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INTELLECTUAL PROPERTY AND TECHNOLOGY TRANSFER IN THE GLOBAL ELECTRIC VEHICLE INDUSTRY

WŁASNOŚĆ INTELEKTUALNA I TRANSFER TECHNOLOGII W GLOBALNYM PRZEMYŚLE POJAZDÓW ELEKTRYCZNYCH

Abstract: This article tries to make sense of how intellectual property regimes, joint venture (JV) requirements and industrial policy instruments are redistributing research and development (R&D) capacity across the global electrified vehicle industry. The evidence base is primary policy texts, corporate annual reports and patent statistics from the European Patent Office (EPO), the International Energy Agency (IEA) and the filings of the major automakers. Whichever dataset I started from, I kept arriving at the same conclusion: the centre of gravity for cell chemistry, battery integration and power electronics now sits in East Asia, and within East Asia it keeps shifting toward the People's Republic of China. No single league table captures this, though. The European Union still leads in vehicle integration and software defined safety, the United States in premium battery electric design and software architecture; Korea sells the highest value cells, and Japan remains well ahead of everyone in fuel cell and solid state research. Reading the evidence through Schumpeter, through Cohen and Levinthal on absorptive capacity, Teece on profiting from innovation, Dunning's eclectic paradigm and Mazzucato's entrepreneurial state, I argue that EV competition in this century amounts to strategic trade policy fused with forced learning, and that states have learned to treat IP appropriability as a weapon.

Zarys treści: Artykuł stanowi próbę wyjaśnienia, w jaki sposób reżimy ochrony własności intelektualnej, wymogi tworzenia wspólnych przedsięwzięć (joint ventures, JV) oraz instrumenty polityki przemysłowej redystrybuują potencjał badawczo-rozwojowy (B+R) w globalnym przemyśle pojazdów zelektryfikowanych. Podstawę empiryczną stanowią źródłowe dokumenty z zakresu polityki publicznej, roczne raporty przedsiębiorstw oraz statystyki patentowe Europejskiego Urzędu Patentowego (EPO) i Międzynarodowej Agencji Energetycznej (IEA), a także zgłoszenia patentowe największych producentów samochodów. Niezależnie od tego, od którego zbioru danych zaczynałem, za każdym razem dochodziłem do tego samego wniosku: środek ciężkości w dziedzinie chemii ogniw, integracji baterii i energoelektroniki leży dziś w Azji Wschodniej, a w jej obrębie wciąż przesuwa się w stronę Chińskiej Republiki Ludowej. Żaden pojedynczy ranking nie oddaje jednak tego obrazu w pełni. Unia Europejska nadal przoduje w integracji pojazdów i w bezpieczeństwie definiowanym programowo, Stany Zjednoczone – w projektowaniu pojazdów w pełni elektrycznych klasy premium i w architekturze oprogramowania; Korea sprzedaje ogniwa o najwyższej wartości, a Japonia wyraźnie wyprzedza pozostałych w badaniach nad ogniwami paliwowymi i akumulatorami ze stałym elektrolitem. Odczytując zebrany materiał przez pryzmat teorii Schumpetera, koncepcji zdolności absorpcyjnej Cohena i Levinthala, ujęcia Teece'a dotyczącego czerpania korzyści z innowacji, paradygmatu eklektycznego Dunninga oraz koncepcji przedsiębiorczego państwa Mazzucato, dowodzę, że konkurencja w sektorze pojazdów elektrycznych w obecnym stuleciu sprowadza się do strategicznej polityki handlowej połączonej z wymuszonym uczeniem się, a państwa nauczyły się traktować możliwość zawłaszczania korzyści z własności intelektualnej (IP appropriability) jako broń.

I. Introduction

Electric mobility is, to my mind, the largest capital allocation event the automotive industry has ever lived through. The IEA counts more than 17 million electric cars sold globally in 2024, more than a fifth of the new car market; China alone took more than 11 million of those, almost two out of every three electric cars sold anywhere.[1] Add Europe and the United States and the three markets covered more than 90% of world sales, which leaves both demand and the IP rents that follow them concentrated in a handful of jurisdictions.[2] Beneath the consumer market runs a far big-

[1] International Energy Agency, *Global EV Outlook 2025*, IEA, Paris 2025, https://www.iea.org/reports/global-ev-outlook-2025, (accessed 30.11.2025).

[2] Ibidem.

ger contest over the underlying technology stack: lithium ion and post lithium cell chemistries, traction motors and inverters, fast charging interfaces, fuel cell systems and the embedded software that ties them together. Whoever holds the patent thicket and the manufacturing know how for these subsystems stands to take an outsized share of the profits from a vehicle fleet the IEA expects to keep growing for decades.

Two questions drew me into this topic. Who is actually ahead in EV technology, and what are the major jurisdictions spending to stay ahead or to catch up? And how are joint venture obligations, local content rules and IP appropriability strategies redistributing global R&D, and with it the question of who profits from innovation? The article proceeds in five parts. Section II sets out the conceptual framework, which borrows from innovation economics, IP and appropriability theory, trade and FDI theory, and the industrial policy literature. Section III compares R&D and patent data for the European Union, the United States, the Republic of Korea, Japan and China. Section IV works through the country cases. Section V turns to joint ventures and forced technology transfer, read through absorptive capacity and the eclectic paradigm, and Section VI draws out the strategic implications.

II. Conceptual framework: Four lenses on EV innovation

A. Schumpeterian creative destruction and endogenous growth

The move from internal combustion engines (ICE) to electrified powertrains is about as pure a Schumpeterian shock as the industry has ever faced. Schumpeter's claim was that capitalism advances through waves of creative destruction, with incumbents displaced by entrants who commercialise radically new technology. What makes the EV case unusual is that it compresses two such waves into one decade: the vehicle's architecture changes (mechanical drivetrains give way to power electronics and software) at the same time as its energy storage chemistry does. Toyota, Volkswagen, General Motors, Ford and Stellantis are all cannibalising their own legacy product lines while fending off vertically integrated entrants like Tesla and BYD. Endogenous growth theory adds a prediction here: in episodes of this kind the rate of innovation depends on the stock of human capital and on public R&D support, because the social returns to fundamental science run well ahead of what private firms can appropriate. That, more than anything, explains why nearly every major jurisdiction has put its public balance sheet behind EV R&D even though cell manufacturing is by now a profitable private business.

