FIT FOR NET-ZERO:

55 Tech Quests to accelerate Europe’s recovery and pave the way to climate neutrality

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The analysis and findings in this report draw on information and views provided by over 100 experts, innovators and entrepreneurs across Europe. They were asked to share their thoughts on how Europe can accelerate clean technology innovation and scale-up. Their comments and suggestions were of great value. They include:

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1. FOREWORD

This study describes how investments in next-generation clean technologies can accelerate Europe's economic recovery and transformation from the bottom-up. It is a practical action plan and investment guide for policymakers and investors to stimulate an economic recovery at the speed and scale needed, and set the EU on track to deliver on its vision of a climate-neutral economy by 2050 that is prosperous, modern, secure and competitive.

We illustrate this with 55 European Technology Quests that are ripe for financial support, offering attractive long-term returns and, together, help form a roadmap to climate-neutrality. Our work shows how these 55 Quests can deliver emissions reductions in line with increased EU ambitions of at least 55% by 2030 and a net-zero trajectory by 2050. The 55 Technology Quests can stimulate new markets worth some €13 trillion over two decades, and secure up to 12.7 million jobs by 2030 – both by creating new jobs, and by transforming existing jobs.

Our results confirm that Europe's clean tech revolution can be as significant as the digital revolution and plays to Europe's core industrial strengths and leadership. We believe that a climate-neutral, competitive, and dynamic Europe, driven through our six identified clusters (hydrogen, gigafactories, electrification, smart grids, bioeconomy, and carbon capture utilization and storage) can set a standard for others and help lead our planet to climate safety and economic sustainability.

This project and its recommendations have benefitted from expert inputs from many eminent innovators, entrepreneurs, corporate strategists, and policymakers, whom we sincerely thank for their invaluable contributions. There has also been no better fit for our teams than to work with Breakthrough Energy – an organization founded by Bill Gates whose mission is to lead the world to net-zero greenhouse gas emissions – to address how Europe seizes this unprecedented moment to boost clean energy investment and innovation to deliver a net-zero future.

Capgemini Invent was founded around a desire to find ground-breaking, transformational solutions to answer the challenges of our time – and to help build those solutions. Europe must work toward the delivery of these 55 clean Technology Quests. The clock starts now.

Paris, October 2020

Cyril Garcia,

CEO of Capgemini Invent

Capgemini Group Executive Board Member in charge of Corporate Social Responsibility October 2020

2. EXECUTIVE SUMMARY

"I will insist that recovery plans don't just bring us out of the crisis but also help us propel Europe forward to the world of tomorrow."

Ursula von der Leyen,
President of the European Commission, State of the European Union Address, September 2020

In July 2020, European leaders launched Next Generation EU, a €750 billion EU recovery fund consisting of grants and loans. This is on top of a €1.074 trillion Multiannual Financial Framework package, the EU's long-term budget covering the years 2021-2027. Of this combined €1.826 trillion, some €550 billion, or 30% of the full recovery-plus-budget package, is earmarked for climate objectives. Now, Member States are beginning to present their own national recovery and resilience plans. As they do, they should be asking a few key questions.

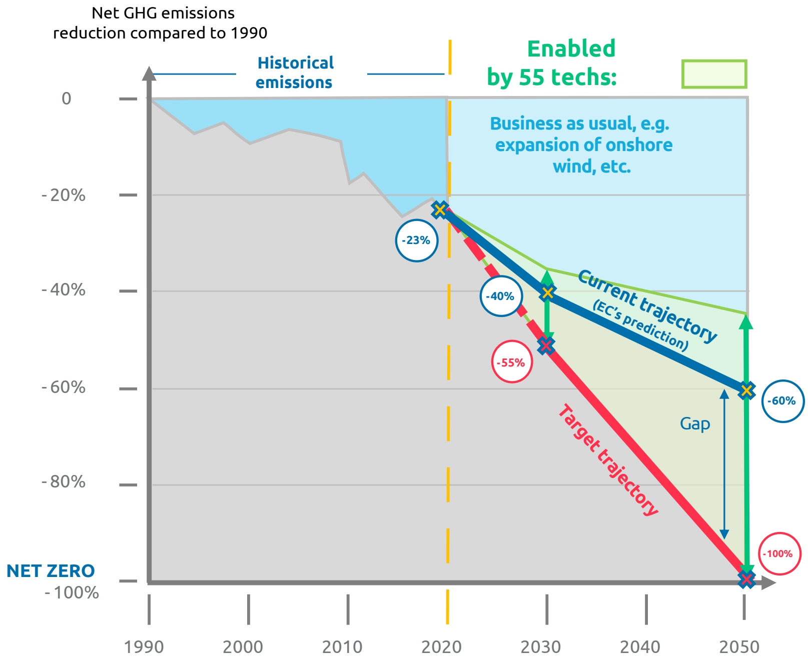
Do the national recovery plans align with the EU's climate law and net-zero emissions target for 2050? How about the 55% emission-reduction target by 2030, which President of the European Commission Ursula von der Leyen proposed in her September 2020 State of the European Union Address? How can we ensure another von der Leyen proposal – that 37% of Next Generation EU funds be directly spent on European Green Deal objectives – is fulfilled?

On a more fundamental level, do national plans contain enough detail to turn political aspirations into real-world projects that ensure emissions reductions are on the trajectory we know we need to beat climate change? If not, what can be done to ensure the plans achieve maximum impact for the economic recovery and the climate?

To answer these questions, Breakthrough Energy commissioned Capgemini Invent and its in-house teams to identify from the bottom up 55 high-impact climate Technology Quests. The selection process was based on a rigorous methodology and a comprehensive review of more than 200 state-of-the-art clean tech projects. Over 100 leading European experts from the private sector, government, NGOs and academia provided valuable input.

At a time when people are facing the most acute financial uncertainty in generations, investing in these Technology Quests will help put the continent's economy on a much firmer footing. They can create sizable and dynamic global markets for clean energy and other fast-growing industries, create millions of good jobs and dramatically improve Europe's ability to address the central challenge that humanity is facing – climate change. The clean technologies identified are at different stages of maturity – some are being researched in labs, while others are already in a demonstration phase or are even deployed in EU Member States. Each and every one is currently being supported by existing ecosystems of European researchers, entrepreneurs, investors and corporations.

Figure 1 - Europe's emissions reduction pathway



[1]Depending on the technology, accounted emissions can be expressed in real physical CO_2 emissions, or CO_2 equivalent emissions if other of the six greenhouses gas emissions are involved, such as methane or refrigerants.

To help unleash these technologies and make them more cost-competitive with high-emission alternatives, the usual 25-year innovation cycle must be compressed and accelerated. This won't be easy – more substantive work and more public support is urgently required – but there is no mistaking: Europe is in pole position to become the global leader in dozens of new climate technologies that are in critical stages of their development.

Key conclusions from this research include:

1. **Dramatic emission reductions are possible in the five key economic areas:** The emissions reductions delivered by these 55 European Technology Quests can help Europe achieve 55% CO_2e[1] reductions below 1990 levels by 2030 and deliver a climate-neutral economy by 2050, across five economic areas (Energy, Industry, Buildings, Transport, Food and Land Use).

2. **More innovation investments mean better jobs:** The 55 Technology Quests will require around €144 billion of public and private investment annually and will support 12.7 million high-quality and resilient jobs. EU and Member State recovery funds can be directed toward accelerating these Quests to make Europe more competitive as the current economic crisis abates. Several recovery plans – including France's and Germany's – suggest that developing new, clean technologies like green hydrogen are now overriding political and investment priorities, which can help spur additional job opportunities.

Figure 2 - Emissions reduction by 2050 per economic area, compared to the current emissions

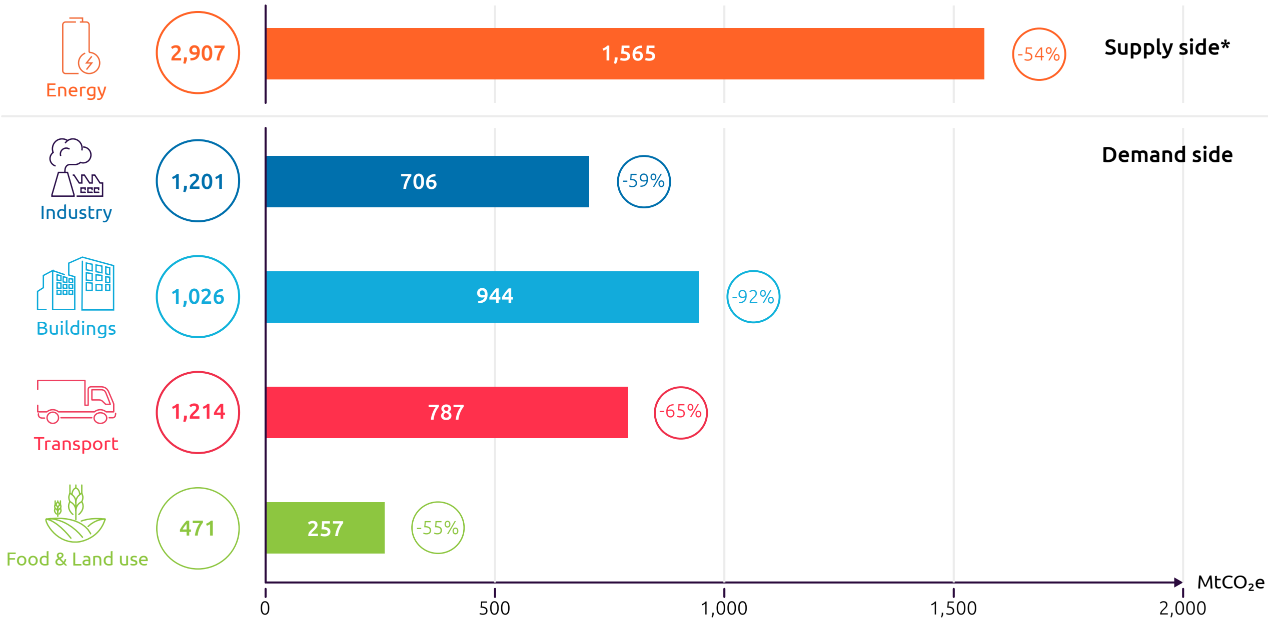
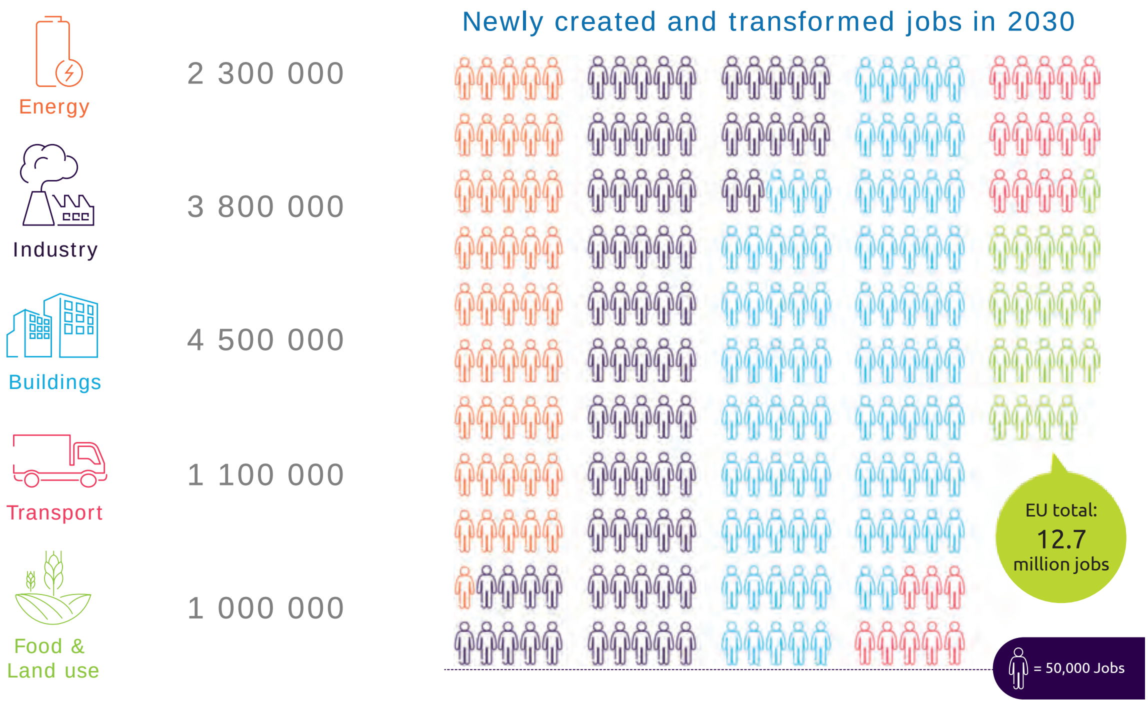


Figure 3 - Jobs secured by the Technology Quests across the 5 economic areas

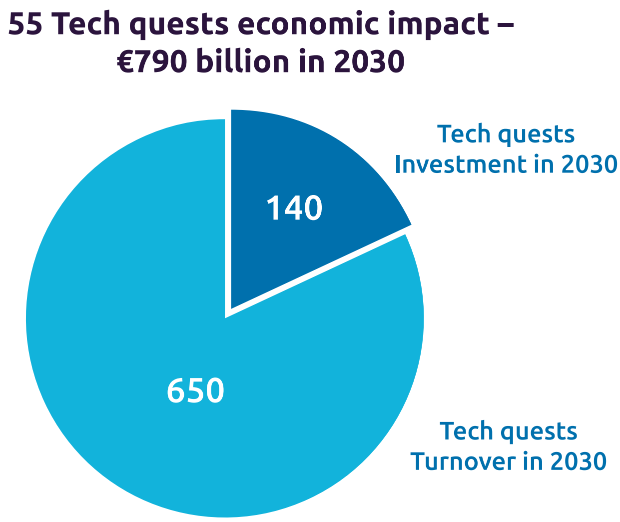


3. **This is a massive economic opportunity:** Over time, these 55 Technology Quests can create €790 billion of gross value added by 2030, building toward a €12.9 trillion opportunity from 2030 to 2050. Innovative investments in all five economic areas (Energy, Industry, Buildings, Transport, Food and Land Use), in electrification, green hydrogen, smart grids, gigafactories, the bioeconomy and carbon capture, utilization and storage will help build the sectors of the future.

4. **There are attractive returns on investment:** Every €1 invested in this clean technology portfolio is expected to generate €9 of future turnover in European markets by 2050.

5. **There are cascading benefits:** Improved air quality, reduction of noise pollution, increased energy independence, more European technology leadership, expansion of low-carbon industries and improved food safety are all benefits these Technology Quests will help deliver.

Figure 4 - European value-add generated by the Technology Quest

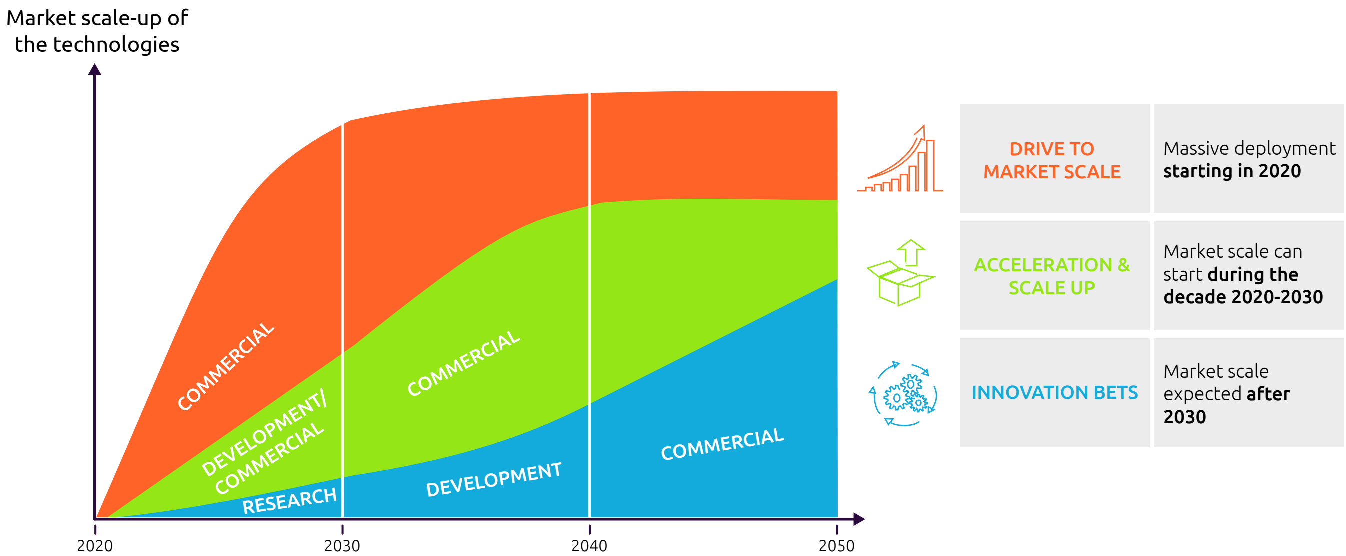


6. **Not all technologies are at the same stage of maturity:** That is why investment in a portfolio of climate Technology Quests is so important. A portfolio approach supports companies and employment across the full spectrum of the innovation cycle, from early-stage demonstration to late-stage deployment in sectors including Energy, Industry, Transport, Buildings and Food and Land Use. A portfolio approach helps secure immediate benefits (emission reduction, jobs, economic recovery, etc.), while also diversifying risk and paving the way for long-term European leadership in the climate technology markets the world will rely on for decades to reach net-zero. The report includes a set of policy and support measures to help set the right framework conditions for projects at different development stages to take off and scale quickly.

This report provides the full list of 55 Technology Quests, the methodology applied, the calculations and assumptions used. We hope the inputs and perspectives contained in this report are useful to teams working to boost clean technology innovation investments in recovery and resilience plans both at the European Union and EU Member State levels.

This is necessary because one of the lessons of COVID-19 is the need to better anticipate and prepare. Therefore, Europe must prioritize forward-looking research and innovation[2] – to build next-generation solutions that form the basis of our long-term economic recovery from this crisis and help ensure we are better prepared as other systemic challenges emerge.

Figure 5 - Market scaling up trajectory between 2020 and 2050, per level of maturity



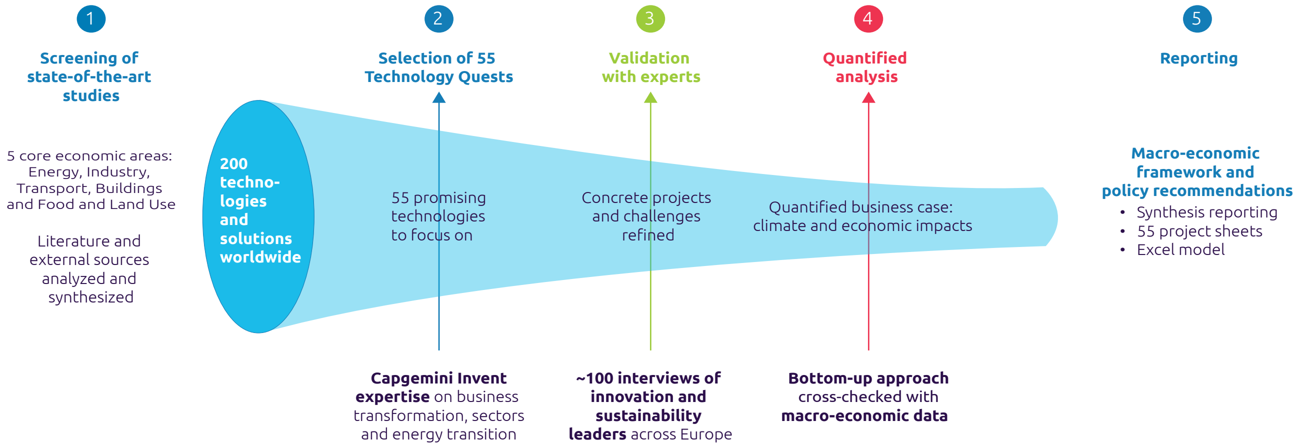
[2]Recent analysis for the US has also underlined the benefit of R&D spending in stimulating the economy: If the US increased R&D spending to 1% of GDP by 2030 (approximately $315 billion annually, i.e., €267 billion), that investment would support 3.4 million US jobs and add $301 billion (€255 billion) in labor income, $478 billion (€405 billion) in economic value, and $81 billion (€68 billion) in tax revenue. https://www.breakthroughenergy.org/reports/r-and-d-impact-report/

3. METHODOLOGY

The general objective of the report is to underscore the role of technology innovation investments, and a supportive policy environment, in shortening the usual 25-year technology-to-scale maturity cycle to about 10 years, and to make significant progress and deliver impacts by 2030. We have studied past technology developments and extrapolated from the experience. This report is bold by nature. The Quests propose investments at speeds which the authors believe are both practical and commensurate with a net-zero emissions goal by 2050. An additional Excel spreadsheet contains the detailed calculations, sources and proxies. Readers are invited to make their own assessment on acceleration and targets proposed.

The study used a five-step approach to research and analyze existing and future technologies, as described in this diagram:

Figure 6 - Methodology of the study



Step 1: Screening state-of-the-art studies

As a first step, our team conducted an in-depth review of the innovation landscape and 200 promising clean technologies used across the five economic areas that contribute to global GHG emissions: energy, industry, buildings, transport and food and land use.

Two criteria were used to short-list each individual technology: its ability to support Europe's sustainable recovery, and to help deliver on the European Green Deal. For each short-listed technology, our analysis led to the identification of:

- Relevant projects – recent or ongoing.
- Promising or successful startups.
- Typical ecosystem players and key stakeholders (public and private).
- Key challenges and enablers.

Step 2: Selection of 55 Technology Quests

A European clean Technology Quest is a concrete and quantified macro-project combining one or several technologies linked in solving a common climate technology challenge. For instance, creating availability of electricity from combined solar generation, storage, and grid (Technology Quest #6).

The following criteria were used for the Technology Quest selection process:

- Contribution to the net-zero trajectory, i.e., impacts in terms of CO_2 mitigation.
- Potential to create new markets.
- Creation of high-quality, well-paid jobs.
- Global innovation leadership over the short-, medium- and long-term.
- Ability to deliver CO_2e[3] emissions reductions and jobs in this decade (2020-2030). This is a key priority to put Europe back on track following the COVID-19 crisis.

55 clean Technology Quests were selected and grouped into three maturity levels:

1. "Drive to market scale": these Quests describe how best-available technologies can and should be massively deployed, starting now.
2. "Acceleration and scale up": projects which address technologies closer to market readiness, with market scale beginning during the decade 2020-2030. In this category, large-scale pilots will need to be operational by 2025, and replicated by 2030 at an EU-wide scale.
3. "Innovation bets": clean technologies for which R&D is still emerging and climate mitigation potential is expected between 2030 and 2050, with market scale expected only after 2030.

[3]Depending on the technology, accounted emissions can be expressed in real physical CO_2 emissions, or CO_2 equivalent emissions if any of the six greenhouses gas emissions are involved, such as methane or refrigerants.

Figure 7 - Distribution of the Technology Quests across the innovation cycle by economic area and maturity

Domain	Innovation bet	Acceleration and scale-up	Drive to market scale	Total
Energy	2	8	3	**13**
Industry	1	8	4	**13**
Buildings	1	2	3	**6**
Transport	3	11	3	**17**
Food and Land Use	2	3	1	**6**
Total	**9**	**32**	**14**	**55**

Step 3: Validation with experts

100+ structured interviews of renowned innovators, entrepreneurs, corporate leaders, strategists, and policymakers were conducted, covering all technologies and economic areas addressed by the study. Experts were invited to share their experience, vision and priorities for the technologies and types of projects identified, then these insights were integrated into project descriptions and quantified analysis.

Experts were also asked to recommend the types of policy and funding support needed from stimulus plans and budgets to boost these Quests. Quest segmentation by maturity helped focus expert input and allowed them to identify policies and investments which will reduce typical scale-to-market cycles from 20-25 years to a shorter timeframe of 10-15 years.

Step 4: Quantitative analysis

The expected results from delivering the 55 Technology Quests were analyzed in a model, focusing on three criteria to help boost a sustainable economic recovery from the COVID-19 crisis:

- Annual reduction of CO_2 emissions;
- Economic impacts in terms of investment needs and turnover generated;
- Jobs created or transformed in Europe, including direct and indirect jobs for domestic and export markets.

These results were calculated[4] at both a project-level as well as estimated according to the projected market sizes in 2030 and 2050.

Step 5: Reporting

The calculations and Quests are summarized in 55 fact sheets, which describe each element of the technology and its impacts. The fact sheets provide a fuller description of the Technology Quests, key issues, typical projects, the CO_2 emissions-reduction potential as well as market and job creation opportunities. The detailed calculations are also available in a spreadsheet that has been made publicly available online alongside this report on Capgemini Invent's website. These 55 Technology Quests build on the EU Commission's own 1.5Tech scenario and provide additional detail on the specific technology mix needed.

> ***"What we really need in order to change the game are innovative facilities and business models that go to scale, supported by EU Green Deal aligned regulations."***
>
> **Diego Pavia**, CEO InnoEnergy

[4]The full description of the methodology and calculations used for the business case approach (quantitative assessment) are provided in the Appendix.

THE EUROPEAN COMMISSION'S 1.5TECH SCENARIO

The 1.5Tech scenario was developed and published by the European Commission in 2018, based on the PRIMES energy system model. This scenario is part of the EC Communication "A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy."[5]

Until 2030, all the published scenarios provide the same figures, based on the existing EU policy framework and following known Member State policies, leading to 45% GHG savings compared to 1990. By 2050, the first five scenarios focus separately on electrification, hydrogen, power-to-X, energy efficiency and circular economy. Their cost-efficient combination is assessed in a sixth scenario that achieves higher emission reductions.

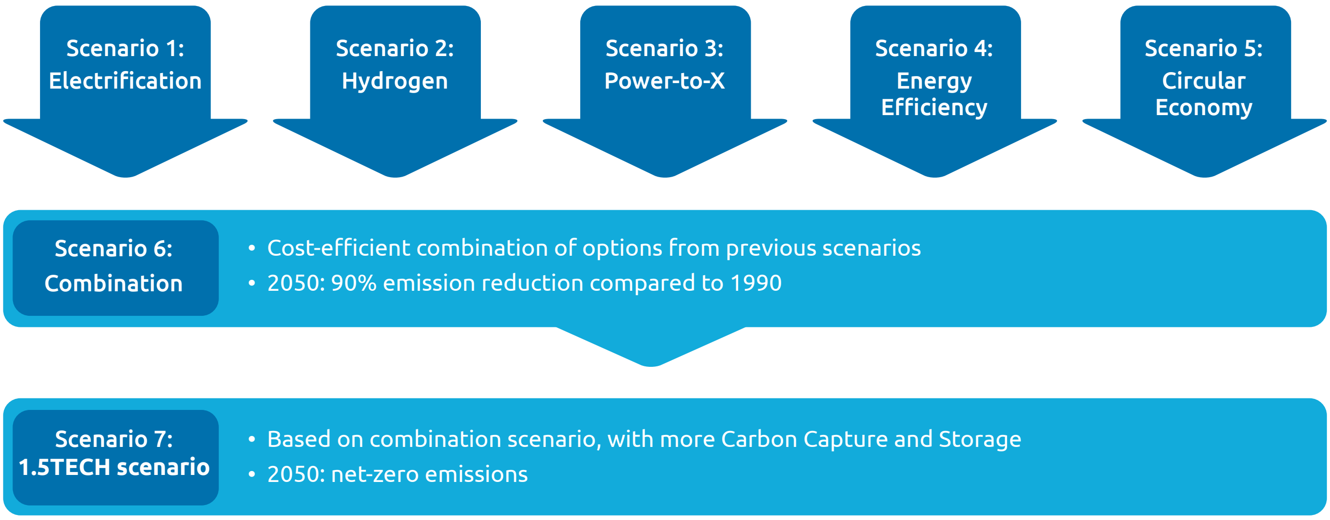
1.5Tech is a more ambitious scenario: it combines options from the previous ones and targets net-zero emissions in 2050. In this scenario:

- hydrogen and power-to-X technologies become important,
- the required electricity generation increases from 3,221 TWh today to 7,948 TWh to feed hydrogen, power-to-X and electrification,
- the 1.5Tech scenario increases the contribution of all technologies by concerted technology development.

The 55 Quests can deliver the 1.5Tech scenario, and cover key strategic technologies aiming to:

- massively green electricity and decarbonize heat,
- shift industrial processes to electricity and hydrogen,
- accelerate decarbonization in buildings by reducing energy demand,
- provide C-liquids and N-liquids to long-distance transports and develop hydrogen and e-mobility for shorter distances,
- reduce emissions of food, crops and livestock.

Figure 8 - Overview of the EC's 1.5 Tech Scenario



[5] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN

4. NET-ZERO EUROPE: CRITICAL PRIORITIES TO DELIVER A SUSTAINABLE RECOVERY

> ***"The message is very clear: in the absence of much faster clean energy innovation, achieving net-zero goals in 2050 will be all but impossible."***
>
> **Dr. Fatih Birol,** Executive Director of the International Energy Agency (IEA)

The COVID-19 pandemic has caused major disruptions and sent shockwaves across the European economy. As a consequence of global lockdown measures, the energy, transport and industrial sectors have been severely affected and unemployment is increasing. IEA data shows that the curtailment of global economic activity and mobility during the first quarter of 2020 reduced global energy demand by 3.8% compared with the first quarter of 2019, which led to a short-term and temporary reduction in global CO_2 emissions.[6] Europe's energy demand declined by as much as 5% over the same period. Government lockdowns have also prompted changes in behavior. More people are teleworking, business and leisure travel has been sharply reduced, and consumers have shifted more of their purchases online.

As countries design economic recovery plans, there is an unprecedented opportunity at the EU and national levels to rethink and transform economic models and build cleaner and more resilient energy and industrial systems.

Recent analyses suggest that investing in clean tech, apart from CO_2 savings, can be virtuous for sustainable economic growth and job creation.

Past recovery packages and quantitative easing have missed out on opportunities to reap these benefits.[7] However, now there is a chance to get it right: In the course of the COVID-19 crisis, governments of the world's 50 largest economies have committed close to $12 trillion (€10 trillion) to the current crisis recovery.[8] It will be critical that this money is invested in a sustainable economic recovery. It is a once-in-a-generation opportunity to mobilize the capital needed to drive the economy toward net-zero.

The EU and its member states have so far pledged around €2.5 trillion in recovery funds,[10] including **€750 billion for "Next Generation EU."** As a comparison, the US put forward a €2 trillion recovery plan called the CARES Act, while China's plan totals €500 billion.

> ***"Europe must rapidly scale and deploy a portfolio of all the clean technologies that are already available, where each adds a bit and together they build a profitable net-zero economy even before 2050."***
>
> **Bertrand Piccard**, CEO Solar Impulse

KEY ELEMENTS OF EUROPEAN RECOVERY PACKAGES: NEXT GENERATION EU, AND NATIONAL RECOVERY PLANS OF FRANCE AND GERMANY[9]

1. Next Generation EU

- €750 billion (€390 billion in grants plus €360 billion in loans) to be spent over three years.
- EC President Ursula von der Leyen announced that 37% of Next Generation EU will be spent directly on European Green Deal objectives. Furthermore, 30% of the Next Generation EU's €750 billion is to be raised through green bonds. (Note: **The projects detailed in this report would all qualify as "green" EU Taxonomy-aligned investments.**)
- The €390 billion in new EU debt will be reimbursed through mechanisms that will require polluters to pay more, especially on non-recycled plastics, aviation and maritime sector emissions. A second revenue source for the reimbursement will be the envisioned carbon border adjustment mechanism.

2. "France Relaunch"

- In September 2020, France presented a €100 billion economic stimulus package.
- About €30 billion will be used on greener energy policies.
- About €6 billion is earmarked for making public buildings and homes better insulated.
- About €9 billion is expected to be spent on the development of a hydrogen industry and other green technologies.[11]

[6]https://www.iea.org/reports/global-energy-review-2020
[7]The climate impact of quantitative easing – LSE Grantham Institute (2017): Found http://www.lse.ac.uk/GranthamInstitute/publication/the-climate-impact-of-quantitative-easing/
[8]A study from Oxford Smith School of Enterprise and Environment pointed out that although this spending is good and ambitious, investments mostly maintain a status quo with only 4% real green policies with long-term potential to reduce GHG emissions: https://www.smithschool.ox.ac.uk/publications/wpapers/workingpaper20-02.pdf

3. Germany's Konjunktur- und Zukunftsprogramm[12]

On 3 June 2020, the governing coalition agreed on a €130 billion package, including:

- an investment package to promote hydrogen technology (€7 billion for new businesses, R&D, and additional €2 billion for international partnerships).
- a doubling of the government's contribution to the "eco-bonus" (from €3,000 to €6,000) that consumers receive when they purchase an electric vehicle with a list price of up to €40,000.
- €2.5 billion for the expansion of state-of-the-art, safe charging infrastructure and in R&D funding for electric mobility and battery cell production.
- a bonus program of €1 billion in 2020 and 2021 to promote forward-looking investments by manufacturers and suppliers in the automotive industry.
- €5 billion in additional funds for the expansion and electrification of rail networks and the overall railway system.
- a grant to reduce the surcharge levied on electricity consumers to 6.5 cents/kWh in 2021, then 6 cents/kWh in 2022.
- €1 billion in additional funding for the CO_2 building renovation program.

