ENTEC

Energy Transition Expertise Centre

Supply chain risks in the EU's clean energy technologies

Report – Supply chain risks in the EU's clean energy technologies

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Prepared for
European Commission, DG ENER under contract N° ENER/C2/2019-456/ SI2.840317

Manuscript completed: August 2023
Published: October 2023

PDF	ISBN 978-92-68-02700-4	doi 10.2833/413910	MJ-03-23-130-EN-N

Acronyms Used in this Report

Acronym	Full description
AC	Alternating Current
AD	Anaerobic Digestion
AMI	Infrastructure for Advanced Metering
Bbl	Barrel
BECC	Bioenergy with Carbon Capture
BIGCC	Biomass Integrated Gasification Combined Cycle technology
BIM	Building Information Modeling
BPIE	Buildings Performance Institute Europe
BtL	Biomass-to-Liquid
CAGR	Compound Annual Growth Rate
CCUS	Carbon Capture Utilisation and Storage
CET	Clean Energy Technologies
CETO	Clean Energy Technology Observatory
CFP	Catalytic Fast Pyrolysis
CHP	Combined Heat and Power
CIndECS	European Climate Neutral Industry Competitiveness Scoreboard
CSP	Concentrated Solar Power
CtL	Coal-to-Liquid
DAC	Direct Air Capture
DC	Direct Current
EASE	European Association for Storage of Energy
EC	European Commission
EEA	European Environment Agency
EHV	Extra High Voltage
EV	Electric Vehicles
GDIP	Green Deal Industrial Plan
GDL	Gas Diffusion Layers
GtL	Gas-to-Liquid
HC	Hydrocarbon
HEMS	Home Energy Management Systems
HFCs	Hydrogen Fuel Cells
HV	High Voltage
HVDC	High-Voltage Direct Current
HVO	Hydrotreated Vegetable Oil
IEA	International Energy Agency
IRA	US-Inflation Reduction Act
IRENA	International Renewable Energy Agency

Acronym	Full description
JRC	Joint Research Centre
LFP	Lithium-Iron-Phosphorus Chemistries
LIB	Lithium-Ion Batteries
MEA	Membrane Electrode Assembly
NMA	Nickel Cobalt Aluminium Oxide
NMC	Nickel Manganese Cobalt oxide
NZIA	Net Zero Industry Act
OEM	Original Equipment Manufacturers
ORC	Organic Rankine Cycle
PEM	Polymer Electrolyte Membrane
PM	Particulate Matter
PVT	PV-Thermal
PWR	Pressurised Water Reactor
RD&I	Research, Development and Innovation
RED	Renewable Energy Directive
RFNBO	Renewable Fuels of Non-Biological Origin
SCADA	Supervisory Control and Data Acquisition
SHC	Solar Heating and Cooling
SMEs	Small and Medium-Sized Enterprises
SMRs	Small and Modular Nuclear Reactors
SSCs	Structures, Systems and Components
STE	Solar Thermal Electricity
TES	Thermal Energy Storage
TLP	Tension-Leg Platform
TRL	Technology Readiness Level
TTES	Tank thermal Energy Storage
UTES	Underground Thermal Energy Storage
WTTES	Water Tank Thermal Energy Storage

Contents

1 Introduction

This study focuses on the clean energy technologies (CET) defined as strategic in the proposed Net Zero Industry Act (NZIA) and considers their strategic importance.[1] The study looks at each technology chosen in the NZIA (and other less strategic but relevant technologies) and uses desk research and expert input to consider the strategic importance of each technology. This comparison is based on three key criteria reflected in the NZIA: the technology's overall impact on the EU's climate goals, the need for building manufacturing capacity for the technology, and the various vulnerabilities that exist for the technology, in terms of competitiveness of EU production, market concentration, security of supply risks, and miscellaneous risk factors.

The supply chains of various energy technologies have come under increased scrutiny in recent years. As strategic dependencies on energy from fossil fuels reduce, especially in response to geopolitical risks and threats, new dependencies take their place. In the context of rapid decarbonisation of the energy sector and other energy-intensive sectors, dependencies are beginning to appear to various clean energy technologies.

The European Commission's (EC) interest in the supply chains of CET has likewise intensified in the past years. Much focus has been placed on the earlier steps of the supply chain, i.e. raw materials. The Joint Research Centre's (JRC) Critical Raw Materials studies, first published in 2016, received their latest iteration in 2023. The European Critical Raw Materials Act has followed these endeavours on raw material supply to "[propose] a comprehensive set of actions to ensure the EU's access to a secure, diversified, affordable and sustainable supply of critical raw materials", including for the energy sector.[2]

Other aspects of the supply chain are also in focus. In terms of the manufacturing of components and devices for CET, many studies, from the EC (including especially the JRC, but also DG ENER, DG REFORM, and DG RTD, among others) and other organisations such as the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA), are building towards policy developments. In this context, the focus on clean energy technology competitiveness in the EU, especially in comparison to other manufacturing hubs such as North America and East Asia (China in particular) has been strong. In the EU, the NZIA has been proposed as part of the Green Deal Industrial Plan (GDIP) of the EU.[3] The NZIA is "…aiming at simplifying the regulatory framework, and improving the investment environment for the Union's manufacturing capacity of technologies that are key to meet the Union's climate neutrality goals and ensure that our decarbonised energy system is resilient whilst contributing to reducing pollution, to the benefit of public health and planetary environmental wellbeing."[4]

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1 EC (2023), COM 161 final: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act)

2 https://ec.europa.eu/commission/presscorner/detail/en/IP_23_1661

3 https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510

4 EC (2023), COM 161 final: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act)

2 Objectives and Scope

The Commission's proposal for a NZIA contains provisions which apply to a very broad set of so-called "net-zero technologies", listed in Article 3.1.a) of the Commission's proposal. Among these technologies, some NZIA provisions focus on a more limited number of specific energy technologies that are perceived to be of high strategic importance: the so-called "strategic net-zero technologies", listed in the Annex of the Commission's proposal. The selection of these technologies is "…based on the overall Net-Zero Industry Act objectives of scaling up the manufacturing capacity of net-zero technologies in the EU, particularly those that are commercially available and have a good potential for rapid scale up." The determination of which technology is considered strategic is based on the following three criteria:[5]

1) **Technology Readiness Level (TRL)**, which refers to the level of maturity of technologies, and is based on the International Energy Agency's classifications.
2) **Contribution to decarbonisation and competitiveness**, which refers to each technology's overall contribution to the EU's achievement of the 2030 Fit for 55 goals, specifically its target of reducing greenhouse gas (GHG) emissions by at least 55% relative to 1990 levels.
3) **Security of supply risks**, which refers to the capability of the EU in manufacturing the components and devices needed for each energy technology, and namely the risk of dependency on imports for these components and devices from third countries with high market share in the component and/or device.

In terms of scope, the proposed NZIA places the focus primarily on the middle stages of a traditional clean energy supply chain, namely the **manufacturing of components and manufacturing and/or assembly of devices**. For example, in the case of a solar photovoltaic (PV) panel, the production of ingots, wafers, cells, and modules are in scope, while quartzite mining and silicon production (upstream of ingots) and solar photovoltaic system installation and maintenance (downstream of module assembly) are not considered in scope.

On this basis, the following technologies have been assigned in the NZIA as strategic net-zero technologies:

1) Solar photovoltaic and solar thermal technologies
2) Onshore wind and offshore renewable technologies
3) Battery/storage technologies
4) Heat pumps and geothermal energy technologies
5) Electrolysers and fuel cells
6) Sustainable biogas and biomethane technologies
7) Carbon capture and storage technologies
8) Grid technologies

2.1.1 Scope of this study

In the context of the NZIA and the wider GDIP, the European Commission's Directorate-General for Energy (DG ENER) has requested an analysis of the strategic aspects of strategic net-zero technologies as well as other net zero technologies relevant to the clean energy transition but not included in the NZIA's Annex. Based on preliminary scoping with the client and the existing

[5] EC (2023), COM 161 final: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act)

similarities between supply chains and technologies, we consider the following "primary" technologies in the context of this study:

1) Solar photo-voltaic systems (including balance-of-system components, such as inverters)
2) Solar thermal technologies (including concentrated solar power)
3) Onshore and offshore wind technologies
4) Ocean energy technologies
5) Batteries (including in e-mobility applications)
6) Other storage technologies (namely thermal and hydrogen storage technologies)
7) Heat pumps
8) Deep geothermal energy technologies
9) Hydrogen electrolysers and fuel cells
10) Sustainable biogas and biomethane technologies
11) Carbon capture and storage
12) Grid technologies (including traditional and smart grid technologies)

The study also reviews a few "secondary" clean energy technologies: considered as important in the EU's energy context but nonetheless not perceived as strategic according to the concerns of the NZIA (and subsequently not listed in the NZIA's annex). These technologies are:

1) Hydropower (and pumped hydro storage)
2) Advanced biofuels
3) Renewable fuels of non-biological origin (excluding hydrogen)
4) Solid bioenergy technologies
5) Nuclear fission
6) Energy efficiency (insulation materials)

For each supply chain, this report's analysis focuses on aspects of the manufacturing of components and manufacturing and/or assembly of final devices for use. Other aspects are generally considered out of scope if they do not directly impact manufacturing and assembly stages in the supply chain. However, some, which may impact a different stage upstream or downstream from manufacturing/assembly, are considered, if they also have secondary impacts on manufacturing/assembly. For example, discussions on critical raw materials are mostly not considered, except in certain aspects, such as in the influence of raw material processing locations on where battery anode and cathode production facilities are located.

Where relevant, the analysis also discusses the following aspects:

- Transportation aspects
- Geopolitical factors
- Labour market dynamics, including labour shortages and needs for upskilling, primarily for manufacturing deployment
- Sustainability issues and relevant regulatory factors, such as resource shortages, climate and environmental impacts, and social aspects
- Market supply power and concentration
- Efficiency and productivity issues of manufacturers

3 Methodology

3.1 Study overview

The study consists of three tasks:

1) Defining indicators for the strategic status of a supply chain
2) Desk research and expert input on strategic supply chains
3) Analysis and ranking of criticalities

3.2 Task 1: Defining indicators for the strategic status of a supply chain

This task reviews existing supply chains to identify and define a set of indicators that describe possible strategic risks associated with an energy technology. Preliminarily, we consider the attributes that impact the strategic importance of a supply chain are as follows:

- **High potential impact in the short-term**. This will relate to technologies with developed supply chains (i.e. with a Technology Readiness Level above 8+), which "...are projected to deliver a significant contribution to the 2030 Fit for 55 target of reducing net greenhouse gas emissions by at least 55% relative to 1990 levels."[6]
    - This impact assessment must also consider future policy development in favour of (or against) the use of specific technologies.
- **High growth requirement for internal EU market production** in order to meet the demand needed for GHG emissions reductions. This indicator mainly refers to **the difference between current and required future manufacturing capacity in 2030** for components and devices associated with the technology in question, considering also the timing required for developing relevant manufacturing capacities. This capacity shortfall may be met by an increase in imports (which also comes with its corresponding potential dependencies) in cases where manufacturing capacity cannot be scaled up quickly enough.
- **Competitiveness threats** regarding manufacturing/assembly of technology, and also components and precursors, in the EU versus third countries, **market concentration** aspects especially with regards to import dependency, **and other vulnerabilities** such as labour shortages, environmental/regulatory risks, logistics issues, and scale-up concerns.

We present each attribute with an indicator score, based on its strategic concern in comparison to other technologies. The score values range from 1 (very low) to 5 (very high), with higher values indicating higher strategic importance for the technology and the associated supply chain(s).

3.3 Task 2: Desk research and expert input on energy supply chains

The first step of this task involved experts who contributed to the previous Trinomics (2021) study[7] to review the current state of similar supply chains. This is an update of the prior study, based on new supply and demand forecasts and supply chain trends since the data collection done in 2020. The update has also involved consultations with relevant stakeholders and experts.

[6] EC (2023), COM 161 final: REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act)

[7] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

The second step involved a review of existing and recent literature on subjects of energy technology supply chains. Sources for this are listed in Table 1. In addition to these sources, various internal reports and draft staff working documents of the EC were also used to develop this analysis.

Table 1: Examples of sources for desk research

Author (Year)	Title	Region studied	Techs studied
EC (2022)	Progress on competitiveness of clean energy technologies	EU	Multiple
EC (2023)	COMMISSION STAFF WORKING DOCUMENT Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity	EU	Multiple
JRC (2016)	Assessment of potential bottlenecks along the material supply chain	EU	Multiple
JRC (2022)	European Climate Neutral Industry Competitiveness Scoreboard (CIndECS) Annual report 2021	EU	Multiple
JRC (2022)	Clean Energy Technology Observatory reports (overall strategic analysis, individual technology status reports, modelling report)	EU	Multiple
JRC (2023)	Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study	EU	Multiple
IEA (2022)	The role of critical materials in clean energy transitions	Global	Multiple
IEA (2022)	Global supply chains of EV batteries	Global	Batteries
IEA (2022)	Special report on solar PV global supply chains	Global	Solar PV
IEA (2023)	Energy technology perspectives	Global	Multiple
Trinomics (2019)	Study on energy technology dependence	EU	Multiple
Trinomics (2021)	Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis	EU	Multiple
KU Leuven (2022)	Metals for clean energy	Europe	Multiple

3.4 Task 3: Analysis and ranking of criticalities

In this task, we have used the data and information gathered in Task 2 to understand and compare the criticalities of the different supply chains. The main output here is a table listing critical aspects of each supply chain, with a qualitative assessment of the supply chain's criticality. This table consists of the following columns:

1) A list of technologies as defined in Section 1.2.
2) Envisioned contribution to the EU's 2030 target for greenhouse gas emissions, based on capacity of installed technology (and volume installed for storage technologies) compared to other similar technologies.
3) Growth needed compared to current EU manufacturing capabilities.
4) Threats to competitiveness of current EU manufacturing, market concentration concerns, and other vulnerabilities in the manufacturing of CET.
5) A final composite score for the strategic status of each technology summing up the assessments of the prior three columns.

4 Rationale for Indicator Scoring and Cross-Technology Comparisons

The primary technologies analysed in this study have been graded according to their relative strategic importance. Three indicators were used to assess this aspect. Their scoring and use are explained below.

The three aspects that define a strategically important technology, based on the NZIA, are:

1) A high level of technological maturity.
2) High contribution to decarbonisation and competitiveness goals.
3) High impact on risks for security of supply.

For these three aspects, the first two aspects are directly reflected in criteria detailed below. However, for the third aspect, a wider description is considered to include various elements that could create a technology risk. In total, the following criteria are considered:

1) For technological maturity, any technology with a TRL level below 8 (according to the International Energy Agency's classification system) is excluded.
2) For high contribution to decarbonisation goals, we consider the potential relative impact of each technology in the future energy system of the EU, considering the updated REPowerEU plan's goals and its role in the energy system in 2030.
3) For high contribution to competitiveness goals and associated security of supply concerns, we have considered two indicators:
    a) High need for EU manufacturing growth in the coming years, to meet the required growth in internal demand.
    b) A measure of competitiveness threats, market concentration, and other supply chain vulnerabilities.

This leads to the three indicators, labelled as "EU demand", "EU manufacturing growth", and "Competitiveness threats, market concentration, and other vulnerabilities", used in the context of this study. For each indicator, ratings were given from "very low" to "very high", corresponding to scores from 1-5. These scores are added together to determine the strategic importance of each technology, with highly strategic technologies receiving the full 15 points, while less-strategic technologies receive points from 3-6.

4.1.1 High EU demand

This indicator represents the impact of a given technology in the EU's energy system in 2030. We are seeking a measure of its comparative role within the supply chain, which differs based on the function and service that each given technology provides. In some cases, this role may be unique, and the impact will thus be adjusted upwards. For example, power generation technologies can be directly compared against each other, based on capacity installed or primary energy input. However, direct comparison of carbon capture and storage technologies with power generation technologies is more difficult, as its role in reducing carbon emissions of existing polluting uses has few, if any, alternatives.

We used various data sources for this indicator per technology:

- For most technologies in the NZIA's strategic technologies list, the REPowerEU plan's modelling exercise provides estimates for the deployment of technologies by 2030 to meet the plan's and Fit for 55's goals and objectives.

- Where necessary, this data was complemented with estimates from industry reports, international reports on specific technologies, and estimations based on existing data.
- The numbers were updated or revised based on expert input where needed.

For most power generation technologies, a figure of GW capacity installed was considered and compared to other energy technologies, based on installation amounts. The initial goal was to use a figure of GWh generated in 2030 per technology, thus accounting for differences in capacity factor. However, it proved difficult to find an accurate measure of this number for most technologies.

For heating technologies, thermal output was compared to other technologies and heating options in the EU energy mix in 2030.

For other devices, other metrics were used based on their specifics, such as GW and GWh installed for storage technologies. Technologies with a unique role, i.e. where alternatives were few and/or immature in terms of TRL, were given higher strategic status as a result.

4.1.2 High growth rate for manufacturing

This indicator is intended to represent the growth needed within the industries connected to an energy technology's supply chain in order to meet internal market demand for a given technology.

Export considerations are excluded here, as these concerns mainly refer to meeting rapidly growing demand for technologies where the EU is currently far from self-sufficient, in terms of meeting EU-level ambitions for climate action.

Data on current EU manufacturing rates for various energy technologies are difficult to find, and estimates for future production are often imprecise and biased. The discrepancy between capacities in announced projects and what is eventually realised is generally high, and varies greatly per component/technology and per region. For example, many battery manufacturing plans in the EU in past years have not materialised or have faced significant delays. Meanwhile, other unannounced projects in East Asia have brought large capacity additions online. Manufacturing growth rates are often considered and discussed by industry associations, but some bias exist in these reports as well. Overall, this data access challenge presented a significant limitation in this analysis.

Dependent on data source, we used the following aspects to understand the growth rate needed for manufacturing:

- Manufacturing needs in 2030 versus most recent estimate of manufacturing capacity or supply. This was considered as a of the percentage compound annual growth rate year-on-year needed for manufacturing capacity to expand to meet EU requirements by 2030.This rate was compared across technologies where available.
- An estimate of current manufacturing capability, based on% of EU demand met with internal production (i.e. demand minus imports). In cases where growth of manufacturing capability was not directly available, annual growth in EU demand was used to assess annual growth in EU manufacturing.
- An estimate of EU manufacturing as a ratio of global manufacturing of the technology, compared to EU demand versus global demand.

The amount of manufacturing growth also indicates potential future import dependency. Exports excluded, the current shortfall in manufacturing versus future demand leaves room for import dependency in the future.

4.1.3 Competitiveness threats, market concentration, and other vulnerabilities

The basket of different threats and vulnerabilities considered under this indicator are more diverse than for the other two indicators. Thus, a qualitative assessment was made based on the current state of the supply chain and its future prospects.

Data was gathered from industry reports and forecasts, international reports, expert surveys and interviews, and other ongoing projects with Trinomics involved on the technology supply chains. The following subjects were considered together in order to build a comparative score across technologies:

- Current size of the EU's market share versus the global market size for each technology, and associated components. Higher scores were given if EU production is comparatively small (e.g. solar panels), a specific and critical component was imported (e.g. smart grid technologies) and/or technology was heavily promoted in competing legislation in other regions. We placed special focus on two regulation packages: The US's Inflation Reduction Act[8] and China's 14th 5-year Plan.[9]
- Market concentration in terms of a (mainly non-EU) country or company. While specific and updated concentration numbers are difficult to ascertain for a rapidly changing energy landscape with many growing technology supply chains, we relied on the most recent available data from technology and industry-specific reports to indicate whether a specific company or country had a very strong presence for a specific technology. Higher scores were also given for technologies historically considered to be vulnerable, and to companies and countries considered to be at higher geopolitical risk than others.
- Current threats to the existing competitiveness of EU manufacturing of specific technologies were considered in light of policies and regulations developed in other regions and countries.
- Other vulnerabilities, such as transportation bottlenecks, labour market shortages, supply chain maturity, and geopolitical risks not considered earlier were also integrated into this indicator.

An additional note on the analysis: in the situation where one or multiple technologies were considered under a single category, their combined impact on competitiveness was considered, qualitatively weighted by their impact. For example, wave and tidal stream energy sources were considered equally in offshore renewable technologies, as the EC's Offshore Renewable Energy Strategy sets a combined goal of 1 GW installed by 2030.

[8] 117th Congress of the United States of America (2022), Inflation Reduction Act of 2022. Available at: https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf

[9] Center for Security and Emerging Technology (2021), Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035. Available at https://cset.georgetown.edu/wp-content/uploads/t0284_14th_Five_Year_Plan_EN.pdf

5 Overall Results for Clean Energy Technologies

The overall results of this study are displayed in Table 2.

The analysis shows that **some technologies have been and remain highly significant from a strategic point of view. These include solar PV systems, wind energy, and batteries.** These technologies will all play a significant role in the EU's energy system in 2030, and similarly contribute significantly to ambitions for the reduction of GHG by 2030 in the energy sector. Likewise, their growth has consistently been expected to be high, while the manufacturing of components and assembly of devices for these technologies remains significantly dependent on foreign imports.

Some technologies have also become far more strategic in the light of recent policies. These include heat pumps, hydrogen technologies (including electrolysers, fuel cells, and storage), and carbon capture and storage. Particularly as a result of the REPowerEU plan, many of these technologies are now expected to significantly contribute to the Fit for 55 goals, while remaining dependent on third countries for components.

Some technologies are also considered of medium strategic importance, for various reasons. For example, ocean energy technologies (namely tidal stream and wave energy devices) are not expected to contribute significantly to the energy sector by 2030. However, the highly ambitious goals set in the EU's Offshore Renewable Energy Strategy would require massive expansions of manufacturing and assembly capacities for the devices (less so components, many of which are utilised in other energy and non-energy devices and technologies) in the EU. Similarly, some grid technologies are produced competitively in the EU, while others depend on components with little EU presence, leading to a higher score for strategic importance.

A few technologies are of lower strategic importance. These include geothermal energy systems, solar thermal systems, sustainable biogas and biomethane technologies, and other storage technologies. These technologies are generally not expected to significantly contribute to the EU's GHG reduction goals in the short term, are produced competitively and at high capacities in the EU, and do not face other significant hurdles in the manufacturing of components and devices.

We have analysed a set of secondary technologies, excluded from the NZIA, which are nonetheless important parts of the future energy system. **Overall, these secondary technologies were found to be far less strategic than the primary set of technologies.** They have less impact in terms of meeting the Fit for 55 goals (e.g. solid bioenergy and bioliquids), less growth requirements for EU production of components and devices (e.g. hydropower), and they generally have a good competitive status in terms of EU production (e.g. RFNBOs and nuclear fission). **The exception is building insulation materials**, covered as part of the energy efficiency technologies, which scores overall at a level of some strategic importance (8).[10] This is due to the significant role of building insulation materials in achieving the REPowerEU plan's goals in terms of reducing energy consumption by almost 20%, and its indirect impact on the successful implementation of other technologies in the plan, e.g. heat pumps.

[10] Note that *"energy system-related energy efficiency technologies"* are considered net zero technologies (albeit not a strategic net zero technology) in the NZIA. This denomination refers to technologies that optimise energy flows in the energy system allowing better system integration of various sectors and better adjustment of demand and supply. Examples include energy management/control systems, including building automation and control systems, heat pumps, industrial automation and control systems, and variable speed drives. Many of the core technologies in this grouping are considered in other technologies in this study. However, insulation materials are in principle excluded from this definition.

The results in Table 2 should be understood with some nuance. The scoring system contained limited granularity, therefore, a similar score across two technologies may not directly indicate that both are exactly equal in terms of strategic importance. This is even more the case with the individual indicators, which have less granularity and sometimes different approaches for how scoring of a given indicator was determined. The results here however should highlight different *categories* of strategic importance, with some being far more strategic than others.

It is also worth noting that this analysis considered a snapshot up to 2030, i.e. the time horizon considered under the proposed NZIA. Clean energy technologies considered strategic until 2030 often remain strategic after 2030 as well. In some cases, the energy system may prioritise technologies differently post-2030. For example, regarding RFNBOs and hydrogen derivatives, we do not foresee a high role for this set of technologies by 2030. On the other hand, we do expect a rise in their relevance beyond 2030, becoming a potentially strategic solution in the longer term, where large shares of RFNBOs might have to be imported. Technologies should therefore be considered as such in the short term (up to 2030), but with possibly changing relevance when looking at longer time periods.

Table 2: Overall results of study, with technologies sorted based on composite score for strategic importance

Tech (primary techs in bold)	High Contribution to EU FF55 goals in 2030	High Growth Rate for manu-facturing, import dependency	Competitiveness threats, market concentration, and other threats	Composite Score
Solar photovoltaic systems	5	5	5	15
Wind (onshore & offshore)	5	4	4	13
Batteries (storage and E-mobility)	5	5	3	13
Heat pumps	5	3	4	12
Carbon capture storage	4	5	3	12
H_2 Electrolysers and Fuel cells	3	4	4	11
Grid technologies	4	3	4	11
Ocean energy techs (wave and tidal)	1	5	3	9
Other storage tech (incl. thermal storage)	3	3	2	8
Energy efficiency (insulation materials)	4	2	2	8
Solar thermal systems	2	2	3	7
Sustainable biogas/biomethane techs	3	3	1	7

Tech (primary techs in bold)	High Contribution to EU FF55 goals in 2030	High Growth Rate for manu-facturing, import dependency	Competitiveness threats, market concentration, and other threats	Composite Score
Geothermal energy systems	1	2	3	6
Nuclear fission	2	2	2	6
RFNBOs (excl. H_2)	2	2	2	6
Bio-liquids (incl. adv. Biofuels)	2	2	2	6
Solid Bioenergy	3	1	2	6
Hydropower (& pumped hydro storage)	2	1	2	5

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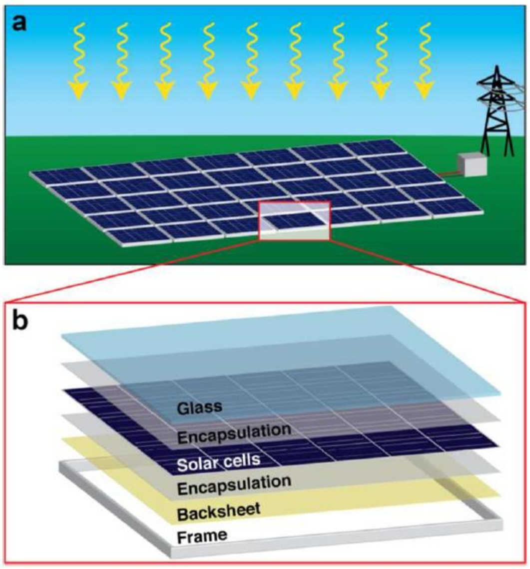
A.1 Annex 1: Solar PV

A.1.1 Introduction

Solar photovoltaic (PV) refers to any technology that converts light into electrical energy using semiconductor materials that exhibit the photovoltaic effect (creation of electrical voltage and electric current upon exposure to light). The individual solid state devices converting light to electricity are called solar (or photovoltaic) cells, and an array of many solar cells form the initial structure of a solar PV module. A solar PV system includes one or more solar modules, and other elements such as supporting structure, cables and inverters, and is designed to produce specific power and voltage output. Figure 1 provides an illustration of a solar PV panel.

Figure 1: Illustration of a solar PV panel[11]



There are a variety of different solar PV technologies, which are commonly differentiated by the semi-conducting materials used for the modules. The two most common sub-groups are: **crystalline silicon** in mono- and polycrystalline forms (MCSi and PCSi), and **thin-film materials** such as Cadmium telluride (CdTe), Copper Indium Gallium Selenium (CIGS), organic materials (polymers or perovskites) and III-V materials. In recent years, the market has come to be dominated by MCSi cells, while a small share of the market (2%) is dedicated to thin film modules for specific use cases.[12,13]

A.1.2 Supply chain overview

For the solar PV supply chain, we focus mainly on the crystalline silicon (c-Si) modules. These can be produced in multiple pathways, which to summarise can be grouped into the following steps:

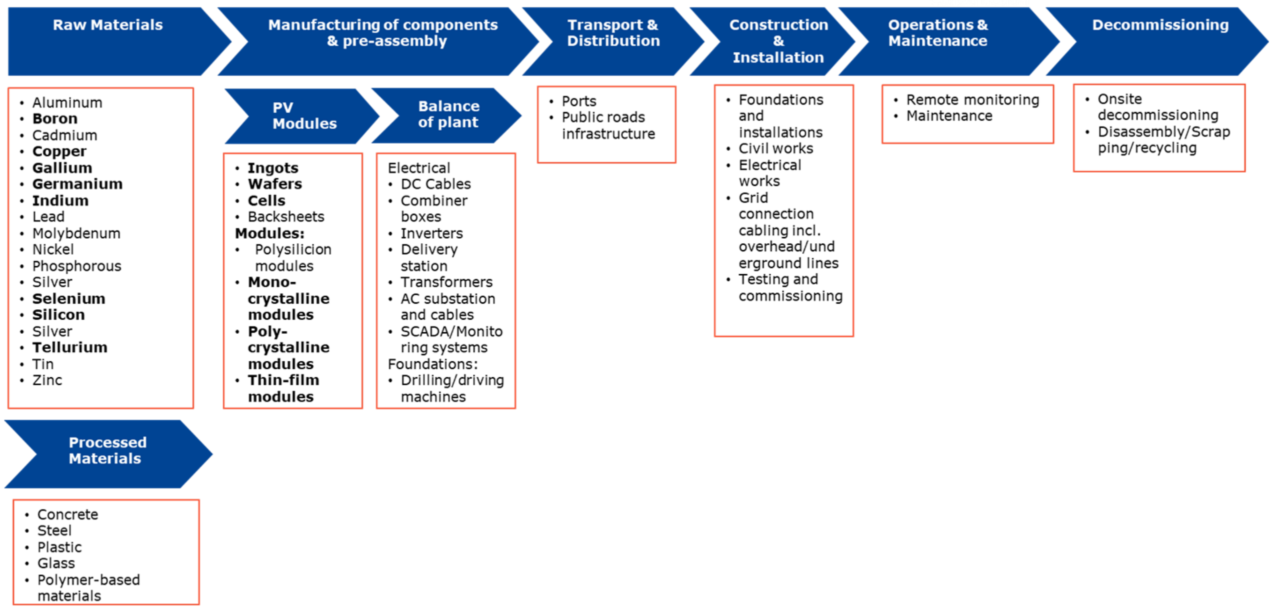
1) High-grade crystalline silicon is purified;

[11] JRC (2020), Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system.
[12] IEA (2022), The Role of Critical Minerals in Clean Energy Transitions
[13] BNEF (2022a), BNEF interactive database. Available at: https://www.bnef.com/

2) This silicon is crystallised into ingots and the ingots are sliced into wafers;
3) Wafers are transformed into solar cells by adding various chemicals and materials;
4) Cells are covered by glass or other material, are attached to a frame and then assembled into a solar module.

An overview of the solar PV supply chain is presented in Figure 2 below.

Figure 2: Overview of Solar PV supply chain.



Source: Trinomics (2021)[14]

In terms of costs, the materials used in crystalline silicon panels contribute a large fraction of total costs, at about 35-50% of a module's final price in 2021. These include crystalline silicon (35-45%) silver (9-23%), glass (11-15%), aluminium (9-12%), copper (5-12%), and polymers (7-10%)[15]. Compared to other energy technologies, the solar PV supply chain has high component presence in terms of international trade.

A.1.3 Assessment per indicator

A.1.3.1 EU demand

In 2021, total solar capacity across the EU exceeded 200 GW.[16] According to the latest European Commission Staff Working Document[17], based on the REPowerEU plan, by 2030, 592 GW of installed solar PV capacity is needed to achieve the 69% share of renewable electricity modelled by the Commission. This would require a CAGR of 12.8%, or average annual additions of about 45 GW for solar PV.

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[14] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[15] IEA (2022), Special Report on Solar PV Global Supply Chains

[16] SolarPower Europe (2023) EU Market Outlook for Solar Power 2022 -2026. Note: SolarPower Europe expresses installed capacity values based on Direct Current (DC).

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230&from=EN

In combination with wind, solar PV is one of the key technologies required to arrive at the share of renewable electricity proposed under REPowerEU, to tackle the GHG emissions reduction challenge posed by the Fit for 55 package. Therefore, this indicator is assessed as **very high.**

A.1.3.2 EU manufacturing growth

To reach the 2030 target for renewables proposed by the Commission and the objectives of the REPowerEU plan, the EU will need to install, on average, approximately 45 GW per year.

EU manufacturers of PV technologies should aim **to reach at least 30 GW of operational solar PV manufacturing capacity by 2030 across the full PV value chain**, in line with the goals set out in the European Solar Photovoltaic Industry Alliance, which is supported under the Union's Solar Energy Strategy.[18]

However, the manufacturing base in the EU is currently low for solar panel manufacturing and almost non-existent for upstream components. SolarPower Europe has set up an EU solar manufacturing map to monitor the presence of EU manufacturing companies along the solar PV value chain. Based on this map, there are currently 132 companies in Europe focused on manufacturing of solar PV components. Out of these, 9.4 GW worth are focused on module production, 1.4 GW on cells, 69.9 GW on inverters, 1.7 GW on ingot & wafer and 23.2 GW on polysilicon. There are also 25 research centres active in the field of solar PV across the EU.[19] The German-based Wacker company is the only European company among the top-five global leaders. It accounts for approximately 20 GW of polysilicon production in Europe.[20]

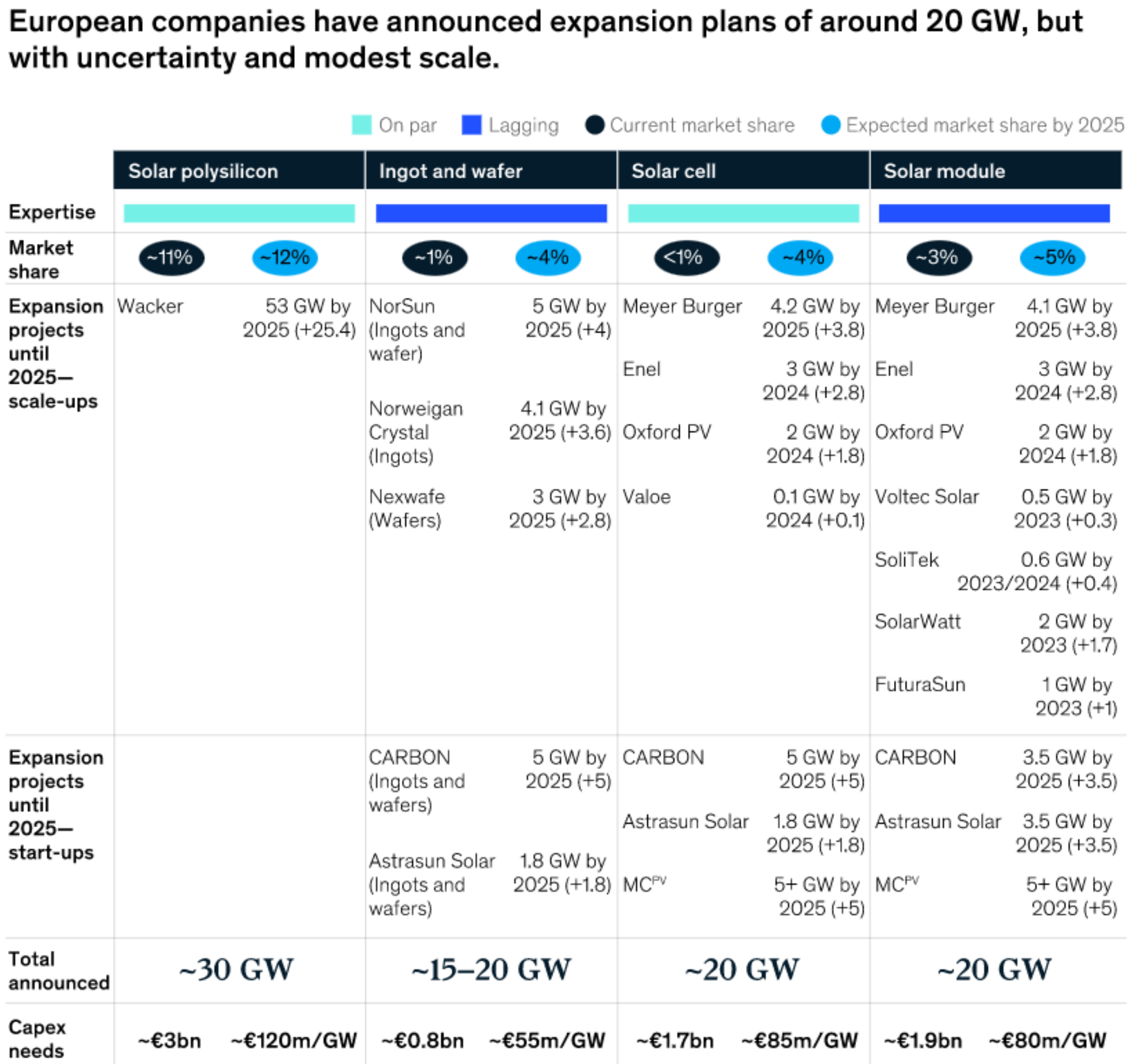
Furthermore, as can be seen from Figure 3, many European companies have announced expansion plans, also based on the policy push steered by the establishing of the European Solar PV Industry Alliance and the Commission's commitment to supporting European manufacturing. For example, Enel's 3Sun is building a 3 GW factory to produce heterojunction cell modules in Sicily, and Meyer Burger's plants in Germany are aiming for 4.2 GW by 2025.

