

# Book 03: IEA ETCS 2025 — Energy Depth

---

IEA Energy Technology Classification System, 2025 update. Added: critical minerals, industrial electrification. Open/public data. Deep coverage of energy technologies.

- [Renewables](#)
  - [Solar PV & Concentrated Solar Power](#)
  - [Wind \(onshore & offshore\)](#)
  - [Hydropower, Tidal & Wave](#)
  - [Geothermal](#)
  - [Bioenergy & Synthetic Fuels](#)
  - [Nuclear \(incl. SMRs\)](#)
- [Grids & Storage](#)
  - [Batteries & Energy Storage](#)
  - [Smart Grids & Digitalization](#)
  - [Electricity Transmission & Distribution](#)
- [Efficiency](#)
  - [Buildings Energy Efficiency](#)
  - [Transport Efficiency](#)
  - [Industrial Energy Efficiency](#)
- [Industry & Hydrogen](#)
  - [Green Hydrogen Production \(electrolysers\)](#)
  - [Industrial Decarbonization \(steel, cement, chemicals\)](#)
  - [Carbon Capture, Utilisation & Storage \(CCUS\)](#)
- [Critical Minerals](#)
  - [Lithium, Cobalt & Nickel \(batteries\)](#)
  - [Copper & Aluminium \(grids & EVs\)](#)
  - [Rare Earths \(wind turbines, EVs\)](#)
  - [LATAM Mining & Critical Minerals Supply](#)
- [Industrial Electrification](#)
  - [CO<sub>2</sub> Transport & Storage Infrastructure](#)

- [Direct Electrification of Industry](#)
- [Hydrogen in Industrial Processes](#)

# Renewables

---

Solar, wind, hydro, geothermal, ocean, bioenergy

# Solar PV & Concentrated Solar Power

## Source Metadata

| Field                | Value                               |
|----------------------|-------------------------------------|
| source               | iea                                 |
| source_version       | ETCS 2025                           |
| source_id            | IEA-SUP-001                         |
| iea_category         | energy_supply                       |
| technology           | Solar PV & Concentrated Solar Power |
| technology_readiness | commercial                          |
| mitigation           | Y                                   |
| adaptation           | N                                   |
| last_checked         | 2026-05-26                          |

## IEA Technology Definition

The IEA classifies solar photovoltaic (PV) and concentrated solar power (CSP) as core renewable energy supply technologies. Solar PV converts sunlight directly into electricity using semiconductor cells, while CSP uses mirrors or lenses to concentrate sunlight and generate thermal energy for power production. The ETP Clean Energy Technology Guide places solar PV among the most mature and rapidly scaling clean energy technologies globally.

## Technology Readiness & Deployment

Solar PV is fully commercial and the fastest-growing power generation technology worldwide. Global installed capacity exceeded 1,600 GW by end-2024, with annual additions surpassing 400 GW. CSP remains at early commercial stage with approximately 7 GW installed globally, primarily in Spain, the United States, and MENA. The IEA Tracking Clean Energy Progress rates solar PV as on track for the Net Zero Emissions scenario, while CSP requires additional policy support.

# Key Metrics & Benchmarks

---

Utility-scale solar PV LCOE has fallen below USD 30/MWh in optimal locations, making it the cheapest source of new electricity in most markets. Module costs have declined over 99% since 1976. CSP with thermal storage can provide dispatchable power at USD 80-120/MWh. China dominates the PV manufacturing supply chain, producing over 80% of wafers, cells, and modules globally.

## LATAM Relevance

---

Latin America has exceptional solar resources, particularly in the Atacama Desert (Chile), northeastern Brazil, and northern Mexico. Chile leads regional solar deployment with over 10 GW installed capacity, including the region's first CSP plants. Brazil's distributed solar PV market is among the fastest-growing globally, driven by net metering policies. Colombia's La Guajira region offers strong solar potential still largely untapped.

## Critical Minerals Link

---

Solar PV manufacturing requires silicon (polysilicon for wafers), silver (cell metallization), copper (wiring and inverters), and aluminium (frames). CSP depends on steel, glass, and specialized heat-transfer fluids. Chile and Peru supply copper essential for solar system balance-of-plant components.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — solar generation and grid integration; IN (Industry) — PV manufacturing and supply chain; XS (Cross-Sectoral) — distributed generation across buildings and industry.

# Wind (onshore & offshore)

## Source Metadata

| Field                | Value                     |
|----------------------|---------------------------|
| source               | iea                       |
| source_version       | ETCS 2025                 |
| source_id            | IEA-SUP-002               |
| iea_category         | energy_supply             |
| technology           | Wind (onshore & offshore) |
| technology_readiness | commercial                |
| mitigation           | Y                         |
| adaptation           | N                         |
| last_checked         | 2026-05-26                |

## IEA Technology Definition

The IEA classifies wind energy under renewable electricity supply, distinguishing onshore and offshore wind as separate technology tracks. Onshore wind uses turbines installed on land to convert kinetic wind energy into electricity, while offshore wind deploys turbines in marine environments (fixed-bottom or floating). Both are categorized as mainstream clean energy technologies in the ETP Clean Energy Technology Guide.

## Technology Readiness & Deployment

Onshore wind is fully commercial with over 1,000 GW installed globally. Offshore wind has reached early commercial maturity, with approximately 75 GW installed, led by China, the UK, and Northern Europe. Floating offshore wind remains at demonstration stage with less than 200 MW deployed. The IEA tracks wind as broadly on track for net zero but flags permitting delays and supply chain bottlenecks as risks to meeting 2030 targets.

## Key Metrics & Benchmarks

Onshore wind LCOE ranges from USD 25-50/MWh in favorable locations. Offshore wind costs have fallen to USD 60-100/MWh for fixed-bottom installations. Modern onshore turbines reach 6-7 MW capacity with rotor diameters exceeding 170 meters. Offshore turbines now exceed 15 MW per unit. Capacity factors range from 25-45% onshore and 40-55% offshore.

## LATAM Relevance

---

Brazil is Latin America's wind leader with over 30 GW installed, primarily onshore in the northeast. Colombia's La Guajira region has world-class wind resources with several GW of projects under development. Chile and Argentina also have significant onshore wind potential in Patagonia and central regions. Offshore wind is nascent in LATAM but Brazil and Colombia have begun regulatory frameworks for offshore development.

## Critical Minerals Link

---

Wind turbines require rare earth elements (neodymium and dysprosium for permanent magnet generators), copper (generators and cabling), steel (towers), and fibreglass or carbon fibre (blades). Offshore installations require significantly more copper for subsea cables. Brazil holds notable rare earth reserves that could support regional wind supply chains.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — wind generation, grid integration, and offshore infrastructure; IN (Industry) — turbine manufacturing and installation; XS (Cross-Sectoral) — hybrid wind-storage systems.

# Hydropower, Tidal & Wave

## Source Metadata

| Field                | Value                    |
|----------------------|--------------------------|
| source               | iea                      |
| source_version       | ETCS 2025                |
| source_id            | IEA-SUP-003              |
| iea_category         | energy_supply            |
| technology           | Hydropower, Tidal & Wave |
| technology_readiness | commercial               |
| mitigation           | Y                        |
| adaptation           | N                        |
| last_checked         | 2026-05-26               |

## IEA Technology Definition

The IEA groups hydropower, tidal, and wave energy under renewable electricity technologies that harness the energy of water. Hydropower (conventional and pumped storage) is the largest source of renewable electricity globally. Tidal and wave (ocean energy) technologies convert marine kinetic and potential energy into electricity through various mechanisms including tidal barrages, tidal stream turbines, and wave energy converters.

