas the footprint increases to 82 kg CO2e/kWh if produced in a higher than EU average carbon grid, such as in Germany. Batteries produced using the average Chinese grid yield a much higher carbon footprint of 100 kg CO2e/kWh[14] (though there are regional differences). This has ramifications for onshoring battery cell manufacturing into Europe. Compared to China, producing battery cells in Sweden would in an average case reduce CO2 emissions by 38%.

[14] The differences between the EU, Sweden, Germany and China are based on the same average emissions for the upstream part (cathode production, anode, refining, raw materials, etc.). Section 3.6 shows the impact of the lowest and highest emissions in the cathode material production pathways.

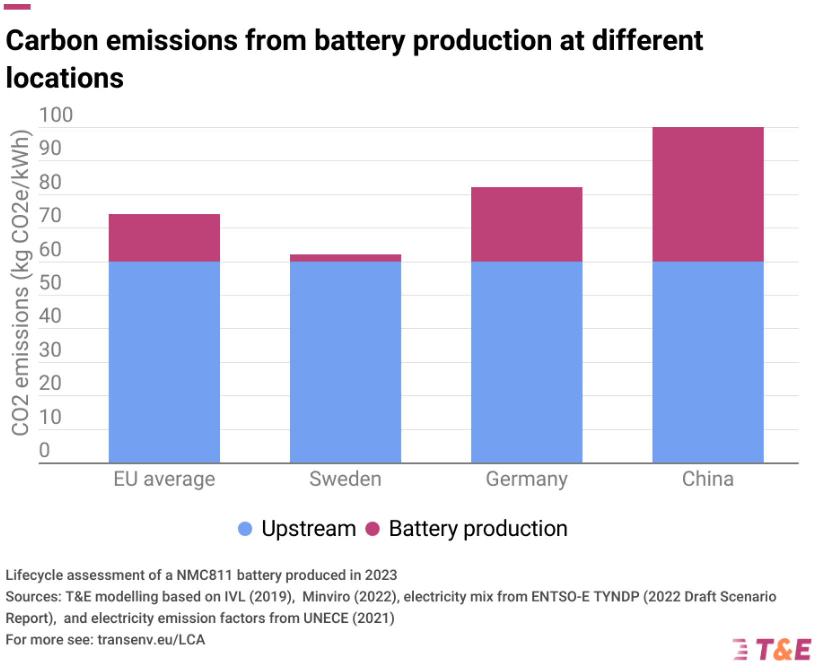


Figure 20: GHG emissions from battery cell production

3.2 Cathode active materials

In cathode production, the most energy-intensive processes are the precipitation during the precursor synthesis and the calcination of the cathode material. T&E analysis using in-house as well as secondary source data and assumptions [45] shows that producing NMC 811 CAM with the EU grid results in a carbon footprint of 26 kg CO2e/kg (including upstream emissions). If the production takes place in Sweden with renewable energy, the carbon footprint decreases to 25 kg CO2e/kg.[15] These figures represent a reduction of 12% and 18%, respectively, compared to CAM produced with the Chinese grid, which emits on average 30 kg CO2e/kg. Excluding upstream emissions, emissions from CAM production processes in Europe would be 34% lower than in China, and in Sweden 51% lower than in China.

Such findings emphasise the importance of localising battery materials production as a strategy for significantly reducing environmental impacts.

[15] The estimated emissions include emissions from raw materials ("Made in Europe with EU grid" scenario, see section 3.6), emissions from precursor synthesis (via precipitation, using natural gas) and cathode production (via calcination, using electricity). The differences between the EU, Sweden and China are based on the same average emissions for the upstream part (material refining and raw material extraction).

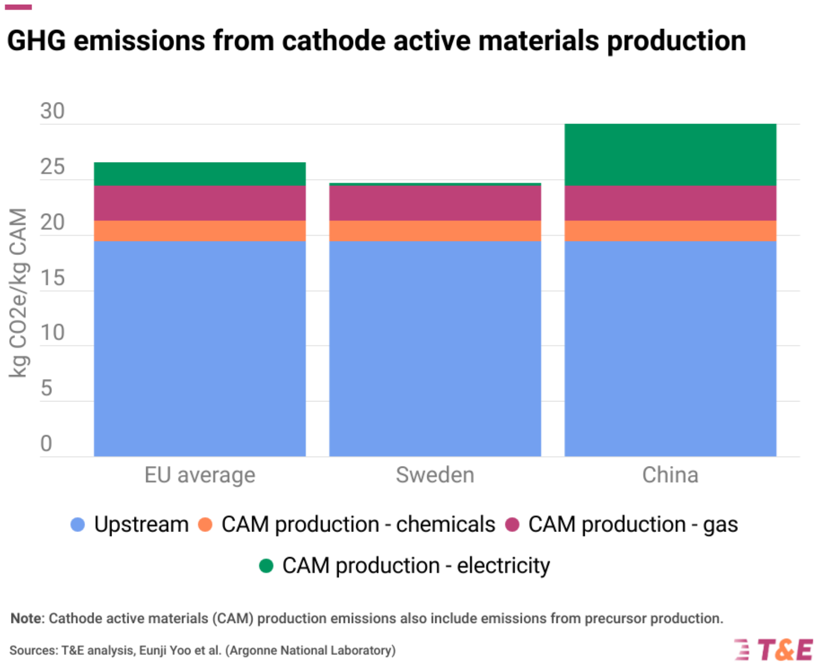


Figure 21: GHG emissions from CAM production

3.3 Lithium hydroxide

Lithium hydroxide is one of the two core lithium products used in lithium-ion batteries. Whereas lithium carbonate is primarily used in LFP (lithium iron phosphate) cathode chemistries, lithium hydroxide is the material of choice for high energy density, nickel-rich cathodes, with most of the announced projects in Europe expected to produce lithium hydroxide to cater to the growing demand.

Generally lithium chemicals have been traditionally produced from either evaporating brine from salt flats (e.g. in South America) or from mining hard rock deposits (e.g. in Australia). Both routes are associated with high carbon emissions and water consumption [46]. At the same time, a new set of technologies - known under the umbrella term as Direct Lithium Extraction (DLE) - is emerging and being tested at scale to efficiently and faster extract lithium from brine sources with lower carbon impact [47] [48]. See section 4.2.2 for more on DLE.

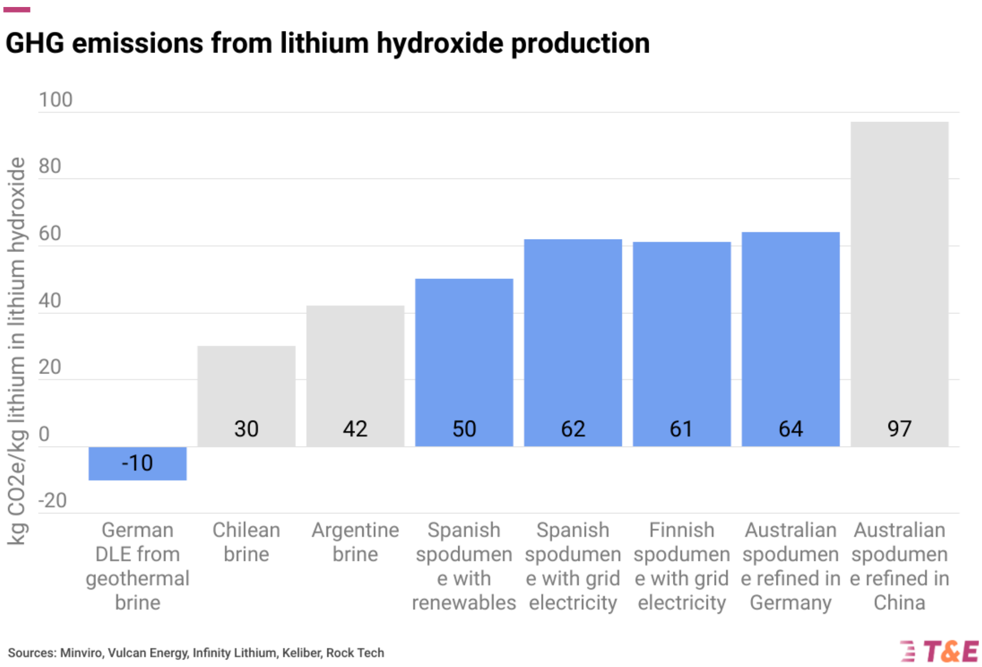


Figure 22: GHG emissions from lithium hydroxide production

A comparison of the GHG emissions from prospective European lithium projects and conventional routes, highlights the impact of production methods as well as geographical locations. Firstly, lithium processed in Europe generates a third fewer emissions than that processed in China, even when the ore itself is sourced from overseas in Australia. Secondly, additional emission reductions can be achieved by locally sourcing spodumene in Europe, especially when coupled with renewable energy, achieving a 50% reduction compared to the Australia-China route. Lastly and most notably, DLE from geothermal sources stands out as the route with the lowest CO2 emissions due to its usage of naturally heated brine, no burning of fossil fuels and usage of electrochemical processes with low consumption of reagents (or chemicals used to separate lithium from other components) [49].

3.4 Nickel sulphate

In T&E's publication "Paving the way to cleaner nickel" [41], a comparison of several nickel sulphate production routes reveals that operations with access to renewable energy and using hydrometallurgical technologies, such as bioheap leaching and pressure oxidation, had the lowest carbon footprint.[16]

The best performing facilities, located in Canada and Finland, generate 70% and 63% fewer CO2 emissions, respectively, than the industry average (as calculated by the Nickel Institute) [50]. Some of the factors contributing to this performance include higher usage of renewable energy, not deploying fuel-based pyrometallurgy (or smelting), and using sulphide ores as input (as opposed to laterite ores), which tend to require less energy.

[16] The carbon footprints were assessed by Minviro, a sustainability and life cycle assessment consultancy company, using LCA methodology.

In contrast, processing laterite ores into nickel pig iron (NPI) to matte to nickel sulphate, as done in Indonesia, generates 5 times more emissions than the industry average, while the high pressure acid leaching (HPAL) route, increasingly popular in Indonesia and deployed by many Chinese companies there, produces almost twice as much emissions than the industry average. Indonesian facilities process laterite ores, requiring more energy input, and rely on coal-based power generation. In addition, the NPI to matte to nickel sulphate route is lengthy and deploys pyrometallurgical processes, resulting in the highest GHG footprint in the industry.

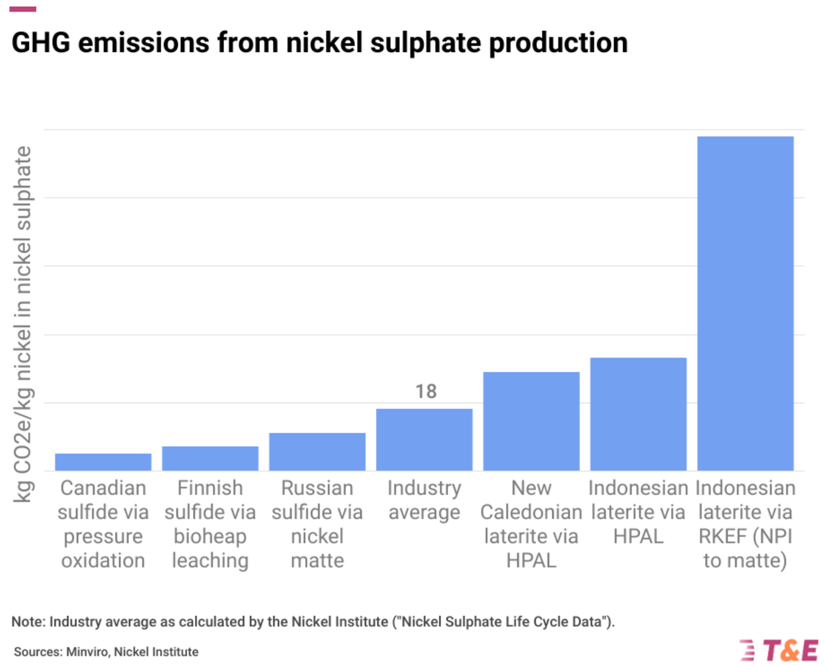


Figure 23: GHG emissions from nickel sulphate production for selected routes

Studies on LCA and decarbonisation pathways for nickel suggest that switching to renewable sources of electricity alone can reduce emissions by up to 40% on average [50] [51] [52]. Other key solutions to mitigate the GHG emissions include using zero-carbon chemicals in the processes and advancing more energy-efficient ore processing techniques, such as bioheap leaching and pressure oxidation for sulphides, as well as heap leaching and atmospheric hydrometallurgical processing for laterites. In addition, decarbonising mining vehicles and streamline logistics, not only in the nickel sector but across the broader metals industry, could further contribute to reducing CO2 emissions.