[18] EC (2023), Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act)

[19] SolarPower Europe (accessed 02/05/2023). Available at: https://www.solarpowereurope.org/insights/interactive-data/solar-manufacturing map

[20] McKinsey & Co. (2022), Building a competitive solar-PV supply chain in Europe. Available at: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/building-a-competitive-solar-pv-supply-chain-in-europe

Figure 3: European companies announcing plans for expansion of manufacturing capacity (as of 2022)[21]



European companies have announced expansion plans of around 20 GW, but with uncertainty and modest scale.

On par | Lagging | Current market share | Expected market share by 2025

	Solar polysilicon	Ingot and wafer	Solar cell	Solar module
Expertise				
Market share	~11% ~12%	~1% ~4%	<1% ~4%	~3% ~5%
Expansion projects until 2025—scale-ups	Wacker: 53 GW by 2025 (+25.4)	NorSun (Ingots and wafer): 5 GW by 2025 (+4) Norweigan Crystal (Ingots): 4.1 GW by 2025 (+3.6) Nexwafe (Wafers): 3 GW by 2025 (+2.8)	Meyer Burger: 4.2 GW by 2025 (+3.8) Enel: 3 GW by 2024 (+2.8) Oxford PV: 2 GW by 2024 (+1.8) Valoe: 0.1 GW by 2024 (+0.1)	Meyer Burger: 4.1 GW by 2025 (+3.8) Enel: 3 GW by 2024 (+2.8) Oxford PV: 2 GW by 2024 (+1.8) Voltec Solar: 0.5 GW by 2023 (+0.3) SoliTek: 0.6 GW by 2023/2024 (+0.4) SolarWatt: 2 GW by 2023 (+1.7) FuturaSun: 1 GW by 2023 (+1)
Expansion projects until 2025—start-ups		CARBON (Ingots and wafers): 5 GW by 2025 (+5) Astrasun Solar (Ingots and wafers): 1.8 GW by 2025 (+1.8)	CARBON: 5 GW by 2025 (+5) Astrasun Solar: 1.8 GW by 2025 (+1.8) MC[PV]: 5+ GW by 2025 (+5)	CARBON: 3.5 GW by 2025 (+3.5) Astrasun Solar: 3.5 GW by 2025 (+3.5) MC[PV]: 5+ GW by 2025 (+5)
Total announced	~30 GW	~15–20 GW	~20 GW	~20 GW
Capex needs	~€3bn ~€120m/GW	~€0.8bn ~€55m/GW	~€1.7bn ~€85m/GW	~€1.9bn ~€80m/GW

Despite the number of EU companies, the manufacturing capacity in Europe is very low in comparison to other global players. The goal of 30 GW of operational solar PV manufacturing capacity in the EU appears very ambitious. This indicator is assessed as **very high** in terms of vulnerability.

A.1.3.3 Competitiveness threats, market concentration and other vulnerabilities

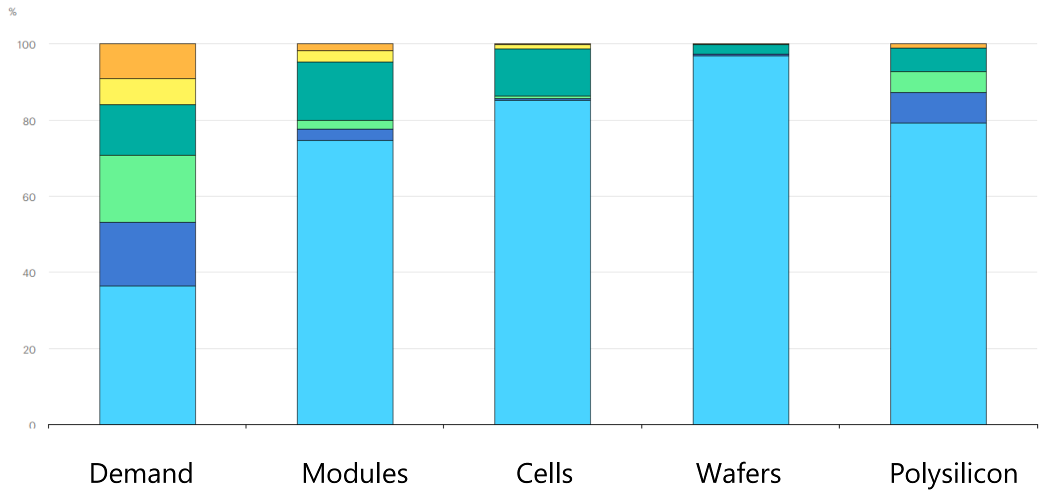
The EU maintains a massive trade deficit across the solar PV supply chain, driven by heavy imports of solar PV modules. China heavily dominates the solar PV supply chain, with over three-quarters of capacity within all supply chain steps coming from Chinese producers. Currently, Europe has some high-grade silicon production, but has negligible ingot and wafer production capacity, and

[21] McKinsey & Co. (2022), Building a competitive solar-PV supply chain in Europe. Available at: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/building-a-competitive-solar-pv-supply-chain-in-europe

has almost entirely reduced its capacities for cell manufacturing due to not being competitive with global manufacturers. About 85% of global solar cell manufacturing is concentrated in China and other Southeast Asian countries (Vietnam, Malaysia, and Thailand) account for most of the remaining production.[22] China is also home to the world's top 10 suppliers of solar PV manufacturing equipment.

Figure 4 shows the manufacturing capacity for solar PV components for different regions, the first column shows the demand for solar PV by region. The figure clearly shows that China has the biggest manufacturing capacity for all components: modules, cells, wafers and polysilicon.

Figure 4: Solar PV manufacturing capacity by country and region, 2021; Legend: Light blue: China, Dark blue: Europe, Lime green: North America, Dark green: APAC, Yellow: India, Orange: ROW



Source: IEA (2023)[23]

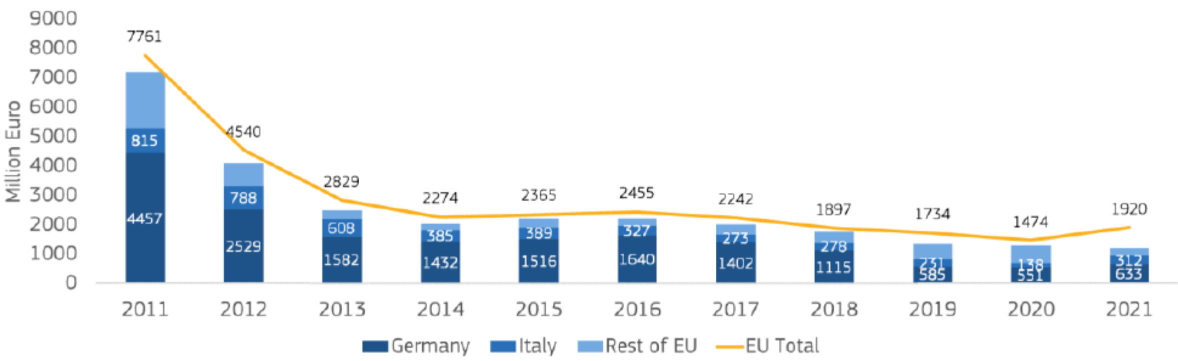
Within the EU, the top two biggest producers are Germany and Italy. Overall, over the period between 2011 and 2021, there has been a reduction in production potential in the EU as can be seen from Figure 5. The top five EU exporting countries are the Netherlands, Germany, France, Italy and Portugal.[24]

[22] IEA (2022), Special Report on Solar PV Global Supply Chains

[23] IEA (2023), Solar PV Global Supply Chains: Executive summary. Available at: https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary

[24] JRC (2022), Photovoltaics in the European Union: Status Report on Technology Development, trends, value chains and markets. Available at: https://setis.ec.europa.eu/photovoltaics-european-union_en

Figure 5: EU total production and top producers for the period 2011-2021



Source: JRC (2022)[25]

An analysis by McKinsey and Co. suggests that the costs of manufacturing PV panels in Europe will be between 20% and 25% higher compared to the current lowest level costs even if scale and excellence effects are achieved. Assuming the achievement of large-scale productions, European companies will still face a competitive disadvantage because of higher labour, material utilities and capital costs. Moreover, the analysis did not consider the high energy prices in Europe which are expected to have a further negative impact on competitiveness.[26]

The level of geographical concentration in global solar PV supply chains can lead to potential challenges at a global level. This high market concentration by China was particularly evidenced during the Covid-19 pandemic, and exposed some vulnerabilities of the Solar PV supply chain: given that China is the biggest manufacturer of solar PV equipment and that Jiangsu province, which is responsible for ~ 60% of the solar production capacity in the country, was strongly hit by the pandemic, the global solar PV supply chain was also affected. SolarPower Europe reported several disruptions to the global solar PV supply chain mostly due to component manufacturers and other suppliers as well as increased logistics problems. In Europe, Italy experienced severe problems; during the Covid-19 pandemic according to the association Italia Solare, one in five solar companies said they were at risk of being pushed out of business and about one quarter were considering cuts to the workforce.

Considering the low competitiveness of the European solar PV manufacturing market, the heavy market concentration in the Solar PV supply chains and the experience during the Covid-19 pandemic of the effects these factors had on creating disruptions for Europe, this indicator is assessed as **very high**.

A.1.4 Overall assessment

With an overall score of **15 points**, the solar PV supply chain is considered **highly strategic**.

[25] Ibid.

[26] McKinsey & Co. (2022), Building a competitive solar-PV supply chain in Europe. Available at: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/building-a-competitive-solar-pv-supply-chain-in-europe

A.2 Annex 2: Solar Thermal Technologies

A.2.1 Introduction

Solar thermal energy refers to any technology that harnesses energy from the sun to generate thermal energy, which can be further converted into electricity or used directly as heat. In contrast to solar photovoltaic (PV), solar thermal technologies do not exhibit the PV effect. Solar thermal technologies consist of two main categories: solar heating and cooling technologies and concentrated solar power (CSP).

- **Solar heating and cooling technologies**, use the most direct method of using sunlight, where a gas or a liquid is heated without conversion of the heat into electricity or kinetic energy. The most common technologies for this process include evacuated tube collectors, glazed flat-plate collectors and unglazed water collectors. Solar cooling can be accomplished via desiccant or absorption chiller systems. In addition, PV-thermal (PVT) hybrid systems, which convert solar radiation into thermal and electrical energy at the same time, are also classified under this category, as the usual aim of hybrid systems is to produce thermal energy first and then electricity. However, although growing, the market share of PVT is still relatively small (751 MWth worldwide by 2021).[27]
- **Concentrated solar technologies**, covers concentrated solar power (CSP), also referred to as solar thermal electricity (STE) or thermodynamic solar, and concentrated solar for industrial processes. These are systems that use mirrors or lenses to concentrate a large area of sunlight into a smaller area to heat a medium (usually a liquid or gas) that is then used in a heat engine process (steam or gas turbine) to drive an electrical generator, thereby generating power. The technology is less popular than photovoltaics due to the higher capital investment cost and lower scalability. **However, one of the features of CSP plants is their thermal energy storage capability, which often ranges between 6 to 9 hours of storage, allowing electricity to be generated also outside daily-sun hours**.[28] Within this technology, three design variants are commercially proven: parabolic trough, solar towers and Fresnel linear designs.[29] In the case of CSHIP, these typically use parabolic through or linear Fresnel technology to provide heat in application areas such as buildings, industrial processes (SHIP), and district heating.[30]

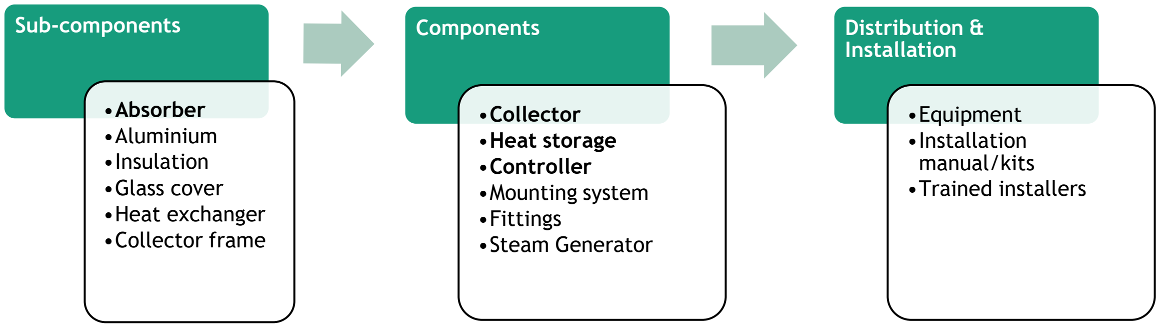
Often, CSP and solar heating are both referred to as solar thermal energy. To avoid confusion on this study, solar heating and cooling consists of flat plate collectors or evacuated heat-pipe tubes and CSP contains all concentrating solar thermal technologies, including (CSHIP).

A.2.2 Supply chain overview

For flat plate collectors or evacuated heat-pipe tubes, the basic elements of their supply chain are presented in Figure 6 below.

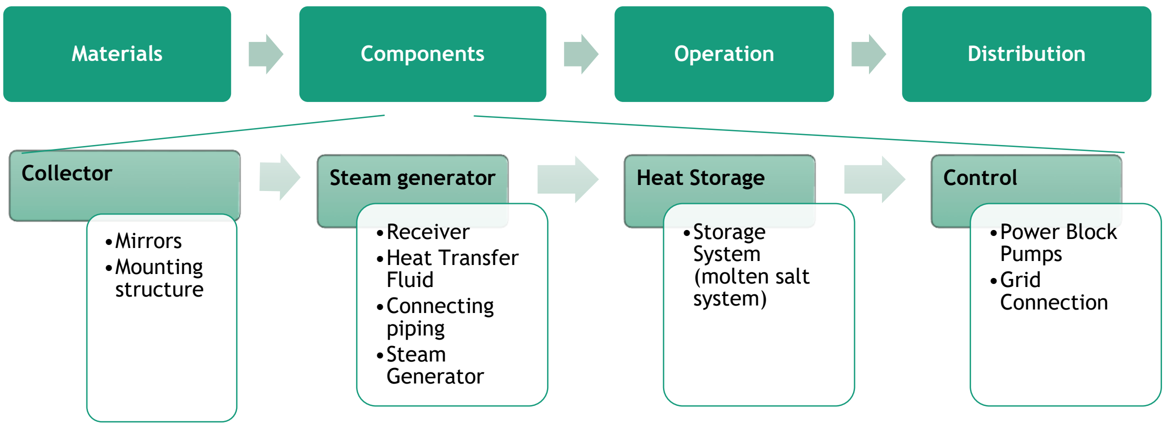
[27] Weiss, w. (2022), Solar Heat Worldwide Edition 2022. Presentation by AEE INTEC for SHC IEA.
[28] Eurobserv'ER (2022), Solar thermal and concentrated solar power barometer 2022.
[29] Clean Energy Technology Observatory (2020), Concentrated Solar Power and Heat in the European Union
[30] Clean Energy Technology Observatory (2020), Concentrated Solar Power and Heat in the European Union

Figure 6: Overview of the main supply chain elements of flat plate collectors and evacuated heat-pipe tubes



Previous supply chain analyses point out that the production of flat plate collectors depends on commonly available materials (glass, copper, etc.).[31] Our analysis suggests that in previous years the European industry has experienced supply chain bottlenecks for components required for collectors and heat storage tank production (namely, vacuum collectors), as well as system components such as pump groups, expansion vessels and solar controllers. In addition, there is an identified need for trained installers.

Figure 7: Overview of the CSP supply chain



Source: Trinomics et al. (2019)[32]

The central elements of CSP systems depend on their design (see Figure 7 for supply chain overview). For solar towers, these include heat transfer fluid, a number of heliostats (mirrors) surrounding the receiver tracking and directing the sunlight to the receiver, a storage system, and a steam generation system. Parabolic trough plants comprise parallel line-ups of long half-cylindrical reflectors that revolve around a horizontal axis to track the sun and concentrate its rays on a horizontal tube and Fresnel plants comprising rows of flat reflectors that pivot, tracking the sun to redirect and concentrate the sun's rays permanently on an absorbing tube.[33] Typically, CSP systems utilises molten salts as heat transfer medium to generate steam that drives the turbine for the generation of electricity and the molten salt system allows to store energy beyond the daylight hours. There is no critical dependency on materials or components for the EU on non-EU countries.

[31] Trinomics et al. (2019), Study on energy technology dependence.
[32] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
[33] Eurobserv'ER (2022), Solar thermal and concentrated solar power barometer 2022.

A.2.3 Assessment per indicator

A.2.3.1 EU demand

Solar heating technologies has experienced a consistent growth in the EU, rising from almost 25 GWth[34] in 2010 to 40 GWth by the end of 2021 (over 57.170 m^2 of collector area).[35] On the other hand, CSP has had limited growth over the last decade, with a total operating capacity of 2,328.8 MWe by the end of 2021, largely concentrated in Spain.[36] New CSP power plant projects have been announced in Spain, with their construction starting in the coming years.

In May 2022 the Commission adopted its EU Solar Energy Strategy[37], emphasizing that the energy demand covered by solar heat (as well as geothermal heat) **should increase at least threefold by 2030**, corresponding to a capacity of around 114 GWth of thermal capacity.[38] In 2022, the industry association Solar Heat Europe published "Our 2020 pledge to deliver a Green Recovery - Energising Europe with Solar Heat"[39]. In this roadmap, the association claims that the EU's current ambition can be surpassed, with solar thermal having the potential to achieve 140 GWth by 2030. This is expected to produce 98 TWh, or 8.4 Mtoe, of energy per year. More specifically, the association estimates solar thermal's contribution per sector to reach the following:

- In the buildings segment – the most relevant segment for solar heating contributions so far – its installed capacity could reach 73 GWth by 2030. As a reference, this level of deployment corresponds to the current installed capacity per capita in Germany (0.16 kWth per citizen).
- With regards to district heating, solar thermal could reach 31 GWth by 2030.
- Finally, for industrial process heat, solar thermal could reach 36 GWth by 2030, which could cover ~10% of the consumption of industrial sectors using predominantly low and medium heat temperature heat, such as manufacturing of food and drinks.

In the case of CSP, the EU Solar Energy Strategy does not provide a specific ambition for CSP installed capacity, but it reiterated its potential role as a technology that can reduce the cost of ensuring network stability and system integration. According to CETO, the IEA SDS scenario expects a rather modest capacity increases of CSP for Europe in 2050, with installed capacity reaching 14 GW, providing around 1% of the region's electricity (45 TWh).[40]

Given the very low impact of CSP on the EU's clean energy mix in 2030, and the lower impact of solar thermal heating compared to heat pumps and other alternative heating sources, this indicator is assigned a **low** rating.

A.2.3.2 EU manufacturing growth

According to Solar Heat Europe, The EU has a strong manufacturing base, supplying over 90% of the current EU demand for solar thermal systems, whilst being also a net exporter globally.[41] With regard to manufacturing growth required to meet 2030 energy and climate targets, the industry players in the solar thermal sector commit to producing and installing all the solar heat capacity planned by the IEA and IRENA for 2050 by 2035.[42]

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[34] GWth refers to thermal capacity (not to be confused with GWh).

[35] The glazed surface of a 1 m^2 solar thermal collector offers 0.7 kWth of thermal capacity. Source: Eurobserv'ER (2022). Solar thermal and concentrated solar power barometer 2022.

[36] Eurobserv'ER (2022), Solar thermal and concentrated solar power barometer 2022.

[37] COM (2022), 221 final. EU Solar Energy Strategy.

[38] Considering the reference year used in the EU solar energy strategy was 2019, in which solar heat accounted for 38 GWth.

[39] https://solariseheat.eu/

[40] Clean Energy Technology Observatory (2020), Concentrated Solar Power and Heat in the European Union

[41] Solar Heat Europe (2022), Energising Europe with Solar Heat - Solar Thermal Roadmap for Europe.

[42] Solar Heat Europe (2022), Energising Europe with Solar Heat - Solar Thermal Roadmap for Europe.

Given the current position of EU solar thermal industry players as exporters of the technology, together with the low import dependency for the main technologies to be deployed in the EU as part of the 2030 ambition, **the risk for this technology is ranked as low.**

A.2.3.3 Competitiveness threats, market concentration, and other vulnerabilities

With regards to solar heat manufacturers, there are no consolidated reports available providing a quantitative comparison of market concentration for the key industrial players.

The EU has high manufacturing capacities, not only serving the EU market but also exporting to non-EU regions such as to the Middle-East, Africa, South and North-America.[43] In particular, Solar Heat Europe evokes Greek producers currently investing in new production lines for both solar collectors and storage systems. Their exports have tripled between 2014 and 2021, while their domestic demand grew only by 33%, hence exports are the main drivers for their growth in manufacturing capacities.

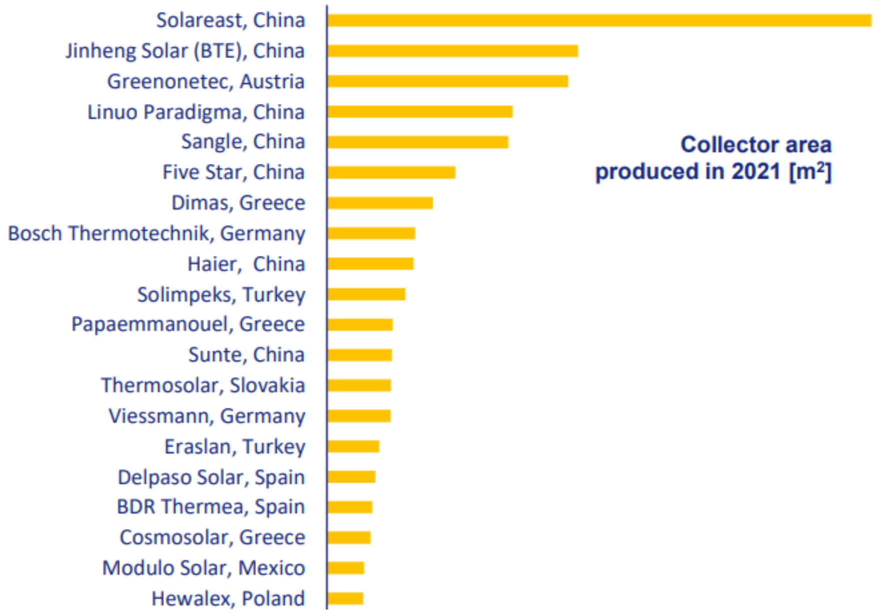
Nevertheless, the European solar thermal industry struggled in 2022 due to the aftershocks of the COVID-19 pandemic and the war in Ukraine.[44] A survey of the German solar collector industry, including major heating technology manufacturers such as Bosch, Viessman and Wolf, revealed that manufacturers faced difficulties to procure materials for collector and heat storage tank production. In particular, vacuum tube manufacturers were reportedly affected by supply chain disruptions, as most German manufacturers purchase vacuum tubes from China, which they assemble into collectors.[45] Other solar heating systems components for which German manufacturers reported significant delays in deliveries were pump groups, expansion vessels and solar controllers.[46]

With regards to Flat plate collectors, the largest solar heat technology in terms of installed capacity, European flat plate collectors regained competitiveness in 2021, recovering from a decline in their production volumes during 2020.[47] European flat plate collector manufacturers reported an increased interest in renewable heat as an alternative to fossil fuels, whose higher prices drove sales growth in 2021.[48] According to Solrico, a solar market research agency focused on the solar heating and cooling sector, in 2021 Chinese manufacturers led the rankings of global manufacturers of flat plate collectors, with seven Chinese companies on the top 20, of which six are ranked in the top 10 (see Figure 8 below).[49] For non-Chinese companies, ten EU-based players are ranked in the top 20. Together the 20 companies listed in the ranking produced around 4.2 GWth (6 million m^2) in 2021. As a point of reference, in China flat plate collectors with a total installed capacity of 5 GWth were added in 2021,[50] while in the EU 1.5 GWth solar thermal capacity was installed in 2021, the large majority of which were flat plate collectors.[51] Some of the large producers in Europe consolidated their market position by receiving new orders for OEM collectors from smaller producers who closed their factories due to declining sales.[52]

43 Eurobserv'ER (2022), Solar thermal and concentrated solar power barometer 2022.
44 REN21 (2023), Renewables 2023 Global Status Report collection, Renewables in Energy Demand.
45 J. Meyer, (2022), Survey of German Solar Collector Industry: 'Daily Struggle to Procure Materials' Solar Thermal World.
46 J. Meyer, (2022), Survey of German Solar Collector Industry: 'Daily Struggle to Procure Materials' Solar Thermal World.
47 Solrico via Solar Thermal World (2022), Economic tailwind for large flat plate collector producers globally.
48 Solrico via Solar Thermal World (2022), Economic tailwind for large flat plate collector producers globally.
49 Solrico via Solar Thermal World (2022), Economic tailwind for large flat plate collector producers globally.
50 Solrico via Solar Thermal World (2022), Economic tailwind for large flat plate collector producers globally.
51 Eurobserv'ER (2022), Solar thermal and concentrated solar power barometer 2022.
52 Solrico via Solar Thermal World (2022), Economic tailwind for large flat plate collector producers globally.

Finally, the EU CSP industry is relatively small, and it is not known for using imported materials with limited supply and availability.[53] The Clean Energy Technology Observatory (CETO) points that EU companies are in a good position as technology suppliers of concentrated solar heat systems for industrial processes.[54] The EU industry has managed to retain industrial leadership in spite of a weak local market. Detailed data on trade for CSP equipment is difficult to come by, however CETO estimates that in terms of the global annual market, global trade likely represents a significant share (over 50%), since most of the commercial CSP projects are developed in countries other than those of the main technology suppliers.[55] The European industry remains active in projects all around the world thanks to its clear technological leadership. As such, it can be expected to benefit from the anticipated investments in CSP worldwide and is active in CSP projects in other regions around the world. However, there is a recent trend with emerging Chinese organisations acting as international project developers and as technology providers, fields where EU industry have traditionally been leaders.[56]

Figure 8: Ranking of the largest flat plate collector manufacturers worldwide



Note: The horizontal axis in the chart was left blank by the original source (Solrico), as a few companies were reluctant to share their production figures publicly.
Source: Solrico via Solar Thermal World (2022)

Besides these international competitiveness threats, the IEA Solar Heating and Cooling (SHC) TCP listed competition with other technologies (solar PV and conventional heating systems) as a major barrier for solar thermal technologies, together with a lack of awareness that solar thermal will be a major future energy source.[57] In addition, the IEA SHC identified insufficient training/education of all stakeholders, from heating companies to planners, installers and end-users, as one of the current barriers to the deployment of solar thermal.[58]

Considering the market concentration and competitiveness threats, solar thermal is rated at **medium risk** in this category.

[53] Clean Energy Technology Observatory (2020), Concentrated Solar Power and Heat in the European Union
[54] Clean Energy Technology Observatory (2020), Concentrated Solar Power and Heat in the European Union
[55] Clean Energy Technology Observatory (2020), Concentrated Solar Power and Heat in the European Union
[56] Clean Energy Technology Observatory (2020), Concentrated Solar Power and Heat in the European Union
[57] IEA SHC (2020), Technology Position Paper - Price Reduction Solar Systems.
[58] IEA SHC (2020), Technology Position Paper - Price Reduction Solar Systems.

A.2.4 Overall assessment

The EU solar heating and cooling industry has a strong industrial position with a large trade surplus, but supply chain shocks such as the COVID-19 pandemic and the Russian invasion of Ukraine can affect its competitiveness. In the case of CSP, the EU industry has managed to retain industrial leadership in spite of the lack of a local market and is active in many CSP projects around the world. Moreover, Chinese players have recently become more active in project development.

With an overall score of **7,** solar thermal technologies are found to be a group of technologies with **low** strategic concern.

A.3 Annex 3: Wind Power

A.3.1 Introduction

Wind power systems transform wind energy into electricity via a rotating shaft and generator mechanism. They can be classified based on their installation characteristics: **onshore or offshore.** Onshore wind turbines have become a mature and highly sophisticated electricity generation technology. Current developments aim to reduce costs and improve efficiency to achieve the ambitious targets for reducing the cost of electricity generation.

For offshore wind parks, wind speeds are typically much higher and more constant than onshore wind speeds. In shallow waters (up to ~50 m), traditional fixed-bottom wind turbine technologies are preferred. As the name implies, fixed-bottom offshore technologies refer to structures where the foundation of the turbine is fixed to the sea floor. A number of solutions are presently available, including steel jacket structures, monopiles, gravity base structures, tripod piled and tripod suction bucket structures.[59]

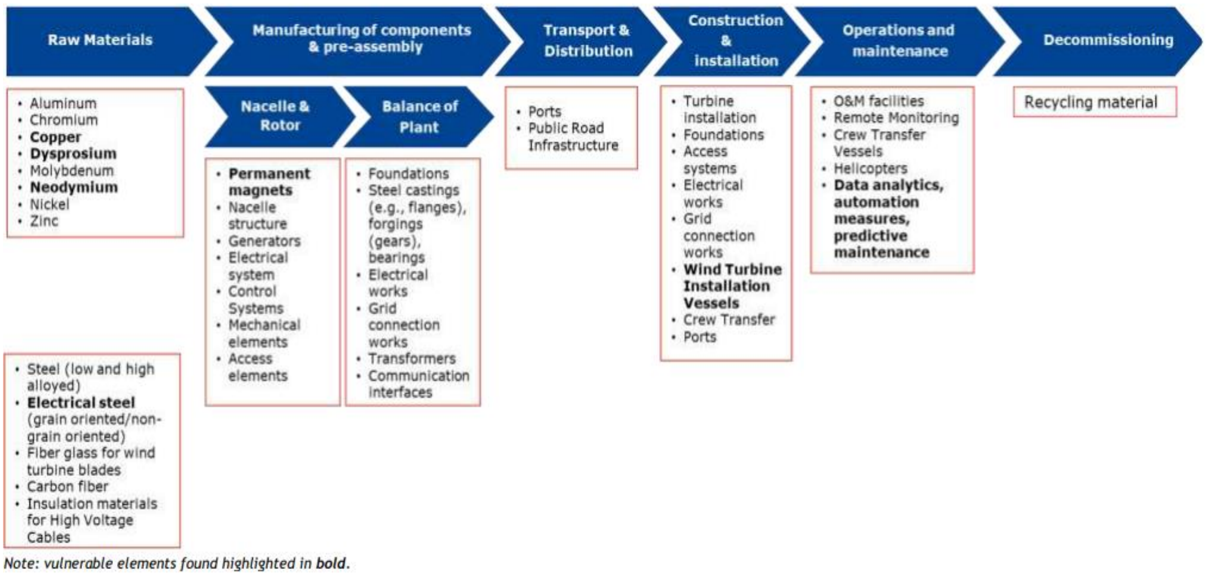
For deeper waters (over 40m), floating turbine technologies are being developed. These are mounted on floating structures usually distinguished by the substructure used to provide the buoyancy and, therefore, stability to the plant, such as Spar-buoy, Semi-Submersible, Tension-leg platform (TLP), Barge or Multi-Platforms substructures. The TRL of the varied floating wind concepts vary, so far Spar-buoy and semi-submersible concepts are the only of these concepts to reach TRL 8-9.[60]

[59] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[60] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

A.3.2 Supply chain overview

Figure 9: Overview of the supply chain for wind power



Source: Trinomics (2021)[61]

Every part and component of the wind turbine plays a significant role in how efficient a wind turbine operates (see Figure 9 for supply chain overview). The basic elements of the wind turbine are the blades, the rotor hub, the rotor shaft, the nacelle, the rotor brake, the gearbox, the generator and controller, the tower and the transformer.[62] These can be grouped in the Nacelle and Rotor assembly, and the Balance of the Plant. The Nacelle and Rotor assembly includes all components to convert kinetic energy of the wind to electric energy (the nacelle structure, generators, electrical and control systems, etc.). The Balance of Plant includes the support structure, electrical equipment and communications equipment needed for transporting the electrical energy to the grid, while the installation of offshore wind parks also requires foundations or floating structures.

Europe has high manufacturing capabilities in components with a high share in wind turbine manufacturing costs (such as towers, gearboxes and blades), as well as in other relevant components (e.g. generators, power converters and control systems). However, a previous study on critical supply chains for energy security noted that many EU generator manufacturers directly import the permanent magnets from suppliers in China and Japan rather than importing the unprocessed rare earth metals.[63] Manufacturing of permanent magnets was not considered a vulnerability in itself, but its vulnerability lays on issues related to the raw material dependencies. The Clean Energy Technology Observatory (CETO) reiterated the criticality of NdFeB magnets, with China's manufacturing capabilities supplying 94% of global production in 2022.[64]

61 Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

62 Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

63 Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

64 Clean Energy Technology Observatory (2022), Wind Energy in the European Union

For the construction and installation stage, wind turbine installation vessels were also identified by the study as vulnerable equipment. These include specialised vessels for the transportation and installation of the turbines, as well as foundation installation vessels. Globally, there is only a limited number of vessels available that are suitable for offshore wind installation and operation[65]:

- There are currently around 15 wind turbine installation vessels for offshore wind farms, with confirmed orders increasing the fleet size up to 28 by 2026.
- In the case of foundation installation vessels, the current fleet of 22 ships is expected to increase to 24 by 2026. Most of these are also commonly used by oil and gas companies, while 14 of these vessels (the larger range) are also used for installing foundations of offshore substations.
- In 2023 there were 31 dedicated cable-laying vessels, with only one new addition to the fleet expected in 2024.
- Besides the previously listed large construction vessels, a variety of smaller vessels support the operations. The majority of these offshore support vessels are not built purposely for offshore wind, and are crucial for offshore operations of the oil and gas industry. Offshore wind developers and contractors tend to contract vessels with the right specifications, such as Dynamic Positioning (DP), high workability, sufficient deck space, low emissions and modern facilities on board. The expected rise in demand for suitable vessels in the second half of the decade creates an opportunity for European shipyards, for the conversion and upgrade of existing vessels or for the build of new assets.
- Finally, service & operation vessels, as well as crew transfer vessels are used for daily windfarm maintenance. There are currently 32 service and operation vessels in operation on offshore wind farms worldwide, and by 2030 the fleet could go up to 100 vessels.

A.3.3 Assessment per indicator

A.3.3.1 EU Demand

Based on REPowerEU Plan projections (excluding the NZIA), the EU requires 510 GW of installed wind capacity by 2030 (including both onshore and offshore), which translates into a CAGR of 12.2% during the 2022-2030 period, or average annual installations of 36 GW. In comparison, the EU's additional demand for wind energy generation capacity was 15GW in 2022, reaching a total wind power installed capacity of 202.7 GW at the end of 2022.[66] Alongside solar PV, wind power constitutes one of the backbones of the EU's ambitions for clean energy and contributes a very significant amount of primary energy input.