## Technology Readiness & Deployment

Conventional hydropower is a mainstream technology with over 1,400 GW installed globally. Pumped storage hydropower provides about 160 GW of grid-scale storage capacity. Hydropower installations more than doubled to over 25 GW in 2024, driven by large projects in China, Africa, and Southeast Asia. Ocean energy (tidal and wave) remains at demonstration or early commercial stage with less than 1 GW deployed globally and is not on track per IEA assessments, requiring rapid scale-up in policy support.

## Key Metrics & Benchmarks

Hydropower LCOE ranges from USD 20-80/MWh depending on site and scale. Pumped storage provides 4-12 hours of discharge at costs of USD 50-150/MWh. Capacity factors for conventional hydro average 40-60%. Hydropower accounts for approximately 3% of projected new renewable power additions to 2030, while pumped storage is seeing faster growth between 2025-2030 than the previous five years.

# LATAM Relevance

---

Latin America depends heavily on hydropower, which supplies over 45% of the region's electricity. Brazil has the world's third-largest hydropower fleet (over 110 GW), and Colombia, Peru, and Chile rely significantly on hydroelectric generation. Climate variability and drought increasingly threaten hydro-dependent grids, making diversification urgent. Pumped storage potential exists across the Andes and Brazilian highlands.

# Critical Minerals Link

---

Hydropower requires large quantities of steel and concrete for dams and infrastructure, copper for generators and transmission, and aluminium for structural components. Ocean energy devices require steel, copper, and specialized marine-grade materials. The mineral intensity per MWh is relatively low compared to other renewables.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — hydroelectric generation, pumped storage, ocean energy; XS (Cross-Sectoral) — water-energy nexus, climate adaptation of hydro assets.

# Geothermal

## Source Metadata

| Field                | Value         |
|----------------------|---------------|
| source               | iea           |
| source_version       | ETCS 2025     |
| source_id            | IEA-SUP-004   |
| iea_category         | energy_supply |
| technology           | Geothermal    |
| technology_readiness | commercial    |
| mitigation           | Y             |
| adaptation           | N             |
| last_checked         | 2026-05-26    |

## IEA Technology Definition

The IEA classifies geothermal energy as a renewable technology that harnesses heat from the Earth's interior for electricity generation and direct heating applications. The ETP Technology Guide distinguishes conventional hydrothermal systems (commercial) from enhanced geothermal systems (EGS), which are at demonstration stage. Geothermal provides baseload renewable power with capacity factors exceeding 80%.

## Technology Readiness & Deployment

Conventional geothermal power is commercially deployed with approximately 16 GW installed globally, led by the United States, Indonesia, the Philippines, Turkey, and Kenya. The IEA projects annual geothermal capacity additions will reach historic highs by 2030, tripling the 2024 rate. However, the IEA rates geothermal as not on track for net zero targets, requiring a rapid step-up in investment and policy support. Enhanced geothermal systems show promise but remain pre-commercial.

## Key Metrics & Benchmarks

Geothermal LCOE typically ranges from USD 50-100/MWh for conventional hydrothermal. Capacity factors of 80-95% make geothermal the most reliable renewable source for baseload power. Direct-use geothermal for heating serves over 100,000 thermal MW globally. The technology produces minimal lifecycle greenhouse gas emissions compared to fossil baseload alternatives.

# LATAM Relevance

---

Latin America sits on the Pacific Ring of Fire, giving it significant geothermal potential. Mexico has the fourth-largest geothermal capacity globally (approximately 1 GW at Cerro Prieto). Chile, Colombia, Peru, and Central American nations have identified substantial untapped geothermal resources along the Andes. Colombia's Nevado del Ruiz and Chiles-Cerro Negro systems are under exploration.

# Critical Minerals Link

---

Geothermal systems require steel and specialized alloys for well casings and piping resistant to high-temperature corrosive fluids. Copper is used in generators and power plant equipment. Geothermal brines can contain lithium as a byproduct, creating potential co-extraction opportunities relevant for battery mineral supply chains, particularly in Chile and Argentina.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — geothermal power generation and direct heat; BU (Buildings) — district heating from geothermal; IN (Industry) — industrial process heat from geothermal sources.

# Bioenergy & Synthetic Fuels

## Source Metadata

| Field                | Value                       |
|----------------------|-----------------------------|
| source               | iea                         |
| source_version       | ETCS 2025                   |
| source_id            | IEA-SUP-005                 |
| iea_category         | energy_supply               |
| technology           | Bioenergy & Synthetic Fuels |
| technology_readiness | early_commercial            |
| mitigation           | Y                           |
| adaptation           | N                           |
| last_checked         | 2026-05-26                  |

## IEA Technology Definition

The IEA classifies bioenergy as energy derived from biomass sources — including agricultural residues, forestry waste, energy crops, and organic waste — used for power, heat, and transport fuels. Synthetic fuels (e-fuels) are produced by combining green hydrogen with captured CO2 to create drop-in hydrocarbon replacements. The ETP Technology Guide categorizes advanced biofuels and synthetic fuels as key alternative fuels for hard-to-abate sectors.

## Technology Readiness & Deployment

Conventional bioenergy (biopower, bioethanol, biodiesel) is commercially deployed globally, accounting for approximately 6% of global energy supply. Advanced biofuels (cellulosic ethanol, bio-jet fuel) are at early commercial stage with limited production capacity. Synthetic fuels remain largely at demonstration or pilot stage, with global production below 1,000 tonnes per year. The IEA flags both advanced biofuels and e-fuels as needing significantly faster deployment to meet net zero targets.

## Key Metrics & Benchmarks

Biopower LCOE ranges from USD 50-120/MWh. Bioethanol production exceeds 100 billion litres annually, led by the United States and Brazil. Sustainable aviation fuel (SAF) production reached approximately 1 billion litres in 2024 but needs to scale tenfold by 2030. Synthetic fuel production costs remain high at USD 3-6 per litre, requiring cheaper green hydrogen and CO2 capture to become competitive.

## LATAM Relevance

---

Brazil is the world's second-largest bioethanol producer and a pioneer in sugarcane-based bioenergy, with a mature flex-fuel vehicle fleet and extensive biomass power generation. Colombia has mandated biodiesel and ethanol blending in transport fuels. The region's abundant biomass resources and low-cost renewable electricity make LATAM a potential hub for advanced biofuels and green hydrogen-based synthetic fuel production.

## Critical Minerals Link

---

Bioenergy has low critical mineral intensity compared to other energy technologies. Catalysts for advanced biofuel and synthetic fuel production use platinum group metals (PGMs) and nickel. Electrolyser components for green hydrogen (needed for e-fuel synthesis) require iridium and platinum, with supply chain risks.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — biopower and biomass heating; TR (Transport) — biofuels and synthetic aviation fuels; IN (Industry) — biomass for industrial process heat; XS (Cross-Sectoral) — waste-to-energy systems.

# Nuclear (incl. SMRs)

## Source Metadata

| Field                | Value                |
|----------------------|----------------------|
| source               | iea                  |
| source_version       | ETCS 2025            |
| source_id            | IEA-SUP-006          |
| iea_category         | energy_supply        |
| technology           | Nuclear (incl. SMRs) |
| technology_readiness | commercial           |
| mitigation           | Y                    |
| adaptation           | N                    |
| last_checked         | 2026-05-26           |

## IEA Technology Definition

The IEA classifies nuclear energy as a low-carbon dispatchable electricity source using controlled nuclear fission. The technology is split between conventional large-scale reactors (Generation III/III+) and Small Modular Reactors (SMRs) with capacities below 300 MW. The ETP Technology Guide positions conventional nuclear as a mature technology and SMRs as an emerging technology at demonstration to early commercial readiness.

## Technology Readiness & Deployment

Conventional nuclear power operates approximately 440 reactors globally with around 390 GW of installed capacity. New large reactor construction continues in China, India, Egypt, Turkey, and the UK. SMRs have seen a surge of interest, with conditional offtake agreements between data centre operators and SMR developers growing from 25 GW at end-2024 to 45 GW by mid-2025. China and Russia have operational SMR-type designs, while NuScale, Rolls-Royce, and others are in advanced licensing stages.