The study is structured around five key economic areas, with one domain supplying energy (Energy) to power the four other demand domains (Industry, Buildings, Transport, Food & Land use):

Figure 9 - Five economic areas studied in the Report

- **Energy:** Energy accounts for 72% of Europe's greenhouse gas emissions, as fossil fuels provide 73% of energy consumed in Europe, while renewable energies account for only 14% despite their quick growth.
    - ◊ Technology Quests impacts: €152 billion total market (turnover + investments) per year in 2030, 2.3 million permanent jobs in 2030, 460 $MtCO_2$ avoided per year in 2030.
- **Industry:** Industry is responsible for 30% (1,201 $MtCO_2e$) of EU27 greenhouse gas emissions, either from energy use or from direct emissions from processes.
    - ◊ Technology Quests impacts: €216 billion total market (turnover + investments) per year in 2030, 2.2 million permanent jobs in 2030, 269 $MtCO_2$ avoided per year in 2030.
- **Buildings:** The building sector is one of the most significant CO_2 emission sources in Europe, with 1,026 $MtCO_2e$, including 387 $MtCO_2e$ direct emissions from 221 million households.
    - ◊ Technology Quests impacts: €245 billion total market (turnover + investments) per year in 2030, 4.5 million permanent jobs in 2030, 355 $MtCO_2$ avoided per year in 2030.
- **Transport**: Transportation in its many forms currently produces over 1,200 $MtCO_2$ per year (30% of total emissions in the EU) as liquid fossil fuels drive most air, marine, road and rail movements.
    - ◊ Technology Quests impacts: €111 billion total market (turnover + investments) per year in 2030, 1.1 million permanent jobs in 2030, 128 $MtCO_2$ avoided per year in 2030.
- **Food & Land Use:** The European agro-sector generates 471 $MtCO_2e$ over the whole value chain (12% of total European greenhouse gas emissions), mainly from soils nitrification, enteric fermentation and manure management.
    - ◊ Technology Quests impacts: €66 billion total market (turnover + investments) per year in 2030, 1.0 million permanent jobs in 2030, 119 $MtCO_2$ avoided per year in 2030.

"We must build pilots at industrial scale and deploy them in numerous countries. This requires organization into climate-neutral project pathways and significant investments. Today's incentives are not sufficient."

Magali Anderson, Chief Sustainability Officer, Lafarge

[9]France and Germany will still have to submit to the EC national recovery and resilience plans on top of their national recovery plans presented here, in order to access money from Next Generation EU.
[10]https://www.imf.org/en/Topics/imf-and-covid19/Policy-Responses-to-COVID-19#C
[11]https://www.gouvernement.fr/france-relance
[12]https://www.bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Public-Finances/Articles/2020-06-04-fiscal-package.html

Figure 10 - Summary of impacts of the 55 Technology Quests

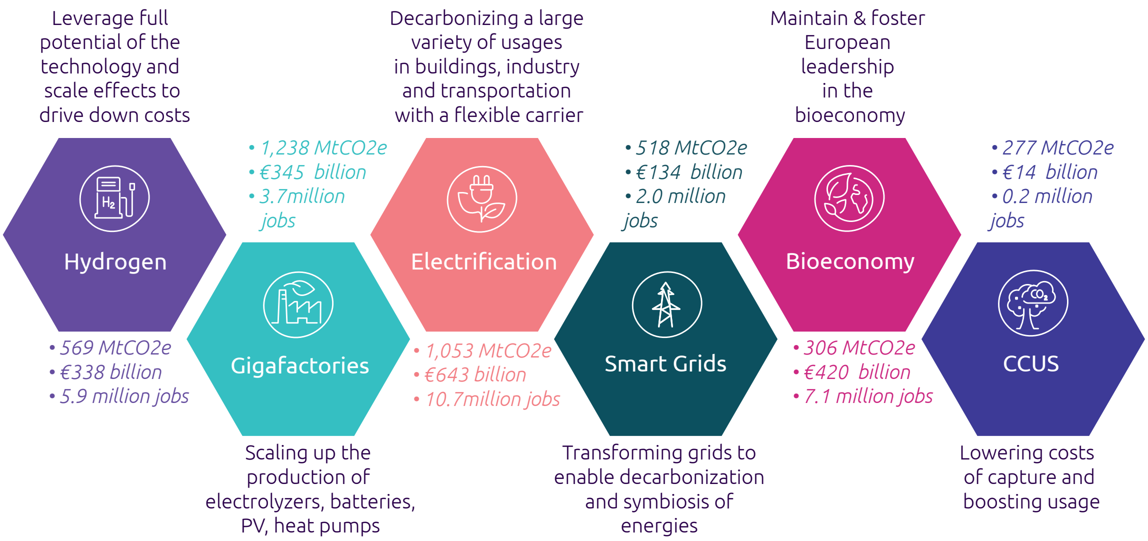
	CO2 reduction (Mt CO_2)		Impacts GVA (€ bn)		Jobs (Million)	
	2030 figures	2050 additional impact	2030 figures	2050 additional impact	2030 figures	2050 additional impact
All economic areas*	871	+1,823	789	+802	12.7	+11.6
Energy	460	+1,105	152	+125	2.2	+1.8
Industry	269	+437	216	+161	3.8	+2.7
Buildings	355	+589	245	+177	4.5	+3.3
Transport	128	+659	111	+263	1.1	+2.7
Food & Land Use	119	+138	66	+76	1.0	+1.1

The 55 Technology Quests are also organized into six acceleration pathways – hydrogen, gigafactories, electrification, grids, bioeconomy and CCUS. These are largely in line with the technology mix identified in the 1.5 TECH scenario of the European Commission's long-term climate strategy.[13,14] Investing in these clusters is a promising avenue for creating European leadership on the clean tech markets of the future.

- In the decade to 2030, large-scale and focused investments in **hydrogen** production infrastructure will create a thriving, low-cost hydrogen economy with transformational impacts across the continent, in multiple industrial sectors and for selected mobility applications.
- **Gigafactories** will be crucial for delivering the necessary scale of production of some clean technologies to achieve the required low costs and cumulative cuts in CO_2 emissions.
- Large-scale **electrification** will be at the heart of Europe's move away from fossil fuels in the years to come, transforming the way industry, buildings and transport are powered.
- Transforming Europe's **grids** through a combination of scaled-up best conventional technologies, plus new clean technologies, will be crucial to enable decarbonization and integration of energy systems.
- By reducing the environmental impact of the entire agricultural value chain from "farm to table," Europe can reduce emissions in the **bioeconomy** by 20% in the decade leading up to 2030, and by 50% by 2050.[15]
- Industrial-scale **carbon capture, utilization and storage** (CCUS) is vital for deep emissions reductions by 2050, especially in industry.

These acceleration pathways are built on groups of technology projects that can be scaled up, are replicable and have the potential to deliver benefits across all of Europe as well as to international markets. They also play to Europe's core industrial strengths and leadership. The impacts by cluster are summarized in the chart below:

Figure 11 - Six acceleration pathways contributing to Europe's net-zero transition - Impacts of each cluster on emissions, GVA and jobs



[13]https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf
[14]The IEA's Energy Technology Perspectives 2020 comes to a similar conclusion, identifying innovation in electrification, hydrogen, bioenergy and CCUS as essential to achieving quicker progress toward net-zero emissions. https://www.iea.org/reports/energy-technology-perspectives-2020
[15]Net-zero agriculture in 2050: how to get there: https://europeanclimate.org/content/uploads/2019/11/02-19-net-zero-agriculture-in-2050-how-to-get-there.pdf

Figure 12 - Distribution of the Technology Quests across the Acceleration Pathways

Tech. Quests #	Area	Title	Acceleration pathways					
			Hydrogen	Gigafactories	Electrification	Grids	Bioeconomy	CCUS
1	ENERGY	GIGA-SCALE MANUFACTURING CAPACITIES OF NEW GENERATION SOLAR MODULES		x				
2	ENERGY	GENERATE 30% MORE ELECTRICITY PER M² WITH BIFACIAL SOLAR PANELS		x				
3	ENERGY	MORE LARGE-SCALE FLOATING OFFSHORE WIND		x				
4	ENERGY	LARGE-SCALE HYDROGEN PRODUCTION AT €1.5/KG BY 2025-2030	x					
5	ENERGY	BIOMETHANE DESIGN-TO-COST INDUSTRIALIZATION TO DRIVE ECONOMIES OF SCALE				x	x	
6	ENERGY	24/7 AVAILABILITY OF ELECTRICITY FROM COMBINED SOLAR GENERATION, STORAGE AND GRID				x		
7	ENERGY	EXPLOIT ALL EUROPEAN PUMP STORAGE CAPACITY		x				
8	ENERGY	BUILD COMPETITIVE LEADERSHIP IN ELECTRICITY STORAGE FOR STATIONARY USE		x				
9	ENERGY	DIGITAL EVERYWHERE AT CUSTOMER, PRODUCTION AND GRID LEVELS TO SMARTLY SOLVE AVAILABILITY AND INTERMITTENCY			x	x		
10	ENERGY	REINFORCE ELECTRIC GRIDS FOR 100% RENEWABLE POWER				x		
11	ENERGY	TRANSFORM GAS GRIDS INTO A NEW MULTI-FOCUSED RESOURCE				x		
12	ENERGY	MASSIVELY DEPLOY HEATING AND COOLING NETWORKS TO REDUCE FOSSIL FUEL DEPENDENCY IN EUROPEAN CITIES AND HELP OPTIMIZE ELECTRIC GRIDS				x		
13	ENERGY	COST-EFFECTIVE AND ENERGY EFFICIENT CO2 AIR CAPTURE AT SCALE						x
14	INDUSTRY	REDUCE THE NEED OF CONCRETE THANKS TO BETTER DESIGN AND ALTERNATIVE CONCRETE FOR EQUIVALENT USAGES					x	
15	INDUSTRY	REPLACE THE USE OF CONCRETE WITH CARBON SINK MATERIALS IN NEW BUILD					x	
16	INDUSTRY	REDUCE SHARE OF PORTLAND CLINKER IN CEMENT AND DEVELOP NEW ALTERNATIVE CLINKERS						
17	INDUSTRY	INDUSTRIALIZE THE USE OF CARBON CAPTURE AND USAGE TO DELIVER ULTRA-LOW CARBON CEMENT PRODUCTION						x
18	INDUSTRY	HYDROGEN REDUCTION OF IRON ORE FOR BASIC OXYGENATED FURNACES AND ELECTRIC ARC FURNACES	x					
19	INDUSTRY	ELECTROWINNING OF IRON ORE FOR ELECTRIC ARC FURNACES			x			
20	INDUSTRY	REUSE PROCESS GASES AND CAPTURE CO2 TO LOWER EMISSIONS OF STEEL INTEGRATED PLANTS						x
21	INDUSTRY	SCALE ONSITE GREEN HYDROGEN PRODUCTION IN REFINERIES	x					
22	INDUSTRY	SWITCH TO LOW-CO2 FUELS FOR HIGH-GRADE HEAT INDUSTRY PROCESSES			x			
23	INDUSTRY	SWITCH TO LOW-CO2 SOLUTIONS FOR LOW-GRADE HEAT INDUSTRY NEEDS			x		x	
24	INDUSTRY	IMPLEMENT MASSIVE ELECTRIC EFFICIENCY PROGRAM FOR ALL EUROPEAN INDUSTRIAL PLANTS			x			
25	INDUSTRY	REDUCE GHG IMPACT OF REFRIGERANTS						
26	INDUSTRY	REDUCE GHG IMPACT OF PLASTIC THROUGH REUSE AND RECYCLING						
27	BUILDINGS	DEEP RENOVATION OF RESIDENTIAL BUILDINGS			x			
28	BUILDINGS	DEVELOP NEXT-GENERATION EQUIPMENT TO INCREASE PERFORMANCE OF DEEP RENOVATION			x			
29	BUILDINGS	DEEP RENOVATION OF PUBLIC BUILDINGS			x			
30	BUILDINGS	AUTOMATE, DIGITIZE AND STREAMLINE CONSTRUCTION PROCESS AND METHODS FOR RENOVATION AND NEW BUILD						
31	BUILDINGS	MASSIVE ELECTRIFICATION OF HEAT WITH LOW-COST HEAT PUMPS		x	x			
32	BUILDINGS	DEVELOP NEXT-GENERATION BUILDINGS ALLOWING ULTRA-LOW CONSUMPTION AND FULLY FLEXIBLE ENERGY MANAGEMENT	x		x			
33	TRANSPORT	SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR AVIATION	x	x				
34	TRANSPORT	SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR LONG-DISTANCE SHIPPING	x	x				
35	TRANSPORT	SCALE UP GREEN N-LIQUID AMMONIA PRODUCTION AND LOGISTICS INFRASTRUCTURE FOR LONG-DISTANCE SHIPPING	x					
36	TRANSPORT	DEPLOY AMMONIA-FUELED VESSELS FOR LONG-DISTANCE SHIPPING	x					
37	TRANSPORT	SHIFT SHORT- AND MEDIUM-DISTANCE FERRIES TO HYDROGEN FUEL-CELL PROPULSION	x					
38	TRANSPORT	DEVELOP HYDROGEN USAGE FOR HEAVY-DUTY ROAD FREIGHT	x					
39	TRANSPORT	SHIFT EUROPEAN TRUCK INDUSTRY TO HYDROGEN	x					
40	TRANSPORT	TRANSITION FOSSIL-POWERED INTERCITY TRAINS TO HYDROGEN	x					
41	TRANSPORT	ELECTRIFY SHORT-DISTANCE TRUCKING, WASTE COLLECTION AND URBAN BUS FLEETS			x			
42	TRANSPORT	FOSTER PRIVATE EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY			x			
43	TRANSPORT	FOSTER PUBLIC EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY			x			
44	TRANSPORT	DEVELOP FASTER, CHEAPER, MORE CONVENIENT TECHNOLOGIES FOR EV CHARGING			x			
45	TRANSPORT	SUPPLY THE EUROPEAN AUTOMOTIVE INDUSTRY WITH "MADE IN EUROPE" LI-ION BATTERIES		x				
46	TRANSPORT	CREATE 100% CIRCULAR BATTERY ECONOMY IN EUROPE			x			
47	TRANSPORT	STIMULATE THE DEVELOPMENT OF NEXT-GENERATION BATTERY TECHNOLOGY FOR MOBILITY USE		x				
48	TRANSPORT	BUILD NEW URBAN MULTI-MODAL TRANSPORT SYSTEMS FOR EASY DOOR-TO-DOOR JOURNEY PLANNING, EXPERIENCE AND PAYMENT						
49	TRANSPORT	LEVER SHARED AUTONOMOUS VEHICLES TO REDUCE THE NUMBER OF CARS IN AN INCREASING NUMBER OF EUROPEAN CITIES BY 30%			x			
50	FOOD & LAND USE	TRANSFORM EUROPEAN AGRICULTURE WITH SUSTAINABLE FARMING TECHNIQUES					x	
51	FOOD & LAND USE	HARNESS THE POWER OF AGRICULTURE 4.0					x	
52	FOOD & LAND USE	REINFORCE PLANTS AND BOOST CROP RESILIENCE TO USE LESS EMISSIONS-INTENSIVE FERTILIZERS AND INPUTS					x	
53	FOOD & LAND USE	TAP INTO THE POTENTIAL OF INSECTS FOR FAST-GROW FEEDSTOCK PROTEINS					x	
54	FOOD & LAND USE	CAPTURE METHANE AND NON-CO2 GHG EMISSIONS FROM CATTLE					x	
55	FOOD & LAND USE	PROMOTE TASTY, AFFORDABLE AND LOW-EMISSION ALTERNATIVES TO MEAT AND DAIRY PRODUCTS					x	

SOME OF THE BIGGEST GAINS CAN BE GENERATED IN COUNTRIES RARELY ASSOCIATED WITH THE TRANSITION TO NET-ZERO

Central and Eastern, and Southern European countries will see significant economic benefits, job opportunities and GHG savings from economic recovery investments in each of the six acceleration pathways identified in this report.

Central and Eastern Europe: The world's showcase for shifting from a coal-reliant to a low-carbon economy?

Figure 13 - Selection of energy transition indicators in countries from Central and Eastern Europe

Country examples	Share of coal in energy mix[16]	Power sector emissions in 2018[17]	Share of renewables in 2018[18]	Renewables NECP target in 2030[19]
Poland	79%	155 $MtCO_2$	11%	21%
Romania	24%	20 $MtCO_2$	24%	30.7%

Two-thirds (50 GW) of the EU's coal power generation capacity, which today is not covered by a coal exit policy, are in Central and Eastern Europe.[20]

- Historically, emissions reduction targets were lower in Central and Eastern Europe than in other regions and phasing out coal was not a priority.
- Electricity production and supply relies on electricity imports, but also on steam coal as a primary energy import, with only a few incentives to sustain investments in renewables development.
- In colder countries, there is also an untapped potential for large-scale energy efficiency improvements.

Renewable energy costs have declined dramatically and are now lower than coal or gas for new utility-scale units. Eastern European countries therefore require support from recovery investments to jump-start these industries. A recent Bloomberg NEF study estimates that shifting to renewables in these countries can unlock €54 billion in investments and save up to 114 $MtCO_2$ for the period between 2018-2030.[21] These figures demonstrate the real potential for Central and Eastern Europe to be a fast-growing clean technology investor and producer in the coming years, and this can in turn spur competitive advantages in other clusters.

This report develops concrete projects to ease Central and Eastern Europe's shift from coal to clean energy, including:

- Launching economically competitive gigafactories to turn Central and Eastern Europe into a clean tech industrial powerhouse.
- Developing hydrogen gas grids to connect Central and Eastern, and Northern European countries, produce cheap renewable power locally, transform it to hydrogen and send it to large ports and industrial clusters.
- Broadening the use of CCU on existing coal- and gas-fired assets (see Technology Quest #13).
- Create CO_2 gas grids in ports and in Central and Eastern Europe's heavy industrial clusters (see Technology Quest #11).
- Switch existing coal networks to geothermal, biomass and/or heating pump sources (see Technology Quest #12).

Central and Eastern Europe is known for its scientific prowess and open mindset toward technological innovation. There is massive potential to leap to the next generation of clean technologies, due to the lack of legacy clean tech installed. By seizing these opportunities, Central and Eastern European countries will also generate other benefits including increased competitiveness for exports and better air quality.

[16] Eurostat, 2019
[17] Ibid.
[18] Ibid.
[19] https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en
[20] Investing in the Recovery and Transition of Europe's Coal Regions White Paper - July 6, 2020 – BloombergNEF
[21] Investing in the Recovery and Transition of Europe's Coal Regions White Paper - July 6, 2020 – BloombergNEF, https://data.bloomberglp.com/professional/sites/24/BNEF-white-paper-EU-coal-transition-Final-6-July.pdf
[22] Southern Europe is defined here as Portugal, Spain, Italy, Greece and Malta
[23] Eurostat, 2019
[24] Eurostat, 2019
[25] https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en

Southern Europe: From megawatt to gigawatt in solar and batteries[22]

Figure 14 - Selection of energy transition indicators in countries from Southern Europe

Countries	Power sector emissions in 2018[23]	Share of renewables in 2018[24]	Renewables NECP target in 2030[25]
Spain	293.6 $MtCO_2$	17%	42%
Portugal	54.6 $MtCO_2$	30%	47%
Italy	332.1 $MtCO_2$	18%	30%
Greece	74.4 $MtCO_2$	18%	35%
Malta	n/a	8%	11.5%

For Southern European countries, renewables are already a reality and solar energy can enable the cost-effective achievement of the EU's 32% renewable energy target for 2030. Beating this benchmark requires developing more grid and storage options, especially if concentrated solar power (CSP) technology will play a meaningful role.

Southern European countries benefit from high potential for wind and solar energy generation throughout the year, and this inexpensive carbon-neutral electricity is vital for Europe. Investments to reinforce the existing grid will accelerate renewable deployment and connect the North of the continent to the South. This would deliver zero-carbon electrical power with minimal losses from places where it can be generated, to places where industrial and household demand is high.

There are also two factors which support the location of next-generation solar PV and battery gigafactories in Southern Europe:

- Currently, most PV components are produced in China with higher life-cycle carbon emissions. This means that solar, while ostensibly being a clean technology, may have a high carbon footprint after all. Producing next-generation panels in Southern Europe in gigafactories powered by green electricity will deliver a double positive effect (see Technology Quests #1 and #2): economic value and jobs in Europe, and reduced life-cycle emissions of the panels installed.
- As solar production is intermittent, solutions to store electricity are needed. These are referenced in several of the proposed Technology Quests such as the development of stationary battery technologies (see Technology Quest #8).

Building on the advantage of cheap solar electricity production, Southern Europe also has the capacity to sustain cost-competitive green hydrogen production (see Technology Quest #4), helping make Europe a leader in a rapidly growing decarbonized industry.

5. EXPERT CONCLUSIONS: ALIGNED EU POLICIES ARE KEY TO ACCELERATING THE DEVELOPMENT & DEPLOYMENT OF CLEAN TECHNOLOGIES

"Every day, talented and audacious people across the globe are creating solutions to make the planet a better place. In the current times, these innovators and their dreams of a sustainable future bring hope and optimism to citizens."

Mariya Gabriel, European Commissioner for Innovation, Research, Culture, Education and Youth, June 2020

Stimulating the rapid development and market-scale commercial application of the 55 Technology Quests is a formidable challenge. Clean technologies require more capital investment and take longer to bring to maturity in comparison to their digital counterparts. Investors and policymakers alike must possess the patience, flexibility and commitment to see these long-term visions through. Fortunately, the European Green Deal provides an overarching framework that has the potential to provide common standards, markets, and technical infrastructure – the fertile conditions required for Europe to succeed in transforming its economy.

Europe is a leader in research and innovation, but the fruits of breakthroughs developed here are too often taken to scale elsewhere (smart cards, the Internet, solar PV technology, etc.). To capitalize on its expertise in R&I, and turn this competitive advantage into innovative production methods and market leadership across five key economic areas, the experts we interviewed, as well as our own analysis, reinforces that Europe also needs:

- **Clear routes to industrial scale:** by investing in essential infrastructure and maximizing the potential of existing industrial and transportation hubs. It also requires a seamlessly functioning EU single market, with cross-border clean tech and energy projects the norm, not the exception.
- **Accelerated innovation cycles:** wind and solar took 20-25 years to mature and become cost-effective. These traditional innovation timescales must be reduced by a decade or more to deliver a net-zero emission economy by 2050.
- **Seamless investment throughout the innovation cycle:** not just seed and early-stage funding, but scale-up support to deliver later-stage businesses and market-scale implementation is required to build confidence in European clean technologies.
- **A conducive policy environment:** facilitating the creation of new clean tech markets, encouraged by incentives that reduce the green premium for sustainable products and services as they become more competitive.
- **Transformation at speed:** to achieve net zero by 2050, we must invest massively and hit key targets by 2030. Acceleration pathways and selected European clean Technology Quests are critical to establish the emissions reduction pathway we know is needed in the months and years ahead.

Policy leadership has helped grow market adoption of solar, wind, LEDs and EVs. It can also help deliver renewed clean technology leadership in other areas with the goal of achieving climate neutrality in Europe by 2050. Eminent innovators, entrepreneurs, corporate strategists and policymakers interviewed for this report put forward a set of **policy recommendations:**

Targeted financial support

Promising technologies, including the 55 Technology Quests, face many challenges before they can be deployed at scale. Unless their cost and performance are demonstrated and validated in real-world conditions, potential buyers may be deterred. Demonstration reduces the economic and institutional risks of new technologies. The EU supports the demonstration of technologies that align with its missions through funding programs, such as InnovFin EDP, Horizon Europe, the EIC Accelerator, the Innovation Fund, the Invest EU's R&I window and European Innovation Partnership's access to finance and innovation program support. Synergies with similar instruments at the national level will be essential to scale up financial support, and to connect the dots between the various programs which hitherto have often been disjointed and duplicative.[26]

Sandbox approach

Some experts called on Europe to adopt a regulatory sandbox approach, creating dynamic, small-scale testing grounds for innovative clean tech products and business models that are not encumbered or held back by existing regulations. A prominent example are the so-called "Green Deals" which successive Dutch governments have offered in exchange for the delivery of sustainable projects in the fields of base materials, biodiversity, water, mobility, energy, climate, food, construction and biobased economy.[27] The purpose of regulatory sandboxes is to enable a safe environment for innovative companies to test services and products in a real-world environment. Such experimentation needs to be accompanied by consumer protection safeguards. As the Dutch example has proven, this approach goes hand-in-hand with innovation. In fact, clean technologies are largely reliant on regulatory sandbox approaches because existing regulatory frameworks – built for the fossil-fuel age – often actually impede the development of greener and more sustainable products and services.

Demand-side measures

Carbon Contracts for Difference (CCfDs) can be used to spur the decarbonization of basic industrial materials such as steel, cement, aluminum and some chemical feedstocks. It is another forward-looking industrial policy that can bring breakthrough technologies to market and accelerate the decarbonization of energy-intensive industries. Despite the vast potential of many of the clean technologies in this report, commercialization and full-scale roll out remains expensive, risky and problematic, due to the generally higher production costs of low-carbon products and services.

CCfDs guarantee producers of ultralow carbon materials a fixed CO_2 price for a certain production volume, covering the difference between the current price and the contracted price. If the CO_2 price is below the contract strike price at production, the producer is compensated, and if the CO_2 price is higher than the guaranteed strike price, then these payments are returned. If deployed across Europe, CCfDs would enable deep decarbonization technologies to become commercially viable quickly, and to be commissioned at speed. This is a very similar model to the one used to support innovation through the EU ETS Innovation Fund from 2020.[28]

Support for strategic value chains

The EU has a solid track record in facilitating strategic value chains, whether that is by bringing transparency to all the steps needed to create a product or service, or by assembling the key actors which interact along the way. In the case of the EU Battery Alliance, for example, all pertinent stakeholders needed to meet Europe's ambitions in this area were assembled – from industry and research to EU Member States and the European Investment Bank. In less than three years, this has made Europe a player in the global battery market, while also initiating a long-overdue reflection about unsustainable and unethical aspects of its supply chain, for instance using child labor to mine cobalt. The recently announced European Critical Raw Materials Alliance will help address such issues, as well as strengthen the supply of sustainable sources which are needed to drive Europe's clean energy ambitions. Where this is not possible, research and innovation may be needed to find alternatives to scarce resources, which can also help lessen excessive dependencies on countries such as China. A promising policy measure which has underpinned the EU's foray into making strategic value chains more sustainable and robust include the Important Projects of Common European Interest (IPCEI) framework, which enables public funding without falling foul of the EU's strict state aid regime.

Experts interviewed for this report also stressed the importance of a **public procurement** in supporting businesses involved in clean technologies and sustainable value chains. For example, public tenders could apply a minimum CO_2 price to bring about a more level playing field. As is, project bidders with the lowest price usually prevail, despite using higher emissions materials or being headquartered in countries with knowingly lax emission regimes. If Europe is serious about building dynamic markets for clean technologies, creating a level playing field that accurately reflects the real carbon footprint of a product or service will be of utmost importance. Bringing such transparency to value chains may be transformational as companies can no longer hide their real climate costs. Promising solutions, such as distributed ledger (blockchain) technologies, should be explored further in this regard.

CO_2 border adjustment

Implementation of a CO_2 border adjustment can help European companies better compete with more carbon-intensive alternatives that are imported from regions with looser carbon constraints. Such a policy would impose a levy on goods coming into the EU in exposed sectors, so that the price of imports from non-EU countries included a CO_2 cost equivalent to the EU's. Such an adjustment could gradually replace EU ETS free allowance allocations and could be an effective and fair way to maintain EU competitiveness.

Implementing the policy will be more complex in some sectors than others. However, with CO_2 prices potentially increasing quickly, a CO_2 border tax would offset disadvantages compared with non-EU competition receiving an indirect subsidy through non-compensation of greenhouse gas emissions. A CO_2 border adjustment would also allow the EU to lever its large Single Market, encouraging other countries to play their part in reducing global CO_2 emissions. If other geographies join, carbon clubs can be created. The larger these become, the bigger the pressure for others to comply. In the long run, the CO_2 border adjustment will only work if other geographies apply a similar approach.

Size and liquidity of venture capital markets

Global leadership in clean tech is still for the taking. China for instance has already made energy investments one of its top priorities with infrastructure development (especially DC high-voltage transmission lines) and the country continues to invest in clean mobility through financial incentives including €1.3 billion of recovery investment allocated to 200,000 new EV charging points.[30] Europe's clean tech market competitors, the US and China, have much larger capital markets, as can be illustrated by the size of an average venture capital fund:

- In **Europe**, the average VC fund has €114 million, with 60% of the funds dedicated to seed funding. Direct funding from the EIF and EIB into companies usually provides ticket sizes (amount invested in the company by the fund) of €50 million and under, while tickets over €100 million are needed for scaling.[31]
- In the **US**, the average fund is $282 million (€250 million), with eight times as much growth-stage capital available compared to Europe.[32]
- **China** is the second-largest venture capital market after the US, with $105 billion of venture investments in 2018.[33] However, recent estimates reveal a sharp decrease (60% decline in new companies' investments in the first quarter of 2020, compared to 2019).[34]

[26]https://www.aeaweb.org/articles?id=10.1257/aer.15000001
[27]https://business.gov.nl/subsidy/green-deal/?gclid=EAIaIQobChMIvLujhND66wIVkNCyCh1Z6ASSEAAYASAAEgKAUfD_BwE
[28]https://ec.europa.eu/clima/policies/innovation-fund_en
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[34]https://theconversation.com/chinese-start-ups-are-being-starved-of-venture-capital-with-worrying-omens-for-the-west-137104#:~:text=China%20now%20has%20the%20largest,of%20private%20enterprise%20until%201988.

As European Commission President Ursula von der Leyen stated in her State of the Union Address of September 2020, "deep and liquid capital markets are essential to give businesses access to the finance they need to grow and invest in recovery and in the future." Europe and private investors must take the opportunity arising in the current crisis to shift Europe from the seed funding-oriented model to a more growth-oriented model which has a stronger engagement in the green economy.

UK'S INVESTMENTS IN THE NET-ZERO ECONOMIC TRANSITION – A WHOLE ECONOMY APPROACH

In 2019, the UK was the first major economy to pass laws to reduce greenhouse gas (GHG) emissions to net-zero by 2050. Having already reduced emissions by 43% compared to 1990 levels, 2019 was also the UK's cleanest year on record, with 48.5% of the UK's electricity produced from low-carbon sources. In 2020, the UK government began to fund a "whole economy approach," committing €20 billion to support low-carbon innovation. This was accompanied by a policy upgrade to accelerate progress toward net-zero emissions by 2050, including:

- **Supporting offshore wind and hydrogen:**
  - ◊ The UK raised its ambition to target the installation of 40 GW of offshore wind by 2030, and it pledged to develop floating offshore turbines.[36]
  - ◊ Providing €31 million in funding for the "Hydrogen Supply Program," with five new hydrogen production projects as part of a €554 million innovation fund dedicated to deploying technologies that can mitigate climate change.

- **Upgrading to a smarter network:**
  - ◊ The UK will invest over €1 billion via National Grid to enable the transition to net-zero, from which €94.2 million will support decarbonization of heat through gas transmission networks.
  - ◊ The UK government also proposed a deadline of fitting at least 85% of homes and small businesses with smart gas and electricity meters by 2024.

- **Decarbonizing road transport:**
  - ◊ €1.1 billion investment in EV charging infrastructure.
  - ◊ The UK government announced that "Clean Air Zones" will be implemented in cities across the UK from 2021.
  - ◊ Bringing forward the ban on the sale of new petrol and diesel cars from 2040 to 2035.
  - ◊ €5.6 billion investment over 5 years for low-carbon public transport and cycle paths

- **Funds for innovation and green start-ups:**
  - ◊ A €1 billion fund to support clean teach innovation, including nuclear fusion and EV battery technologies.
  - ◊ A €44.5 million fund has been announced to support green start-ups.
  - ◊ €222.6 million for a UK sustainable innovation fund.
  - ◊ €111 million for research and development in direct air capture technologies.

- **Reducing emissions from agriculture and land use:**
  - ◊ €712.3 million investment has been announced for the "Nature for Climate" fund to restore forest cover and peatland and offset carbon emissions.

- **Balancing emissions from industrial processes:**
  - ◊ An €890.2 million investment in carbon capture, utilization and storage projects to support the UK's ambition to build the first fully deployed carbon capture and storage cluster by the mid-2020s.
  - ◊ This will be enhanced by a push to increase industrial energy and resource efficiency and process electrification.