Based on this, wind energy technology is rated **very highly** in terms of EU demand for 2030.

A.3.3.2 EU manufacturing growth

Although European demand for wind power is growing, the current installation pace is not sufficient to reach EU's energy and climate targets for 2030.[67] Although the annual demand in 2022 was 28%

[65] Wind Europe (2022), Offshore wind vessel availability until 2030: Baltic Sea and Polish Perspective.

[66] EurObserv'ER (2023), Wind energy barometer 2023

[67] As per REPowerEU objectives set out in the REPowerEU Plan, COM/2022/230 final, and accompanying Commission Staff Working Document Implementing the Repower EU Action Plan: Investment Needs, Hydrogen Accelerator and achieving the Bio-Methane Targets Accompanying the Document: Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU Plan, SWD/2022/230 final, 18.05.2022

higher than in 2021, the current demand pace is still less than half of the pace required to reach the 2030 target.

The EU current manufacturing capabilities in major wind energy components are well suited for covering the *current* demand of this technology. However, the annual deployment rates would need to increase fourfold if components are to be sourced from the EU in the *future*, which could result in supply chain bottlenecks for the sector.[68]

Using the growth rate of EU's manufacturing capacity during the 2010-2020 period as a reference, CETO (2022) estimates suggest that investments in the manufacturing supply chain of wind will be needed to avoid new import dependencies and match the accelerated deployment in the second half of the decade.[69] However, these estimates were based on the CTP-MIX projection of 439 GW by 2030, which is far below REPowerEU's projections of 510 GW. The extra ambition will put higher pressure on EU manufacturing of components and turbine assembly. Therefore, the manufacturing growth needs of the EU are rated as **high.**

A.3.3.3 Competitiveness threats, market concentration and other vulnerabilities

A review of global operational manufacturing facilities of wind energy components suggests that European manufacturers currently have a **high competitive advantage** in this technology, accounting for ~31% of the global wind turbine value chain.[70] As of 2021, five of the ten biggest wind turbine manufacturers in the world are based in the EU.[71] They are only superseded by manufacturers from China who dominate the global manufacturing of components with around 45% of the market share. [72]

Due to the high costs of shipping turbine components, such as blades, nacelles, platforms, towers and vessels, currently only less than 20% of their global production is traded inter-regionally.[73] The EU wind power industry is currently strong with regards to wind turbines, with a positive trade balance in wind-related goods towards non-EU countries. However the EU's **trade balance is deteriorating**, due to increasingly negative trade balances with China and India.[74] Moreover, a key challenge for wind energy manufacturing in Europe is the establishment of local content requirement in their export markets. Current trends on regulatory and trade policies are pushing manufacturers of wind turbine components to build their supply chains in countries in which wind parks are installed, this will likely start a trend in which companies are pushed to set up new factories in the U.S, Taiwan, Korea, and/or Japan.[75] Common policies used by countries include local manufacturing requirements, subsidies or incentives for building local manufacturing capacity, and import tariffs. According to the IEA, in 2023, more than 20

[68] Clean Energy Technology Observatory (2022), Wind Energy in the European Union
[69] Clean Energy Technology Observatory (2022), Wind Energy in the European Union
[70] Clean Energy Technology Observatory (2022), Wind Energy in the European Union
[71] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
[72] Clean Energy Technology Observatory (2022), Wind Energy in the European Union
[73] IEA (2023), Energy Technology Perspectives 2023.
[74] Clean Energy Technology Observatory (2022), Wind Energy in the European Union
[75] Bloomberg NEF (2022), Wind Power in 2020s Must Focus on Capability, Not Cost.

countries have implemented local content requirements for wind energy.[76,77] Notable examples include:

- In Brazil, developers need to use local equipment in order to be eligible for low-cost financing from the country's development bank.
- In the USA, the Inflation Reduction Act (IRA) provides additional tax credits for domestic production of offshore wind components. To claim the additional credit, developers must certify that any steel, iron, or manufactured product that is a component of a facility upon completion of construction was produced in the United States.
- Moreover, several countries, including Canada and Indonesia have imposed anti-dumping duties. The European Commission also imposed anti-dumping duties on imports of steel wind towers from China in 2021, ranging from 7.2% to 19.2%, after an investigation revealed that Chinese towers valued at around EUR 300 million were being imported at dumped prices.[78] Notably, in 2021 the United States imposed anti-dumping duties and countervailing duties with rates up to 73% on imported wind towers from Spain upon entry into the USA.[79] Spanish industry stakeholders reported these tariffs have diminished their exports to the USA.[80]

The global market of wind turbine manufacturing has become more concentrated over the past years. The wind supply chain mainly comes from four regions: Europe, India, China and the United States (US), with each of the regions producing all the major components in a wind turbine.[81] Among the top 10 Original Equipment Manufacturers (OEMs) of 2021, Chinese OEM's held 45% of the market share, followed by European (34%) and North American (9%) companies. In terms of manufacturing capacities of major wind energy components, China's market share ranges between 33% (bearings) and 58% (gearbox), while EU manufacturing shows market shares from 11% (blades) to 47% (castings), followed by India, the US, and Brazil.[82]

In terms of companies, there are currently about five major players outside of China, down from 10 in 2015.[83] There have been significant merger and acquisition activities, such that only five companies account for 94% of all manufacturing installations outside of China in 2021.[84] Moreover, in 2022 the four Non-Chinese industry leaders (Vestas (DK), GE Renewable Energy (US), Nordex (DE) and Siemens Gamesa (DE-ES)) reported lower revenues and worsening losses, citing supply chain disruptions and high costs resulting from the effects of Covid-19 and Russia's invasion of Ukraine.[85]

As of early 2023, capacity expansion plans of key onshore and offshore wind component manufacturers point to China maintaining its leadership position in the near future. China accounts for 80-90% of announced manufacturing capacity additions of onshore nacelles, blades and towers,

76 IEA (2023), Energy Technology Perspectives 2023.
77 In the case of European Member States, the current European legal framework does not facilitate the implementation of local content measures within each Member State, although countries such as France are starting to apply it based on 'good practice and voluntary commitments' (e.g. in France; see Wind Europe (2022), France commits to 40 GW offshore wind by 2050).
78 REGULATION (EU) 2021/2239 of 15 December 2021 imposing a definitive anti-dumping duty on imports of certain utility scale steel wind towers originating in the People's Republic of China.
79 WTO (2021), United States of America: Definitive antidumping duties on imports of utility scale wind towers from Malaysia and Spain.
80 El Pais (2023), Los fabricantes de molinos de viento despiden a centenares de trabajadores en un año.
81 BloombergNEF (2022), Wind Power in 2020s Must Focus on Capability, Not Cost.
82 Clean Energy Technology Observatory (2022) Wind Energy in the European Union
83 BloombergNEF (2022), Wind Power in 2020s Must Focus on Capability, Not Cost.
84 BloombergNEF (2022), Wind Power in 2020s Must Focus on Capability, Not Cost.
85 IEA (2023), Energy Technology Perspectives 2023.

and for offshore wind it accounts for 35% of announced manufacturing capacity additions for nacelles, 75% for towers and 60% for blades.[86] North America and Asia Pacific account for around 50% of announced expansions for offshore nacelles, while Europe covers 25% of all announced manufacturing additions for offshore blades.[87]

Regarding cost of manufacturing, European onshore wind turbine manufacturers' profitability has recently been under pressure due to increased raw material prices, supply chain difficulties and temporarily reduced orders. Equipment manufacturers like Vestas, Siemens Gamesa Renewable Energy and Nordex, as well as suppliers, including Flender, have been affected. These companies increased their selling prices last year, but the cost growth outstripped the price increase, resulting in negative earnings before interest and taxes for the largest producers in 2022.[88]

Other vulnerabilities in the supply chain may also have upstream or downstream impacts on component manufacturing and device assembly for wind turbines. A notable challenge relates to the need for trained professionals for the construction and installation of offshore wind parks, as well as operations and maintenance activities, in order to match the expected rise in demand. The 'EU Strategy on Offshore Renewable Energy' identified shortages of skilled and qualified personnel could be a barrier for offshore wind deployment.[89]. This barrier may impact manufacturing of components upstream as well.

Especially, given the deteriorating trade balance and the increasing implementation of local content requirements on the export markets of EU wind turbine manufacturers, there are current concerns for the wind energy sector, leading to rating this indicator as **high**.

A.3.4 Overall assessment

The EU wind power industry is currently strong, but faces a deteriorating trade balance, as EU producers face rising costs resulting from the effects of Covid-19 and Russia's invasion of Ukraine, paired with the establishment of local content requirement in their export markets.

With an overall score of 13, wind energy is highlighted as a highly strategic technology.

[86] IEA (2023), Energy Technology Perspectives 2023.

[87] IEA (2023), Energy Technology Perspectives 2023.

[88] FitchRatings (2023), Rising Costs Squeeze European Wind Turbine Manufacturers' Margins. Available at: https://www.fitchratings.com/research/corporate-finance/rising-costs-squeeze-european-wind-turbine-manufacturers-margins-07-02-2023

[89] COM/2020/741 final COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future

A.4 Annex 4: Ocean Energy Technologies

A.4.1 Introduction

Offshore renewable technologies refer to offshore wind energy and ocean energy sources.[90] Since offshore wind energy is discussed in the wind energy annex, we discuss here oceanic energy sources. These sources use tidal streams, waves, difference in ocean water temperature, and differences in salinity to generate electricity. Devices producing electricity with temperature gradients are not applicable for mainland Europe, and those using salinity gradients are at an early TRL. As per the proposed NZIA, we focus here on technologies at a TRL level of 8 and relevant for manufacturing for internal use in the EU. Tidal energy devices are the most mature form of ocean energy, and wave energy devices have more recently crossed the threshold into commercialisation. We focus here on these two technologies.

Tidal energy devices with mature tech stacks (TRL 8+) rely on either a horizontal axis turbine (HAT) or a tidal kite. HATs use rotors in a tidal stream to rotate a turbine. Tidal kites are a technology where a kite, tethered to a turbine on the sea floor, glides in the tidal stream causing the turbine to rotate and generate electricity. Both technologies are in a commercial or precommercial stage and are expected to become prominent options in the EU's ocean energy mix.

For wave energy, there are multiple competing technologies at a TRL above 8. These include point absorbers (floating structures bobbing on waves), oscillating water column devices (using waves to compress and de-compress trapped air), attenuation-based devices (which generate electricity from the movement caused by wave energy), and overtopping devices (which use water height increases from waves to generate electricity).

Currently, these energy sources have yet to reach widespread manufacturing and/or deployment, and their costs estimates have wide ranges. Nonetheless, expectations are that costs will decrease dramatically due to economies of scale and innovation in the coming years, to the point of becoming competitive with other energy sources. These costs variations lead to difficulty in developing a clear understanding of the supply chain risks of ocean energy technologies.

A.4.2 Supply chain overview

Wave and tidal energy devices use multiple means to generate electricity from wave and tidal energy. Moreover, much of the underlying technologies and sub-components used in wave and tidal energy devices do not have mature supply chains. Due to these two reasons, we do not go into detail for the supply chain of each technology within this report but focus on the general European supply chain at a higher level. Generally, the supply chain can consist of the following steps:

1) Assessments and engineering
2) Raw materials and refinement
3) Manufacturing of components
4) Logistics and transportation
5) Assembly and installation
6) Operations and maintenance
7) Decommissioning

[90] EC (n.d), Offshore renewable energy. Available at: https://energy.ec.europa.eu/topics/renewable-energy/offshore-renewable-energy_en

The components used in ocean energy devices are rather similar across the main wave and tidal technologies, except for a few structural and PTO components. Table 3 summarises the main components across two of the most commercialised wave and tidal energy technologies. Most of the costs of wave and tidal technologies come from the device's structural and mechanical components. For example, in a fixed bottom HAT tidal stream device, about 65% of the total cost is from components, while the rest is divided between installation, contingency, and development (engineering and assessment) costs.[91]

Table 3: Main components for main technologies of wave and tidal energy sources. Source: CETO (2022)[92]

Device	Structural components	Power take-off system (generator)	Other installation and infrastructure
Point absorber (wave energy)	Surface floaters, vertical column, reaction plates, mounting for PTO system, mooring/foundation system	Generator, hydraulic system, frequency converter, transformer, umbilical cable, control system, bearings and linear guides	Subsea cables, connectors and terminations, O&M vessels, cable shore landing, subsystem integration
Fixed-bottom HAT (tidal energy)	Pile, cross-arm, nacelles, PTO mounting, mooring/foundation system	Generator, gearbox, driveshaft, hydraulic system, frequency converter, transformer, umbilical cable, control system, bearings and linear guides, rotors	Subsea cables, O&M vessels, cable shore landing, subsystem integration

A.4.3 Assessment per indicator

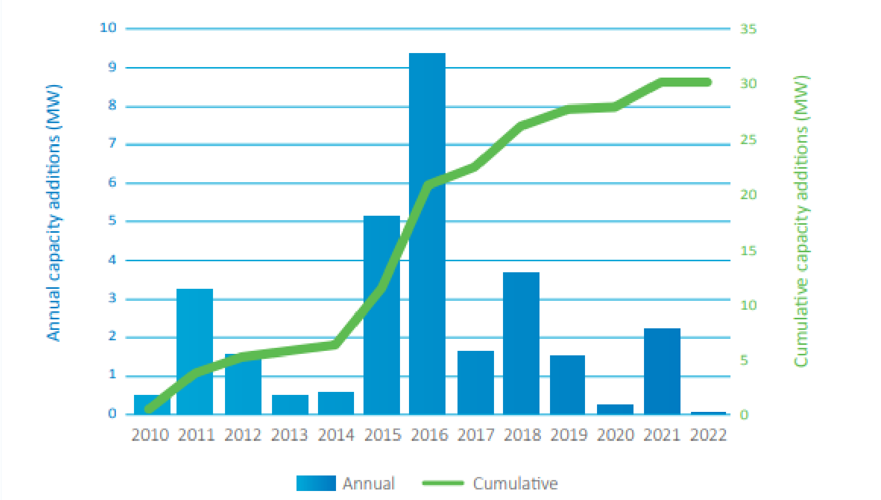
A.4.3.1 EU demand

The European Commission targets (within the Offshore Renewable Energy Strategy) for these sources at least 1 GW installed by 2030 and 40 GW by 2050.[93] IEA's optimistic Net Zero Emissions scenario also predicts that by 2030 globally 27 TWh/yr of ocean energy can be harvested. These numbers are far below those of other more mature clean energy technologies, such as solar panels and wind turbines at hundreds of GWs installed each by 2030. Therefore, the demand for this technology is comparatively very low, and the tech is considered of **very low** criticality in this respect.

91 CETO (2022), Ocean Energy in the European Union.
92 CETO (2022), Ocean Energy in the European Union.
93 EC (n.d), Offshore renewable energy. Available at: https://energy.ec.europa.eu/topics/renewable-energy/offshore-renewable-energy_en

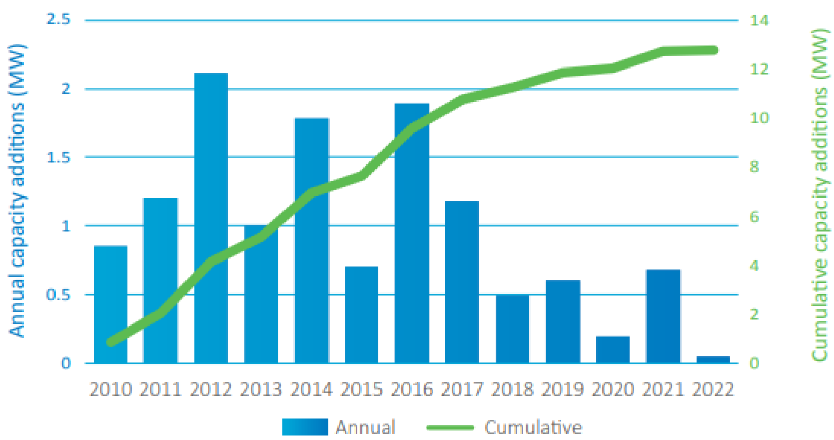
A.4.3.2 EU manufacturing growth

Figure 10: Tidal stream capacity additions in Europe



Source: Ocean Energy Europe (2023)[94]

Figure 11: Wave energy capacity additions in Europe



Source: Ocean Energy Europe (2023)[95]

For 2022, a negligible amount of wave and tidal energy was installed (see Figure 10 and Figure 11). This was just part of a general declining trend that has kicked-off after a period with high installation rates in the mid-2010s. As of 2022, Europe runs a cumulative 13.4 MW of wave and tidal devices[96], with the majority from tidal sources. These sources contributed overall 80.6 GWh to European clean electricity generation.[97]

[94] Ocean Energy Europe (2023), Ocean Energy Key Trends and Statistics 2022.
[95] Ocean Energy Europe (2023), Ocean Energy Key Trends and Statistics 2022.
[96] This figure excludes some devices that were installed but later decommissioned, as is common with maturing technologies such as tidal and wave energy devices.
[97] Ocean Energy Europe (2023), Ocean Energy Key Trends and Statistics 2022.

Projections estimate a steady growth for both types of devices in the coming years. In Europe, 0.5 MW of wave energy and 1.4 MW of tidal stream energy devices are set for installation in 2023. Wave energy capacity will predominantly come from full-scale devices, installed in the UK, Spain, and Portugal. For tidal stream devices, the Netherlands and UK lead European installations.[98] It is assumed that these devices will need to be primarily developed and manufactured in or near the countries of installation. With this assumption, manufacturing numbers are far behind what is required to meet the supply needed to reach the ambition of 1 GW capacity installed by 2030 (i.e. a 48% compound annual growth rate).[99] The need for a very rapid growth gives this technology a **very high** rating in terms of vulnerability.

A.4.3.3 Competitiveness threats, market concentration and other vulnerabilities

The EU maintains a strong position in the development and deployment of wave and tidal energy devices. However, both the US and China have also strongly promoted these technologies in their recent industrial strategies (namely the Inflation Reduction Act and the 14th 5-Year Plan, respectively). Chinese investments in RD&I for ocean energy have grown greatly in recent years, and consequently China has caught up in terms of patent numbers with the EU. Thus, the EU's initially strong position with heavy RD&I investment into ocean energy is faltering due to global competition. The EU is at risk of losing its significant advantage in this area. Nonetheless, it is worth highlighting the immature nature of these technologies and their associated supply chains, which leads to less clarity about the overall prospects of the supply chain's global competitiveness until 2030.

There is yet to appear a developed market for ocean energy devices and, therefore, market concentration issues are less applicable for this technology. The main producers of tidal energy devices are scattered across the EU (mainly the Netherlands, France, and Ireland), the UK, Canada, the US, and China. For wave energy devices, companies are also from a diverse and long list of countries, including the UK, Ireland, the US, Denmark, Sweden, France, and Australia. Overall, market concentration does not appear to be currently relevant for this technology.

Lastly, the novelty of ocean energy creates concerns about the supply chains of the relevant tidal and wave energy technologies. Namely, vulnerabilities in the supply chain can be unclear and difficult to assess. This requires some additional strategic focus for this technology.

Overall, competitiveness concerns are rated to be a **medium** vulnerability.

A.4.4 Overall assessment

The total score for the technology is 9, which makes it **of average strategic concern**.

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[98] Ocean Energy Europe (2023), Ocean Energy Key Trends and Statistics 2022.
[99] Ocean Energy Europe (2023), Ocean Energy Key Trends and Statistics 2022.

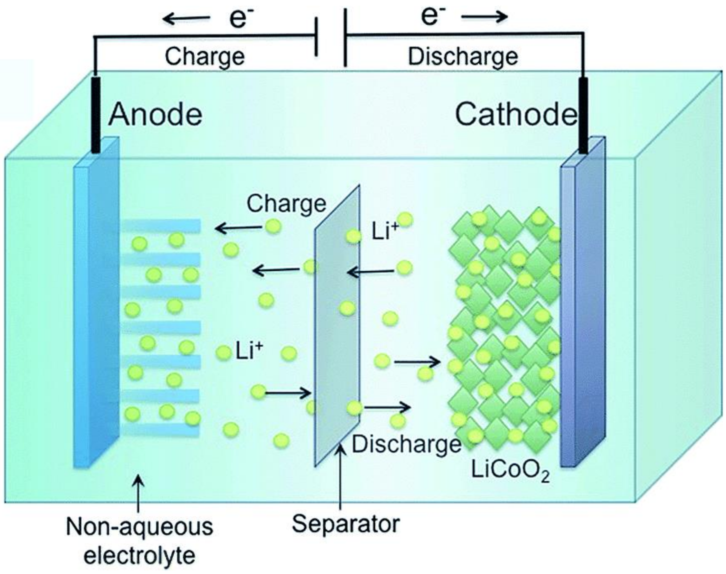
A.5 Annex 5: Batteries

A.5.1 Introduction

Batteries are energy storage technologies based on the principle of electrochemistry. They can convert chemical energy into electrical energy. Batteries are based on a wide range of different chemistry processes. They can be divides into primary (single use) and secondary (rechargeable) batteries. The proposed Batteries Regulation defines five main categories of batteries: portable, light means of transport, automotive, electric vehicles and industrial.[100]

Given the predominance of Lithium (Li)-ion batteries (LIB), the focus will be on this type of technology. LIB operate based on the movement of lithium ions from a negative (anode) to a positive electrode (cathode) while using a non-aqueous electrolyte solution as a conductive medium. This is illustrated in Figure 12. Lithium is the lightest metal and has a very high standard reduction potential (>-3.0V). These characteristics give Li a favourable energy content.

Figure 12: Overview of working principle behind LIB[101]



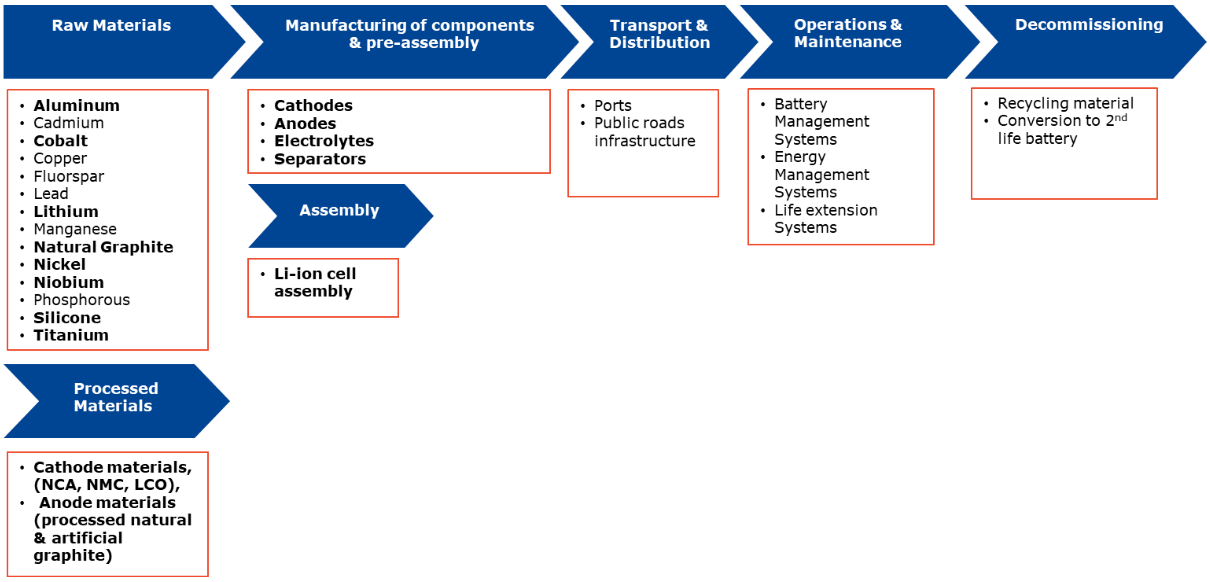
There are multiple cathode chemistries possible for lithium-ion batteries, for electric vehicles (EV) the main ones being Nickel Manganese Cobalt oxide (NMC) and Nickel Cobalt Aluminium oxide (NCA). More recently, Lithium-Iron-Phosphorus (LFP) chemistries are also becoming common due to their lower use of critical materials and performance improvements.

[100] COM(2020) 798 final

[101] Civilsdaily (2019), Nobel Prize in Chemistry: for Lithium-ion battery. Available at: https://www.civilsdaily.com/news/nobel-prize-in-chemistry-for-lithium-ion-battery/

A.5.2 Supply chain overview

Figure 13: Overview of the batteries supply chain



Source: Trinomics (2021)[102]

The LIB supply chain involves the procuring of raw materials, processing into cathode and anode materials, further manufacturing of components (especially cathodes, anodes, electrolytes, and separators), cell assembly, transportation and installation into end-uses, operation and maintenance, and decommissioning. An overview of the battery supply chain is provided above in Figure 13**.** Materials represent about 50-70% of a battery's final cost, and thus much focus is placed on this aspect of the battery supply chain. Europe currently still lacks the capacity to process materials required to produce LIB; the continent is dependent on foreign suppliers of anode and NCA cathode materials and delivers about 18% of Nickel Manganese Cobalt oxide and 15% Lithium Cobalt oxide processed materials. These volumes are not enough to satisfy the European demand for LIB.[103]

For NCA and NMC batteries, the cathode represents 15 to 25% of the costs of an EV battery pack and the anode slightly over 5%, and other costs besides the main components represent over 50% of total costs. For stationary storage, materials represent 65 to 80% of total battery pack costs, with the rest amounting to labour, overhead, margins and other costs. But while the main components (anode, cathode, electrolyte and separator) account for the largest part of the costs of a stationary battery pack, when considering the total system cost, these represent around 30% of the battery storage system.[104]

[102] Trinomics (2021), Lithium

[103] JRC (2020), Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study. Available at: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[104] Triropolos, I., Tarvydas, D., Lebedeva, N., et al. (2018), "Li-ion batteries for mobility and stationary storage applications.", JRC Science for Policy Report (2018)

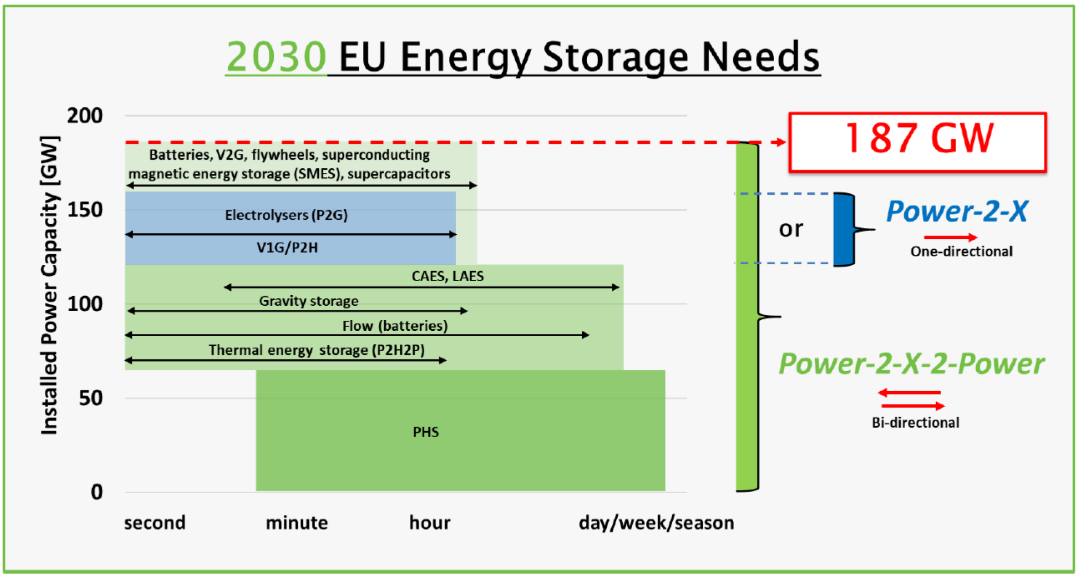
A.5.3 Assessment per indicator

A.5.3.1 EU demand

The impact of batteries on the EU's achievement of Fit for 55 goals will relate to use cases in both the energy storage sector and the e-mobility sector. By 2030, the REPowerEU modelling predicts that 1694 GWh of batteries will be in use across the EU in e-mobility and storage applications.

The EU's overall demand for energy storage – especially the swiftly decarbonising electricity sector – will significantly increase from 11% of the final electricity demand in 2021 to 24% in 2030.[105] The European Association for Storage of Energy (EASE), estimates that energy storage power capacity requirements at EU level will be approximately 200 GW by 2030, and 600 GW by 2050.[106] Figure 14 shows the EU energy storage needs for 2030 for different energy storage technologies. Under this demand scenario, 67 GW installed power capacity is assigned to batteries based on the numbers in the European Commission's study on energy storage.[107]

Figure 14: EU Energy Storage Needs for 2030[108]



E-mobility is the main use case for batteries, representing about 90 GWh of batteries installed in 2021 (compared to 5 GWh for energy storage).[109] The demand for these batteries will continue to grow rapidly, and e-mobility will continue to contribute the lion's share of the 1,694 GWh installed by 2030. More than 50 million electric vehicles are expected to be deployed in the EU by 2030 (representing ~ 1.5 TWh of batteries).[110] Currently, battery-based e-mobility appears as the most promising technology for decarbonising light- and medium-weight transport, and, therefore, batteries play a very significant role in achieving the GHG reduction goals of the EU as per the Fit for 55 package.

Based on these considerations, the EU demand is deemed to be **very high**.

[105] https://energy.ec.europa.eu/topics/research-and-technology/energy-storage/recommendations-energy-storage_en
[106] European Association for Storage of Energy (2022), Energy Storage Targets 2030 and 2050.
[107] European Commission (2020), Study on energy storage - Contribution to the security of the electricity supply in Europe.
[108] European Association for Storage of Energy (2022), Energy Storage Targets 2030 and 2050.
[109] KU Leuven (2022), Metals for Clean Energy: Pathways to solving Europe's raw materials challenge.
[110] Clean Energy Technology Observatory (2022), Batteries for energy storage in the European Union

A.5.3.2 EU manufacturing growth

In terms of component production, the EU produces also no cathode or anode materials, relying instead on manufacturers in China, Korea, and Japan. This dependency is expected to remain highly vulnerable for the EU's battery supply chain.

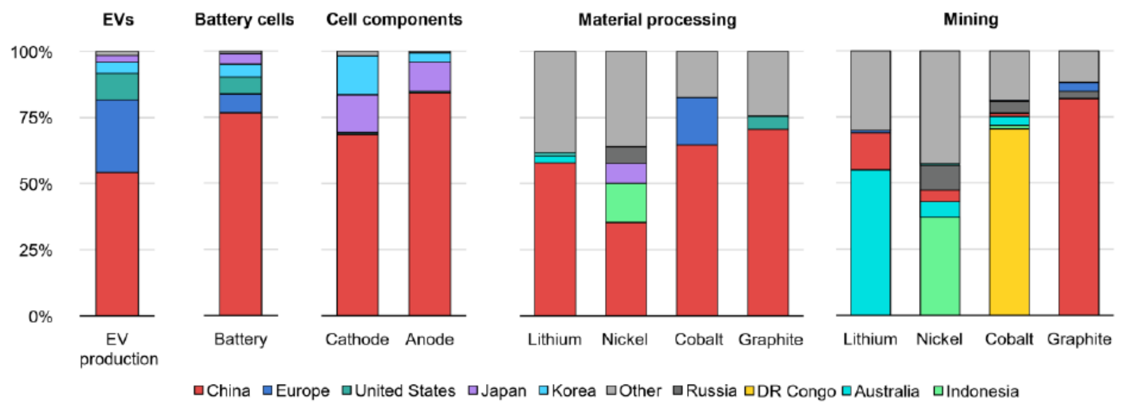
In terms of cell production, European production capacity reached **44 GWh** in mid-2021 and already has an estimated nameplate capacity 75 GWh/year, primarily within the EU-located factories of East Asian companies. Companies are rapidly expanding manufacturing capacity, partly thanks to efforts from the European Battery Alliance, and are on track to meet 89% of demand by 2030.[111] While this capacity may take some years to materialise as factories ramp up production, this nonetheless indicates that **manufacturers are rapidly expanding production inside the EU** to meet necessary demand, especially that of car producers near battery factories.[112] The NZIA specifies the EU's **manufacturing capacity target** for batteries as at least **550 GWh in 2030.**[113]

Given that the projected manufacturing capacity target for battery technologies by 2030 is more than 12 times greater than the current cumulative energy capacity, the need for EU manufacturing growth is assessed as **very high**.

A.5.3.3 Competitiveness threats, market concentration and other vulnerabilities

Asia, and more specifically China, have historically dominated across the LIB supply chain. Figure 15 shows the geographical distribution of production/capacity by region and different elements of the battery supply chain in 2021.

Figure 15: Geographical distribution of production/capacity by element of the supply chain in 2021[114]



[111] SWD (2022), 643 final, Progress on competitiveness of clean energy technologies.

[112] EC (2023), Staff Working Document: Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity.

[113] EC (2023), Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act). COM (2023), 161 final.

[114] JRC (2022), Batteries for energy Storage in the European Union. Available at: https://setis.ec.europa.eu/batteries-energy-storage-european-union_en

Production of anode and cathode materials in the EU is unlikely to grow significantly in the timespan relevant for the NZIA (namely until 2030). Processing facilities for these chemicals tend to be set close to where their needed inputs are refined, which are primarily in East and Southeast Asia. Moreover, environmental and social concerns and high permitting requirements in the EU make it highly unlikely that such plants would be installed in time to meet Europe's growing needs for LIB. Thus, this **dependency on anodes and cathodes sourced from Chinese, Korean, and Japanese sources is expected to remain** at least in the short and medium term.

In cell assembly EU is gradually increasing its weight. In 2018, only about 3% of the global production capacity of lithium-ion battery cells was located in the EU. About 66% of production capacity was in China, and 20% was in South Korea, Japan and other Asian countries. However, estimated European production capacity is at 75 GWh/year by the end of 2022 and is expected to continue increasing significantly. After China, the EU is becoming the world's second largest battery cell producer, generating 800,000 jobs and around 250 billion euros per year.[115,116] Europe is catching up with Asia in terms of investments in the battery sector. In fact, Europe invested significantly more than China in the sector in 2019 (60 billion euros vs 17 billion euros).[117]

The **EU is very strong in the development of final products (EVs and stationary storage).** The EU remains a net exporter of electrified passenger vehicles, producing about 19% of global output (1.3 million cars) and has strong manufacturing of storage batteries. China remains a larger producer of electric buses, while other heavy-duty vehicles are in earlier stages of development. For stationary storage, the main provider in the utility-scale market is Fluence, co-owned by Siemens and AEG. In the small-scale storage market, a few companies including Tesla, Sonnen, and LG Chem are currently active in Europe, with BYD increasing its market presence as well.[118]

Market concentration is a significant issue for batteries. The top four companies producing battery cells, all East-Asian, account for 73% of global production, indicating a high level of concentration.[119] Most of EU production being currently set up is via these larger companies. Moreover, Chinese, Korean, and Japanese sources for refined materials, components, and cells significantly dominate the supply chain.

Overall, taking the above considerations into account, the battery value chain in Europe is becoming stronger and more competitive. Nonetheless, vulnerabilities on cathode and anode materials, and regarding market concentration remain. Furthermore, a recent publication by the European Court of Auditors highlights several risks for the EU in its ambition to become a global battery powerhouse. These include access to raw materials, fierce competition by countries like the US to attract manufacturers and concerns over rising raw materials and energy prices.[120] Therefore, an overall score of **medium** is suggested.