## Key Metrics & Benchmarks

Large nuclear plant LCOE ranges from USD 40-100/MWh with capacity factors typically above 80%. SMR cost projections range from USD 60-120/MWh but remain unproven at commercial scale. Nuclear provides approximately 10% of global electricity and about 25% of low-carbon electricity. Typical construction timelines are 7-12 years for large reactors; SMRs aim for 3-5 year build cycles through factory fabrication and modular assembly.

# LATAM Relevance

---

Argentina, Brazil, and Mexico operate nuclear power plants, with Argentina pioneering the CAREM-25 small modular reactor, one of the most advanced SMR projects globally. Brazil is constructing Angra 3 to expand its nuclear fleet. Chile and Colombia have explored nuclear feasibility studies. Nuclear can complement variable renewables in LATAM grids, providing firm low-carbon baseload power.

# Critical Minerals Link

---

Nuclear energy requires uranium fuel, zirconium alloys for fuel cladding, hafnium for control rods, and specialized steel for pressure vessels. SMRs may use high-assay low-enriched uranium (HALEU). Latin America has uranium deposits in Brazil and Argentina, though most supply comes from Kazakhstan, Canada, and Australia.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — nuclear power generation, SMR deployment, grid stability; IN (Industry) — nuclear-powered industrial heat (SMR applications); XS (Cross-Sectoral) — hydrogen production via nuclear heat.

# Grids & Storage

---

Transmission, distribution, battery and other storage

# Batteries & Energy Storage

## Source Metadata

| Field                | Value                      |
|----------------------|----------------------------|
| source               | iea                        |
| source_version       | ETCS 2025                  |
| source_id            | IEA-SUP-007                |
| iea_category         | energy_supply              |
| technology           | Batteries & Energy Storage |
| technology_readiness | commercial                 |
| mitigation           | Y                          |
| adaptation           | N                          |
| last_checked         | 2026-05-26                 |

## IEA Technology Definition

The IEA classifies battery energy storage systems (BESS) and other storage technologies as critical enablers of clean energy transitions. Grid-scale batteries store electricity for later dispatch, providing flexibility, frequency regulation, and peak shaving. The category also includes pumped hydro, compressed air, and emerging long-duration storage technologies such as flow batteries and thermal storage.

## Technology Readiness & Deployment

Battery storage is the fastest-growing power technology today. Global deployment reached 108 GW of new battery storage capacity in 2025, up 40% from 2024. Lithium-iron phosphate (LFP) chemistry accounts for approximately 90% of grid-scale deployments. The IEA considers battery storage on track for net zero targets, though long-duration storage (beyond 4-8 hours) remains at early commercial or demonstration stage and needs accelerated deployment.

## Key Metrics & Benchmarks

Lithium-ion battery pack costs have fallen below USD 140/kWh on average and continue to decline. Grid-scale BESS typically provides 2-4 hours of storage, with costs around USD 150-250/kWh installed. Battery manufacturing capacity is concentrated in China (over 75% of global cell production). LFP dominates stationary storage while NMC and emerging sodium-ion chemistries compete for different applications.

# LATAM Relevance

---

Battery storage deployment in Latin America is accelerating, driven by the need to integrate growing solar and wind capacity. Chile has commissioned several utility-scale BESS projects to manage grid congestion in the north. Brazil's auction frameworks are beginning to include storage. Argentina and Chile's lithium reserves position the region as a potential battery manufacturing hub, though current value-addition remains focused on raw material extraction.

# Critical Minerals Link

---

Batteries are the single largest driver of critical mineral demand growth. LFP batteries require lithium and phosphate; NMC batteries additionally need nickel, cobalt, and manganese. Chile holds 26% and Argentina 6% of global lithium production. Battery recycling is emerging as a critical supply chain strategy, with cobalt and nickel recovery rates improving.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — grid-scale storage, renewable integration; TR (Transport) — EV batteries and vehicle-to-grid; IN (Industry) — battery manufacturing; XS (Cross-Sectoral) — distributed storage, behind-the-meter systems.

# Smart Grids & Digitalization

## Source Metadata

| Field                | Value                        |
|----------------------|------------------------------|
| source               | iea                          |
| source_version       | ETCS 2025                    |
| source_id            | IEA-CRS-001                  |
| iea_category         | cross_cutting                |
| technology           | Smart Grids & Digitalization |
| technology_readiness | early_commercial             |
| mitigation           | Y                            |
| adaptation           | N                            |
| last_checked         | 2026-05-26                   |

## IEA Technology Definition

The IEA classifies smart grids and energy system digitalization as cross-cutting technologies that enable the integration of variable renewables, demand-side flexibility, and distributed energy resources. Smart grids encompass advanced metering infrastructure (AMI), distribution automation, real-time monitoring, demand response platforms, and AI-driven grid optimization. Digitalization spans the entire energy value chain from generation forecasting to consumer engagement.

## Technology Readiness & Deployment

Smart grid components are at varying readiness levels: smart meters are commercially deployed in many advanced economies, while AI-driven grid optimization and virtual power plants are at early commercial stage. The IEA emphasizes that grid flexibility is essential for accommodating growing penetrations of solar PV, wind, EVs, and heat pumps. Investment in grid modernization needs to accelerate significantly to match the pace of renewable deployment.

## Key Metrics & Benchmarks

Global investment in electricity grids reached approximately USD 400 billion in 2024. Smart meter deployment exceeds 1 billion units worldwide. Demand response capacity is growing but represents less than 5% of peak demand in most markets. The IEA estimates that digitalizing grids could reduce curtailment of renewables by 30-40% and defer significant transmission infrastructure investment.

# LATAM Relevance

---

Latin American grids face challenges from rapid renewable growth, long transmission distances, and distribution system losses. Brazil's smart meter rollout is expanding under ANEEL regulation. Chile is investing in grid digitalization for its renewable-rich northern system. Colombia's grid modernization plan addresses integration of distributed solar and regional interconnections. Grid losses in LATAM average 15-20%, significantly above OECD norms, making digitalization economically compelling.

# Critical Minerals Link

---

Smart grid infrastructure requires copper (wiring and power electronics), silicon (semiconductors), rare earth elements (sensors and electronics), and aluminium (conductors). The demand for power electronics components (using silicon carbide and gallium nitride) is growing rapidly with grid modernization.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — grid management, flexibility services; IC (ICT) — digital platforms, AI for energy; BU (Buildings) — smart building integration; XS (Cross-Sectoral) — demand response across all end-use sectors.

# Electricity Transmission & Distribution

## Source Metadata

| Field                | Value                                   |
|----------------------|-----------------------------------------|
| source               | iea                                     |
| source_version       | ETCS 2025                               |
| source_id            | IEA-SUP-008                             |
| iea_category         | energy_supply                           |
| technology           | Electricity Transmission & Distribution |
| technology_readiness | commercial                              |
| mitigation           | Y                                       |
| adaptation           | N                                       |
| last_checked         | 2026-05-26                              |

## IEA Technology Definition

The IEA classifies electricity transmission and distribution (T&D) infrastructure as foundational to clean energy transitions. This includes high-voltage AC and DC transmission lines, substations, transformers, power electronics (FACTS devices, HVDC converters), and distribution networks. The timely expansion and modernization of grids is identified as a critical bottleneck for achieving net zero targets.

## Technology Readiness & Deployment

Conventional T&D infrastructure is fully mature and commercially deployed. HVDC technology for long-distance, high-capacity transmission is at commercial stage and expanding rapidly, particularly in China and Europe. The IEA flags that grid expansion is not keeping pace with renewable deployment in most regions. Permitting and planning processes for new transmission lines typically take 5-15 years, creating structural delays in the energy transition.