B. Appropriability and the profiting from innovation logic

Arrow's information paradox is the natural starting point: knowledge is a non rival, partially excludable good, and a buyer cannot value it without first seeing it, so firms will chronically underinvest in R&D unless IP rights or secrecy drive a wedge between marginal cost and price. Teece sharpened the point by separating innovators in "tight" appropriability regimes, where patents and trade secrets really do exclude imitators, from those in "weak" regimes, where the contest is settled by complementary assets (manufacturing scale, distribution, brand). Cell manufacturing sits firmly in the weak category. Process know how and supplier ecosystems count for more than any discrete patent there, and the leading Chinese, Korean and Japanese cell makers built their defensible positions out of complementary assets, not litigation. Fuel cell stacks and solid state electrolytes are a different story; those regimes remain comparatively tight, which is why Toyota's fuel cell portfolio of more than 12,000 patented inventions and its 1,300 patent solid state portfolio amount to real economic moats.[3]

C. International production, the eclectic paradigm and forced learning

Dunning's eclectic (OLI) paradigm explains where and why firms internalise production across borders in terms of ownership, location and internalisation advantages. Take a Korean cell maker like LG Energy Solution. Its ownership advantage lies in proprietary cell formats and process recipes. Location advantage now points to the United States, because of IRA local content rules, and to Indonesia, because of nickel feedstock. And internalisation logic favours JVs, since Korean firms want to keep process IP in house while sharing balance sheet risk and passing local content tests. Cohen and Levinthal's absorptive capacity framework supplies the complementary lens: what a firm can assimilate from outside depends on its own prior R&D, and the productivity of any technology transfer arrangement is conditional on it. The empirical work on Sino foreign automotive JVs bears this out; knowledge spillovers accrue disproportionately to the largest, most R&D intensive Chinese partners, while smaller suppliers gain little. None of this would have surprised Friedrich List,

[3] Knowmade, *Hydrogen-based Fuel Cell Electric Vehicles: A Winning Bet for Toyota?*, Valbonne 2022, https://www.knowmade.com/technology-news/energy-technology-news/fuel-cells-news/toyota-patent-portfolio-analysis-hydrogen-based-fuel-cell-electric-vehicles-a-winning-bet-for-toyota/, (accessed 19.11.2025); Knowmade, *Solid State Battery Patent Landscape: Q3 2025 Update*, Valbonne 2025, https://www.knowmade.com/technology-news/press-release/q3-2025-innovation-in-solid-state-battery-knowmades-latest-insights/, (accessed 29.11.2025).

whose 19th century infant industry argument anticipated the whole playbook: use trade and investment policy to keep a new industry alive long enough for it to build the absorptive capacity that turns imported knowledge into innovation of its own.

D. Industrial policy, strategic trade and the entrepreneurial state

Krugman, and Brander and Spencer, gave industrial policy its strategic trade rationale. In oligopolistic industries with steep learning curves, where a few firms compete globally and unit costs fall quickly with cumulative output, a credible domestic subsidy can shift rents toward national champions. It is hard to think of a better fit than EV cells, motors and fuel cell stacks, given the fixed costs and experience curves involved and how few global producers there are. Mariana Mazzucato's entrepreneurial state thesis pushes further, holding that the public sector has historically carried the early stage risk for general purpose technologies, the lithium ion battery among them; its foundational chemistry came out of publicly funded laboratories in the 1970s and 1980s. Between them, these two strands explain why 2022 to 2025 produced a near simultaneous wave of EV industrial policy: the United States Inflation Reduction Act, the European Critical Raw Materials Act, Korea's Secondary Battery Industry Innovation Strategy, Japan's Green Transformation framework. Every one of these measures pairs an R&D component with a localisation or content rule meant to anchor the learning curve on national territory.

III. Comparative R&D, investment and IP data

Table 1 sets out the headline national EV/battery programmes, their stated public outlays, time horizons and primary legal sources. Reading it, two things struck me. Only China and Japan publish headline figures in trillions of national currency; the EU's IPCEI structure and the US IRA work through foregone tax revenue and conditional loan authority, so their true fiscal cost resists like for like comparison. The policy mixes also differ more than the headline numbers let on. Europe leans on coordinated state aid plus a binding upstream raw materials regulation. The United States runs a consumer facing tax credit gated on local content. Korea funds R&D directly for a small group of national champions, Japan blends private finance leverage with METI certification, and China pairs purchase tax exemptions with a tradable NEV credit market.

Table 1. Headline EV/battery programmes by jurisdiction

Jurisdiction	Headline EV/ Battery Programme	Stated Public Outlay	Time Horizon & Vehicle Scope	Primary Source
European Union	IPCEI Batteries I & II + Horizon Europe + Innovation Fund	≈ €6.1 bn (≈ US$ 6.7 bn) IPCEI state aid; €518 m (≈ US$ 570 m) Horizon Europe (2021 to 24); €1 bn (≈ US$ 1.1 bn) Innovation Fund battery call (Dec. 2024)	BEV/PHEV cell value chain to 2028; CRMA targets to 2030	EC Press IP/19/6705; IP/21/226; CRMA Reg. (EU)2024/1252
United States	Inflation Reduction Act §§ 30D, 45X + DOE LPO ATVM/ Title XVII	US$ 7,500 per qualifying vehicle (consumer credit); >US$ 14.5 bn DOE LPO commitments FY24; ~US$ 7.54 bn StarPlus conditional commitment (Dec. 2024)	BEV/PHEV/ FCEV; FEOC exclusions from 2024/25; rules to 2032	Pub. L. 117–169; 89 Fed. Reg. 37,706 (May 6, 2024)
Republic of Korea	K-Battery / Secondary Battery Industry Innovation Strategy	₩50 trillion (≈ US$ 38 bn): ₩19.5 tn (≈ US$ 15 bn) R&D + ₩30.5 tn (≈ US$ 23 bn) capex; ₩20 tn (≈ US$ 15 bn) industry pledge by LGES, Samsung SDI, SK On	BEV cells, anode less / solid state to 2030	MOTIE Press Release (Nov. 1, 2022)
Japan	Green Transformation (GX) Strategy + GI Fund	¥150 trillion (≈ US$ 1 trn) public and private through ~2033; >¥1 trn (≈ US$ 7 bn) battery capacity commitments by Toyota, Nissan, Panasonic	BEV, PHEV, FCEV, HEV; targets 120 GWh capacity by 2030	METI Basic Policy on GX (Feb. 10, 2023)