[35] *https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1655*
[36] *https://www.evwind.es/2019/12/19/uk-government-affirms-40-gw-offshore-wind-energy-commitment/72645#:~:text=It%20was%20revealed%20that%20the,development%20of%20floating%20wind%20turbines*

CONCLUSIONS

In her first State of the European Union Address, European Commission President Ursula von der Leyen presented the European Green Deal as the cornerstone of her mandate to achieve "systemic modernization across our economy, society and industry," as well as an avenue to "shaping the world we want to live in."

In many ways, the European Green Deal is the culmination of Europe's long-standing and pioneering leadership in highlighting the perils of climate change. Early advances in key clean tech innovations, such as wind and solar, originated here. But that is neither a guarantee of future success nor a promise that political aspirations will inevitably lead to the desired outcomes. Net-zero emissions cannot be legislated or regulated alone. And climate neutrality in 2050 will largely be the result of decisions that are taken today, and in the years to come.

One thing is certain: no transformation of the magnitude envisioned has ever occurred without major breakthroughs in technology. What was yesterday the steam engine, assembly line or telegraph may well be green hydrogen, direct air capture or advanced batteries tomorrow.

Then, as now, no one can predict the future or vow success but that has never stopped those who want to build a better world. It is our hope and wish that this analysis can help bring about a step change in the pursuit of net-zero emissions, not in the vision which is exemplary but in the implementation, which will occur one project – or Quest – at a time.

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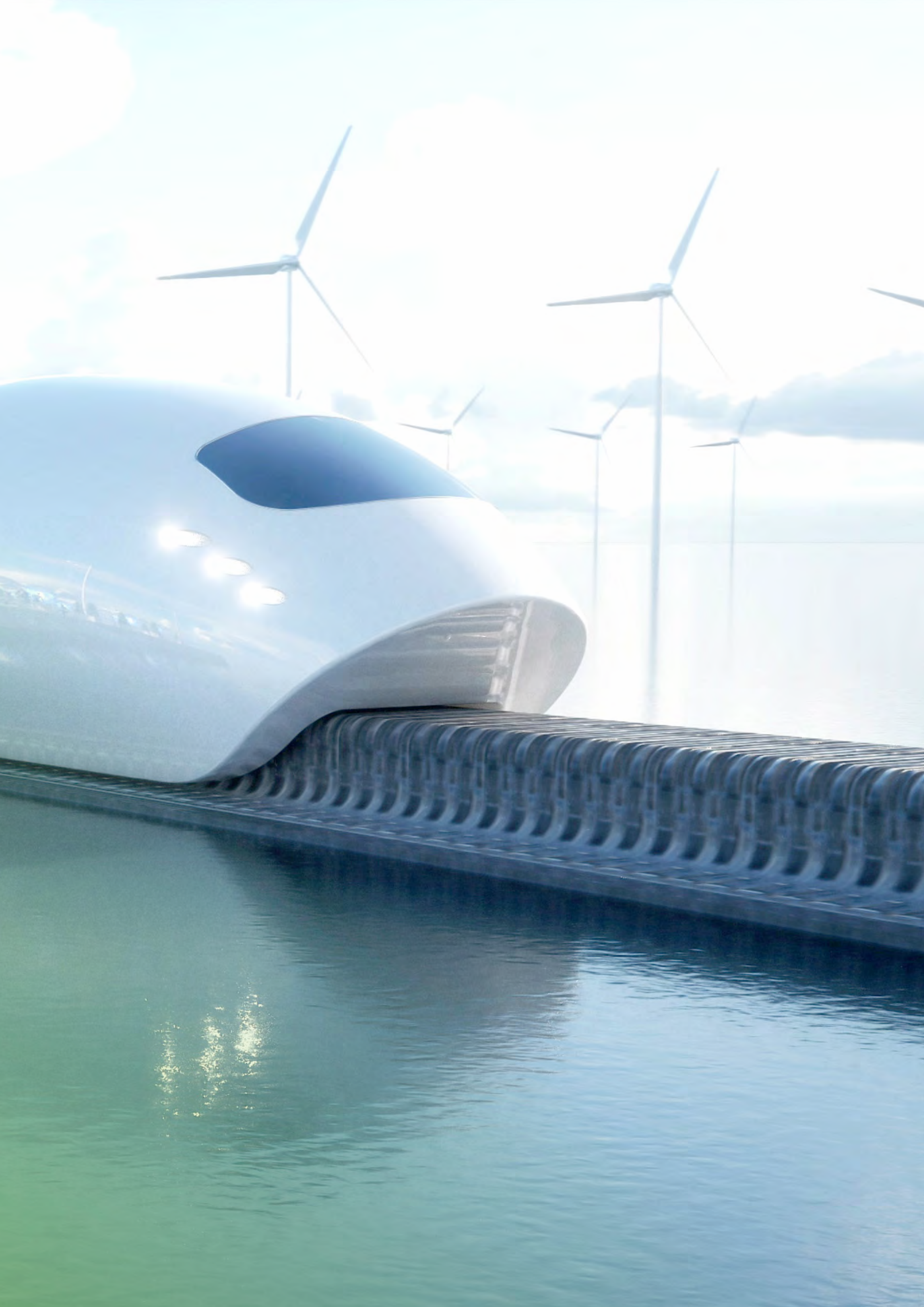
55 TECH QUESTS TO ACCELERATE EUROPE'S RECOVERY AND PAVE THE WAY TO CLIMATE NEUTRALITY



ENERGY

TRANSITIONING FROM FOSSIL FUELS TO CLEANER ENERGY REQUIRES RAPID ADVANCEMENT OF VARIOUS RENEWABLE ENERGY TECHNOLOGIES, QUICKLY SCALING UP THEIR DEPLOYMENT, AND GREATLY IMPROVING GRID SYSTEMS

Current situation and challenges

Energy is the lifeblood of the EU's economy. The story of economic expansion over the past two centuries is in a large part the story of fossil fuels – first coal, then oil and gas. Today, energy production and consumption is responsible for two-thirds of global anthropogenic carbon emissions. In 2017, fossil fuels still accounted for 73% of Europe's energy consumption, with renewables at just 14% (despite their rapid recent growth), followed by nuclear at 13%.

Fossil fuels have historically dominated the energy market because, simply put, they have the ability to convey a considerable amount of energy in small volumes. They are easily transportable. They can be stored in gas, solid and liquid forms. And they are cheap.

But fossil fuel usage also has significant drawbacks and major limitations. First, fossil fuel usage often wastes a considerable amount of energy, including lost heat from combustion engines, power plants and high-temperature industrial processes. Second, fossil fuels emit massive amounts of the greenhouse gases fueling climate change.

In charting a course toward a future powered by more clean energy, the first step is to identify ways to save energy. In the context of this report, the technology challenges that can help all of us – homeowners, businesses, governments, etc. – save energy are discussed in the Industry, Buildings and Transport sections. However, energy efficiency can only get us so far – it is essential to also decarbonize the energy we produce, transport and consume.

For clean energy technologies to truly be able to supplant fossil fuels, they first must overcome several of their own unique current challenges:

- The amount of clean energy produced must increase dramatically. Doing so will create economies of scale, helping drive down the costs of technologies like floating offshore wind, bifacial solar panels, and green hydrogen.
- To ensure end-users have access to clean power 24/7, clean energy intermittency issues must be addressed.
- Whereas fossil fuels essentially have three main forms (coal, oil and gas) that are able to meet most energy needs, clean energy technologies are more varied, and each technology has its own drawbacks and benefits. Despite this diversity of supply and a wide range of transmission methods, clean power must be easy to access and easy to use.

> ***"We need to accelerate grid investments. Our vision is that we will have integrated systems (power/gas/heat) where the optimization currency will be a ton of CO_2 in complement of euros and enhanced by digital and AI capabilities."***
>
> **Laurent Schmitt.** General Secretary ENTSO-E

Solutions, projects and scale-up

From fossil fuels to clean energy: Volumes and costs

Decarbonized energy carriers are supposed to grow dramatically by 2050[1] – electricity will grow from 2,750 TWh to 3,400 TWh, while hydrogen and its related synthetic fuels will jump from nearly zero to 1,800 TWh.

Supporting the scale-up of renewable energy production is essential, both to increase the volume produced to help offset fossil fuel use, and to leverage economies of scale to lower costs. Europe is poised to achieve technology breakthroughs in the following fields:

- Scale-up of the manufacturing of new solar technologies so they can reach 30% efficiency within five years. This includes multi-junction cells (III-V and/or perovskites on silicon), and large-scale bifacial solar plants that harvest more sunlight.
- 5-6 GW-scale gigafactories that can manufacture these new solar technologies. After 15 years of Chinese market supremacy, this can help Europe regain its competitive edge in solar manufacturing. 19 GW annual production capacity of next-generation modules could be achieved by 2030 if work toward that goal began now.
- The offshore wind industry can work to solve usage constraints as the sea near the shore becomes increasingly crowded. 60% of Europe's offshore wind potential could be unlocked by 2030 by creating 53 GW of floating offshore wind capacity.
- Production costs and performance must be improved for biogas by creating six large-scale biogas competitiveness hubs by 2030.

Solved intermittency and availability

Semi-base and baseload fossil-fuel power generation need to be replaced. This can be achieved through concentrated solar plants in Southern Europe and in Northern Africa (with grid connections). These facilities could potentially provide a 70%-95% load factor – i.e., 6,000-8,000 hours annually of baseload assuming 24/7 availability.

Progress on storage technologies beyond Li-ion is also crucial. Specifically:

- Large-scale renewable + hybrid storage projects to develop viable alternatives to Li-ion batteries.
- Long-duration storage, from six hours to several days.

Finally, the role of digital technologies is key to increase flexibility; increase the control of demand, supply and storage; improve aggregation of demand, etc. Smart digital technologies must be deployed at all scales and locations, including homes, districts, transportation modes, cities, industries, grids, power plants and buildings.

Improve and enhance electric grids

Traditionally, fuels and the power they generate have been consumed separately. Electricity, gas and liquid fuels each have their own supply chains that are largely independent from one another. By 2030, hydrogen will have penetrated the market, and electricity will be used more widely, including in the generation of hydrogen. Sites producing large quantities of renewable energy will be needed in every region in Europe, but not necessarily close to where that energy is consumed. Grids need to expand and be improved as they transport more electricity.

Greener gases, pure hydrogen, CO_2, heat and cooling will also have to be transported or reused in new, circular usages.

Regional approach

Gigafactories can be developed everywhere in Europe. In particular, Central and Eastern European countries that have maintained a strong industrial base (as demonstrated by the region's automotive industry) could benefit.

Regardless of seashore profile, floating offshore wind is applicable in all countries with a coastline.

Solar's potential is particularly strong in Southern Europe and the region could be a key producer of cheap hydrogen which could then be transported via pipelines to Northern Europe.

Impacts

- **€151 billion total market (turnover + investments) per year in 2030.**
- **2.3 million permanent jobs in 2030.**
- **460 MtCO_2 avoided per year in 2030.**

List of projects - ENERGY

From Fossil to Clean: Volumes and costs

#1 - GIGA-SCALE MANUFACTURING CAPACITIES OF NEW GENERATION SOLAR MODULES
Build gigafactories based on perovskite and III-V multi-junction high efficiency cells by 2030

#2 - GENERATE 30% MORE ELECTRICITY PER M² WITH BIFACIAL SOLAR PANELS
Large-scale bifacial solar plant and gigafactory

#3 - MORE LARGE-SCALE FLOATING OFFSHORE WIND
Unlock 80% of Europe's offshore wind potential through a rapid scale-up of new generation floating wind structures

#4 - LARGE-SCALE HYDROGEN PRODUCTION AT €1.5/KG BY 2025-2030
Develop renewables and electrolyzers to scale up low-cost green hydrogen

#5 - BIOMETHANE DESIGN-TO-COST INDUSTRIALIZATION TO DRIVE ECONOMIES OF SCALE
Create six large-scale competitiveness hubs and reduce costs by 30% by 2025

Solved intermittency and availability

#6 - 24/7 AVAILIBILITY OF ELECTRICITY FROM COMBINED SOLAR GENERATION, STORAGE AND GRID
Build trans-Mediterranean grid and electricity daytime baseload with Concentrated Solar Power (CSP)

#7 - EXPLOIT ALL EUROPEAN PUMP STORAGE CAPACITY
Retrofit existing hydro-plants for pump storage

#8 - BUILD COMPETITIVE LEADERSHIP IN ELECTRICITY STORAGE FOR STATIONARY USE
Develop viable short- and long-duration storage alternatives to Li-ion battery

#9 - DIGITAL EVERYWHERE AT CUSTOMER, PRODUCTION AND GRID LEVELS TO SMARTLY SOLVE AVAILABILITY AND INTERMITTENCY
Flexibility along the whole smart energy value chain across Europe at all spatial and temporal scales

Optimize and redesign grids

#10 - REINFORCE ELECTRIC GRIDS FOR 100% RENEWABLE POWER
Develop grids, HVDC, storage and innovative technologies to build a robust grid for all Europe

#11 - TRANSFORM GAS GRIDS INTO A NEW MULTI-FOCUSED RESOURCE
Repurpose Europe's gas grids for biomethane, H_2, and CO_2 and focus them on industry needs and dense urban areas

#12 - MASSIVELY DEPLOY HEATING AND COOLING NETWORKS TO REDUCE FOSSIL FUEL DEPENDENCY IN EUROPEAN CITIES AND HELP OPTIMIZE ELECTRIC GRIDS
District Heating and Cooling (DHC) can leverage thermal storage, thermal efficiency and energy sourced from geothermal, renewables and waste to help improve air quality, reduce noise and curtail heat islands

#13 - COST-EFFECTIVE AND ENERGY EFFICIENT CO_2 AIR CAPTURE AT SCALE
Direct Air Capture to simplify and ease the energy transition challenge

[1] *World Resource Institute, remaining part being industrial processes, agriculture, land use change and waste.*
[2] *1.5TECH scenario https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf*

GIGA-SCALE MANUFACTURING CAPACITIES OF NEW GENERATION SOLAR MODULES

Build gigafactories based on perovskite and III-V multi-junction high efficiency cells by 2030

ENERGY

From fossil to clean energy: volumes and costs

IN A NUTSHELL...

- **Issue:** The efficiency of crystalline silicon cells is reaching its technical limits. Moreover, in the last 15 years China has produced most of the world's solar PV
- **Solution:** Multi-junction cells associated with silicon industrial know-how to reach higher levels of field efficiency. Large scale 4.0 factories to drive down costs and allowing large reallocation of production to Europe
- **Key impacts:** 37.9 $MtCO_2e$ avoided, €1.8 billion total market, 14,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

An innovative EU next-gen PV program would rely on two pillars: (i) structured industrial and R&D partnerships to innovate and test rapidly; (ii) large manufacturing plants to scale up innovation. The main project focus is on increasing manufacturing facilities while R&D/industrial clusters are described here as support infrastructure. Both are outlined as follows:

Project type 1: Solar R&D and industrial clusters

Establish three R&D and industrial clusters by 2021 to support continuous improvement, with the must-have objective of deeply integrating technological innovation with manufacturing processes:

- One in Germany to leverage first-class R&D labs (ISC Konstanz, Fraunhofer ISE, Solar Factory of the Future, FAU, etc.), and strong R&D partnerships like Solliance with manufacturers.
- One in Italy to leverage first class R&D labs (University of Rome Tor Vergata, Italian Institute of Technology, University of Naples, etc.) and the experience of manufacturers such as Enel.
- One in Lithuania, in association with western EU R&D institutions: to leverage the competencies of existing module manufacturers.

Projects that inspired this analysis: French IPVF industrial and R&D cluster.

Project type 2: Giga-scale manufacturing plants for the production of new-generation cells

Build manufacturing plants for the production of multi-junction cells (III-V and/or perovskites on silicon) with individual output capacity in the 3-10 GW range.

- The manufacturing plants will supply the expected EU demand with part of the production exported. Ultimately, these new cells are likely to be mounted as bifacial modules to further boost panel yields (see #2 for specific projects on bifacial technology).
- The manufacturing plants can be deployed in Germany, Italy, France, Spain and Eastern Europe as they have industrial know-how which can be scaled up, with the support of specific manufacturers (Enel, Burger Meyer, Wacker Polysilicon AG, etc.) and R&D and industrial clusters.

Projects that inspired this analysis: Oxford PV and Burger Meyer 125 MW perovskite-on-silicon solar cell manufacturing line. Chinese plants with current silicon technologies in the 3-10 GW size range. Industry 4.0 manufacturing plants in other industries (e.g. BOSCH).

Why this technology and project are needed to reach net-zero

Net-zero scenarios modelled by the JRC show that Europe must install up to 600 GW PV generation capacity by 2030 and over 1 TW by 2050[1] to reach its climate and energy objectives . The European market will grow 10-15% per year and reach close to 80 GW by 2030. In this race, Europe has a unique opportunity to develop and deploy new generation PV modules.

New generations of cells such as III-V and perovskites are instrumental to Europe's come-back on the PV scene. Combined with standard silicon cells, multi-junction structures now reach over 40% efficiency in labs. The theoretical efficiency of crystalline silicon cells cannot exceed 30%, and is often far lower in practice. For instance, average efficiency in the EU stands at around 12%. Europe has world class solar R&D programs, but little concrete application pilots and manufacturing lines, while Asian players have been betting on these technologies. For example, the Chinese GCL announced the extension of its perovskites production line from 10 MW to 1 GW by 2021, to quickly gain market share.

Europe has world-class solar clusters in IPVF (FR), Fraunhofer (DE), and IMEC (BE) with other important clusters in EPFL (CH), and ECN (NL). In such clusters research and industry must closely work together to face the following challenges for a quick and strong take-off of these technologies in 2022-2025:

- adapt well-proven silicon manufacturing solutions to deploy multi-junction module production.
- increase the perovskite cells size and durability.
- divide the manufacturing cost of III-V materials by two orders of magnitude.
- lauch first manufacturing lines by 2022-2025.

All R&D projects funded by European governments and the EU should have a strong industrial component, and reciprocally no industrial projects should be funded without an R&D component to maintain innovation and competitiveness.

From the regulatory perspective, tenders also need to include environmental criteria such as embedded CO_2 emissions, social criteria such as local jobs, and efficiency criteria per square meter.

Impacts

	2030	2050
CLIMATE IMPACT	**37.9 $MtCO_2e$ avoided**	**253.2 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€1.8 billion total market** €3.7 billion cumulated investment by 2030, €400 million yearly average (2020-2030) €1.4 billion turnover in 2030	**€4.9 billion total market** €3.4 billion cumulated investment by 2050, €200 million yearly average (2030-2050) €4.7 billion turnover in 2050
JOBS	**14,000 total jobs** 6,000 construction jobs for investment 8,000 production jobs for turnover	**31,000 total jobs** 3,000 construction jobs for investment 28,000 production jobs for turnover

#1 [1]https://www.researchgate.net/publication/340320166_How_photovoltaics_can_contribute_to_GHG_emission_reductions_of_55_in_the_EU_by_2030

GENERATE 30% MORE ELECTRICITY PER M² WITH BIFACIAL SOLAR PANELS

Large-scale bifacial solar plants and gigafactories

ENERGY

From fossil to clean energy: volumes and costs

IN A NUTSHELL...

- **Issue:** Current PV efficiency reaches its limits and deployment can be hampered by land use constraints
- **Solution:** Bifacial solar plants harvest light reflected from the ground via the Albedo effect to increase efficiency by 9%, and generate up to 40% more power when combined with tracking systems
- **Key impacts:** 18.9 MtCO_2e avoided, €900 million total market, 7,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: High-yield bifacial solar farms with tracking systems by 2030

Set up PV farms combining several technologies (bifacial/soil coverage/tracking systems) by 2030.

- Bifacial panels can be mounted with perovskites/II-V technology cells (see project #1 for projects on new generation solar panels).
- They can be deployed across Europe, and increased efficiency can help open less sunny/profitable markets in Northern and Eastern Europe.
- Solar plant developers, solar module components manufacturers (of tracking systems, inverters, etc.) and R&D labs must cooperate on these projects to ensure incremental innovation, cost reduction and efficiency monitoring.

Projects that inspired this analysis: 2 MW SoliTek bifacial solar plant is the first of its kind in Europe. Equipped with top of the line bifacial glass-glass solar panels and a horizontal single-axis sun tracking system, it will generate up to 30% more electricity than a conventional solar power plant, for an investment of €2.6 million.

Project type 2: Giga-scale bifacial manufacturing plants

Build bifacial module gigafactories of 5 GW capacity by 2030.

- The manufacturing plants will supply the expected EU demand with part of the production exported. Ultimately, these new cells are likely to be mounted as bifacial modules to further boost panel yields (see #2 for specific projects on bifacial technology).
- The manufacturing plants can be deployed in:
    - Italy: to leverage existing bifacial solar manufacturing capacities.
    - Spain: to take advantage of the dynamic local PV market, skilled and flexible workforce and proximity with potential export markets in North Africa.
    - Lithuania: which has already deployed bifacial modules production capacities, and started installing the first EU bifacial module plants.

Projects that inspired this analysis: Enel's Catane 200 MW cell production facility launched in 2019 could be replicated to drive down costs and generate manufacturing jobs in the EU.

Why this technology and project are needed to reach net-zero

Net-zero scenarios modelled by the JRC show that building up to 600 GW PV generation capacity by 2030 and over 1,000 GW by 2050 would contribute to reach a 55% GHG reduction by 2030 and net-zero emissions by 2050[2]. The European market will grow 10-15% per year and reach close to 50 to 80 GW by 2030. In this race, Europe has a unique opportunity to develop and deploy new generation PV modules.

Bifacial PV collects light from reflection of the ground to reach about 9%[3] supplementary efficiency. The developers of initial projects claim potential efficiency gains of 20-25%. Their higher upfront costs are compensated over the project's lifetime, especially since bifacial modules are more resistant and have longer warranties (up to 30 years).

Analysts expect this technology to take up between 40 and 60%[4] of the European PV market by 2030. While Asian players are just gearing up and adapting their production lines to this new technology, some EU players such as Norwegian REC or German SolarWorld Industries have started to bet on their ability to ramp-up production and regain market shares in PV.

In addition to contributing to pan-European re-industrialization, deploying additional solar panel capacity will contribute to reaching the EU's net-zero ambition, while limiting the land-use that large solar projects require.

To reach this target, sustained deployment of bifacial PV farms and a rapid ramp-up of manufacturing capacities across Europe are key. From a regulatory perspective, public institutions can support deployment by setting efficiency requirements per square meter in public tenders and accelerating permits.

Impacts

	2030	2050
CLIMATE IMPACT	**18.9 $MtCO_2e$ avoided**	**162.5 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€900 million total market** €1.9 billion cumulated investment by 2030, €0.2 billion yearly average (2020-2030) €700 million turnover in 2030	**€3.2 billion total market** €2.9 billion cumulated investment by 2050, €100 million yearly average (2030-2050) €3 billion turnover in 2050
JOBS	**7,000 total jobs** 3,000 construction jobs for investment 4,000 production jobs for turnover	**20,000 total jobs** 2,000 construction jobs for investment 18,000 production jobs for turnover

#2 [2]https://www.researchgate.net/publication/340320166_How_photovoltaics_can_contribute_to_GHG_emission_reductions_of_55_in_the_EU_by_2030
[3]https://www.nrel.gov/docs/fy19osti/74090.pdf
[4]https://www.dnvgl.com/to2030/technology/solar-pv-powering-through-to-2030.html and https://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf

MORE LARGE-SCALE FLOATING OFFSHORE WIND

Unlock 80% of Europe's offshore wind potential through a rapid scale-up of new generation floating wind structures

ENERGY

From fossil to clean energy: volumes and costs

IN A NUTSHELL...

- **Issue:** Nearshore shallow sea is already saturated with industrial activities, while 80% of Europe's offshore wind resource potential is located in water more than 60 m deep, which is too deep for conventional offshore wind installations
- **Solution:** Large scale floating wind turbine projects will drive down costs on offshore wind farms
- **Key impacts:** 48.6 $MtCO_2e$ avoided, €26.6 billion total market, 399,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Floating wind farms at GW scale

- WindEurope's High Scenario calls for 99 GW of offshore wind installations by 2030. According to the 1.5TECH EU scenario, developed for the European Commission, 450 GW must be installed by 2050[5].
- The project aims to boost commercial deployment of floating wind, with the deployment of deep-water floating wind farm projects at GW scale to drive down costs.
- Projects should be deployed in seas in the north of Europe. Both deep waters (between 50 m and 220 m) and high wind speeds are abundant in the North Sea, and off the coast of Scotland and England in the Atlantic. As such, countries around the North Sea are a strong knowledge cluster, with most offshore wind capacity installed and several floating wind projects etiher commissonned or under construction.
- Estonia, Latvia and Lithuania are also good areas for capacity deployment, given large untapped potential in the Baltic Sea.
- Portugal, Spain and France are also developing floating wind pilots. Their projects should be deployed on the Atlantic coast and in the Mediterranean, where deep waters start close to the coastline.
- Developing these projects requires continued cooperation between wind farm developers and electrical and mechanical system engineering companies to improve the reliability of platforms and drive down costs.
- Government/regulatory bodies have a crucial role in setting targets and creating offshore wind tenders. National ambitions, as outlined in the National Energy and Climate Plans, also need to be raised.

Why this technology and project are needed to reach net-zero

Wind power is a key enabler in Europe's transition towards a net-zero emissions economy, delivering low-carbon electricity and supporting world-class regional industrial value chains. Onshore wind may represent just two-thirds of installed capacity by 2030, and offshore wind will be key to achieving Europe's climate and energy goals. The National Energy and Climate Plans (NECP) of all Member States project over 70 GW of aggregate installed offshore wind capacity by 2030[6]. However, according to the European Commission's long-term climate strategy scenarios, a much higher capacity will be required to reach its net-zero target[7], with up to close to 450 GW of offshore wind by 2050.

At the pre-commercial level, as noted by the Wind Europe association[8], 6 floating offshore wind projects are to be commissioned between 2019 and 2020 in Europe (in Portugal, Spain, Sweden and the UK), and a total of 11 will have begun production by 2023. For example, the 25 MW WindFloat Atlantic floating wind project, 20 km off the coast of Portugal, is in its last phase of construction. Once operational, it will supply electricity to 60,000 homes with three wind turbines of 8.4 MW each.

Despite this enormous deployment potential, just 4-5 GW are expected to be installed by 2030. Projects are moving to commercial scale but an accelerated deployment is needed, especially in the permitting and capacity auction stages. Larger deep offshore volumes will play a crucial role in driving down costs, from around €200/MWh to €40-60/MWh before 2030. To achieve this, 100 floating wind projects are needed by 2030 to deliver the EU's offshore wind deep water potential and competitive leadership.

Impacts

	2030	2050
CLIMATE IMPACT	**48.6 $MtCO_2e$ avoided**	**331.1 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€26.6 billion total market** €184.8 billion investment by 2030, €18.5 billion yearly average (2020-2030) €8.1 billion turnover in 2030	**€85.2 billion total market** €900 billion investment by 2050, €30 billion yearly average (2020-2050) €55.2 billion turnover in 2050
JOBS	**398,000 total jobs** 277,000 construction jobs for investment 121,000 production jobs for turnover	**1,278,000 total jobs** 450,000 construction jobs for investment 828,000 production jobs for turnover

#3 [5] *https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf (figure 24)*
[6] *https://windeurope.org/newsroom/news/necp-analysis-permitting-problems-still-a-major-stumbling-block/*
[7] *1.5TECH scenario (one of the 2 scenarios out of 8 reaching net-zero emissions by 2050) plans up to 1200 GW installed wind capacity by 2050, among which 450 GW of offshore. https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf*
[8] *https://windeurope.org/wp-content/uploads/files/policy/position-papers/Floating-offshore-wind-energy-a-policy-blueprint-for-Europe.pdf*

#4

LARGE-SCALE HYDROGEN PRODUCTION AT €1.5/KG BY 2025-2030

Develop renewables and electrolyzers to scale up low-cost green hydrogen

ENERGY

From fossil to clean energy: volumes and costs

IN A NUTSHELL...

- **Issue:** At around €6 per kg, green hydrogen is not competitive today with fossil energies (parity at €1/kg equivalent to €25/MWh)
- **Solution:** Create gigascale integrated hydrogen projects and electrolyzer factories to increase volumes and bring costs down to €1.5 per kg in Southern Europe and €3 per kg in Northern Europe as soon as 2030
- **Key impacts:** 38.2 $MtCO_2e$ avoided, €10.6 billion total market, 150,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

The goal is to ramp up industrial demand and large-scale supply rapidly, bringing green hydrogen costs down to competitive levels with natural gas, liquid fuels and grey hydrogen (€1.5 per kg in Southern Europe, €3 per kg in Northern Europe).

Project 1: Deploy giga-scale green hydrogen production sites

Establish three R&D and industrial clusters by 2021 to support continuous improvement, with the must-have objective of deeply integrating technological innovation with manufacturing processes

Identify specific locations, with existing infrastructures (such as significant gas grid, and industrial players of different types) and potential for renewable energy. They will produce and deliver green hydrogen to multiple industrial offtakers. Symbiosis economy will be generated between captured CO_2 from steel and cement industry with liquid e-fuel plants combining hydrogen with reused CO_2.

Deploy five electrolyzer plants of 1 GW capacity each by 2025.

Develop dedicated large-scale low-cost renewable energy generation capacity to supply the electrolyzers. Depending on the nearby potential, develop GW size plants of offshore wind, onshore wind, and solar photovoltaic.

Examples of regions to target in priority for the industrial hubs include: South Holland-Zeeland-Antwerp in the Netherlands and Belgium, Rhein-Ruhr region in Germany, Tarragona in Spain, Marseille-Fos, Rhône and Dunkerque in France, Lombardy-Veneto in Italy, Bratislava-Vienna in Slovakia and Austria.

Main stakeholders include local authorities, solar PV and wind power plant developers, utility companies, gas grid operators, electrolyzer producers, industry players (in industrial chemistry, electronic component manufacturing, metalworking, glass, and hydrogen vehicles production).

Projects that inspired this analysis: 2x40GW Hydrogen Europe initiative, NorthH₂ project in the Netherlands, Green Spider project in Spain

Project 2: Deploy giga-scale electrolyzer manufacturing plants

Currently the main electrolyzer manufacturers are European. Upscale the size of plants and upgrade the plant floors to Industry 4.0 best practices to feed the market and maintain the production in Europe.

Why this technology and project are needed to reach net-zero

Hydrogen is a versatile energy carrier. Today it is widely used in industrial processes and in specific merchant applications. In Europe the equivalent of 325 TWh were used in 2015[9]. However today, 95% of the global production is produced from gas and coal[10]. Nine tons of CO_2 are emitted for each ton of hydrogen produced with steam methane reforming (SMR), corresponding to 270 gCO_2 per low heating value kWh of hydrogen and 225 gCO_2 per high heating value kWh of hydrogen. The current cost of hydrogen produced with fossils for the industry in captive and merchant uses is in the €1 to €1.5 range per kg out of the plant.

Green hydrogen created through electrolysis with decarbonized electricity provides a promising opportunity to significantly reduce carbon emissions. The final objective is to replace most fossil fuels with green hydrogen and its derivated synthetic fuels. Hydrogen Europe states that hydrogen has the potential to replace up to 665 TWh and 2,251 TWh of fossil demand respectively in 2030 and 2050[11], in industry, transportation, buildings and energy sectors. The 1.5Tech scenario prepared for the European Commission displays similar figures, with 1,791 TWh in 2050 split in 790 TWh of hydrogen consumed directly in final sectors, 523 TWh used to produce e-gas and 476 TWh to produce e-liquids.

Cost is a major challenge, as €25 per MWh of natural gas is equivalent to €1 per kg of hydrogen, and €0.6 per liter of gasoline (cost without tariffs) is equivalent to €2.5 per kg of hydrogen, while electrolysis with the current cost of wind and solar PV renewables are closer to €6 per kg.

Increasing both supply and demand is key in reducing costs, and can best be achieved in places where existing assets can be leveraged. These places include industrial clusters, solar or wind power plants, renewable curtailment, and extensive gas grids.

In Northern Europe the cost of hydrogen could drop to €3 per kg by 2030, with a giga-scale approach to hydrogen electrolyzer plants in selected industrial clusters and electricity provided by large offshore wind farms.

In Southern Europe and North Africa the cost of hydrogen could drop to €1.5 per kg by 2030, with a giga-scale approach to hydrogen electrolyzer plants with electricity provided by large solar plants, associated with wind, and transport to Northern Europe through shipping and grids.