# Key Metrics & Benchmarks

---

Global electricity grid length exceeds 80 million km. Annual grid investment reached approximately USD 400 billion in 2024 but the IEA estimates this needs to nearly double by 2030. HVDC lines can transmit power over 2,000+ km with losses below 3%. Transformer lead times have extended to 2-3 years globally due to supply chain constraints. Distribution system upgrades are critical for accommodating distributed generation, EVs, and heat pumps.

## LATAM Relevance

---

Latin America faces significant transmission challenges connecting remote renewable resources to demand centres. Brazil's HVDC backbone transmits Amazonian hydropower and northeastern wind over thousands of kilometres. Chile's single-circuit transmission from the Atacama solar region to Santiago is a recognized bottleneck. Regional interconnections between Colombia, Ecuador, Peru, and Chile remain limited, constraining cross-border electricity trade and system resilience.

## Critical Minerals Link

---

T&D infrastructure is the largest single demand sector for copper, which is essential for conductors, cables, transformers, and substations. Aluminium is used extensively in overhead transmission lines. Transformer cores require grain-oriented electrical steel. LATAM's copper production (Chile and Peru account for 37% of global supply) directly supports global grid expansion.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — transmission planning, grid expansion, interconnections; IN (Industry) — cable and transformer manufacturing; XS (Cross-Sectoral) — electrification infrastructure enabling all sectors.

# Efficiency

---

Buildings, appliances, industry efficiency

# Buildings Energy Efficiency

## Source Metadata

| Field                | Value                       |
|----------------------|-----------------------------|
| source               | iea                         |
| source_version       | ETCS 2025                   |
| source_id            | IEA-END-001                 |
| iea_category         | end_use                     |
| technology           | Buildings Energy Efficiency |
| technology_readiness | commercial                  |
| mitigation           | Y                           |
| adaptation           | N                           |
| last_checked         | 2026-05-26                  |

## IEA Technology Definition

The IEA classifies buildings energy efficiency as an end-use technology cluster covering heat pumps, building envelope improvements (insulation, glazing, air sealing), efficient lighting and appliances, and building electrification. The ETP Technology Guide tracks heat pumps as a key technology for decarbonizing space and water heating, alongside deep retrofits and near-zero-energy building standards.

## Technology Readiness & Deployment

Heat pumps are commercially mature with global sales reaching approximately 10 million units per year in residential and commercial applications. Air-source heat pumps dominate the market, while ground-source systems serve colder climates. LED lighting penetration exceeds 50% globally. Building energy codes are tightening in advanced economies but remain weak or absent in many developing regions. The IEA considers heat pump deployment broadly on track but flags building envelope retrofit rates as far too low.

## Key Metrics & Benchmarks

Heat pumps deliver 3-5 units of heat per unit of electricity consumed (COP 3-5), making them 2-4 times more efficient than gas boilers. Global heat pump stock exceeds 200 million units. Deep building retrofits can reduce energy consumption by 50-70%. The buildings sector accounts for approximately 30% of global final energy consumption and 26% of energy-related CO2 emissions.

# LATAM Relevance

---

Latin American buildings face growing cooling demand due to rising temperatures and urbanization. Air conditioning adoption is expanding rapidly in Brazil, Colombia, and Mexico, making efficient cooling technologies a priority. Heat pump adoption for heating is relevant in southern Chile and Argentina. Building energy codes exist in Brazil, Colombia, Chile, and Mexico but enforcement and retrofit rates remain low. Urban informal housing presents unique efficiency challenges.

# Critical Minerals Link

---

Heat pumps require copper (heat exchangers, compressors), aluminium (evaporators), and specialized refrigerants. Efficient appliances and LED lighting use silicon, gallium, and indium. The mineral intensity of building efficiency technologies is modest compared to power generation, but volumes are significant given the massive scale of the buildings sector.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: BU (Buildings) — heat pumps, insulation, building codes, efficient appliances; ES (Energy Systems) — demand-side flexibility from smart buildings; XS (Cross-Sectoral) — building-integrated renewables.

# Transport Efficiency

## Source Metadata

| Field                | Value                |
|----------------------|----------------------|
| source               | iea                  |
| source_version       | ETCS 2025            |
| source_id            | IEA-END-002          |
| iea_category         | end_use              |
| technology           | Transport Efficiency |
| technology_readiness | commercial           |
| mitigation           | Y                    |
| adaptation           | N                    |
| last_checked         | 2026-05-26           |

## IEA Technology Definition

The IEA classifies transport efficiency under end-use technologies, encompassing electric vehicles (battery EVs and plug-in hybrids), hydrogen fuel cell vehicles, vehicle lightweighting, and modal shift. The ETP Technology Guide tracks EVs as one of six key clean energy technologies alongside solar PV, wind, batteries, electrolyzers, and heat pumps. Hydrogen vehicles target heavy-duty transport, shipping, and aviation where battery electrification faces limitations.

## Technology Readiness & Deployment

Battery electric passenger vehicles are commercially mature, with global sales exceeding 17 million units in 2024. Electric buses and two/three-wheelers are scaling rapidly in China and Southeast Asia. Hydrogen fuel cell vehicles remain at early commercial stage with limited fleet deployments, primarily in buses and trucks. The IEA projects the growing EV fleet will displace 8 million barrels of oil per day by 2030 in the Net Zero scenario. Electric heavy-duty trucks are emerging but face range and charging infrastructure challenges.

## Key Metrics & Benchmarks

EVs now represent approximately 20% of new car sales globally. Battery costs for automotive applications have fallen below USD 140/kWh. EV energy efficiency is 3-4 times higher than internal combustion engines on a well-to-wheel basis. Charging infrastructure exceeds 4 million public charge points globally. Hydrogen fuel cell costs remain significantly higher than battery electric alternatives for most passenger vehicle applications.

## LATAM Relevance

---

EV adoption in Latin America is growing from a low base, led by Brazil, Colombia, Chile, and Costa Rica. Chile hosts the largest electric bus fleet outside China (over 2,000 units in Santiago). Brazil's auto industry is pivoting from flex-fuel to hybrid and electric vehicles. Colombia has implemented EV purchase incentives and is electrifying its BRT systems. Charging infrastructure across the region remains underdeveloped relative to vehicle sales.

## Critical Minerals Link

---

EVs are the largest driver of lithium, cobalt, and nickel demand growth. Each EV battery contains 8-12 kg of lithium, 5-20 kg of nickel, and 5-10 kg of cobalt (NMC chemistry). Copper usage per EV is 2-4 times higher than for combustion vehicles. LATAM's lithium triangle (Chile, Argentina, Bolivia) and copper belt are critical to global EV supply chains. Hydrogen fuel cells require platinum group metals.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: TR (Transport) — EVs, fuel cells, charging infrastructure, modal shift; ES (Energy Systems) — vehicle-to-grid, transport electricity demand; IN (Industry) — vehicle and battery manufacturing.

# Industrial Energy Efficiency

## Source Metadata

| Field                | Value                        |
|----------------------|------------------------------|
| source               | iea                          |
| source_version       | ETCS 2025                    |
| source_id            | IEA-END-003                  |
| iea_category         | end_use                      |
| technology           | Industrial Energy Efficiency |
| technology_readiness | commercial                   |
| mitigation           | Y                            |
| adaptation           | N                            |
| last_checked         | 2026-05-26                   |

## IEA Technology Definition

The IEA classifies industrial energy efficiency as end-use technologies that reduce energy intensity in manufacturing and industrial processes. This includes high-efficiency motors and drives, waste heat recovery, process optimization, industrial heat pumps, and energy management systems. The ETP Technology Guide tracks these as essential for reducing the 37% share of global final energy consumed by industry.