3.5 Manganese sulphate

The manganese sulphate market is currently dominated by China, which supplies around 93% of the global demand [53]. While the country will continue to be the main producer of manganese sulphate, new capacities in other regions are planned for the next several years, including in Europe. According to an LCA assessment by the consultancy company Minviro, producing manganese sulphate in Europe, when using renewable sources of energy generates 59% fewer CO2 emissions compared to production in China, making it a more sustainable option for pCAM and CAM producers.

The production route considered in the analysis involves the production of manganese metal (via electrowinning) and its subsequent dissolution into manganese sulphate, with the main contributor to the carbon footprint being the embodied emissions from the electricity grid mix both in China and Europe [54] [55].

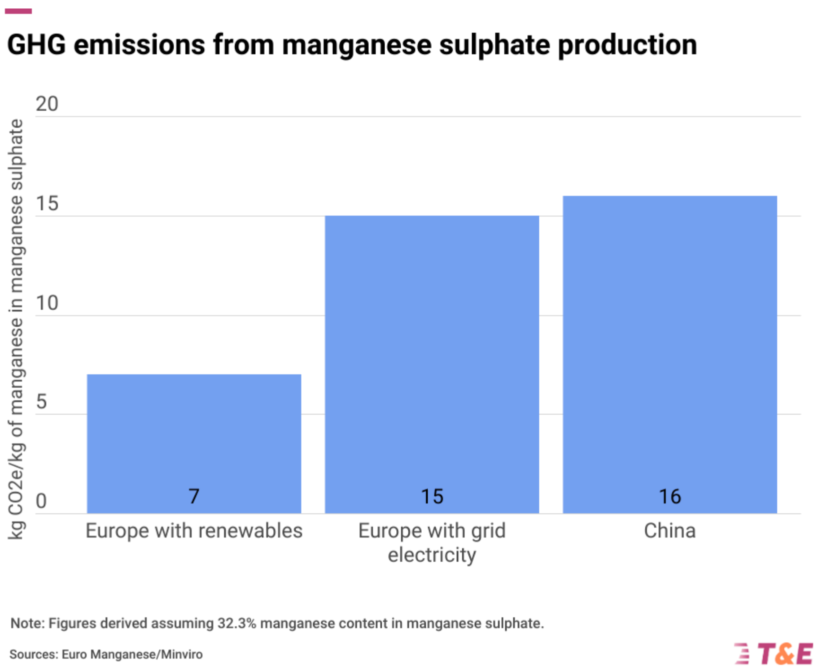


Figure 24: GHG emissions from manganese sulphate production

3.6 Overall climate benefit

Beyond the geopolitical advantage, onshoring the production of batteries and battery materials in Europe offers environmental benefits, particularly in reducing CO2 emissions, thanks to Europe's larger share of renewable energy sources, lower transportation emissions compared to importing products from distant locations and broader sustainability policies in place in the region.

Battery cell manufacturing in Europe can save on average 25% in CO2 emissions when using the average grid, and up to 38% when using a higher share of renewables (i.e. as in Sweden), compared to the current average manufacturing processes in China. Similarly, CAM production in Europe results in a 12% reduction in CO2 emissions on average (i.e. with the EU grid) and 18% in a lower carbon the scenario (i.e. Sweden), compared to China. Moreover, in terms of raw materials, the combined emissions from locally produced lithium hydroxide, nickel sulphate and manganese sulphate in Europe can lead to a significant decline in the carbon footprint of 71% per kWh of NMC 811 cathode, compared to processing in China.[17]

[17] The scenario "Made in Europe with Renewables" includes lithium via Direct Lithium Extraction (DLE) in Germany, nickel via bioheap leaching in Finland, and manganese via electrowinning and metal dissolution in Europe using renewable energy. The scenario "Made by China-controlled supply chain" comprises Australian spodumene processed in China, nickel via HPAL in Indonesia (with Chinese investments) and manganese produced with the Chinese grid mix. The carbon footprint measured in kg CO2e/kg of metal in chemicals was converted into kg CO2/kWh of NMC811 cathode.

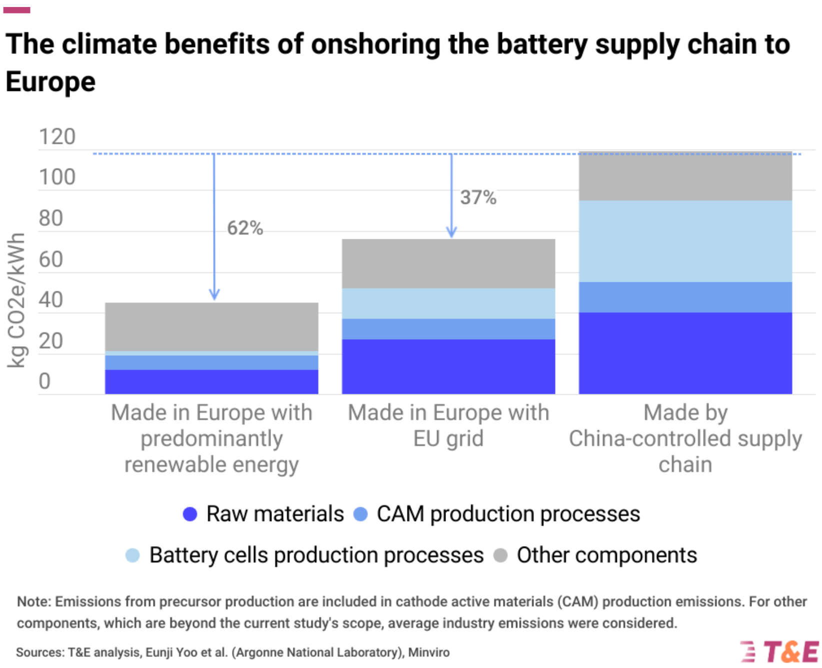


Figure 25: GHG emissions from raw materials, cathode and battery production

Altogether, when aggregating these emissions, battery packs made in Europe result in 37% carbon footprint reduction on average (i.e. made with EU grid) compared to China and 62% reduction when produced with renewables-dominated energy sources and innovative production routes for cathode raw materials.[18]

On a cumulative basis, if Europe were to achieve full local production of battery cells and cathodes to meet its entire demand, the potential cumulative CO2 savings between 2024 and 2030 could reach approximately 133 Mt of CO2, comparable to the emissions produced by entire Chile or the Czech Republic in 2022 [1].

4. Challenges on the European way to success

4.1 Raw materials availability

As Europe strives to create a domestic battery industry, raw materials availability remains one of the core challenges, due to limited domestic resources, coupled with growing global demand and intensified competition for these raw materials.

T&E analysed the raw materials demand from vehicle electrification and energy storage systems on an end use basis, as well as the first use demand arising from the midstream (CAM and pCAM) manufacturers, and how this compares to the domestic mined supply availability. The overall results show that domestic supply from primary mined and secondary sources can on average cover around 35%-70% of end use demand and 45%-100% of first use demand by 2030.

[18] More savings would be possible by including best in class production routes for anode materials and other components which are not in the scope of this study.

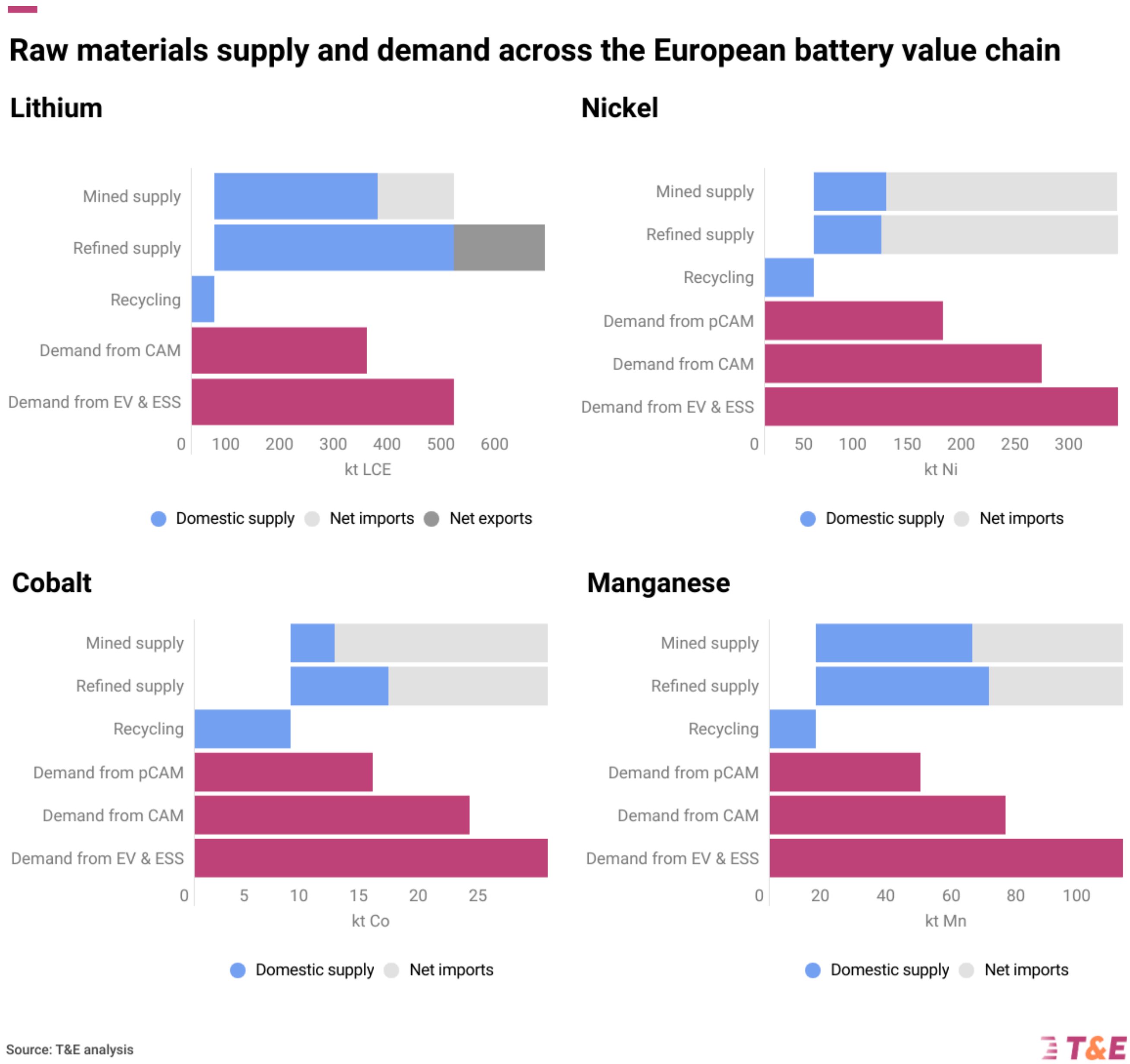


Figure 26: End use and first use demand coverage by domestic supply and imports

When it comes to lithium, the expected mined supply could meet 100% of the first use demand at CAM plants by 2030 if all projects come online on schedule and volume planned and over 70% of the end use demand from electric vehicle and energy storage system batteries.

In the nickel space, the announced supply from primary mined and secondary sources is expected to cover 68% of the demand from pCAM plants, around 45% from CAM plants and nearly 35% of the overall battery end use demand by 2030. The remainder will need to be sourced from third countries.

The supply of mined and recycled cobalt is estimated to meet nearly 80% of the demand at pCAM plants, over 50% at CAM plants and 40% of the end use demand, with the remaining gap filled by imports.

The manganese mined and recycled supply is estimated to meet the needs of pCAM plants, around 85% at CAM plants and 58% of the overall end use demand from electric vehicle and energy storage system batteries. The demand for manganese is projected to increase in the next decade, as it is emerging as a substitute for cobalt and nickel in some chemistries due to its abundance, low cost and ability to deliver relatively high energy densities. The primary supply of manganese in Europe is projected to come from a project in the Czech Republic which intends to process mined waste from a decommissioned mine

It is important to note that the coverage of demand by domestic supply is rather theoretical. Metals are some of the most traded products globally, meaning their production in Europe does not guarantee that they will remain in the region. Nonetheless, establishing a local battery value chain with matching capacities at each stage can ensure that raw materials are consumed in the region. In addition, recycling will increasingly contribute to local supply availability over the next decades, provided that Europe succeeds in creating a closed loop system.

Overall, Europe will continue to be reliant on foreign imports of battery metals to the extent of around 30% to 65% by 2030, depending on the metal.

It is clear from the above that Europe will continue to rely on the global market to secure critical battery materials for decades to come. It is therefore in the EU's interest to ensure there is a diverse and transparent raw materials market, as well as pursuing its own onshoring efforts. The EU should support all initiatives to diversify the market away from today's concentration, including the Minerals Security Partnership. Critically, the EU should pursue its own resource diplomacy, turning its Strategic Partnerships into a pipeline of projects by de-risking investment into the countries concerned. The recent US-EU led effort to develop the Lobito corridor in Africa is a great example which should be replicated in more African countries. Ultimately, for the most strategic materials - e.g. nickel - the EU and its member states should even consider buying direct stakes and equity in the projects directly.