Impacts

	2030	2050
CLIMATE IMPACT	**38.2 $MtCO_2e$ avoided**	**129.4 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€10.6 billion total market** €1 billion cumulated investment by 2030, €100 million yearly average (2020-2030) €10.5 billion turnover in 2030	**€33.5 billion total marke** €1.3 billion investment by 2050, €65 million yearly average (2030-2050) €33.5 billion turnover in 2050
JOBS	**150,000 total jobs** 2,000 construction jobs for investment 149,000 production jobs for turnover	**491,000 total jobs** 1,000 construction jobs for investment 490,000 production jobs for turnover

#4 [9] https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf
[10] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf
[11] ibidem

#5

BIOMETHANE DESIGN-TO-COST INDUSTRIALIZATION TO DRIVE ECONOMIES OF SCALE

Create six large-scale competitiveness hubs and reduce costs by 30% by 2025

ENERGY | From fossil to clean energy: volumes and costs

IN A NUTSHELL...

- **Issue:** The total production volume of biogas is still small, and uptake is occurring at different rates depending on the available sources. Technical & economic barriers (i.e. high investment costs) play a major role in hindering the wider uptake of biogas as a source of sustainable energy.
- **Solution:** A set of industrial and R&D clusters with large demonstrators to share knowledge and to reduce the end-to-end development costs by standardizing the approach in a 'design-to-cost' mode
- **Key impacts:** 87.3 $MtCO_2e$ avoided, €35.1 billion total market, 527,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

- Set up six large-scale biogas R&D and competitiveness hubs by 2025, including coverage of:
  - » Biomethanization infrastructures based on different technologies for biogas production and research tests.
  - » Establish research laboratories to explore technology applications for increasing biodigester efficiency.
  - » Training centers to close the knowledge gap.
- The goal of the project is to overcome the techno-economical barriers[12] in biogas production (such as infrastructural challenges – i.e. limited access to refueling stations and to vehicle gas – or frequent need for repair and lack of attention paid to maintenance of biogas plants), identify the best industrialization pathways for the sector, push down costs of biomethane by at least 30% by 2025, and structure the EU biogas value chain.
- Hubs should be set up where existing know-how exists (leading countries in the biogas production in the EU are Austria, Germany, Italy, Czech Republic, Netherlands and France) and potential commercial demand can be leveraged:
  - » Three hubs could be set up in existing knowledge clusters in Germany, the Netherlands, and Italy. These three countries have among the greatest number of biogas production installations (and the largest). Their strong industrial activities and power needs also contribute, together with progressive regulatory frameworks, to promote biogas technologies.
  - » Despite limited involvement in this industry today, Eastern Europe has significant potential for at least three biogas hubs: Hungary, Lithuania, Latvia and Slovakia use mainly natural gas for heating and power in CHP plants, which could be blended with biomethane. In addition, Poland is a large consumer of natural gas in industrial processes and heat production and could therefore be another potential hub. About a third of the manure and slurry volume provided as the organic waste of agricultural production in Poland could be processed into biogas for local use.[13]
- Various stakeholders are key to the success of the project, notably:
  - » An R&D laboratory with a research focus on microbiome, optimal feedstock, and methanation processes.
  - » Project developers and local authorities keen to ensure technical and commercial success.
  - » Monitoring and control system providers, to develop optimized monitoring solutions to pilot the methanization process and increase yield.
  - » Local feedstock providers (farmers for crop residues and manure, water waste treatment plant).

Projects that inspired this analysis: The CertiMétha project in France gathers key players in the biogas sector (Evergaz, K-REVERT, Biogaz Vallée, and others) around an established infrastructure for biomethanization, with a total investment of €4.8 million. The infrastructure includes an analysis laboratory, digesters from 1 to 400 m3 to test large-scale anaerobic digestion processes, and a training center for biogas engineers. This project will contribute to improving the design of biogas production plants, reducing infrastructure costs in the industry.

Why this technology and project are needed to reach net-zero

Biogas and biomethane are both potential solutions to support the fast decarbonization of multiple economic sectors currently using gas for heating, transport and power production. Additionally, biogas and biomethane have synergies with the circular economy and bioeconomy and generate significant numbers of local jobs[14]. Multiple positive impacts are delivered by biogas (including GHG reduction from farming livestock, biodiversity conservation with sequential cropping, and reduced use of chemical fertilizers) which have been valued at €40-70/MWh of biomethane produced[15].

European policymakers took important decisions in favor of biogas in 2019, with the EU Fertilizing Products Regulation published in June 2019 which opened new markets for digestate and bio-based products[16]; the amended Annex V of REACH published in October 2019 exempts digestate from registration[17]. This provides support to the development of the sector, even though essential mechanisms are still missing, such as a robust European system of Guarantees of Origin (GOs) for biomethane.

Although the technology of anaerobic digestion and conversion to biomethane is already deployed at commercial scale, biogas production suffers from industrial value chain issues (such as a scattered market, lack of coordination between stakeholders, and lack of knowledge sharing). In addition, there are technical issues (such as a lack of knowledge on the microbiome, efficiency and reliability issues, etc.). That is why the cost of biomethane is around €95/MWh today, as compared to the average wholesale price for natural gas at €10/MWh at the end of 2019, a record low in Europe. Even pioneer member state, Germany, only delivers less than 1% of its natural gas demand in biomethane. An industrial value chain approach is necessary to standardize installations and processes to significantly increase volumes and reduce costs.

Impacts

	2030	2050
CLIMATE IMPACT	**87.3 $MtCO_2e$ avoided**	**153 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€35.1 billion total market** €85.4 billion cumulated investment by 2030, €8.5 billion yearly average (2020-2030) €26.6 billion turnover in 2030	**€51.6 billion total market** €149.7 billion cumulated investment by 2050, €5 billion yearly average (2020-2050) €46.6 billion turnover in 2050
JOBS	**527,000 total jobs** 128,000 construction jobs for investment 399,000 production jobs for turnover	**773,000 total jobs** 75,000 construction jobs for investment 698,000 production jobs for turnover

#5 [12] https://www.sciencedirect.com/science/article/pii/S2211467X19301075
[13] thttps://www.mdpi.com/2071-1050/11/22/6515/pdf
[14] https://www.ieabioenergy.com/wp-content/uploads/2018/08/anaerobic-digestion_web_END.pdf
[15] https://atee.fr/system/files/2019-12/CRE%20Rapport-Gaz%202019.pdf
[16] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1009&from=EN
[17] https://eur-lex.europa.eu/legal-content/EN/PIN/?uri=uriserv:OJ.L_.2019.259.01.0009.01.ENG

24/7 AVAILABILITY OF ELECTRICITY FROM COMBINED SOLAR GENERATION, STORAGE AND GRID

Build trans-Mediterranean grid and electricity daytime baseload with Concentrated Solar Power (CSP)

ENERGY

Solved intermittency and availability

IN A NUTSHELL...

- **Issue:** TPV solar plants provide only intermittent power, which is not solved with Li-ion battery storage that only provide one to four hours of storage
- **Solution:** Large scale CSP in EU and North Africa with AC-DC grid, with 15-18 hours storage to provide base production (90-100% load factor) at €50/MWh in 2030
- **Key impacts:** 30 $MtCO_2e$ avoided, €12.3 billion total market, 184,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Concentrated Solar Power (CSP) plants can now provide baseload generation 24/7 when they combine solar fields generating up to three to four times the power of the installed turbine and 14 to 18 hours of storage.

The aim of the project is to leverage solar and land resources around the Mediterranean basin with grid integrations that benefit both the host countries (in terms of investment and jobs) and Europe (in terms of clean power imports and outlets for CSP component manufacturers). Further down the line, these projects can be replicated in Turkey and Algeria.

Build CSP plants by 2030 in Spain, Greece, Cyprus, Southern Italy and Northern Africa.

Combine plants in Southern Morocco and Tunisia with 2,000 km of HV power lines on land and 250 km of subsea HVDC to transport electricity to Southern Europe, via Gibraltar and Southern Sicily. About 65% of the power produced is to be imported to Europe, and 35% is to be consumed locally.

Large volumes will help cut LCOE from €120/MWh in 2019 to less than €50/MWh in 2030 and 25€/MWh in 2050[18]

Main stakeholders include: local utility companies, project developers, and startups innovating in the field of heat storage components (such as ceramics, salt, and sand). Governments also have a key role to play in pushing for solar+storage or specific CSP tenders in Europe.

Projects that inspired this analysis: CSP plant Noor Ouarzazate III in Morocco has 24-hour operating capacity thanks to a 7.5 h molten salt storage (150 MW solar output, 600 MW heat storage), CSP plant Noor Energy 1 in Dubai, 700 MW 15-hour storage, load factor 100%, €75/MWh for CSP.

Why this technology and project are needed to reach net-zero

CSP progress suffered from plummeting costs of solar PV in recent years to reach only 2.4 GW installed capacity in Europe. However, progress in thermal storage and incremental digital improvement for increased yield means this technology remains an interesting choice for Southern Europe and North Africa, where the solar potential is significant. With the world's largest CSP plant coming online in Dubai (by the end of 2020), CSP technology has set new records in terms of installed generation capacity, storage, LCOE, but also business models. Indeed, the 700 MW CSP capacity with 15-hour storage will provide baseload power 24/7 and hit a price of €70/MWh, under a 35-year PPA[19].

IRENA predicts that Europe could install 5 GW capacity in just a few years if supportive policy and investment frameworks are put in place[20]. New CSP and storage technologies (based on ceramics, and sand) reach 1,000°C of heat, far above the current 550°C theoretical limit, and will help open up new markets such as the industrial sector. New technologies can leverage the knowledge acquired so far on CSP, such as the use of molten salt for storage, and start to move away from old, expensive CSP designs to combine with other renewables such as PV and wind, at a lower cost.

Impacts

	2030	2050
CLIMATE IMPACT	**30 MtCO_2e avoided**	**66.4 MtCO_2e avoided**
ECONOMIC IMPACT	**€12.3 billion total market** €32.7 billion investment by 2030, €3.3 billion yearly average (2020-2030) €9 billion turnover in 2030	**€17.7 billion total market** €35.9 billion investment by 2050, €1.8 billion yearly average (2030-2050) €15.9 billion turnover in 2050
JOBS	**184,000 total jobs** 49,000 construction jobs for investment 135,000 production jobs for turnover	**266,000 total jobs** 27,000 construction jobs for investment 239,000 production jobs for turnover

#6 [18] *https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf*
[19] *https://www.acwapower.com/en/projects/noor-energy-1/*
[20] *http://helioscsp.com/european-concentrated-solar-power-capacity-to-reach-as-high-as-5-gw-by-2030/*

EXPLOIT ALL EUROPEAN PUMP STORAGE CAPACITY

Retrofit existing hydro-plants for pump storage

ENERGY

Solved intermittency and availability

IN A NUTSHELL...

- **Issue:** Intermittent power generation (PV solar, wind) needs to triple by 2030, creating the need for long term storage (that is greater than 12 h, lasts several days, and is inter-seasonal)
- **Solution:** Retrofit existing hydro-dams for reversible pump-storage
- **Key impacts:** €4.2 billion total market, 63,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

This project targets the development and upscaling of long-term storage capacity, taking advantage of existing pump storage applications and developing new technologies.

Project type 1: Retrofit existing hydropower installations to store and generate an additional 79 TWh/year of electricity

Connecting an existing dam with a newly built reservoir at differing levels of elevation will create a pumped-storage hydroelectricity (PSH) plant. Key features of the retrofit program will be:

- By 2030, multiply by five[21] the PSH output in the EU.
- Involve existing assets to reduce investment costs.
- Conserve unspoiled environments by retrofitting existing installations, even though EU taxonomy considers hydropower to be harmless towards ecosystems[22].

Project type 2: Go beyond the geographic constraints, and massively adopt new forms of hydro storage. Generate 300 TWh/year[23] of output by 2050.

- Traditional PSH potential is capped by geographical constraints.[24] To by-pass this limit, closed-loop PSH can be used. Closed-loop PSH, unlike most existing PSH, does not rely on a natural water flow. For instance, underground PSH, which is a sub-type of closed-loop PSH, relies on an abandoned mine shaft to fill in the role of the lower water reservoir, such as with the ongoing Callio project in Finland.
- Meanwhile, the MAREX project, a seawater storage initiative, relies on a man-made water reservoir (which is not connected to any fresh water stream, making it closed-loop) located near the sea. The project will help integrate a nearby wind power project by storing up to 6 GWh, and is expected to be completed by 2024[25] at a cost of €700 million[26].

Projects that inspired this analysis: MAREX, GIBREX, GIRONES & RAÏMATS, P-PHES NAVALEO, Callio.

Why this technology and project are needed to reach net-zero

Reaching a net-zero emissions economy requires a full[27] penetration of renewable energy in Europe's electricity mix, involving non-dispatchable renewables, such as wind and solar energy.

Electricity grids and networks need to be flexible and smart to guarantee a balance between power generation and consumption. In 2018, 467[28] TWh/year of variable power (wind and solar PV) was generated in the EU28, with pump storage covering below 7%, at 29 TWh/year[29]. By 2030, intermittent power generation is likely to triple and reach 1,300 TWh/year[30].

Hydro pump-storage has two key advantages:

An established track record: hydro storage has been developed for years in conjunction with national power grids, and has proven to be a reliable balance mechanism, technically as well as economically.

Local economy: hydropower sector can rely on existing, strong industrial clusters in Europe. Projects can be launched quickly, benefitting EU companies and delivering local jobs.

Yet traditional hydropower pump storage (with two mountain dams linked together), even at its maximum potential, will not be nearly enough to enable electricity decarbonisation in Europe. Geographical surveys and studies concluded that the current PSH output can doubled, at most.

Closed-loop PSH could fill in the gap once all montainous potential has been used. Furthermore, closed-loop PSH, though less profitable than traditional PSH, is still more profitable than battery storage. Current closed-loop pumped storage requires a €80/kWhcapacity investment[31], while Li-ion batteries requires €140/kWhcapacity[32]. Furthermore, closed-loop facilities have a longer lifetime than the batteries, making the cost per cycle even more competitive.

Impacts

	2030	2050
CLIMATE IMPACT	**Storage is a lever to renewable penetration (no double counting of the decarbonation)**	**Storage is a lever to renewable penetration (no double counting of the decarbonation)**
ECONOMIC IMPACT	**€4.2 billion total market** €42.1 billion investment by 2030, €4.2 billion yearly average (2020-2030)	**€5.1 billion total market** €102.4 billion investment by 2050, €5.1 billion yearly average (2030-2050)
JOBS	**63,000 jobs**	**77,000 jobs**

#7

[21]JRC for European Commission, page 9 (storage in 2011) and figure 16 (achievable potential of T2 scenario, at 20 km, EU area) https://setis.ec.europa.eu/system/files/Assessment_European_PHS_potential_online_0.pdf
[22]Taxonomy: Final report of the Technical Expert Group on Sustainable Finance
[23]To be compared with 467 TWh wind and power generation today (ENTSO-E statistical factsheet 2018), multiplied by 5 to 10 in the 2050 scenarios.
[24]JRC for European Commission, figure 16 (achievable potential of T2 scenario, at 20 km, EU area) https://setis.ec.europa.eu/system/files/Assessment_European_PHS_potential_online_0.pdf
[25]ENTSO-E project sheet : https://tyndp.entsoe.eu/tyndp2018/projects/storage_projects/1030
[26]Operator website : http://www.organicpowerinternational.com/glinsk-energy-storage-hub/
[27]EC, figure 23, the least ambitious scenario proposes nearly 56% of solar and wind in the electricity mix by 2050. https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[28]ENTSO-E statistical factsheet 2018
[29]JRC for EC, page 9: https://setis.ec.europa.eu/system/files/Assessment_European_PHS_potential_online_0.pdf
[30]https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[31]TYNDP (Ten Year Network Development Plan) of ENTSO-E. Calculated using several pumped hydro projects: MAREX, GIRONES and RAÏMATS, P-PHES NAVALEO, Gibrex
[32]Bloomberg

#8

BUILD COMPETITIVE LEADERSHIP IN ELECTRICITY STORAGE FOR STATIONARY USE

Develop viable short- and long-duration storage alternatives to Li-ion battery

ENERGY

Solved intermittency and availability

IN A NUTSHELL...

- **Issue:** Li-ion represents more than 80%[33] of the battery storage market in Europe. Promising non-Li-ion storage technologies are not scaling up, despite interesting characteristics for grids
- **Solution:** Develop non-Li-ion stationary battery technologies quickly
- **Key impacts:** €3.5 billion cumulated investment, 5,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Batteries are critical for the decarbonization of the transport[34], power, and building[35] sectors. However, Europe is far from the ultra-high performance (technically and economically) required from current battery technologies.

Regarding stationary uses, although Li-ion battery technology is being developed on a massive scale by the automotive sector, Li-ion might not be the go-to choice for stationary storage for environmental and economic reasons. Many technologies aside from Li-ion are competing to fill this need, including:

- Organic: quinone electrolyte, graphene electrodes
- Flow batteries: vanadium, zinc-bromide
- Zinc-air batteries.

Project: €1.7 billion innovation program for 1-100 MW storage plants, providing 1-12 hours of short to medium duration storage, via 40 tenders

Launch 40+ tenders for new battery technologies to seed European industrial innovation clusters, using contracts for difference on output where relevant:

- 40 tenders, €1.7 billion upscaling budget.
- Conclude tenders before 2025 to facilitate commissioning of project life and enable upscale before 2030.
- Program based on 1 to 100 MW power output, with 1 to 12 hours of storage, and an average 300 MWh capacity.
- Budget around €140/kWh of storage capacity initially with a target to reach €50/kWh in 2030.
- Tender for grid storage as well as behind-the-meter installations, linking with renewable tenders where efficient.
- Technology-neutral tenders, excluding Li-ion.

Why this technology and project are needed to reach net-zero

Reaching a net-zero emissions economy requires a full[36] penetration of renewable energy in Europe's electricity mix, involving non-dispatchable renewables, such as wind and solar energy.

Electricity grids and networks need to be flexible and smart to guarantee balance between generation and consumption. In 2018, 467[37] TWh/year of variable power (wind and solar PV) was generated in the EU28, covering about 15% of electricty demand. By 2030, intermittent power generation is likely to triple and reach 1,300 TWh/year[38].

Scaling up storage and system services (frequency and flexibility) is critical for Europe's net-zero emissions future. Batteries provide aforementioned services, and have the following two advantages, compared to other technologies:

- Battery system services can be activated faster than mechanical devices (such as pumped hydro).
- Battery scalability allows for decentralized use, including behind the meter (where power is generated or consumed).

Tenders to foster alternative chemistry innovation can develop European alternatives to Li-ion to prepare for 2030 renewable electricity markets and meet the net-zero emissions 2050 target. The tender design should include a technology roadmap that targets the delivery of a €50/kWh cost by 2030, from today's Li-ion costs of €140/kWh[39].

For reference, in 2019, 1 GWh[40] of utility scale battery storage capacity was commissioned in Europe. The tenders proposed previously implies 12 times (12 GWh of capacity) this amount, spread across several years.

Impacts

	2030	2050
CLIMATE IMPACT	**Storage is an enabler that does not directly cut significant emissions.**	**Storage is an enabler that does not directly cut significant emissions.**
ECONOMIC IMPACT	**400 million total market** €3.5 billion investment, €350 million yearly average (2020-2030)	**€1.9 billion total market** €38 billion investment, €1.9 billion yearly average (2030-2050)
JOBS	**5,000 jobs**	**29,000 jobs**

#8 [33]IRENA, figure 1, « UTILITY-SCALE BATTERIES: INNOVATION LANDSCAPE BRIEF »
[34]See project #45 (batteries for transport)
[35]See project #32 (disruptive buildings with renewables and electrical and thermal storage)
[36]EC, figure 23, the least ambitious scenario proposes nearly 56% of solar and wind in the electricity mix by 2050. https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[37]ENTSO-E statistical factsheet 2018
[38]https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[39]Bloomberg
[40]European Market Monitor for Energy Storage (EMMES). 1.4 GWh in 2018.

#9

DIGITAL EVERYWHERE AT CUSTOMER, PRODUCTION AND GRID LEVELS TO SMARTLY SOLVE AVAILABILITY AND INTERMITTENCY

Flexibility along the whole smart energy value chain across Europe at all spatial and temporal scales

ENERGY

Solved intermittency and availability

IN A NUTSHELL...

- **Issue:** In the past, energy flexibility and availability were provided by the large share of dispatchable fossil production. In the future, the availability of energy and stability will be challenged by additional uses of electricity and the intermittency of renewable energy
- **Solution:** Improve system flexibility with smart solutions at all space and time scales. Develop digital solutions combined with demand response, storage, dispatchable decarbonized production and smart operation of grids
- **Key impacts:** €31 billion total market, 466,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Flexibility and smart energy developments are needed to solve energy intermittency and availability issues at all space scales (such as customer, building, district, city, region, country, and pan-European scales), and in different temporal windows, including by second, hour, day, intraday, weekly and seasonal. Digital is a key component in all the smart market segments detailed below. The digital chain includes the deployment of sensors and actuators, edge computing, local and wide area communication, control command applications and platforms, analytics and AI solutions, data business and operating models.

Projects aiming at enhancing energy availability and flexibility should articulate one or several of the following technology and market segments:

- Smart homes and smart building at renovation or newbuild scale. Involved technologies include smart appliances, monitoring, control and automation of storage, loads and decentralized energy resources (DER), energy management system (EMS), building management system (BMS), HAN gateway, meters, communication infrastructure.
- Smart districts, Smart cities. Involved technologies will articulate the hypervision of services (such as waste, cleaning, lighting, mobility, energy, etc.) to the citizen with the requirements of energy availability and flexibility through smart management of the demand and of the service infrastructures and offers.
- Smart mobility. Involved technologies include the management of EV charging infrastructure, of charging hourly demand, of alternative shared and public mobilities (i.e. demand response).
- Smart renewable power plants. Technologies combine digital infrastructure and energy storage in so-called Virtual Power Plant (VPP).
- Smart system management at national and regional levels (transmission and distribution networks). This technology quest focuses on smart and flexible system management, while the next technology quest #10 will focus on grid equipment and mileage. Smart system management technologies include aggregation services and virtualizing both demand and power generation, operations performance of smart grids, smart metering, technical and non-technical leakage control, EMS, WAMS, front-end communication, SCADA, DMS, AMI head end, CMS, DRMS, balance scheduling and grid planning intelligence, prosumer (both consuming and generating energy) information system and customer portals, and billing of innovative tariffs schemes.
- Main stakeholders include public authorities, energy regulators, TSOs, utilities, citizens' associations, and project developers.

The smart projects will include but will not be restricted to electricity. In the past, waste of energy has been important due to the separate vertical management of the energy carrier's production, storage and usage. Symbiosis is increasingly required between electricity, thermal and gas worlds at each level. It will be even more necessary with the uptake of new carriers such as hydrogen, e-gas and e-liquids.

Projects that inspired this analysis: European Commission's initiative BRIDGE (portfolio of smart grids and energy storage projects), Equigy Project (collaboration of European TSOs on flexibility platforms), INTERFLEX project (use of local flexibilities to relieve distribution grid constraints and increase share of renewables), FlexCoop (demand response for energy cooperatives), INVADE (flexibility management platform for e-vehicles and batteries).

Why this technology and project are needed to reach net-zero

The deployment of smart solutions can help to make distribution grids more flexible, to cope with more frequency variations and to reduce imbalances between supply and demand. They can enable active consumers and energy communities, supporting their participation in the energy markets. All segments of the power industry are affected by these changes. In Europe, investments remained stable at nearly USD 50 billion[41], with rising expenditures allocated to upgrading and refurbishing the existing grid as variable renewables and electrification become more important. Additionally, there are around 1,000 R&D and demonstration projects totaling around EUR 5 billion of investment, out of which 80% are invested in smart network management, demand-side management and integration of distributed generation and storage[42].

Solutions include implementing interconnectors, measuring energy flows in real-time, integrating renewable energy and new forms of consumption (such as electric vehicles) and managing efficiently energy storage, with the help of digital and automated tools. From this, flexibility should emerge both on a spatial scale (taking the form of a smart building or a smart city, for instance) and a temporal scale (from second and intra-hour generation prediction to inter-seasonal scale).

The Equigy Project for instance, launched in April 2020, gathers several European transmission system operators to develop an energy flexibility platform in order to better integrate variable renewable energy generation and mitigate the resulting fluctuations of supply and demand. This innovative digital infrastructure is already being deployed in four countries: the Netherlands, Germany, Italy and Switzerland. More broadly, the BRIDGE Initiative, created by the European Commission in 2014, is an investment avenue with a total budget of €484 million dedicated to various energy flexibility projects, involving over 500 companies.

Impacts

	2030	2050
CLIMATE IMPACT	**Grids are considered enablers not directly cutting a considerable level of emissions.**	**Grids are considered enablers not directly cutting a considerable level of emissions.**
ECONOMIC IMPACT	**€31 billion turnover**	**€43.5 billion turnover**
JOBS	**466,000 jobs**	**652,000 jobs**

[41] *https://www.iea.org/reports/smart-grids*
[42] *https://ses.jrc.ec.europa.eu/*

REINFORCE ELECTRIC GRIDS FOR 100% RENEWABLE POWER

Develop grids, HVDC, storage and innovative technologies to build a robust grid for all Europe

ENERGY | Optimize and redesign grids

IN A NUTSHELL...

- **Issue:** New and future electricity flows, offer and demand balancing and the management of power quality will challenge the existing grid, due to massive electrification, hydrogen and renewable generation uptake
- **Solution:** Develop new grids and reinforce existing grids based on new production and consumption flows. Conventional and HVDC lines can help increase grid reliability, renewables integration and jobs creation. Underground cabling needs to be considered
- **Key impacts:** €16.6 billion total market, 250,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

Project type 1: Refurbish and extend the existing grids for EHV and bidirectional energy flows

Invest in refurbishing and extending the existing power grid to adapt it for increased variable energy flows. Invest in new electricity routes in the production zones are changing; there is a higher demand for electricity due to new uses linked to green hydrogen and electrification. Grids must support the evolution of the future electricity consumption profile both in TWh and load factors.

Reinforcing the grid's concern lines, stations and substations including switch breakers, transformers, capacitors, reactors, reclosers, meters and their control-command systems is required.

Project type 2: Develop and upscale use of new grid technologies

- Key and innovative technologies that have the potential to transform power delivery include:
- High and medium voltage equipment (FACTS, PMU, RTU),
- HVDC,
- Ultra-high voltage transmission,
- Superconductivity.

Scaled up investments in new technologies need to be implemented in Europe by 2030 and 2050 in order to prepare electric grids to the next level of requirements regarding the growing quantity of intermittent power.

Main stakeholders: TSOs, ENTSO-E, cable industry players and associations (such as Europacable), regulators, project developers, utilities, and citizens associations.

Clusters: Large European companies such as Siemens, ABB, Schneider and large TSOs drive this market, rather than local clusters.

Projects that inspired this analysis: Various advanced projects at EU level already identified as Projects of Common Interest are key for renewables integration, grid stability, resilience, and flexibility. They should be supported to avoid delays, especially in the North Sea region and other national corridors.

Why this technology and project are needed to reach net-zero

In 2020, Europe had 1,000 GW of production assets connected by 300,000 km of transmission lines and 10,000,000 km of distribution lines, the latest being served by 240,000 direct employees[43]. According to the ENTSO-E-G Ten Years Network Development Plan (TYNDP), the grid will have to connect 1,400 GW production by 2030 and 1,800 GW by 2050[44].

A significantly adapted network infrastructure is required to decarbonize EU's electricity. High-voltage direct current (HVDC) is an increasingly important method for transferring large amounts of electrical power for the pan-European transmission grid, but the deployment of meshed HVDC offshore grids is currently being hindered by the high cost of converter technology, lack of experience with protection systems and fault clearance components and immature international regulations and financial instruments.
As described in the EU Governance Regulation of the Clean Energy Package, member states must reach 15% interconnection by 2030. Grid expansion lags renewable power development in various countries. A major hurdle for infrastructure projects is the permitting process. Although there were some simplifications to accelerate grid expansion on a federal level, these simplifications must be adopted at the local level, but local processes are not always updated promptly. Additionally, local resistance complicates the permitting process which translates into delays in grid expansion projects.

Further, electrical power transmission with lower losses is critical to the success of renewables. This is illustrated by the fact that solar power insolation factors range from 9% to 18% across the EU. If 10% of annual renewable generation projects were to relocate to a better location, it would increase global output by 5%.

Impacts

	2030	2050
CLIMATE IMPACT	**See opposite column**	**Grids are enablers in the decarbonization of the power production mix. No additional CO_2 emission reductions are realized beyond reducing emissions from power generation.**
ECONOMIC IMPACT	**€16.6 billion total market** €166.4 billion investment by 2030, €16.6 billion yearly average (2020-2030)	**€8.3 billion total market** €249 billion investment by 2050, €8.3 billion yearly average (2020-2050)
JOBS	**250,000 jobs**	**125,000 jobs**

#10 [43]*https://www3.eurelectric.org/powerdistributionineurope/*
[44]*https://tyndp.entsoe.eu/tyndp2018/*

TRANSFORM GAS GRIDS INTO A NEW MULTI-FOCUSED RESOURCE

Repurpose Europe's gas grids for biomethane, H_2, and CO_2 and focus them on industry needs and dense urban areas

ENERGY

Optimize and redesign grids

IN A NUTSHELL...

- **Issue:** The share of conventional fossil gases will shrink with decarbonization, electrification and greater use efficiency. In parallel, hydrogen, CO_2, biomethane and e-gas will need to be transported
- **Solution:** Retrofit existing natural gas grids to transport H_2 and CO_2 and develop new-built H_2 and CO_2 networks, starting from industrial clusters. In dense areas, adapt natural gas grids to green gas requirements. In less dense areas, decommission gas grids to concentrate green gas availability in dense areas
- **Key impacts:** €31.2 billion cumulated investment and 47,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

An innovative EU next-gen PV program would rely on two Reshape Europe's gas network infrastructures to fit the H_2 CCUS and synthetic fuels projects by 2030 and beyond. Before 2030, start focusing on industrial clusters, key ports and key interconnections needed by the hydrogen and CO_2 circular economy. In Europe, there are 30 integrated steel plants with blast furnaces, 250 cement plants, 80 refineries, and 50 fertilizer plants[45]. These installations are often gathered in industrial clusters and are well connected to motorway, water and rail corridors. Ten major port areas handle over 100 mt of annual goods, gather concentrations of the above industrial sites and are starting and ending points to the freight corridors, typically Rotterdam, Amsterdam, Antwerp, Hamburg, Bremerhaven, Marseille-Fos, Le Havre, Sines, Valencia, Genova, and Trieste.

Project type 1: Develop 2,000 km of CO_2 grids

CO_2 grids are needed inside industrial clusters or ports to connect sites capturing CO_2 (steel, cement, refineries) with sites reusing CO_2 to generate liquid e-fuels, e-gas and possibly with inland or submarine sequestration sites: 1,000 km of new grids and 1,000 km of converted methane grids in main industrial clusters and ports by 2030. This enables 100-200 km grid for a few large international port areas, 10-100 km in several inland industrial clusters, one or two inter-regional and submarine connections.

Project type 2: Develop 10,000 km of H_2 grids by 2030

The development of H_2 grids should focus on helping to massify hydrogen production and to quickly lower costs. Start with connecting large renewable plant areas with onsite hydrogen generation (offshore wind in North Sea, wind in Eastern Europe, solar PV in Southern Europe) to consumption areas. Connect consumer industries such as cement, steel, refineries, e-fuel plants in a few important ports and industrial areas. Before 2030, there could be:

- 5,000 km new onshore and offshore H_2 grids.
- 5,000 km switch of existing gas grids to H_2.

Project type 3: Transform and better allocate gas grid purposes (reverse, H_2, focusing on denser areas)

- Focus available green gas (biomethane, H_2) in urban areas and industrial clusters.
- Decommission gas grids in the lower density areas.
- By 2030 transform 700,000 km of grids to smarter grid: reverse compression between pressure levels to ease biomethane and H_2 injection, manage variable energy content, intraday demand response and storage.

Why this technology and project are needed to reach net-zero

Several types of European gas grids exist today:

- Gas (methane) grids: 4,800 TWh consumed yearly today. 250,000 km of transport grids and 2,000,000 km of distribution grids[46]. Reducing natural gas consumption in Europe is a requirement in all net-zero scenarios, even in 'transition countries' after 2030, once they have moved away from coal with an intermediary step relying on gas. Greening the gas content is possible with biomethane of a maximum potential of 800 TWh, with hydrogen.
- Hydrogen grids: 1,500 kilometers exist in Northern Europe (BE, NL, GE, FR) between industrial clusters[47]
- The CO_2 grids were estimated to be 1,300 km long in Europe[48] (mostly UK, NO, some in NL, DE, FR).