Jurisdiction	Headline EV/ Battery Programme	Stated Public Outlay	Time Horizon & Vehicle Scope	Primary Source
China	NEV subsidies (2010 to 22) + Dual Credit + NEV tax exemption + provincial industrial policy	RMB 152.1 bn (≈ US$ 21 bn) central NEV subsidies 2010 to 22; CATL alone received US$ 809.2 m gov't support in 2023; per vehicle tax break up to RMB 30,000 (≈ US$ 4,100) in 2024 to 25	BEV, PHEV, FCEV under MIIT Dual Credit (28% in 2024, 38% in 2025)	MIIT Dual Credit Reg.; MOF/STA/ MIIT Announcement No. 10 (Jun. 2023)

Source: own compilation based on: European Commission, *State Aid: Commission Approves €3.2 Billion Public Support by Seven Member States for a Pan European Research and Innovation Project in All Segments of the Battery Value Chain*, press release IP/19/6705, Brussels, 9.12.2019, https://ec.europa.eu/commission/presscorner/detail/en/IP_19_6705, (accessed 19.11.2025); European Commission, *State Aid: Commission Approves Up to €2.9 Billion Public Support for Pan European Research and Innovation Project Along the Entire Battery Value Chain*, press release IP/21/226, Brussels, 26.01.2021, https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226, (accessed 24.11.2025); Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818, codified as amended at I.R.C. § 30D, 2022, https://www.congress.gov/bill/117th-congress/house-bill/5376/text, (accessed 20.11.2025); Ministry of Economy, Trade and Industry (METI), *Basic Policy on the Realization of GX*, Tokyo 2023, https://www.meti.go.jp/english/press/2023/0210_003.html, (accessed 28.11.2025); Ministry of Industry and Information Technology (MIIT), *Parallel Management Regulation for Corporate Average Fuel Consumption and New Energy Vehicle Credits*, Beijing 2023, https://www.miit.gov.cn/jgsj/zbys/qcgy/art/2023/art_715c0eb3e15f4665b7d88cd56fc8b2e0.html, (accessed 11.11.2025); Ministry of Trade, Industry and Energy (MOTIE), *Secondary Battery Industry Innovation Strategy: Korea, the World's Top Battery Power by 2030*, Seoul 2022, https://www.investkorea.org/ik-en/cntnts/i-3025/web.do, (accessed 13.11.2025); Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials (Critical Raw Materials Act), OJ L, 2024/1252, 3.05.2024, https://eur-lex.europa.eu/eli/reg/2024/1252/oj, (accessed 29.11.2025); U.S. Department of the Treasury and Internal Revenue Service, Clean Vehicle Credits Under Sections 25E and 30D; Transfer of Credits; Critical Minerals and Battery Components; Foreign Entities of Concern, 89 Fed. Reg. 37,706, 6.05.2024, https://www.federalregister.gov/citation/89-FR-37706, (accessed 30.11.2025).

The corporate numbers tell much the same story. Volkswagen Group reported R&D expenditure of approximately €21.0 billion (≈ US$23 billion) in 2024, still the largest figure anywhere in the automotive industry.[4] Toyota and Mercedes-Benz come next. BYD has meanwhile moved past Honda and is closing on Ford, having booked

[4] Volkswagen AG, *2024 Annual Report*, Wolfsburg 2025, https://annualreport2024.volkswagengroup.com/group-management-report/sustainable-value-enhancement/research-and-development.html, (accessed 23.11.2025); Rho Motion data, as reported in: T. Langenbucher, *Analyse: So viel investierten Autohersteller 2024 in Forschung und Entwicklung*, ecomento.de, 30.04.2025, https://ecomento.de/2025/04/30/so-viel-investierten-autohersteller-2024-in-forschung-und-entwicklung-analyse/, (accessed 10.11.2025).

RMB 54.2 billion (≈ US$7.5 billion) of R&D in 2024 and more than RMB 180 billion (≈ US$25 billion) cumulatively since its founding.[5]

Hyundai Motor Group used its 2024 "Hyundai Way" investor day to commit ₩120.5 trillion (≈ US$92 billion) through 2033 across battery, autonomy and hydrogen, and later added a ₩77.3 trillion (≈ US$59 billion) mid term plan for 2026 to 2030, of which ₩30.9 trillion (≈ US$23 billion) is earmarked for R&D.[6] The two fastest growing R&D budgets in absolute terms, though, belong to Tesla and BYD. BYD alone employs more than 100,000 engineers across eleven research institutes, a headcount no single European OEM's R&D organisation comes close to matching.[7]

The patent statistics point the same way. Battery technology filings at the EPO rose 24.0% year on year in 2024, which made batteries the office's fastest growing field for the second year running.[8]

What I find most striking is that every one of the top ten battery filers at the EPO is Asian: LG Energy Solution, CATL, Samsung SDI, Panasonic, ATL, Eve Energy, SK On, Prime Planet Energy & Solutions, BYD and Toyota. Between them they account for 55% of the EPO's battery applications.[9] Just three European companies (Volvo Group, Volkswagen and Robert Bosch) make the top fifteen. Battery circularity, meaning recycling and reverse logistics IP, shows the shift even more starkly: one recent count finds 3,496 battery recycling patent filings in China against 548 in the United States and 65 in Korea, with Chinese filings peaking in 2023, and Brunp, a CATL subsidiary, ranks among the most active applicants.[10]

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5 BYD Co. Ltd., *2024 Annual Report*, Shenzhen 2025, https://www1.hkexnews.hk/listedco/listconews/sehk/2025/0324/2025032401238.pdf, (accessed 14.11.2025).