4.2 Technology & innovation

The battery value chain is long and complex and building it from scratch, as Europe is currently undertaking, is an immense task that will require investments, technological innovation and diverse skill sets.

In raw materials processing and battery component production, technological innovation can increase efficiency, reduce costs, improve the environmental impacts and provide an overall competitive advantage.

4.2.1 Cathode active materials production

Cathode active materials production involves complex, multi-step processes and is energy intensive. Consequently, producing it locally with renewable energy sources inherently leads to cleaner cathode active materials, positioning Europe with a distinctive advantage in global competition with other regions.

The industry standard for NMC cathode active material, the most produced by European battery cell factories, manufacturing utilises a ‘co-precipitation’ technique, involving the preparation of the pCAM product (i.e. a mixture of nickel sulphate, cobalt sulphate and manganese sulphate), the mixing of the pCAM with lithium hydroxide or lithium carbonate (known as ‘lithiation’) and the post-treatment (i.e. coating) to create the final cathode active material product [56] [57].

LFP cathode materials, commonly produced in China today, can be produced via several techniques broadly classified into solid phase synthesis, which is a relatively mature technology and involves raw materials in a solid powder form, with precursors being mixed and ground, then calcined; or liquid phase synthesis, which is a newer technology but increasingly favoured by researchers due to shorter processes and lower energy consumption and may involve, among other techniques, co-precipitation, similarly to NMC synthesis [58] [59].

Considering the complexity and energy intensive nature of the cathode manufacturing processes, innovation efforts in this area are directed towards reducing the number of production steps, reducing energy consumption, carbon footprint, water consumption and waste (e.g. sodium sulphates).

For example, US-based Nano One’s M2CAM™ (Metal direct to Cathode) One-Pot process enables CAM to be made directly from metal powders, by combining multiple traditional steps - e.g. feedstock conversion, precursor formation, lithiation and coating steps - into one reaction, shortening the production times from days to hours, according to the company [60]. The process also employs bio-derived reagents which burn up reducing the waste [61]. Companies like BASF and Umicore have partnered with Nano One to scale up the production of next-generation CAM using this process [62][63]. This means that CAM facilities being rolled out in Poland and Germany will likely be able to benefit from this innovation.

4.2.2 Raw materials refining

With the demand of critical minerals on the rise, much innovation is happening in the space of minerals refining and processing, notably lithium and nickel in the case of batteries. Such innovation is critical not only to ensure a competitive advantage, but to phase-out emissions and fossil fuels from this emission intensive part of the value chain.

When it comes to innovation in the lithium space, Direct Lithium Extraction (DLE) holds the potential for reduced land footprint (compared to brine ponds), carbon intensity, fresh water usage and reagent usage. In particular, DLE from geothermal brines relies on geothermal power plants to bring the brine to the surface. The integration of DLE with geothermal energy production offers the potential to supply power and heat for downstream lithium extraction operations with zero carbon emissions and zero fossil fuel consumption [64] [47] [65].

Generally, DLE can be applied on several types of brines such as conventional salar brines in South America and unconventional geothermal brines and oilfield brines often present in the Global North including Europe. Major DLE techniques include adsorption (the most adopted), ion exchange, membrane separation, solvent extraction, and others [66].

In Europe, several projects are underway that plan to use DLE technologies to extract lithium from geothermal brines, including:

- Vulcan Energy Resources in the Upper Rhine Valley, Germany;
- Lithium de France in Alsace, France;
- Eramet in Alsace, France;
- Northern Lithium in the UK;
- Cornish Lithium in the UK, planning to utilise Australian technology to extract lithium from brines [67].

Their combined capacity is 92 kt LCE by 2030, or 15% of total announced capacities in Europe.

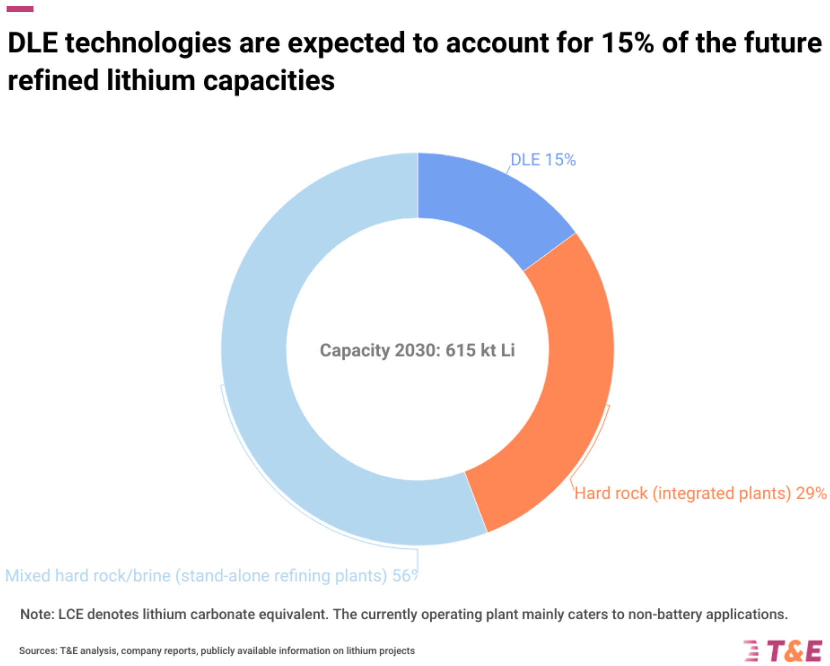


Figure 27: Announced lithium refining capacities by feedstock source/production rout

Other innovations being developed in Europe include reducing the number of steps to eliminate the need for beneficiation and calcination by Infinity Lithium in Spain and electrifying (or using green hydrogen) for key processes to reduce emissions thanks to the switch to renewables [68] [69].

In the nickel space, bioheap leaching is considered an effective hydrometallurgical process for recovering nickel from sulphide ores previously considered uneconomical to exploit [70]. It has reduced environmental impact compared to other processes due to lower energy consumption, reduced usage of harmful chemicals and less landscape damage [41]. Only two nickel projects in the world are currently employing or planning to adopt this method, and notably, one of them is based in Europe. This highlights Europe's leading role in the commercialisation of this cleaner nickel processing route. Compared to heap leaching, most nickel in Indonesia is processed using a more polluting and energy intensive HPAL route.

In Europe, bioheap leaching is deployed by Terrafame, partially owned by commodity trader Trafigura, in Finland, accounting for 60% of the European nickel sulphate production and over 20% of the cobalt sulphate production. In addition, Hellenic Minerals in Cyprus uses heap leaching - a process similar to bioheap leaching but without involving microbial activity - to process nickel and cobalt from laterite ores.

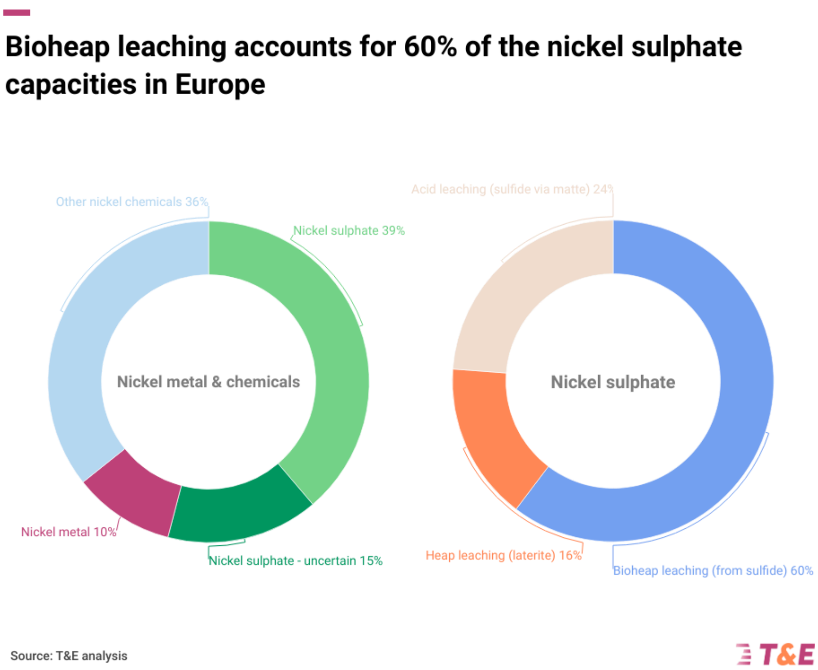


Figure 28: Nickel sulphate capacities by source/production route

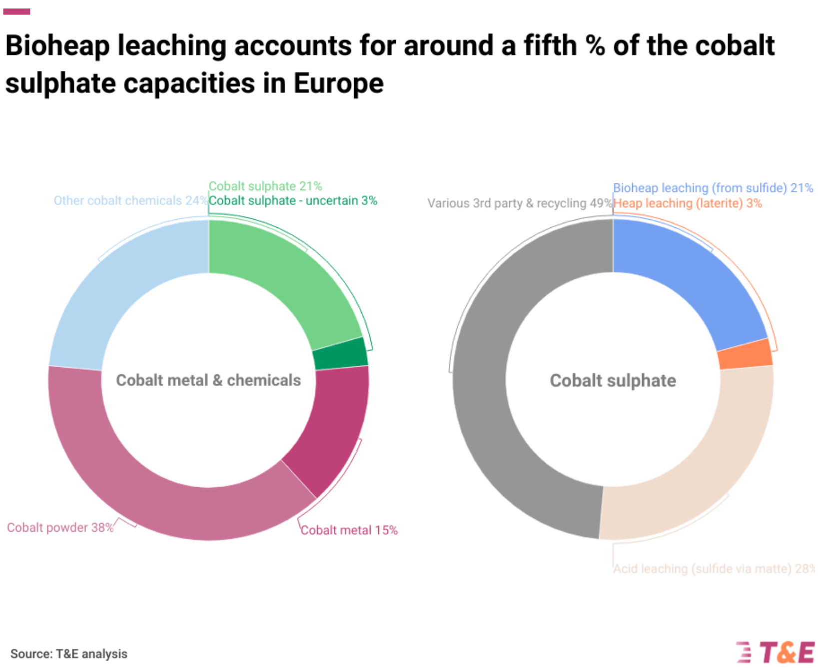


Figure 29: Cobalt sulphate capacities by source/production route

Other best practices to be implemented in Europe include recycling water and/or reagents (e.g. sulphates) as planned by European Metals in the Czech Republic, Vulcan in Germany, Infinity Lithium in Spain, etc [71] [72] [73]. In addition, ongoing innovations focus on adopting more sustainable reagents and chemicals, such as lower carbon chemicals produced with renewable sources of energy, or benign, low toxicity chemicals like methanesulfonic acid, which is biodegradable and can serve as an alternative to sulphuric acid [74].

4.2.3 Battery recycling

Generally, recycling processes can be broadly classified as follows, although each recycler may use a variation or combination of different individual steps:

- Pyro-hydrometallurgy (pyro-hydromet), using heat to recover battery components (mainly metallic components);
- Hydrometallurgy (hydromet), following an initial pre-processing of batteries (can be mechanical, e.g. milling, shredding; physical, e.g. sieving; or thermal, e.g. pyrolysis) and using chemical processes to separate and extract the metal compounds from black mass into products that can be reintroduced as cathode precursors;
- Direct recycling, involving mechanical and/or physical separation of battery components into battery-grade ready materials and thus avoiding thermal or chemical processes; in early stages of development [75].

In Europe, Umicore has pioneered the recycling of batteries via pyro-hydrometallurgy, drawing from its experience of recycling precious metals from electronic waste, and established itself as an industry frontrunner when it opened a battery recycling plant in Belgium in 2010. To cater to the expanding battery market, the company intends to further scale up this technology in the next few years.

Nonetheless, in the long term, hydromet is expected to be increasingly adopted by newcomers and gain market share compared to pyro-hydromet. This shift is due to several advantages of the former, including higher efficiency in recovering valuable materials, especially when it comes to lithium, and reduced carbon emissions compared to the pyrometallurgical processes [76].

Hydromet is an established process in related sectors (i.e. metal refining from ores), but needs to be optimised and fine-tuned for recovery of materials found in batteries. Today, the Finnish company Fortum operates the first commercial-scale hydrometallurgical recycling facility and the largest in terms of capacities in Europe. Companies to follow suit include Northvolt, Eramet, Orano and BASF, among others. T&E's analysis of data from Circular Energy Storage indicates that the share of material recovery capacities via hydromet is projected to increase to 80% in 2030, up from just 1% in 2021.

As the feedstock for hydromet, black mass - a mix of valuable nickel, cobalt, lithium and manganese chemicals produced by shredding battery scrap - is poised to emerge as an important intermediate product, marking a key frontier in recycling. The further processing of black mass into battery-grade materials in Europe will be crucial for creating a circular economy.