## Technology Readiness & Deployment

Most industrial energy efficiency technologies are commercially available. High-efficiency electric motors (IE3/IE4 class) are mandatory in many markets. Waste heat recovery systems are deployed in energy-intensive industries including cement, steel, and chemicals. Industrial heat pumps capable of delivering temperatures up to 150°C are at early commercial stage. The IEA rates industrial efficiency improvement as not on track, with global energy intensity declining at only 1-2% per year versus the 4% needed for net zero.

## Key Metrics & Benchmarks

Electric motor systems account for approximately 45% of global electricity consumption. Upgrading to high-efficiency motors and variable speed drives can reduce motor system energy use by 20-30%. Industry accounts for 37% of global final energy consumption. Best available technologies could reduce energy consumption in many industrial subsectors by 25-40% compared to current averages. Energy management systems (ISO 50001) are adopted by over 50,000 certified sites globally.

# LATAM Relevance

---

Latin American industry faces significant energy efficiency gaps. Mining (Chile, Peru), food processing (Brazil, Colombia), and cement production are major energy consumers in the region. Industrial electricity tariffs in LATAM are relatively high, improving the economic case for efficiency investments. Brazil's PROCEL program and Colombia's PROURE initiative promote industrial efficiency, though adoption of best available technologies remains limited in small and medium enterprises.

# Critical Minerals Link

---

High-efficiency motors use rare earth permanent magnets (neodymium). Power electronics for variable speed drives require silicon carbide and gallium nitride. Industrial heat pumps use copper and specialized refrigerants. The critical mineral footprint of efficiency measures is relatively low, making them cost-effective decarbonization strategies.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — process optimization, motors, waste heat recovery; ES (Energy Systems) — industrial demand management; XS (Cross-Sectoral) — energy management systems, circular economy approaches.

# Industry & Hydrogen

---

Industrial decarbonisation, clean hydrogen production

# Green Hydrogen Production (electrolysers)

## Source Metadata

| Field                | Value                                     |
|----------------------|-------------------------------------------|
| source               | iea                                       |
| source_version       | ETCS 2025                                 |
| source_id            | IEA-CRS-002                               |
| iea_category         | cross_cutting                             |
| technology           | Green Hydrogen Production (electrolysers) |
| technology_readiness | early_commercial                          |
| mitigation           | Y                                         |
| adaptation           | N                                         |
| last_checked         | 2026-05-26                                |

## IEA Technology Definition

The IEA classifies electrolyzers as a key clean energy technology for producing green hydrogen by splitting water using renewable electricity. The ETP Technology Guide identifies electrolyzers alongside solar PV, wind, batteries, EVs, and heat pumps as the six pillar technologies of the clean energy transition. Electrolyser types include alkaline (most mature), proton exchange membrane (PEM), and solid oxide (SOEC, at demonstration stage).

## Technology Readiness & Deployment

Green hydrogen is at early commercial stage. Global investment in low-emissions hydrogen production climbed to nearly USD 8 billion in 2025, with year-on-year growth of 80%. Electrolyser deployment growth to 2030 is comparable to solar PV's early ramp-up trajectory. A record number of technologies advanced in technology readiness level across the hydrogen value chain during 2024-2025. However, actual deployed electrolyser capacity remains a fraction of announced project pipelines, and the IEA flags the need for faster final investment decisions.

# Key Metrics & Benchmarks

---

Alkaline electrolyser costs range from USD 500-1,400/kW, while PEM systems cost USD 1,000-2,000/kW. Green hydrogen production costs range from USD 3-8/kg depending on electricity costs and utilization rates. The IEA projects costs could fall to USD 1.5-3/kg by 2030 in regions with excellent renewable resources. Global electrolyser manufacturing capacity is expanding rapidly, with China dominating production.

## LATAM Relevance

---

Latin America is positioned as a potential green hydrogen export hub due to abundant low-cost renewable resources. Chile's National Green Hydrogen Strategy targets becoming a top-three exporter by 2040. Colombia, Brazil, and Uruguay have also launched hydrogen strategies. The Atacama region's solar resources and Patagonia's wind resources offer some of the world's lowest-cost renewable electricity, potentially enabling competitive green hydrogen production below USD 2/kg.

## Critical Minerals Link

---

PEM electrolyzers require iridium and platinum catalysts, creating supply chain risks given concentrated production in South Africa and Russia. Alkaline electrolyzers use nickel electrodes. SOEC systems require rare earth elements. Electrolyser stacks also use titanium, zirconium, and specialty steels. Reducing platinum group metal loading is a key research priority.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: ES (Energy Systems) — hydrogen production, power-to-gas; IN (Industry) — electrolyser manufacturing, industrial hydrogen supply; TR (Transport) — hydrogen for fuel cells; XS (Cross-Sectoral) — sector coupling, energy storage via hydrogen.

# Industrial Decarbonization (steel, cement, chemicals)

## Source Metadata

| Field                | Value                                                 |
|----------------------|-------------------------------------------------------|
| source               | iea                                                   |
| source_version       | ETCS 2025                                             |
| source_id            | IEA-END-004                                           |
| iea_category         | end_use                                               |
| technology           | Industrial Decarbonization (steel, cement, chemicals) |
| technology_readiness | demo                                                  |
| mitigation           | Y                                                     |
| adaptation           | N                                                     |
| last_checked         | 2026-05-26                                            |

## IEA Technology Definition

The IEA classifies industrial decarbonization technologies as solutions targeting the three hardest-to-abate industrial sectors: steel, cement, and chemicals. These sectors produce approximately 70% of industrial CO2 emissions. Key technology pathways include hydrogen-based direct reduction of iron (H-DRI), electrification of process heat, alternative cement chemistries (including supplementary cementitious materials), catalytic process innovation in chemicals, and circular economy approaches.

## Technology Readiness & Deployment

Most deep industrial decarbonization technologies are at demonstration or early commercial stage. Hydrogen-based steelmaking (H-DRI) is being piloted by SSAB/HYBRIT in Sweden and others in Europe. Low-clinker cements and supplementary materials are commercially available but adoption is slow. Green ammonia and methanol production from green hydrogen are at pilot to early commercial scale. The IEA rates heavy industry decarbonization as not on track for net zero, requiring massive scale-up of investment and innovation.

# Key Metrics & Benchmarks

---

Steel production accounts for approximately 7% of global CO2 emissions, cement for 7%, and chemicals for 4%. H-DRI steel currently costs 20-40% more than conventional blast furnace steel. Global steel production exceeds 1.9 billion tonnes annually. Cement production reaches approximately 4.2 billion tonnes. The IEA estimates that reaching net zero requires near-zero-emission steel and cement to reach commercial scale by 2030.

## LATAM Relevance

---

Brazil is the world's ninth-largest steel producer and a major cement and chemicals market. Colombia and Peru have significant cement industries. LATAM's access to low-cost renewable electricity and green hydrogen potential positions the region for low-carbon industrial production. Brazil's charcoal-based steelmaking (using planted eucalyptus) is already partially decarbonized. Carbon pricing mechanisms in Chile, Colombia, and Mexico create incentives for industrial decarbonization.

## Critical Minerals Link

---

Industrial decarbonization increases demand for hydrogen (requiring electrolyser minerals), advanced catalysts (platinum group metals for chemical processes), and specialty alloys for high-temperature electrification. Circular economy approaches in industry can reduce overall mineral demand by improving recycling rates of steel, aluminium, and copper.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — steel, cement, chemicals decarbonization; ES (Energy Systems) — industrial hydrogen demand; XS (Cross-Sectoral) — circular economy, carbon pricing, green procurement.