6 Hyundai Motor Co., *Hyundai Way Strategy Announced at 2024 CEO Investor Day*, press release, 28.08.2024, https://www.hyundainews.com/en-us/releases/4227 (accessed: 15.11.2025); Hyundai Motor Co., *2026 to 2030 Mid Term Investment Plan*, press release, 2025, https://www.hyundainews.com/releases/4554, (accessed 18.11.2025).

7 BYD Co. Ltd., *Remarks of Chairman Wang Chuanfu at the China Innovation and Technology Festival*, 29.12.2024, https://carnewschina.com/2024/12/30/byd-has-the-most-rd-personnel-as-an-automaker-and-nearly-110000-engineers-ceo-says/, (accessed 12.11.2025).

8 European Patent Office, *Patent Index 2024*, EPO, Munich 2025, https://www.epo.org/en/about-us/statistics/patent-index-2024, (accessed 16.11.2025).

9 Ibidem.

10 European Patent Office and International Energy Agency, *Innovation in Batteries and Electricity Storage: A Global Analysis Based on Patent Data*, 2020, https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage, (accessed 17.11.2025); C.-H. Lee, *Global Patent Analysis of Battery Recycling Technologies: A Comparative Study of Korea, China, and the United States*, "World Electric Vehicle Journal" 2024, vol. 15, no. 6, art. 260, https://doi.org/10.3390/wevj15060260, (accessed 26.11.2025).

Table 2. EV relevant patent leadership by technology cluster (2024 EPO data and corporate disclosures)

Technology Cluster	Top Filers (2024 EPO IPF data)	Geographic Concentration	Key Datum
Lithium ion cell chemistry & packs	LG Energy Solution, CATL, Samsung SDI, Panasonic, ATL, SK, BYD, Toyota	All top 10 filers Asian; Asia ~55% of EPO battery filings	Battery filings +24.0% YoY at the EPO in 2024
LFP & cell to pack architectures	CATL, BYD, Gotion, EVE Energy	Chinese domiciled IP > 50% in LFP	CATL holds ~50%+ of global LFP cell production
Solid state batteries	Toyota, Samsung SDI, LG Energy Solution, CATL	Japan/Korea lead patent stock; China leads research head count	Toyota >1,300 solid state patents; CATL >1,000 SSB researchers
Hydrogen fuel cell systems	Toyota, Hyundai, Honda, Bosch	Japan and Korea dominate	Toyota's FC portfolio > 12,000 patented inventions
Battery circularity / recycling	Brunp (CATL subsidiary), Sumitomo, Umicore, Redwood, Li-Cycle	China leads recycling patent filings by a wide margin	3,496 recycling patents filed in China vs 548 in the US and 65 in Korea

Source: own compilation based on: European Patent Office and International Energy Agency, I*nnovation in Batteries and Electricity Storage: A Global Analysis Based on Patent Data*, 2020, https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage, (accessed 17.11.2025); European Patent Office, *Patent Index 2024*, EPO, Munich 2025, https://www.epo.org/en/about-us/statistics/patent-index-2024, (accessed 16.11.2025); Knowmade, *Solid State Battery Patent Landscape: Q3 2025 Update*, Valbonne 2025, https://www.knowmade.com/technology-news/press-release/q3-2025-innovation-in-solid-state-battery-knowmades-latest-insights/, (accessed 29.11.2025); SNE Research, *Global EV Battery Market Share* 2024, 2025, https://www.sneresearch.com/en/insight/release_view/371/page/0, (accessed 20.11.2025).

IV. Country profiles

A. China: From forced joint ventures to frontier exporter

China abolished the 50:50 joint venture requirement, along with the cap on the number of JVs a foreign automaker could hold, on 1 January 2022, repealing rules

that had stood since 1994.[11] What replaced the old scaffolding is the Dual Credit system, which obliges automakers to earn fuel economy credits alongside a separately calculated NEV credit. The NEV ratio was set at 28% for 2024 and climbs to 38% in 2025, an escalator steep enough that foreign OEMs effectively must electrify their Chinese line ups or buy credits from the domestic incumbents.[12] There is a certain irony in the timing. The JV mandate that once forced Western automakers to share design and production know how with SAIC, FAW and Dongfeng was lifted just as the technological gradient reversed; these days it is Chinese cell makers, motor makers and software houses doing the sending. CATL holds 37.9% of the global EV battery market and more than half of LFP cell production. BYD, out of Shenzhen, spends US$7.5 billion a year on R&D and exports battery technology under licence, not just vehicles, to OEMs in Brazil, Türkiye, Indonesia and Hungary.[13] By the IEA's count, China hosted around 85% of global battery cell manufacturing capacity in 2024, while in the European Union the Korean cell makers' market share fell from nearly 80% in 2022 to 60% in 2024, largely to the benefit of their Chinese rivals.[14]

Two theoretical points follow from this. In Cohen and Levinthal's terms, three decades of mandatory JVs raised the absorptive capacity of Chinese OEMs to the point where the requirement had nothing left to do; the policy worked itself out of a job. In Teece's terms, value capture has migrated from the ICE drivetrain, where IP was relatively tight, to the cell and pack stack, where IP is weak and scale is everything, and where China's complementary assets (giga scale plants, lithium and rare earth refining capacity, captive logistics) carry the day. The defensive reactions came late. The European Commission imposed definitive countervailing duties of between 7.8% and 35.3% on China origin BEVs in October 2024, and the U.S. Trade Representative put a 100% Section 301 tariff on the same vehicles, both of them the reflexes of jurisdictions that had already ceded the cell battle.[15]

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[11] China State Council, *Notice on the Issuance of the Special Administrative Measures for the Access of Foreign Investment (Negative List)*, *2021 Edition*, Beijing 2021, https://en.ndrc.gov.cn/news/mediarusources/202112/t20211230_1310943.html, (accessed 28.11.2025).