Better vertical and process integration is an important industrial focus throughout the battery value chain. In recycling, the integration facilities with pCAM and CAM operations in a closed loop system can cut the number of production steps, thereby reducing the complexity, costs and emissions associated with non-integrated facilities. For example, among the prominent European market players, Northvolt in Sweden, BASF in Germany and Orano in France plan to integrate their pCAM and/or CAM facilities with recycling at the same site.

All in all, Europe has already experience in waste recycling (via pyro-hydromet) and raw materials refining (via hydromet), which can be leveraged for the advancement of battery recycling. There are three key challenges to scale recycling processes in Europe effectively:

- Accessing affordable clean energy: Industrial electricity prices in Europe were 155% higher per kWh than in China during the first half of 2023 [77]. This disparity in energy costs significantly impacts the competitiveness of recycling processes.
- Securing feedstock, notably black mass: While black mass can come from both scrap and end-of-life batteries, today it is mostly exported to Asia (mainly China and South Korea) for further refining and cathode production. This not only increases Europe's dependency on external markets for battery materials but also contributes to higher CO2 emissions, posing sustainability risks. This highlights the need to establish integrated recycling facilities that can process batteries locally and potentially integrating cathode production to streamline processes, within a closed-loop system.
- Higher material recovery rates: Achieving consistently high recovery rates across various feedstock compositions can be challenging due to feedstock variability and different economic incentives for specific metals. Today the best available hydromet technologies already allow for recovery rates of over 95% for nickel and cobalt from black mass. Ongoing innovation initiatives are underway to improve recovery rates, particularly for lithium, as well as other components such as graphite and plastics, which have been technologically more challenging to reclaim or economically unviable.

4.3 Skills & expertise

The battery value chain in Europe is poised to generate around 1.5 million direct and indirect jobs by 2030, with two-thirds of opportunities being created at OEM level for electric vehicles production and one-third in batteries, battery materials, raw materials and recycling [78].

T&E analysis of the existing project pipeline shows that building battery cell manufacturing, cathode manufacturing, lithium refining and battery recycling capacities could generate up to around 190,000 direct jobs in Europe in 2030. T&E assumes that around 90 jobs are created by 1 GWh of battery cell manufacturing [79], 10 jobs by 1 kt of CAM capacity and pCAM capacity,[19]

[19] T&E estimate based on information publicly disclosed by projects.

12 jobs by 1 kt of LCE refining capacity (or 10 jobs by 1 kt lithium hydroxide capacity),[20] and 15 jobs per kt of battery recycling capacity [80].

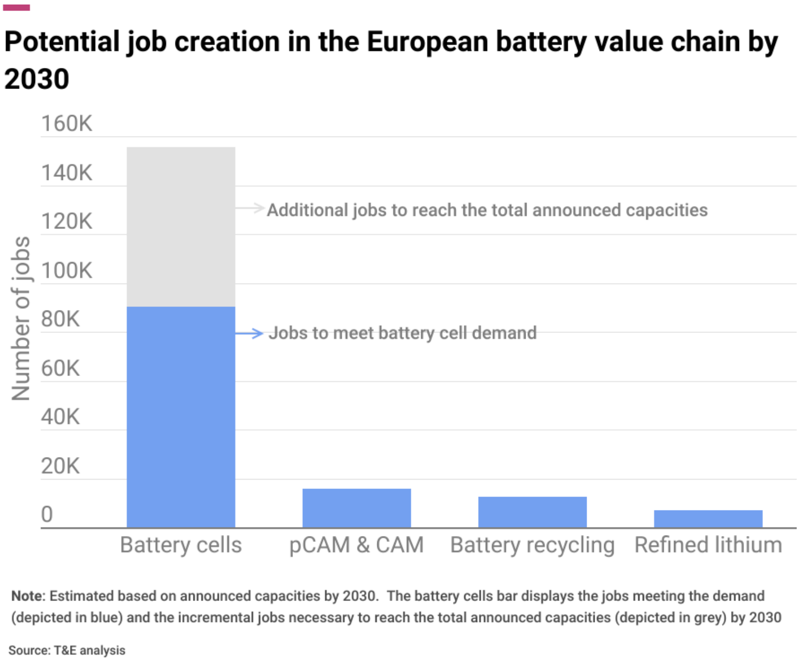


Figure 30: Potential job creation in the European battery value chain based on capacities by 2030

While Europe currently lacks significant home-grown capacity and expertise to manufacture battery materials at scale, a closer examination of the skills necessary reveals a horizontal alignment with the broader metals and chemicals industries. For example, key competencies in the battery value chain include:

- Metallurgy, or hydrometallurgy in particular. This process relies on chemicals and reagents to extract metals from their ores, concentrates and other less pure forms (such as black mass in the case of battery recycling);
- Chemical engineering;
- Process engineering;
- Electrochemistry (for battery cell manufacturing).

The table below summarises allied industries employing principles, techniques and processes that are transferable to battery materials applications.

Industry	**Transferable principles, techniques and processes**	**Battery value chain addressed**
(Petro)chemicals	Separation techniques, process optimisation; Chemical synthesis, property optimisation	Raw materials, cathodes

[20] T&E estimate based on information publicly disclosed by projects.

Pharmaceuticals	Separation and purification, chemical synthesis, property optimisation	Raw materials, cathodes
Catalysts manufacturing (e.g. automotive)	Chemical synthesis, property optimisation, particle size control, process optimisation	Cathodes
Material science (e.g. metals and alloys, semiconductors, composite materials, ceramics, polymers)	Chemical synthesis, material structure characterisation and optimisation, property optimization, particle size control, process optimisation	Cathodes
Fertiliser industry	Separation and purification, process optimisation	Raw materials
Wastewater treatment	Separation and purification, process optimisation	Raw materials

Table 2: Transferable principles, techniques and processes to battery materials

The chemical industry - including chemicals, petrochemicals and pharmaceuticals - employs around 1.9 million people across the EU [81]. The petrochemicals sector in particular, with a workforce of over 200,000 and prominent presence in countries such as Germany, France, the Netherlands and Italy, could provide a potential talent pool for the battery materials processing industry [82]. With the anticipated decline in the use of oil fuel in the mid to long term, as forecasted by the IEA predicting a peak in oil demand by 2030, there is an opportunity for raw material processing industries in Europe to attract, hire and upskill these experienced workers [83].

More broadly, the chemical industry is the basis of the skills and expertise that are necessary for the upstream and midstream minerals sectors. Europe has world-leading chemicals companies such as BASF (Germany), Ineos (UK), Evonik Industries (Germany), Solvay (Belgium), Johnson Matthey (UK), Umicore (Belgium) and Haldor Topsoe (Denmark), some of which are also piloting cathode materials and recycling plants [84].

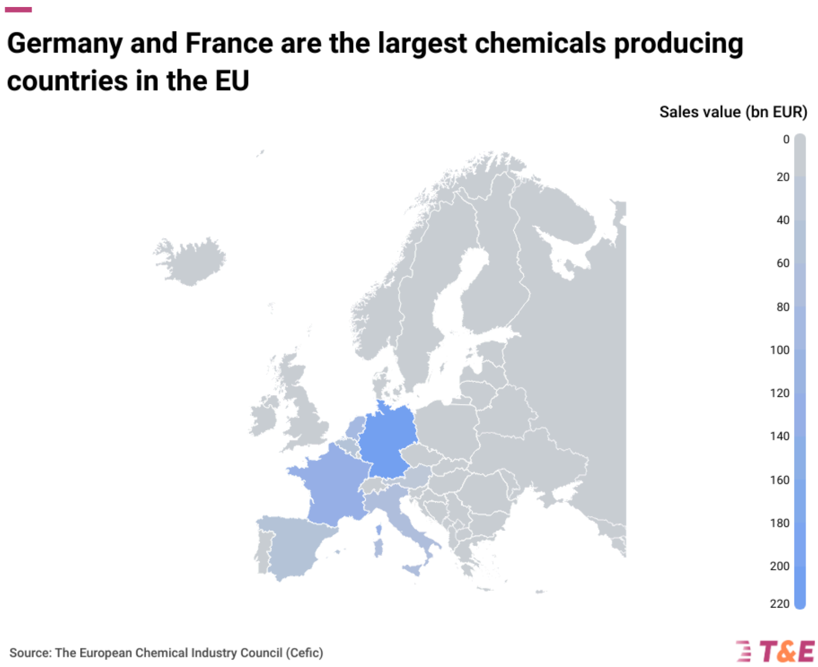


Figure 31: The main chemicals producing countries in EU27

Beyond getting the skills from similar industries, another important aspect is to bring academia and the minerals industry closer together to adapt educational and vocational programmes (including apprenticeships) to the future minerals sector needs. Europe used to have many mining schools, which also taught metallurgy more broadly, which can be revived and reopened. Crucially, close collaboration between companies and universities is important to create the right types of specialty engineers and chemists and in the right regions. This is already done in some member states. For example, Finland is one of the top countries with best expertise in minerals globally, due to a decades' long approach of VTT Technical Research Centre of Finland working closely with businesses in the country [85] [86] [87].[21] In addition, government support for the development of industrial clusters, wherein projects are strategically located in close proximity to one another, facilitates knowledge sharing and a deeper pool of skilled labour. This environment would encourage employees to move freely between companies, leading to a more dynamic and competitive industry ecosystem.

Finally, a strategy that some companies in the battery value chain, such as Northvolt [88], are already deploying is to bring the talent and expertise from abroad (i.e. Asia) and use that initial workforce to train local workforce at scale.

At the same time, Asian battery makers are setting up shop across Europe, notably in Poland and Hungary, benefiting from state aid support, but there are concerns that they tend to hire personnel from their home countries for senior and expert positions without the knowledge and skills trickling down to the local population. National state aid programmes should be designed with conditionality in mind to ensure development of local expertise and infrastructure in such

[21] Finland was ranked No. 1 country in geological databases and availability of labor/skills in the Fraser Institute's 2021 Fraser Institute's Annual Survey of Mining Companies. In the 2022 survey, Finland ranked No. 4 country in geological databases and No. 10 in availability of labor/skills.

cases. Also, reports indicate that Asian companies investing in the battery value chain in Eastern Europe do not typically bring R&D activities, which have the potential to induce technological spillovers, although this may change in the future [89] [90].

For example, the US IRA encourages the creation of a skilled labour pool through registered apprenticeships, with employers qualifying for tax credits if they ensure that a specific percentage of labour hours spent on project construction or repairs is performed by apprentices (10% in 2022, increasing to 15% by 2024 [91].

In Europe, the implementation of smarter national policies should ensure that more local value is added and skills are expanded by introducing conditionality on local workforce and R&D to state aid.

4.3.1 Case study: battery recycling in France

Among the EU countries, France successfully already attracted a number of battery cell, cathode, battery recycling and lithium projects. Dunkirk in particular is emerging as France's battery valley, housing industry players such as battery cell producers Verkor and Prologium (developing solid-state batteries), the cathode and battery recycling joint venture of Orano and XTC, as well as the recycling joint venture of Eramet and Suez.

In the long term, the French battery recycling market will be dominated by three main joint ventures planning a combined material recovery capacity of 95 kt batteries by 2030:

- Suez and Eramet JV, where Suez will focus on pre-processing of batteries and Eramet, drawing expertise from the mining and metals business, will focus on material recovery from black mass;
- Orano and XTC JV, with Orano, a nuclear fuel cycle company, leveraging its expertise in the recovery of uranium, alongside China-based XTC contributing with cathode manufacturing expertise;
- Veolia and Solvay partnership, with Veolia, a water and waste management company, already active in battery pre-processing and Solvay bringing expertise in the chemical extraction of battery metals.

In battery pre-processing, the country currently has small scale operations, but significant expansions are planned in the next several years. In 2030, these capacities are expected to reach 120 kt batteries, of which 80% will be built by the players mentioned above, and the remaining 20% by companies such as Li-Cycle, Mecaware and SNAM.

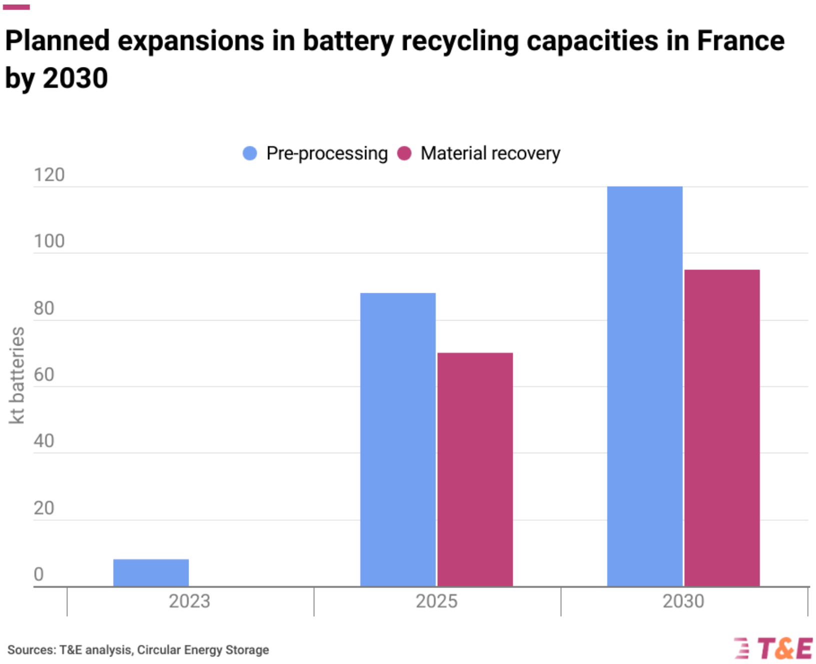


Figure 32: Planned expansions in battery recycling capacities in France by 2030

As illustrated by these joint ventures, collaboration plays a crucial role in sharing investment risks, but also in pooling expertise and know-how. Eramet's experience in mining and metals, Orano's know-how in uranium recovery, Solvay's expertise in chemicals and Suez' and Veolia's specialisation in water and waste management are great examples of leveraging skills from various sectors into the battery recycling sector.