[115] European Courte of Auditors (2022), Becoming the world's second largest battery producer. Available at: https://www.eca.europa.eu/lists/ecadocuments/ap22_02/ap_batteries_en.pdf

[116] COM (2018), 293 final, Strategic Action Plan on Batteries

[117] Euractiv (28/08/2020), Europe is 'closing the gap' on battery manufacturing, Northvolt says. Available at: https://www.euractiv.com/section/energy-environment/news/europe-is-closing-the-gap-on-battery-manufacturing-northvolt-says/ Euractiv (30/07/2020) EU invests EUR350m in first domestic battery Gigafactory. Available at: https://www.euractiv.com/section/batteries/news/eu-invests-e350m-in-first-domestic-battery-gigafactory/

[118] JRC (2022), Batteries for energy Storage in the European Union. Available at: https://setis.ec.europa.eu/batteries-energy-storage-european-union_en

[119] JRC (2022), Batteries for energy Storage in the European Union. Available at: https://setis.ec.europa.eu/batteries-energy-storage-european-union_en

[120] European Court of Auditors (2023), Europe is in danger of losing the battery race. Available at: https://www.eca.europa.eu/en/news/NEWS-SR-2023-15

A.5.4 Overall assessment

With an overall score of **13 points**, the batteries supply chain is considered **highly strategic**.

A.6 Annex 6: Other Storage Technologies

A.6.1 Introduction

Decarbonising the existing energy sector relies largely on volatile renewable energy sources like solar and wind power. The availability of these resources is both seasonal and dependent on conditions external to human control, like the weather itself. To harmonise the availability of energy and the demand curve determined by human activity, storage of energy/electricity is becoming an increasingly pressing necessity as more and more volatile renewable production capacity comes online. Electrification of the energy system reduces primary energy consumption due to the efficiency gains on the end-use side, however, storing electricity itself remains a technologically challenging task – especially in the longer term, for balancing seasonal mismatches in supply and demand. Energy storage right now is dominated by pumped hydro storage, with lithium-ion batteries being the fastest expanding technology today. Pumped hydro storage, however, has serious geographical limitations[121] and lithium-ion batteries are not yet economically viable for seasonal storage[122].

A key solution to the problem of long-term economical energy storage, therefore, remain the **thermal energy storage** (TES) options, allowing for heat itself to be stored in the summer and used in the winter – or conversely, the summer utilisation of a cold medium stored in the winter for the increasing cooling needs[123]. Based on its round-trip efficiency, thermal storage options remain the best, most economical solution for thermal electricity generation plants.

The basic components of TES systems are a heat storage medium, a heat exchange system with transfer fluid, and a containment system. Thermal storage can be classified based on the medium used to store energy in the form of heat - including water, phase-change materials, building cores and the ground. These solutions are already in use today to provide flexibility options mainly in existing co-generation and district heating systems, incorporating sensible solutions, like tank thermal energy storage (TTES), underground thermal energy storage (UTES) and water tank thermal energy storage (WTTES) applications. The use of molten salts as thermal storage is common in concentrated solar power applications, and some aspects of the supply chain for this technology is also discussed in the annex on solar thermal technologies.

Another solution for the storage of electricity can be **hydrogen storage**. Hydrogen has two main components; a storage compartment and a compressor. Hydrogen as an energy vector can be stored in many forms – physically, as hydrogen molecules in gaseous or liquid state, or chemically, as hydrogen derivatives. Storage in its physical forms is the only option currently employed on any significant scale – examples of it can be found in the US and the UK[124]. Underground natural gas storage already plays an important role in meeting flexibility requirements in today's energy systems - the global storage capacity being close to 430 billion cubic metres (about 10% of global gas demand)[125]. Similarly, hydrogen is expected to have an important role in the energy system – balancing seasonal demand swings, mitigating price fluctuations, providing security in case of supply disruptions. With the ongoing decarbonisation effort, hydrogen will take the place of natural gas physically as well, being stored in salt caverns, depleted gas fields, aquifers or hard rock caverns

[121] JRC (EC) (2022), Hydropower and pumped hydropower storage in the European Union
[122] Joule (2019), Long-Duration Electricity Storage Applications, Economics, and Technologies
[123] IRENA (2022), Smart Electrification with Renewables – Driving the transformation of energy services.
[124] International Journal of Hydrogen Energy (2019), Large-scale storage of hydrogen
[125] IEA (2022), Global Hydrogen Review

like natural gas right now. Salt cavern storage for hydrogen is a tried and tested technology but depleted gas fields and aquifers need more research.

This analysis focuses on the supply chains of these two alternative storage technologies, while lithium-ion batteries and pumped hydro storage are covered in other annexes.

A.6.2 Supply chain overview

The storage supply chain for hydrogen storage and thermal storage (excluding molten salts) relies on components that are highly common across other supply chains. These include piping, valves, electronic control equipment, pumps, heat exchangers, tanks, and receiver tubes. In terms of device assembly and installation, thermal storage depends on similar processes as most heating system installations, such as heat pumps.

A.6.3 Assessment per indicator

A.6.3.1 EU demand

The EU's overall demand for energy storage – especially the swiftly decarbonising electricity sector – will increase significantly from about 120 TWh (as of 2021) to 288 TWh (24% of total EU electricity demand) in 2030.[126] This will have to be partially met by storage technologies considered here, namely thermal and hydrogen storage.

For thermal energy storage, IRENA's projections for global demand expect a threefold increase compared to the current installed capacity, placing the demand at 800 GWh by 2030. This requires a USD 13-28 billion investment in the 2020s. Molten salt storage is expected to occupy the lion's share of this market, with an expansion to 94 GWh installed capacity being already in the pipeline, and an estimated potential to reach 491-631 GWh installed capacity by 2030 in the more ambitious scenarios.[127] Other, currently not as mature technologies, such as solid-state and liquid air storage, is expected to become viable later on. The rest of the capacity expansion (~200-300 GWh) by 2030 is expected to be provided by currently mature (mainly TTES) technologies.

The current global installed capacity of thermal energy storage is 234 GWh. 13.9 GWh capacity of this is specifically for space cooling applications. For these applications, IRENA projections expect that the installed capacity will double and reach 25 GWh before 2030, with an investment need between USD 560 million and USD 2.82 billion.

Molten salt storage is the technologically and economically most mature and most used technology, with 21 GWh installed global capacity, with solid-state and liquid air variants also becoming available in the longer term.[128] The EU Member States applying thermal storage on a larger scale already are France, Germany, Greece, Ireland, Italy, Spain and Sweden – with a total installed capacity of 1227 MW[129]. More than 90% of this capacity is located in Spain.

The EU's demand for storage is in a rapid growth, expected to double in less than a decade. With the geographical limitations of hydropower and the pumped hydro storage capacity mostly exploited already[130] (60-70% by some estimations[131]), the technologically mature options of thermal and hydrogen storage is expected to carry a significant portion of this growth. Much of this growth

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126 EC (2023), SWD 57 final: Energy Storage - Underpinning a decarbonised and secure EU energy system.
127 IRENA (2020), Innovation Outlook: Thermal Energy Storage
128 IRENA (2020), Innovation Outlook: Thermal Energy Storage
129 EC (2020), Study on energy storage – Contribution to the security of the electricity supply in Europe
130 JRC (EC) (2022), Hydropower and pumped hydropower storage in the European Union
131 Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

in storage will come from other sources, however, such as batteries and other storage technologies. Nonetheless, given the need for some heat-based storage on the demand side, and the significant role of hydrogen storage in the EU's hydrogen plans, the EU's demand for hydrogen storage and thermal storage is deemed to be of **medium (3)** criticality.

A.6.3.2 EU manufacturing growth

Storage uptake in the EU is lagging behind the demand generated by the accelerating wind and solar deployment. This poses a great threat and an obstacle to the smooth continuation of the energy transition in Europe. The current installed energy storage capacity of Europe is 120 TWh (as of 2021) while the estimated necessary storage capacity will reach 288 TWh by 2030. In 2020, only 0.8 GW additional storage capacity was realised in the EU[132], but even the 2.8 GW additional capacity that came online in 2022[133] falls far behind the necessary 14 GW/year growth rate that would achieve the target.

It is difficult to find direct estimates of EU manufacturing of thermal storage, as the major capacity is within the form of storage tanks in heating systems. This capacity and the relevant technologies are assumed to be well-developed in the EU.

For hydrogen storage, in theory, the EU has a more than sufficient storage capacity in its current natural gas storage facilities. However, its current position and the expected gradual phase-out of natural gas makes it hard to estimate the rate at which these facilities will be made available for hydrogen storage instead. Planned hydrogen storage facilities – announced, in a concept, demo or feasibility stage – in the EU have overall approximately 41 TWh capacity. Out of this 27 TWh in (repurposed) salt caverns and 14 TWh in depleted natural gas fields. Additionally, 60 GWh is planned in hard rock caverns.[134] This capacity, therefore, constitutes less than 5% of the projected demand by 2030, meaning that 95% of the demand would either have to be met via other means – including pumped hydro storage and batteries – or the existing plans for hydrogen storage expansion would have to be greatly accelerated.

Overall, we assign a **medium (3)** score for other storage technologies due to vulnerabilities from the need for EU manufacturing growth.

A.6.3.3 Competitiveness threats, market concentration and other vulnerabilities

Out of the 25 major component suppliers for molten salt thermal storage systems Alstom Power/Alstom, Schott, Rioglass, Abengoa, AREVA, SENER, Siemens, Saint-Gobain and Flabeg are from Europe[135]. These companies can cover all the manufacturing of all major components necessary for this technology. Other thermal storage systems (e.g. TTES) are generally covered by heating system producers, e.g. those discussed in the heat pumps annex.

Hydrogen storage requires two main components; a storage compartment and a compressor[136]. Major compressor manufacturers in the EU are Siemens and MAN in Germany, Nuovo Pignone (based in IT but owned by GE from the US), Atlas Copco in Sweden and Ingersoll Rand in Ireland.

[132] EASE (2022), Energy Storage Targets 2030 and 2050 – Ensuring Europe's Energy Security in a Renewable Energy System
[133] EC (n.d), Recommendations on energy storage. Available at: https://energy.ec.europa.eu/topics/research-and-technology/energy-storage/recommendations-energy-storage_en
[134] IEA (2022), Global Hydrogen Review
[135] NREL (2015), Domestic Material Content in Molten-Salt Concentrating Solar Power Plants
[136] International Journal of Hydrogen Energy (2019), Large-scale storage of hydrogen

Compressors were identified as a non-vulnerable element of the European supply chain in previous studies[137], while there are some dependencies on Chinese manufacturers (discussed further in the heat pumps annex). About 4000 TWh of natural gas storage is online worldwide, a 1000 TWh of it is currently available in Europe[138], mostly in still operational natural gas fields. With the progression of the energy transition, the majority of this is expected to become gradually available for hydrogen storage instead. Underground gas storage sites were being developed in the recent past (2018) in five EU Member States – the Czech Republic, Germany, Italy, Poland and Portugal – by European companies, like Bilfinger Tebodin, Saipem, Control Process[139]. The geographical dispersion of hydrogen storage capacities does not show unhealthy concentration among regions

Some other aspects also create vulnerability for these storage technologies. Social awareness and acceptance is not following the increasing need for thermal storage. The (poor) condition of the building stock can prevent the adoption of energy efficiency measures, which would create more thermal storage together with decarbonised heating systems. The lack of expertise, good practices and the lack of confidence of professionals in the technology also poses a hindrance.[140] Furthermore, the lack of clarity when it comes to regulation also poses a risk in hydrogen storage applications.[141]

The EU remains competitive for other storage technologies, but the lack of expertise and changing regulation is an issue. The building stock's readiness for the application of systems with thermal storage options is questionable. Social awareness and acceptance is an issue. Overall, the comparative impact of these risks on the score of supply chain risk is **low (2)**.

A.6.4 Overall assessment

Overall, this technology is assessed to have a **score of 8,** i.e. of **low** strategic significance.

[137] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[138] TNO (2020), Large-scale energy storage in salt caverns and depleted fields

[139] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[140] Energy Research and Social Science (2021), Why it's so hard? Exploring social barriers for the deployment of thermal energy storage in Spanish buildings

[141] Renewable and Sustainable Energy Reviews (2022), Towards underground hydrogen storage: A review of barriers

A.7 Annex 7: Heat Pumps

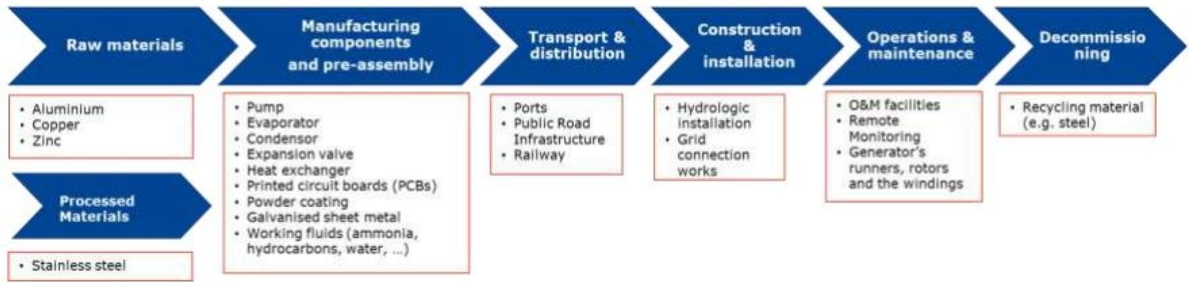
A.7.1 Introduction

Heat pumps use electricity to transfer heat from a reservoir to an indoor area or to water, using refrigerant fluids to transport the heat. The refrigerant fluid is compressed and decompressed to store and release heat as needed, at specific parts of a refrigeration cycle, such that thermal efficiencies (amount of heat output divided by amount of energy input) of 300% to 500% can be reached. These high thermal efficiencies are possible because unlike gas boilers, which can at most come close to 100%, heat pumps use an energy reservoir different from their energy input for the heat. Heat pumps have high up-front costs but can be a cheaper option over their lifetime than other heating options.

Most heat pumps retrieve heat from the air (about 80% of demand), with others that use water sources or the ground as the heat reservoir. Most heat pump demand is for heat pumps that transfer heat for indoor air warming, while hydronic heat pumps heat up water.

A.7.2 Supply chain overview

Figure 16: Overview of heat pump value chain



Note: vulnerable elements found higlighted in bold
Source: Trinomics (2021)[142]

Heat pump technology is very mature and highly similar to air cooling units, with the refrigeration cycle running in reverse and optimised for different operational conditions. The devices are made of chemical, electrical, and mechanical components, primarily compressors (25% of overall costs), electronics (23%), heat exchangers (15%), and the housing (13%). An additional important raw material is the refrigerant fluid, which is discussed later as well. Many components of heat pumps have mature supply chains and are commonly produced for other devices as well, including evaporators, tanks, valves, pumps, alongside the aforementioned primary components (Figure 16).

[142] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

A.7.3 Assessment per indicator

A.7.3.1 EU demand

Globally, heat pumps currently deliver around 10% of the world's building heating needs.[143] Heat pump demand in Europe outpaces the rest of the world, with predictions of nearly 7 million devices installed based on policy objectives as of November 2022 (I.e. excluding the Net Zero Industry Act).[144] Based on ambitions updated by the REPowerEU plan, Europe will aim to install another 30 million heat pumps by 2030.[145]

In Europe, demand for heat pumps is (comparatively) exploding, with 20% average annual growth between 2019 and 2021.[146] Maintaining this growth in the coming years will be necessary to meet REPowerEU's ambitions. 18.8 GW of heat pumps were sold and installed in 2021, reaching a cumulative installed capacity of 140 GW across the EU.[147] These capacity additions increase to 51 GW per year by 2030, based on the updated REPOWEREU plan.[148] This extensive heating demand will make up a significant portion of building heating, and a smaller portion of low-temperature heating for industrial and commercial uses.

Given the extensive demand for heat pump installations in the coming years until 2030, and its growing share in heating for buildings and potentially other (higher-temperature) uses, this technology gets a **very high** rating for demand.

A.7.3.2 EU manufacturing growth

The EU is a well-developed manufacturer of heat pumps; production in the EU has been growing consistently and reached 3b EUR value in 2021.[149] Nonetheless, current growth rates are not enough to catch up with production numbers within ambitions and announcements. The Net Zero Industry Act aims for strengthening Europe's manufacturing of heat pumps, aiming for 31 GW per year by 2030, while the current manufacturing capacity in Europe is 14 GW per year. In the IEA's Net Zero Scenario, based on announced projects (as of April 4th, 2023), European production is required to reach 60 GW per year.[150] Moreover, much of the capacity addition is in air-to-water systems, while significant demand growth is projected for air-to-air systems.

Considering the established industrial base, but also the need for larger growth, heat pumps reach a **medium** rating for EU manufacturing growth needs.

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[143] IEA (2023), Energy Technology Perspectives 2023
[144] IEA (2022), The Future of Heat Pumps
[145] European Commission (2022), COM (2022) 108: REPowerEU: Joint European Action for more affordable, secure and sustainable energy
[146] European Commission (2022), COM (2022) 108: REPowerEU: Joint European Action for more affordable, secure and sustainable energy
[147] EHPA (2023), Market Report 2022
[148] EC (2023), Staff Working Document: Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity
[149] Clean Energy Technology Observatory (2022), Heat Pumps in the European Union
[150] https://www.iea.org/data-and-statistics/charts/heat-pump-manufacturing-capacity-by-country-or-region-according-to-announced-projects-and-in-the-net-zero-scenario (accessed on April 18th, 2023)

A.7.3.3 Competitiveness threats, market concentration and other vulnerabilities

While the EU's production needs to ramp up greatly to meet demand, many companies are investing in production capacity in Europe, including Veissman, Bosch, Panasonic, and others, with CETO (2022) reporting on expert predictions of at least EUR 3.3 billion of investments flowing towards heat pump manufacturing until 2025.[151]

Nonetheless, rapid growth in EU demand is outpacing growth in EU production. The EU remains the technology leader in air-to-water, ground-to-water, and brine-to-water heat pumps. Yet with air-to-air heat pumps, globally-competitive manufacturers from Asia and North America are rapidly meeting European demand for these devices and causing rapid growth in trade deficits. EU trade balance in heat pumps has consistently dropped in the past years and hit a deficit in 2020. This deficit continues to grow, with 390m EUR in 2021.[152]

Experts indicated that this deficit is primarily due to highly competitive HVAC system manufacturers from North America and Asia moving into the air-to-air heat pump market. The traditional capabilities of European heat pump manufacturers of hydronic and ground-based systems are different from those needed for producing air-to-air systems. While many non-European manufacturers are increasing production capacities in Europe, the better portability of air-to-air systems compared to hydronic, ground-to-air, and water-to-air systems grants them lower logistics costs and a more global market.

For the hydronic heat pumps market, experts also indicated that Chinese manufacturers are rapidly scaling up capacity and can become competitors to European production in the short term.

Competitiveness concerns have also hit heat pumps at the component level. Compressors, the highest value component in the heat pump, are now heavily imported into the EU from more competitive producers in China. Electronics have also traditionally been imported from East Asian manufacturers. These dependencies are expected to remain for the near future, as support towards expanding manufacturing capacity takes a few years to materialise as production.

In terms of market concentration, the heat pump market is not concentrated in any specific region or with a specific company (or companies). Multiple East Asian, European, and North American manufacturers have strong capabilities in producing heat pumps, and investments in increasing production capacity are strong, especially in the EU. This state of the market is expected to continue until 2030.

Lastly, a commonly-mentioned vulnerability in the heat pump manufacturing supply chain relates to labour shortages. In component and device manufacturing, we found little mention of labour shortages in the EU; however, there is an ongoing shortage of heat pump installers in the EU. This shortage is projected to become worse in the coming years. The European Heating Industry estimates that 1.5 million installers are employed across the EU[153], a number that needs to increase by 50% to reach pre-NZIA targets for heat pump deployment. Moreover, 50% of the existing workforce also needs to be retrained, particularly due to new refrigerant regulations (the F-Gas Regulation).[154] These regulations replace the use of refrigerants with high GHG potential with some refrigerants that have much lower GHG potential. However, the new refrigerants may be flammable

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151 https://www.iea.org/data-and-statistics/charts/heat-pump-manufacturing-capacity-by-country-or-region-according-to-announced-projects-and-in-the-net-zero-scenario (Accessed on April 18th, 2023)

152 Clean Energy Technology Observatory (2022), Heat Pumps in the European Union

153 European Heating Industry (2022), Heating systems installers: Expanding and upskilling the workforce to deliver the energy transition.

154 Clean Energy Technology Observatory (2022), Heat Pumps in the European Union

or otherwise hazardous (such as propane) and would require additional certification for installers. Worsening this upskilling need is that employment in this sector is stagnant in many EU countries. While these labour shortages can impact other aspects of the supply chain, they can nonetheless create some vulnerability for EU manufacturing of heat pumps upstream from demand. For example, the uncertainty surrounding the local installation of heat pumps may reduce the willingness to invest in manufacturing capacity additions in some regions in the EU.

Overall, these competitiveness aspects for heat pumps are considered of **high** vulnerability from a strategic viewpoint.

A.7.4 Overall assessment

With an overall score of **12**, heat pumps are found to be a **strategic** technology.

A.8 Annex 8: Geothermal Energy Systems

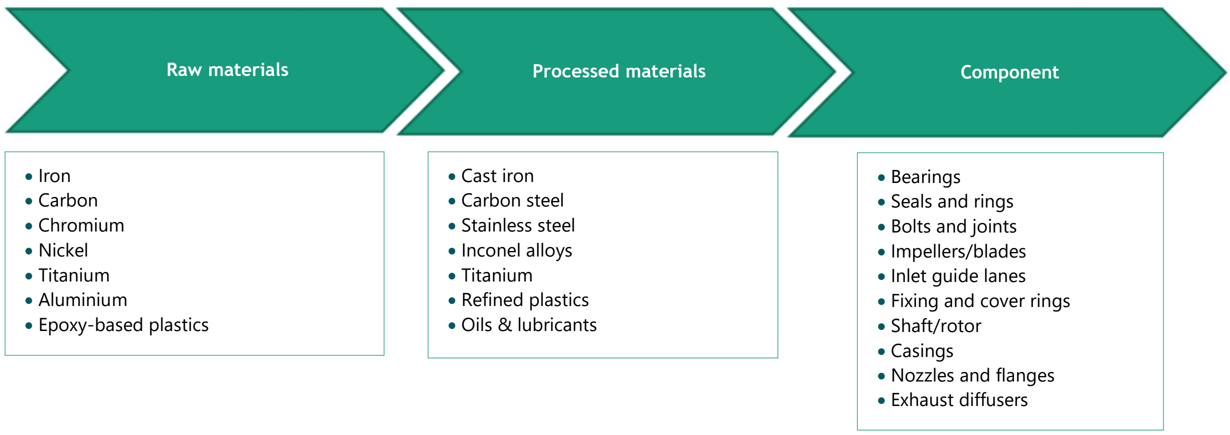
A.8.1 Introduction

Geothermal energy is heat contained by the earth's crust that can be used either directly or for electricity generation – with the help of geothermal steam turbines or binary cycle turboexpanders. These are mature and commercially proven technologies, and as such, already utilised in a diverse manner – for space and district heating purposes, powering industrial processes, water heating, as well as in aqua- and horticulture.

The advantage of geothermal energy is that it can act as baseload power, without seasonal or diurnal variations, regardless of weather conditions. It is compatible with both centralised and decentralised energy generation systems. The disadvantages lie with the comparatively high capital investment costs and resource development risks – often due to the lack of subsurface data – as well as the lack of awareness and perceived environmental concerns[155], therefore complicated licensing processes. As electrification is occupying the centre of attention in public policy, heating from geothermal sources faces competitive disadvantage in many regions without accessible high fluid temperatures at shallow depths.

A.8.2 Supply chain overview

Figure 17: Overview of upstream elements of geothermal supply chain



The geothermal supply chain shown in Figure 17 is particularly characteristic of geothermal power generation. When not overlapping with the power generation, the supply chain for direct utilisation of geothermal heat is interconnected instead with the supply chain of ground source heat pumps and the district heating industry – requiring wells, circulation pumps, transmission and distribution pipelines and various forms of heat extraction equipment. Geothermal energy is produced via both steam turbines and turbo expanders, both of which are discussed in this annex. The content here primarily refers to deep geothermal energy, as surface-level geothermal energy is discussed next to other heat pumps as ground-source heat pump.

[155] IEA (2010), Renewable Energy Essentials: Geothermal

A.8.3 Assessment per indicator

A.8.3.1 EU Demand

Geothermal energy, in principle, is abundantly available in all regions of the world, including Europe.[156] Globally, the utilisation of geothermal energy for electricity generation has been in a robust but slow growth in the past decades, reaching a total installed capacity of 10.6 GW in 2019, from only 5.9 GW in 2000. IEA own projections place the global installed production capacity at 18.5 GW by 2030.[157] In particular, it already provides a significant portion of the electricity demand in Iceland (25%), El Salvador (22%), Kenya (17%), the Philippines (17%), and Costa Rica (13%), with the United States, the Philippines, Indonesia, Mexico and Italy being the biggest geothermal electricity producers in absolute terms.[158]

The EU's own net capacity for geothermal electricity production was 877 MWe in 2021 (out of the total global installed capacity of 15.96 GWe)[159], with an economic potential for 19 GWe in total. While this potential is expected to reach 22 GWe in Europe alone by 2030, and 522 GWe by 2050, in terms of actual growth, geothermal power production of the EU is currently falling behind global trends.

For heat production within the EU, geothermal is expected to reach 1.2 GWth capacity in 2030 based on modelling supporting the REPowerEU plan. District heating and cooling especially plays a prominent role in driving this process with a 6% annual growth rate. Most of the newly installed capacity coming online in recent years are located in Turkey, with large EU consumers of geothermal heat – such as Italy – and Iceland seemingly stopping these investments in the recent past.[160]

The current share of geothermal energy in the final energy consumption of the EU is less than 2% - geothermal electricity production being particularly insignificant standing at only 0.1%. The projections, even in the long-term 2050 future, do not foresee a significant increase in these numbers – with geothermal electricity production reaching 0.2% and geothermal energy for direct heat applications achieving a 2.0% share only.[161]

Based on the literature and expert opinions/projections, the geothermal energy demand's contribution to the composite score of the technology's strategic position – even in the long-term – is **very low (1)**.

A.8.3.2 EU manufacturing growth

The only EU member state with a significant manufacturing output in geothermal electricity production is Italy. In steam turbine production, Italy is 2nd globally with 240 MW capacity output, and in turboexpander production, it is 3rd with 102.2 MW capacity output – with the steam turbine production happening exclusively for the domestic market, and the turboexpander production being done mostly for export purposes[162]. Other EU countries with any amount of production in the past (2005-2015) is Germany (12.7 MW) and France (11.0 MW) – with Germany being a net importer of geothermal power technologies, installing significantly more capacity than produced. The

156 JRC (EC) (2022), Deep Geothermal Heat and Power in the European Union
157 IEA (2022), Geothermal power generation in the Sustainable Development Scenario, 2000-2030
158 IEA (2010), Renewable Energy Essentials: Geothermal
159 IRENA (2023), Global Geothermal Market and Technology Assessment
160 JRC (EC) (2022), Deep Geothermal Heat and Power in the European Union
161 EC (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
162 CEMAC (2018), Global Value Chain and Manufacturing Analysis on Geothermal Power Plant Turbines

manufacturer Ansaldo-Tosi leads the European market with about 30% of installed capacity. Prominent players also include Mitsubishi Turboden, Fuji, Ormat, and GE/Nuovo Pignone.

The EU manufacturing seems to be capable of keeping up with the otherwise sluggish growth of demand, therefore the manufacturing growth score is **low (2)**.

A.8.3.3 Competitiveness threats, market concentration and other vulnerabilities

The global geothermal market in both steam turbines and turboexpander technologies is concentrated in a handful of manufacturing countries. While the global players in steam turbine production are fairly evenly distributed over the globe – with Japan, Italy, the US, France, Mexico, Russia, India and China all occupying a measurable market share – Japan dominates the market, alone accounting for 82% of the global manufacturing. Italy is a distant second with 10% of the Japanese output, exclusively produced for the domestic market. When it comes to turboexpanders, the picture is very similar, with Israel occupying ¾ of the global market[163]. The 2nd largest manufacturer of turboexpanders is the US with only 25% of Israel's output, while Italy comes as a distant 3rd with about 8% of the Israeli manufacturing, produced largely for export purposes.

The global geothermal power market is dominated by a few major manufacturers – none of them from the EU: Toshiba, Mitsubishi, Ormat and Fuji – together accounting for 80% of the installed capacity[164].

Furthermore, geothermal energy faces serious social acceptance issues – deep drilling especially is known to cause small earthquakes[165], which hinders public/local acceptance and has the potential of becoming a political risk.

The global market is dominated by a few countries (outside of Europe) in each market segment, the EU's position in inventions is diminishing, and the technology faces significant social acceptance issues, therefore the score on the compound supply chain risk of the technology is **medium (3)**.

A.8.4 Overall assessment

With an overall score of **6**, geothermal technologies are **not considered strategic** from a supply chain risk perspective.

163 CEMAC (2018), Global Value Chain and Manufacturing Analysis on Geothermal Power Plant Turbines

164 JRC (EC) (2017), Supply chain of renewable energy technologies in Europe

165 Energy Policy (2021), Tell me how you feel about geothermal energy: Affect as a revealing factor of the role of seismic risk on public acceptance

A.9 Annex 9: Hydrogen Electrolysers and Fuel Cells

A.9.1 Introduction

In 2020, the European Commission (EC) published its communique on 'A hydrogen strategy for a climate-neutral Europe' in which it emphasised the importance of hydrogen as 'key priority' to achieve the Union's climate neutrality goals[166]. In its strategic vision 'A Clean Planet for All', the EC foresaw a 13-14% share of hydrogen in Europe's energy mix by 2050[167] - mainly as a vector of energy storage and a complementing measure for electrification in transport and industrial processes.

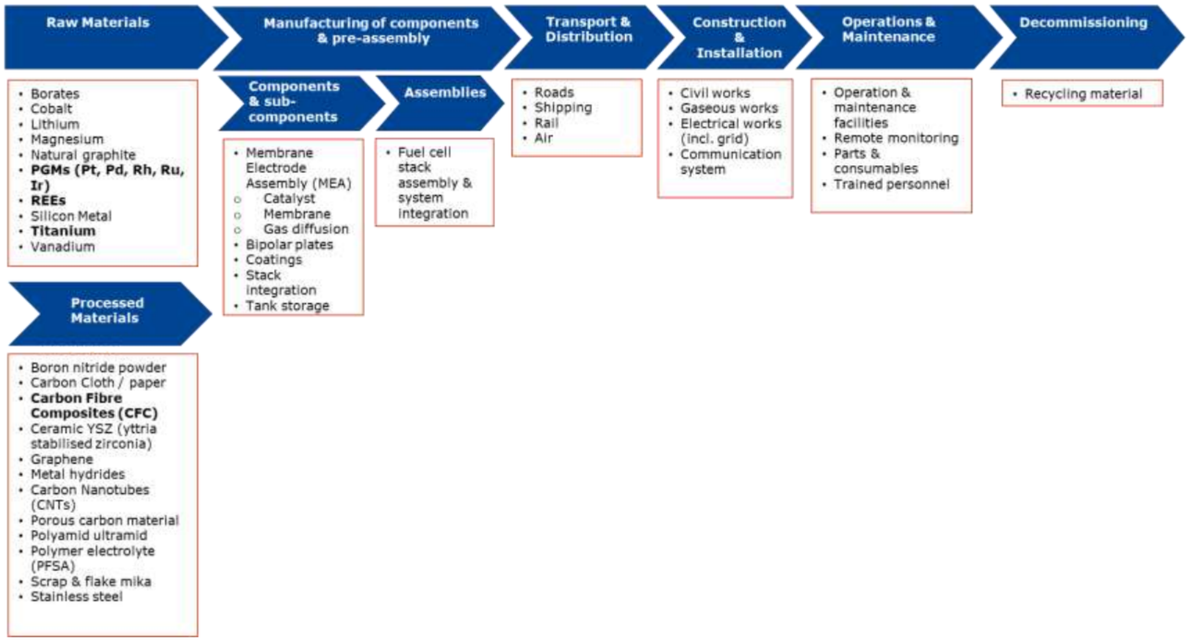
Hydrogen fuel cells (HFCs) are devices converting hydrogen and oxygen into electricity without combustion and GHG emissions, producing only water as a by-product. The fuel cells consist of two electrodes – the so-called anode and cathode – and some kind of an electrolyte – a conductor for ions. In HFCs, the hydrogen gets separated on the anode into its proton and electron. The proton is then directed onto the cathode to form water molecules with the added oxygen, whereas the electron is directed through an external circuit, creating a flow of electrons.

Electrolysers – like fuels cells – consist of an anode and a cathode separated by an electrolyte, and they use the same processes as fuel cells too - only in reverse. They consume electrical energy and split the feedstock water into hydrogen and oxygen. Based on the conducting membrane used, electrolysers can be differentiated into polymer electrolyte membrane (PEM), alkaline, and solid-oxide type electrolysers. In PEM electrolysers, water is being separated on the anode side into oxygen and ions, and with electrons introduced into the system (in the form of electricity), hydrogen molecules are being formed on the cathode. In alkaline electrolysers, hydrogen and OH- ions are being formed on the cathode from water and electrical current, and with the OH- being transported to the anode, water and oxygen is produced. In solid-oxide fuel cells O2- ions are produced on the cathode (from air and electricity being introduced to the fuel cell) and transported to the anode.

[166] EC (2020), A hydrogen strategy for a climate-neutral Europe
[167] EC (2018), A Clean Planet for all

A.9.2 Supply chain overview

Figure 18: HFC supply chain, with vulnerable elements highlighted



Source: Trinomics (2021)[168]

Fuel cells (supply chain shown in Figure 18) require limited maintenance and no lubricants for their operation, and no particular component in its production stands out in cost or supply risk.[169] In terms of materials, some criticalities exist (with platinum group metals, especially platinum, palladium, iridium, ruthenium, and rhodium, titanium, and rare earth elements).

For electrolysers, balance of plant components are rather similar across all three types of electrolysers, including compressors, water purification systems, dryers, and electrical systems. Some components for the electrolyser stack, such as bipolar plates, GDL (gas diffusion layers), MEA (membrane electrode assembly) differ per technology. ARUP details these components in a recent study.[170]

A.9.3 Assessment per indicator

A.9.3.1 EU Demand

Hydrogen plays a comparatively small role in total emission reductions by 2030, according to IEA, however it has a vital role in sectors where emissions are hard to abate. The global demand, therefore, is expected to double from the current (2020) 94 Mt to 180 Mt by 2030[171] - half of this increase coming from new applications enabled by the decreasing costs of production. In 2021 alone more than 200 MW of electrolyser capacity entered into operation – a threefold increase on

[168] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[169] Ibid.

[170] ARUP (2022). Assessment of Electrolysers, final report

[171] IEA (2022), Global Hydrogen Review

2020 – this way the total installed capacity reaching 0.5 GW.[172] With all projects currently in the pipeline realised by 2030, the global installed capacity could reach 240 GW[173]. In 2022, hydrogen accounted for less than 2% of Europe's energy consumption[174], mainly in refining, ammonia and fertiliser production[175], almost all of it produced via the reforming of natural gas.

Based on IEA's projections, the global demand for hydrogen fuelling HFCs range between 0.7 Mt (based on the stated policies) and 8 Mt (based on announced pledges) by 2030.[176] Similar trends projected to the EU would mean a demand for HFCs between 56 kt and 640 kt in Europe. The Clean Energy Outlooks Analysis and Critical Review report (2022) reviewed a number of studies and found great variation in the 2030 European transport sector's projected hydrogen uptake – estimating it to be anywhere between 0 and 5 Mt[177].

The REPowerEU plan, proposed by the EC, aims to increase the domestic production of green hydrogen to 10 Mt by 2030 – basically meeting the current demands and therefore decarbonising the existing hydrogen industry – with an additional 10 Mt imported from outside the EU covering the expected increase in hydrogen consumption by then. This translates to a 65 GW installed electrolyser capacity (expressed in hydrogen output) within the EU by 2030[178] – a steep increase (of 98.6% CAGR) from 135 MW total capacity across the EU, EFTA and UK in 2021[179] - and 40 GW capacity installed within its neighbourhood.

While hydrogen plays a relatively small role in the energy system today, the EC has very ambitious targets particularly for domestic hydrogen production. This means that from a demand perspective, the electrolysers' risks should be deemed very high. The limited uptake of HFCs in the EU – with significant uncertainties, particularly by 2030 – however means that the HFC supply chain's strategic risks are low. Together the impact on the composite score is **medium (3)**.