[12] Ministry of Industry and Information Technology (MIIT), *Parallel Management Regulation for Corporate Average Fuel Consumption and New Energy Vehicle Credits*, Beijing 2023, https://www.miit.gov.cn/jgsj/zbys/qcgy/art/2023/art_715c0eb3e15f4665b7d88cd56fc8b2e0.html, (accessed 11.11.2025).

[13] SNE Research, *Global EV Battery Market Share 2024*, 2025, https://www.sneresearch.com/en/insight/release_view/371/page/0, (accessed 20.11.2025).

[14] International Energy Agency, *Global EV Outlook 2025*, op. cit.

[15] Commission Implementing Regulation (EU) 2024/2754 of 29 October 2024 Imposing Definitive Countervailing Duties on Imports of New Battery Electric Vehicles Originating in the People's Republic of China, OJ L, 2024/2754, 29.10.2024, https://eur-lex.europa.eu/eli/reg_impl/2024/2754/oj, (accessed 21.11.2025); Office of the United States Trade Representative, *Section 301 Statutory*

B. European Union: IPCEI, Horizon Europe and the Critical Raw Materials Act

The EU's response has been generous and fragmented at the same time. Two Important Projects of Common European Interest (IPCEIs) for batteries, approved in December 2019 and January 2021, authorised €3.2 billion (≈ US$3.5 billion) and €2.9 billion (≈ US$3.2 billion) of member state aid for cell, materials and recycling R&D; the second of the two was projected to pull in a further €9 billion (≈ US$9.9 billion) of private investment by 2028.[16] On top of that, Horizon Europe put €518 million (≈ US$570 million) into 79 battery projects across 34 calls between 2021 and 2024, and the Innovation Fund's December 2024 battery call added a €1 billion (≈ US$1.1 billion) budget aimed squarely at cell manufacturing capacity in Europe.[17]

The supply side complement is the Critical Raw Materials Act (Regulation (EU) 2024/1252), in force since 23 May 2024. It binds the Union, by 2030, to source at least 10% of its annual consumption of strategic raw materials from domestic extraction, 40% from domestic processing and 25% from recycling, and it caps dependency on any single supplier at 65% at every stage of the value chain.[18] The vulnerability it addresses is real enough: EU lithium demand is expected to grow twelvefold by 2030 and twenty one fold by 2050, while China currently controls something like 60% of global lithium refining and over 90% of rare earth refining capacity.[19] Seen

Four Year Review: Determination on China Origin Electric Vehicles, Washington, DC 2024, https://ustr.gov/about-us/policy-offices/press-office/press-releases/2024/september/ustr-finalizes-action-china-tariffs-following-statutory-four-year-review, (accessed 17.11.2025).

[16] European Commission, *State Aid: Commission Approves €3.2 Billion Public Support by Seven Member States for a Pan European Research and Innovation Project in All Segments of the Battery Value Chain*, press release IP/19/6705, Brussels, 9.12.2019, https://ec.europa.eu/commission/presscorner/detail/en/IP_19_6705, (accessed 19.11.2025); European Commission, *State Aid: Commission Approves Up to €2.9 Billion Public Support for Pan European Research and Innovation Project Along the Entire Battery Value Chain*, press release IP/21/226, Brussels, 26.01.2021, https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226, (accessed 24.11.2025).

[17] Batteries Europe Secretariat, *Overview of International R&D&I Battery Funding and Global Benchmarks for Battery KPIs*, 2024, https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e50bf2c079&appId=PPGMS, (accessed 27.11.2025).

[18] Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials (Critical Raw Materials Act), OJ L, 2024/1252, 3.05.2024, https://eur-lex.europa.eu/eli/reg/2024/1252/oj, (accessed 29.11.2025).

[19] European Commission, *European Critical Raw Materials Act*, https://commission.europa.eu/topics/competitiveness/green-deal-industrial-plan/european-critical-raw-materials-act_en, (accessed 24.11.2025); International Energy Agency, *Global Critical Minerals Outlook 2025*, IEA, Paris 2025, https://www.iea.org/reports/global-critical-minerals-outlook-2025, (accessed 25.11.2025).

through strategic trade theory, the CRMA is a credible commitment to a domestic learning curve subsidy. A guaranteed procurement floor lowers the cost of capital for European cell makers, and it tells foreign investors that the EU is content to stay a price taker for vehicles while becoming a price maker for upstream materials.

C. United States: The IRA's industrial policy pivot

The Inflation Reduction Act of 2022 is widely regarded as the most consequential industrial policy intervention the United States has attempted since the Cold War. For EVs the operative provision is the recodified Section 30D consumer credit, worth up to US$7,500 per vehicle and split evenly between a critical minerals credit and a battery components credit of US$3,750 each.[20] Treasury's final rule of 6 May 2024 requires 60% North American value add on battery components for vehicles placed in service in 2024 and 2025, and sets the critical minerals threshold at 50% for 2024 and 60% for 2025, with both ratcheting upward toward 2032.[21] There is a hard exclusion as well. From 2024, no credit attaches to a vehicle whose battery contains components manufactured or assembled by a "Foreign Entity of Concern" (FEOC), which in practice means an entity controlled by China, Russia, Iran or North Korea; from 2025 the same goes for FEOC sourced critical minerals.

The credit does not stand alone. The Department of Energy's Loan Programs Office (LPO) deployed roughly US$14.5 billion of conditional commitments to the EV battery supply chain in fiscal year 2024 by itself, US$7.54 billion of that going to StarPlus Energy LLC for two lithium ion cell and module plants in Kokomo, Indiana.[22] Mazzucato could have written the underlying logic herself: the federal government underwrites the long tailed risk of building a domestic cell ecosystem, critical mineral feedstocks included, at a moment when private capital, staring at Chinese

[20] Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818, codified as amended at I.R.C. § 30D, 2022, https://www.congress.gov/bill/117th-congress/house-bill/5376/text, (accessed 20.11.2025).