As per T&E's interviews with market players, building pilot plants provides a platform for training personnel, who can gain hands-on experience, test and fine-tune recycling processes and pass on lessons learned to new employees joining the large-scale operations. In addition, companies early on, in the public consultation stage can raise awareness about their future plans in the region including disseminating information and organising workshops for students at universities and technical schools, as e.g. done by Eramet among others.

Regarding market-related challenges, recyclers require long term certainty with both suppliers and customers. This is valid for the entire battery chain, but more so for recyclers, positioned at the end of the chain. To make investment decisions, they must secure sufficient feedstock volumes at predictable prices over a long horizon, considering that the majority of batteries reach end-of-life after 10 years (although until then they can fill the volumes with production scrap at gigafactories). At the same time, they need to ensure that there is a market for the recovered products from black mass, i.e. a pCAM and CAM market. This underscores the importance of forging strategic commercial agreements as well as the importance of building a battery value chain with aligned capacities along each stage.

One risk for Europe is that without a robust customer market, recyclers may decide to process black mass into an intermediate marketable product - but not battery grade - such as mixed hydroxide precipitate (MHP, containing nickel and cobalt) or technical grade lithium and sell it overseas. This would also be counterproductive to EUs' efforts of preventing material leakage, such as classifying black mass as hazardous waste to avoid the export of it to third countries.

4.4 Funding

Scaling up production along the battery value chain demands significant investments in both capital expenditures (Capex), which cover upfront costs for infrastructure and equipment, and operating expenses (Opex), which may include ongoing costs such as those related to energy, labour, water, chemicals and raw materials. Given China's lead in both technology and knowhow to scale factories on the one hand, and higher input costs in Europe on the other, onshoring the battery value chain into Europe comes at a cost.

Compared to China, establishing a battery cell factory in Europe is 47% more expensive (costing around 100 million EUR/GWh) and takes longer due to a lesser degree of expertise and know-how [92]. Given the higher energy and labour costs, Opex in Europe can be up to 70% more expensive than in China. T&E forecasts that the battery demand in Europe will reach around 1,000 GWh by 2030. Meeting this demand would require an investment of around EUR 100 billion for battery cells only at a Capex intensity of 100 million EUR/GWh [92]. If the full announced capacities would materialise (1.8 TWh), significantly surpassing the demand and implying potential for export, the investments would rise to EUR 175 billion by 2030.

As of today, the costs of building and operating a cathode active material plant in Europe are comparable to the US, excluding the US IRA production tax credits. When compared to China, the Capex for constructing such a plant in Europe is 27% higher (or around 14,000 EUR/tonne of capacity), while the Opex is up to 13% higher when including raw materials, labour, electricity and water costs (around 45 EUR/kg) and nearly double that of China when excluding raw materials costs (around 15 EUR/kg).

In addition to China leading in costs, the 10% production tax credit from the US IRA provides US companies with a competitive edge over their European counterparts (on top of the 45 USD/kWh at cell level that can be transferred across the value chain). Given that several European cathode producers plan facilities in North America, potentially receiving priority due to the US IRA incentives, it becomes crucial for the EU to level the playing field to ensure the business case to manufacture locally. T&E analysis shows that an Opex support of 10% in Europe would be equivalent to 4-5 EUR/kg cathode including raw materials, or 1-2 EUR/kg cathode excluding raw materials. Crucially, any such support should be predictable, easy to access and output-based, avoiding the current complex grant and subsidy rules prevailing at the EU level.

Despite a flurry of lithium project announcements in Europe, the region remains the most expensive in terms of building and operating lithium hydroxide plants. T&E analysis shows that an Opex support of 16% from the EU to sustainable lithium projects could fill the gap with the US. In absolute terms this is equivalent to 600 EUR/t of lithium hydroxide (or 0.6 EUR/kg of lithium hydroxide), excluding raw materials costs.

Overall, T&E estimates that developing all the announced capacities for battery cell manufacturing, CAM and pCAM manufacturing and lithium refining in Europe (including non-EU countries) will require EUR 215 billion in Capex and EUR 61 billion in annual Opex, coming primarily from private investment.

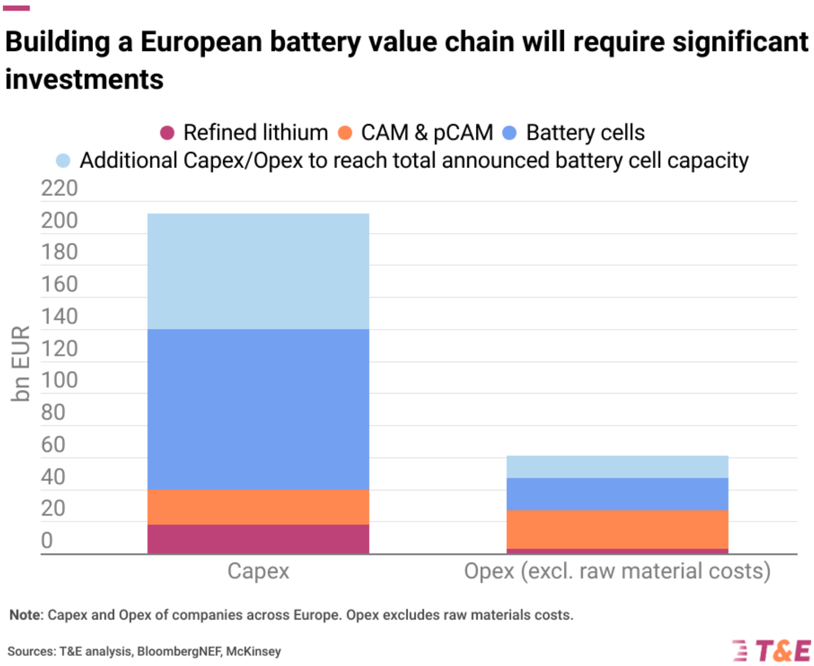


Figure 33: Required Capex and annual Opex for the production of refined lithium, CAM and pCAM, and battery cells in Europe by 2030

However, considering the significant financial requirements and to ensure the level playing field for companies investing into Europe, the EU should consider presenting an EU-wide package close in ambition to the US IRA. T&E estimates that for European companies to reach a similar level of Opex costs (in absolute terms, in EUR/t) as that of US companies the US IRA incentives, supporting up to 10% of the Opex for CAM and pCAM production and 16% of Opex for lithium hydroxide production would be required. In total, this support would amount to around EUR 2.6 bn annually to EU-based companies.[22]

[22] More details on the assumptions behind this analysis can be found in the Methodology section of the report.

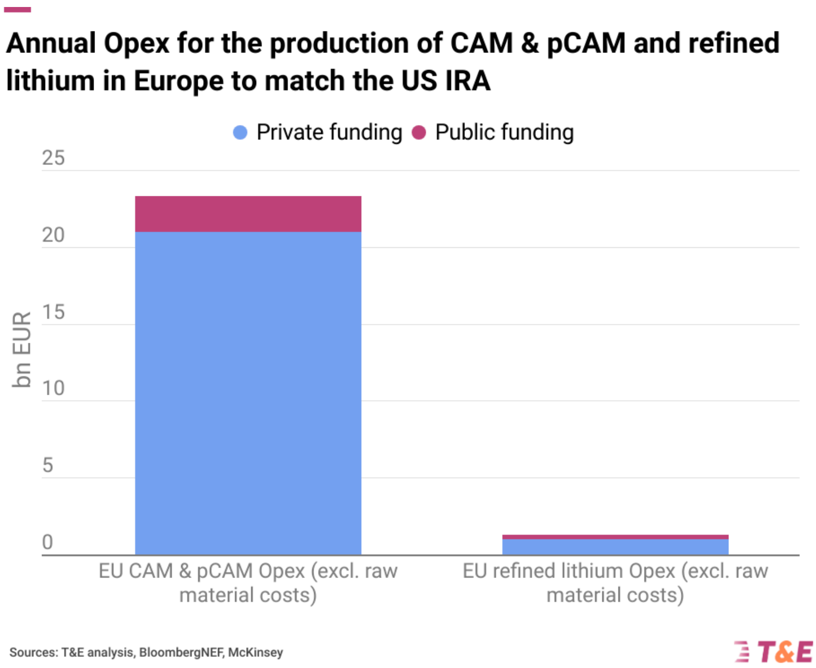


Figure 34: Estimated annual Opex support for the production of CAM & pCAM and refined lithium in the EU by 2030 to match the US IRA

5. A blueprint for industrial strategy in Europe

5.1 European potential exists

Decarbonisation of the economy is not possible without a massive scale-up of green technologies and their resilient supply chains. Within the global race to onshore the future green supply chains, the battery value chain stands out as one of the most valuable. Over half of the investments into key cleantech globally today - including solar, wind and hydrogen - goes into batteries. By 2030, the investment needs into batteries are more than three-quarters of the EUR 90 bln overall cleantech needs by 2030 according to Commission's own estimates for the Net Zero Industry Act. This places the battery supply chain at the top of the global cleantech race, explaining the fierce competition between China, US, Europe and many others.

A significant potential to onshore best-in-class factories and responsible minerals supply exists across Europe: all of our battery cells can be produced domestically from 2026, over half of cathode active materials - the most valuable battery compound - can be manufactured in the EU, and 100% of lithium itself can be sourced locally.

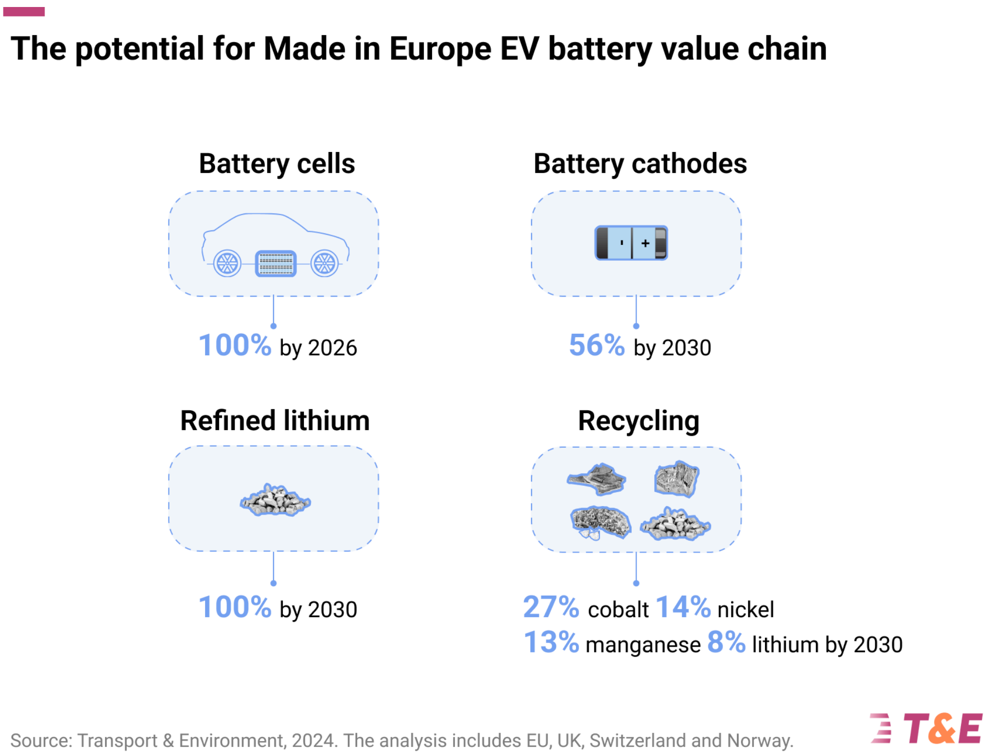


Figure 35: The potential for Made in Europe EV battery value chain

What's more, doing this locally can also be a good environmental policy. Local manufacturing means Europe can set and enforce environmental and social standards, as well as stipulate the effective and meaningful engagement of local communities. The sourcing rules in the new EU Battery regulation mean that not only batteries and materials produced in Europe, but any lithium, nickel, cobalt and graphite from anywhere in the world have to be sourced responsibly.