A.9.3.2 EU manufacturing growth

Europe is currently a net importer of HFCs, with nearly all fuel cells imported, mostly from China.[180] In 2021, the EU companies were responsible for a 198 MW produced HFC capacity, with most manufacturers (Viessmann, Bosch, Sunfire) based in Germany[181].

Europe currently holds a very strong position in manufacturing electrolysers, with about 25% of global capacity mostly as alkaline electrolysers. However, much of this electrolyser capacity is not used for renewable/low carbon hydrogen production. Nonetheless, many companies have announced plans to extend their electrolyser production capacity in Europe to meet EU demands for green hydrogen based on the REPowerEU plan, including ThyssenKrupp Nucera, Nel Hydrogen, John Cockerill, Sunfire, Siemens, McPhy, and Topsoe.

The current electrolyser manufacturing capacities of the EU (1.75 GW/year) are insufficient to meet the EC's development goals – as it would take ~35 years for the current manufacturing capacity to bridge the gap between the already installed capacity and the EC's stated goals. The Joint Declaration, co-signed by the EC and the stakeholders of the manufacturing industry, aims to

172 All electrolyser capacity figures herein refer to hydrogen output capacity.
173 IEA (2022), Electrolysers
174 https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en
175 https://hydrogeneurope.eu/clean-hydrogen-monitor-2022/
176 IEA (2022), Global Hydrogen Review
177 EC (2022), Clean Energy Outlooks: Analysis and Critical Review
178 EC (2022), Implementing the REPowerEU Action Plan
179 JRC (EC) (2022), Water electrolysis and hydrogen in the European Union
180 EC (2023), Net Zero Industry Act
181 E4Tech (2021), The Fuel Cell Industry Review

increase the domestic manufacturing capacity tenfold by 2025.[182] Without realising this ambitious goal, the EU will remain dependent on importing a significant portion of the target capacity by 2030.

Especially the very high growth rate needed in the electrolyser production capacity to meet the stated policy goals of the EC means that manufacturing growth has a **high (4)** impact on the composite risk score of hydrogen technologies.

A.9.3.3 Competitiveness threats, market concentration and other vulnerabilities

Asia and North America appear to have a commanding market share in fuel cell production – with most HFC assemblers and system integrators headquartered outside the EU – but industrial activity in Europe led to a steady increase in production capacities and assembling activities in the EU as well[183], with a slightly increasing market share between 2017 and 2021.[184] In 2021, 65% (about 1500 MW) of the global shipments of HFCs originated from Asia, with North America occupying the second place, being responsible for 26% (about 600 MW) of the global production, and Europe a distant third with only 9% (200 MW).[185] European companies are, however, well positioned to take a significant role in the growing market for catalysts, membrane electrode assemblies, bipolar plates and gas diffusion layers. The continent is partially active in producing these components for fuel cells already, and provides about 25% of the global supply.[186] Multiple companies have plans to increase the fuel cell manufacturing capacity in Europe, including Symbio in France, planning to produce 200.000 fuel cells by 2030.[187]

Europe is a global leader in electrolysis technology, with about 20 European companies working on developing electrolysis systems. No other region currently can match the European depth and breadth in electrolysis across all technologies and components.[188] However, for the technological leadership to translate into commercial leadership, EU companies have to further increase their production capacities – as stated in the Electrolyser Joint Declaration of the Commission. Reaching the goals stated in the REPowerEU plan, achieving a 10 Mt annual domestic hydrogen production is a significant incentive in this, with the manufacturers' stated goal to reach 25 GW by 2025 already (from an estimated 2.5 GW in 2022)[189]. China is the largest global producer of hydrogen (in 2022, mostly from non-renewable sources still), and the third largest market for HFCs globally[190] with 95% of the HFC buses being used there[191]. While electrolysers are large devices that are not commonly traded internationally, China alone is responsible for 70% of the global shipments of electrolysers (40% being also locally produced[192]), with the EU and the US lagging significantly behind, having a 15% market share each.

182 EC (2022), European Electrolyser Summit Joint Declaration
183 EC (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
184 E4Tech (2021), The Fuel Cell Industry Review
185 E4Tech (2021), The Fuel Cell Industry Review
186 Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
187 IEA (2023), Energy Technology Perspectives 2023
188 EC (2019), Value Added of the Hydrogen and Fuel Cell Sector in Europe
189 EC (2022), European Electrolyser Summit Joint Declaration
190 CSIS (2022), China's Hydrogen Industrial Strategy. Available at: https://www.csis.org/analysis/chinas-hydrogen-industrial-strategy#:~:text=Analysis,-Vision&text=China%20is%20the%20largest%20producer,in%20refineries%20or%20chemical%20facilities.
191 IRENA (202), Hydrogen https://www.irena.org/Energy-Transition/Technology/Hydrogen
192 IEA (2022), Energy Technology Perspectives

Three quarters of the electrolyser production is currently made up by the alkaline type, the rest is by PEM electrolysers. Particularly the components for alkaline electrolysers – the most mature technological option - can be sourced within Europe[193], using the fewest critical materials (apart from nickel). Europe has a relatively strong position in terms of supplying components – such as bipolar plates, catalysts, gas diffusion layers and membranes, providing around 25% of global supply, behind North America (44%), followed by Asia (31%)[194].

Other risk worth mentioning is several of the raw materials required by both electrolysers and HFCs show significant price volatility[195]. This in turn raises the risks for investing in manufacturing capacity extensions and is eventually reflected in the price of the end product.

The high market share of China in the overall production of electrolysers and HFCs has a high impact on the strategic status of these technologies. These risks are moderated by the fact that the most mature electrolyser technology, the alkaline type, can be produced with limited dependence on non-EU sources (excluding raw materials, such as nickel from Indonesia[196]). Overall, these competitiveness and market concentration aspects have a **high (4)** impact on the strategic status of electrolysers and HFCs.

A.9.4 Overall assessment

With an overall score of 11, electrolysers and fuel cells are found to be a **strategic** technology.

193 JRC (EC) (2022), Water electrolysis and hydrogen in the European Union

194 Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

195 SIA (2022), Electrolyser materials: overall assessment of supply chain sustainability and vulnerabilities

196 IEA (2023), Energy Technology Perspectives

A.10 Annex 10: Sustainable Biogas and Biomethane Technologies

A.10.1 Introduction

Biomass can be transformed into fuel, heat and/or power through various technologies shortly described in the table below, showing the variety of routes & feedstock options:

Table 4: Bio-based energy technologies. Source: author, based on CETO (2022)[197]

Technology	Feedstock[198]	Fuel (output)	Maturity (TRL)	Capacity /production in EU (2020)
Combustion	Solid, gaseous & liquid (incl. waste)	Heat, Power or Combined Heat and Power (CHP)	TRL 8-9	Prod. 919 TWh[199]
Pyrolysis	Solid & liquid (incl. waste)	Pyrolysis oil	TRL 3-5	Pilots
Gasification[200]	Solid (incl. waste)	CO, H_2 for (on-site) H, P or CHP	TRL 6-7	Pilots
Anaerobic digestion (Fermentation)	Biodegradable biomass (incl. waste)[201]	Biogas (for CHP) or biomethane	TRL 8-9	Cap. 11.7 GWe
Pelletisation (Torrefaction)	Wood & mills by-products	Domestic & industrial pellets	TRL 9	Prod. 18.1 Mt

Some main concerns with bioenergy relate to feedstock and land competition (bioeconomy), availability and affordability, impact on biodiversity and land use, unmature supply chains, potential air pollution (for combustion). These concerns apply in practice to all technology routes, depending on the feedstock.

This annex refers to technologies used for anaerobic digestion to create biogas, possibly further refined to biomethane.

A.10.2 Supply chain overview

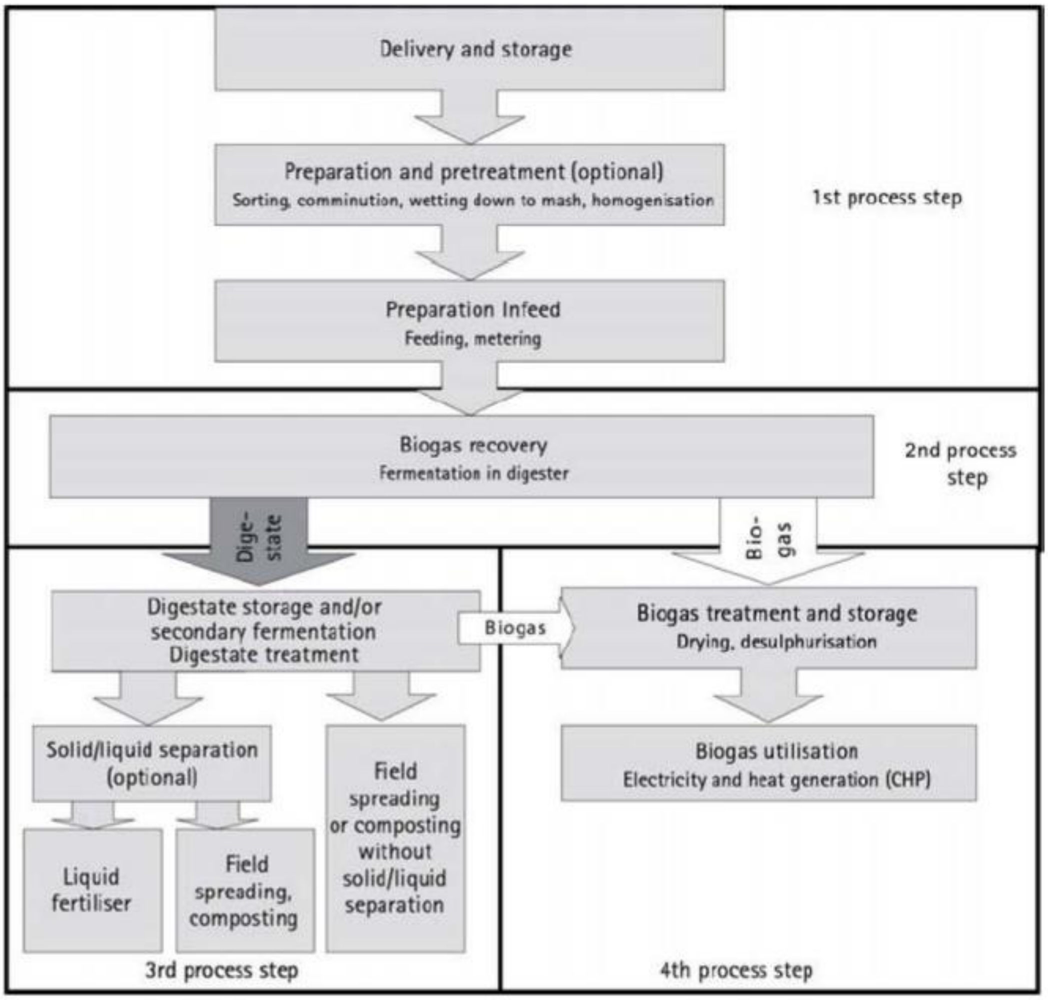
Anaerobic digestion (AD) processes feedstock with microorganisms under anaerobic conditions to produce biogas, a mixture of methane, carbon dioxide and some minor contaminants, breaking down biodegradable material in the absence of oxygen. The AD process can be divided into four

[197] CETO (2022), Bioenergy in the European Union
[198] Only illustrative
[199] 79 Mtoe, CETO (2022), Bioenergy in the European Union
[200] https://www.eubia.org/cms/wiki-biomass/pyrolysis-and-gasification/gasification/
[201] Biogas plants are agriculture-based (agricultural residues and energy crops), industrial (food and beverage industry waste, organic municipal solid waste, and sewage sludge), and landfill gas, using as feedstocks (substrate) e.g. wet biomass and organic waste, such as agricultural, municipal and industrial organic residues and wastes, sewage sludge, animal fats and slaughtering residues, sewage sludge from wastewater treatment and also aqueous biomass (micro and macro algae).

stages. Biologically speaking they are consecutive stages, but they usually take place simultaneously inside the digester: Hydrolysis; Acidogenesis; Acetogenesis; Methanogenesis.[202]

Biogas is used to produce electricity and/or heat (via gas engines, Stirling engines, gas turbines, or micro turbines), or could be upgraded to biomethane (bio-natural gas) by removing CO_2 and contaminants to be used as transport fuel or injected into the natural gas grid. There are two main anaerobic digestion processes, depending on temperature: thermophilic digestion (at 50-60 °C) and mesophilic (at 25-40 °C), the first requiring lower digester volume (lower retention time) and better removing pathogen and virus, but entailing more expensive technology and higher energy consumption. The anaerobic digestion process may operate as a wet or a dry process, depending on the water content and the physical characteristics of the feedstocks fed into the digester. The quantity and chemical parameters of the feedstock determine the amount of biogas produced. The general configuration is depicted in the following figure and is usually similar in each biogas plant. The treatment of the digestate and the use or application of the biogas produced are about the main differences between plants.

Figure 19: Usual process step of biogas plants, (c) Paterson, 2012



Source: European Biogas Association (EBA), 2021[203]

[202] DiBiCoo (2020), Categorisation of European Biogas Technologies

[203] DiBiCoo (2020), Categorisation of European Biogas Technologies

A.10.3 Assessment per indicator

A.10.3.1 EU demand

The REPowerEU plan aims to substantially increase the production of biomethane, while the NZIA acknowledges that, to achieve the 2030 objectives, a focus is needed on sustainable biogas and biomethane.[204] There is no mention for other bio-based technologies. At the same time, net-zero technology products will also yield benefits to other strategically important economic sectors, such as farming and food production, contributing sustainably to EU food security and to providing an increasing outlet for bio-based alternatives through circular economy.

For over 2 decades ago, Europe has been by far the main market of biogas worldwide[205], with a share of more than 2/3 of worldwide biogas production, representing in 2020 a share of 3.7% of natural gas. The EU market stagnated over the last years[206], with biogas and biomethane production amounting to ~18 billion Nm3 in 2020[207], among which only 3 billion Nm3 is of biomethane.[208] The required specific target for biomethane production set by REPowerEU is at 35 billion Nm3 by 2030 (or about 30 Mtoe), meaning almost doubling the production of biogas in 9 years[209], and reaching about 10% of usual natural gas demand.[210] For biogas in total, there is a projected gross inland demand of 30.4 Mtoe by 2030. This value remains far smaller than the heating contribution of heat pumps in 2030, while remaining significant for high-temperature uses where heat pumps are (for now) less suitable.

Given the smaller role of biogas versus other more prominent technologies in final energy consumption in 2030, we arrive at a **medium** rating for this technology for demand.

A.10.3.2 EU manufacture

Given its leading position in biogas deployment[211], the European industry has built a strong expertise and good position in all components of the supply chain, including digestors, treatment of biogas and digestate, or automation systems.

The Global Markets Insights estimates the market size in 2018 around 3b EUR with Anaerobic Digestion accounting for over 70% of the market revenue[212], and forecasts the European biogas market to exhibit a CAGR[213] of 10.4% by 2025 (and 7% worldwide[214]). The availability of feedstock, in addition to supportive policies to decarbonise the gas sector are the key drivers to steer biogas deployment.

[204] Although it should be noted that Art 3 of NZI (definition of net-zero technologies) does not comprise bio-based technologies.
[205] Renewable Energy (2018), Biogas: Developments and perspectives in Europe
[206] SWD (2023) 68: Investment needs assessment and funding availabilities to strengthen EU's Net-Zero technology manufacturing capacity
[207] Or equivalent 9.5Mtoe, assuming a heating value of 22 MJ/m3
[208] CETO (2022), Bioenergy in the European Union
[209] EBA (2021), EBA Statistical Report. Available at: https://www.europeanbiogas.eu/new-report-highlights-biomethane-ramp-up-and-best-pathways-for-full-renewable-gas-deployment/
[210] Eurostat (n.d), Natural gas supply statistics. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_supply_statistics
[211] Renewable Energy (2018), Biogas: Developments and perspectives in Europe https://www.sciencedirect.com/science/article/pii/S096014811830301X?via=ihub
[212] GMI (2019), Europe Biogas Market. Available at: https://www.gminsights.com/industry-analysis/europe-biogas-market
[213] Compound Annual Growth Rate, https://www.investopedia.com/terms/c/cagr.asp
[214] GMI (2019), Biogas Market. Available at: https://www.gminsights.com/industry-analysis/biogas-market

The EU is the main manufacturer of biogas equipment, and past growth rate (mainly the decade of 2005-2015) has demonstrated the adequation of EU manufacturing capabilities to deployment needs and future targets. One challenge will be refinement from biogas to biomethane, where the EU industry is leading.

Thus, despite little vulnerability for biogas in terms of EU manufacturing growth needs, some vulnerability exists for biomethane which yields a **medium rating for EU manufacturing growth needs** altogether.

A.10.3.3 Competitiveness threats, market concentration, and other vulnerabilities

The EU biogas/methane sector produces 2/3 of global biogas production followed by the US (mainly landfill recovery) and China (mainly household digesters in rural areas). The continent's producers are ready to meet the 35 bcm goal by 2030, which will require an investment of 70-80 billion euros. Globally competitive EU manufacturers are leading and ready to deploy markets in developing and emerging countries for the import of sustainable biogas/biomethane technologies.[215] The EBA lists more than 30 manufacturing and suppliers of plant components (e.g. fermenters, enzymes, CHP, equipment, control and instrumentation systems, insulation, covers and foils, separation systems like membrane or scrubbing, gas cleaning, hygiene systems, waste treatment, pumps, etc.).[216] Some key market participants (mainly from Germany) include AB Energy; Approvis Energy Systems; Agraferm Technologies AG; Biogest; BTA International GmbH; EnviTec Biogas; Kemira; Viesmann Group; Weltec Biopower; Planet Biogas Global GmbH; Strabag; DSM; BDI-Bioenergy International GmbH; Scandinavian Biogas Fuels International AB; Gasunie; Xergi. These EU companies are extensively engaged in research & development to gain competitive edge.

Building on the strong technology basis from the chemical industry, various European companies (like Air Liquide, Evonik, Pentair or Gruppo AB) provide technologies for biogas to biomethane upgrading, which will more than likely become a trend in the coming years (to replace natural gas or be used as fuel in transport).

The biogas/biomethane market has developed significantly across Europe, and the major components manufacturers are also Europe-based. Hence the EU industry has strong capabilities in producing and operating biogas plants but also upgrading them to biomethane equipment. Investments in increasing production capacity is currently not seen as an issue, with EU manufacturing as global leader. Outside of the EU, in comparison to other clean energy technologies, little market concentration exists for components and devices for biogas/biomethane production. This state of the market is expected to continue until 2030.

According to the Biomethane Industry Partnership (BIP[217]), biomethane can be scaled up based on existing, mature technology.[218] Research, development and innovation will support a better commercialisation, towards more cost-effective technologies. The agenda of the BIP, through its Task Force 5[219], aims at identifying the current status of RD&I in biomethane production, grid connection and end-use applications, which will probably identify new areas of technological improvement.

[215] DiBiCoo (2020), Categorisation of European Biogas Technologies

[216] EBA (2018), Companies catalogue.

[217] https://commission.europa.eu/news/european-commission-and-industry-leaders-launch-biomethane-industrial-partnership-2022-09-28_en

[218] https://bip-europe.eu/

[219] BIP Europe (2022), BIP Work Programme.

The biogas and biomethane industry do not face technology gaps, but rather challenges like the mobilisation of sustainable feedstocks, the delivery of permitting, the ability to inject biomethane in gas grid, possible support schemes (due to low economic viability) and the valorisation of green biogenic fertiliser. Multi-stakeholder dialogue will be needed to ensure the smooth valorisation of waste streams (food waste, wastewater, agricultural residues) into biogas/biomethane without replacing food production or impacting land use. Such dialogue should engage local authorities, agriculture, academia and research, civil society, manufacturing industry, gas and energy sectors.

Overall, these competitiveness vulnerabilities receive a **very low** rating in comparison to other clean energy technologies.

A.10.4 Overall assessment

With an overall score of 7, biogas/biomethane technology is found to be **of low strategic concern**.

A.11 Annex 11: Carbon Capture Utilisation and/or Storage (CCUS)

A.11.1 Introduction

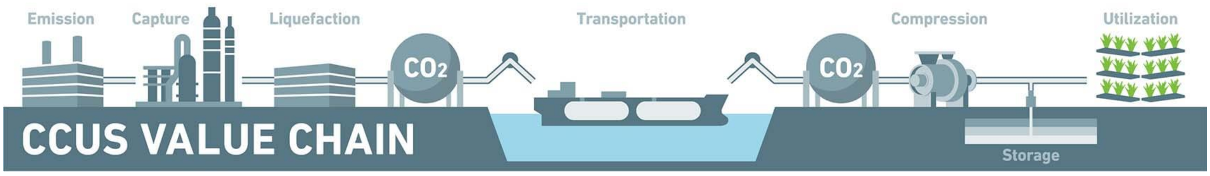
The technologies used to capture, use or permanently store carbon dioxide (CO_2) are collectively known as carbon capture, utilisation and storage, or CCUS. The CO_2 captured is compressed and transported by ship or pipeline (other forms of transport such as by trucks and barracks are also possible but not as common) to a geological formation deep below ground for permanent storage. Alternatively, CO_2 can be used to make products, such as building materials or consumer goods. The CCUS value chain is shown in Figure 20.

Other applications of CCS include the production of low-carbon hydrogen, Direct Air Carbon Capture (DACCS) as well as its application to capture emissions from bio-energy combustion plants (BECCS). The latter two are considered negative emissions technologies.

CCUS technologies are primarily appealing for use in industrial sectors where decarbonisation via electrification and renewables, hydrogen, or other clean technologies proves highly difficult. This is especially the case with heavy industries that use high temperatures in their processes, e.g. cement production.

Many of the pathways for converting CO_2 are currently in early development stage, TRL 8 and below, and are thus out of scope from this analysis. Furthermore, given that the focus of the Net Zero Industry Act (NZIA) is on CCS, given its potential for contributing to GHG emission abatement (as compared to CCU, which has a much lower abatement potential), this will also be the main focus of this analysis. Some discussion in the competitiveness aspects will however refer to CCUS in general.

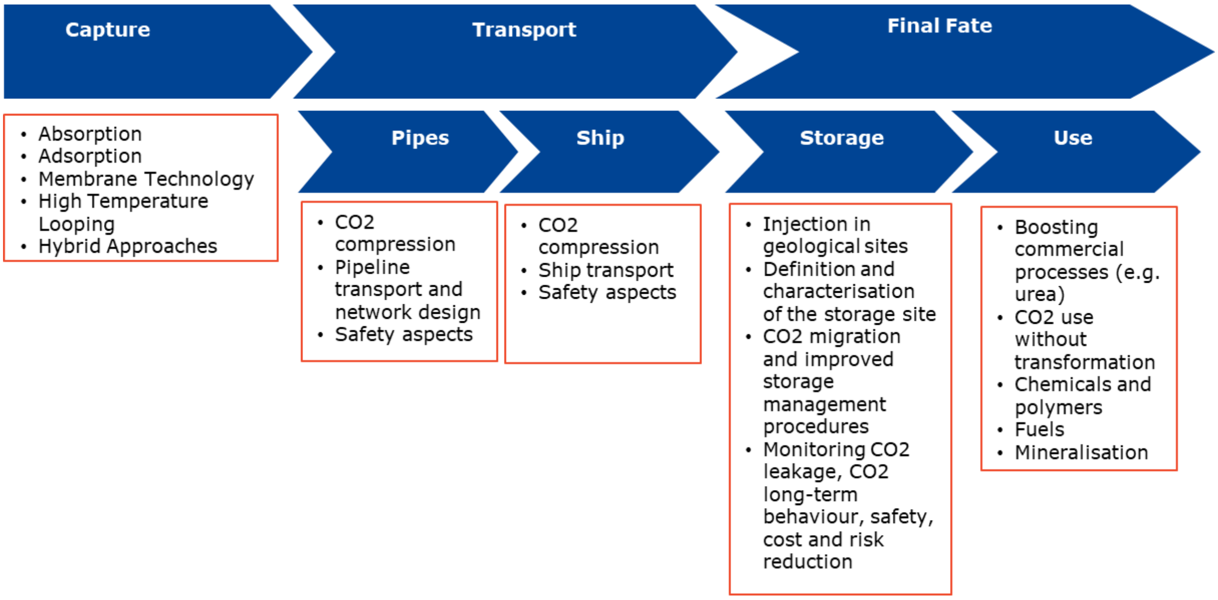
Figure 20: CCUS value chain[220]



[220] Source: Energy Transition (2022), What is needed from CO_2 transport, an essential element of the CCUS value chain? Available at: https://solutions.mhi.com/blog/what-is-needed-from-co2-transport-an-essential-element-of-the-ccus-value-chain/

A.11.2 Supply chain overview

Figure 21: Overview of CCUS supply chain[221]



An overview of the CCUS supply chain is shown in Figure 21. As mentioned in the introduction, CCUS encompasses a large variety of different technologies. On the capture side, there exist different technologies based on absorption, adsorption, membranes, and hybrid approaches. The choice of the technology depends on a variety of factors, one of the main ones being the source of CO_2 emissions and the CO_2 concentration (point source versus diluted; pure versus impure). Point-source capture refers to the case where a large emission source, like an industrial facility, is equipped with a technology to capture and divert the CO_2 to storage, preventing it from being emitted. On the other hand, Direct Air Capture (DAC) is used to capture CO_2 from the air, with two main technological approaches available: solid and liquid DAC.[222] Solid DAC relies on solid adsorbents operating at ambient to low pressure (i.e. under a vacuum) and medium temperature (80-120 °C). Liquid DAC is based on an aqueous basic solution (such as potassium hydroxide), which releases the captured CO_2 through a series of units operating at high temperature (between 300 °C and 900 °C). There are 18 DAC plants in operation worldwide, including in the UK and in Norway. All of these plants are small scale, and the large majority of them capture CO_2 for utilisation with only two plants storing the captured CO_2 in geological formations for removal.[223]

For the transport portion of the value chain, also several options are possible. Currently, the most common ones are via pipes or by ship, but other options are also possible. Finally, if the CO_2 is to be used, there are many different reactions to convert the CO_2 into a range of different products. Some of the key products can be grouped into the following categories: chemicals and polymers, fuels, mineralisation, direct CO_2 use or boosting existing processes.

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[221] Own elaboration based on JRC (2022) Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en

[222] https://www.iea.org/reports/direct-air-capture

[223] https://www.iea.org/reports/direct-air-capture

A.11.3 Assessment per indicator

A.11.3.1 EU demand

Currently, nearly 3 million tonnes (Mt) of CO_2 per year are captured and stored in Europe, specifically in Norway, in the Sleipner and Snohvit projects.[224] However, based on NZIA, a Union-level objective to achieve 50 Mt of annual injection capacity in CO_2 storage has been proposed.[225] Expert stakeholders estimate a demand for annual storage services in the European Economic Area (EEA) to grow to 80 Mt of CO_2 in 2030 and to reach at least 300 Mt of CO_2 in 2040.

In the longer term, all credible scenario modelling shows that CCS will be needed to meet the goals set out in the Paris Agreement. Based on the EU's long-term strategic vision described in the "Clean Planet for All" communication[226], the 1.5 °C compliant scenarios (1.5 LIFE and 1.5 TECH) depend on the deployment of CCS to achieve climate neutrality and foresee an important role for CCU. In these scenarios CCUS technologies are forecasted to remove between 281 and 606 Mt of CO_2 in 2050.[227]

In particular, CCUS represents one of the only options available to decarbonise sectors such as cement production. Compared to the current capacity, the 50 Mt/yr CO_2 injection capacity target by 2030 can be considered relatively high. Thus, the EU demand for this technology is given a **score of high (4)**.

A.11.3.2 EU manufacturing growth

If the goal under the NZIA of 50 Mt/yr of CO_2 injection capacity by 2030 is to be achieved, at least 47 Mt of additional capacity will need to be realised in the next six years. Including this year, this leads to a CAGR of 49% for EU demand. Given that the projected injection capacity of CO_2 by 2030 is more than 16 times greater than the current one, and much of the installed capacity will come from EU manufactured devices, the need for EU manufacturing growth is assessed as **very high (5)**.

A.11.3.3 Competitiveness threats, market concentration and other vulnerabilities

The **EU can be considered a leader when it comes to developing CCUS in industry**.[228] While the focus in the mid-2000s was on CCUS applied to utilities, this has slowly been changing in the direction of industry. In the cement sector, HidelbergCement is one of the key companies active on CCUS. Companies such as AirLiquide, BASF, Borealis, ExxonMobile and TOTAL have been involved in developing CCUS in the area of chemicals and oil and gas. ArcelorMittal is involved in several CCUS projects for the steel industry (Dunkirk and Ghent steel plants). Tata Steel is another company, considering CCUS to decarbonise its steel production. In contrast, in North America, CCUS projects

[224] JRC (2022), Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en

[225] EC (2023) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act). COM (2023) 161 final.

[226] COM (2018) 773 – A clean planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy

[227] CCUS Projects Network (2021), CCUS in Europe at the verge of a real breakthrough. Available at: https://ccuszen.eu/sites/default/files/HLR2021_CCUS-in-Europe-at-the-verge-of-a-real-break-trough.pdf

[228] JRC (2022), Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en

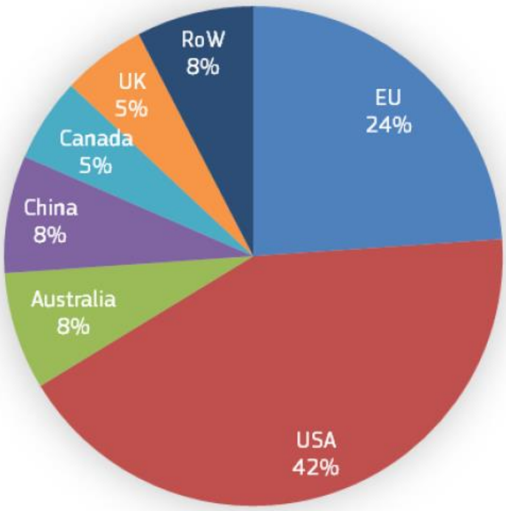
are more focused on sectors such as ethanol production, natural gas processing and power generation.[229]

The Global CCS Institute has assembled a technology compendium of commercially available CCS technologies worldwide.[230] Out of the 16 companies listed as major CO_2 capture technology providers, five are EU companies (AirLiquide (FR), Axens (FR), Leilac Group (CALIX) (EU), Saipem (IT), Shell (NL)). On CO_2 transport, 5 companies were identified out of which 2 in the EU (MAN Energy Solutions and Svanehøj). On CO_2 storage, none of the companies listed are in the EU. On the full value chain, 2 companies (Linde (DE) and Schlumberger (FR)) are EU companies. The **EU is relatively well positioned on CO_2 capture technologies. However, with regards to transport, storage and full value chain the EU is behind the USA and Canada.**[231] In fact, the NZIA recognises the need to create incentives for storage capacity in Europe as a way to boost the CCUS supply chains by proposing the target of 50 Mt CO_2 injection capacity/yr by 2030.

Research by the Joint Research Center (JRC)[232] shows that, out of the 186 companies identified as having worldwide CCUS related activity, 45 (24%) are European or are active in the field through their European subsidiaries. The USA is leading the way, as 42% of the key companies identified are American or based in the USA, as can be seen in Figure 22.

Globally, the US (26%) and Canada (20%) are leading the way in CCUS investments, with Japan in third place with 14% of the global share of investments and the EU with a share of 11%.[233]

Figure 22: Key companies identified with activity in CCUS by country[234]



[229] JRC (2022), Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en.

[230] GCCSI (2022), State of the Art: CCS Technologies 2022. Available at: https://www.globalccsinstitute.com/wp-content/uploads/2022/05/State-of-the-Art-CCS-Technologies-2022.pdf

[231] JRC (2022), Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en

[232] JRC (2022), Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en

[233] Ibid.

[234] JRC (2022), Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en

Among EU Member States, France has the highest share of public investments in CCUS research and development. Next come Germany (24%) and the Netherlands (11%), closely followed by Poland (10%). Within the EU, Germany, France, the Netherlands, Italy and Spain are the top 5 countries in private R&D investment in CCUS.[235]

Although the USA's share of CCUS companies is almost double that of the EU, there are still several players with substantial shares and the EU is in second place regarding the presence of key companies involved in CCUS. Furthermore, within the EU several Member States have public and/or private investments in CCUS technologies.

Given that CCUS technologies are not yet widely deployed (even though the technologies are commercially mature) there is still a need for thorough supply chain identification and mapping. The lack of more granular information on the supply chain constitutes a potential vulnerability although this vulnerability is not particular to the EU.

Based on the above considerations the overall score for is assigned in this category is **medium (3).**

A.11.4 Overall assessment

With an overall score of **12 points,** the CCUS value chain is considered **strategic**.

[235] JRC (2022), Carbon Capture Utilisation and Storage in the European Union. Available at: https://setis.ec.europa.eu/carbon-capture-utilisation-and-storage-european-union_en

A.12 Annex 12: Grid Technologies

A.12.1 Introduction

In this annex, we discuss both traditional grid infrastructure and smart grid infrastructure.

Traditional grid infrastructure are the classic and more mature devices and networks used to transfer electricity from producers to consumers. Generally speaking, these grids are divided into low- (under 1 kV) and medium-voltage (under 36 kV; MV) distribution grids and lines and high- (under 150 kV; HV) and extra-high voltage (over 150 kV; EHV) transmission systems. Both distribution and transmission grids often use alternating current (AC), but both can also use direct current (DC) depending on needs, existing infrastructure, and efficiencies for each current type in each situation. Technologies on these grids include cables, conductors, and converters, but also some digital infrastructure such as supervisory control and data acquisition (SCADA) systems. As of 2020, the EU electricity network transported 22% of final energy consumed. This share is expected to grow quickly in the coming years as industry and transportation end uses for energy are rapidly electrified.[236]

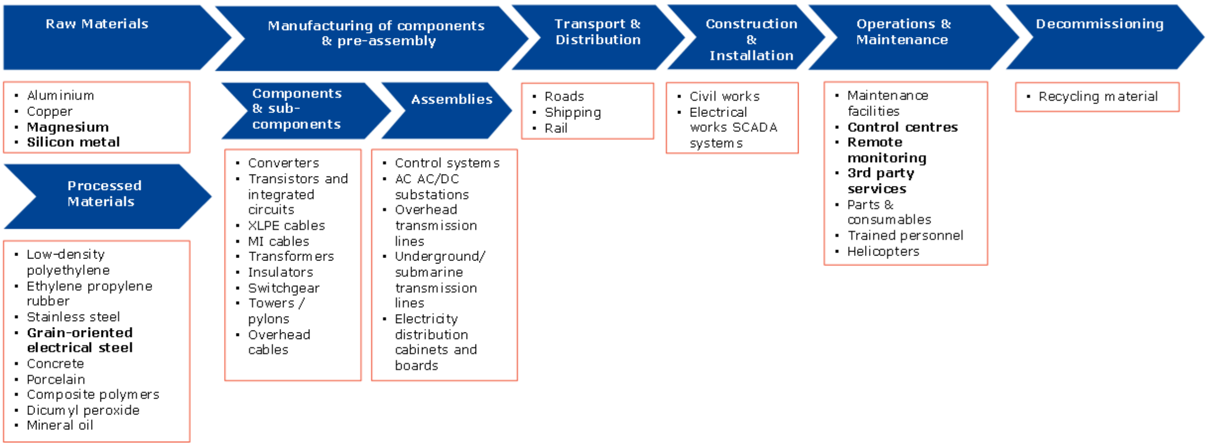
Smart grid infrastructure are those newer devices and software that can facilitate better integration of renewable energy sources, allow for better cooperation of various actors, and improve grid resilience and security of supply. This is formalised within the EU's action plan on digitalizing the energy system, which also presents measures to overcome potential challenges for digitalisation.[237] In the context of this report, we focus on the most important smart grid technologies, including infrastructure for advanced metering (AMI), smart EV charging, and home energy management systems (HEMS).