In the future, a big transformation of gas grids will reshape their usage:

- Gas grids transport ten times more energy than power grids for the same investment cost per kilometer. Hence, it will become more cost-competitive to transport hydrogen rather than electricity, both on short and longer distances (submarine, mainland).
- Residential and commercial buildings will need less energy and no gas at all in low-density areas (heating pumps, solar roof, biomass, etc.).
- Hydrogen will become a key energy carrier. The required amount of renewable power capacity is at least twice the GW capacity of electrolyzers producing the hydrogen. Production and use are not necessarily neighbors, although more widespread H_2 use will change this.
- Hydrogen grids will be needed to transport the hydrogen produced by mega-scale plants (50-200 MW) or giga-scale plants (1-3 GW) to industries for their own processes or to plants synthetizing e-liquid fuels.
- Carbon captured from industrial clusters and large ports will be transported to plants that will produce C-liquid fuels. In 2050, the 1.5Tech scenario plans a production of 45 MToe of e-gas and 41 MToe of e-fuel, needing 270 Mt of CO_2 coming from direct air capture and from industrial processes.

Impacts

	2030	2050
CLIMATE IMPACT	**See opposite column**	**Gas grids are enablers of the gas energy transitions (Biomethane, Power to H_2 to X, CCS). No additional CO_2 savings.**
ECONOMIC IMPACT	**€3.1 billion total market** €31.2 billion investment by 2030, €3.1 billion yearly average (2020-2030)	**€5 billion total market** €151.4 billion investment by 2050, €5 billion yearly average (2020-2050)
JOBS	**47,000 jobs**	**76,000 total jobs**

#11 [45]Capgemini analysis based on maps published by the corresponding European business associations. Rounded figures.
[46]Capgemini analysis based on ENTSO-G, CEER and MARCOGAZ sources. Rounded figures.
[47]Shell hydrogen study, 2017 (BE 613 km, GE 376 km, FR 303 km, NL 237 km)
[48]https://ieaghg.org/docs/General_Docs/Reports/2013-18.pdf

MASSIVELY DEPLOY HEATING AND COOLING NETWORKS TO REDUCE FOSSIL FUEL DEPENDENCY IN EUROPEAN CITIES AND HELP OPTIMIZE ELECTRIC GRIDS

District Heating and Cooling (DHC) can leverage thermal storage, thermal efficiency and energy sourced from geothermal, renewables and waste to help improve air quality, reduce noise and curtail heat islands

ENERGY | Optimize and redesign grids

IN A NUTSHELL...

- **Issue:** Heat is a major part of European energy needs. It is mostly produced from fossil fuels, as are most existing district heating networks. Individual air conditioning for commercial and residential sectors is growing quickly and placing stress on the grid
- **Solution:** Shift existing industrial and DHC networks to decarbonized energy (geothermal energy, biomass, waste). Create new decarbonized DHC networks
- **Key impacts:** 197.4 $MtCO_2e$, €8.9 billion total market, 133,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

Project type 1: Shift existing fossil heating networks to geothermal energy

The project goal is to convert 300 DHC systems with existing coal, gas or fuel heating networks to geothermal energy by 2030, and 600 by 2050.

- Lead surface exploration campaigns in cities or industry platforms across Europe by 2023 (currently using gas, oil or coal), use the best subsoil know-how from the oil industry. Launch tenders for drilling operations, with decreasing costs for increasing volumes (as in Mexico).
- At the surface level, upgrade the existing heating networks with up-to-date 4.0 smart grid control and command, and customer metering.
- A dedicated Georisk fund will secure private financing for the exploration. The public guarantee against the risk of not finding resources lowers financial fees. Each public euro invested in the guarantee fund generates €10-€20 of final investment.
- Main stakeholders include city authorities, energy service and subsoil companies, utilities, developers, and georisk funds.

Projects that inspired this analysis: HeatNet NWE, REWARDHeat, Sinfonia, Guarantee funds across the EU.

Project type 2: Create new decarbonized district heating or cooling networks

The project goal is to launch 2,100 DHC networks by 2030 in the locations identified in project type 1, and 5,600 by 2050 (30% market share).

- Networks may be deployed where relevant, leveraging 4th-generation DHC (4DHC) experimented through the HeatNet project and on 5DHC currently tested in the REWARDHeat project. Northern countries will focus on district heating networks (preferring geothermal heating pumps), while southern countries (such as Greece, Italy and Spain) will deploy cooling networks.
- Projects must be implemented at European or national levels, but they must be managed at a local level.
- Studies must be launched as soon as possible, as the study and the operational phase will require time.
- Occasionaly, geothermal/climatic profiles are identified to classify project locations, in order to encourage European cities in similar situations to share key learnings.
- Authorizations will be required for regulatory purposes.
- Main stakeholders include city authorities, energy service and subsoil companies, utilities developers.

Projects that inspired this analysis: HeatNet NWE, REWARDHeat, Sinfonia, Vienna Viertel Zwei, Flexynets, STORM.

Why this technology and project are needed to reach net-zero

DHC networks are a way to introduce massively decarbonized heat from sources like biomass, geothermal energy, heat pumps, and waste energy. A cooling network in parallel, based on absorption or large-scale heating pumps, can generate heat that is either recycled for district heating networks or stored in the subsoil for later usage, greatly increasing the global efficiency.

Heating and cooling in buildings and industry represents over 50% of the final energy demand in the EU[50], and relies mainly on fossil fuels, which put at risk both European energy independence and climate goals. There are today around 5,000 district networks providing 10% of European heating needs (556 TWh[51]), and up to 25-50% in Eastern and Nordic countries. These heating networks are still fueled at 65% with coal, gas and oil.

Using fossil fuels for individual heating in cities is a major source of air pollution and microparticles. Plus, coal-based heating networks are highly emissive, often old, and typically found in industry platforms or in Central and Eastern European cities. Additionally, the need for cooling increases with climate change, and individual cooling systems contribute to peaks of power demand, expensive additional investments in power grids, noise, heat islanding, metallic waste from appliances, high refrigerant leakage and a lower overall performance than in a centralized system.

Deep geothermal networks represent a complementary solution for heating and cooling, reducing emissions, air pollution, small particles, noise, power peaks, needs for more grid investment as well as heat islanding. Additionally, the geothermal potential for new networks or the retrofit of existing ones is very high: areas with geothermal district heating potential already constitute 25% of the EU population[52].

Fourth-generation district heating networks with ultralow temperature water loops and decentralised heating pumps — together with geothermal or waste sources — are solutions for net-zero buildings and are already widespread in new districts.

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (existing): 4.9 $MtCO_2e$ avoided** **Project type 2 (new): 192.6 $MtCO_2e$ avoided**	**Project type 1 (existing): 9.7 $MtCO_2e$ avoided** **Project type 2 (new): 288.9 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**Project type 1 (existing): €600 million total market** €6 billion cumulated investment by 2030, €0.6 billion yearly average (2020-2030) **Project type 1 (existing): €0.6 billion total market** €6 billion cumulated investment by 2030, €0.6 billion yearly average (2020-2030)	**Project type 1 (existing): €0.4 billion total market** €12 billion cumulated investment by 2050, €0.4 billion yearly average (2020-2050) **Project type 1 (existing): €0.4 billion total market** €12 billion cumulated investment by 2050, €0.4 billion yearly average (2020-2050)
JOBS	**Project type 1 (existing): 9,000 total jobs** **Project type 2 (new): 124,000 total jobs**	**Project type 1 (existing): 6,000 total jobs** **Project type 2 (new): 112,000 total jobs**

#12 [49]Based on mechanisms set by the Georisk project: https://www.georisk-project.eu/
[50]https://ec.europa.eu/energy/topics/energy-efficiency/heating-and-cooling_en?redir=1
[51]https://www.euroheat.org/wp-content/uploads/2016/03/DHC-Vision-for-DHC-2012.pdf
[52]https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/geodh_final_publishable_results_oriented_re-port.pdf
[53]http://www.afpg.asso.fr/wp-content/uploads/2019/08/APFG_GUIDE_BoucleEau_05082019.pdf

COST-EFFECTIVE AND ENERGY EFFICIENT CO_2 AIR CAPTURE AT SCALE

Direct Air Capture to simplify and ease the energy transition challenge

ENERGY

IN A NUTSHELL...

- **Issue:** Direct air capture is essential in all net-zero and 1.5 TECH scenarios, but strong challenges remain, such as caustic material use, high energy intensity and cost
- **Solution:** Direct air capture pilot plants to improve the technology, business models and reduce costs
- **Key impacts:** €20 million total market in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

- Set up ten direct air capture plants of 2,400 tCO_2 annual capture capacity, associated with renewable power generation and waste heat generation to supply low-carbon energy.
- The aim of the project is to foster technology improvements to reduce the negative impact of such technology and drive down costs, to prepare for future needs in sectors where emissions are impossible to abate and where direct carbon removal will ease the energy transition.
- All ten plants should be built in areas with potential offtakers for the captured CO_2 to make projects more profitable:
  - Seven plants should be built in the Netherlands and Northern Germany to lever the presence of industrial players, especially refineries. As the Rotterdam area sets to become a major hydrogen industrial cluster with synthetic fuel producers, demand for CO_2 will rise significantly.
  - Three plants should be built in Spain in order to leverage cheap solar energy and make use of large amounts of curtailment. The large concentration of greenhouse gases produced in crop culture necessitate a rapid and efficient roll-out of CO_2 capture.
- Such projects will be developed in partnership with:
  - Industrial offtakers (such as farming, oil, and chemical companies) in order to create commercial outlets and create industrial synergies. For instance, the heat needed for the DAC process could be recovered from waste heat of industrial stakeholders/power plants nearby.
  - Renewable energy developers.
  - R&D labs should be involved to follow the impact and support incremental improvements, particularly to reduce energy intensity.

Projects that inspired this analysis: Climeworks created modular CO_2 collectors that can be stacked to build machines of any size, aiming at industrialization of construction with larger volumes. Their Zurich plant captures CO_2 used to grow crops in a greenhouse nearby. Ultimately the company aims at selling that service as an offset by burying CO_2 underground. The energy used is produced by solar and heat from municipal waste incinerators on which the CO_2 collectors sit. The plant costs between €2.5 and €3.5 million, and uses 2.5 MWh of heat and 0.5 MWh of power per ton of CO_2 as it captures 900 tCO_2 per annum.

Why this technology and project are needed to reach net-zero

Most IPCC scenario modelling 1.5°C paths include a share of carbon dioxide removal, and the two European Commission scenarios reaching net-zero target by 2050 show extensive use of carbon dioxide removal (CDR), including Direct Air Capture technologies (DAC) from 2050. The 1.5Tech scenario plans 266 $MtCO_2$ capture and 200 $MtCO_2$ of direct air capture. While technologies like BECCS are preferred due to their ability to provide negative emissions, they also have side effects such as impact on air quality and need for large biomass resources. Thus, a mix of various technologies may prove useful.

Several low- and high-temperature DAC technologies are under investigation, launched by half a dozen companies in the world, with a few pilots and commercial examples in operation. Several challenges remain for a large-scale deployment of this technology:

- The current scale of operations does not offer fixed technological costs. The IEA[54] estimates the cost to be within a wide range of \$100-\$1000 per captured ton of CO_2. Players such as Climeworks-Antecy, Global Thermostat, Carbon Engineering claim to be able to decrease the cost within a €50-€100 range per tCO_2 by 2030.
- The process is highly energy-intensive (for both electricity and heat): 0.14-0.22 Mtoe/$MtCO_2$ extracted[55], e.g. a middle value of 2 TWh per $MtCO_2$ captured according to the IEA.
- A review of the low-temperature (LT) and high-temperature (HT) processes led in 2018 by the LUT University[56] estimates the need in energy to 1.5 TWh of electricity for HT process and 0.25 TWhel plus 1.75 TWhth for the LT process. Heat can be provided by low-grade waste energy.
- In all cases the LUT study foresees a better competitiveness for LT process, which costs in favorable conditions as in Morocco could lower down to €60-€100 per tCO_2 range and €20-€50 per tCO_2 in 2050. The higher figure represents the cost if the heat must be paid for, the lower figure if free waste heat is reused.

Impacts

	2030	2050
CLIMATE IMPACT	**0.02 $MtCO_2e$ avoided**	**160.4 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€20 million total market** €80 million investment by 2030, €8 million yearly average (2020-2030) €10 million turnover in 2030	**€8.3 billion total market** €53.5 billion investment by 2050, €1.8 billion yearly average (2020-2050) €6.5 billion turnover in 2050
JOBS	**300 total jobs** 100 construction jobs for investment 200 production jobs for turnover	**124,000 total jobs** 27,000 construction jobs for investment 97,000 production jobs for turnover

#13 *[54]https://www.iea.org/reports/direct-air-capture*
[55]Ibidem.
[56]Techno-economic assessment of CO_2 direct air capture plants, Mahdi Fasihi, Olga Efimova, Christian Breyer, LUT university, 2018

INDUSTRY

REDUCING CARBON INTENSITY OF INDUSTRY TO ENSURE SUSTAINABLE GROWTH IN EUROPE

Current situation and challenges

Industry is responsible for 30% (1,201 MtCO_2e) of EU27 greenhouse gas emissions, either from:

- **Energy use**: burning fossil fuels to obtain high-grade or low-grade heat, using non-renewable electricity.
- **Direct emissions from process**: for instance, the chemical reaction involved with cement production generates CO_2 as a by-product.

Achieving a low carbon industry is of paramount importance, not only to reach the 2050 carbon neutrality target, but also to allow economic growth for EU companies and workers.

The more challenging issues lie in core highly emissive chemical processes such as the production of cement or the reduction of iron ore, where substitutes, hydrogen or electrowinning can provide solutions.

The second technology challenge remains sustainable high-grade heat generation. High-grade heat requires high temperatures (above 300°C) that cannot be achieved simply with electrical resistors; and without profitable sustainable heat, the industry may turn toward fossil fuels. Hydrogen, a renewable and carbon-free fuel, can be a mainstream source for high-grade heat, once it becomes more affordable.

Regarding electric efficiency, low grade heat and cooling, the technology challenge relies mostly in the penetration rate of the best already available technologies and in the circular economy.

> **"We should lever the full potential of hydrogen across the value chain – let's learn from the Chinese approach on PV, as they now dominate the market," Diederik SAMSOM**, Head of Cabinet of Executive Vice-President of the European Commission Frans Timmermans

Solutions, projects and scale-up

Steel and cement industries are responsible for at least 30% of the industry emissions[1]. Therefore, several of the proposed solutions focus on these two industries. Carbon capture, for storage (CCS) or usage (CCU), is also a candidate to reduce carbon emissions while keeping businesses thriving.

As of today, heat generation is carbon-intensive, due to the heavy use of fossil fuels. Therefore, several solutions arise to tackle this; some of which can also be applied to cement and steel production.

Most of the proposed solutions follow the logic below:

- Step 1, in the short term: launch tenders financed by green transition funds to kick start innovation, by allowing several pilot sites to be profitable while using breakthrough technologies.
- Step 2, 2020-2030 horizon: the construction and operation of pilot sites to foster cost reductions in breakthrough technologies, through learning experience, as well as scale-up.
- Step 3, 2030-2050: affordability of the breakthrough technologies enables sector-wide use. Carbon pricing also helps to bridge the economic gaps.

Major energy efficiency programs could also be launched, with the objective to accelerate penetration of best available technologies, practices and processes regarding:

- Electric motors that are widely used in equipment, fans, compressed air, conveyors, etc.
- Low-grade heat, with reuse from high-grade heat waste, high temperature heat pumps, industrial heat networks, waste, biomass and geothermal energy.
- Best cooling technologies, best use of refrigerants.

Finally, plastics industry could also both curb its emissions impact and its waste impact through innovative biomaterials and chemistry pathways.

Impacts

- **€216 billion total market (turnover + investments) per year in 2030.**
- **3.8 million permanent jobs in 2030.**
- **269 MtCO_2 avoided per year in 2030.**

Regional approach

The regions surrounding Antwerp (Belgium), Düsseldorf (Germany) and Rotterdam (Netherlands) display several noteworthy synergies. These industrial areas gather major CO_2 emitters (cement industries, steel industries, refineries), while also being located near underground CO_2 storage sites (mostly, North Sea oil and gas wells), and chemical industries that may use CO_2 as an input. Furthermore, the nearby offshore wind turbines of the North Sea could supply green electricity for the hydrogen creation process, as well as other industrial processes.

List of projects - INDUSTRY

Core processes for cement, steel and chemical industries

#14 - REDUCE THE NEED FOR CONCRETE THANKS TO BETTER DESIGN AND ALTERNATIVE CONCRETE FOR EQUIVALENT USAGES
New concrete and better use in construction

#15 - REPLACE THE USE OF CONCRETE WITH CARBON SINK MATERIALS IN NEW BUILD
Lower the climate impact of buildings with wood and alternative concrete

#16 - REDUCE SHARE OF PORTLAND CLINKER IN CEMENT AND DEVELOP NEW ALTERNATIVE CLINKERS
Low-GHG and new cements

#17 - INDUSTRIALIZE THE USE OF CARBON CAPTURE AND USAGE TO DELIVER ULTRA-LOW CARBON CEMENT PRODUCTION
CCU solutions for cement industry

#18 - HYDROGEN REDUCTION OF IRON ORE FOR BASIC OXYGENATED FURNACES AND ELECTRIC ARC FURNACES
Use green hydrogen from renewables and electrolysis to decarbonize steel industry

#19 - ELECTROWINNING OF IRON ORE FOR ELECTRIC ARC FURNACES
Electrifying iron ore reduction enables to shift iron ore usage from high-GHG emissive BF/BOF integrated steel plants to low-GHG EAF plants

#20 - REUSE PROCESS GASES AND CAPTURE CO_2 TO LOWER EMISSIONS OF STEEL INTEGRATED PLANTS
Recycle and reuse process gases in the blast furnace and basic oxygenated furnace with CC

#21 - SCALE ON-SITE GREEN HYDROGEN PRODUCTION IN REFINERIES
Shift from fossil-based H_2 to decarbonized H_2 for feedstock usage

Heat supply

#22 - SWITCH TO LOW-CO_2 FUELS FOR HIGH-GRADE HEAT INDUSTRY PROCESSES
Co-processing of waste and biomass in furnaces (from 300° to over 1000°C)

#23 - SWITCH TO LOW-CO_2 SOLUTIONS FOR LOW-GRADE HEAT INDUSTRY NEEDS
Recovery from high-grade heat waste, high-temperature heat pumps, bioenergy, geothermal energy, symbiosis heat networks

Electric efficiency

#24 - IMPLEMENT MASSIVE ELECTRIC EFFICIENCY PROGRAM FOR ALL EUROPEAN INDUSTRIAL PLANTS
High-efficiency motors, equipment and services along with digital and Industry 4.0

Other industrial products

#25 - REDUCE GHG IMPACT OF REFRIGERANTS
Mainstream the use of low-GHG refrigerants in all sectors

#26 - REDUCE GHG IMPACT OF PLASTIC THROUGH REUSE AND RECYCLING
Develop technology solutions to increase circularity of plastics

[1]EEA, 2018 data.

REDUCE THE NEED FOR CONCRETE THANKS TO BETTER DESIGN AND ALTERNATIVE CONCRETE FOR EQUIVALENT USAGES

New concrete and better use in construction

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Cement production accounts for 2%[1] of global CO_2 emissions; low-GHG alternatives exist but have not sufficiently penetrated the market yet
- **Solution:** Boost the use of biobased concrete, starting with 10,000 tons in 2030
- **Key impacts:** 2.0 $MtCO_2e$ avoided, €2.8 billion total market, 42,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

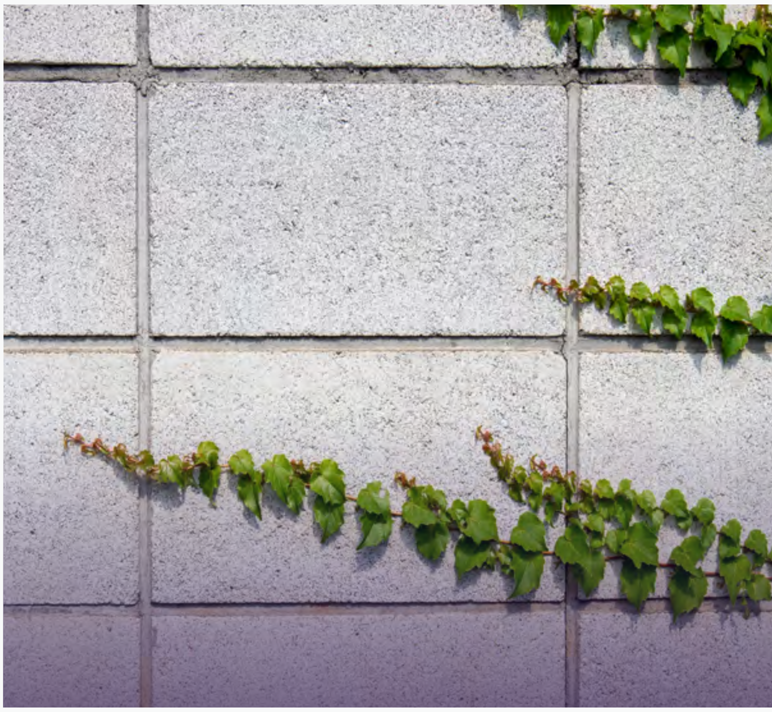
Project opportunity and ambition

- Incentivize and allow architects to reduce use of concrete: more efficient design of buildings and use of hollow structures.
- Launch technical studies to assess areas and sectors in which biobased concrete can be rapidly and effectively deployed.
- Update the European and national building standards to drive the adoption of biobased concrete and favor use of hollow-shaped concrete:
  - ◊ Concrete standards should be performance-based rather than composition-based.
  - ◊ Standards for calculating mechanical stress in buildings may have to be adapted to facilitate adaptation of shaped, hollow, and concrete blocks.
- Work with local authorities to encourage and reward the use of low-carbon building materials in public tenders.
- The success of the target described later is dependent on the collaboration between a range of stakeholders from the construction value chain. These include: the cement and concrete producers, the architects and contractors as well as local authorities.

Projects that inspired this analysis: Green-cast, Isobio and Novhisol.

Why this technology and project are needed to reach net-zero

- Concrete uses cement, the production of which is responsible for 2%[2] of total European CO_2 emissions.
- As global construction activities gear up, there is an urgent need for sustainable concrete no longer based on Portland cement, the basis of the construction industry for the past 200 years
- Most CO_2 emissions from Portland cement production are so-called process emissions. They are linked to the decomposition of limestone (calcium carbonate) into calcium oxide. And, CO_2 is the byproduct of the production process.
- Various alternatives of concrete are identified, they can be based on hemp and lime, non-heated clay, and fly ash, which is waste from thermal plants. For example: the 'green' concrete developed by the Drexel engineers, is based on old Egyptian technology, a form of alkali-activated cement that utilizes slag, an industrial byproduct, and limestone which does not require heating to produce.
- The target is to reach a market penetration rate of 30% by 2050, which is equivalent to 84 million tons[3] of concrete.



Impacts

	2030	2050
CLIMATE IMPACT	**2.0 $MtCO_2e$ avoided**	**5.9 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€2.8 billion total market** €3 billion turnover	**€8.4 billion total market** €8.4 billion turnover
JOBS	**42,000 jobs**	**126,000 jobs**

#14 *[1]From EPFL data (0.6 tCO_2e/ton of cement, https://www.research-collection.ethz.ch/handle/20.500.11850/301843), EC (163 Mt of cement produced in 2016, and 4.59 $GtCO_2e$ emissions in 2015)*
[2]From EPFL data (0.6 tCO_2e/ton of cement, https://www.research-collection.ethz.ch/handle/20.500.11850/301843), EC (163 Mt of cement produced in 2016, and 4.59 $GtCO_2e$ emissions in 2015)
[3]See calculation for market size of concrete

REPLACE THE USE OF CONCRETE WITH CARBON SINK MATERIALS IN NEW BUILD

Lower the climate impact of buildings with wood and alternative concrete

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** New building construction is an emission-intensive process, with carbon-intense materials and high energy needs for transportation and equipment operation
- **Solution:** Upscale alternative comprehensive construction materials and approaches, using electric equipment (machines and vehicles), geothermal energy, and green areas
- **Key impacts:** 28.5 $MtCO_2e$, €131.7 billion total market, 2.5 million jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

Build 500 buildings in each European country by 2025 using low GHG-intensity materials and construction methods, with construction materials split between wood and low-GHG emitting cement.

Project type 1: Wood buildings

Build 250 buildings from wood in each European country by 2025, sourcing 100% of the materials from Europe and using cross-laminated timber (CLT, sourced wherever possible from a local wood supply) in each country before 2025. These will be built in 10 European regions, corresponding to 10 different types of buildings: including offices, detached houses and apartment blocks.

- Building regulations will have to be adjusted accordingly.
- Use of electric machines and equipment, like in the city of Oslo, where the goal was not only to build a structure from low-GHG-emitting materials, will reduce emissions from construction activities, creating a 'net-zero construction site' using low emissions and locally sourced materials, where possible.
- Include other low-carbon technologies for a comprehensive approach (geothermal heating, heating pumps, and other eco-materials such as hemp, earth, etc.).
- Document key learnings from the project in terms of supply, market, regional constraints and difficulties in order to provide strong recommendations for scale-up.

Projects and stakeholders that inspired our analysis: National Wood Processing Cluster (Czech Republic), Lithuanian Prefabricated Wooden House Cluster, Altiflex (Danish building support supplier)

Project type 2: Low-GHG emitting cement buildings

Build 250 low-GHG cement-based buildings in each European country by 2025, sourcing 100% of the materials from Europe and using various techniques (see Industry part for more details on low-GHG cement). These will be built in 10 regions of Europe and include 10 different types of buildings, some detached houses, others apartment blocks, etc.

As for project type 1, electric machines and equipment as well as other low-carbon technologies will be used, and the key learnings will be documented.

Why this technology and project are needed to reach net-zero

- The construction industry accounts for 11% of global emissions, mainly because it uses a lot of concrete. This is especially the case in Southern Europe, where many buildings are made from cement (the production of which accounts for 2% of total European emissions). The choice of materials plays an important role in reducing energy demand and GHG emissions in the lifecycle of buildings. Alternatives to concrete, such as wood and low-carbon cement, produce less emissions, are carbon-neutral or even carbon-negative, and recyclable. Timber houses can have a negative carbon footprint, with 1m^3 of spruce able to store 0.8 $MtCO_2$.
- Scandinavia is a European leader and 40% of Norway is covered in forests: its wood is exported for manufacturing into glulam and CLT in Austria and Germany, before being reimported into Norway for building construction.
- Construction activities are energy-intensive and use heavy machinery, equipment, and vehicles. The use of electric construction equipment reduces GHG emissions and projects combining both new materials and electric equipment considerably reduce emissions.

Impacts

	2030	2050
CLIMATE IMPACT	**28.5 $MtCO_2e$ avoided**	**42.8 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€131.7 billion total market** €131.7 billion turnover in 2030	**€197.6 billion total market** €197.6 billion turnover in 2050
JOBS	**2,502,000 jobs**	**3,753,000 jobs**

REDUCE SHARE OF PORTLAND CLINKER IN CEMENT AND DEVELOP NEW ALTERNATIVE CLINKERS

Low-GHG and new cements

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Cement production accounts for 2%[4] of EU CO_2 emissions, and processes (excluding energy emissions) from clinker production alone generate 66% of those emissions
- **Solution:** Replacing clinker with substitutes (less clinker per unit of cement) can cut emissions by 18%[6]. Also, use of alternative clinkers (to replace the classic Portland clinker) achieves a 17%[7] cut in CO_2 emissions
- **Key impacts:** 6.8 $MtCO_2e$ avoided, €5.2 billion total market, 78,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

Project type 1: Lower the share of clinker and adapt construction standards accordingly

Launch technical studies to determine which construction types are the most compatible with lower clinker-factor cement.

- In Europe, cement contains on average 73%[8] of ordinary Portland clinker.
- Introduce a lower clinker-factor cement: 60%.
- By 2030, the use of a lower clinker-factor cement on tenders for public construction work (bridges, buildings, etc.) helps ensure market uptake.

This would need to be paired with a supportive regulatory framework to ensure longevity.

Project type 2: Develop alternative clinkers on four pilot sites by 2025 hosted in cement production facilities to cut cement CO_2 emissions

- Launch feasibility study to select best-suited alternative clinker composition using existing research over six months.
- Launch industrial trials of alternative cements based on selected alternative clinkers for a year and a half on four real-size facilities producing 450 kilotons of cement across Europe (Poland, France, Italy, Germany) with different cement producers.
- Involve stakeholders across the construction value chain, including: the four cement production facilities that host the pilots, architects and contractors hired to test alternative cements on a construction site, and local authorities to commission construction work using new cement.
- Support market uptake of alternative cement through green public procurement programs and regulations.
- Revise EU and national standards to support the adoption of the new alternative cements on construction sites.

Why this technology and project are needed to reach net-zero

About 66%[9] of emissions from the cement manufacturing process come from the transformation of limestone at high temperature (decarbonation process) to produce clinker, which is traditionally composed of 75% limestone and 25% clay.

CEM I (ordinary Portland cement) contains 95% clinker. European standards EN197-1 allow other cement types with a clinker to cement ratio varying from 5% to 95%. Today in Europe, the average clinker to cement ratio (also called clinker factor) over all cement types is equal to 0.73. The most sold cement type is CEM II-A, where clinker is substituted with limestone up to a maximum substitution of 20%.

Introducing alternative decarbonized raw material into clinker composition such as recycled cement paste from demolition waste, air-cooled slag, and waste lime help lower emissions of the decarbonization phase of about 30% compared to ordinary Portland cement clinker. This technology is applicable to 100% of all building works by 2050 and 25% by 2030, and a lower clinker ratio in cement is applicable to the whole construction market.

Projects and existing pilots that inspired this analysis are:

- The AETHER project, which focused on a new type of clinker that can be used within existing industrial installations. This alternative clinker delivers a 25% to 30% cut in CO_2 emissions compared with conventional Portland cement as well as a 15% decrease in energy consumption due to a lower temperature needed for heat for raw materials transformation (1,225-1,300°C vs. 1,400-1,500°C for Portland's cement). Other types of low-CO_2 footprint clinkers are Sulpho-Aluminate Clinker (SAC), Ferro-Aluminate Clinker (FAC) or Calcium Aluminate Clinker.
- The Futurecem project 'Green Concrete II' reduces the clinker rate in cement by replacing it with 40% fillers, namely calcined clay and limestone. This low-clinker cement has the same performance as Portland cement and is being used to build two bridges in Denmark.

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (lower clinker ratio): 4.3 $MtCO_2e$** **Project type 2 (alternative to Portland clinker): 2.5 $MtCO_2e$**	**Project type 1 (lower clinker ratio): 17.4 $MtCO_2e$** **Project type 2 (alternative to Portland clinker): 5.8 $MtCO_2e$**
ECONOMIC IMPACT	**Project type 1 (lower clinker ratio): €3.3 billion total market** €3.3 billion turnover in 2030 **Project type 2 (alternative to Portland clinker): €2.0 billion total market** €2 billion turnover in 2025	**Project type 1 (lower clinker ratio): €13 billion total market** €13 billion turnover in 2050 **Project type 2 (alternative to Portland clinker): €4.6 billion total market** €4.6 billion turnover in 2050
JOBS	**Project type 1 (lower clinker ratio): 49,000 jobs** **Project type 2 (alternative to Portland clinker): 29,000 jobs**	**Project type 1 (lower clinker ratio): 196,000 jobs** **Project type 2 (alternative to Portland clinker): 69,000 jobs**

#16 [4]From CEPFL data (0.6 tCO_2e/ton of cement), EC (163 Mt of cement produced in 2016, and 4.59 $GtCO_2e$ emissions in 2015)
[5]From CEPFL data: 0.28 tCO_2e/ton of clinker for energy part, 0.54 tCO_2e/ton of clinker for process part. www.research-collection.ethz.ch/handle/20.500.11850/301843
[6]See calculations
[7]See calculations
[8]https://www.research-collection.ethz.ch/handle/20.500.11850/301843
[9]From EPFL data: 0.28 tCO_2e/ton of clinker for energy part, 0.54 tCO_2e/ton of clinker for process part.

INDUSTRIALIZE THE USE OF CARBON CAPTURE AND USAGE TO DELIVER ULTRA-LOW CARBON CEMENT PRODUCTION

CCU solutions for cement industry

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** The calcination phase in the cement industry is responsible for 66%[10] of cement emissions
- **Solution:** Capture unavoidable process emissions and reuse the CO_2 in industries such as concrete or petrochemicals
- **Key impacts:** 14.9 $MtCO_2e$ avoided, €1.1 billion total market, 16,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

The project goal is to scale up and industrialize carbon capture at cement kilns and CO_2 usage in the cement and concrete industry to capture 14% of cement production emissions by 2030 and 56% by 2050[11].

Project 1: Carbon capture by direct separation

Launch pilot projects of carbon capture by direct separation in 10% of all cement kilns with the ambition to capture a total of 7.8 $MtCO_2$ each per year by 2030.