From a purely climate perspective, manufacturing some of the more energy intensive and valuable materials in Europe can also slash their carbon emissions. Compared to the cathode active material currently produced in China, European material would come with a reduced carbon footprint of 12%. Local sources of nickel would be 85-95% lower in emissions than the current supply from Indonesia, while lithium will come with an up to 50% improvement to Australian ore processed in China or even reach negative values in the case of DLE. Overall, if all batteries and cathodes were made in Europe rather than imported from Asia, and the local minerals potential was fully exploited, CO2 emissions in the order of 133 Mtonnes can be saved by 2030, comparable to the emissions produced by entire Chile or the Czech Republic in 2022 [1].

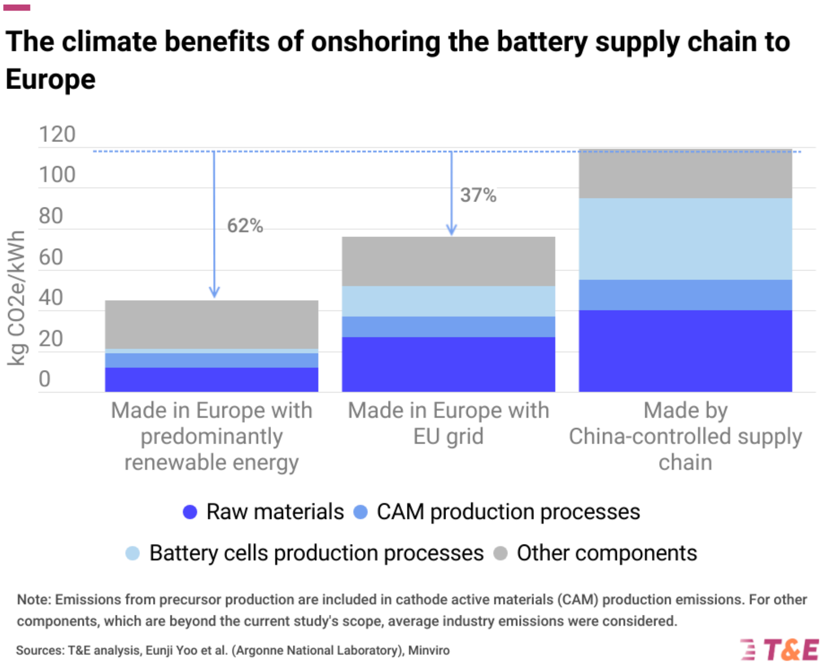


Figure 36: GHG emissions from raw materials, cathode and battery production

But reaping these benefits will not be easy. On the one hand, significant challenges in scaling this potential exist ranging from building new expertise and skilled workforce, securing the raw materials needed for all these battery facilities and providing sufficient but proportionate funding support. On the other hand, Europe is not doing any of this in a vacuum but at the time of heightened geopolitical rifts and a fierce "battery arms race" across the world. A year on since we started our risk assessment index, an estimated 54% of battery plans in Europe are still at risk of either being delayed or cancelled due to the better conditions abroad.

5.2 How can Europe make it happen?

Europe does not have the cash bazooka of the US IRA, nor the command capitalism of China. So what are those strengths that we do have that can help us succeed?

Ironically, the West once had a lead in battery technology in the 1970s and 1980s. But the interest in clean tech subsided as the oil price fell, just as China started to acquire the technological knowhow. Fast forward to today and China has an unprecedented lead following decades of ambitious policy and long-term investment agenda. The first lesson is that this is a long haul game and should not be undermined by short-term politics or election plays.

Some attempts to rebuild were also seen in the US in the early 2000s when Obama's Recovery Act supported battery, solar and other green start-ups. But no ambitious climate policy meant that no local demand was in sight. So the second lesson is that this cannot be built on subsidies alone, important as financial support is, but requires a market pull. So to build this sector, an ambitious and stable green policy framework, notably the 2025 - 2035 car CO2 framework in the EU and the ZEV mandate in the UK, is paramount.

Today Europe is home to the world's largest consumer block and market. 38 million electric vehicles will be necessary by 2030 to meet the car emissions goals. The EU will need over 1 TWh of batteries in the same timeframe, making the region an excellent business case for any investor. All this is in large part thanks to forward-looking policies, such as the European Green Deal and the 2035 zero emission car goal, that create a monumental green business opportunity and investor certainty.

But this decarbonisation push cannot result in deindustrialisation. This means that electric cars, battery cells and minerals that go into them are -to at least a sufficient share - produced in Europe by all manner of companies bringing local jobs and growth.

Europe therefore needs to create a clear business case to invest locally.

For more than a year since T&E and many others called for this, there has been some progress. A number of helpful policy frameworks have been agreed, notably the Net Zero Industry Act designed to accelerate battery factories and other cleantech industries across Europe, and the Critical Raw Materials Act set to secure responsible supply of critical metals, including recycling. The relaxation of state aid rules have also helped to avoid some of the battery investments, notably Northvolt's plans in Germany, from being delayed in favour of the US but mostly benefits companies in Germany and France. Overall, 58% of Europe's battery demand is already supplied locally.

But the risks remain manyfold. First, the imports of Chinese-made electric cars are posing an immediate risk to the very survival of Europe's automotive giants. 1 in 5 electric cars sold across the EU last year was built in China, with the shipments of BYD, MG and other Chinese brands growing quickly. Second, no fresh EU-wide investment on the scale of the US IRA is so far in sight, while some carmakers have started to ask for the upcoming 2025 car CO2 goal to be relaxed. This risks undermining the key pull to invest into electrification across the European market. Third, while some progress has been made on battery cells, huge gaps in the midstream, notably cathode materials, remain. With most expertise and lower costs in China, the question is how can Europe quickly ramp up these often low margin high volume industries?

Ultimately, the EU is just at the start of its journey to onshore the supply chain with most of the battery and materials factories yet to start operating commercially, and most of the supply chains yet to be secured. The task ahead is monumental, but it can be done.

5.3 T&E's blueprint on industrial strategy (recommendations)

Clear policy

Clear long-term policy is paramount to investment certainty. Europe's recently announced 2040 climate framework, aiming for -90% carbon reduction, makes the case for scaling clean tech in Europe and decarbonising transport even faster than foreseen under the EU Green Deal. Given the global race, Europe cannot afford to spend another 5 years reviewing its Car CO2 standards and debating the long-term trajectory. Instead, governments and companies across the continent should double down on fast implementation and delivery.

As such, it is critical to:

- **Keep the 2025-2035 car CO2 regulation unchanged** and not review or weaken the targets, alongside other key Fitfor55 transport policies;
- Without delay, put in place additional measures to meet the 2040 -90% climate target in road transport, including **faster corporate fleet electrification** and measures to phase-out fossil cars from the existing cars fleet, such as scrappage;
- Keep regulations ambitious, **technology smart** and simple (no "climate neutrality" confusion) to provide a clear push for investors and the market to timely invest into the EV value chain.

Made in EU

Decarbonisation of Europe's transport system cannot result in deindustrialisation. EV value chain from charging networks to battery and chemical production offers many new business and job opportunities that will more than compensate for the jobs lost in fossil fuel industries. It is critical that electric cars, battery cells and most materials that go into them are produced in Europe. What matters is location, not the ownership of companies.

The climate policies therefore need to be accompanied by measures to reward local manufacturing. But this should not result in protectionism from meaningful competition or slowing down of the EV uptake; instead any policy to reward Made in EU should be accompanied by accelerated EV production plans.

European Commission and national governments should:

- Build **resilience aspects** into various public procurement and subsidy rules around electric cars and battery value chain manufacturing, such as the NZIA provisions allowing for local bids to be prioritised. E.g. loans under the European Investment Bank to EV or battery manufacturers and EU grants under the EU Innovation Fund should require firm offtake agreements for locally sourced components and materials.
- Reward more **sustainable local manufacturing** (carbon emissions, environmental stewardship and responsible business conduct). This can be done via ambitious battery carbon footprint rules that should be proposed without delay. Similarly, national EV subsidies or clean manufacturing contracts can be used, as is currently done in France with its "eco score" concept. This should be based on a harmonised EU-wide methodology on how to calculate the performance to uphold the single market.
- Add **conditions on local labour** engagement and upskilling into the national subsidies given to the EV battery supply chain facilities under the state aid rules.

Another issue is the growing electric car and battery cell production overcapacity in China. While in the short run European consumers stand to gain from cheaper EVs, they may be left with less choice in the long run, as Chinese (and American) carmakers gain huge market power.

Foreign battery cells and components flooding the EU market can also severely disrupt European industry and could put thousands of existing and future jobs on the line. The political and economic impacts of this could be dangerous.

This means Europe should also revamp its **trade policy** to fit its industrial strategy objectives. This means:

- Bringing the announced anti-subsidy probe into Chinese EVs to an effective conclusion and, if unfair subsidies are found, **increasing the EV import tariffs** to at least 25%. T&E estimates this will bring between EUR 3 and 6 billion [93] in additional revenue to EU and national budgets.
- In the absence of stronger Made in EU measures, increasing **import tariffs on battery cells** might be the last resort to help the local capacity scale on time.

Funding

The European Green Deal needs to be beefed up by a sizable investment package at EU level to help scale the technologies and create the business case to invest in Europe. This includes:

- Introducing a EUR 400 billion **Green Industry Fund** between 2025-2034, with priority investment to de-risk and scale manufacturing of clean battery value chain technologies, notably cathode active material and battery recycling. The Fund should boost the resources of already existing and scalable EU financing instruments: the EU Innovation Fund and the InvestEU Fund.
- Quickly operationalise the **EU Battery Fund** (under the EU Innovation Fund) to ensure the first auction is up and running no later than Q4 2024, that best-in-class cleanest projects are rewarded and focusing on the OPEX to bridge the cost gap and the midstream of the battery supply chain.
- The **InvestEU Fund** should focus on projects facing economic or technological risks, enabling public banks (National Promotional Banks and the EIB Group) to take higher risks and scale up the manufacturing of battery cells and key components. This should include support to both Capex and Opex with predictable and upfront support via production loans. InvestEU should also crowd in private investments, similar to the recent support scheme to Northvolt [94].
- The **European Investment Bank** (EIB) should enhance its support to best-in-class projects in the EV batteries value chain. The bank should step up support to critical raw materials, including refining and recycling. The EIB should ensure complementarity with national funds set up in France (Critical Metals Fund) and Germany to support raw materials and provide co-financing and risk-sharing instruments (like first loss guarantees to mitigate the risks for investors under the national schemes). The EIB Group should provide guarantees and counter-guarantees to commercial banks for investments across the EV value chain to de-risk private investments contributing to the green industrialisation of the EU.
- Focus the research and innovation funding on affordable, scalable and sustainable alternatives to batteries, eg resource-light chemistries.

Building the supply chain

Focus in the next few years has to shift from regulatory frameworks to their effective implementation, i.e. execution of the battery supply chain projects in Europe. This means:

- Sharp **focus** on cathode active materials and minerals processing, in order to scale the announced projects in Europe. CRMA's Strategic Projects should be selected in line with the 2030 benchmarks: at least 40% should be in the area of minerals processing. The EU financial arms, notably EIB, should be brought in to ensure the successful scale up of the selected projects. Investments should go into fossil-free sustainable processes from the outset, e.g. bioheap leaching in the case of nickel or direct lithium extraction in the case of lithium.
- European downstream players, notably automotive, battery and renewables companies should work closer with local players in the supply chain, providing **firm long-term offtake** guarantees and investing/co-partnering to scale nascent companies.
- High ESG criteria should be built into the European private investment framework to give local manufacturers an upper hand, e.g. via smart **taxonomy** rules around minerals processing and refining.
- Building out large scale renewables capacity should go hand in hand with scaling the battery value chain in Europe to enable companies to decarbonise all manner of industrial processes.

When it comes to battery **raw materials** themselves, a mixed strategy of local and international is key. Locally,

- Europe should double-down on scaling **recycling** and metallurgical recovery capacities to ensure valuable battery waste is turned into new battery cells locally and not exported to Asia. This means prioritising integrated recyclers as strategic projects under CRMA, and limiting end-of-life battery and black mass exports outside of Europe.
- Prioritising innovative technologies with less impact, notably repurposing tailings from the existing mining sites, or "**remining**" (as is planned in Czechia) as part of CRMA's implementation.

Internationally,

- Turning the **Strategic Partnerships** into a pipeline of responsible global projects with secured offtake for EU downstream companies and increased value to the resource-rich countries. Focus should be on de-risking investments in resource-rich countries, e.g. Argentina in South America, the Philippines in Asia and African nations. The European Commission and the member states should consider buying stakes (equity) in the most strategic projects globally and investing into the transport and energy infrastructure to enable those as part of Europe's Global Gateway programme.
- Building a diverse supply chain and transparent market for raw materials, notably via the EU's involvement in the **Minerals Security Partnership** and similar initiatives.