[236] European Commission expert group on electricity interconnection targets (2020) Fourth report - Contribution of the Electricity Sector to Smart Sector Integration

[237] COM (2022)552 final, Digitalising the energy system – EU action plan.

A.12.2 Supply chain overview

Figure 23: Overview of traditional grid infrastructure supply chain

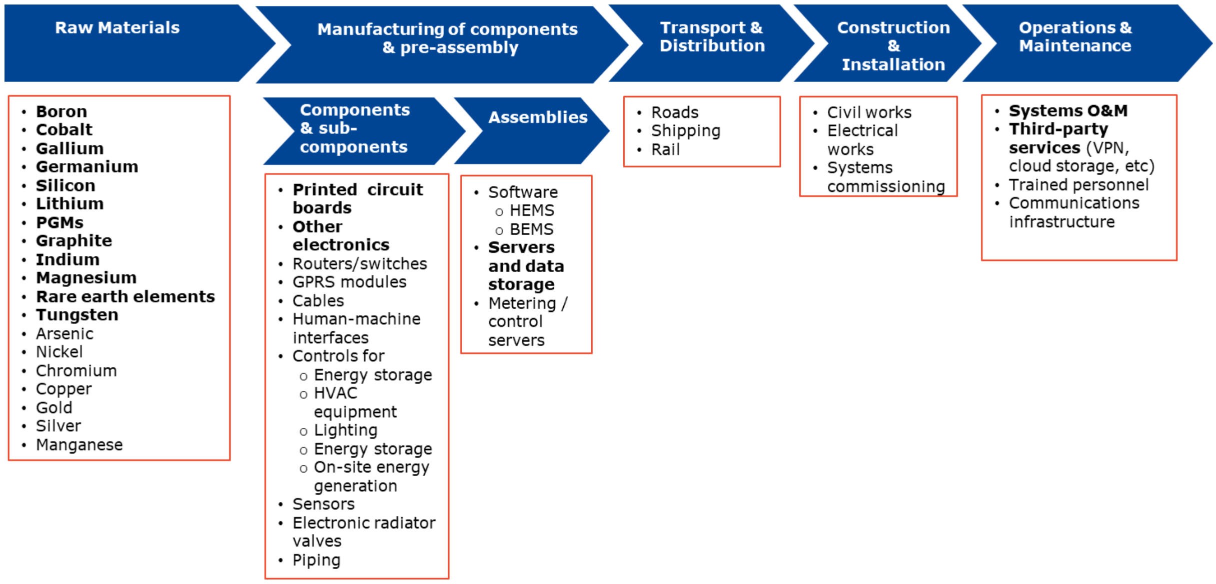


Note: vulnerable elements found higlighted in **bold**
Source: Trinomics (2021)[238]

Focusing first on traditional grid infrastructure, the supply chain in the EU is mature and well-developed (see Figure 23). The EU has high capabilities in all aspects of the supply chain, excluding some raw and processed materials.[239] Particularly at the component manufacturing and device assembly stages, few particular vulnerabilities or dependencies were observed, which are discussed later in the Competitiveness assessment below.

[238] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
[239] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

Figure 24: Overview of supply chain for home energy management systems



Source: Trinomics (2021)[240]

For smart grid infrastructure, we focus on the supply chains for AMI, smart EV charging, and HEMS:

1) For AMI, this technology refers to the metering devices for measuring end-user energy use, along with the communications and database infrastructure to monitor and account for this energy use.
2) For smart EV charging, these refer to the power electronics and switches used for charging, along with communications and control infrastructure used for planning and automating charging at specific times.
3) HEMS (see Figure 24), which consists of building-based automation and control systems, comprises the software and hardware infrastructure needed for digitalising home energy use. In terms of hardware, these systems relate to a wide array of different devices, tailored for each building and use case based on its needs.

There are quite a few common hardware components across these technologies. These commonalities include general electronics (electronic boards, semi-conductors, micro-processors, human-machine interfaces), power electronics (routers, switches, power cables), control and communications components (GPRS modules, programmable logic controllers (PLCs) and other specific control systems, sensors), and piping.

It is important to note that the market for grid technologies, especially smart grid infrastructure, is highly dynamic and fluid. Market segments do not have clear boundaries and companies often develop products that apply to multiple segments, or move from production in one market to production for another market. This is especially the case given the similarity in the components and software needed for these devices, and the similarity of their end-uses. While we attempt to separate these technologies and their associated markets here, we emphasise that these devices and markets should be thought of as a larger whole rather than three separate markets (as might be the case e.g. with solar PV and wind turbines).[241]

[240] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[241] More discussion on this subject can be found in EC (2020) SWD 953: Clean Energy Transition – Technologies and Innovations.

A.12.3 Assessment per indicator

A.12.3.1 EU demand

For traditional grid infrastructure, the ENTSO-E TYNDP for 2022 presents 135 billion euros of investments in 42,800 km of transmission grid expansions within the next years.[242] For HVDC cables, in particular, European demand has grown and will continue to grow greatly in the coming years, especially for use in underground and subsea applications. IEA's projections are that total installed HVDC lines in Europe, at 10,000 km as of 2022, will be at about 38,000 km in 2030 (i.e. 18% CAGR).[243] While a significant expansion of network capacity, these values are small in comparison to the current high-voltage network in Europe, rated at about 394,000 km, based on the latest ENTSO-E inventory.[244]

Smart grid infrastructure is less mature than traditional infrastructure, and has less precise demand projections. While AMI is common or rapidly expanding across European countries, smart charging and HEMS are further behind. Globally and within specific countries, these technologies are projected to have CAGRs of above 10% in the next few years, with some as high as 30%.[245] The EU's action plan on digitalising the grid outlines measures to boost this expansion in the coming years.[246]

Combining the EU demand for all grid technology together, the criticality of demand in this category is particularly driven by rapid growth of smart grid infrastructure. In addition, the exceptional role of grid infrastructure (both traditional and smart) in facilitating the electrification and decarbonisation of many sectors, and becoming a replacement for many (fossil-based) energy carriers, results in higher criticality of EU demand. Overall, this technology receives a **high** rating in terms of EU demand.

A.12.3.2 EU manufacturing growth

For traditional grid infrastructure, the EU has historically had an excellent manufacturing base. For cables, in 2016, Europe had annual manufacturing capacity of around 11,300 km for HV cables.[247] The EU produces above necessary need for internal use for many components in this supply chain, and is in most cases a net exporter by value (discussed further in next subsection). Production capabilities for EU manufacturing of smart grid technologies have proven difficult to find. Nonetheless, it is expected that the EU has maintained its leading position in developing most hardware and software components for smart grid technologies, as well as digital technologies used in the traditional grid.[248] These components include PLCs, power electronics, embedded electronics, and sensors, where the EU produced roughly one-fifth of global production in 2020.[249] The EU does, however, remain dependent on imports for some components, discussed further in the next subsection.

[242] ENTSO-E TYNDP (2022), https://tyndp2022-project-platform.azurewebsites.net/projectsheets. Note that some projects in the TYNDP are planned to come online after 2030.
[243] IEA (2023), Energy technology perspectives.
[244] 2018 and 2021 Data from ENTSO-E: https://www.entsoe.eu/data/power-stats/
[245] COM (2022) 643 final, Progress on competitiveness of clean energy technologies
[246] COM (2022) 552 final, Digitalising the energy system – EU action plan.
[247] ENTSO-E and Europacable (2018), Forecast demand and manufacturing capacity for HVAC and HVDC underground and submarine cables.
[248] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
[249] EC (2020), Study on the electronics ecosystem

Overall, there remains a need to rapidly expand EU manufacturing in the coming years for both traditional and smart grid technology to meet the needed demand in the EU. Nonetheless, the growth in this technology is a smaller challenge compared to other technologies, granting it a **medium** rating in this indicator.

A.12.3.3 Competitiveness threats, market concentration and other vulnerabilities

For traditional grid infrastructure, the EU has historically had a globally competitive position. In 2018, the EU was a net exporter (by value) of many components and devices used in transmission and distribution grids, including converters, insulators, and high-voltage circuit breakers and switches.[250] Based on the latest EU-level production, export, and import data (from 2021), the EU remains a strong producer and exporter.[251] However, demand may be above supply for some components and devices for traditional grid infrastructure in the coming years, in case manufacturing capacity growth cannot keep up with demand growth. The EU also currently depends on external sources for a few key components, e.g. for multi-terminal HVDC systems used in offshore grids, for which it depends on Chinese manufacturers[252], and for large transformers (over 500kVA) for which it has been a net importer for years.[253]

Generally, traditional grid infrastructure is characterised by some degree of market concentration. Infrastructure rated at higher capacities are generally more concentrated, with the supply of many components forming highly concentrated markets. For power transformers, for example, 8 manufacturers represent about 40% of the global market[254], while for cables, only 3 manufacturers represented over 50% of the European Economic Area's production.[255] The market for low-voltage grid components is more fragmented. However, the EU is a net exporter of many relevant components; for the remainder, imports are usually a small fraction of EU demand (and thus internal production is high).[256] Overall, market concentration is perceived as a minor strategic risk for traditional grid infrastructure for the EU.

Smart grid technologies contain both components of traditional infrastructure and modern electronic components, including those listed in Section 1.2. In the following text, we focus on the latter, as the former is mostly described within traditional grid infrastructure. The EU has a globally competitive position for many of these components, but maintains its import dependency for some critical components, including semiconductors, microprocessors, electronic boards, and servers.

Many companies have smart grid infrastructure production capacity in Europe, such as Itron, Siemens AG, and General Electric (for AMI), ABB and Schneider Electric (for smart charging). For HEMS, traditional companies highly active in Europe (including Honeywell Technologies, Siemens, and Schneider Electric) are meeting new entrants such as Tesla, Tribe, and Kiwigrid.[257] Thus, the market was previously highly concentrated among incumbent service providers, and new entrants

[250] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[251] See Dataset ds-056120 at Eurostat: https://ec.europa.eu/eurostat/web/prodcom/database

[252] DG ENER (2020) Workshop: Horizon 2050 power system and the role of HVDC technologies in a highly decentralised RES generation

[253] See Dataset ds-056120 at Eurostat: https://ec.europa.eu/eurostat/web/prodcom/database

[254] IEA (2023), Energy technology perspectives.

[255] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[256] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

[257] For a more complete list and sources, see CETO (2022), Smart grids in the European Union

in the building automation and control area are now lowering the level of concentration. Nonetheless, US suppliers hold the largest share of the market for these devices.

The market for smart grid technologies is less mature than traditional grid infrastructure, with highly dynamic and changing characteristics. Therefore, markets for these technologies do not exhibit a clear concentration, except in the production of semiconductors in East Asia. The various companies active in this area vary greatly in geography as well.

Smart grid infrastructure (and to a lesser extent traditional grid infrastructure) has two other vulnerabilities that dramatically increase its strategic status:

1) Very high dependence on semi-conductors. Given the highly-concentrated and highly-strategic nature of the semiconductor industry, the dependence of these devices on semi-conductor production in other regions has been a significant concern, highlighted by the recent semi-conductor shortage of the late 2010s to early 2020s. The topic of semiconductor market concentration and vulnerabilities is discussed in more detail in the recent JRC (2023) report.[258]
2) Software requirements and regulations. The functionality and thus growth of smart grid infrastructure depends on the software used in its operation. In addition to regulatory concerns (such as the GDPR regulation), cyber-resilience and security concerns also create vulnerabilities for the deployment of smart grid infrastructure. Some of these requirements have been recently codified within the most recent revision to the Network Code for cybersecurity aspects of cross-border electricity flows.[259]
3) Nascent technology with little standardisation. Although smart grid technologies are maturing quickly, they nonetheless do not present mature supply chains for which vulnerabilities can be clearly identified. Standards are quickly forming for all smart grid technologies, yet the existing lack of standardisation across the various devices can present difficulties in predicting the vulnerability of this supply chain. This presents an additional hidden risk with these technologies.

Given the critical dependencies of some smart grid technologies, this indicator receives a **high** rating.

A.12.4 Overall assessment

With a total score of **10** across all indicators, grid technologies are considered to be **strategic**.

[258] JRC (2023), Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study.

[259] https://acer.europa.eu/news-and-events/news/acer-submits-european-commission-revised-network-code-electricity-cybersecurity

A.13 Annex 13: Hydropower & Pumped Hydro Storage

A.13.1 Introduction

The principle behind hydropower technologies is utilizing the water's potential and/or kinetic energy by turning it into mechanical power via turbines and other devices and thus generating electricity. Since this procedure can be done entirely fuel-free, hydropower is a clean source of energy. This hydropower practically manifests in the energy system in four ways; storage power plants (SPP), run-of-river power plants (ROR), pumped hydro storage (PHS), and hidden hydropower (i.e. in water infrastructure/distribution systems).

The principle of pumped hydro storage (PHS) is to store electricity in the form of the potential energy of water via using the electricity surplus of low demand hours to powering a pump elevating water to a reservoir in a physical high point of the system, and releasing it back to a lower reservoir in peak demand hours.

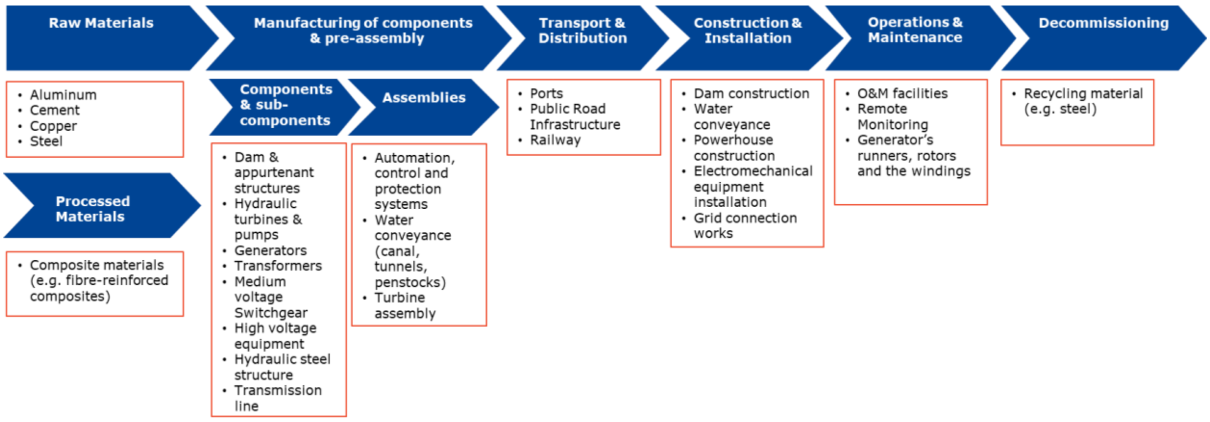
Hydropower is not only a renewable source of energy itself but also offers flexibility options for the operation of the entire energy grid via the storage of excess electricity – integrating the volatile and increasingly important solar and wind power generation into the existing system. This means that hydropower has a potentially key role in achieving the European decarbonisation and energy independence goals of the coming decades. On the other hand, hydropower generation and energy storage is a complex sector within the water-energy-food-ecosystem nexus. It is a mature technology with 80-90% overall efficiency, a characteristically long lifespan, high flexibility and availability – but also a socially controversial one with high and adverse ecological impacts.[260]

Despite the controversy, hydropower is currently the market leader of low-carbon and renewable electricity technologies, with a global installed capacity of 1360 GW, and a 4250 TWh production volume in 2021. Furthermore, the EU hosts 44 GW of pumped hydro storage[261], which constitutes ¼ of the global capacity (approximately 165 GW in 2020[262]).

[260] CETO (2022), Hydropower and Pumped Hydropower Storage in the European Union
[261] CETO (2022), Hydropower and Pumped Hydropower Storage in the European Union
[262] Hunt et al. (2020), Global resource potential of seasonal pumped hydropower storage for energy and water storage

A.13.2 Supply chain overview

Figure 25: Hydropower and pumped hydro storage supply chain



Source: Trinomics (2021)[263]

The hydropower supply chain (Figure 25) is rather complex and on the component level it includes electro-mechanical equipment such as turbines, generators, transmissions, as well as the civil structures like weirs, dams, tunnels, pipes, and the Operation and Maintenance (O&M) equipment controlling the system. Generally, the electro-mechanical equipment is responsible for 1/3 and the civil structures for 2/3 of the investment costs.[264]

A.13.3 Assessment per indicator

A.13.3.1 EU demand

The EU's declared goal – in accordance with the REPowerEU plan – is to limit its primary energy demand to 11,397 TWh by 2030[265] via energy efficiency measures. The electricity production itself was 2,641 TWh in 2022[266] , but with current trends in electrification, the share of electricity in the primary energy demand is expected to grow substantially in the coming decades.

The EU currently has a 154 GW hydropower installed generation capacity. Modelling of the EU energy system following from the REPowerEU plan results in an additional net capacity installed amounting to 133 GW by 2030. This is far lower than those expected for other clean power generation technologies, such as wind power (510 GW) and solar power (592 GW). However hydropower does attain higher capacity factors, and it thus provides more electrical energy overall. In 2021, hydropower contributed 12% of the EU's primary electricity generation – about 348 TWh.[267] With a similar capacity factor, by 2030 the input of hydropower would be 649 TWh, a smaller number nonetheless than other clean energy technologies.

[263] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
[264] Ibid.
[265] EC (n.d), Energy efficiency directive. Available at: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en
[266] Council of the EU (2023), How is EU electricity produced and sold? Available at: https://www.consilium.europa.eu/en/infographics/how-is-eu-electricity-produced-and-sold/#:~:text=In%202022%2C%20the%20EU%20produced, followed%20by%20coal%20(15.8%25).
[267] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics

This means that the decarbonised electricity demand will be much higher than what hydropower generation can provide. 55% of the hydropower potential is already utilised on the current economically mature technological level[268] (60-70% according to other estimations[269]) – meaning that without any technological leaps the potential hydropower generation capacity of the EU is limited to about 430-550 TWh generation output (with less being economically feasible).

For PHS, demand for new installations also expected to remain rather low. EU demand for energy storage driven by the swiftly decarbonising electricity sector will also increase significantly in the future. The installed energy storage capacity of 60 GW as of 2022 will have to reach approximately 200 GW installed capacity by 2030[270]. PHS currently is responsible for meeting 44 GW of this demand[271] with 50-70% of the potential capacity already utilised. This means, that the demand for energy storage is expected to far outgrow the potential of economical PHS capacity of Europe in this decade already.
With the demand being substantially higher but the physically available potential remaining limited, the demand's risk on the composite supply chain risk of the technology is expected to be **low (2)**.

A.13.3.2 EU manufacturing growth

The EU countries with growing hydropower capacities in 2020-2021 are Austria (added 150 MW), Greece (added 21 MW), and Spain (added 16 MW). The preceding five years Portugal, Austria, Italy, and France invested in additional hydropower generation capacities, including PHS (1050 MW in Portugal and 360 MW in Austria). Previous studies found the hydropower sector to be of strategic importance, while their supply chains remain non-critical[272, 273]. Europe alone hosts more than half of the global equipment manufacturers, and is in a strong position on the international market[274] with Voith (DE) and Andritz (AT) occupying 32.5% of the global hydro turbine market[275].

Given the EU's very strong manufacturing prowess in the main components of hydropower, and the high level of maturity with regard to installation of the technology, EU manufacturing growth seems very capable of meeting the 133 GW growth needed by 2030. Thus, this indicator receives a **very low (1)** score.

A.13.3.3 Competitiveness threats, market concentration and other vulnerabilities

The EU is a leader in hydropower development and technological innovation, research, export and market development.[276] Overall, in 2019, the EU27 export of hydropower parts and turbines amounted to a total value of EUR 421 million. With the import limited to EUR 142 million, the trade balance of hydropower parts for the EU is robustly positive.

268 CETO (2022), Hydropower and Pumped Hydropower Storage in the European Union
269 Hydropower Europe (n.d), Vision of the HYDROPWER EUROPE Forum. Available at: https://hydropower-europe.eu/about-hydropower-europe/vision-of-the-forum/
270 EC (n.d.), Recommendations on energy storage. Available at: https://energy.ec.europa.eu/topics/research-and-technology/energy-storage/recommendations-energy-storage_en
271 CETO (2022), Hydropower and Pumped Hydropower Storage in the European Union
272 CETO (2022), Hydropower and Pumped Hydropower Storage in the European Union
273 Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
274 CETO (2022), Hydropower and Pumped Hydropower Storage in the European Union
275 Power Technology (n.d), Hydro turbine manufacturers in the power industry. Available at: https://www.power-technology.com/buyers-guide/hydro-turbine-manufacturers/
276 CETO (2022), Hydropower and Pumped Hydropower Storage in the European Union

Generally, the turbine manufacturers play the most central role in the hydropower supply chain. While their main output remains the turbine itself, they typically supply generators and other necessary equipment too[277], and the overall market performance of the hydropower plants is usually connected to the hydropower turbines[278]. Large-scale manufacturers of turbines used in hydropower plants are well distributed across the globe and are present in Europe – like Voith (DE) and Andritz (AT). The market of large-scale units – above 10 MW – is, however, dominated by a rather small number of companies. The turbine market, in terms of Mwe output, is shared between China (45.9%), the EU (32.4%) and the US (17.2%) on fairly equal terms.

The position of hydropower generation and energy storage within the water-energy-food-ecosystem nexus means that hydropower has several regulatory barriers to overcome, balancing the water security and environmental-ecological interests (as stated i.e. in the Water Framework Directive 2000/60/EC) with the power generation potential. For example, hydropower generation must co-exist with hydrological and morphological considerations, avoiding interruptions and alterations as much as possible, maintaining continuity and stable conditions for the aquatic environment. Building of a new reservoir often results in conflicting interests regarding land-use for residential and agricultural purposes instead. The alternative utilisation of the water resources, i.e. for irrigation or recreational purposes, are often competing rather than complementing options to hydropower generation. This means some restrictions on the available potential and often a political risk and social acceptance issues. There are however some options for growing hydropower generation with fewer social and environmental impacts. For example, modernisation of the existing hydropower plants and developing plants in existing infrastructure (e.g. existing barriers, water and wastewater networks, irrigation canals, and pumped hydro storage in mines) are options that involve very little or no change in land use.

The EU is well positioned in the manufacturing of hydropower components, with a positive trade balance and a decent share of the global market. The EU is a leader in development and innovation. The most limiting factors seem to be regulatory, and physical limitations on the generation potential. The other vulnerabilities' effect on the composite score is therefore **low (2)**.

A.13.4 Overall assessment

With a composite score of 5, hydropower and pumped hydro storage is **not considered to be a strategic technology**.

[277] US DoE (2022), Hydropower Supply Chain Deep Dive Assessmen

[278] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

A.14 Annex 14: Advanced Biofuels

A.14.1 Introduction

Renewable fuel technologies are important for reducing carbon emissions from transportation, enhancing energy security, and diversifying energy sources. Advanced biofuels, which are produced from feedstocks that don't compete with food production or cause land use change, are expected to play a significant role in this transition. According to the Renewable Energy Directive (RED II) 2018/2001 (The European Parliament, 2018), it is possible to produce such fuels from the initial feedstock listed in the Annex IX part A/B of the directive[279]. The Fit for 55 legislative proposals aim to increase the targets for the use of advanced biofuels and renewable fuels of non-biological origin (RFNBO). The biggest challenge for the large-scale deployment of advanced biofuels is the availability and access to eligible feedstock under the 2018 REDII. Significantly, the REPowerEU projections do not foresee an increase in the demand of advanced biofuels as part of transport demand, compared to "Fit for 55" projections[280]. Moreover, as part of the ReFuel Initiative, the Parliament and the Council have agreed on a set of obligations for aviation fuel suppliers to guarantee a minimum share of SAF from 2025 and, from 2030, a minimum share of synthetic fuels, with both shares increasing progressively until 2050[281]. REPowerEU projections estimate a gross inland consumption of approximately 11.2 Mtoe of biofuels by 2030.

The use of advanced biofuels does not pose significant technology lock-in risks, as they can utilise existing infrastructure, transport and distribution networks, and fuel stations. In the short term, advanced biofuels can make substantial contributions to decarbonising transport, diversifying energy sources in the transport sector, ensuring energy security, and reducing dependence on energy imports. They offer the significant advantage of achieving high greenhouse gas emissions reductions in the short term by utilising waste and residues and leveraging existing infrastructure. Advanced biofuels are particularly crucial for decarbonising sectors such as aviation, shipping, and heavy road transport. Since biofuels rely on local biomass resources and have shorter supply chains, they provide excellent opportunities to reduce energy poverty through local value generation and more stable prices. They also enhance the security of energy supply and resilience of the EU energy system.

There are existing commercial options (e.g. anaerobic digestion for biomethane, hydrogenated vegetable oil, lignocellulosic ethanol production), but their installed capacity is currently low (0.43 Mt/y) with limited planned production (1.85 Mt/y)[282]. Innovative technologies like biomass gasification for Fischer-Tropsch synthetic fuels and biomethanol production have been successfully demonstrated in industrial settings and are ready to scale up, while next generation technologies are also progressing. Other renewable synthetic fuels such as solar fuels, microbial fuels, and micro-algae fuels are mostly at the laboratory stage. For the purpose of the present study, the scope of this Annex only covers technologies with a TRL of 8 or higher.

[279] DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources.
[280] S&P Commodity Insight, Europe agrees on renewable hydrogen consumption targets.
[281] https://www.consilium.europa.eu/en/press/press-releases/2023/04/25/council-and-parliament-agree-to-decarbonise-the-aviation-sector/
[282] Clean Energy Technology Observatory, 2022. Advanced Biofuels in the European Union. Status report on technology development, trends, value chains and markets.

A.14.2 Supply chain overview

In this section, we provide an overview of the various technological pathways for the production of advanced biofuels, primarily based on the report on advanced biofuels provided by the Clean Energy Technology Observatory[283].

Pre-treatment and enzymatic hydrolysis to sugars (TRL 8-9): Lignocellulosic material can be converted to sugars through pre-treatment and enzymatic hydrolysis. The conversion includes the following steps:

- pre-treatment, usually thermal or thermochemical, to disrupt the cellular structure and facilitate access to enzymes;
- enzymatic hydrolysis, to break the large carbohydrates (cellulose and hemicellulose) down into monomeric C5-C6 sugars;
- fermentation of the sugars to alcohol using yeasts, other species of fungi or bacteria.

Several processes can be used, including physical processes (steam explosion, thermohydrolysis), chemical (acid hydrolysis, alkaline hydrolysis, organic solvolysis or biologic) and combined (catalysed steam explosion, ammonia or CO_2 explosion). Steam explosion is the most widely used pre-treatment technology.

Pyrolysis (TRL 7-8) is the thermochemical process converting biomass into bio-oils, gases and a solid product (biochar) to be used as intermediate energy carrier in the absence of oxygen, and at lower temperatures than combustion or gasification (450 – 600 °C).[284] The process distinguishes slow, fast and flash pyrolysis. The most frequently used reactors for slow pyrolysis, are drum, rotatory kilns, and screw/Auger reactors. Fast pyrolysis systems use fluidised bed, rotating cones, entrained flow, vacuum, and ablative reactors. Catalytic Fast Pyrolysis (CFP) employs various catalysts that promote cracking, dehydration, deoxygenation reactions to produce a bio-oil. Flash pyrolysis uses fluidised bed, circulating fluidised bed reactors or downer reactors.[285] The technology to produce upgraded pyrolysis oil, developed originally for heat, power, and food industry applications, are at pre-commercial, initial demonstration stage. Although some pilot and demo projects are currently ongoing, the technology is not yet at the maturity levels of other pathways for biofuels. Nonetheless, pyrolysis has a high potential for the production of biofuels in the future. Thus, while it is mentioned here, it does not directly impact the scoring regarding the strategic importance of biofuels.

Hydroprocessing of oils, fats and bioliquid intermediates (TRL 9): Hydroprocessing (also called hydrotreating) can be applied to oils and fats to produce HVO (Hydrotreated Vegetable Oil) also called HEFA (Hydroprocessed Esters and Fatty Acids) drop-in biofuels. Hydroprocessing consists of a range of catalytic processes including hydrotreating and hydrocracking for the removal of sulphur, oxygen and nitrogen. According to the CETO report[286], Europe is a world leader in HVO/HEFA production, with several commercial-size plants currently in production.

Gas fermentation through microorganisms to alcohols (TRL 8-9): A range of microorganisms can produce intermediates such as ethanol, butanol and acetic acid from CO and H_2-rich gases (syngas)

[283] Clean Energy Technology Observatory, 2022. Advanced Biofuels in the European Union. Status report on technology development, trends, value chains and markets.

[284] Basu, P. (2018) Biomass Gasification, Pyrolysis and Torrefaction. Elsevier. Available at: https://doi.org/10.1016/C2016-0-04056-1.

[285] Clean Energy Technology Observatory, 2022. Advanced Biofuels in the European Union. Status report on technology development, trends, value chains and markets.

[286] Clean Energy Technology Observatory, 2022. Advanced Biofuels in the European Union. Status report on technology development, trends, value chains and markets.

or CO-rich gases via fermentation.[287] Acetogenic bacteria convert CO, H_2 and CO_2 derived from biomass or waste materials into acetic acid (Drake et al 2008). Gases can originate from industrial waste off gases or syngas from biomass gasification. Syngas fermentation is a hybrid thermochemical/biochemical pathway that combines the gasification process and the fermentation in syngas fermentation process. The pathways for gas fermentation through microorganisms to alcohols can be used to produce other products and alcohols such as butanol that are better suited than ethanol as drop-in biofuel intermediates.

Transesterification of triglycerides (TRL 9): The most prevalent biofuel in the EU is Fatty Acid Methyl Ester (FAME), historically referred to as biodiesel. While in the past it was principally made from vegetable oils (rapeseed, palm oil etc.), there is now a growing focus on using waste or used cooking oils and animal fats. FAME conversion takes place by a chemical process known as transesterification.

Biomethanol synthesis (TRL 8): Today methanol is produced at industrial scale from synthesis gas, typically generated from natural gas, in a steam reformer using heterogeneous catalysts (copper, nickel, palladium, and platinum). Methanol is also of importance in the fuel synthesis of transport fuels, such as methyl ethers (e.g. Dimethyl ether (DME) or as marine fuel.

Methanol to Gasoline synthesis (TRL 8): The Methanol-to-Gasoline (MtG) process is currently deployed in several commercial plants. The route has also demonstrated the conversion of methanol into diesel and kerosene. The core reaction of the Methanol to Gasoline pathway is the reaction of one molecule of carbon monoxide with two molecules of hydrogen to form one molecule of methanol. The conversion takes place in the presence of relatively inexpensive catalysts at temperatures between 220-275 °C and pressures of 5-10 MPa. Methanol is a liquid fuel but not a drop-in transportation fuel. However, it can be converted into a drop-in gasoline (C4-C12) using the Methanol-To-Gasoline process (MTG) in fixed beds and fluidised beds of proprietary catalysts.

A.14.3 Assessment per indicator

A.14.3.1 EU demand

A binding 5.5% target by 2030 obligation on suppliers for advanced biofuels and RFNBOs has been agreed, building on the targets in the 2018 RED II. Within this blended target, 1% of fuel supply must be RFNBO. However, challenges with accessing advanced biofuels mean that it is likely that the RFNBO share will be higher than 1%. Based on REPowerEU projections, there will be a consumption of approximately 11 Mtoe of biofuels in 2030, which is much lower than that predicted for e.g. biogas at 30.4 Mtoe. The demand for advanced biofuels is therefore rated as **low**.

A.14.3.2 EU manufacture growth

Currently, the European biofuels market is largely dominated by first-generation biofuels that are made from food-based sources. However, starting in 2012, the European Commission implemented restrictions on the production and use of these fuels through the Low ILUC directive. This directive sets a limit of 5% on their utilisation, and we are approaching that threshold. However, with the implementation of new measures supporting the production of alternative biofuels as outlined in the RED II in 2018, significant changes are anticipated in the biofuels market in the upcoming years. It is expected that the production of advanced biofuels will grow rapidly by 2030.

[287] Munasinghe, P. C., & Khanal, S. K. (2010), Syngas fermentation to biofuel: evaluation of carbon monoxide mass transfer coefficient (kLa) in different reactor configurations. *Biotechnology progress*, *26*(6), 1616-1621.

The rising consumption of biofuels is also partly driving an increasing demand for new biodiesel facilities. An example of this is the Cargill advanced biodiesel plant completed in Ghent, Belgium, in June 2022, converting waste oils and residues into renewable fuel. It will be targeted to the maritime and trucking sectors[288].

It is worth stressing the biodiesel production capacity increase in the EU between 2006 and 2012, from 7 billion litres to 25 billion litres per year, while the actual production was around 50% of nominal capacity in 2013 and has increased to 78% in 2020. Among the projects and operational plants in the EU for advanced biofuels, there are two commercial plants producing pyrolysis oil and bio methanol, and several first-of-a-kind plants producing pyrolysis oil, bioethanol and biomethanol and FT liquids.[289] The combined production capacity of those plants is a little above 1 billion litres per year (compared to the roughly 20 billion litres of bioethanol and biodiesel produced in the EU in 2020). Given the expected limited increase in demand and the proven manufacturing capacity of the EU, manufacturing growth is rated as **low**.

A.14.3.3 Competitiveness threats, market concentration and other vulnerabilities

Advanced biofuels are faced with the challenge of limited access to feedstock, competing with other uses, most importantly, animal feed. In addition, as explained above, their limited installed capacity and planned production reduces competitiveness concerns for EU manufacturing. In this setting, Germany is expected to become the EU's top biodiesel producer in 2022 with 3.86 billion litres, followed by France at 2.06 billion litres and Spain at 1.35 billion litres. The Netherlands is expected to be the EU's top renewable diesel[290] producer this year at 1.22 billion litres, followed by Italy at 800 million litres and Spain at 460 million litres. Therefore, Germany leads the production of biofuels in the EU. The sector of advanced biofuels is just emerging, and the number of commercial plants is still quite low, while international trade is very limited. Though featuring some degree of concentration in the EU, the market with a small size does not suggest specific market concentration concerns.

Another minor concern on vulnerability of the biofuels supply chain relates to the feedstock. The main concern lies in the availability of sustainable biogenic resources, depending on the feedstock and fuel consumption assumptions. The RED II regulations restrict the use of food-based feedstocks to avoid competition with food production and indirect land use changes. Biomass cultivated for this purpose requires land, water, and nutrients, making it limited in availability. Additionally, residues, another source of biomass, are also limited because their quantity cannot be increased to meet growing demand (despite the fact that the percentage of valorisation of these residues can be increased, up to a certain limit). The ability to meet the demand for sustainable biomass largely depends on the anticipated demand for advanced biofuels, which is influenced by factors such as the penetration of electric vehicles, transportation needs, and industrial usage. Lastly, the reliance on critical materials is relatively low in renewable fuel production.

Overall, these strategic concerns for advanced biofuels are considered to be **low**.

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[288] https://www.cargill.com/agriculture/bioro-biodiesel-refinery

[289] Clean Energy Technology Observatory, 2022. Advanced Biofuels in the European Union. Status report on technology development, trends, value chains and markets.

[290] Renewable diesel and biodiesel, despite using similar organic feedstocks, present distinct production processes. Biodiesel production involves a relatively simple chemical reaction known as transesterification. As a result, biodiesel is typically blended with petroleum diesel for use in modern diesel engines. On the other hand, renewable diesel undergoes a more complex production process, yielding a drop-in hydrocarbon fuel that meets the same technical specifications as petroleum diesel. Consequently, renewable diesel can be used as a complete substitute for petroleum diesel without requiring any modifications to existing engines or infrastructure.

A.14.4 Overall assessment

Overall, given the relatively low expected contributions to "Fit for 55" goals for 2030, the low market size and manufacturing growth rate, and the very good current EU position in their production, advanced biofuels are rated with a composite score of **6**, and therefore a generally **low strategic concern**.