- Direct separation consists of heating up the raw materials of clinker without getting the materials in direct contact with the fumes (see LEILAC project). The CO_2 emitted from the raw material decarbonation can then be channeled, with a high concentration.
- Assess candidate locations for direct separation projects at industrial scale (based on the existence of a market or outputs for captured CO_2).
- Incentivize the retrofitting of cement kilns as cement plants have a lifetime of 30 to 50 years.
- Push for quick standardization of 'green' cement products on the market to ensure market uptake and economic viability, as carbon capture amounts to more than 50%[12] of cement production cost.
- Key stakeholders include cement producers, contractors and architects, and law-makers.
- Set up support mechanisms such as carbon border adjustment.

Projects that inspired this analysis: LEILAC project in Lixhe, Belgium.

Project 2: Oxyfuel combustion in cement kilns

Launch pilot projects of oxyfuel combustion to retrofit 10% of all cement kilns and capture 8.2 $MtCO_2$[13] per year by 2030.

- Oxyfuel is the process of using pure oxygen instead of air to burn a fossil fuel. Therefore, the fumes can be cycled several times (thanks to the oxygen content), and the exhaust is rich in CO_2.
- Launch a feasibility assessment of oxyfuel combustion in cement kilns, using studies carried out on oxyfuel combustion in boilers.
- Identify industrial sites and launch industrial scale pilot projects creating synergies between cement plants producing CO_2 and neighboring chemical or petrochemical plants for CO_2 usage on eight big production sites, one in each of the following countries: Poland, Slovakia, Czech Republic, Romania, Germany, France, Italy and Spain.
- Key stakeholders to involve are cement producers, the SINTEF (Norwegian cluster with expertise in the subject), the European Cement Research Association, gas grid operators to transport CO_2, national and European authorities to push for public acceptance.

Projects that inspired this analysis: Norway through the SINTEF, Germany, Italy, France (industrial clusters).

Why this technology and project are needed to reach net-zero

Improvement of energy use in cement industry (switching fuels) can only cut emissions up to 34%[14]. Without carbon capture, use and storage, the emissions from the process would remain, and prevent reaching net-zero cement.

- Direct separation has been demonstrated by Leilac 2, capturing 80%[15] of CO_2 from the process (excluding CO_2 from energy combustion).
- Oxyfuel combustion (process of using pure oxygen instead of air to burn a fossil fuel) can cut up to 90% of post-combustion emissions: the Westküste100 project led by LafargeHolcim in Germany is expected for instance to capture 1 $MtCO_2$ per year by 2030 and use it or part of it to produce jet fuel.
- Captured CO_2 can also be reused in recycled concrete granulates to increase material strength. Active clusters on this topic are France (Fastcarb project and Solidia tests), Germany (targeted as a market by startup CarbonCure) and Sweden (targeted as a market by startup CarbonCure).

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (direct CO_2 separation): 7.8 $MtCO_2e$ avoided** **Project type 2 (oxyfuel): 7.1 $MtCO_2e$ avoided**	**Project type 1 (direct CO_2 separation): 31.3 $MtCO_2e$ avoided** **Project type 2 (oxyfuel): 32.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**Project type 1 (direct CO_2 separation): €680 million total market** €3 billion cumulated investment by 2030, €340 million yearly average (2020-2030), €340 million turnover in 2030 **Project type 2 (oxyfuel): €400 million total market** €1.9 billion cumulated investment by 2025, €200 million yearly average (2020-2030), €200 million turnover in 2030	**Project type 1 (direct CO_2 separation): €1.8 billion total market** €14 billion cumulated investment by 2050, €460 million yearly average (2020-2050), €1.4 billion turnover in 2050 **Project type 2 (oxyfuel): €0.8 billion total market** €5.8 billion cumulated investment by 2025, €200 million yearly average (2020-2050), €600 million turnover in 2050
JOBS	**Project type 1 (direct CO_2 separation): 10,000 total jobs** 5,000 construction jobs from investment 5,000 operation jobs from turnover **Project type 2 (oxyfuel): 6,000 total jobs** 3,000 construction jobs from investment 3,000 operation jobs from turnover	**Project type 1 (direct CO_2 separation): 27,000 total jobs** 6,800 construction jobs from investment 20,500 operation jobs from turnover **Project type 2 (oxyfuel): 12,000 total jobs** 3,000 construction jobs from investment 9,000 operation jobs from turnover

#17 [10]From EPFL data: 0.28 tCO_2e/ton of clinker for energy part, 0.54 tCO_2e/ton of clinker for process part. www.research-collection.ethz.ch/handle/20.500.11850/301843
[11]See calculation
[12]https://www.globalccsinstitute.com/archive/hub/publications/201688/global-ccs-cost-updatev4.pdf
[13]See calculation
[14]The complementary percentage of 66%, which was given earlier for the emissions from calcination process.
[15]https://www.project-leilac.eu/leilac-pilot-plant

HYDROGEN REDUCTION OF IRON ORE FOR BASIC OXYGENATED FURNACES AND ELECTRIC ARC FURNACES

Use green hydrogen from renewables and electrolysis to decarbonize steel industry

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Steel production accounts for 35%[16] of EU's total industrial emissions, mostly due to iron reduction with coke derived from coal
- **Solution:** Green hydrogen based on direct reduction of iron ore (DRI) could cut emissions of the sector by 15% in 2050
- **Key impacts:** 13.7 $MtCO_2e$ avoided, €6.1 billion total market, 9,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

Reach 6% of the total steel market by 2030 using hydrogen-based iron ore reduction

- Draft a sector roadmap that assesses the key steps for upgrading switching existing plants, i.e. retrofitting or replacing the blast furnaces (which transforms iron ore into pig iron) with green hydrogen DRI facility and a shaft furnace (which transforms iron ore into direct reduced iron, or DRI). DRI can then be charged into an electric arc furnace, skipping altogether the basic oxygenated furnace step that usually follows the blast furnace.
- Having a shaft furnace on-site, which currently may use natural gas instead of hydrogen, will help reduce the length of the retrofit process. Furthermore, the sites must have a supply of green hydrogen (either from the market or produced on-site with electrolyzers).
- Stakeholders include steel plants operating the selected pilot sites, a green hydrogen supplier, the national authority to coordinate finance schemes, the 'Green Steel for Europe' project consortium and its partners (including ESTEP, EUROFER, BFI, CEPS, IMZ, and CSM) for know-how and industry uptake.
- To secure the market uptake, it needs to be ensured that green steel remains competitive compared to regular steel with a financial support scheme (such as carbon border adjustment, carbon price, and feed-in tarriffs) and guaranteed outputs through green public procurement programs to counterbalance high prices.
- Location: Steel producing regions that have sites equipped with BF/BOF in Northern Spain, the Ruhr region, North of France, Sweden, Poland and the Czech Republic.

Projects that inspired this analysis: HYBRIT project in Sweden, which will consume 2633 kWh of green hydrogen and emit 25 kg of CO_2 per ton of steel compared to the Swedish average of 1.6 t of CO_2 per ton of steel, for a production cost 30% higher than average.

Why this technology and project are needed to reach net-zero

- 60% of steel is produced through the primary route, which consists of melting iron ore pellets and coke in a blast furnace (BF) to produce pig iron. It then goes through a basic oxygenated furnace (BOF) to produce liquid steel[19] This process emits 1.88 tCO_2 per ton of steel[19] due to the use of coal to reduce iron ore into pig iron. The secondary route consists of melting scrap in an electric arc furnace (EAF) to obtain liquid steel. The emissions from the secondary route depend on the electricity used to power the EAF, and amount on average to 0.5 tCO_2 per ton of steel produced.[20]
- The direct reduction technology reduces iron ore in a shaft furnace with green hydrogen and reduces iron ore into DRI which can be fed in an electric arc furnace to produce liquid steel. Therefore, effectively by-passing the carbon-intensive primary route mentioned above.
- As such, to reduce GHG emissions on a large scale in Europe, emphasis should be on the replacement or retrofitting of existing BF/BOF brownfield plants. Those plants are spread across Europe but are mainly located in Slovakia, Poland, Czech Republic, Austria, Northern Spain and the Ruhr region.
- The aim is to roll out this technology on 33% of BF/BOF (or 20% of the total steel market) in Europe by 2050.
- Ramping up the green hydrogen direct reduction will require new skills and create new jobs as well as provide flexibility to the steel industry. However, it will also add pressure on the demand for green hydrogen in Europe.
- Temporary support mechanisms must be put in place to offset the high prices of green hydrogen, as compared to coal and natural gas, and cover the cost differential between fossil-based steel and green steel.

Impacts

	2030	2050
CLIMATE IMPACT	**13.7 $MtCO_2e$ avoided**	**43.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€6.1 billion total market** €1.5 billion investment by 2030, €150 million yearly average (2020-2030) €5.9 billion turnover	**€19 billion total market** €3.6 billion investment between 2030 and 2050, €180 million yearly average (2030-2050) €18.8 billion turnover
JOBS	**91,000 total jobs** 2,000 construction jobs for investment 89,000 production jobs for turnover	**285,000 total jobs** 3,000 construction jobs for investment 282,000 production jobs for turnover

#18 [16]Wortler, et al., 2013: 1.88 tCO_2e/ton of steel. EUROFER: 160 Mt of steel production:
https://www.eurofer.eu/assets/Uploads/European-Steel-in-Figures-2020.pdf
In Depth Analysis EU, EC, (868 $MtCO_2e$ emitted by industry, figure 11):
https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[17]Definition: https://www.metallics.org/pig-iron.html
[18]Definition: https://www.metallics.org/dri.html
[19]Wortler, et al., 2013
[20]http://www.carmeuse-steel.com/news/co2-impact-steel-making-industry

ELECTROWINNING OF IRON ORE FOR ELECTRIC ARC FURNACES

Electrifying iron ore reduction enables to shift iron ore usage from high-GHG emissive BF/BOF integrated steel plants to low-GHG EAF plants

INDUSTRY

Core processes for cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** Iron and steel production is based on coal and accounts for 35%[21] of EU's total industrial emissions. About 90% of these emissions come from iron and coke reduction
- **Solution:** Electrowinning of iron ore avoids the use of carbonated reductants and lifts the scrap availability constraint, which currently limits the use of electric arc furnaces
- **Key impacts:** 2.6 MtCO_2e avoided, €0.2 billion total market, 3,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

- The aim of this R&D program is to accelerate the scale-up of steel making based on electrowinning, from laboratory level to industrial trials.
- The project aims to launch pilots in plants equipped with an electric arc furnace (EAF), preferably located near an important source of renewables coupled with a storage solution to power the EAF without interruption.
- The objective is to further test the technology (TRL 8 validated) and monitor profitability.
- Stakeholders include steel producers operating the pilot plant, utility companies to supply green power, and a third party to supply the electrowinning electrolyzer.
- The program research will be in a region where green power is affordable and abundant, such as Sweden, the Netherlands or Germany, which have abundant offshore wind power production. Poland may also be a candidate as it plans to invest in 5 GW of offshore wind farms by 2030.
- The project provides momentum to the steel sector to cut 17%[22] of its emissions by 2050.

Projects that inspired this analysis: Siderwin project, which piloted the production of 25 tons of steel annually. The pilot achieved a CO_2 emissions reduction of 87%[23] as compared to BOF/BF steel production and reduced direct energy consumption by 31%.

Why this technology and project are needed to reach net-zero

- There are currently 500 steel plants in Europe, of which 30 are integrated steel plants equipped with blast furnaces and basic oxygenated furnaces for primary production of steel. The rest is produced by electric arc furnaces, through a secondary production route.
- Steel is produced at 60% through a primary route[24], which consists of melting iron ore pellets and coke in a blast furnace to produce pig iron. It then goes through a basic oxygenated furnace to produce liquid steel. This process emits 1.88 tCO_2 per ton of steel due to the use of coal to reduce iron ore into pig iron. The secondary route, based on scrap melting in an electric arc furnace (EAF), only emits on average 0.5 tCO_2 per ton of steel produced[25]. However, it only covers 40% of the European production due to limited steel scrap availability.
- The electrowinning technology overcomes the limited steel scrap availability issue by processing iron-ore into an EAF. It therefore has the potential to help increase the EAF production route compared to production from the BF/BOF route. It is energy efficient as the iron-ore conversion takes place at a low temperature (110°C) and there are no losses due to conversion (as opposed to direct reduction based on green hydrogen). However, this technology can only reach demonstration stage by 2030. It also needs to be combined with a storage solution to ensure a continuous supply of electricity to the EAF. The final target is to achieve 33%[26] of blast furnaces and basic oxygenated furnaces and switch their production to EAF via electrowinning by 2050.
- Carbon border adjustment measures must be put in place so that producers from Europe and outside Europe bear the same carbon cost. Alternatively, other temporary support mechanisms must be put in place to offset the high prices of green electricity compared to coal and natural gas.

Impacts

	2030	2050
CLIMATE IMPACT	**2.6 $MtCO_2e$ avoided**	**51.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€180 million total market** €500 million cumulated investment by 2030, €50 million yearly average (2020-2030) €130 million turnover in 2030	**€2.2 billion total market** €7.8 billion cumulated investment by 2030, €260 million yearly average (2020-2050) €2.0 billion turnover in 2050
JOBS	**3,000 total jobs** 1,000 construction jobs for investment 2,000 production jobs for turnover	**33,000 total jobs** 4,000 construction jobs for investment 29,000 production jobs for turnover

#19 [21]Wortler, et al., 2013: 1.88 tCO_2e/ton of steel. EUROFER: 160 Mt of steel production: https://www.eurofer.eu/assets/Uploads/Europe-an-Steel-in-Figures-2020.pdf)
In Depth Analysis EU, EC, (868 $MtCO_2e$ emitted by industry, figure 11): https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[22]See calculation
[23]Siderwin project, https://www.siderwin-spire.eu/content/home
[24]https://www.eurofer.eu/assets/Uploads/European-Steel-in-Figures-2020.pdf
[25]http://www.carmeuse-steel.com/news/CO_2-impact-steel-making-industry
[26]See penetration, in respect to current share of BF/BOF (primary route)

REUSE PROCESS GASES AND CAPTURE CO_2 TO LOWER EMISSIONS OF STEEL INTEGRATED PLANTS

Recycle and reuse process gases in the blast furnace and basic oxygenated furnace with CC

INDUSTRY

Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** In Europe, 90%[27] of GHG emissions from steel production come from iron reduction from coke, which occurs in the blast furnace
- **Solution:** Recycling process gases (CO and H_2) from the blast furnace back into the process limits emissions and the need for coke as a reductant
- **Key impacts:** 16.8 $MtCO_2e$ avoided, €1.8 billion total market, 27,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

- The aim of the project is to replicate and scale up the existing technology of recycling top gases from blast furnaces.
- The first step is to carry out an assessment and mapping of existing top gases blast furnaces recycling projects and the required steps to retrofit blast furnaces with the recycling equipment to recover CO_2.
- Launch pilot plants equipped with blast furnaces, producing a significant quantity of steel (above three million tons yearly) and preferably located near a chemical park to ensure outputs for captured CO_2 will be selected. The technology is already available hence scale up can be carried out rapidly.
- The project starts with one full-scale integrated pilot plant, producing 3.3 million tons of steel per annum. The aim is to have finished the retrofit by 2025. The technology will then be replicated on 6% of the European steel production.
- Stakeholders include steel producers, chemical platforms, local authorities to discuss potential CO_2 storage and experts such as the EUROFER Sustainability for Steel Construction Products Committee, the European Steel Technology Platform and the Green Steel for Europe Consortium for knowledge sharing.
- Key geographical clusters which have recycling projects are the Ruhr region, Poland, Slovakia, Czech Republic, Austria, and Northern Spain as they possess integrated steel making plants with blast furnaces.

Projects that inspired this analysis: Steelanol project (carbon capture and usage in Ghent); LKAB project in Lulea (Sweden).

Why this technology and project are needed to reach net-zero

- Most European steel (about 60%[28]) is made via the primary route, which consists of melting iron ore pellets and coke in a blast furnace to produce pig iron. It then goes through a basic oxygenated furnace to produce liquid steel. BF and BOF installations have an average lifetime of 15 to 20 years and are used across Europe to produce steel but are predominant in Eastern Europe.
- To decrease the amount of CO_2 emitted while keeping the current infrastructures in place, steel plants can invest in technologies that capture CO_2, H_2, and CO from the top gases leaving the blast furnace and reinject them into the furnace after preheating.
- This has a double benefit: reinjected gases act as reducing agents, decreasing the quantity of coke and coal needed to reduce iron ore, and less CO_2 is emitted from the top gases.
- To maximize the technology potential, the carbon captured in excess that cannot be reinjected into the furnaces can be sold to other industrial plants to produce biofuels. This is the case with the Steelanol project located in Ghent, Belgium, which uses CO_2 captured from a steel plant furnace to produce bioethanol.

Impacts

	2030	2050
CLIMATE IMPACT	**16.8 $MtCO_2e$ avoided**	**53 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€1.8 billion total market** €11.4 billion cumulated investment by 2030, €1.1 billion yearly average (2020-2030) €650 million turnover in 2030	**€3.3 billion total market** €36.2 billion cumulated investment by 2050, €1.2 billion yearly average (2020-2050) €2 billion turnover in 2050
JOBS	**27,000 total jobs** 17,000 construction jobs for investment 10,000 production jobs for turnover	**49,000 total jobs** 18,000 construction jobs for investment 31,000 production jobs for turnover

#20 [27]*Roland Berger, The future of steelmaking, May 2020*
[28]*https://www.eurofer.eu/assets/Uploads/European-Steel-in-Figures-2020.pdf*

SCALE ON-SITE GREEN HYDROGEN PRODUCTION IN REFINERIES

Shift from fossil-based H_2 to decarbonized H_2 for feedstock usage

INDUSTRY | Core processes for the cement, steel and chemical industries

IN A NUTSHELL...

- **Issue:** The industrial sector consumes 90% of European hydrogen, however most of this hydrogen is produced using fossil fuels
- **Solution:** Create new industrial clusters and a steering European entity to reach 12% green hydrogen in refineries' consumption by 2030
- **Key impacts:** 2.1 $MtCO_2e$ avoided, €1 billion total market, 15,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

- This project aims to accelerate the shift from grey hydrogen to green hydrogen production, which is based on the electrolysis from renewable sources. It will start by launching a call for participation to select refineries that are interested in investing in large scale green hydrogen installations on-site or in purchasing green hydrogen.
- The target is to start with five real-size electrolyzer pilot projects of 175 MW each by 2025. Green hydrogen will avoid 75% of GHG emissions compared to the current carbon footprint of grey hydrogen. By 2030, the objective is to scale up to 3.7 GW electrolyzer projects installed to supply 12% of the refinery demand of H_2.
- On average, a refinery consumes 30,000 tons of hydrogen yearly, of which 25% comes from on-site processes (not replaceable) and 75% is sourced externally. Green hydrogen can replace this external sourcing.
- Hydrogen can be used to store renewable energy before being consumed, and excess hydrogen can be sold to neighboring industrial chemical or steel plants.
- Stakeholders: oil and gas players operating refineries in Europe, chemical and steel companies, specialized organizations such as Hydrogen Europe, and the Fuel Cells and Hydrogen Joint Undertaking.
- Geographical clusters: Benelux and the Rhine region, Southern France, Northern Italy, Portugal, as well as secondary clusters in Ireland, Finland, Lithuania, North East Spain and Romania. Also, involve big chemical companies, oil and gas companies, and experts' societies such as FuelsEurope and Concawe.

Projects that inspired this analysis: the REFHYNE initiative in Germany, the MULTIPLHY initiative in Rotterdam, HySynergy in Denmark, and Delfzijl in the Netherlands (see details in following section).

Why this technology and project are needed to reach net-zero

- Industry consumes 90% of European hydrogen which is mostly grey hydrogen produced from fossil fuels. In the refining sector, 6% of emissions are associated with the production of hydrogen consumed. As refineries account for 23% of industrial emissions (23% of 868 $MtCO_2e$[29], thus 199 $MtCO_2e$), this yields to 12 $MtCO_2$ emitted yearly for hydrogen used in refineries.
- This consumption pattern is expected to slightly drop or remain stable up to 2050, of which 66% should be used for biofuels and 33% for traditional refined products.
- Producing green hydrogen on-site using electrolyzers will considerably lower these emissions. Starting with a 12%[30] market penetration by 2030 to help set the pace to reach 30% by 2050.
- This project will contribute to achieving the 2030 proposition set by Hydrogen Europe of 2×40 GW electrolyzer capacity for the EU and its neighbors (such as North Africa and Ukraine) alike[31]. The roadmap estimates that Europe's 40 GW can be split into a 6 GW captive market (hydrogen production at the demand location) and a 34 GW hydrogen market (hydrogen is transported), demonstrating the need of industrial cooperation in clusters.
- Several projects based on this technology have already been launched, such as:
  - ◊ REFHYNE: 10 MW Polymer Electrolyte Membrane electrolyzer at the Wesseling site in the Rheinland Refinery Complex, expected to start operating in 2020.
  - ◊ MULTIPLHY: High-Temperature Electrolyzer system supported by a consortium involving the CEA, Neste (the world's leading provider of renewable diesel and renewable jet fuel), plant builder Paul Wurth, and cleantech company Sunfire in Rotterdam.
  - ◊ HySynergy: supported by Shell and Everfuel in Fredericia, Denmark, for a 20 MW electrolyzer from 2022-2023 for €20 million, and it could be scaled up to 1 GW.

Impacts

	2030	2050
CLIMATE IMPACT	**2.1 $MtCO_2e$ avoided**	**5.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€990 million total market** €920 million investment by 2030, €92 million yearly average (2020-2030) €900 million turnover in 2030	**€2.3 billion total market** €1.8 billion investment between 2030 and 2050, €90 million yearly average (2030-2050) €2.3 billion turnover in 2050
JOBS	**15,000 total jobs** 1,000 construction jobs for investment 14,000 production jobs for turnover	**35,000 total jobs** 1,000 construction jobs for investment 35,000 production jobs for turnover

#21 [29]*In Depth Analysis EU, EC, figure 11: https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf*
[30]*See calculation*
[31]*https://www.hydrogen4climateaction.eu/2x40gw-initiative*

SWITCH TO LOW-CO_2 FUELS FOR HIGH-GRADE HEAT INDUSTRY PROCESSES

Co-processing of waste and biomass in furnaces (from 300° to over 1000°C)

INDUSTRY | Heat supply

IN A NUTSHELL...

- **Issue:** Heat in industry for high-temperature processes is produced mostly from fossil fuels. About 61%[32] of industry CO_2 emissions come from the supply of high-grade heat created by fossil fuel combustion
- **Solution:** Generalize the use of biomass or waste as feedstock for high-temperature production processes in the cement, steel and food industries
- **Key impacts:** 26.7 $MtCO_2e$ avoided, €7.4 billion total market, 110,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

- This project will increase the substitution rate of low CO_2 fuels in high-grade heat processes for all industries. This enables a 20% reduction in CO_2 emissions by 2050.
- This can be achieved by using multiple sources, i.e. biomass, end-of-life tires, industrial commercial and municipal solid waste, construction and demolition waste, plastics, textiles, paper residues, biomass waste, waste oils and solvents. However, a focus on non-hazardous domestic waste is planned specifically for this project at a European scale.
- Initial investment required targets light retrofitting in the form of storage facilities for waste, sorting capacities including magnetic separation, and fine shredding. There is little environmental impact resulting from the combustion of waste as the cement kiln temperature is around 1,400°C as compared to 950°C in regular municipal incinerators. As such, there is only a negligible quantity of residues.
- The targeted roll-out requires the development of regional clusters involving all stakeholders: industries, local authorities and waste providers.

Projects that inspired this analysis are substitution projects in the industry, which include the Allmendingen cement plant in Germany and the Retznei plant in Austria. Both plants run on 100% alternative fuels. Additionally, there is the Brevik plant in Norway, which uses 72% of alternative fuels.

Why this technology and project are needed to reach net-zero

- Biomass and waste represent only 10% of supply for process heating[33]. Waste valorization is best suited to treating district waste or plastic waste, as the very high temperatures remove residues and toxic emissions.
- The cement industry has already developed the substitution of fossil fuel sources to produce high-grade heat, currently reaching an average thermal substitution rate of 40%[34] in Europe. Other industries, especially the steel industry and the food industry, must follow suit to cut down emissions from the combustion process while using non-upgraded waste.
- Inspiring projects in the cement industry are the following:
  - ◊ The Allmendingen plant in Germany operated by Schwenk Cement uses 100% alternative fuels. The cement plant recycles exhaust gases to dry municipal sludge and produce heat for the cement kiln.
  - ◊ The Retznei plant in Austria operated by LafargeHolcim uses 35% construction and demolition waste for its processes.
- The main obstacle to this technology is the identification of alternative waste and biomass sources while also ensuring a stable supply.

Impacts

	2030	2050
CLIMATE IMPACT	**26.7 $MtCO_2e$ avoided**	**106.9 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€7.4 billion total market** €7.4 billion turnover in 2030	**€29.4 billion total market** €29.4 billion turnover in 2050
JOBS	**110,000 jobs**	**441,000 jobs**

#22 [32]Capgemini analysis, based on Eurostat (534 $MtCO_2e$ for high-grade industrial heat) and In Depth Analysis EU, EC, figure 11 (868 $MtCO_2e$ for industrial emissions): https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_fig-ures_20190722_en.pdf
[33]https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118592/towards_net-zero_emissions_in_the_eu_energy_system_-_insights_from_scenarios_in_line_with_2030_and_2050_ambitions_of_the_european_green_deal_on.pdf (page 37)
[34]https://cembureau.eu/media/1892/cembureau-what-is-coprocessing.pdf

SWITCH TO LOW-CO_2 SOLUTIONS FOR LOW-GRADE HEAT INDUSTRY NEEDS

Recovery from high-grade heat waste, high-temperature heat pumps, bioenergy, geothermal energy, symbiosis heat networks

INDUSTRY

Heat supply

IN A NUTSHELL...

- **Issue:** Low-grade heat accounts for 840 TWh[35], which could partly be covered by wasted heat generated from high-temperature processes, cooling, or even geothermal
- **Solution:** Develop renewable energies (such as biomass, geothermal, and heating pumps), symbiosis and circular reuse of wasted high-grade heat, heat networks within large industrial clusters and ports
- **Key impacts:** 50.8 $MtCO_2e$ avoided, €7.2 billion total market, 107,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Power generation and low-grade heat reuse from lost high-grade heat, by 2030 covering 10% of the low-grade heat demand in industry, and avoiding 27 $MtCO_2e$

- Launch tenders for power generation from high-grade and low-grade heat reuse (organic Rankine cycles for Combined Heat Power, TFC Trilateral Flash Cycle, etc.) in the industrial context.
- Typically, high-grade heat users in the steel, cement, and glass industries, in addition to their internal efficiency set-ups (such as regeneration, pre-heating, and others), could provide low-grade heat (taken from their waste heat), to nearby consumers.
- Projects are expected to deliver new technologies before 2025, to be scaled up in Europe by 2030.

Projects that inspired this analysis: H-REII project, Tasio project

Project type 2: Heat recovery, reuse and industrial heating network in industry clusters, by 2030 covering 3% of the low-grade heat demand in industry, and avoiding 8 $MtCO_2e$

- In large multi-industry or port clusters with both high-grade waste (such as metals, minerals, and chemistry) and low-grade needs.
- Build 600 MW of heat recovery installations and network grids if the infrastructure is not readily available.

Project type 3: Direct use of deep geothermal energy in industry, by 2030 covering 5% of the low-grade heat demand in industry, and avoiding 12 $MtCO_2e$

- Support 40 exploratory studies by 2022 and 30 drillings by 2025.
- 20 industrial plants successfully switch from fossils (in priority coal) to geothermal energy.
- Set up a georisk guarantee fund to limit risk exposure related to not finding appropriate geothermal resources, in order to foster private funding and lower financial cost.
- Priority to countries with largest potentials, i.e. Eastern Europe, Germany, France, Italy, and the Netherlands.

Projects that inspired this analysis: Rittershoffen geothermal plant of Roquette Group, Tuscan brewery 'Vapori di Birra' in Italy

Project type 4: Heat-cooling symbiosis high-temperature heating pumps in agro-industry, by 2030 covering 1% of the low-grade heat demand in industry, and avoiding 3 $MtCO_2e$

- Build 600 MW recovery capacity from high-temperature heat pumps.
- 1 kW of electrical power will typically generate at the same time 3 kW of cold and 4 kW of heat. If used alone for cold, 4,000 W of heat will be wasted. If used alone for heat, 3 kW of cold will be lost.
- When the cold and low-grade heat are simultaneously needed, high-temperature heating pumps (thermo-refrigerated pumps) can be used for agro-industry and other industries.
- When a plant does not simultaneously use heat and cold, the project can still ensure recovery with a heat exchanger, and distribution to the consumer through a heat or cold network.

Why this technology and project are needed to reach net-zero

Low-grade heat is a significant part of emissions in specific industrial sectors. These emissions could be reduced through renewables (such as biomass, heat-pumps, and geothermal energy), or by setting up a circular, industrial symbiosis approach, under which excess high-grade heat in one company could be used as low-grade heat in another.

- The industrial sector in EU consumes 2,800 TWh and is responsible for 862 $MtCO_2$ annually.
- High-grade heat (from 300°C to over 1,000°C) accounts for 70% of industrial heat and 62% of its CO_2 emissions, i.e. 1,960 TWh and 534 $MtCO_2$, mostly in metal, mineral, glass, and chemical industries.
- Low-grade heat (from 60°C to 300°C) accounts for 30% of heat, i.e. 840 TWh and 327 $MtCO_2$, mostly in food, paper, textile and partly in the above-mentioned sectors.
- Most of this heat is generated by fossil energies (gas, coal and partly liquids). This fossil-based heat could be replaced by renewable energies such as deep geothermal energy, potentially available on 25% of the European surface, high-temperature (above 100°) industrial heating pumps, biomass and biogas.
- Symbiosis is a way to ensure the excess high-grade heat is in one industrial facility is used in another facility.
  - ◊ A technical potential of 400 TWh waste heat from high-grade heat could be recovered to generate power and feed low-grade heat needs. The heat can be used in the same industrial plant, or between neighboring plants within similar industrial clusters (typically a metal or chemical plant close to a paper or food plant).
  - ◊ Another symbiosis to be looked after is between heat and cold needs. In the agro-industry, a high-temperature heating pump can produce cold and push the heat to feed low-grade needs, rather than losing it to the air.
  - ◊ Having a heat network within the industrial cluster is key to transporting the waste heat from high-grade industries or cold industries to neighboring industries, and if applicable to nearby city district heating (longer network).

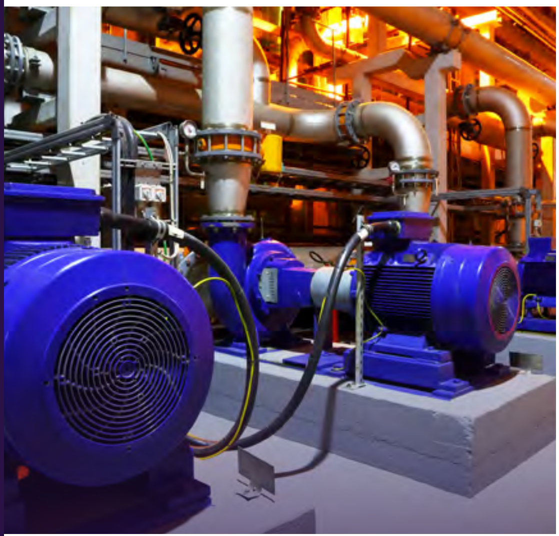
Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (reuse and CHP): 26.7 $MtCO_2e$** **Project type 2 (reuse in heat networks): 8.4 $MtCO_2e$** **Project type 3 (deep geothermal energy): 12.4 $MtCO_2e$** **Project type 4 (cold-heat symbiosis): 3.3 $MtCO_2e$**	**Project type 1 (reuse and CHP): 80.1 $MtCO_2e$** **Project type 2 (reuse in heat networks): 25.1 $MtCO_2e$** **Project type 3 (deep geothermal energy): 37.3 $MtCO_2e$** **Project type 4 (cold-heat symbiosis): 9.8 $MtCO_2e$**
ECONOMIC IMPACT	**Project type 1 (reuse and CHP): €5.4 billion total market** €5.4 billion turnover in 2030 **Project type 2 (reuse in heat networks): €700 million total market** €700 million turnover in 2030 **Project type 3 (deep geothermal energy): €900 million total market** €900 million turnover in 2030 **Project type 4 (cold-heat symbiosis): €230 million total market** €610 million investment by 2030, €61 million yearly average (2020-2030), €170 million turnover in 2030	**Project type 1 (reuse and CHP): €16.1 billion total market** €16.1 billion turnover in 2030 **Project type 2 (reuse in heat networks): €2.0 billion total market** €2.0 billion turnover in 2030 **Project type 3 (deep geothermal energy): €2.8 billion total market** €2.8 billion turnover in 2030 **Project type 4 (cold-heat symbiosis): €600 million total market** €1.8 billion investment by 2050, €60 million yearly average (2020-2050), €500 million turnover in 2050
JOBS	**Project type 1 (reuse and CHP): 80,000 jobs** **Project type 2 (reuse in heat networks): 10,000 jobs** **Project type 3 (deep geothermal energy): 14,000 jobs** **Project type 4 (cold-heat symbiosis): 3,000 jobs**	**Project type 1 (reuse and CHP): 241,000 jobs** **Project type 2 (reuse in heat networks): 29,000 jobs** **Project type 3 (deep geothermal energy): 42,000 jobs** **Project type 4 (cold-heat symbiosis): 8,000 jobs**

IMPLEMENT MASSIVE ELECTRIC EFFICIENCY PROGRAM FOR ALL EUROPEAN INDUSTRIAL PLANTS

High-efficiency motors, equipment and services along with digital and Industry 4.0

INDUSTRY | Electric efficiency



IN A NUTSHELL...