Do it all, sustainably

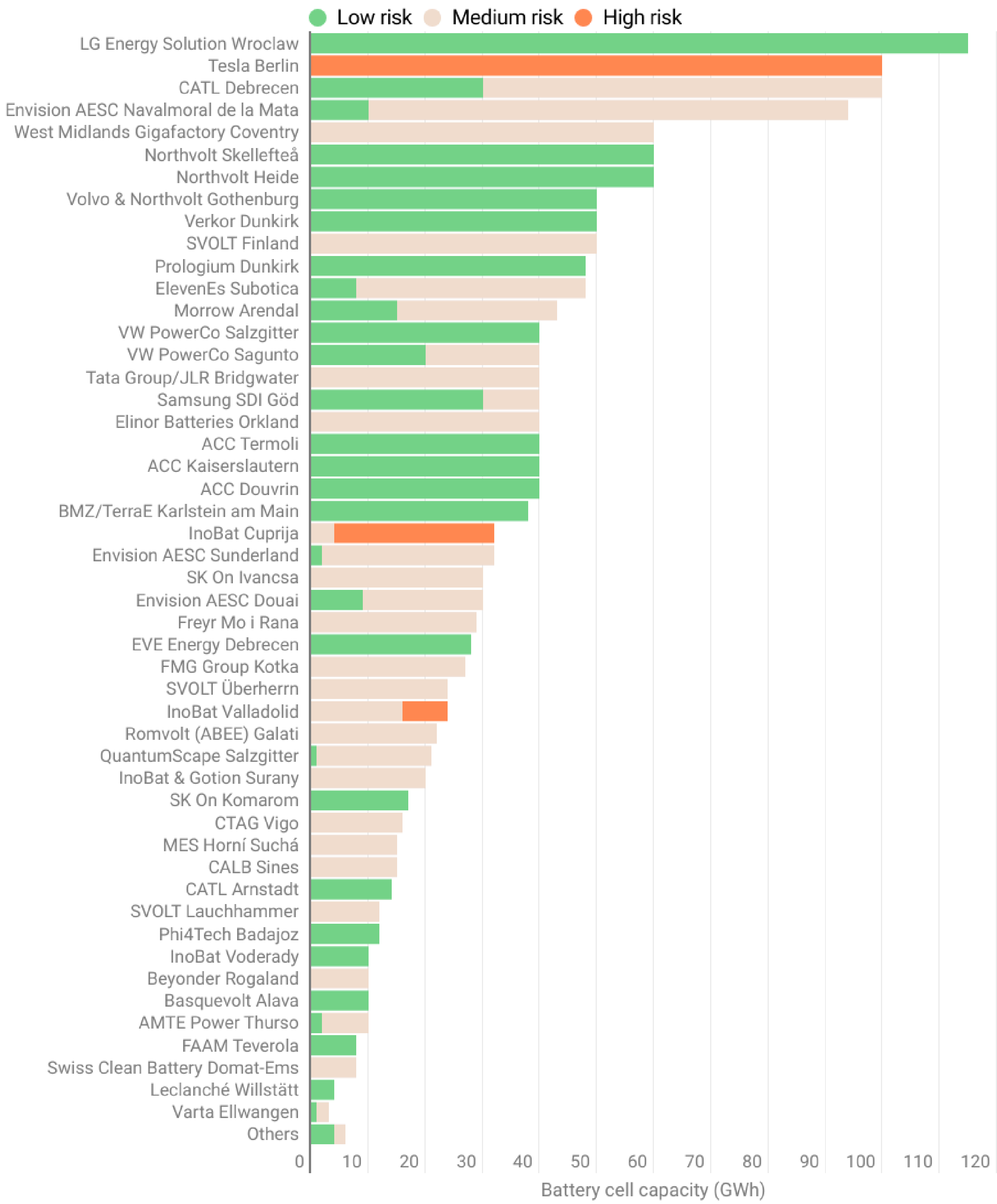
Sustainability in its broadest sense - as higher social and environmental stewardship, responsible business conduct and respect of local communities and Indigenous Peoples - is one of Europe's USPs and should be the leitmotif of this entire transformation.

This includes:

- Quick and ambitious implementation of the human rights and environmental **due diligence** provisions under the EU Battery Regulation, with a positive spillover effect globally. This should result in downstream companies engaging to improve the conditions on the ground, not cancelling problematic suppliers out.
- Bringing Europe's own mining laws in line with global best practice, notably upgrading the EU Extractive Waste Directive to require filtered tailings and better tailings categorisation, monitoring and management.
- Requiring companies to operate in accordance with highest standards globally, implementing the OECD's guidelines for responsible business as a minimum. Particular attention should be given to better biodiversity practices, including requiring companies to conduct baseline assessment of habitats, to be able to better monitor and mitigate their impact. Further, mining companies operating globally should be assessed against the Initiative for Responsible Mining Assurance (IRMA) standard to guarantee higher standards and greater transparency.
- The fastest way to secure permits is to do things right, which means early and meaningful engagement of local communities and Indigenous Peoples, following the principles of Free, Prior and Informed Consent (FPIC). Grievance mechanisms and access to remedy schemes should also be put in place, to also ensure greater accountability.

Annex 1: Risk assessment of European gigafactories

Risk assessment of European gigafactory plans



Source: T&E analysis of publicly announced battery production projects planned up to 2030

Annex 2: Methodology

1. Battery demand

The battery demand in Europe (defined as EU, UK, Norway and Switzerland) was calculated taking into account the following factors:

- Annual sales of new vehicles and vehicle electrification rates, modelled in-house by T&E's inits EU Transport Roadmap Model (EUTRM). The EUTRM models the EU's fleet of light-duty and heavy-duty vehicles and is used to assess the impact of the CO2 standards on fleet composition, energy and oil consumption, and CO2 emissions;
- Battery capacities for each vehicle segment (in kWh), using data from GlobalData and TNO [95, 96].

The battery demand presented in the report is in the Regulatory scenario, a scenario developed by T&E which aligns with EU regulations on CO2 emission standards for light and heavy duty vehicles.

Vehicle category	2025	2030	2035	2025	2030	2035
	Electrification rate (% share)			New EV sales (in million units)		
Cars (BEV)	25%	62%	100%	3.6	9.6	15.8
Cars (PHEV)	9%	3%	0%	1.3	0.5	0.0
Vans	4%	38%	98%	0.1	1.0	2.9
Buses	36%	90%	100%	0.006	0.017	0.018
Coaches (1)	5%	42%	63%	0.002	0.013	0.020
Trucks (1)(2)	6%	28%	50%	0.03	0.15	0.26

Table 3: Electrification rate and sales of electric vehicles in Europe

(1) Includes battery electric and fuel cell vehicles.

(2) Trucks include small, medium, heavy, vocational, special and other truck segments; battery electric and fuel cell vehicles.

Average battery size (kWh)	2025	2030	2035
Cars & vans (BEV)	71	74	74
Cars (PHEV)	15	16	16
Buses (BEV)	267	253	253
Coaches (BEV)	702	627	622
Small trucks (BEV)	118	110	110
Medium trucks (BEV)	390	350	350
Heavy trucks (BEV)	702	627	622
Special heavy, vocational, other trucks (BEV)	489	457	449
Coaches and trucks (fuel cell - FCEV)	140	140	140

Table 4: Average battery size by vehicle type

2. Battery gigafactories

T&E tracks the nameplate capacity of battery cell factories planned in Europe based on publicly available information. The expected production was calculated taking into account progressive capacity utilisation rates and scrap ratios, both depending on the maturity of the plant. It was assumed that in the early stages, plants will have lower utilisation rates and higher scrap rates which are expected to improve over time (e.g. reaching 85% capacity utilisation rate and 5% scrap rate after several years of operations).

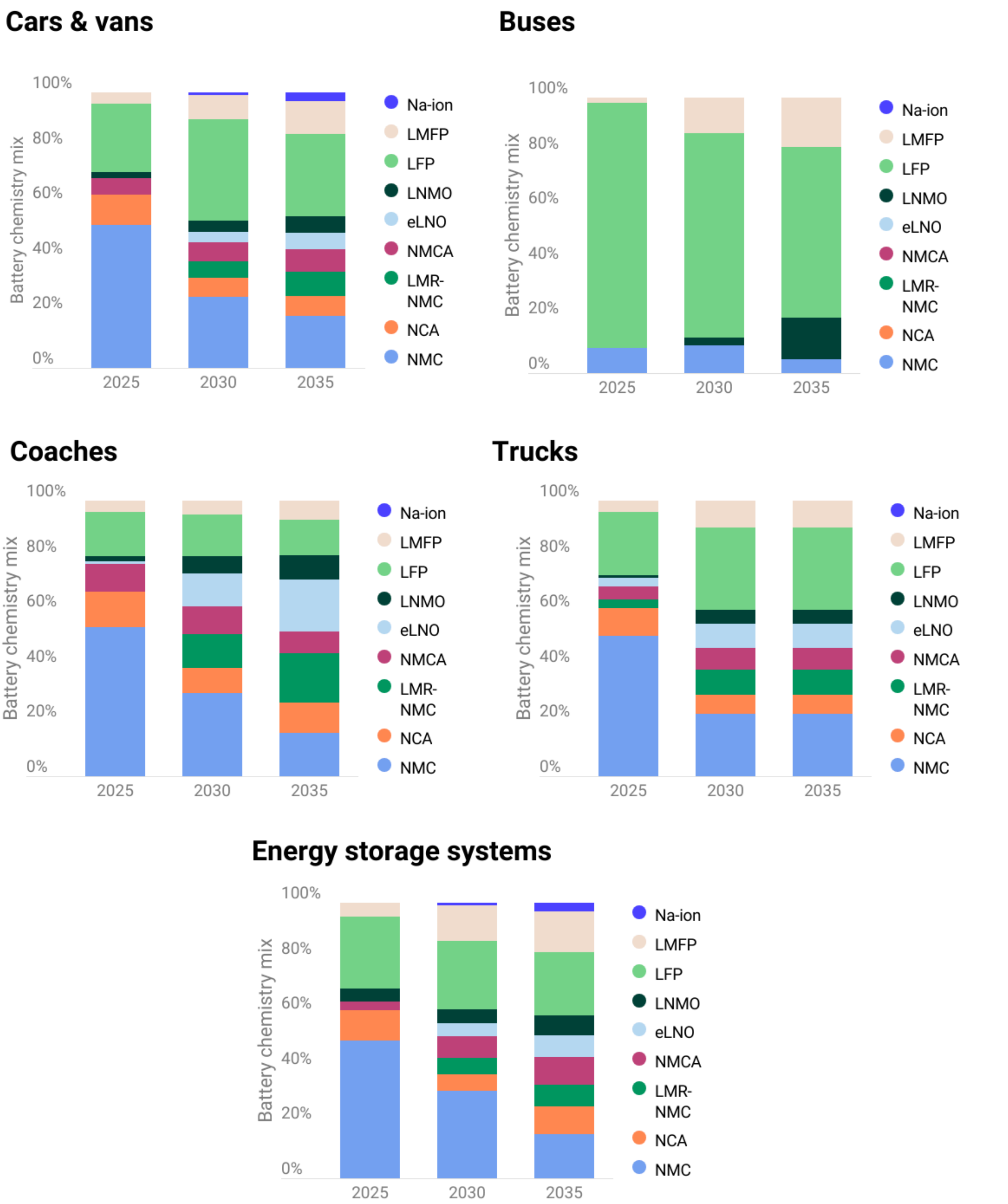
T&E's risk assessment of European gigafactories analyses their status, assigning a risk category (low, medium, high) to each phase of each plant. Risk is defined as the risk of the plant being delayed, scaled down or not materialising. T&E used information from publicly available sources, their expert judgement and interpretation of this information, along with and in-house estimates.

The risk category is calculated based on a scoring system that takes into account six equally weighted factors, each with a rating of 0 to 2, where 0 is low risk and 2 is high risk. These factors are: 1. Secured funding 2. Secured location 3. Construction status & permitting 4. Investments from European OEMs or support from the EU 5. Already planned projects in the US 6. Cooperation with the US OEMs.

3. Cathode active materials & precursors

The demand for CAM and pCAM (in kt) was determined taking into account the estimated battery demand (in GWh), the chemistry mix, as well as cathode and precursor mass per kWh for each chemistry, with data sourced from BloombergNEF [97]. Additionally, yield losses from manufacturing processes were considered, i.e. 2% for the precursor manufacturing stage and 2% for the cathode manufacturing stage [98]. For example, 1 kWh of battery in 2030 would require on average 1.6 kg of cathode and 1.4 kg of precursor.

Regarding the chemistry mix, the following splits were assumed for cars, trucks, buses and coaches, based on data from BloombergNEF, but also T&E's own assumptions on the evolution of chemistries.