A.15 Annex 15: Renewable Fuels of Non-Biological Origin

A.15.1 Introduction

For the purpose of this study, Renewable Fuels of Non-Biological Origin (RFNBO) cover liquid and gaseous fuels derived from hydrogen combined with CO_2 from fossil sources such as fuel gases, from DAC (Direct Air Capture) technologies or from other non-renewable and natural sources. In parallel to the growing development of the hydrogen sector and carbon capture technologies, the production of RFNBO is an opportunity to produce drop-in fuels starting from the supply chains of renewable hydrogen and capturing CO_2.[291]

Depending on the synthesis reactions used within the conversion pathways, the output fuels could be methane for natural gas vehicles and/or directly injected into the natural gas grids, as well as synthetic drop-in liquid fuels for gasoline, kerosene or diesel. Other RFNBOs include fuels and chemicals as alcohols (e.g. methanol, ethanol) and ammonia[292]. The latter two are already at full commercial levels and well-established, resulting in the substitution of fossil-based methanol and ammonia depending only on the supply of renewable H_2 and CO_2.[293] Since there is no need to replace already existing infrastructure for the production and distribution of ammonia and methanol, these are not treated within this Annex.

RFNBOs consisting in hydrocarbons produced from synthesis processes are drop-in fuels to be used in the current fuel infrastructures and vehicles. Depending on the product, most parts of the existing fossil fuel infrastructure can also be used for alternative fuel supplies, without any changes or with minimal modifications. For these reasons, downstream supply-chain processes, including storage, transport and distribution are considered beyond the scope of this assessment. Therefore, this assessment focuses on the production supply chain of e-methane (CH_4) (methanation with renewable hydrogen and CO_2), and e-diesel, e-gasoline and e-kerosene via the Fischer-Tropsch process and Direct Air Capture (DAC).[294]

[291] European Commission, Directorate-General for Energy, Breitschopf, B., Zheng, L., Plaisir, M., et al., *The role of renewable H_2 import & storage to scale up the EU deployment of renewable H_2 : report*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2833/727785

[292] Clean Energy Technology Observatory: Renewable fuels of non-biological origin in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets.

[293] Clean Energy Technology Observatory: Renewable fuels of non-biological origin in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets.

[294] Clean Energy Technology Observatory: Renewable fuels of non-biological origin in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets.

A.15.2 Supply chain overview

Figure 26: Production pathways of various power-to-liquid fuels

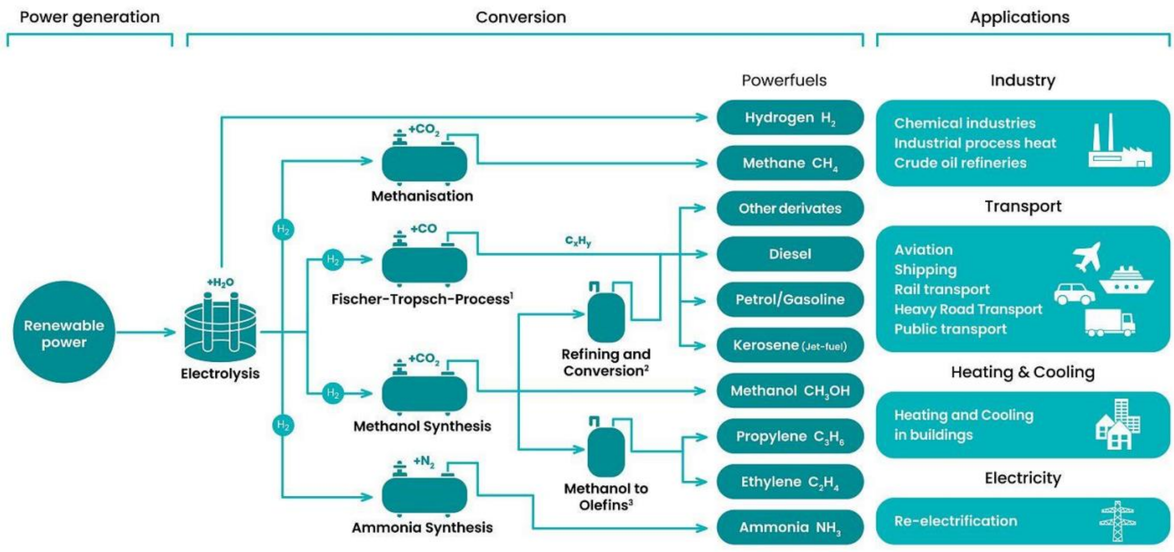


Figure 26 gives an overview of production processes in various power-to-liquid fuels, which are further discussed below.

Power-to-gas via methanation

Methanation, following a Sabatier reaction, refers to the reaction between CO_x and hydrogen to produce methane. Power-to-gas systems utilizing CO_2 methanation can solve the issue of intermittent power production from renewables such as solar and wind. The green CH_4 produced from renewable electricity can be stored and converted back to electricity when needed. Despite the highly exothermic nature of CO_2 methanation, the reaction is thermodynamically favoured at low temperatures. However, catalysts are necessary to lower the high activation barriers and speed up the reaction[295].

Nickel-based catalysts are the most widely used for their low price and high conversion rate. The reactors are generally fixed bed reactors, and typical thermodynamic parameters are 8 bar and 180-350 °C of temperature. On the other hand, ruthenium (Ru)-based catalysts show high activity and stability across a broad range of operating conditions. Other transition metals such as iron (Fe) and cobalt (Co), as well as noble metals such as rhodium (Rh) and palladium (Pd) have also shown catalytic activity in CO_2 methanation[296].

Power-to-liquid via Fischer-Tropsch process

Fischer-Tropsch (FT) synthesis is a technology that has a long history of production of gasoline and diesel from coal. Recently great interest has been generated in using this relatively well-established technology downstream to other bio or non-bio conversion pathways producing syngas. Today the

[295] Tan, C. H. et al. (2022), Current Developments in Catalytic Methanation of Carbon Dioxide—A Review, Frontiers in Energy Research, 9, p. 1031. doi: 10.3389/FENRG.2021.795423/BIBTEX.

[296] Tan, C. H. et al. (2022), Current Developments in Catalytic Methanation of Carbon Dioxide—A Review, Frontiers in Energy Research, 9, p. 1031. doi: 10.3389/FENRG.2021.795423/BIBTEX.

Fischer-Tropsch pathway to synthetic, liquid hydrocarbons is commonly used in biomass-to-liquid (BtL), gas-to-liquid (GtL) and coal-to-liquid (CtL) processes[297], where an upstream gasification process produces gases mainly composed by CO and H_2 to be processed into the FT-reactors. Generally, such gases must be cleaned by tars and other contaminants to produce a high purity syngas to run the desired reactions.

As regards to e-fuel production, there is already the possibility to perform direct FT-fuel synthesis from CO_2-based feed gas, but this pathway is still at a very early stage of development (requiring further catalyst developments and first lab scale demonstration). On the other hand, several PtFT-fuels demo plants that include a shift from CO_2 to CO have been operated successfully and further larger-scale plants have been announced.

Carbon Capture and Use

The production of e-fuels requires CO_2, attainable from various sources such as combustion gases (from both bio or fossil fuels), industrial processes (e.g. off gases), biogenic CO_2, and CO_2 captured directly from the air. We refer here to the Annex on CCUS for the supply chain analysis of this technology.

A.15.3 Assessment per measure

A.15.3.1 EU demand

Renewable hydrogen and e-fuels will play a crucial role in meeting the EU binding target of 42.5% renewable energy by 2030. Based on the proposed revision of the Renewable Energy Directive (RED), industry's consumption of hydrogen will have to come for 42% from RFNBOs by 2030. In transport, at least 5.5% of the fuel mix must be composed of advanced biofuels and RFNBOs (combined binding target). Within this blended target, 1% of fuel supply must be RFNBO. Little detail is provided on the industrial target, which is expected to be revealed with the final draft. It was estimated[298] that the consumption of RFNBOs in 2030 will be of 29 Mtoe based on REPowerEU projections.

Given the expected increase in RFNBOs production, the increase in demand for the catalysts needed for the FT and methanation reactions is considered as **low**.

A.15.3.2 EU manufacturing growth

With the view of meeting the deployment targets, it was estimated[299] that the 1% RFNBO target mentioned above is equivalent to 53% of refinery hydrogen consumption. Therefore, the transport target can be met without requiring investment in hydrogen refuelling infrastructure or onward conversion of RFNBO hydrogen to synthetic liquid fuels[300], using the targets of the revised RED. However, if the targets of the REPowerEU plan are used as reference, then there will be a greater need for renewable hydrogen.

Nonetheless, it should be highlighted that the factor influencing the EU's manufacturing dependency for RFNBOs relates not so much to the production of the particular technologies

[297] Schmidt, P. and Weindorf, W. (2016), Power-to-Liquids Potentials and Perspectives for the Future Supply of Renewable Aviation Fuel. Dessau-Roßlau, Germany.

[298] S&P Global Commodity Insight, Back in the driving seat? Europe agrees on renewable hydrogen consumption targets.

[299] S&P Global Commodity Insight, Back in the driving seat? Europe agrees on renewable hydrogen consumption targets.

[300] Idem.

addressed in this Annex, namely the catalysts for the necessary chemical reactions, for which the EU features several specialised manufacturers with the necessary skills and production capacity.[301] Catalysts are widely produced in the EU and used for various applications, and therefore it is expected that there will be a need to increase manufacturing in order to accommodate the need for the production of RFNBOs. This leads to **low** score in terms of EU manufacturing growth.

A.15.3.3 Competitiveness threats, market concentration and other vulnerabilities

As highlighted above, given the targets set out in the REPowerEU and the revision of the RED, RFNBOs are expected to play an important part in the deployment of renewable hydrogen. However, we expect that the competitiveness of RFNBOs will be greatly influenced by the availability of excess of renewable electricity, taking into account the expected overall higher demand due to the electrification of the economy[302]. Linked to this, another element affecting the competitiveness of RFNBOs is the cost of renewable electricity given the competition of various uses (e.g. for the use of hydrogen either as fuel, or for industrial processes, steel and fertiliser production).

RFNBO production does not witness a global market leader yet, since it relies on the nascent hydrogen and CCU/CCS markets. Again, the manufacturing dependency of the EU for the production of RFNBOs relates not so much to the technologies involved in the conversion of hydrogen into power fuels, but rather to the availability of renewable hydrogen. This is turn, is dependent on the availability of solar PV and wind power, and consequently the availability of their devices.

Concerning the manufacturing of catalysts necessary for FT and methanation reactions, the following EU enterprises are active, as part of catalyst industry association (European Catalyst Manufacturers Association): Albemarle Catalysts Company BV (NL), Axens (FR), BASF SE (DE), Clariant (DE), Ecovyst (UK), Evonik (DE), Eurecat (FR), Eurosupport (NL), Grace GmbH & Co. KG (DE), Haldor Topsoe A/S (DK), Honeywell UOP (BE), Johnson Matthey plc (UK), LyondellBasell (NL), Shell/CRI/Criterion (BE). Several manufacturers are present in Europe, mainly active in Germany and the Benelux region (Belgium, Netherlands, and Luxembourg). Generally, the vulnerabilities of RFNBOs relate to the availability of excess renewable energy and their net energy conversion ratio in comparison to direct use of electricity or hydrogen and energy consumption for providing (capture) CO_2 or N_2. However, this is not specific to the production of RFNBOs in the EU and is at most a minor vulnerability.

Overall, this technology is rated with a **low** rating for strategic concerns related to competitiveness, market concentration, and other vulnerabilities.

A.15.4 Overall assessment

With a **score of 6**, RFNBOs are considered of low strategic concern for the EU.

[301] https://catalystseurope.org/images/Documents/2022CatalystsEuropecontributiontoGreenDeal_FINAL.pdf

[302] Clean Energy Technology Observatory: Renewable fuels of non-biological origin in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets.

A.16 Annex 16: Solid Bioenergy Technologies

A.16.1 Introduction

Biomass can be transformed into fuel, heat and/or power through various technologies shortly described in the table below, showing the variety of routes & feedstock options:

Table 5: Bio-based energy technologies. Source: author, based on CETO (2022)[303]

Technology	Feedstock[304]	Fuel (output)	Maturity (TRL)	Capacity/production in EU (2020)
Combustion	Solid, gaseous & liquid (incl. waste)	Heat, Power or CHP	TRL 8-9	Prod. 919 TWh[305]
Pyrolysis	Solid & liquid (incl. waste)	Pyrolysis oil	TRL 3-5	Pilots
Gasification[306]	Solid (incl. waste)	CO, H_2 for (on-site) H, P or CHP	TRL 6-7	Pilots
Anaerobic digestion (Fermentation)	Biodegradable biomass (incl. waste)	Biogas (for CHP) or biomethane	TRL 8-9	Cap. 11.7 GWe
Pelletisation	Wood & mills by-products	Domestic & industrial pellets	TRL 9	Prod. 18.1 Mt

Some main concerns with bioenergy relate to feedstock and land competition (bioeconomy), availability and affordability, impact on biodiversity and land use, unmature supply chains, potential air pollution (for combustion). These concerns apply in practice to all technology routes, depending on the feedstock.

This annex refers to technologies used for **combustion, pyrolysis, gasification and pelletisation**.[307] Although pyrolysis and gasification technologies have yet to reach maturity levels set for the NZIA, they have high potential for replacing existing use of biomass via combustion and pelletisation. Thus, they are also briefly discussed in this report, but will not directly impact the scoring regarding the strategic importance of biomass technologies.

A.16.2 Supply chain overview

Biomass combustion of solid, gaseous and liquid biomass occurs at small and large scale for heat and CHP. It's mature, commercial technology. Combustion produces heat (under the form of steam or hot water), which can then be transformed into CHP. There are three types of steam boilers to produce CHP: grate boilers (1-10MWe), Bubbling Fluidised Bed Combustion & Circulating

303 CETO (2022), Bioenergy in the European Union
304 Only illustrative
305 79 Mtoe, CETO (2022), Bioenergy in the European Union
306 https://www.eubia.org/cms/wiki-biomass/pyrolysis-and-gasification/gasification/
307 Torrefaction and hydrothermal processing are not covered in this paper

Fluidised Bed Combustion (large scale). Scale factor is critical regarding global efficiency, pollutant emissions, and fuel flexibility. They are made of corrosion-resistant materials, to face the content of ashes (alkali, chlorine and heavy metals). Advanced controlled systems with automatic fuel feeders can reduce Particulate Matter (PM) and pollutant emissions to very low levels, even at small scale. Heat (steam or hot water) is used directly or is used in steam turbines (>2MWe), steam engines (200 kW-6 MWe), Organic Rankine Cycle (ORC), and Stirling engines (<100kW). Small scale occurs in stoves and small boilers (using wood logs, wood chips, or pellet with possibly automatic feeding and advanced control systems, and heat exchanger to feed in water circuit), which is also a mature technology.

For **Pyrolysis**, we refer to the information contained in the Annex on advanced biofuels.

Gasification is a thermo-chemical conversion process of biomass into a mixture of carbon monoxide, hydrogen, methane and carbon dioxide (syngas), at high temperature (700-1500 °C), by partial oxidation with limited oxygen. It includes the following steps: i) preheating and drying; ii) thermal decomposition; iii) partial combustion of some gases and char; iv) gasification of char and gaseous components[308]. This mixture is most of the time used as fuel for CHP (in gas engines or gas turbines) but can also be upgraded to produce renewable methane[309]. Gasifiers are categorised into three main types: fixed bed gasifiers, fluidised gasifiers (typically 800–1000 °C, more tolerant to feedstock properties, but producing more tar) and the entrained flow gasifiers (typically at 1400 °C & pressure {20–70 bar}, requiring more pre-treatment). Extremely high temperatures (~ 4000 °C) during plasma gasification allow the complete dissociation of the feedstock into syngas and complete breakdown of tars and other gas contaminants, and is particularly promising for waste gasification. Gasifiers are made of metal alloys. They often contain corrosion-resistant materials such as copper, brass, epoxy lined steel and stainless steel. Some flue gas contaminants (e.g. particulates, alkali metals, fuel-bound nitrogen, tars, sulphur, or chlorine) require clean-up methods.[310] Typical gasification plant capacities range from a few hundred kW for heat production, and from 100 kW to 1 MWe for CHP with a gas engine, and up to 10 MW for gas turbines systems operating at higher efficiency than a steam cycle. At larger scales (>30 MWe), gasification-based systems can be coupled with a gas turbine with heat recovery and a steam turbine (combined cycle) in a Biomass Integrated Gasification Combined Cycle (BIGCC) technology, thus offering higher efficiency of 40 - 50% for 30-100 MW plant capacity.

Biomass pelletisation process consists usually of three steps: feedstock/raw material[311] pre-treatment, pelletisation and post-treatment (incl. cooling). Moisture content of the feedstock should be reduced from above 50% to 10-15% (to increase efficiency and reduce smokes), with rotary drum dryers, superheated steam dryers, flash dryers, spouted bed dryers or belt dryers. The raw material is then reduced to small particles (precise sizing), and finally compressed against a heated metal plate using a roller (under pressure and temperature, lignin and resins act as binding agent between biomass fibres). Energy consumption of the pelletisation plant depends on the characteristics of the raw material (incl. moisture content).

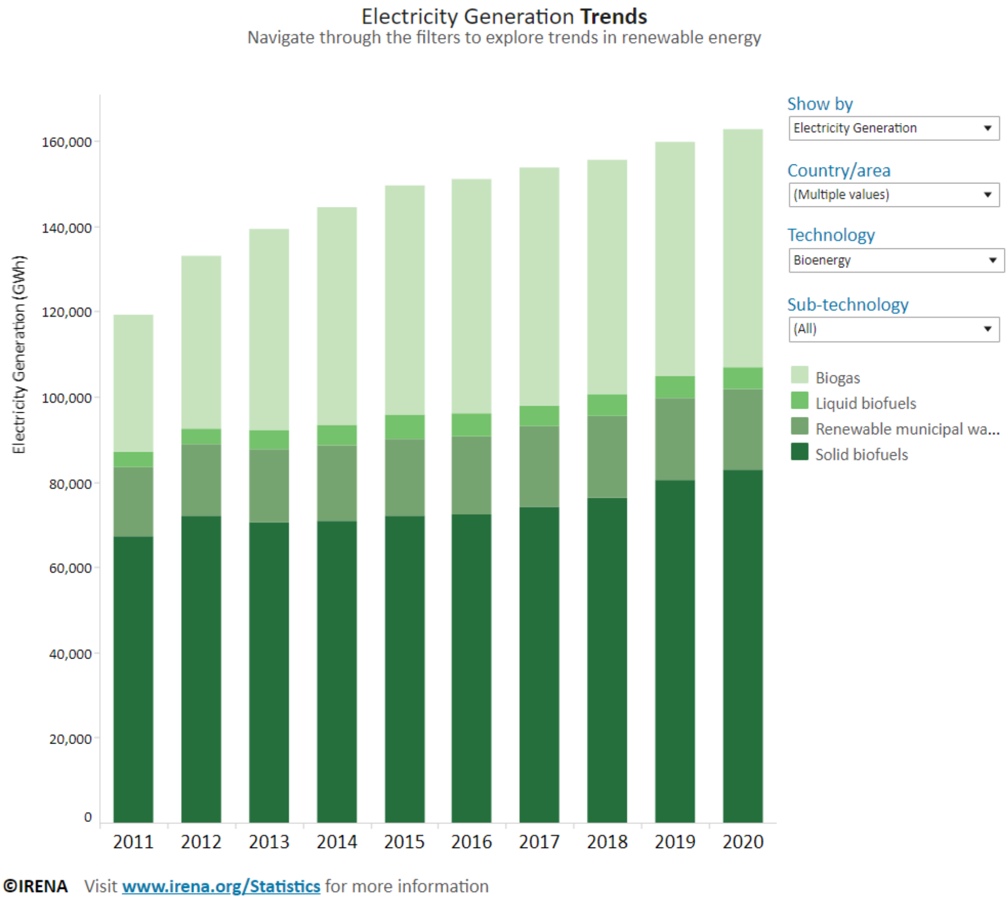
[308] Prabir Basu, 2018b
[309] https://www.europeanbiogas.eu/wp-content/uploads/2021/11/BioGas_GASIFICATION_final.pdf
[310] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis
[311] Raw materials used are forest residues, sawdust, wood shavings, wood wastes, agricultural residues like straw, switchgrass etc (IRENA, 2019)

A.16.3 Assessment per measure

A.16.3.1 EU demand

The past trend (over the last decade) has shown a slight, progressive increase in the production of energy (electricity) from solid bioenergy, as depicted by IRENA's visual (while the rate is faster for biogas).

Figure 27: Biomass use in electricity generation

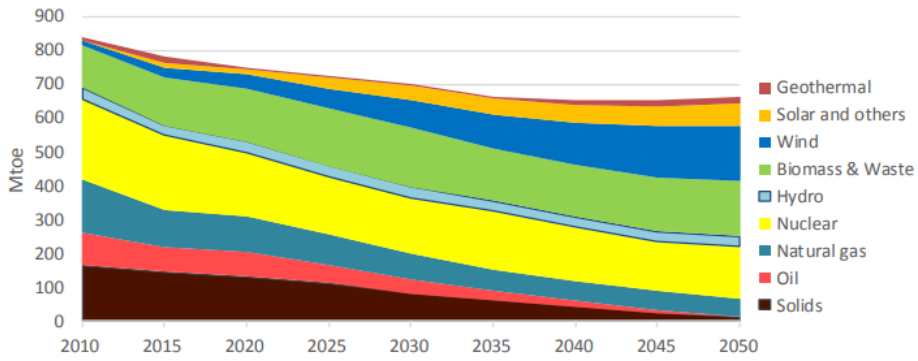


Source:[312]

Unlike for biogas/biomethane, the REPowerEU plan does not fix a specific target for solid and other gaseous bioenergy. The modelling performed for the REPowerEU project also highlights a potential of 159.5 Mtoe consumption of biomass waste, and 96.6 Mtoe of biosolids. However, it is unclear which technologies and processes these consumption values relate to, considering their differences with other industry predictions. According to the LTS[313] (baseline scenario, hence with very limited energy consumption decrease, as depicted by figure 20 in the LTS, leading to the highest increase in bioenergy production), bioenergy represented 144 Mtoe of the total primary energy production in 2015 (~18.5% share), and could increase up to 162 Mtoe by 2050 (with a peak of ~175Mtoe in 2030), which means an increase of 12.5% (and a final share of 24.5%).

[312] https://www.irena.org/Energy-Transition/Technology/Bioenergy-and-biofuels
[313] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

Figure 28: Primary energy production in baseline LTS scenario



Source: Eurostat (2010, 2015), PRIMES[314]

According to Bioenergy Europe, in 2017 (EU28[315]), mobilised biomass of all types produced energy that accounted for 144 Mtoe. Around 69.6% of the biomass consumed in Europe consists of woody biomass, 18.3% of agricultural biomass, and 12.1% of biowaste[316]. Regarding the end-use application, around 50.9% was used in large scale power plants, bioliquid plants, heat plants, CHP plants and biogas plants, while around 49.1% was used in smaller scale boilers and stoves, producing 74.7% of heat, 13.4% of electricity and 11.9% of transport fuel.

According to ETIP Bioenergy[317], bioenergy is key to achieving EU targets in terms of renewable energy by 2030 and beyond. Depending on the scenario used as reference, the gross inland bioenergy consumption by 2050 will amount to 170-252 Mtoe, as depicted by the following figure. However, the main growth would be expected for the production of biofuels, mainly to decarbonise the transport sector, which is still the hard to abate sector.

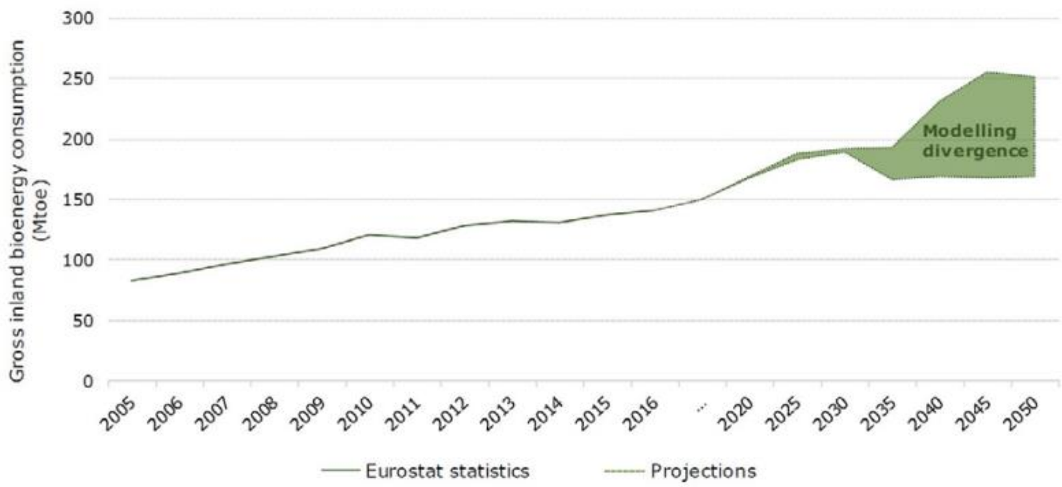
[314] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

[315] https://bioenergyeurope.org/about-bioenergy.html

[316] Examples of solid biomass feedstocks are wood industry by-products, wood from silviculture, waste wood, tall fescue, switchgrass, short rotation coppice, miscanthus, hedges, green waste

[317] ETIP (n.d.), The importance of bioenergy in achieving the european energy transition. Available at: https://www.etipbioenergy.eu/images/ETIP_Bioenergy_Position_Paper_Importance_of_bioenergy.pdf

Figure 29: Gross inland bioenergy consumption 2005-2016 and projections until 2050 based on mitigation scenarios



Gross inland bioenergy consumption during the period 2005-2016 and projections until 2050 based on mitigation scenarios. Sources: Eurostat 2018 and EC DG JRC

Source: ETIP (n.d.)[318]

Given the very limited increase of bioenergy versus other more prominent technologies in final energy consumption in 2030 and beyond, despite its still significant expected contribution to the 2030 energy mix, we arrive at a **medium** rating for this technology for demand.

A.16.3.2 EU manufacture

Given its leading position in **solid biomass combustion deployment**[319], the European boiler industry has built a strong expertise and good position in all components of the supply chain. Globally, decarbonisation policies are a key driver for the industrial boiler market development and growth rate, expected to be at 3.3% from 2022 to 2030. Demand might be pulled by Asia Pacific.[320]

Although it is still at a low maturity level (TRL 6-7), European players have already started deploying **gasifiers**[321] across Europe. According to Impactful Insights, the Europe biomass gasification market size reached 205.5 TWh in 2022. IMARC Group expects the market to reach 277.0 TWh by 2028, meaning a growth rate (CAGR) of 5% over that period[322] (the same rate is expected globally[323]).

The availability of feedstock is a key driver to steer biogasification deployment. However, if gasification deployment turns effectively in more efficient valorisation of solid biomass (incl. waste streams), it might replace some existing solid biomass technologies, to support hard to decarbonise sectors to move to zero emissions. Significant RD&I is still needed before reaching full maturity.

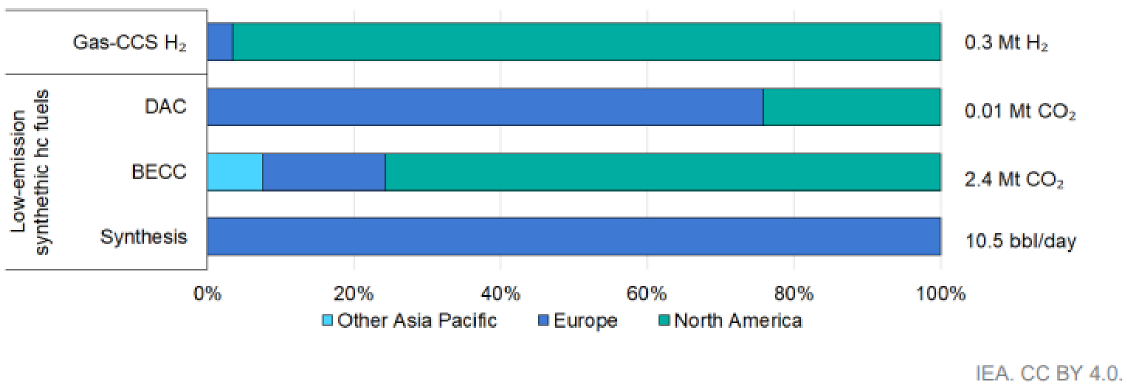
Pelletisation has reached a maturity of TRL 9. In 2020, the EU production was 18.1 million tonnes (Bioenergy Europe Statistical report 2021), making it the world's major pellet producer, with Germany leading. In Europe, pellet consumption increased by 7% globally compared to 2019,

[318] ETIP (n.d.), The importance of bioenergy in achieving the european energy transition. Available online.
[319] https://www.sciencedirect.com/science/article/pii/S096014811830301X?via%3Dihub
[320] https://www.marketsandmarkets.com/Market-Reports/industrial-boiler-market-130210505.html?gclid=CjwKCAjwgqejBhBAEiwAuWHioIaozlNcshuwuA9pQ8CuI0YRFCH6rR-WAxc9cFP6uYK2-_8oi6ptchoCNtYQAvD_BwE
[321] https://www.ieabioenergy.com/wp-content/uploads/2021/03/Hrbek-Gasification-developments-in-Europe-USA.pdf
[322] https://www.imarcgroup.com/europe-biomass-gasification-market
[323] https://www.thebrainyinsights.com/report/gasification-market-13152

reaching 39.8 million tonnes, the largest global pellet consumer market (with Italy being the largest residential market). Feedstock availability and mobilisation is probably the main constraint for the further deployment of pellet manufacturing. Irrespective of its growth, the EU manufacturing sector is well established and will have the capacity to produce the supply chain components required.

The EU is generally an excellent manufacturer of solid bioenergy equipment, and the past growth rate of this technology and its massive presence across the continent demonstrated the industry's ability to meet the required installation target. One challenge will be to remain a leader in lower-level technologies (like gasification) to continue strengthening the EU industry and maximising the valorisation of biomass feedstock. For example, the following figure illustrates the case of bioenergy with carbon capture and storage (BECC(S)), to be more present in North America than in Europe.

Figure 30: Shares in global installed operating capacity of large-scale clean energy technologies



Notes: DAC = direct air capture; BECC = bioenergy with carbon capture; Gas-CCS H_2 = natural gas-based hydrogen production with CCS; hc = hydrocarbon; bbl = barrel. Shares are based on nominal capacity. Synthesis refers to low-emission synthetic hydrocarbon fuels production.

Sources: IEA analysis based on company announcements.

Source: IEA (2023)[324]

Therefore, with a strong presence and capacity across Europe and little vulnerability for solid bioenergy in terms of EU manufacturing growth needs, and a small need for RD&I, a **very low rating for EU manufacturing growth needs** seems reasonable.

A.16.3.3 Competitiveness threats, market concentration, and other vulnerabilities

In 2020, the global biomass boiler market was segmented into North America, Europe, Asia Pacific, Latin America and Middle East & Africa. EU countries like Germany, Finland, Sweden and Austria[325] are adopting biomass for the production of energy. North America is a growing market for biomass boiler, and Asia Pacific is anticipated to become the fastest growing market for biomass boiler (in countries like India, Japan, and China).[326] Nonetheless, European companies remain very strong in this sector, including Harp Renewables Limited (IE), Weiss (FR), Binder Energietechnik GmbH (DE),

[324] IEA (2023), Energy Technology Perspectives 2023.

[325] Austria appears to be a main player in EU, particularly in the residential sector, according to EHI heating market report, available at https://ehi.eu/wp-content/uploads/2022/09/EHI-2021-Heating-Market-Report.pdf

[326] https://www.fortunebusinessinsights.com/industry-reports/biomass-boiler-market-100732

Sugimat (ES), Imperative Energy Limited (IE), Eric-Son (IT), Uniconfort srl (IT), Act Group (AT), Ariterm Sweden (SE), Danstoker (DK), Hephaestus Group (EL), EcoHeat Technologies (LT), Osby Parca (SE), MetalESG Sp. Zoo (PL), JSC Stropuva (LT).[327] UK companies are also among the top biomass boiler manufacturers. Fortune Business Insights lists among the major companies that are present in the biomass boiler market: Babcock & Wolcox (DK), Amec Foster Wheeler, Thermax, Siemens (DE), IHI Corporation, Doosan Heavy Industries, Thyssenkrupp (DE), Eco vision, Hurst, Innasol Limited, AbioNova, and DP CleanTech.[328]

Similarly for gasifier producing companies, Europe has a leading position. Some European companies[329] have built expertise and good position in all components of the supply chain, like Holz Kraft (DE), Valmet (FI), Air Technic SRO (CZ), Meva Energy (SE), EQTEC (ES), BIOS Bioenergiesysteme GmbH (AT), Bio2CHP (EL), Choren Industrietechnik GmbH (DE), Europlasma SA (FR), BTG Biomass Technology Group (NL), Royal Dahlman BV (DE), Xylowatt (BE), Eosol Design srl (RO), HR-Energiemenegement GmbH (DE), Bioenergy 2020 GmbH (AT), Enviroburners OY (FI), or Inerco (ES). Some have already started deploying their technology worldwide.

For mature technologies like biomass boiler manufacturing, a high concentration exists in Europe. For gasification, globally competitive EU manufacturers are leading and ready to deploy markets in developing and emerging countries for the import of gasification technologies.[330]

Bioenergy is a common priority of smart specialisation for several regions across EU. Accordingly, in 2016 the smart specialisation platform on energy has supported the creation of an interregional partnership for bioenergy and smart specialisation working in four priority areas: biofuels, biomass, biogas and knowledge transfer.[331]

In September 2016, the European Industrial Bioenergy Initiative (EIBI) and the European Biofuels Technology Platform (EBTP) were merged to the European Technology and Innovation Platform Bioenergy (ETIP Bioenergy).[332] ETIP Bioenergy, while addressing all kind of feedstock (forestry, agriculture and waste) seems to focus more on technology development for biofuels, and less on direct heat/power production[333] (e.g. workgroups on conversion technology or end use, most position papers, etc.).

In 2019, the ETIP Bioenergy organised a workshop on emerging technologies in Brussels[334], where it appears that again EU players, both from research and the industry, were at the forefront of technology development, addressing bioliquid production.

Combustion is the most common way of converting solid biomass fuels to energy, providing over 90% of the energy generated from biomass globally. But the rapid development of second-generation liquid biofuel technologies to produce transport fuels could create competition for feedstocks between the two uses (IEA 2010).[335]

More recently, for the 2023 European Biomass Conference, Isabella De Bari[336], the General Chair of the Conference[337] reminded that "*To move biobased industries forward, the build-up of local scenarios in a global framework is required in order to promote integration of more renewable sources at a*

[327] https://www.energy-xprt.com/products/?keyword=biomass+boiler
[328] https://www.fortunebusinessinsights.com/industry-reports/biomass-boiler-market-100732
[329] https://www.energy-xprt.com/companies/keyword-biomass-gasification-6406/location-europe
[330] https://www.europeanbiogas.eu/wp-content/uploads/2021/11/BioGas_GASIFICATION_final.pdf
[331] https://s3platform.jrc.ec.europa.eu/bioenergy
[332] https://www.etipbioenergy.eu/about-ebtp/the-role-of-etip-bioenergy/european-industrial-bioenergy-initiative-eibi
[333] https://www.etipbioenergy.eu/about-ebtp/ebtp-working-groups/working-group-3-end-use
[334] https://www.etipbioenergy.eu/ws-emerging-technologies
[335] https://www.ctc-n.org/technologies/biomass-combustion-and-co-firing-electricty-and-heat
[336] Isabella De Bari is *Head of ENEA Laboratory for the processes and technologies for biorefineries and green chemistry, and EUBCE 2023 Conference General Chair*
[337] https://www.eubce.com/message-from-the-2023-conference-general-chair/

local level, which undoubtedly is a key element in stimulating local opportunities. An exchange of ideas is required to define the role of biomass in the move towards a decarbonised and sustainable circular bioeconomy, and also conversations are essential in identifying the appropriate recent and future aspects that will assist in influencing and attracting public, private, and novel investments."