[21] U.S. Department of the Treasury and Internal Revenue Service, Clean Vehicle Credits Under Sections 25E and 30D; Transfer of Credits; Critical Minerals and Battery Components; Foreign Entities of Concern, 89 Fed. Reg. 37,706, 6.05.2024, https://www.federalregister.gov/citation/89-FR-37706, (accessed 30.11.2025).

[22] U.S. Department of Energy, Loan Programs Office, *LPO Announces Conditional Commitment to StarPlus Energy to Construct Lithium-Ion Battery Factories in Indiana*, 2024, https://www.energy.gov/node/4846758, (accessed 16.11.2025); U.S. Department of Energy, *IRA Year Two: A Clean Future in Clear Focus*, 2024, https://www.energy.gov/lpo/articles/ira-year-two-clean-future-clear-focus, (accessed 15.11.2025).

cost dominance, would not mobilise on its own. The political economy costs are not small. The FEOC rule forced a wholesale restructuring of supply contracts; LG Energy Solution, SK On and Samsung SDI entered new JVs with GM, Ford and Stellantis, and Japanese and European chemical firms onshored cathode precursor production. Still, the IRA has managed in three years what fifteen years of fragmented federal grants had not, pulling approximately US$200 billion of private cell manufacturing investment commitments into the United States.[23]

D. Republic of Korea: The K-Battery Strategy

Korea's Ministry of Trade, Industry and Energy (MOTIE) announced the Secondary Battery Industry Innovation Strategy on 1 November 2022, and it did not hide its ambition: the stated aim is a "technology super gap" between Korean cell makers and their rivals by 2030. The strategy commits ₩50 trillion (≈ US$38 billion) of public money, ₩19.5 trillion (≈ US$15 billion) for R&D and ₩30.5 trillion (≈ US$23 billion) of capex, and the three national champions, LG Energy Solution, Samsung SDI and SK On, matched it with a further ₩20 trillion (≈ US$15 billion) of their own.[24] The targets: 40% global market share by 2030, a 150 billion won (≈ US$110 million) pre feasibility programme for next generation battery R&D, and an industry pilot line for all solid state cells. Korea already ranked as the world's second largest battery producing country in 2024, with its three cell makers holding a combined 18.4% of global EV battery installed capacity.[25]

This is what a small open economy does when it cannot hope to build a closed home market. Rather than try, Korea underwrites R&D for three vertically integrated firms and lets them carry that knowledge abroad through JVs, above all in the United States (LGES and GM Ultium, SK On and Ford BlueOval, Samsung SDI and Stellantis StarPlus) and in Indonesia (Hyundai and LGES Karawang). Korea also happens to hold a long standing free trade agreement with the United States, which makes its firms IRA compatible. That accident of treaty history has turned Korean

[23] Atlas Public Policy, *U.S. Investments in Electric Vehicle Manufacturing*, 2023, https://atlaspolicy.com/wp-content/uploads/2023/05/U.S.-Investments-in-Electric-Vehicle-Manufacturing-2023.pdf, (accessed 23.11.2025).

[24] Ministry of Trade, Industry and Energy (MOTIE), *Secondary Battery Industry Innovation Strategy: Korea, the World's Top Battery Power by 2030*, Seoul 2022, https://www.investkorea.org/ik-en/cntnts/i-3025/web.do, (accessed 13.11.2025); LG Energy Solution, Samsung SDI, and SK On, *Joint Press Release on Solid State Roadmap*, 2022, https://www.investkorea.org/ik-en/cntnts/i-3025/web.do, (accessed 13.11.2025).

[25] SNE Research, *Global EV Battery*…, op. cit.

cell makers into the principal beneficiaries of the FEOC architecture, and the consequences will run for at least a decade.

E. Japan: Green Transformation and the solid state bet

Japan's Green Transformation (GX) framework, laid out in METI's Basic Policy of February 2023, targets ¥150 trillion (roughly US$1 trillion) of combined public and private investment over ten years, spread across sixteen designated sectors of which EVs and storage batteries are two.[26] The headline corporate pledge came jointly from Toyota, Nissan and Panasonic: more than ¥1 trillion (≈ US$7 billion) of incremental capex to lift Japanese cell capacity by half, to 120 GWh, by 2030.[27] On 6 September 2024, METI certified Toyota's production plans for next generation BEV batteries and all solid state batteries under the Supply Assurance Plan for Batteries, 9 GWh per year of planned capacity in aggregate.[28]

Japan is betting on the leapfrog. Toyota holds more than 1,300 solid state battery patents and the largest automotive fuel cell patent portfolio anywhere, more than 12,000 patented inventions.[29] The Mirai and the Hilux Hydrogen prototype are the commercial face of an institutional conviction that hydrogen has a real role in heavy duty and long range transport where BEVs do not make economic sense. One can read the wager in Schumpeterian terms: with BEV technology settling into a paradigm where Chinese and Korean rivals hold decisive cost advantages, Japan has chosen to bet on the next paradigm instead, solid state and fuel cells, where its accumulated absorptive capacity runs deepest. The risk is obvious enough. Should mass production of solid state cells slip past 2030, Chinese and Korean second movers will erode much of what Toyota's patent portfolio is currently worth.

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[26] Ministry of Economy, Trade and Industry (METI), *Basic Policy on the Realization of GX*, Tokyo 2023, https://www.meti.go.jp/english/press/2023/0210_003.html, (accessed 28.11.2025).

[27] *Japanese Offensive in Battery Production*, electrive, 6.09.2024, https://www.electrive.com/2024/09/06/japanese-offensive-in-battery-production/, (accessed 13.11.2025).

[28] Toyota Motor Corp., *Toyota's Next Generation BEV Battery Development and Production Plan Certified by METI*, press release, 6.09.2024, https://global.toyota/en/newsroom/corporate/41100223.html, (accessed 18.11.2025).

[29] Knowmade, *Hydrogen-based Fuel Cell Electric Vehicles*…, op. cit.; Knowmade, *Solid State Battery*…, op. cit.