# Carbon Capture, Utilisation & Storage (CCUS)

## Source Metadata

| Field                | Value                                        |
|----------------------|----------------------------------------------|
| source               | iea                                          |
| source_version       | ETCS 2025                                    |
| source_id            | IEA-CRS-003                                  |
| iea_category         | cross_cutting                                |
| technology           | Carbon Capture, Utilisation & Storage (CCUS) |
| technology_readiness | early_commercial                             |
| mitigation           | Y                                            |
| adaptation           | N                                            |
| last_checked         | 2026-05-26                                   |

## IEA Technology Definition

The IEA classifies CCUS as a cross-cutting technology covering the capture of CO2 from industrial processes or power generation, its transport, and permanent geological storage or utilization in products. The ETP Technology Guide includes post-combustion capture, pre-combustion capture, oxy-combustion, and direct air capture (DAC). CCUS is considered essential for decarbonizing hard-to-abate sectors and delivering negative emissions when combined with bioenergy (BECCS).

## Technology Readiness & Deployment

Average annual investment in CCUS has grown more than 15-fold since 2020 to over USD 5 billion in 2025, with several landmark projects reaching final investment decisions. However, almost 90% of announced CCUS projects have not yet reached final investment decision. Chemical absorption from industrial sources (natural gas processing, hydrogen production) is at early commercial stage. Post-combustion capture from power generation and direct air capture remain at demonstration stage. The IEA rates CCUS as not on track, requiring major acceleration.

# Key Metrics & Benchmarks

---

Global operational CO<sub>2</sub> capture capacity is approximately 50 Mtpa across about 40 facilities. Capture costs range from USD 15-25/tCO<sub>2</sub> for natural gas processing to USD 40-120/tCO<sub>2</sub> for power generation and USD 250-600/tCO<sub>2</sub> for direct air capture. The IEA Net Zero scenario requires CCUS capacity to reach over 1 Gtpa by 2030. The United States leads in operational capacity, supported by the 45Q tax credit.

## LATAM Relevance

---

CCUS deployment in Latin America is nascent but has significant potential. Brazil's Petrobras operates CO<sub>2</sub> reinjection in pre-salt oil fields at a scale exceeding 10 MtCO<sub>2</sub>/year, one of the world's largest CO<sub>2</sub> storage operations. Colombia, Argentina, and Mexico have identified geological storage potential in depleted oil and gas fields and saline aquifers. LATAM's large industrial base in steel, cement, and petrochemicals provides capture opportunities. Policy frameworks for CCUS remain underdeveloped in most LATAM countries.

## Critical Minerals Link

---

CCUS technologies require specialty steels and alloys for high-pressure CO<sub>2</sub> transport pipelines. Capture solvents and sorbents use various chemical compounds. Direct air capture systems require significant quantities of potassium hydroxide or solid sorbent materials. The mineral intensity of CCUS is moderate but the steel demand for CO<sub>2</sub> pipeline networks is substantial.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — industrial carbon capture, BECCS; ES (Energy Systems) — power sector CCS, DAC; XS (Cross-Sectoral) — CO<sub>2</sub> transport infrastructure, carbon utilization, negative emissions.

# Critical Minerals

---

Minerals essential for clean energy transition (2025 addition)

# Lithium, Cobalt & Nickel (batteries)

## Source Metadata

| Field                | Value                                |
|----------------------|--------------------------------------|
| source               | iea                                  |
| source_version       | ETCS 2025                            |
| source_id            | IEA-MIN-001                          |
| iea_category         | critical_minerals                    |
| technology           | Lithium, Cobalt & Nickel (batteries) |
| technology_readiness | commercial                           |
| mitigation           | Y                                    |
| adaptation           | N                                    |
| last_checked         | 2026-05-26                           |

## IEA Technology Definition

The IEA's Global Critical Minerals Outlook classifies lithium, cobalt, and nickel as essential battery minerals driving the energy transition. Lithium is the core element in all major lithium-ion battery chemistries (LFP, NMC, NCA). Cobalt and nickel enable higher energy density in NMC and NCA cathodes used in EVs and grid storage. The IEA tracks demand, supply, prices, and geopolitical concentration for each mineral.

## Technology Readiness & Deployment

Mining and refining of all three minerals are commercially established industries. Lithium demand rose by nearly 30% in 2024 alone, significantly exceeding the 10% annual growth rate seen in the 2010s. In the IEA Stated Policies Scenario, lithium demand grows fivefold from today to 2040. Nickel demand is projected to double, while cobalt demand grows 50-60% by 2040. The shift toward LFP chemistry reduces cobalt and nickel intensity per battery but total demand still grows with fleet electrification.

# Key Metrics & Benchmarks

---

Global lithium production exceeded 180,000 tonnes (lithium carbonate equivalent) in 2024. Australia, Chile, and China dominate lithium supply. The Democratic Republic of Congo supplies over 70% of cobalt. Indonesia has become the world's largest nickel producer. Near-term lithium markets appear well-supplied, but the IEA projects markets will move into deficit by the 2030s as EV adoption accelerates beyond current mine project pipelines.

## LATAM Relevance

---

Latin America supplies 35% of the world's lithium, led by Chile (26%) and Argentina (6%), and holds more than half of global lithium reserves in the Lithium Triangle (Chile, Argentina, Bolivia). The region's lithium is primarily extracted from brine deposits in salt flats. Regional efforts to move up the battery value chain include Chile's national lithium strategy and Argentina's investment incentives for lithium processing. Brazil has emerging hard-rock lithium deposits.

## Critical Minerals Link

---

This is the core critical minerals page for battery supply chains. Lithium, cobalt, and nickel demand are directly driven by EV and storage battery deployment. Recycling and second-life applications are emerging but currently recover less than 5% of lithium and 10-15% of cobalt from end-of-life batteries. Diversifying supply and developing recycling infrastructure are IEA priorities for supply chain resilience.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — mining, refining, battery manufacturing; TR (Transport) — EV battery demand; ES (Energy Systems) — grid storage battery demand; XS (Cross-Sectoral) — supply chain governance, ESG standards in mining.

# Copper & Aluminium (grids & EVs)

## Source Metadata

| Field                | Value                            |
|----------------------|----------------------------------|
| source               | iea                              |
| source_version       | ETCS 2025                        |
| source_id            | IEA-MIN-002                      |
| iea_category         | critical_minerals                |
| technology           | Copper & Aluminium (grids & EVs) |
| technology_readiness | commercial                       |
| mitigation           | Y                                |
| adaptation           | N                                |
| last_checked         | 2026-05-26                       |

## IEA Technology Definition

The IEA's Global Critical Minerals Outlook identifies copper and aluminium as foundational metals for electrification and grid expansion. Copper is essential for electrical conductors, motors, transformers, EV wiring, and renewable energy systems. Aluminium is used in transmission lines, solar panel frames, EV lightweight structures, and heat exchangers. The IEA tracks copper as the mineral with the largest established market among energy transition metals.

## Technology Readiness & Deployment

Copper and aluminium mining and smelting are mature commercial industries. Copper demand from clean energy technologies is projected to grow by 30% by 2040 under current policies. The IEA's Global Critical Minerals Outlook 2025 warns of a potential 30% copper supply shortfall by 2035 due to declining ore grades, rising capital costs, limited new discoveries, and long development timelines. Aluminium supply is more diversified but energy-intensive smelting creates decarbonization challenges.

# Key Metrics & Benchmarks

---

Global copper mine production reached approximately 22 million tonnes in 2024. An EV uses 2-4 times more copper than an internal combustion vehicle. A single offshore wind turbine requires 8-30 tonnes of copper. Electricity grids are the largest demand sector for copper. Aluminium production exceeds 70 million tonnes annually, with China producing over 55%. Recycled aluminium requires 95% less energy than primary production.

## LATAM Relevance

---

Latin America accounts for 40% of global copper production, led by Chile (27%) and Peru (10%). The region's copper mines are critical to global electrification and grid expansion. Declining ore grades in Chilean mines and water scarcity in the Atacama are pressing challenges. Brazil is a significant bauxite producer (aluminium ore) and hosts aluminium smelters powered by hydroelectricity. Mexico and Colombia also contribute to regional copper and aluminium supply chains.