- **Issue:** EU industry consumes 400 TWh of electricity via mechanical motors, pumps, fans, air compressors, cooling and conveyors, which are often inefficient
- **Solution:** By 2030, conduct an energy efficiency audit in all industrial facilities in Europe and drive implementation of 80% of the recommended measures, including replacement of least performing equipment with best available technologies
- **Key impacts:** 19.9 $MtCO_2e$ avoided, €280 billion cumulated investment, 420,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

Launch massive electric efficiency audit and replacement program.

- Process Scope (equipment using electric motors): mechanical equipment, pumps, fans, air compressors, cooling and conveyors.
- Technical scope: motors and equipment, end-to-end efficiency, performance monitoring systems, sensors, optimized maintenance and management (Industry 4.0).
- Between 2020 and 2022, launch pilot projects targeting 100 industrial sites from every sector across Europe (10 sectors x 10 company audit test sites to find upscaling improvement efficiency).
- Each sector pilot attributed via tender.
- Pilots' objective is to elaborate and validate the technical, financial and delivery approaches.
- Additional pilots' objective is to prepare upscaling to serve 100% of European industries by 2030. This is done by replacing 40% of the least efficient equipment with high-performance electric motors and best Industry 4.0 practices.
- Approach and financing scope: address change inside a multisite company and provide financial solutions.
- Public support design: may include public tenders for large scale equipment change, providing subsidies such as Contract for Difference against base (TCO) total cost of ownership.
- Platforming: support the launch of motor procurement platforms to increase volumes supplied by European producers and lower costs of European funding.
- Scale up audits and implementation at European scale.

Key stakeholders:

- Labelled operation and maintenance service providers, OEM service branches, energy performance consultancies.
- ESCOs, financial services, public authorities to finance investments needed and lower the risk of operation funding through guaranteed funds.

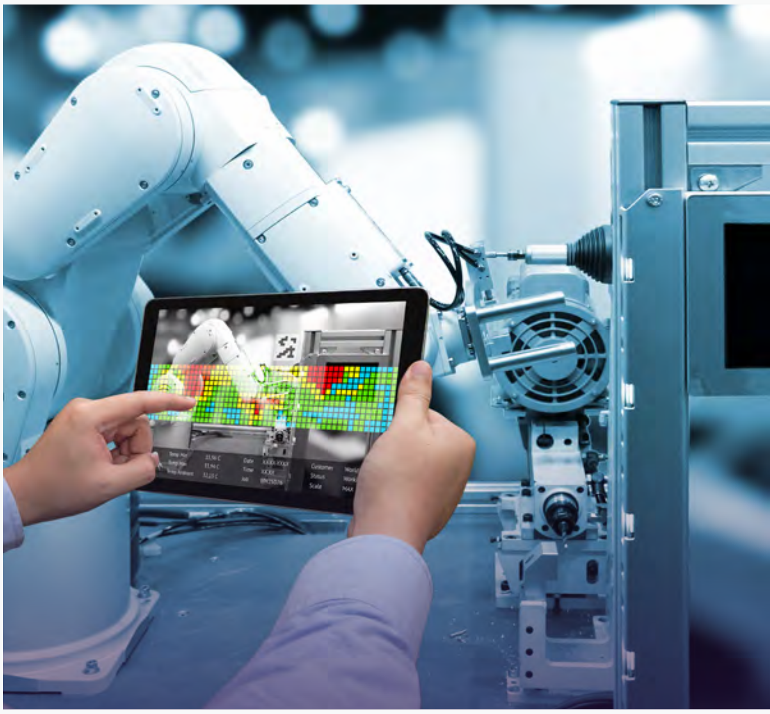
Projects that inspired this analysis: Task Energy Audits for Motor Systems of the Electric Motor Systems Annex (EMSA) of the IEA Technology Collaboration Program on Energy Efficient End-Use Equipment (4E) (framework), Motorbox (company offer), WienerBerger - Plant Improvement Program, Viktovice - performant machineries, Metron, Energisme (companies' offers).

Why this technology and project are needed to reach net-zero

Electric motors are key components of core industrial processes in industries (e.g. presses or rolls) as well as auxiliary systems (such as compressed air, ventilation or water pumping). According to the IEA, 40% of industrial electricity consumption comes from motor use. However, over 50% of this energy use is not optimized.

Therefore, there is a need to identify electricity losses and sort out efficiency measures which have a 30% potential electricity saving via the improvement and replacement of motors.

Identify these potential savings in an efficient manner by using digital solutions. In the long term, data collection from sensors on motors (installed after the audit) extends efficiency measures with predictive maintenance.



Impacts

	2030	2050
CLIMATE IMPACT	**19.9 $MtCO_2e$ avoided**	**24.6 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€28 billion total market** €280 billion cumulated investment by 2030, €28 billion yearly average (2020-2030)	**€3.3 billion total market** €66.5 billion cumulated investment between 2050 and 2030, €3.3 billion yearly average (2030-2050)
JOBS	**420,000 jobs**	**50,000 jobs**

REDUCE GHG IMPACT OF REFRIGERANTS

Mainstream the use of low-GHG refrigerants in all sectors

INDUSTRY | Other industrial products

IN A NUTSHELL...

- **Issue:** To achieve the phase-out of EU HFC (hexafluorocarbons) by 2030 requires further support, especially in the development of alternative refrigerants
- **Solution :** Program to support industries to use new low-GHG refrigerants
- **Key impacts :** 70.4 $MtCO_2e$ avoided, €3.5 billion total market, 53,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

- Support the development of alternative refrigerants to ensure HFC (hexafluorocarbons) phase-out in 2030.
- Ensure distribution of these new alternative low-GHG products to all final sectors (including industry, buildings, and automotive).
- Technical scope: small/medium/large DX; pumped/flooded; Process Chillers.
- Technical solutions: ammonia, CO_2 (R744), Water (R718), R-455A, R-32, natural alternatives.

Main stakeholders:

- Product distributors, resellers, labelled operation and maintenance service providers, OEM service branches.
- ESCOs, financial services, public authorities to finance the investments needed and lower the risk of operation funding through guarantee funds.

Projects that inspired this analysis: Danfoss DIRcalc™ (software to design the use of CO_2 alternatives to refrigerant use).

Why this technology and project are needed to reach net-zero

Adopted in 1987, the Montreal Protocol aims at reducing emissions of chlorofluorocarbons (CFCs) responsible for the hole in the ozone layer by replacing them with the hexafluorocarbons (HFCs) which today equip most refrigeration appliances. Currently, 97% of CFCs have been eliminated and the ozone layer is being restored. However, HFCs are powerful GHG: their global warming power is 2,000 times greater than that of CO_2 and their lifetime in the atmosphere exceeds 13 years. Moreover, driven by higher demand for cold, HFC emissions due to refrigerants have been increasing since 1990 by 10 to 15% annually.

In 2015, the EU agreed to phase out HFCs in 2030 for all refrigerants use. The achievement of this target is monitored by the European Partnership for Energy and the Environment (EPEE). This regulation states that it will be forbidden to refill equipment with fluids having a global warming potential (GWP) of greater than 150. In addition to the phase-out target, the long-term objective for 2030 is to reduce global greenhouse gas emissions from refrigerants by a factor of 5. Given the emissions in 2015 (183 $MtCO_2e$), the final GHG emission target is 38 $MtCO_2e$.

This phase-out is making progress. Virgin R-404A and refrigerants with a GWP above 2,500 have been banned since 2020, and ultra-low GHG solutions are available on the market. However, some small industries, like the food sector, may require additional support to identify the best technologies to use. In some cases, innovative processes need to be developed to better adapt alternative solutions to a specific process (e.g. meat in food industry).

Impacts

	2030	2050
CLIMATE IMPACT	**70.4 $MtCO_2e$ avoided**	**87.1 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€3.5 billion total market** €3.5 billion turnover in 2030	**€3.5 billion total market** €3.5 billion turnover in 2050
JOBS	**53,000 jobs**	**53,000 jobs**

REDUCE GHG IMPACT OF PLASTIC THROUGH REUSE AND RECYCLING

Develop technology solutions to increase circularity of plastics

INDUSTRY | Other industrial products

IN A NUTSHELL...

- **Issue:** Europe produced 62 Mt of plastics in 2018 mainly from fossil sources while 70% of total plastic waste is sent to landfills or is burned
- **Solution :** Develop chemical plastic recycling alternatives to reach the target of having 50% of European plastic waste recycled in 2030
- **Key impacts :** 13.5 $MtCO_2e$ avoided, €19.7 billion total market, 296,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

Project type 1: Inventory of existing recycling processes and scale at European level

- Assess all existing innovative processes enabling the use of plastic waste as substitutes to fossil resources in chemical production (e.g. pyrolysis, catalytic hydrogasification with plasma and others).
- Undertake technical-economic studies and assess regulatory frameworks to confirm Europe scale-up opportunities.
- Develop best technologies to reach 20% of plastic waste (not already recycled by other processes) from chemical recycling in 2030.
- A European consortium involving key chemical industry stakeholders and circular plastic initiatives must be created to deploy the best available technologies at an industrial scale.
- Initial projects will be deployed in Germany and Spain, where technologies already exist. The technologies will then be deployed in all European countries.

Projects that inspired this analysis: PolyCE (European project).

Project type 2: Create new chemical recycling processes

To fully achieve scale, new processes need to be found, specifically in the field of chemical recycling.

- Support laboratories and corporate R&D to fund specialized laboratory or industrial pilots for new plastic recycling processes. For instance, via processes of gasification, pyrolysis, solvolysis, and depolymerization.
- This project type targets 30 new R&D initiatives to be launched in 2021, with expected results in 2025.

This research will be done and applied at pilot scale. Promising technologies will be integrated into the existing pool of the European consortium created in project type 1. These will be tested at industrial scale.

Projects that inspired this analysis: for pilots, Chemcycling (BASF process), Ecomethylal (European project).

Why this technology and project are needed to reach net-zero

The European plastic industry produces around 60 million tons of plastic[36] annually, generating 160 $MtCO_2e$[37] per annum. Future scenarios predict that a 56% reduction in total plastic life cycle emissions is possible through demand reduction, substitution and recycling (mechanical and chemical)[38]. In parallel, the European Commission aims to recycle at least 50% of plastic waste in 2030.

Today, 30% of plastics are recycled, mostly through mechanical processes. However, this method has high sorting requirements and decreases material quality in each cycle. This recycling rate can only be improved by using chemical processes to break down the chemical structure of plastics from polymer to monomers. These new products will then be used as a raw material in chemical industries.

Several chemical recycling projects already exist. These include Chemcycling[39] and Ecomethylal[40]. The first one is an industrial project launched in 2018 by BASF in partnership with Quantafuel. It uses pyrolysis to reduce plastic waste into pyrolysis oil before feeding it in a steam cracker. The Ecomethylal project addresses the plastics which are usually put in landfills, i.e. non-recyclable plastic waste (NRPW), and aims at removing 3.6 tons of plastic waste during the project period.

Such projects must now be tested and deployed in Europe. General barriers to industrial deployment of such technologies are market uptake and acceptance from regulators.

Impacts

	2030	2050
CLIMATE IMPACT	**13.5 $MtCO_2e$ avoided**	**46.2 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€19.7 billion total market** €15.9 billion investment by 2030, €1.6 billion yearly average (2020-2030) €18.1 billion turnover in 2030	**€66.2 billion total market** €56.7 billion investment by 2050, €1.9 billion yearly average (2020-2050) €64.3 billion turnover in 2050
JOBS	**296,000 total jobs** 24,000 construction jobs for investment 272,000 production jobs for turnover	**992,000 total jobs** 28,000 construction jobs for investment 964,000 production jobs for turnover

#26 [36]Plastics – the Facts 2019 - plasticseurope.org: https://www.plasticseurope.org/application/files/1115/7236/4388/FINAL_web_version_Plastics_the_facts2019_14102019.pdf
[37]reinvent-project.eu/sectors
[38]Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century, Energy Transitions Commission
[39]https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy/mass-balance-approach/chemcycling.html
[40]https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=5747

BUILDINGS

ACCELERATE RENOVATION OF BUILDINGS ACROSS EUROPE BY INCORPORATING MORE ENERGY-EFFICIENT COMPONENTS; ENSURE 100% OF NEW BUILDS ACHIEVE NET-ZERO EMISSIONS.

Current situation and challenges

Residential properties account for 75% of all European buildings, providing homes for 221 million households, with the rest being a mix of wholesale and retail premises, offices, factories, schools, universities, hotels, sports facilities, hospitals and other public buildings.

More than 40% of all residential buildings were constructed before 1960, when energy efficiency and other regulations were very limited. As a result, the building sector is one of the most significant CO_2 emission sources in Europe, with 28 billion m² of floor space generating 1,100 $MtCO_2e$ (600 $MtCO_2e$ direct emissions, 500 $MtCO_2e$ for electricity), to be cut down to 200 $MtCO_2$ in 2050. Of this, 430 $MtCO_2e$ of direct emissions come from 20 billion m² of residential space.

A crucial factor for Europe's net zero emissions target is that 75% of today's building stock will still exist in 2050. As a result, the renovation of almost all existing buildings to achieve a near-zero emission status is a top priority. In addition, from 2020 all new buildings, both residential and non-residential, must be near-zero, both for immediate low emission performance and to avoid retrofitting of these buildings before 2050.

Solutions

Fast and early progress must be made to achieve the following targets:

- **A minimum annual renovation rate of at least 3%** – about 360 million m² in the residential sector, or 4.4 million households per year[1].
- **Cut buildings' emissions from 1,026 $MtCO_2$ today to 81 $MtCO_2$ in 2050** – through energy efficiency measures (insulation), on-site energy production facilities (PV and geothermic systems), electrification (heat pumps) including smart sensors and meters.
- **Achieve an average deep renovation cost per m²** of €310 in residential buildings and €465 in public buildings.

The projects proposed on the next page are concrete enablers to meet these targets, helping to:

- **Increase the renovation rate from around 1% today to 3%** – through large-scale residential renovation programs, one-stop-shops to empower citizens[2] and smart procurement for public buildings.
- **Maintain the renovation rate at 3%** – in dense and expensive urban areas.
- **Maintain the performance of retrofitting operations** – in medium performance buildings.

> ***"With heat pumps, we have a clean technology with enormous potential. Governments need to focus on the renewable heat industry like they did on renewable electricity, and offer recovery financing and funding packages as well as end-user information to accelerate adoption and build-up of market leadership."***
>
> **Thomas Nowak**, General Secretary EUROPEAN HEAT PUMP ASSOCIATION (EHPA)

Projects and scale-up

2021 onwards: Begin retrofitting the least efficient buildings, by

- Launching between 1,000 and 2,000 neighborhood projects[3] across Europe, each renovating between 20,000 m² and 50,000 m².
- Promoting large scale renovation programs, utilizing the Energiesprong model, and one-stop-shop approaches to empower citizens.
- Targeting at least 50 passive hospitals and 100 passive schools by 2025, per country, levering off-site construction techniques.

2021 for action from 2030 onwards: Accelerate development of innovative renovation solutions, to

- Deliver next-generation renovation packages by 2030, for retrofitting in medium energy efficient buildings.
- Showcase smart energy independent buildings across Europe by 2030.

Impacts

- **€245 billion total market (turnover + investments) per year in 2030.**
- **4.5 million permanent jobs in 2030.**
- **355 $MtCO_2$ avoided per year in 2030.**

List of projects - BUILDINGS

Deep renovation

#27 - DEEP RENOVATION OF RESIDENTIAL BUILDINGS
Programs to increase the energy performance of renovations and increase the rate of renovations to cover 100% of the European building stock, starting now

#28 - DEVELOP NEXT-GENERATION EQUIPMENT TO INCREASE PERFORMANCE OF DEEP RENOVATION
Next-generation easy-to-use and low-cost equipment such as vacuum insulation panels and windows, PCM, aerogels, PV windows and PV façades, smart sensors

#29 - DEEP RENOVATION OF PUBLIC BUILDINGS
Public exemplarity through procurement programs to reach the required level of performance of the public building stock (administrative buildings, hospitals, educational buildings)

Low-cost renovation and new build process

#30 - AUTOMATE, DIGITIZE AND STREAMLINE CONSTRUCTION PROCESS AND METHODS FOR RENOVATION AND NEW BUILD
Overhaul construction sector's obsolete renovation models to reduce costs, lighten the disturbance of occupants and increase renovation rate

Green and flexible energy in buildings

#31 - MASSIVE ELECTRIFICATION OF HEAT WITH LOW-COST HEAT PUMPS
Multiply the number of installed heat pumps and bet on synergies with the electric vehicles industry to launch low-cost heat pump factories

#32 - DEVELOP NEXT-GENERATION BUILDINGS ALLOWING ULTRA-LOW CONSUMPTION AND FULLY FLEXIBLE ENERGY MANAGEMENT
Highly autonomous buildings based on onsite storage facilities (hydrogen, thermal storage, geothermal, batteries), heating pumps and smart energy management

[1]For comparison purposes, the successful Energiesprong program performed in the Netherlands completed about 10,000 renovation projects in a country with about 7.8 million households, achieving more than 15,000 kWh of final energy savings per house.
[2]In addition to stronger policies and regulations towards buildings' energy efficiency and GHG emissions
[3]Comprehensive neighborhood renovation programs in Europe enable economies of scale (through design, procurement, transports and logistics), make the deep renovation easier (addressing networks, grids, eco-conception and urban planning) and facilitate ESCOs involvement.

DEEP RENOVATION OF RESIDENTIAL BUILDINGS

Programs to increase the energy performance of renovations and increase the rate of renovations to cover 100% of the European building stock, starting now

BUILDINGS | Deep renovation

IN A NUTSHELL...

- **Issue:** The current 0.2% deep renovation rate[1] remains too low (at least 3% is required and going to appropriate depth)[2]
- **Solution:** Massively replicate successful renovation programs and regional initiatives at scale, based on standard methodologies and industrialized components to reduce investment per m²
- **Key impacts:** 46.4 $MtCO_2e$, €111 billion total market, 2.1 million jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

Standardized methodological and technical renovation programs such as Energiesprong must be massively scaled to national level, in each EU country. Building energy performance is proven to be very low and can be almost net zero energy (nZEB, passive buildings and similar proofs).

Similarly, new renovation technologies can be deployed through the renovation process: scan-to-BIM, BIM, 3D printing, prefabricated components and off-site construction, as well as much more efficient heating and cooling equipment, including heat pumps[3] and solar water heaters.

The programs can also install PV systems (panels, solar roof tiles), a deployment of smart appliances and smart meters to enable optimization, flexibility and demand response schemes in all buildings.

Financing schemes can rely on promotional public money and future energy savings and involve ESCOs, banks, utilities, municipalities' tax schemes[4], subsidies and dedicated blended funds managed by specialists using thousands of accredited experts such as KfW's home efficiency program in Germany.

Project type 1: Neighborhood scale replication of industrialized renovation

Local authorities can mobilize relevant neighborhoods and create regulatory sandboxes to launch massive renovation calls for tenders to initiate neighborhood renovation programs (20,000 m² to 50,000 m² each). Regional project coordinators can be identified and empowered, including PPPs[5], to manage an ecosystem of suppliers, manufacturers, designers, architects, urban planners, BIM editors, engineers, public and finance bodies. Beyond economies of scale (through design, procurement, transport and logistics), neighborhood level interventions will enable local networks, grids, eco-conception and better urban planning. Energy savings are worth billions and will facilitate investments.

Launch 40 to 50 million m² of area retrofits through 1-2,000 projects across the EU in 2021.

Project type 1: Building level comprehensive program replication

Replicate existing deep renovation models at relevant scale. Lever one-stop-shop and platform approaches to accredit and pay experts which empower homeowners and guide them through the process.

Target: 0.3-0.4% in overall renovation rate based on this type of programme[6] in 2021 in all EU regions focusing on collective and individual housing (against 0.2% today).

Inspirational projects and stakeholders: Energiesprong, Superhomes, HEART, ACE Retrofitting (Energy cities), Ile de France Energies, Save the homes, Fithome, Turnkey retrofit, KfW, BPIE.

Why this technology and project are needed to reach net-zero

Buildings account for around 40% of EU energy use of which about half is required for heating and cooling. Europe will not reach net-zero emissions unless buildings are much more efficient and carbon-neutral. Three quarters of Europe's buildings will still be standing in 2050 and so the energy-efficient renovation of these buildings needs to happen at scale and be prioritized.

The current residential building deep renovation rate is just 0.2%[7] in a market of 221 million residential households[8]. This is far too slow to reach 2030 and 2050 targets. Starting with the worst-performing buildings, home renovation needs to cover 6.6 million households a year. This ambitious objective requires large projects, now.

The buildings sector is fragmented and organized for new construction and therefore must reorganize for renovation rates and approaches to reach net-zero targets: coordinated renovation programs using digital tools and aggregating actors from the industry to help standardize and industrialize the renovation process. This would lead to faster and more efficient processes as well as lower cost operations. High upfront renovation costs are also an obstacle that can be removed by smart finance facilities linked to high-quality industrialization and economies of scale. Renovated homes also command higher market values (comfort, extension, layout, etc.) that are also benefits for the projects.

Impacts

	2030	2050
CLIMATE IMPACT	**46.4 $MtCO_2e$ avoided**	**139.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€111 billion total market** €111 billion turnover	**€111 billion total market** €111 billion turnover
JOBS	**2,109,000 total jobs**	**2,109,000 jobs**

#27 [1]https://ec.europa.eu/energy/sites/ener/files/documents/1.final_report.pdf
[2]Taking the 3% EU target for public building renovation (https://ec.europa.eu/energy/content/setting-3-target-public-building-renovation_en)
[3]Geothermal HP in Northern/Central Europe or aerothermal in Southern countries
[4]See FITHOME project's financing scheme
[5]Private public partnerships
[6]In the Netherlands, Energiesprong has achieved ~10,000 renovations in several years in a 7.8 million households country (0.13%). An EU rate of, 0.3% to 0.4% represents some 800,000 households.
[7]https://ec.europa.eu/energy/sites/ener/files/documents/1.final_report.pdf
[8]https://www.statista.com/statistics/868008/number-of-private-households-in-the-eu/#:~:text=Europe%3A%20number%20of%20private%20households%202017&text=This%20statistic%20shows%20the%20number,amounted%20to%20approximately%20221.3%20million.

DEVELOP NEXT-GENERATION EQUIPMENT TO INCREASE PERFORMANCE OF DEEP RENOVATION

Next-generation, easy-to-use and low-cost equipment such as vacuum insulation panels and windows, PCM, aerogels, PV windows and PV facades and smart sensors

BUILDINGS | Deep renovation

IN A NUTSHELL...

- **Issue:** Up-front investments for promising new technologies in insulation and building renovation are too high
- **Solution:** Boost the development of early TRL technologies improving insulation and renovation performance with new standardised materials and high-performing electric equipment at lower costs
- **Key impacts:** 1.4 MtCO_2e avoided, €1.1 billion total market, 21,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

- Launch the next-generation renovation packages, in a similar way as project Surefit[9], with additional targets.
- Technologies to include in the packages: bio-aerogel panels integrated with PCM, PV vacuum glazing windows, roof and window heat recovery devices, solar-assisted heat pumps, ground source heat pumps, evaporative coolers, integrated solar thermal/PV systems and lighting devices. These are prefabricated for rapid retrofit with minimal disruption to occupants, ensuring high levels of occupant comfort/indoor environmental quality as well as low risk of moisture-related problems and summer overheating.
- Replicate the initiative in five European clusters with specific local focus (especially regarding heating and cooling issues) and extend the package with:
  - Additional smart tools integrated to the equipment (sensors, meters, adaptative windows etc.).
  - The identification and incorporation of eco-materials[10] to be used for insulation purposes and integrated into the package.
- Develop specific packages tailored to specific building profiles (who uses the buildings, the climate of the area they're located in, equipment availability and type of building), to cover 15 to 20 different building configurations for several climate zones.
- Include and coordinate key stakeholders: research institutes (such as Fraunhofer Institute), chemicals and refrigerant suppliers, glass, concrete and steel manufacturers, PV developers and installers, heat pump producers, eco-material suppliers, BIM editors and off-site constructors.
- Ensure coordination and communication between clusters and actors in order to avoid duplication, leveraging best practices and tackling transversal technical barriers.
- Target 15 to 20 renovated buildings using leading-edge technologies, to be easily replicated by 2025.

Projects that inspired this analysis: Surefit (coordinated by the Portuguese Instituto de Soldadura e Qualidade), INNOVIP, Prefab LT Cluster, Fraunhofer Institute.

Why this technology and project are needed to reach net-zero

Europe's renovation rate needs to be above 3% to deliver a net-zero emission housing stock by 2050. The $kgCO_2e/m^2$ savings are harder to deliver in many homes without better-performing materials and techniques at a lower cost. Promising technologies such as PCM and heat recovery devices need to scale up dramatically to optimize energy consumption, heating and cooling management, saving additional $kgCO_2e/m^2$.

In dense urban areas thin insulation materials are required for space conservation (maintaining asset value), otherwise renovation operations will not be undertaken by these property owners. Cities also need to deploy PV systems to harvest enough solar energy (while allowing them to keep roof space for green roofs). To achieve this, PV systems integrated to the windows or walls must be included in the next-generation renovation packages.

Impacts

	2030	2050
CLIMATE IMPACT	**1.4 $MtCO_2e$ avoided**	**61.9 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€1.1 billion total market** €1.1 billion turnover	**€11.1 billion total market** €11.1 billion turnover
JOBS	**21,000 jobs**	**211,000 jobs**

#28 [9]https://cordis.europa.eu/project/id/894511
[10]Ecomaterials such as straw and hemps are inherently 100% recyclable

DEEP RENOVATION OF PUBLIC BUILDINGS

Public exemplarity through procurement programs to reach the required level of performance of the public building stock (administrative buildings, hospitals, educational buildings)

BUILDINGS | Deep renovation

IN A NUTSHELL...

- **Issue:** Many public buildings were built before the implementation of energy efficiency regulations and do not meet current standards
- **Solution:** Involve public players to activate large economies of scale through group public procurements and collective campaigns
- **Key impacts:** 44.8 MtCO_2e, €34.8 billion total market, 660,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

Project type 1: Deliver low-emissions net-zero 2050 hospitals across EU

Deliver passive energy hospitals (nZEB or similar ambitious low-GHG targets) by 2030, all integrated with smart meters and responsive equipment.

Lever shared procurement platforms campaigns and make use of prefabricated components.

In each country:

- Define country specific procurement guidelines.
- Start with 10 hospitals in 2021, building on the past Klinikum Frankfurt Höchst experience.
- Capitalize on the lessons learned from the first ones to launch the 40 additional renovations until 2030.

NB: Some specific adjustments and/or exceptions in the current national public market rules can be considered in some countries to encourage tight collaboration among suppliers (open BIM solutions or digital twins are key for such matters).

Project type 2: Lever modular construction to build 100 passive/near-zero schools in every EU country

- Deliver 100 passive energy schools per country using a comprehensive modular approach, starting in 2021 with the most energy-inefficient schools. Integrate smart meters and responsive equipment.
- Define country-specific procurement guidelines.
- Follow the inspiring British school cases implemented with McAvoy.
- Lever shared procurement platforms and campaigns.

Projects that inspired this analysis: EU PUBREP coordinated by South Pole, RenoWatt (Belgium), PEDIA school retrofitting program (Cyprus), UK's schools modular program in around 15 weeks (McAvoy and others.), Powerskin+ (Portugal, Czech Republic, Slovenia), Frankfurt Höchst Klinikum (Germany) - passive hospital , The Green Lighthouse (Denmark) (first public carbon neutral building, built in less than a year in a close public-private partnership). Older inspiring initiatives include RES hospitals (2011-2013) and the DEEP project (2006-2007).

Why this technology and project are needed to reach net-zero

Public buildings represent significant volumes of total buildings at national and European scale. They have large energy demand and can be upgraded through industrialized approaches, through common procurement campaigns. EU27 tertiary buildings emit 250 $MtCO_2e$ per year, with 75 $MtCO_2e$ coming from public buildings.

Many public buildings were built before the implementation of energy efficiency regulations and so there are great savings available by adapting them, and many also require modernization to increase comfort. Specifically, schools and hospitals are known to be very energy-inefficient making them unnecessarily significant energy consumers (with 3-4 times the consumption of residential buildings per square meter) and they have long utilization periods, thus making a strong economic case for energy efficiency modernization.

Furthermore, governments need to show leadership in energy efficiency. Given strong regulatory and negotiation power, public authorities can shift the construction industry, requiring specific performance, materials and technologies (supporting technologies such as BIM tools and 3D printing, prefabricated and off-site construction, ground-source heat pumps, air-source heat pumps (in South Europe), and green cool roofs (to avoid heat island effect and include eco-materials).

Impacts

	2030	2050
CLIMATE IMPACT	**44.8 $MtCO_2e$ avoided**	**134.5 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€34.8 billion total market** €34.8 billion turnover	**€52.1 billion total market** €52.1 billion turnover
JOBS	**660,000 jobs**	**991,000 jobs**

AUTOMATE, DIGITIZE AND STREAMLINE CONSTRUCTION PROCESS AND METHODS FOR RENOVATION AND NEW BUILD

Overhaul construction sector's obsolete renovation models to reduce costs, lighten the disturbance of occupants and increase renovation rate

BUILDINGS | Low-cost renovation and new build process

IN A NUTSHELL...

- **Issue:** Efficient construction, renovation tools and processes are being developed but the adoption rate is too slow
- **Solution:** Demonstrate the benefits of various technologies using five clusters and coordinate clusters to spread skills in a collaborative way
- **Key impacts:** 67.4 MtCO_2e avoided, see #15 and #28 for total market and jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

This program will involve five clusters across Europe, working on close to 200 buildings before 2023.

The portfolio of projects will include:

- Renovation projects (around 150) and new buildings (around 50).
- Residential (collective and individual) and non-residential (malls, offices, universities, and others) buildings.
- Replicable types of buildings (social housing, schools, standardized buildings, swimming-pools and gymnasiums, and others).

The objective is to accelerate construction process automation and improve the reliability and the efficiency of digital tools which are useful for renovation and construction processes.

Digital tools will have strong potential to improve building sustainability and lower the environmental impacts:

- Scan to BIM using Lidar or drones, etc.
- BIM 6D features to integrate lifecycle information.
- Integration of BIM data with building sensors to improve energy and indoor environmental performance.
- EnerBIM/BIMsolar solutions which integrate solar panels sizing with ROI information.
- Open BIM approaches to ease software interoperability, as promoted by BuildingSMART at the global level.
- Digital twin technology for at least five projects, inspired by SPHERE project which gathers 20 partners from 10 EU countries (target -25% GHG emissions, -25% construction time).
- Digital building pass gathering all key information on the building lifecycle (like CN BIM).

Construction techniques will favor ready-to-use and fit-for-purpose components:

- Prefabricated/off-site or even modular components.
- 3D printing/additive manufacturing, like Batiprint3D™ technique used on Yhnova project.

The project will follow a regulatory sandbox approach to test collaborative ways of working between stakeholders (as underway in the UK and the Netherlands) instead of a segmented approach with diluted responsibility and lack of coordination, often linked to inadequate regulatory rules and enforcement (e.g. France).

Projects that inspired this analysis:

- *BIM-SPEED: Harmonized Building Information Speedway for energy-efficient renovation, 13 demonstration cases, 22 partners*
- *BIM4EEB: BIM-based fast toolkit for Efficient renovation of residential buildings, six BIM tools, demo cases in Italy, Finland and Poland*
- *BIMERR: BIM-based holistic tools for energy-driven renovation of existing residences*

Why this technology and project are needed to reach net-zero

The construction industry has not evolved to use automated processes in recent decades, while other industries such as the automotive industry have:

- Transport and logistics to and from the site are not optimized, leading to high indirect GHG emissions.
- Productivity has not increased for years and may be decreasing in some countries due to a lack of skills, more complex buildings (due to regulations and technologies) the retaining of old processes and tools.
- The sector produces a lot of waste (construction and demolition waste are the largest waste streams in the EU: 374 Mt in 2016, 36% of EU waste[11]).

Additionally, renovation projects are labor-intensive and long lasting.