The well-established solid bioenergy industry (high maturity) does not seem to face technology gaps that hinder its expansion, but rather challenges of a different nature such as the mobilisation of sustainable feedstocks due to increasing competition with other bio-industrial developments (among which biofuels).

Overall, these competitiveness vulnerabilities of solid bioenergy receive a **low** rating in comparison to other clean energy technologies.

A.16.4 Overall assessment

With an overall score of 6, solid bioenergy technology is found to be **of low strategic concern**.

A.17 Annex 17: Nuclear Fission

Nuclear energy generation technologies are technologically mature ways of electricity generation, based on the production of steam from the heat released by the fission of atoms (usually uranium and plutonium), powering steam turbines.[338] The most common design of nuclear power plants operating in the EU and in the world are based on pressurised water reactor (PWR) technology[339].

There has been some recent interest generated by utilities and research organisations from at least seven EU Member States in new small and modular nuclear reactors (SMRs).[340] SMRs are advanced nuclear reactors with a capacity of less than 300 MW, usually linked to electricity and heat production (for industrial and district heating purposes), as well as hydrogen production. This interest is driving a process towards a European industrial model for SMR deployment in the early 2030s.[341] However, SMRs are not yet commercially viable, and their technology development status stands at TRL 4.[342]

A.17.1 Supply chain overview

The nuclear fission technology supply chain is highly complex (see Figure 31 below). The layout of nuclear power plants comprises two main parts: the nuclear island and the conventional (turbine) island. The former comprised of the containment building, auxiliary building, and fuel handling area, whereas the conventional island contains the generation turbine which extracts thermal energy from pressurised steam and converts it into electrical energy.[343] In the case of PWR, the main components include the reactor pressure vessel, steam generator, pressuriser, piping systems, reactor coolant pumps, fuel rods, and control rods. [344]

A high number of nuclear components need to satisfy nuclear-grade safety quality levels, which are stricter than commonly used industrial quality standards.[345] Most of these components are located in the nuclear 'island' (i.e., in the reactor, fuel and waste, and safeguard and auxiliary buildings).

Suppliers of nuclear structures, systems and components (SSCs) and services are required to maintain a nuclear-specific quality assurance programme. These certificates increase the costs for provision of products and services, reducing the number of qualified suppliers for the nuclear industry.[346]

Based on this insight, a previous study on the resilience of critical supply chains for energy security[347] found critical vulnerabilities in the manufacturing and assembly stage, namely nuclear-grade certified suppliers for primary circuits, rods and other components/services for the nuclear island, as well as certified service providers for nuclear operation and maintenance (O&M) activities.

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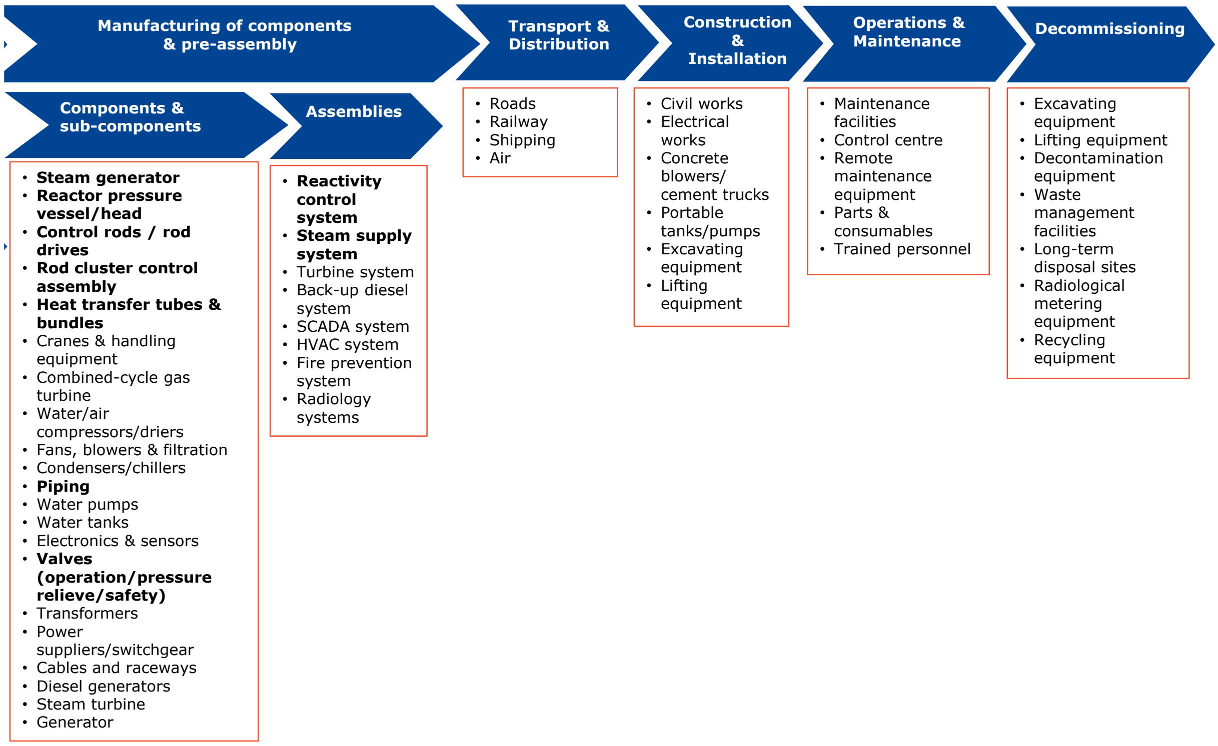
338 Trinomics et.al. (2021), Study on Resilience of the critical supply chains for energy security and the clean energy transition during and after the COVID-19 crisis.
339 World Nuclear Association (2023), Nuclear Power Reactors. Accessed on 22 May, 2023.
340 European Commission, Small Modular Reactors and Medical Applications of Nuclear technologies, Publications Office of the EU, Luxembourg, 2022
341 COM (2022) 643 final, Report from the Commission to the European Parliament and the Council: Progress on competitiveness of clean energy technologies.
342 IEA (2019), Innovation Gaps – Analysis - IEA, Paris
343 See: https://www.nuclear-power.com/nuclear-power-plant/nuclear-island/
344 Trinomics et.al. (2021), Study on Resilience of the critical supply chains for energy security and the clean energy transition during and after the COVID-19 crisis.
345 Nuclear Energy Institute (2010), Supply Chain Map – Nuclear Reactor Components
346 Deloitte for FORATOM (2019), Economic and Social Impact Report
347 Trinomics et.al. (2021), Study on Resilience of the critical supply chains for energy security and the clean energy transition during and after the COVID-19 crisis.

Figure 31: Overview of the value chain for nuclear fission



Note: critical dependencies found highlighted in **bold.**
Source: Trinomics & Artelys (2021)[348]

A.17.2 Assessment per indicator

A.17.2.1 EU demand

The EU nuclear generation capacity consists of 100 nuclear power reactors (97 GWe) as of 2023[349], which generate about 22% of the EU's electricity.[350] Only two nuclear reactors are currently under construction in the EU, located in France and Slovakia, with a joint capacity of 2.1 GWe estimated to become operational by 2024 but 5 more are under planning in various stages of progress with an overall capacity of 7.2 GWe, and 30.1 GWe further capacity expansion is in the proposal stage within the Member States.[351]

Nuclear power is included in the EU's medium-term climate and energy plans. In its REPowerEU plan, the EU recognises the role of nuclear-based hydrogen in substituting natural gas, promoting the production of fossil-free hydrogen. Almost all currently existing nuclear power plants in the EU are expected to be decommissioned by 2050, while Member States will need to make decisions with regards to the replacement of their plants.

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[348] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis - Publications Office of the EU (europa.eu)

[349] World Nuclear Association (2023), Nuclear Power in the European Union - World Nuclear Association (world-nuclear.org). Updated May 2023. Website accessed on 17 May, 2023.

[350] European Council (2022), https://www.consilium.europa.eu/en/infographics/how-is-eu-electricity-produced-and-sold/#:~:text=In%202022%2C%20the%20EU%20produced, followed%20by%20coal%20(15.8%25).

[351] World Nuclear Association (2023), Nuclear Power in the European Union. Updated May 2023. Website accessed on 23 May, 2023.

The increasingly ambitious climate targets combined with the unprovoked Russian invasion of Ukraine and its impacts on energy security have prompted some Member States to extend the operation of their nuclear power plants beyond their original design life[352] and/or to allow building new plants:

- The Netherlands reversed a previous decision to phase out nuclear power, announcing plans in 2021 to build two new nuclear units. The preliminary plans would see two nuclear reactors of between 1000 – 1650 MWe gross capacity to be completed around 2035, although there are no specific plans yet for starting their construction.[353]
- In 2022, France's government announced plans to build 6 new EPR-2 nuclear reactors at three sites as part of the country's national low carbon strategy plan. With an investment plan of between EUR 50-60 billion, the six reactors would have a joint capacity of almost 10 GWe. The first reactor is planned to be operational by 2035.[354]
- Belgium had plans to phase out the last of its seven reactors by 2025, but in January 2023 the Belgian government updated its energy strategy and now plans to extend the life of two nuclear reactors by 10 years (until 2036).[355]
- In 2023 Sweden proposed law changes to allow the building of new nuclear power plants.[356]

REPowerEU projections expect EU electricity production from nuclear power to remain fairly stable until 2030. However, the World Nuclear Association notes that a slight decrease from the current EU capacity can be expected in the 2023 – 2030 period, due to the closure of a number of reactors outweighing the capacity gains from new reactors.[357]

Nuclear power with a stable but not increasing demand, therefore, ranks **low** on this indicator, as the EU's forecasted capacity cannot be expected to grow significantly in the – for nuclear expansion projects – relatively short timeframe until 2030.

A.17.2.2 EU manufacturing growth

There are currently no quantitative indicators for assessing the expected growth of EU manufacturing of nuclear components by 2030.

With all ongoing, planned and proposed extension projects realised, approximately 40% of the current nuclear generation capacity will be replaced in the EU in the coming decades. There is, however, significant uncertainty both in the timeline and in the plausibility of these projects. At any rate, given the experience with the timespan required for the realisation of projects of such scale, it can be assumed that no more than the already planned capacity extension will be realised by or before 2030 – amounting to approx. 9.5% (9.3 GWe) of the current generation capacity. This constitutes a rather small share compared to other technologies.

Given the extent of confirmed plans to start the construction of new nuclear power plants in the EU in the coming years (before 2030), paired with the current manufacturing landscape of the EU nuclear industry, as well as its competitive position as technology and services provider, we

[352] European Commission (2016), Nuclear Illustrative Programme

[353] World Nuclear Association (2023), Nuclear Power in the Netherlands | Dutch Nuclear Energy | Holland Nuclear Power - World Nuclear Association (world-nuclear.org). Updated December 2022. Website accessed on 17 May, 2023.

[354] World Nuclear Association (2023), Nuclear Power in France | French Nuclear Energy - World Nuclear Association (world-nuclear.org). Website accessed on 17 May, 2023.

[355] Euronews (2023), Belgium extends life of its nuclear power industry by 10 years | Euronews

[356] World Nuclear News (2023), Changes to Swedish law proposed to enable nuclear new build : Nuclear Policies - World Nuclear News (world-nuclear-news.org)

[357] World Nuclear Association (2023), Nuclear Power in the European Union - World Nuclear Association (world-nuclear.org). Updated May 2023. Website accessed on 17 May, 2023.

conclude the EU manufacturing industry is not expected to grow considerably by 2030. Therefore, nuclear power ranks **low** on this indicator.

A.17.2.3 Competitiveness threats, market concentration and other vulnerabilities

In the past, nuclear power plants were mostly manufactured by national vertically-integrated companies, however the current market for new build and replacement of SSCs has international vendors competing for projects (given they meet national content requirements).[358] Major international nuclear energy technology vendors include Framatome (FR), Candu (CA), Rosatom (RU) Westinghouse (US), GE Hitachi (US/JP), Mitsubishi Heavy Industries (JP), Toshiba (JP), Doosan (KR), KEPCO (KR), SNPTC (CN), CNNC (CN), CGN (CN) and NPCIL (IN).[359] Particularly, CGN, or the China General Nuclear Power Group, is the largest constructor of NPPs worldwide.[360] In terms of market share, however, Russia's Rosatom dominates the global market of NPP construction with a 74% share, and 34 on-going international projects[361]. Within the EU, both Bulgaria and Hungary have standing plans/binding agreements with Rosatom, commissioning new units/power plants[362]. In the current geopolitical climate, given the economic sanctions against Russia, this poses an extreme risk on the project realisation.

In the EU, the main nuclear technology vendor is Framatome, with four major industrial sites based in France. Framatome has previously indicated its ability to provide 50% of safety classified and auxiliary equipment, as well as instrumentation and control through its own global supply chain, with the remainder being sourced internationally. [363]

For very large modern nuclear reactors (Gen III+) the forging of the reactor becomes an important supply chain bottleneck. Pressure vessels require plants and equipment which are scarce worldwide, and which can produce only a few vessels per year (alongside orders from other industry sectors).[364] Forging capacity of about 140 – 150 M (14-15,000 tonnes) is needed, and these should accept hot steel ingots of 500 – 600 tonnes.[365] Specifically, heavy forging capacity in operation is concentrated in Japan, China, France, Italy, Germany, Czechia and Russia. The EU currently offers several options for pressure vessel equipment, listing 8 forging presses in operation (see Table 6 below), with most of them supplying pressure vessels for EU and international nuclear power plants. Individual large presses throughput stands at around four pressure vessels per year, though the potential is greater than this.[366] Furthermore, new capacity is being built in Japan and China.

[358] World Nuclear Association (2020), Heavy Manufacturing of Power Plants - World Nuclear Association (world-nuclear.org)
[359] Kaser (2014), The World Nuclear Supply Chain – an Overview
[360] European Commission (2020), Clean Energy Transition – Technologies and Innovations. SWD(2020) 953
[361] Rosatom (n.d.), Rosatom key figures. Available at: https://www.rosatom-europe.com/en/global-presence/key-figures/
[362] Szulecki et al. (2023), Russian nuclear energy diplomacy and its implications for energy security in the context of the war in Ukraine
[363] International Framework for Nuclear Energy Cooperation (2017), Global Supply Chain and Localisation, Issues and Opportunities: A Conference on the Customer Dialogue – Summary Conference Report.
[364] Trinomics (2021), Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis - Publications Office of the EU (europa.eu)
[365] World Nuclear Association (2021), Heavy Manufacturing of Power Plants - World Nuclear Association (world-nuclear.org)
[366] Ibid.

Table 6: Companies with heavy forging capacity in operation in the EU. Source: World Nuclear Association (2021)

Company	Heavy forging press (tonnes)	Max. ingot (tonnes)
Framatome, Creusot Forge (FR)	11,300, 9,000	500
GIVA Forgiatura (IT)	6,000	150
Pilsen Steel (CZ)	10,200, 12,000	250
Vitkovice (CZ)	12,000	250
Saarschmiede (DE)	8,670, 12,000	370
Società delle Fucine (SdF) (IT)	12,600	530
OMZ Skoda JS (CZ)	NA	NA
Equipos Nucleares SA (ENSA) (ES)	Nil, uses forgings to make RPVs	NA

The EU nuclear fission industry also faces supply chain challenges derived from the reduced construction rate for nuclear power plants in the region. Specifically, challenges related to the obsolescence of SSCs and the EU's lack of availability of qualified personnel to design, build and operate the plant, including in the products and services supply chain. This affects not only new-build reactors, but also the operation and maintenance activities, or upgrade of existing operating units. [367] Moreover, technical barriers to import limit the capacity for sourcing components internationally.[368]

The International Atomic Energy Agency (IAEA) has established a COVID-19 operational experience network. Measures taken by nuclear facility operators include reducing staffing, introducing remote work, hygiene measures, medical screening, self-isolation and travel restrictions.[369] Operators have conducted reviews of spares in order to ensure the availability of critical materials and parts in case of supply chain restrictions. While acknowledging that supply chain restrictions could theoretically have a long-term impact on new nuclear projects or major refurbishments, the IAEA indicates that "no [IAEA] Member State reported the enforced shutdown of any nuclear power reactor resulting from the effects of COVID-19 on their workforce or essential services such as supply chains."[370] It must be noted that business continuity plans of nuclear operators had assessed the risks and determined adaptation measures to pandemics already before the COVID pandemic hit.

Finally, the Long-Term Strategy of the European Commission notes other challenges for nuclear energy, such as public acceptance issues in some Member States and increasing competitiveness of other energy sources as well as uncertain electricity market prices.[371]

Based on the above, nuclear fission energy ranks **low** in this indicator.

[367] World Nuclear Association (2020), Launch of the World Nuclear Supply Chain: Outlook 2040 report

[368] International Framework for Nuclear Energy Cooperation (2017), Global Supply Chain and Localisation, Issues and Opportunities: A Conference on the Customer Dialogue – Summary Conference Report.

[369] IAEA (2020), IAEA Steps up Support for Nuclear Facility Operators during COVID-19 Crisis

[370] IAEA (2020), The operation, safety and security of nuclear and radiation facilities and activities during the COVID-19 Pandemic

[371] European Commission (2018), In-depth Analysis in Support of the Commission Communication COM(2018) 773 A Clean Planet for All

A.17.3 Overall assessment

With an overall score of 6 nuclear fission is **not considered a strategic technology** in terms of the future EU demand, expected manufacturing growth, and current competitiveness threats, market concentration and other vulnerabilities.

A.18 Annex 18: Energy Efficiency – Insulation Materials

A.18.1 Introduction

Building (thermal) insulation materials are used in the construction sector to prevent heat from passing building materials, while providing comfort to occupants. The proper installation of high-quality insulation materials is crucial for a successful insulation system. Insulation is an important technology for reducing energy consumption by preventing heat/cold losses in buildings. The appropriate level and type of insulation are influenced by the weather and the expected performance of the building, depending on the thermal conductivity of the materials (which is typically lower than 0.1 W/(m.K)).

There are several ways to classify insulation material based on their physical (solid, liquid, or gaseous) or chemical (fossil, wood/vegetal, or mineral-based) characteristics, the temperature level they are used for (low, medium, high like for industrial application, such as oven insulation).

This paper looks only at insulation material for buildings (i.e., low temp), looking at the 3 categories[372]:

- traditional building insulation materials comprising plastic foam (e.g. expanded and extruded polystyrene, polyurethane) and mineral wool (e.g. stone or glass)[373], and other materials like polyethylene, polyvinyl, wood and organic fibre

Prefabricated systems for deep energy retrofits of residential buildings[374]

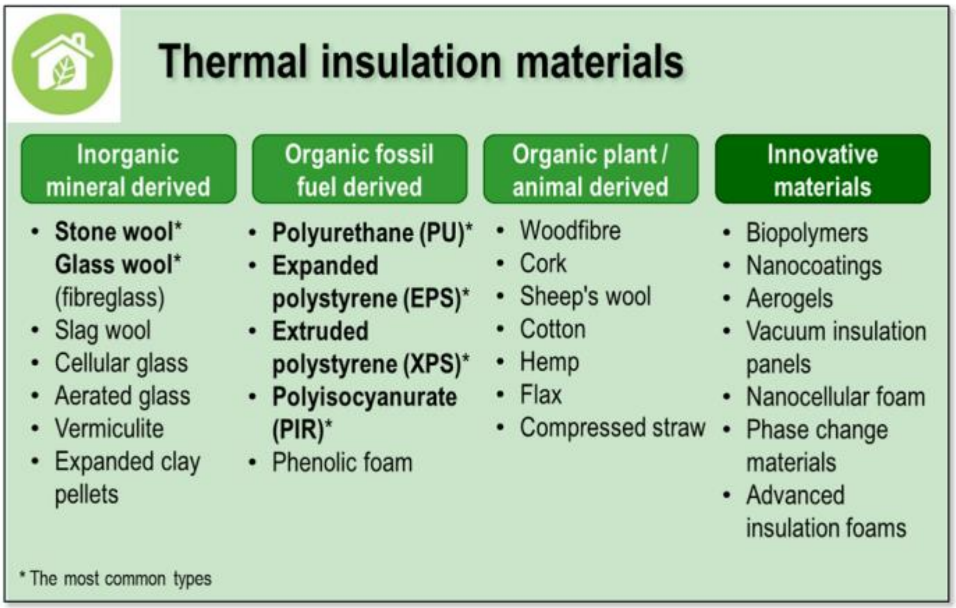
Advanced insulation materials for building envelopes (e.g. super insulating materials (SIM), phase change materials, etc.)[375]

A.18.2 Supply chain overview

Insulation materials improves the thermal performance of the building envelope. Several insulation materials can be used to reduce energy use in new buildings (near-zero-energy buildings) as well as in deep renovation projects (Figure 32). The types of material are depicted in the next figure.

[372] https://www.bpie.eu/publication/construction-value-chain/
[373] https://purios.com/en/blog/insulating-materials-types-of-thermal-insulating-materials-in-buildings-application-and-properties#:~:text=The%20most%20common%20thermal%20insulation,favourable%20physical%20and%20chemical%20parameters
[374] https://www.bpie.eu/wp-content/uploads/2016/02/Deep-dive-1-Prefab-systems.pdf
[375] https://www.bpie.eu/wp-content/uploads/2016/02/Deep-dive-2-Advanced-insulation-materials.pdf

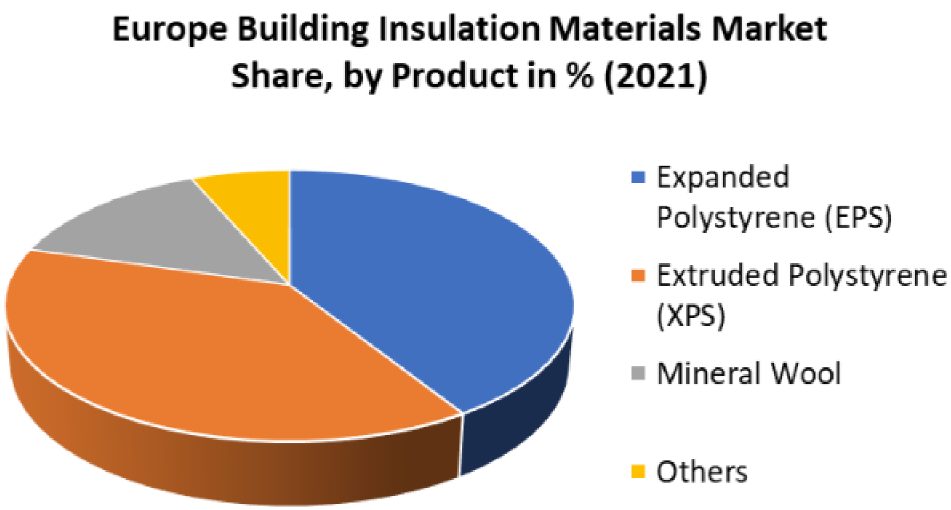
Figure 32: Types of materials used in thermal insulation of buildings



Source: JRC (2018)[376]

Today, the largest market potential for insulation materials in building is dominated by the materials offering the best performance per unit cost, such as mineral (stone and glass) wool and plastic (polymeric) foams such as polystyrene and polyurethane (Figure 33). In the future it is expected that new emerging insulation solutions with similar or higher performances based on biotic renewable or biopolymers will be adopted by the market.

Figure 33: Building Insulation Materials Market in Europe

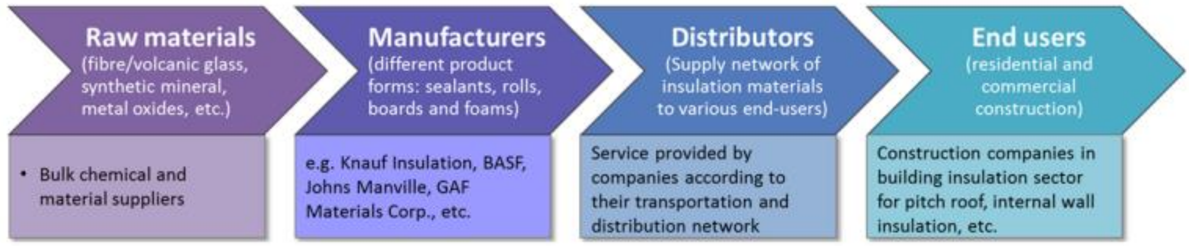


Source: Stellar Market Research[377]

[376] JRC (2018), Competitive landscape of the EU's insulation materials industry for energy-efficient buildings.
[377] https://www.stellarmr.com/report/Europe-Building-Insulation-Materials-Market/1251

The value chain of the building thermal insulation materials comprises a multi-level network of raw material suppliers, manufacturers of finished insulation products and distributors to end-users, such as construction companies (cf. Figure 34).

Figure 34: Value chain of building insulation material



Source: JRC representation with data from Visiongain, 2017; JRC (2018)[378]

Different raw materials (i.e. cokes, base chemicals, minerals, metal oxides, etc.) are required for producing building insulation products, with their underlying industries.

A.18.3 Assessment per measure

A.18.3.1 EU demand

The Renovation Wave sets the objective to at least double the annual energy renovation rate by 2030, and to foster deep energy renovations. According to Buildings Performance Institute Europe (BPIE), the current annual deep renovation rate stands at only 0.2% on average in the EU. If the EU is to achieve both its 2030 climate target (the building sector GHG emissions should decrease by 60% by 2030) and climate neutrality by 2050, this figure must drastically (by a factor of 15) increase to reach 3% by 2030 and be maintained up to 2050 (by 2030, 70% of the renovations taking place should be deep).[379] Deep renovation also holds the potential to deliver on multiple other benefits for individuals and society. This makes a paradigm shift on deep renovation even more important.

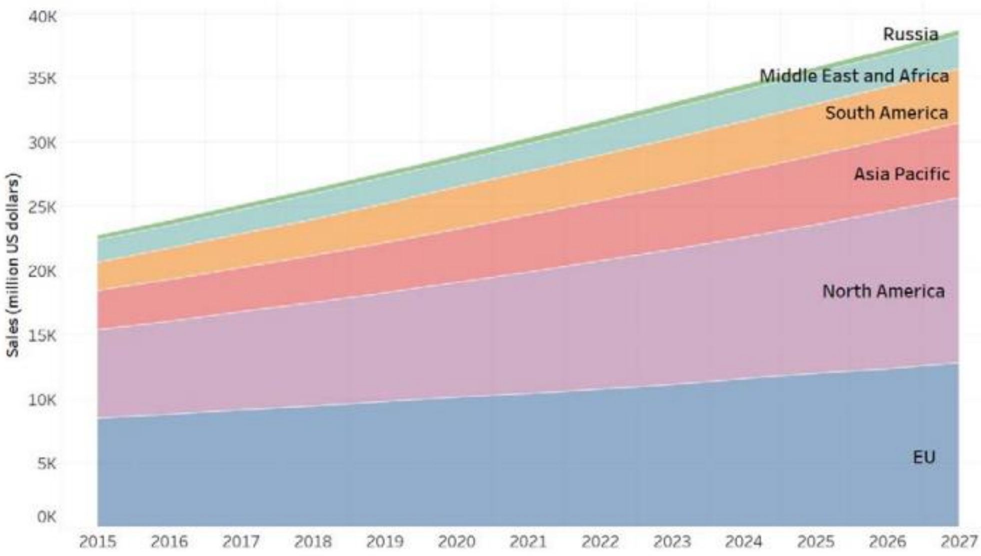
Deep renovation is a process of capturing, in one (or a few) step(s), the full potential of a building to reduce energy demand. It achieves the highest possible energy savings and leads to a very high energy performance, with the remaining minimal energy needs fully covered by renewable energy, while also delivering an optimal level of Indoor Environmental Quality to occupiers.

The increase of demand for thermal insulation materials in building applications is driven by climate policies, and particularly the renovation wave, and was expected to be at a CAGR of 3.48% in the EU (2016-2027).[380] Comparatively, thermal insulation plays a highly significant role in the future energy landscape that is difficult to cover with any alternatives, namely the reduction of energy consumption needs as developed in the REPowerEU plan.

Based on the above, building insulation material ranks **high** in this indicator.

[378] JRC (2018), Competitive landscape of the EU's insulation materials industry for energy-efficient buildings.
[379] https://www.bpie.eu/wp-content/uploads/2021/11/BPIE_Deep-Renovation-Briefing_Final.pdf
[380] https://publications.jrc.ec.europa.eu/repository/handle/JRC108692

Figure 35: Global market forecast for building thermal insulation, by region



Source: JRC representation with data from Visiongain, 2017; JRC (2018)

A.18.3.2 EU manufacture

According to Stellar Market Research[381], the European Building Insulation Materials market size in 2021 was valued at 10.54 billion USD. The total revenue is expected to grow at CAGR of 2.99% between 2022 and 2027, which is a little bit lower than the forecast of JRC mentioned previously (3.48%). This would allow reaching nearly 12.58 billion USD in 2027, which is aligned with JRC forecast back in 2018, expecting the demand to reach 12.77 billion USD by 2017.

According to JRC, between 2012 and 2016, it is estimated that more than 127 billion euros for energy renovations on average per year have been invested in the EU-28, for all renovation levels (84.4 billion euros for 'light' renovations, 36 billion euros for 'medium' renovations and 6.9 billion euros for 'deep' renovations).[382]

According to another study published by JRC in 2018, the EU's demand for thermal insulation materials in building applications (in terms of value) was projected to increase at a CAGR of 3.5% between 2016 and 2027 (Figure 35). Wool minerals (glass and stone wool) and plastic foams (EPS, XPS, PUR) are the most sought after materials for building insulation.[383] This CAGR is expected to become slightly higher, due to the high ambitions for energy efficiency in the REPowerEU plan following from the goal to reduce energy consumption overall by 20%. Nonetheless, these CAGR values are far lower than the CAGRs expected for other clean energy technologies, which are generally above 10%.[384] Most of this demand is expected to be supplied via local manufacturers, as the EU has a very strong industrial base in insulation materials (discussed further in the next subsection).

The achievement of an annual deep renovation rate of 3% as well as the transition to 'near-zero-energy buildings' brings important structural changes in the construction and materials sectors. Given that the trend is clear and that the political discussions have been ongoing for more than a decade, these sectors are supposed to have anticipated the needs, and certainly started to adapt

[381] https://www.stellarmr.com/report/Europe-Building-Insulation-Materials-Market/1251
[382] https://publications.jrc.ec.europa.eu/repository/handle/JRC122347
[383] JRC (2018), Competitive landscape of the EU's insulation materials industry for energy-efficient buildings.
[384] See examples based on IEA scenarios in KU Leuven (2022), Metals for Clean Energy.

and develop in order to become more competitive, resource-efficient and sustainable. This is of course an important assumption, which has not been verified with the industry (due to time constraint). However, we advise not to take this for granted, and be cautious with the fact that maybe the material industry is not ready to ramp up as fast as required. At the same time, the real pace will mainly depend on the construction sector, which will pull the demand.

The successful implementation of the revised Energy Performance of Buildings Directive would also depend on the effective functioning and competitiveness of construction and material sectors in the EU. It is therefore necessary that high-quality materials are produced and delivered timely at an appropriate price.

Based on the above, building insulation material ranks **low** in this indicator.

A.18.3.3 Competitiveness threats, market concentration, and other vulnerabilities

JRC has analysed the competitive intensity of the global building insulation market and conducted a SWOT analysis of the major European companies operating in the insulation materials industry. It shows that the competitiveness of the European industry of thermal insulation materials in relation to other international competitors is **moderate to strong**. Six out of the top ten manufacturers worldwide are European companies and some of them are world leaders in the production of insulation materials.[385]

Overall, in 2018, the EU was a **net exporter of insulation materials**. With many European companies acting at different steps of the value chain of insulation products, the current supply of insulation materials in the EU could be considered as sustainable. However, in order to meet the increasing insulation requirements needed in buildings (cf. demand section), the European industry should strengthen its innovation capability and look further to the development of advanced insulation materials for both renovation of the EU building stock and construction of 'near-zero-energy buildings'.

At a worldwide level, the construction industry experiences shortages of essential building materials (among which insulation material), rising prices, disruptions in the supply chain up- and downstream, since the beginning of the COVID-19 pandemic and, in some cases, already prior to it.[386]

Since the acceleration of the renovation rate across Europe, exacerbated with the COVID-19 pandemic, shortage in the supply of insulation material (like other construction materials and products), has occurred everywhere, "building contractors being warned of delays"[387] (2021), also in the USA, "abundance has been lacking in the context of ongoing supply chain disruptions and worker shortages"[388] (2022), or in the UK "Brexit and the COVID-19 pandemic have become the perfect storm for construction companies who depend on daily lorry deliveries"[389] (2022).

The competitive intensity of the global building insulation market was estimated from different perspectives using the Porter's five forces[390]:

385 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108692/kj1a28816enn.pdf
386 https://www.suretybondprofessionals.com/shortage-of-building-materials/
387 https://www.cmogroup.com/insulation-shortage-halts-construction-plan-ahead-and-have-a-plan-b-say-experts/
388 https://insulation.org/io/articles/industry-not-insulated-from-supply-chain-issues/
389 https://welpmagazine.com/shortages-in-the-insulation-market/
390 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108692/kj1a28816enn.pdf

- Competitive rivalry: due to the growth rate expected for the building insulation market in the next 10 years and the high product differentiation offered by major players, the competition in the market could slow down.
- The threat of new entrants is evaluated as low to moderate, due to higher production cost of building insulation materials of new entrants as compared to existing producers.
- The overall bargaining power of suppliers is considered moderate.
- Low R&D investments and lack of skilled manpower represent barriers to the development of alternative substitutes for insulation materials. Their low availability and higher production cost make the potential substitutes uneconomical for the end use industry. Therefore, the threat of substitutes is low.
- A large number of buyers are active and most of them consider backward integration, resulting in the high bargaining power of buyers.

Consequently, the incumbent insulation material industry has a competitive advantage.

The top 10 global companies producing thermal insulation products are: BASF SE (Germany), Beijing New Building Material Group Co. Ltd. (China), GAF (USA), Johns Manville (USA), Kingspan Group (Ireland), Knauf Insulation (Germany), Owens Corning Corporation (USA), Rockwool International (Denmark), Saint Gobain (France) and Synthos S.A. (Poland). Six out of the 10 major manufacturers of building insulation materials are European companies.[391] The Stellar Market Research confirms the top 10, and adds: Huntsman Corporation (US), Firestone Building Products Company (US), Cabot Corporation (US), Covestro AG (Germany), URSA Insulation, S.A. (Spain), Paroc Group Oy (Finland), Atlas Roofing Corporation (US).[392]

These key EU companies provide together a complete range of insulation materials for buildings applications and are major producers of one or two of them. For example, Rockwool group produces only mineral wool, but is the world leader of stone wool insulation products.

There are many other large companies and SMEs in the EU that manufacture and supply materials for insulating residential and non-residential buildings, both new and being renovated. For example, the polyurethane insulation industry in the EU involves about 61,800 companies, providing 258,000 jobs (PU Europe, 2017).

Advanced insulation materials for building envelopes are seen as an opportunity for industrial innovation. Europe is a leader in innovation for deep renovation of buildings and has the potential to become an export market of these new techniques (e.g. prefabricated systems) in the future. Innovative opportunities will be driven by the increasing insulation thickness requirements as well as consumer demand/preferences, manufacturer choice, prices and resources. New government initiatives and regulation can also be a driver for innovation.

The competitiveness of the European industry of thermal insulation materials for building applications in relation to non-EU international competitors is considered moderate to important. However, a global growing demand could affect such competitiveness.

Europe should preserve its leadership in innovation for thermal insulation products, driven by its very ambitious targets for the deep renovation of buildings. There is also a need to invest further in research for development of smart solutions (e.g. reflective coatings, phase change materials, etc.), advanced materials with super insulating properties and IT integration (BIM).

Based on the above, building insulation material ranks **low** in this indicator.

[391] Ibid.
[392] https://www.stellarmr.com/report/Europe-Building-Insulation-Materials-Market/1251

A.18.4 Overall assessment

With an overall score of **8**, building insulation is considered a **medium strategic technology** in terms of the future EU demand, expected manufacturing growth and current competitiveness threats, market concentration and other vulnerabilities.

MJ-03-23-130-EN-N

ISBN 978-92-68-02700-4

Publications Office
of the European Union