Sources: BloombergNEF, T&E analysis

Figure 37: Chemistry mix by vehicle type

On the supply side, T&E identified the following CAM and pCAM projects to be developed in Europe by 2030.

Company	Country	Product
BASF	Germany	CAM, pCAM(?)
EcoPro & Samsung SDI JV	Hungary	CAM
EGE Kimya	Poland	pCAM
Finnish Minerals Group & Beijing Easpring JV	Finland	CAM
Finnish Minerals Group & Freyr	Finland	CAM
Finnish Minerals Group & CNGR JV	Finland	pCAM
Freyr & Aleees JV	Norway	CAM
Haldor Topsoe	Denmark	CAM
Huayou Cobalt	Hungary	CAM
IBU-tec	Germany	CAM
Northvolt	Sweden	CAM, pCAM
Orano & XTC JV	France	CAM, pCAM
Pure Battery Technologies	Germany	pCAM
Umicore	Poland, Finland	CAM, pCAM
Umicore & Volkswagen JV	Poland	CAM, pCAM

Table 5: Companies planning CAM and pCAM plants in Europe by 2030

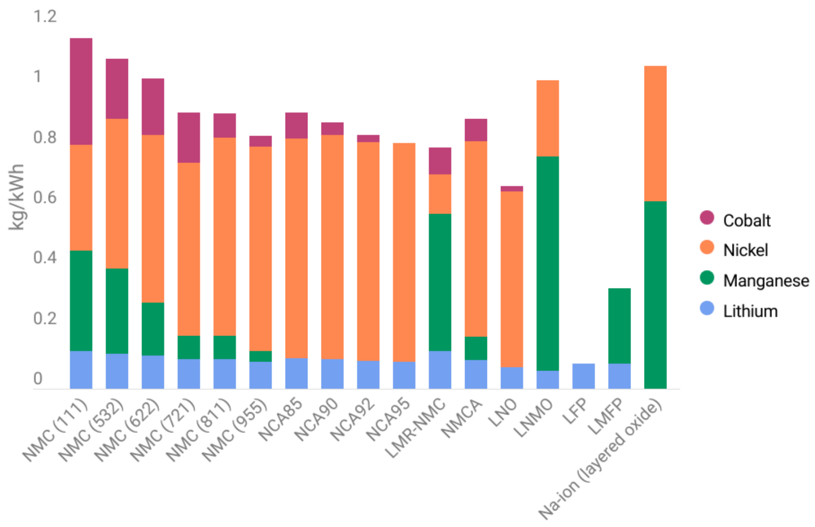
4. Raw materials

The demand for raw materials was estimated based on the following factors:

- Battery chemistry mix for cars, trucks, buses, coaches and energy storage systems, sourced primarily from BloombergNEF [99] [100];
- Metal intensity data for each chemistry (in kg/kWh), sourced from BloombergNEF [97];
- Assumed material losses from production processes added to the net demand of raw materials, resulting in gross demand (i.e. 2% for cathodes, 2% for precursors, 11% from battery cell production on average) [98].

The raw materials volumes are presented on a metal content basis for lithium, nickel and cobalt. Lithium volumes are expressed in lithium carbonate equivalent (LCE), except in the battery recycling section where lithium volumes available for recycling are shown in kt of metal contained.

Metal content by chemistry



Sources: BloombergNEF, Wood Mackenzie

Figure 38: Metal mass by chemistry

To assess Europe's full potential for refined lithium supply, all operating and publicly announced future projects have been considered. However, it is important to note that the nameplate capacity figures presented are indicative of the potential and real-world production may vary. The list of companies planning projects includes integrated and stand-alone refining plants (and excludes companies with mining operations only). The Jadar project in Serbia led by Rio Tinto was not included as it is currently put on hold.

Company	Country	Type	Capacity in 2030 (kt LCE)	Capacity in 2030 (kt Li)
AMG Lithium	Germany	Refinery	17.6	3.3
Bondalti Chemicals & Neometals	Portugal	Refinery	21.9	4.1
British Lithium & Imerys	UK	Integrated	20.0	3.8
Cornish Lithium	UK	Integrated	6.8	1.3
Cornish Lithium & Geothermal Engineering	UK	Integrated	1.0	0.2
Eramet & Electricité de Strasbourg	France	Integrated	10.0	1.9
European Metals	Czech Republic	Integrated	25.8	4.8
Green Lithium	UK	Refinery	43.9	8.3
Imerys	France	Integrated	29.8	5.6
Infinity Lithium Corp.	Spain	Integrated	29.2	5.5
Keliber Oy	Finland	Integrated	13.2	2.5
LevertonHELM	UK	Refinery	21.6	4.1
Lithium de France	France	Integrated	32.0	6.0
Lithium Iberia	Spain	Integrated	26.3	5.0
Livista Energy	Germany	Refinery	32.0	6.0
Livista Energy	UK	Refinery	30.0	5.6
LusoRecursos Portugal Lithium	Portugal	Integrated	18.7	3.5

Company	Country	Type	Capacity in 2030 (kt LCE)	Capacity in 2030 (kt Li)
Northern Lithium	UK	Integrated	6.6	1.2
Northvolt & Galp	Portugal	Refinery	28.1	5.3
RockTech Lithium	Germany	Refinery	21.1	4.0
RockTech Lithium	Romania	Refinery	21.1	4.0
Tees Valley Lithium	UK	Refinery	84.3	15.8
Viridian Lithium	France	Refinery	21.9	4.1
Vulcan Energy Resources & Enel Green Power	Italy	Integrated	0.0	0.0
Vulcan Energy Resources	Germany	Integrated	42.1	7.9
Zinnwald Lithium	Germany	Integrated	10.5	2.0
Total			**615.4**	**115.7**

Table 6: Announced lithium projects in Europe by 2030

Company	Country	Products
Hellenic Minerals	Cyprus	Nickel sulphate
Nornickel	Finland	Nickel sulphate, nickel metal
Terrafame	Finland	Nickel sulphate
Glencore	Norway	Nickel metal
Sibanye Stillwater	France	Nickel metal, other nickel chemicals
Vale	UK	Nickel metal

Table 7: Nickel refining operations in Europe

Company	Country	Products
Hellenic Minerals	Cyprus	Cobalt sulphate
Nornickel	Finland	Cobalt sulphate
Terrafame	Finland	Cobalt sulphate
Umicore	Finland	Cobalt sulphate and other cobalt chemicals, cobalt powder
Glencore	Norway	Nickel metal
Jervois		Cobalt powder
Sibanye Stillwater	France	Other cobalt chemicals

Table 8: Cobalt refining operations in Europe

5. Battery recycling

The future availability of recycled batteries (in GWh) was calculated based on the battery demand in the Regulatory scenario developed by T&E and multiple assumptions related to end-of-life batteries and production scrap (or scrap generated by gigafactories), including:

- End-of-life batteries from electric vehicles: 100% collection rate from 2025 onwards, assuming maximum potential; a battery lifespan of up to 20 years following a gradual retirement curve with the majority of vehicles reaching end-of-life between year 10 and 15; a share of 30% of batteries assumed to be used in second life applications for around 5 years longer (sources: T&E, Circular Energy Storage [101], BloombergNEF [99] [100]);

- End-of-life energy storage system batteries: 100% collection rate; average lifespan of around 10 years (sources: T&E, BloombergNEF [102] [100]);
- Production scrap: estimated as part of T&E's gigafactory capacity and production analysis. Lower capacity utilisation rates and higher scrap ratios were assumed during the initial stages of plant production ramp-up and a maximum 85% capacity utilisation and 5% scrap ratio after several years of operations.

To ensure comparability with announced recycling projects in Europe by 2030, the recycling availability of batteries in GWh was converted into kilotonnes (kt) of batteries, using yearly pack energy density data from BloombergNEF for electric cars [97]. The project pipeline figures were sourced from Circular Energy Storage [103].

Furthermore, the metal recovered from battery recycling was derived by considering the chemistry mix of the recycling feedstocks and the metal mass for each chemistry, sourced from BloombergNEF [97], as well as assumed recovery rates for lithium, nickel, cobalt and manganese, supported by the Battery Regulation. Recovery rates for 2025 were estimated by T&E.

	2025	2027	2030	2035
Lithium	46%	50%	80%	80%
Nickel	89%	90%	95%	95%
Cobalt	90%	90%	95%	95%
Manganese	89%	90%	95%	95%

Table 9: Recovery rates for lithium, nickel, cobalt and manganese

While this analysis excludes certain battery applications such as micromobility, maritime and consumer electronics, it is important to note that including them would further increase Europe's recycling potential.

6. Climate benefits of onshoring in Europe

The carbon emissions analysis focused on NMC 811 batteries and encompassed several production scenarios: "Made in Europe with Predominantly Renewable Energy", "Made in Europe with EU grid" and "Made by China-Controlled Supply Chain".

Emissions associated with battery cell production across these scenarios were modelled in-house by T&E [104] based on data from Minviro [105] and IVL [106].

Cathode-related emissions were estimated taking into account emissions from cathode and precursor production processes (e.g. precursor synthesis via precipitation, using natural gas; cathode production via calcination, using electricity) from secondary sources [45]. These emissions were then applied to the Swedish, average EU and Chinese electricity grids, depending on the scenario [104].

Raw materials emissions for each scenario were calculated as follows:

- "Made in Europe with Predominantly Renewable Energy": emissions associated with best production routes, e.g. lithium via Direct Lithium Extraction (DLE) in Germany, nickel via bioheap leaching in Finland, and manganese via electrowinning and metal dissolution in Europe using renewable energy;
- "Made in Europe with EU Grid": emissions from raw materials produced with EU grid, e.g. lithium in Finland, manganese in Czech Republic, or industry averages for nickel and cobalt;
- "Made by China-Controlled Supply Chain": emissions associated with China-controlled production routes, e.g. Australian spodumene processed in China, nickel via HPAL in Indonesia, manganese produced with the Chinese grid mix.

It must be noted that the analysis does not factor in emissions from transportation, except for raw materials mining and refining. Therefore, the benefits associated with onshoring the supply chain may be even greater than those presented in this report.

7. Skills & expertise

In order to estimate the number of jobs needed to build the announced capacities at gigafactories, CAM and pCAM plants, lithium refining and battery recycling, the following data was estimated per unit of capacity, respectively. The data was sourced from EIT InnoEnergy [79], CEPS Energy Climate House [80] and T&E estimates based on projects for which data was available (i.e. 13 lithium companies and 9 CAM and pCAM companies reported future job requirements).

Battery value chain stage	Number of jobs per unit of capacity	Total number of jobs
Battery cells	90 per GWh	~158 k
CAM & pCAM	10 per kt CAM & pCAM	~16 k
Refined lithium	12 per kt LCE (or 10 per kt LiOH)	~13 k
Battery recycling	15 per kt batteries input	~7 k

Table 10: Potential job creation in the European battery value chain based on capacities by 2030

8. Funding

To calculate the investments required for the battery value chain stages discussed in the report, T&E gathered data from multiple sources and also made its own estimations and relied on proxy data, due to the scarcity of readily available figures on Opex and Capex:

- Battery cells: Capex data for gigafactories was sourced from the European Commission, which referenced BloombergNEF data [92]. Opex excluding raw materials was calculated as an aggregate of labour, electricity and water costs per kWh of NMC 811 battery produced across regions during 2022 and 2023, with the European average based on Germany and Poland. The data was retrieved from BloombergNEF's bottom-up battery cost model (BattMan).

- CAM/pCAM: Capex figures were estimated or obtained from public sources [107]. Battery Opex, described above, was used as a proxy for CAM Opex, due to lack of data. This Opex data was converted from USD/kWH to EUR/kg CAM and averaged for the years 2022 and 2023. It was assumed that CAM and pCAM plants have similar costs.
- Refined lithium: Capex and Opex figures were estimated based on discussions with McKinsey and publicly available data on individual projects.

Battery cells	**Capex intensity**	**Opex excl. raw materials**
Europe	EUR 100 million per GWh	EUR ~20 per kWh
China	EUR 68 million per GWh	EUR ~12 per kWh
USA	EUR 94 million per GWh	EUR ~20 per kWh

CAM/pCAM	**Capex intensity**	**Opex incl. raw materials**	**Opex excl. raw materials**
Europe	EUR ~14,000 per t	EUR ~45 per kg	EUR ~15 per kg
China	EUR ~11,000 per t	EUR ~40 per kg	EUR ~8 per kg
USA	EUR ~14,500 per t	EUR ~45 per kg	EUR ~15 per kg

Refined lithium	**Capex intensity**	**Opex excl. raw materials**
Europe	EUR ~26,000 per t of LiOH	EUR ~3,600 per t of LiOH
China	EUR ~9,000 per t of LiOH	EUR ~2,400 per t of LiOH
USA	EUR ~20,000 per t of LiOH	EUR ~3,300 per t of LiOH

Table 11: Estimated Capex and Opex across the battery value chain in Europe, China and the US

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