V. Joint ventures, tech transfer and the new economics of forced learning

Table 3 maps the principal tech transfer levers now in use across the major jurisdictions. Three patterns run through it.

Table 3. Tech transfer and localisation levers in major EV jurisdictions

Jurisdiction	Tech Transfer / Localisation Lever	Mechanism	Strategic Effect on R&D Allocation
China (legacy)	50:50 JV requirement (1994 to 2021); cap of two JVs per OEM	Foreign Investment Catalogue + State Council Notices	Forced Western OEMs (VW, GM, Toyota) to localise design centres in Shanghai/Beijing
China (post 2022)	JV requirement abolished; replaced by Dual Credit, NEV mandate, and provincial subsidy targeting	Negative List 2021; MIIT Reg.; provincial procurement	Domestic incumbents (BYD, CATL, Geely) now technology senders, not just receivers
EU	Strategic projects framework + state aid IPCEI + countervailing duties	CRMA Strategic Projects; CBAM; anti subsidy investigation	Pulls Chinese cell makers (CATL, BYD, Envision) into European brownfield JVs (Hungary, Spain)
United States	FEOC exclusion + battery component & critical mineral content thresholds	IRA § 30D; Treasury final rule	Pushes Korean firms to onshore (LGES and GM, SK and Ford, Samsung SDI and Stellantis)
Korea	Inbound R&D credits + outbound "chaebol anchored" JVs	Special Tax Restriction Act; Strategic Materials Designation	Reinforces Korea as hub and spoke battery exporter; minimises dilution of core IP
Japan	Conditional GX subsidies; supply assurance certification	METI Battery Supply Assurance Plan (2023, 2024 amendments)	Anchors next gen (solid state) production domestically while licensing legacy chemistries abroad

Source: own compilation based on: China State Council, *Notice on the Issuance of the Special Administrative Measures for the Access of Foreign Investment (Negative List)*, 2021 Edition, Beijing 2021, https://en.ndrc.gov.cn/news/mediarusources/202112/t20211230_1310943.html, (accessed 28.11.2025); Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818, codified as amended at I.R.C. § 30D,

2022, https://www.congress.gov/bill/117th-congress/house-bill/5376/text, (accessed 20.11.2025); *Japanese Offensive in Battery Production*, electrive, 6.09.2024, https://www.electrive.com/2024/09/06/japanese-offensive-in-battery-production/, (accessed 13.11.2025); Ministry of Industry and Information Technology (MIIT), *Parallel Management Regulation for Corporate Average Fuel Consumption and New Energy Vehicle Credits*, Beijing 2023, https://www.miit.gov.cn/jgsj/zbys/qcgy/art/2023/art_715c0eb3e15f4665b7d88cd56fc8b2e0.html, (accessed 11.11.2025); Ministry of Trade, Industry and Energy (MOTIE), *Secondary Battery Industry Innovation Strategy: Korea, the World's Top Battery Power by 2030*, Seoul 2022, https://www.investkorea.org/ik-en/cntnts/i-3025/web.do, (accessed 13.11.2025); Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials (Critical Raw Materials Act), OJ L, 2024/1252, 3.05.2024, https://eur-lex.europa.eu/eli/reg/2024/1252/oj, (accessed 29.11.2025); Stanford Center on China's Economy and Institutions, *How Much Do China's Joint Venture Requirements Promote Knowledge Transfers to Domestic Firms?*, "China Briefs" 2024, https://sccei.fsi.stanford.edu/china-briefs/how-much-do-chinas-joint-venture-requirements-promote-knowledge-transfers-domestic, (accessed 11.11.2025); Toyota Motor Corp., *Toyota's Next Generation BEV Battery Development and Production Plan Certified by METI*, press release, 6.09.2024, https://global.toyota/en/newsroom/corporate/41100223.html, (accessed 18.11.2025).

The first is that the formal JV mandate has had its day as the main vehicle for forced technology transfer. China abolished its version in 2022 and no other major jurisdiction has adopted one since. The volume of forced learning has, if anything, gone up. The IRA's FEOC architecture and the EU's CRMA strategic projects framework both reproduce the JV mandate's economic effect, local production of complex products using foreign know how, just through different legal machinery. Call it "second generation forced learning": the JV survives, but as a commercial response to bundled localisation rules and content thresholds rather than a freestanding regulatory requirement. And the JVs really do transfer knowledge. The empirical literature on Sino foreign automotive JVs finds genuine productivity spillovers to domestic firms outside the JV; on average, a 10 percentage point rise in JV market share goes along with a 10% productivity gain among non JV domestic competitors.[30]

The second pattern is a reversal in the direction of knowledge flow, though for cell chemistry only, not vehicle integration. Through the 1990s and 2000s, Western automakers pushed ICE engineering, platform architecture and lean manufacturing know how into their Chinese partners. In the 2020s the traffic runs the other way. CATL licenses LFP cell production to Ford for the Marshall, Michigan plant under a manufacturing services agreement. BYD has licensed its Blade Cell architecture to Tesla, and to Stellantis and Leapmotor. Volkswagen paid approximately US$700 million for a stake in the Chinese EV software firm Xpeng in 2023, essentially

[30] Stanford Center on China's Economy and Institutions, *How Much Do China's Joint Venture Requirements Promote Knowledge Transfers to Domestic Firms?*, "China Briefs" 2024, https://sccei.fsi.stanford.edu/china-briefs/how-much-do-chinas-joint-venture-requirements-promote-knowledge-transfers-domestic, (accessed 11.11.2025).

buying access to its E/E architecture.[31] Vehicle integration is the exception; safety engineering, ADAS calibration, brand and dealer ecosystems remain strengths of the Western and Japanese incumbents.

Third, JV economics now collide with antitrust and trade defence policy, and the collision is redirecting capital around the world. The European Commission's countervailing duty investigation into China origin BEVs closed in October 2024 with definitive duties running from 7.8% (BYD) to 35.3% (SAIC), while deliberately leaving Chinese OEMs an exit: manufacture in Europe and the duties fall away. CATL has taken up that invitation in Hungary and Spain, BYD in Hungary and Türkiye, and Geely across several European markets through the Polestar and Volvo brands.