## Critical Minerals Link

---

This is the core page for copper and aluminium in the energy transition. Copper faces the most acute supply-demand tension among transition minerals. Substitution options are limited for electrical applications. Aluminium can partially substitute for copper in some conductor applications but with efficiency penalties. Recycling rates for both metals are relatively high (copper ~30%, aluminium ~35% of supply from secondary sources) but insufficient to close projected gaps.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — mining, smelting, refining; ES (Energy Systems) — grid copper demand, transformer manufacturing; TR (Transport) — EV copper and aluminium demand; XS (Cross-Sectoral) — recycling, circular economy, water-energy-mining nexus.

# Rare Earths (wind turbines, EVs)

## Source Metadata

| Field                | Value                            |
|----------------------|----------------------------------|
| source               | iea                              |
| source_version       | ETCS 2025                        |
| source_id            | IEA-MIN-003                      |
| iea_category         | critical_minerals                |
| technology           | Rare Earths (wind turbines, EVs) |
| technology_readiness | commercial                       |
| mitigation           | Y                                |
| adaptation           | N                                |
| last_checked         | 2026-05-26                       |

## IEA Technology Definition

The IEA classifies rare earth elements (REEs) as critical minerals essential for permanent magnet technologies used in wind turbines, EV motors, and industrial applications. Key REEs for clean energy include neodymium, praseodymium, dysprosium, and terbium, which are used to manufacture high-performance NdFeB (neodymium-iron-boron) permanent magnets. The IEA's dedicated Rare Earth Elements 2025 report tracks supply, demand, and concentration risks.

## Technology Readiness & Deployment

Rare earth mining and processing is a mature industry, though highly concentrated geographically. Demand for rare earth elements is growing 50-60% through 2040 under the IEA Stated Policies Scenario. Direct-drive wind turbines (using permanent magnets) and EV traction motors are the primary demand drivers. Efforts to develop rare earth recycling and alternative magnet technologies are at R&D to early commercial stage. China dominates the entire REE value chain from mining through magnet manufacturing.

## Key Metrics & Benchmarks

China produces approximately 60% of rare earth mine output and over 85% of refined rare earth products. A single offshore wind turbine can require up to 600 kg of rare earth magnets. Each EV motor uses approximately 1-2 kg of rare earth elements. Global REE mine production reached approximately 350,000 tonnes in 2024. Recycling currently recovers less than 1% of rare earths from end-of-life products, though several pilot plants are scaling.

# LATAM Relevance

---

Brazil holds approximately one-fifth of global rare earth reserves, making it a strategically important potential supplier for diversification away from Chinese dominance. However, Brazil currently produces only small to moderate volumes of rare earths. The Serra Verde project in Goias and CBMM's niobium-REE operations represent emerging production capacity. Colombia and other LATAM nations have identified but not yet developed rare earth deposits.

# Critical Minerals Link

---

This is the core page for rare earth supply chains. The extreme geographic concentration of REE processing in China creates significant supply chain vulnerability for wind and EV industries globally. The IEA emphasizes the need for supply diversification, recycling technology development, and research into REE-free motor and generator designs. Trade restrictions on REEs have historically caused price spikes and supply disruptions.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — REE mining, refining, magnet manufacturing; ES (Energy Systems) — wind turbine permanent magnets; TR (Transport) — EV motor magnets; XS (Cross-Sectoral) — supply chain security, trade policy, recycling.

# LATAM Mining & Critical Minerals Supply

## Source Metadata

| Field                | Value                                   |
|----------------------|-----------------------------------------|
| source               | iea                                     |
| source_version       | ETCS 2025                               |
| source_id            | IEA-MIN-004                             |
| iea_category         | critical_minerals                       |
| technology           | LATAM Mining & Critical Minerals Supply |
| technology_readiness | commercial                              |
| mitigation           | Y                                       |
| adaptation           | N                                       |
| last_checked         | 2026-05-26                              |

## IEA Technology Definition

The IEA's Global Critical Minerals Outlook and Latin America commentary identify the region as a globally significant supplier of energy transition minerals. This page synthesizes the IEA's assessment of Latin America's role across copper, lithium, nickel, rare earths, graphite, and manganese supply chains. The IEA projects Latin American mining and refining value to reach USD 154 billion amid regulatory reforms to attract foreign capital.

## Technology Readiness & Deployment

Latin American mining is a mature commercial industry with world-class operations in copper (Chile, Peru), lithium (Chile, Argentina), iron ore (Brazil), and bauxite (Brazil). The region is at early stages of developing midstream processing and downstream manufacturing capacity for battery materials and components. Regulatory modernization is underway in Chile (lithium nationalization framework), Argentina (RIGI investment incentives), and Brazil (critical minerals strategy) to capture more value from the energy transition.

# Key Metrics & Benchmarks

---

Latin America accounts for 40% of global copper production, 35% of lithium production, and holds more than half of global lithium reserves. The region supplies significant shares of nickel (Brazil, Cuba), tin (Bolivia, Brazil, Peru), and molybdenum (Chile, Peru). Brazil alone holds around one-fifth of global reserves in graphite, nickel, manganese, and rare earth elements, but as of today produces only small to moderate amounts of these materials.

## LATAM Relevance

---

This page is the central LATAM reference for critical minerals in the Cleantech Taxonomy. The IEA highlights that Latin America's mineral wealth positions it as a pivotal region for global clean energy supply chains, but moving up the value chain requires investment in processing infrastructure, skills development, ESG governance, and enabling policies. Water scarcity in Chilean and Peruvian mining regions, indigenous community rights, and environmental regulation are key constraints on expansion.

## Critical Minerals Link

---

Comprehensive LATAM mineral supply: Chile (copper 27%, lithium 26% of global), Peru (copper 10%, zinc, silver), Argentina (lithium 6%), Brazil (iron ore, bauxite, rare earths, graphite, nickel, manganese), Bolivia (tin, lithium), Mexico (copper, silver, fluorspar), Colombia (coal, nickel, emeralds). The IEA recommends diversifying refining and processing away from China, creating opportunities for LATAM midstream investment.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — mining, mineral processing, smelting; XS (Cross-Sectoral) — ESG governance, water-energy-mining nexus, community engagement, trade policy, circular economy; ES (Energy Systems) — mineral demand from renewable deployment.

# Industrial Electrification

---

Electrification of industrial processes (2025 addition)

# CO<sub>2</sub> Transport & Storage Infrastructure

## Source Metadata

| Field                | Value                                  |
|----------------------|----------------------------------------|
| source               | iea                                    |
| source_version       | ETCS 2025                              |
| source_id            | IEA-CRS-004                            |
| iea_category         | cross_cutting                          |
| technology           | CO2 Transport & Storage Infrastructure |
| technology_readiness | early_commercial                       |
| mitigation           | Y                                      |
| adaptation           | N                                      |
| last_checked         | 2026-05-26                             |

## IEA Technology Definition

The IEA classifies CO<sub>2</sub> transport and storage infrastructure as the downstream component of the CCUS chain, covering dedicated CO<sub>2</sub> pipelines, ship transport, injection wells, and geological storage in depleted oil/gas fields or saline aquifers. The ETP Technology Guide emphasizes that shared CO<sub>2</sub> transport and storage infrastructure (hubs and clusters) is critical to reducing unit costs and enabling CCUS deployment at the scale needed for net zero.

## Technology Readiness & Deployment

CO<sub>2</sub> pipeline transport is commercially proven, with over 8,000 km of CO<sub>2</sub> pipelines operating primarily in North America for enhanced oil recovery. Dedicated geological storage (not EOR) is at early commercial stage, with projects like Northern Lights (Norway) and the Alberta Carbon Trunk Line (Canada) demonstrating shared infrastructure models. CO<sub>2</sub> ship transport is emerging as an alternative for regions without pipeline access. The IEA identifies infrastructure development as a critical bottleneck for CCUS scale-up.