The American Section 301 tariff, raised to 100% on China origin BEVs, works much the same way; it has accelerated Chinese investment in Mexico under USMCA and pushed capacity into Brazil. Strategic trade theory would have predicted as much. Once state subsidies have shifted rents to a foreign producer, the most a defensive measure can usefully do is convert the incentive to substitute imports into an incentive for inward FDI, and that is exactly how the EU and U.S. measures are built.

VI. Strategic implications and conclusion

Three conclusions stay with me from all of the above. The first is that "who is most advanced in EV technology?" has no single scalar answer, however often the question gets asked that way. China is the lowest cost producer, the largest market, and the dominant patent holder in LFP and battery circularity. Korea owns nickel rich high energy cells and the high value end of cell exports. Japan keeps a clear lead in solid state and fuel cell research; the European Union remains preeminent in vehicle integration, premium brand value and the upstream regulatory architecture (CRMA, CBAM); the United States leads in software architecture, premium BEV design and, through Tesla, the operating economics of factory scale cell production. Leadership, in short, is technology specific. The real strategic question for any firm or government is which subsystem it wants to lead.

[31] Ford Motor Co., *Ford Taps Michigan for New LFP Battery Plant*, press release, 13.02.2023, https://media.ford.com/content/fordmedia/fna/us/en/news/2023/02/13/ford-taps-michigan-for-new-lfp-battery-plant--new-battery-chemis.html, (accessed 21.11.2025); XPeng Inc. and Volkswagen Group, *Framework Agreement on Strategic Technical Collaboration and Strategic Minority Investment*, press release, 26.07.2023, https://ir.xiaopeng.com/news-releases/news-release-details/xpeng-and-volkswagen-group-announce-entry-framework-agreement, (accessed 12.11.2025).

Second, the past five years have produced the tightest policy convergence industrial economics has seen since the 1980s. Every major jurisdiction now runs some combination of consumer subsidy, supply side localisation rule and R&D subsidy. Per the IEA's World Energy Investment 2025, battery and EV manufacturing investment commitments now exceed US$500 billion globally, roughly 40% of which has actually been committed to date.[32]

If even half of these commitments materialise, the global battery manufacturing footprint at least doubles by 2030. Hence the obvious danger: overcapacity, then a price war, and a price war rewards the lowest cost producer, which almost certainly means the Chinese incumbents, unless the IRA, the CRMA and their cousins manage to carve out durable protected markets. A second danger is older and well documented in the political economy literature, namely capture. Subsidies tend to outlive their usefulness, and the incumbent rents they create are politically hard to remove.

Third, the mineral resource layer is coming to shape IP and joint venture economics as much as patent and JV law do. The CRMA, the IRA's FEOC rules and the Australian and Canadian critical minerals frameworks now taking shape all reduce to a single proposition: in an electrified world, where the refining and recycling capacity sits matters as much as where the patents do.[33] The absorptive capacity logic applies here too; the countries building capability in materials processing today are the likeliest source of the next generation of cell innovators. And, as Mazzucato has been arguing for years, almost none of it would be financeable without the state's balance sheet behind it.

The destruction of the ICE order, meanwhile, is creating new oligopolies, and their composition will be settled in large part by the policy choices of the next five years.

Where does all this leave us? The global EV industry sits mid way through a Schumpeterian transition that industrial policy is actively steering. JV requirements are giving way to content rules, FEOC exclusions and resource leverage instruments, which have much the same economic effect in a different legal form. The European Union, the United States, Korea, Japan and China are each betting on the subsystems they want to dominate, and the interaction of those bets will set the

[32] International Energy Agency, *World Energy Investment 2025*, IEA, Paris 2025, https://www.iea.org/reports/world-energy-investment-2025, (accessed 25.11.2025).

[33] Office of the United Nations High Representative for the Least Developed Countries, *Critical Minerals for the Energy Transition: A Roadmap for Cooperation*, 2024, https://www.un.org/en/climatechange/critical-minerals, (accessed 26.11.2025); International Energy Agency, *Critical Minerals Policy Tracker*, IEA, Paris 2025, https://www.iea.org/data-and-statistics/data-tools/critical-minerals-policy-tracker, (accessed 22.11.2025).

post 2030 structure of the industry. For policymakers the central trade off runs between the appropriability gains of national champions and the welfare losses of balkanised markets; for firms, between the locational efficiency of single source manufacturing and the political risk discount that single sourcing now carries. The theories I have leaned on throughout do not predict a single equilibrium. What they do, and it is enough, is clarify the degrees of freedom each jurisdiction actually has. The coming decade will show which combinations of those freedoms hold up, and which turn out merely to have been expensive.

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Summary

The article examines how intellectual property regimes, joint venture requirements and industrial policy instruments are reshaping the geography of research and development in the global electric vehicle industry. Drawing on primary policy documents, corporate annual reports and patent statistics, it compares the European Union, the United States, the Republic of Korea, Japan and China in terms of public support programmes, corporate R&D budgets and patent leadership across technology clusters. The analysis shows that leadership is technology specific rather than national: China dominates low cost cell production, LFP chemistry and battery recycling patents; Korea leads in high energy, nickel rich cells; Japan in solid state and fuel cell research; the European Union in vehicle integration and the upstream regulatory architecture; and the United States in software architecture and premium battery electric design. The formal joint venture mandate, abolished in China in 2022, has given way to a second generation of forced learning, in which local content thresholds, Foreign Entity of Concern exclusions, critical raw materials rules and countervailing duties reproduce its economic effect through different legal means. Read through the Schumpeterian, absorptive capacity, appropriability, eclectic paradigm and entrepreneurial state perspectives, these findings suggest that the central trade off for policymakers lies between the appropriability gains of national champions and the welfare losses of balkanised markets, and that the policy choices of the coming years will largely determine the structure of the industry after 2030.