# Key Metrics & Benchmarks

---

Global CO<sub>2</sub> storage capacity in operation is approximately 50 Mtpa. The IEA Net Zero scenario requires this to exceed 1 Gtpa by 2030. CO<sub>2</sub> pipeline transport costs range from USD 2-15/tCO<sub>2</sub> depending on distance and volume. Ship transport adds USD 10-30/tCO<sub>2</sub>. Geological storage site characterization typically takes 3-7 years. Storage costs in well-characterized formations range from USD 5-30/tCO<sub>2</sub>.

## LATAM Relevance

---

Latin America has significant geological CO<sub>2</sub> storage potential in sedimentary basins across Brazil, Argentina, Colombia, and Mexico. Brazil's pre-salt formations already store over 10 MtCO<sub>2</sub>/year through Petrobras reinjection operations. Colombia's depleted oil and gas fields and Argentina's Vaca Muerta region offer additional storage capacity. Shared infrastructure planning is nascent, and regulatory frameworks for dedicated CO<sub>2</sub> storage are still under development in most LATAM jurisdictions.

## Critical Minerals Link

---

CO<sub>2</sub> transport infrastructure requires large volumes of carbon steel and specialty alloys for corrosion-resistant pipelines and wellheads. Compressor stations use copper and high-performance alloys. The steel demand for building out a global CO<sub>2</sub> pipeline network comparable to natural gas infrastructure would be substantial. LATAM's steel production capacity could serve regional CO<sub>2</sub> infrastructure needs.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — CO<sub>2</sub> pipeline and storage infrastructure; ES (Energy Systems) — CCUS-enabled power generation; XS (Cross-Sectoral) — shared infrastructure planning, regulatory frameworks, geological survey and characterization.

# Direct Electrification of Industry

## Source Metadata

| Field                | Value                              |
|----------------------|------------------------------------|
| source               | iea                                |
| source_version       | ETCS 2025                          |
| source_id            | IEA-END-005                        |
| iea_category         | end_use                            |
| technology           | Direct Electrification of Industry |
| technology_readiness | early_commercial                   |
| mitigation           | Y                                  |
| adaptation           | N                                  |
| last_checked         | 2026-05-26                         |

## IEA Technology Definition

The IEA classifies direct electrification of industry as end-use technologies that replace fossil fuel combustion in industrial processes with electrical alternatives. This includes electric arc furnaces for steelmaking, industrial heat pumps for low-to-medium temperature processes, electromagnetic heating (induction, microwave, infrared), electric kilns for ceramics and cement, and plasma torches for high-temperature applications. The ETP Technology Guide tracks electrification as a key pathway alongside hydrogen and CCUS for industrial decarbonization.

## Technology Readiness & Deployment

Electric arc furnace (EAF) steelmaking is commercially mature and accounts for approximately 30% of global steel production using recycled scrap. Industrial heat pumps delivering temperatures up to 150°C are at early commercial stage, with emerging systems targeting 200°C and above. Electric kilns and high-temperature electrification (above 400°C) for cement, glass, and ceramics remain at demonstration to early commercial stage. The economics of industrial electrification improve as renewable electricity costs decline and carbon prices rise.

## Key Metrics & Benchmarks

Industry consumes approximately 37% of global final energy, with about two-thirds as heat. Low-temperature heat (below 150°C) accounts for roughly 30% of industrial heat demand and is most amenable to electrification. EAF steelmaking uses approximately 400-500 kWh per tonne of steel. Industrial electricity's share of final industrial energy consumption needs to rise from approximately 21% today to over 30% by 2050 in the IEA Net Zero scenario.

# LATAM Relevance

---

Latin America's abundant renewable electricity makes industrial electrification economically attractive. Brazil's steel industry already operates significant EAF capacity using hydroelectric and biomass-based electricity. Chile's mining sector is electrifying haul trucks and processing equipment. Colombia's food and beverage industry has potential for industrial heat pump adoption. Low renewable electricity costs in LATAM could attract energy-intensive industries seeking to decarbonize.

# Critical Minerals Link

---

Industrial electrification increases demand for copper (electrical infrastructure, motors), silicon carbide and gallium nitride (power electronics), and rare earth magnets (high-efficiency motors). Electric arc furnaces require graphite electrodes. The overall mineral intensity is lower than hydrogen-based alternatives for many temperature ranges, making electrification a mineral-efficient decarbonization pathway where feasible.

# Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — industrial process electrification, EAF steelmaking, electric kilns; ES (Energy Systems) — industrial electricity demand, grid capacity planning; XS (Cross-Sectoral) — sector coupling, demand-side flexibility from industrial loads.

# Hydrogen in Industrial Processes

## Source Metadata

| Field                | Value                            |
|----------------------|----------------------------------|
| source               | iea                              |
| source_version       | ETCS 2025                        |
| source_id            | IEA-CRS-005                      |
| iea_category         | cross_cutting                    |
| technology           | Hydrogen in Industrial Processes |
| technology_readiness | demo                             |
| mitigation           | Y                                |
| adaptation           | N                                |
| last_checked         | 2026-05-26                       |

## IEA Technology Definition

The IEA classifies the use of green and low-carbon hydrogen in industrial processes as a cross-cutting decarbonization pathway. Key applications include hydrogen direct reduction of iron (H-DRI) for steelmaking, hydrogen as chemical feedstock (green ammonia, green methanol), high-temperature industrial heat via hydrogen combustion, and hydrogen as a reducing agent in non-ferrous metallurgy. The IEA's Global Hydrogen Review tracks these applications alongside hydrogen production and infrastructure.

## Technology Readiness & Deployment

Industrial use of hydrogen is well-established in oil refining and ammonia production, but these currently rely on grey hydrogen from natural gas. Green hydrogen applications in industry are at demonstration to early commercial stage. H-DRI steelmaking pilots are operational in Sweden (HYBRIT/SSAB) and several European projects. Green ammonia plants are under construction in multiple regions. The IEA notes a record number of hydrogen technologies advancing in readiness level during 2024-2025, but deployment remains far below net zero requirements.

# Key Metrics & Benchmarks

---

Global hydrogen demand is approximately 95 Mt/year, almost entirely grey hydrogen. Industry consumes about 55% of hydrogen (primarily refining and ammonia). Green hydrogen from electrolysis represented less than 1% of total supply in 2024. H-DRI steel production costs are 20-40% higher than conventional blast furnace route. Green ammonia costs approximately USD 600-900/tonne versus USD 250-400/tonne for conventional ammonia. Cost competitiveness depends on green hydrogen reaching USD 2/kg or below.

## LATAM Relevance

---

Latin America's potential for low-cost green hydrogen makes it well-positioned for industrial hydrogen applications. Chile's green hydrogen strategy targets export-oriented ammonia and steel production. Brazil's large steel and chemicals sectors are natural candidates for hydrogen-based decarbonization. Colombia's refinery sector in Barrancabermeja and Cartagena could transition to green hydrogen feedstock. The region's abundant renewable resources could enable green hydrogen production costs below USD 2/kg, making industrial applications economically viable.

## Critical Minerals Link

---

Industrial hydrogen applications require the same electrolyser minerals as hydrogen production (iridium, platinum, nickel for catalysts). H-DRI steelmaking shifts mineral demand from coking coal to hydrogen and iron ore. Green ammonia synthesis uses iron-based catalysts. The overall mineral footprint of hydrogen-based industrial decarbonization is shaped primarily by electrolyser requirements for iridium and platinum group metals.

## Cleantech Taxonomy Crosswalk

---

Maps to Cleantech Taxonomy sectors: IN (Industry) — H-DRI steel, green ammonia, industrial hydrogen heat; ES (Energy Systems) — hydrogen production and distribution; XS (Cross-Sectoral) — sector coupling, hydrogen economy, trade in hydrogen-based commodities.