To tackle these issues, the construction industry needs a deep transformation of its methods, tools, processes and ways of working:

- The automation of the construction process will enable anticipation, optimization, scale-up and fast on-site deployment.
- Off-site construction reduces work duration, footprint and cost while improving quality and safety.
- Building Information Modelling (BIM), and especially Open BIM, is a powerful tool for collaboration, anticipation, information sharing and follow-up on construction phases. Its penetration on European construction sites is a key challenge.
- All actors need upskilling to gain knowledge about the current possibilities offered by modern technologies to apply them in practice. This can be reached by mobilizing competitive clusters for training, encouraging interactions between companies and local consortia, easing access to training for SMEs (95% of the European construction market).

Impacts

	2030	2050
CLIMATE IMPACT	**67.4 $MtCO_2e$ avoided**	**121.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	*See #15 and #28 (no double counting)*	*See #15 and #28 (no double counting)*
JOBS	*See #15 and #28 (no double counting)*	*See #15 and #28 (no double counting)*

#30 [11]*https://www.eea.europa.eu/themes/waste/waste-management/construction-and-demolition-waste-challenges*

MASSIVE ELECTRIFICATION OF HEAT WITH LOW-COST HEAT PUMPS

Multiply the number of installed heat pumps and bet on synergies with the electric vehicles industry to launch low-cost heat pump factories

BUILDINGS | Green and flexible energy in buildings

IN A NUTSHELL...

- **Issue:** Heat pumps have higher upfront investment requirements than gas boilers
- **Solution:** Industrialize heat pump manufacturing to decrease investment requirements
- **Key impacts:** 192.9 MtCO_2e avoided, €28.6 billion total market, 429,000 jobs in 2030

Innovation bet | Acceleration and scale-up | **Drive to market scale**

Project opportunity and ambition

On the supply side:

The project aims to provide EU27 countries with enough heat pump equipment for the renovation wave and for new buildings by 2050. Megafactories will increase productivity and lower investment requirements. As a result, heat pumps will be more competitive and accessible.

- Build 36 heat pump megafactories by 2030 (each with ~150,000 units per year capacity), for example in Northern Italy and Poland[12]. Existing manufacturers and car manufacturers shifting some production lines to heating pumps (very accessible for the assembly phase) can compete for these.
- These megafactories will manufacture the components as well as assemble the heat pumps.
- They will include smart devices and modular production lines, following the Japanese Daikin factory Texas Technology Park which achieved a productivity increase of close to 50%.
- The new megafactories will specialize to cover the specific need for heat pumps in Europe (geothermal and water in Western, Central and Nordic Europe, aerothermal in Southern Europe) and several heat pumps sizes (residential, electric cars and industrial).

On the demand side:

- Support heat pump markets through funding schemes, subsidies or tax reductions.
- Objective: from about 1.3 million heat pumps sold in 2018 to about 5.5 million units in 2030.

Why this technology and project are needed to reach net-zero

Electrification of heating and cooling equipment is necessary to reach near zero emissions for buildings. A way to do this is by powering infrastructure with renewables (geothermal or PVs). According to the IEA, heat pumps can save 50% of the buildings sector's CO_2 emissions and 5% from the industrial sector's.

Heating pumps are key components within the net-zero solution set. However, up-front investment requirements are still relatively high compared to oil or gas equipment. Over time, prices will decrease with the industrialization of production accompanied by a massive demand boost.

The goal is to manufacture of 55 million heat pump units by 2030 for three sectors: residential, commercial buildings and industry.

This missing supply gap will require 36 megafactories (each producing 150,000 units per year) by 2030, and at least five of these must be built by 2025. In order to seize the opportunity, the automotive industry can shift part of its production lines (plants) to produce heat pumps in just a few months.

Over the medium term, small heat pumps will be required for heating and cooling in electric cars, and so there is a synergy. Non-residential buildings can provide a demand of about 40% of the residential requirement but size varies (less units are required with a larger capacity; this makes them more efficient in terms of investment/m²). For non-residential, an additional manufacturing capacity of 40% x 6.1 x ½ = 1.2 million units equivalent is required (an extra demand equal to the current European heat pump market size).

Impacts

	2030	2050
CLIMATE IMPACT	**192.9 $MtCO_2e$ avoided**	**481.4 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€28.6 billion total market** €12.8 billion investment by 2030, €1.3 billion yearly average (2020-2030) €27.3 billion turnover	**€27.4 billion total market** €39.3 billion investment by 2050, €0.9 billion yearly average (2020-2050) €39.3 billion turnover
JOBS	**429,000 jobs** 19,000 construction jobs for investment 410,000 production jobs for turnover	**604,000 jobs** 14,000 construction jobs for investment 590,000 production jobs for turnover

#31 [12]For industrial, strategic, economic and geographic reasons (skills, capacities, logistics and needs); further detailed location studies may suggest additional regions.

DEVELOP NEXT-GENERATION BUILDINGS ALLOWING ULTRA-LOW CONSUMPTION AND FULLY FLEXIBLE ENERGY MANAGEMENT

Highly autonomous buildings based on onsite storage facilities (hydrogen, thermal storage, geothermal, batteries), heating pumps and smart energy management

BUILDINGS | Green and flexible energy in buildings

IN A NUTSHELL...

- **Issue:** Today's state-of-the-art buildings are passively optimised. Next challenge is to manage volatile consumption and production flows, increase positive decarbonized energy balance and optimize need for grid connection investment
- **Solution:** Energy-independent and flexible buildings based on smart energy management systems, on site RES, heat pumps, storage facilities (hydrogen, thermal storage, geothermal storage, batteries)
- **Key impacts:** 2 $MtCO_2e$, €69.1 billion total market, 1,314,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

The target is to launch 10 regional clusters of expertise across Europe and create a total of 500 energy-independent buildings by 2025, before the prototypes can be replicated at a European scale. The main objectives are next-generation flexibility, thermal and power load management, energy performance and total cost ownership reduction, covering all buildings specifics across European regions.

Such high-performance buildings are created through integrated solutions combining PV systems, batteries, hydrogen storage, thermal storage, geothermal power, and heating pumps, with smart management systems and/or responsive energy systems.

- Identify 10 regional clusters across Europe, each gathering research, construction and renovation companies, energy cleantech providers, digital firms, social scientists and industry.
- Build a total of 1,000 new buildings or 8,000 lodgings for the 10 clusters (100 buildings and 800 lodgings per cluster), with a representative mix of collective or individual housing in urban and suburban zones.
- To ensure each building remains low-carbon, new technologies will be utilized, including: photovoltaic (PV) solar facades/windows, high-performance batteries, hydrogen/combined heat and power/hydrogen fuel cells, and less mature thermal storage technologies (phase change material (PCM), thermochemical energy storage).
- Building regulations will have to be adjusted accordingly.
- Establish key learnings from the expertise clusters in order to replicate at a lower cost this solution on a larger scale across the EU.

Projects that inspired this analysis: Heat4Cool, PowerSkin+, REFLEX, Sylfen's Smart energy hub, Celsius, CombioTES, HybridGeoTABS, the Create project, Smartflex.

Why this technology and project are needed to reach net-zero

Thermal end-uses (space heating, hot tap water, and cooling) represent a major part of energy consumption in Europe, and buildings emit over a third of European GHG emissions.

Several new low-carbon energy technologies are ready and must be digitally integrated to create flexible, low-emission buildings able to produce and store increased shares of own energy using thermal and electric renewables, as well as optimize their energy use and the need for grid capacity. The intermittency of renewable energies such as solar makes it necessary to link them with storage systems, such as batteries, hydrogen storage, or thermal storage through geothermal energy.

Recent pilot projects, such as the French startup Sylfen associating digital and reversible electrolyzer/fuel cell stack demonstrate that 70% energy autonomy can be achieved in urban buildings, requiring less grid and being more flexible towards both on-site and external intermittent grid supply.

The optimization of energy use needs to be considered at a building, at neighborhood level (smart districts), in relation with both local resources and national and European gas and power systems. It relies on the integration of smart energy management systems, which optimize auto-consumption and storage, and predict consumption patterns based on weather data and historical consumption behavior.

Impacts

	2030	2050
CLIMATE IMPACT	**2 $MtCO_2e$ avoided**	**5.9 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€69.1 billion total market** €69.1 billion turnover	**€207.4 billion total market** €207.4 billion turnover
JOBS	**1,314,000 jobs in 2030** 1,314,000 production jobs for turnover	**3,941,000 jobs in 2050** 3,941,000 production jobs for turnover

TRANSPORT

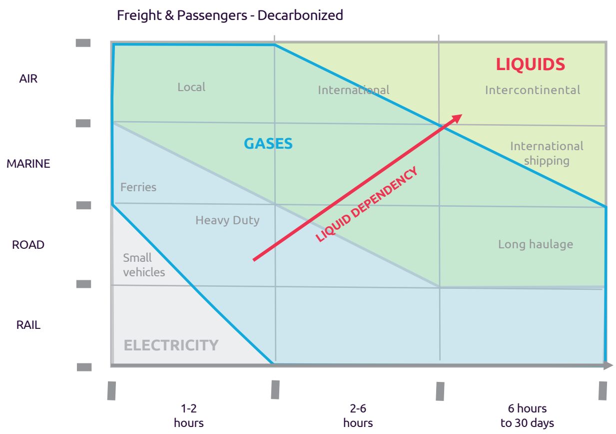
A FUNDAMENTAL SHIFT AWAY FROM FOSSIL FUEL DERIVED ENERGY SOURCES, REPLACED BY CLEAN ALTERNATIVES, AND SUPPORTED BY CHARGING AND GIGA-SCALE BATTERY INFRASTRUCTURE

Current situation and challenges

Transportation in its many forms currently produces over 1,200 $MtCO_2$ per year, 30% of total emissions in the EU. Liquid fossil fuels drive most air, marine, road and rail movements, from most captive usage to less captive (see figure below). Fossil liquids are dense in energy, convenient for logistics and not easy to replace. In Europe, they currently account for 72% of primary energy use.

The daunting challenge ahead is to free transportation from liquid fossil fuel usage[1] and to develop the new clean technologies and associated infrastructure that will enable sustainable and convenient private and public transportation.

Figure 15 - Dependency on liquid fossil fuel usage per transportation type



> **"We need political quotas for the use of synthetic fuels in aviation to accelerate mass production."**
>
> **Markus Pieper**, Member of the European Parliament

Solutions, projects and scale-up

Three types of transportation energy sources – synthetic liquid fuels, hydrogen and electricity – combined with new mobility modes, are directly contributing to decarbonization in all forms of transportation. Demand for transportation energy will fall from 360 Mtoe today to around 200 Mtoe by 2050, made up of:

- Synthetic liquids: 40 Mtoe[2].
- Biomass liquids: 30 Mtoe.
- Hydrogen and gases: 50 Mtoe.
- Electricity: around 50 Mtoe.
- A small share of fossil fuels: 25 Mtoe, down from 340 Mtoe today.

An array of technologies is needed, from higher to lower liquid dependency:

1. Synthetic liquid fuels - mostly for air and maritime use

Giga-scale synthetic fuels production facilities are needed before 2030, close to transport hubs, ports and airports. They will synthetize at scale:

- Carbon-based synthetic fuels such as kerosene, methanol or ethanol in plants consuming green hydrogen and carbon captured from industry (circular economy in industrial hubs).
- Ammonia liquid fuels, especially for marine transportation, with its dedicated logistics. The production of green ammonia from green hydrogen can also serve the chemical industry.

Carbon-based synthetic fuels can be used by nearly all standard airplanes and vessels. To be able to run on ammonia, vessels need to be retrofitted with dedicated fuel cells and ammonia management systems.

2. Pure hydrogen – for intermediary marine, road and rail use

Pure hydrogen in its different forms, combined with fuel cells, is a solution when liquids are not required for smaller range journeys (more space available onboard) but where electricity is not a solution (battery limits and charging times). Beyond ferries and trains, Europe must focus on trucks, buses and other road heavy duty vehicles: develop its own models of vehicles, implement infrastructures including charging points along corridors and for captive fleet.

3. Ease the adoption and use of e-mobility

The European electric vehicle market is expected to reach six to seven million per year by 2030[3], with most net-zero scenarios requiring 80% of passenger car stock to be electric by 2050. The key to this is a huge expansion in private and public charging infrastructure and access to vast quantities of Li-ion batteries.

4. Cheaper, cleaner and more efficient batteries made in Europe

Industrial scale battery production in Europe will be achieved by the development of ten li-ion gigafactories in 2030, supported by large scale battery recycling facilities to ensure reuse of vital components and limit environmental impacts.

5. New forms of urban mobility

The ongoing proliferation of high-emission private motor vehicles carrying individuals is not compatible with the achievement of Europe's net-zero targets. Yet public transport alternatives are not always accessible, with disjointed infrastructure, scattered data and multiple payment points.

Public, shared and free-floating transport systems must be developed, providing door-to-door flexibility, reliability and convenience and offering a viable alternative to cars. Streamlined mobility systems offering multiple modes of shared transportation across Europe will be essential, accessed and paid for securely using standardized, user-friendly IT platforms. Private and public operators must work jointly to solve the data, business models and technology challenges.

Impacts

- **€111 billion total market (turnover + investments) per year in 2030.**
- **1.1 million permanent jobs in 2030.**
- **128 MtCO_2 avoided per year in 2030.**

List of projects - TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

#33 - SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR AVIATION
Establish giga-scale production facilities in industrial clusters and transportation hubs

#34 - SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR LONG-DISTANCE SHIPPING
Establish giga-scale production facilities in industrial clusters and transportation hubs

#35 - SCALE UP GREEN N-LIQUID AMMONIA PRODUCTION AND LOGISTICS INFRATSRUCTURE FOR LONG-DISTANCE SHIPPING
Green ammonia and energy production facility at large ports

#36 - DEPLOY AMMONIA-FUELED VESSELS FOR LONG-DISTANCE SHIPPING
Retrofit existing vessels to shift from fossil fuel combustion engines to ammonia fuel-cell propulsion engines

Pure hydrogen for medium-distance marine, road and rail use

#37 - SHIFT SHORT- AND MEDIUM-DISTANCE FERRIES TO HYDROGEN FUEL-CELL PROPULSION
Retrofit existing ferries to shift from fossil fuel combustion engines to H_2 fuel-cell propulsion engines

#38 - DEVELOP HYDROGEN USAGE FOR HEAVY-DUTY ROAD FREIGHT
Deploy hydrogen refueling stations along the key pan-European road corridors

#39 - SHIFT EUROPEAN TRUCK INDUSTRY TO HYDROGEN
Develop EU-based production of fuel-cell heavy-duty trucks, buses and waste vehicles

#40 - TRANSITION FOSSIL-POWERED INTERCITY TRAINS TO HYDROGEN
Develop and deploy urban/suburban hydrogen-powered trains

Ease the adoption and use of e-mobility

#41 - ELECTRIFY SHORT-DISTANCE TRUCK TRANSPORT, WASTE COLLECTION AND URBAN BUS FLEETS
Low-GHG, silent and clean air city transportation: last-mile logistics, public transport and services

#42 - FOSTER PRIVATE EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY
Massively deploy charging points at private homes and offices

#43 - FOSTER PUBLIC EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY
Slow to fast charging for urban areas and ultra-fast charging deployment projects along major transit routes

#44 - DEVELOP FASTER, CHEAPER, MORE CONVENIENT TECHNOLOGIES FOR EV CHARGING
Lever European R&D to invent disruptive charging solutions that will be highly competitive on global market

Cheaper, cleaner and more efficient batteries made in Europe

#45 - SUPPLY THE EUROPEAN AUTOMOTIVE INDUSTRIES WITH "MADE IN EUROPE" LI-ION BATTERIES
Li-Ion battery gigafactories to serve the increasing e-mobility market and develop jobs and know-how in Europe

#46 - CREATE A 100% CIRCULAR BATTERY ECONOMY IN EUROPE
Establish an extensive network of battery collection and recycling facilities to lower the GHG footprint of batteries and re-use precious resources

#47 - STIMULATE THE DEVELOPMENT OF NEXT GENERATION BATTERY TECHNOLOGY FOR MOBILITY USE
Lever European R&D to invent disruptive alternative battery technologies to Li-ion and invest in gigafactories to manufacture these new solutions

New forms of urban mobility

#48 - BUILD NEW URBAN MULTIMODAL TRANSPORT SYSTEMS FOR EASY DOOR-TO-DOOR JOURNEY PLANNING, EXPERIENCE AND PAYMENT
Public-private platforms leveraging AI, data and end-to-end payment business models, and reinforcement of physical mobility equipment and infrastructure

#49 - LEVER SHARED AUTONOMOUS VEHICLES TO REDUCE THE NUMBER OF CARS IN AN INCREASING NUMBER OF EUROPEAN CITIES BY 30%
Large scale deployment of automated vehicles in shared fleets and public transport

[1] *https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf, Scenario 1.5TECH, Gross Inland Consumption, Non-Energy uses*
[2] *https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf*
[3] *https://about.bnef.com/electric-vehicle-outlook/*

SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR AVIATION

Establish giga-scale production facilities in industrial clusters and transportation hubs

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

IN A NUTSHELL...

- **Issue:** Biofuels for aviation are neither price-competitive nor technologically mature, due to a lack of development projects
- **Solution:** Production of e-fuels for aviation (e-kerosene) within five facilities in strategic hubs (if relevant they can also provide e-fuels for maritime transport)
- **Key impacts:** 10 $MtCO_2e$, €1.9 billion total market, 28,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The goal of the project is to create five facilities in major European airports, with a total electrolyzer capacity of 6 GW. The project will result in 3 million tons of green liquid e-fuel for airplanes produced per year, 500,000 t of hydrogen produced per year, and 9.3 $MtCO_2$ captured per year.

- Identify five European cargo airports, ideally coupled with a maritime port (such as Hamburg, Amsterdam, Valencia or Piraeus/Athens).
- In each location, build one facility by 2030 to enable additional yearly production of 600,000 t of synthetic hydrocarbon fuels for aviation (e-kerosene), leading to a total additional output of three million tons in Europe.
- A total electrolyzer capacity of 6 GW is needed, either produced on-site or complemented with hydrogen supplied by pipes.
- To ensure a genuinely sustainable production of alternative fuel, the facilities must have access to a large supply of green electricity, ideally sourced from nearby offshore wind or solar power plants.
- Incentivizing policies and technological progress (such as aircraft energy efficiency and e-kerosene production processes) are also required to further develop the e-kerosene market and encourage the retrofitting of existing planes.
- The same facility, combining carbon and green hydrogen, can produce hydrocarbon fuels for several modes of freight: e-kerosene for aviation with project #33, and methanol for maritime vessels with project #34.
- Key stakeholders to involve include public authorities, energy providers, airports, flag carriers (such as for example KLM Royal Dutch Airlines in Amsterdam, or Lufthansa in Frankfurt), and freight forwarders.

Projects that inspired this analysis: Copenhagen airport's partnership with transport operators (Orsted, Maersk, SAS, DSV Panalpina) for an e-fuel factory by 2030, Joint Venture in Oslo between Sunfire GmbH, Climeworks AG, Paul Wurth SA and Valinor for an e-kerosene factory by 2026.

Why this technology and project are needed to reach net-zero

Aviation is a major source of CO_2 emissions in the EU, accounting for about 3% of total emissions[1] and being the second highest emitting sector in transport, after road vehicles[2]. It remains difficult to reduce the emissions of the sector: existing planes are amortized over long periods of time, and bio-based fuel is much more expensive (€950-1,015/ton) than fossil-based kerosene (€600/ton)[3]. Nonetheless, developing green propulsion and fuel production technologies remains necessary to reach a net-zero carbon economy: bio-based jet fuels, generating no emissions during combustion are one such solution. Though rarely used nowadays, biofuel output potential (between 0.355 and 2.3 million tons can be produced per year) will increase in the years to come, reaching between 0.55 and 3.5 million tons in 2025 according to the European Aviation Environmental Report[4] .

Adding 1 million tons through the project proposed here already represents twice the output capacity by 2025 under the moderate scenario (550 t) and approximately the same as the total increase predicted (3.5 Mt - 2.3 Mt = 1.2 Mt) under the maximum output scenario in 2025. The challenge is to produce liquid carbon neutral fuels sustainably, profitably and at an industrial scale. To make e-fuels competitive in aviation, production technology and costs must be improved, with public authorities incentivizing private investments and prioritizing renewable fuels. Additionally, new infrastructure must be built at strategic locations, such as production facilities within transportation hubs.

Few projects have been launched in Europe to demonstrate this technology, due to its high costs. However, in May 2020, the Copenhagen municipality formed a partnership with several transport operators such as Orsted and Maersk to create an industrial-scale production factory supplying sustainable fuel for the city's airports, but also for maritime and road transports, with a maximum capacity of 250,000 tons per year by 2030. This justifies the idea of a production hub, designed to the supply of both e-fuel for aviation (project #33), and for maritime shipping (project #34).

Impacts

	2030	2050
CLIMATE IMPACT	**10 $MtCO_2e$ avoided**	**100 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€1.9 billion total market** €1.5 billion cumulated investment by 2030, €0.1 billion yearly average (2020-2030) €1.7 billion turnover in 2030	**€15.9 billion total market** €12.2 billion cumulated investment by 2050, €0.4 billion yearly average (2020-2050) €15.5 billion turnover in 2030
JOBS	**28,000 total jobs** 2,000 construction jobs for investment 26,000 production jobs for turnover	**239,000 total jobs** 6,000 construction jobs for investment 233,000 production jobs for turnover

#33 [1]https://ec.europa.eu/clima/policies/transport/aviation_en#:~:text=to%20climate%20change%3F-,Direct%20emissions%20from%20aviation%20account%20for%20about%203%25%20of%20the,and%20a%20non%2DEU%20country.
[2]https://www.easa.europa.eu/eaer/topics/overview-aviation-sector/emissions
[3]https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf
[4]Ibid

SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR LONG-DISTANCE SHIPPING

Establish giga-scale production facilities in industrial clusters and transportation hubs

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

IN A NUTSHELL...

- **Issue:** LNG, the cleanest fuel currently available at an industrial scale, still emits CO_2; Liquid biofuels represent a promising alternative but are not cost-competitive
- **Solution:** Scale production to drive down the cost of e-fuels for shipping (methanol)
- **Key impacts:** 7.7 $MtCO_2e$, €3.6 billion total market, 55,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The goal of the project is to create five port facilities across the EU, each dedicated to the production of 1 million tons of e-fuel (methanol) each year for European and international cargo shipping, with a total electrolyzer capacity of 10.5 GW. The project will result in 5 million tons of green liquid e-fuel for ships produced per year as of 2030, consuming 850,000 tons of hydrogen and 6.875 $MtCO_2$ per year.

- Identify five European cargo ports ideally coupled with airports (such as Hamburg, Amsterdam, Valencia or Piraeus/Athens).
- In each location, build one facility by 2030 which enables an additional yearly production of 1 million tons of synthetic hydrocarbon fuels for cargo shipping (methanol).
- A total electrolyzer capacity of 10.5 GW is needed, either built on-site or streamlined with hydrogen provided by pipes.
- To ensure a genuinely sustainable production of alternative fuel, the facilities must have access to a large supply of green electricity, ideally sourced from nearby offshore wind or solar power plants.
- In addition to the new facilities, incentivizing policies and technological progress (engine energy efficiency, e-fuel production processes) is required for developing of the methanol fuel market and to encourage the retrofitting of existing ships which will run on methanol.
- Within this project dedicated to e-fuels for the marine sector, additional synergies can be achieved through the simultaneous provision of e-kerosene to airports, as described in project #33.
- Key players to involve include public authorities, energy providers, port operators, shipping lines operators, and freight forwarders.

Projects that inspired this analysis: Copenhagen municipality partnership with transport operators (Orsted, Maersk, SAS, DSV Panalpina) for an e-fuel factory by 2030.

Why this technology and project are needed to reach net-zero

While international shipping represents 2 to 3% of all greenhouse gas emissions in the world, maritime transport accounts for 3.7% of CO_2 emissions in the EU, 30% of which are produced by container ships[5]. The European Commission published its first report on the matter in 2019[6], studying 11,600 ships over 5,000 gross tonnage of various sizes (container ships, roll-on and roll-out passenger ships, bulk carriers, tankers), representing almost 40% of the global merchant fleet.

The European Commission already implemented compulsory emission and fuel monitoring for high tonnage cargo or passenger ships in 2013.

Several technological and operational improvements have been proposed to reduce this environmental impact, such as reducing speed or implementing energy efficient systems.

But LNG, the cleanest fuel currently available at an industrial-scale, still emits CO_2: therefore, it remains necessary to find a zero-emission fuel for shipping, as encouraged by the European Parliament in the context of the Green Deal[7].

E-fuels (methanol, hydrogen or ammonia) are produced from electricity, which can come from renewable sources to minimize further carbon emissions. The hydrogen produced from electrolysis can be used directly or synthesized with carbon monoxide or nitrogen to produce methanol or ammonia respectively.

Alternative fuels need to become competitive with classic fuels in terms of cost. Additionally, infrastructure and typical operations, like storage and security protocols, will also need to be adapted.

Impacts

	2030	2050
CLIMATE IMPACT	**7.7 $MtCO_2e$ avoided**	**61.8 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€3.6 billion total market** €2.6 billion cumulated investment by 2030, €0.3 billion yearly average (2020-2030) €3.4 billion turnover in 2030	**€28.3 billion total market** €37.9 billion cumulated investment by 2050, €1.3 billion yearly average (2020-2050) €28.3 billion turnover in 2050
JOBS	**55,000 total jobs** 4,000 construction jobs for investment 51,000 production jobs for turnover	**424,000 total jobs** 19,000 construction jobs for investment 405,000 production jobs for turnover

#34 [5]*https://ec.europa.eu/clima/news/commission-publishes-first-annual-eu-report-CO2-emissions-maritime-transport_en*
[6]*https://ec.europa.eu/clima/news/commission-publishes-first-annual-eu-report-CO2-emissions-maritime-transport_en*
[7]*https://www.europarl.europa.eu/doceo/document/TA-9-2020-0005_EN.html*

SCALE UP GREEN N-LIQUID AMMONIA PRODUCTION AND LOGISTICS INFRASTRUCTURE FOR LONG-DISTANCE SHIPPING

Green ammonia and energy production facility at large ports

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

IN A NUTSHELL...

- **Issue:** Ammonia is a promising zero-emissions fuel for shipping, but is still produced mainly from grey hydrogen and remains much more expensive than traditional fuel
- **Solution:** Test and deploy at scale production facilities of green ammonia for use as e-fuel for maritime shipping
- **Key impacts:** €4.3 billion total market, 65,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

In line with Project #36 (1,160 ships converted to ammonia fuel-cell propulsion engine), the goal of the project is to reach a yearly production capacity of 5 Mt of green ammonia fuel for European and international cargo shipping, consuming 840,000 tons of hydrogen per year as of 2030. The scaling up of the project will follow the technological advancements in ammonia-powered ships, as the first engines developed by the ShipFC Project will be finalized in 2023.

The project will optimize the process of sustainable ammonia production using green hydrogen, to drive progress in maritime ammonia-powered propulsion and deploy at a large-scale ammonia storage and refuelling.

- Identify large cargo ports in the EU, with easy access to renewable energy (ideally sourced from nearby offshore wind or solar power plants) to ensure a genuinely sustainable production of alternative fuel: preferably Southern Europe such as Spain or Portugal.
- Build facilities in these locations to enable a yearly production of 5 Mt of green ammonia fuel for cargo shipping by 2025.
- For 2030, the project aims at a total production of five million tons of green ammonia (enough to power 1,160 cargo ships per year[8]).
- Key players to involve include public authorities, energy providers, port operators, shipping lines operators, and freight forwarders.

Projects that inspired this analysis: ShipFC consortium project, NoGAPS Project.

Why this technology and project are needed to reach net-zero

Ammonia (NH_3) is traditionally used in the agricultural sector to produce fertilizers (10.2 million tons of such nitrogen fertilizer are used in the EU[9]). Recently its application in shipping fuel has been extensively discussed, since its use does not emit CO_2 due to the lack of a carbon atom in the NH3 molecule. This makes it an ideal technology for a zero-emissions economy. It can be stored in high temperatures in a liquid form, though adapted safety measures must be implemented. Ammonia can also be produced anywhere, allowing Europe to close the gap with leading nations in this technology (such as China, contributing 40% of the global supply of ammonia).

However, ammonia production needs to be carbon-neutral, using green hydrogen obtained from electrolysis. Nowadays, ammonia production heavily relies on fossil fuels and is far from carbon-neutral, emitting 1.8% of all global CO_2 emissions[10]. Furthermore, ammonia is still much more expensive and less available than heavy fuel oil traditionally used by vessel operators. Thirdly, ammonia-powered ships have yet to be designed, as no suitable ship engine exists for now.

Several European projects are dedicated to proving the feasibility of ammonia ships before 2025. Launched in January 2020, the ShipFC project gathers 14 European firms and organizations to create the first commercial ship powered by green ammonia by late 2023. The initiative is already looking into retrofitting different kinds of ships with ammonia fuel cells and has received €10 million of funding from the EU. MAN Energy Solutions is also working on a two-stroke ammonia ship engine, to be showcased by 2024. Finally, the NoGAPS Project, launched in May 2020 studies the challenges for ammonia supply chains that must be addressed to allow large-scale deployment of NH_3-powered ships in Europe.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in ships converted to green ammonia.*	*Counted in ships converted to green ammonia.*
ECONOMIC IMPACT	**€4.3 billion total market** €2.6 billion cumulated investment by 2030, €0.3 billion yearly average (2020-2030) €4.1 billion turnover in 2030	**€28.3 billion total market** €8.3 billion cumulated investment by 2030, €0.3 billion yearly average (2020-2050) €16.3 billion turnover in 2050
JOBS	**65,000 total jobs** 4,000 construction jobs for investment 61,000 production jobs for turnover	**249,000 total jobs** 4,000 construction jobs for investment 245,000 production jobs for turnover

#35 [8]*See calculation in the Excel spreadsheet*
[9]*https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_mineral_fertiliser_consumption*
[10]*https://www.ft.com/content/2014e53c-531f-11ea-a1ef-da1721a0541e*

DEPLOY AMMONIA-FUELED VESSELS FOR LONG-DISTANCE SHIPPING

Retrofit existing vessels to shift from fossil fuel combustion engines to ammonia fuel-cell propulsion engines

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

IN A NUTSHELL...

- **Issue:** Carbon-free alternatives to fuel oil have yet to be adopted at a large scale by cargo transportation
- **Solution:** Launch demonstration projects of long-range zero-emissions maritime ammonia fuel
- **Key impacts:** 13.6 MtCO_2e, €5.8 billion cumulated investment, 9,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The goal of the project is to launch, as soon as an ammonia-powered ship engine has been validated in Europe, the retrofitting of 10% of long-distance merchant ships across the EU by 2030 (1,160 ships)[11]. This will demonstrate the operational feasibility and the commercial viability of ammonia-powered long-distance merchant ships.

- Identify strategic cargo ports in the EU, with easy access to future facilities of green ammonia production (see Project #35) and renewable energy.
- Launch the retrofit of 1,160 ships to ammonia-powered engines by 2030.
- Main stakeholders include public authorities, energy providers, green hydrogen specialists, port operators, shipping lines operators, freight companies, commercial ship manufacturers, fuel cell technology specialists, and institutes of technology.
- N.B.: the project can be adapted to smaller port-based ships.

Projects that inspired this analysis: ShipFC consortium project, NoGAPS Project.

Why this technology and project are needed to reach net-zero

Ammonia (NH_3) is traditionally used in the agricultural sector to produce fertilizers (11.8 Mt of such nitrogen fertilizer are used in the EU yearly[12]). But recently, ammonia's application in shipping fuel has been extensively discussed, since its combustion does not emit CO_2 due to the lack of a carbon atom in the NH_3 molecule; this makes it an ideal technology for a zero-emissions economy. It can be stored in high temperatures in a liquid form, however adequate safety measures must be implemented. Ammonia can also be produced anywhere, allowing Europe to close the gap with the leading nations in this technology (such as China, providing 40% of all supplies of ammonia in the world), and make Europe less dependent on imports.

However, ammonia production needs to be carbon-neutral, using green hydrogen obtained from electrolysis. Nowadays, ammonia production mainly relies on fossil fuels and is far from carbon-neutral, emitting 1.8% of all global CO_2 emissions[13]. Furthermore, ammonia is still much more expensive and less available than the heavy fuel oil traditionally used by vessel operators. Thirdly, ammonia-powered ships have yet to be designed, as no ship engine exists at the moment.

Several European projects are dedicated to proving the feasibility of ammonia ships before 2025. Launched in January 2020, the ShipFC project gathers 14 European firms and organizations to create the first commercial ship powered by green ammonia by late 2023. The initiative is already looking into retrofitting different kinds of ships with ammonia fuel cell and has received €10 million of funding from the EU. MAN Energy Solutions is also working on a two-stroke ammonia ship engine, to be showcased by 2024. Finally, the NoGAPS project, launched in May 2020, studies the challenges for ammonia supply chains that must be addressed to allow large-scale deployment of NH_3-powered ships in Europe.

Impacts

	2030	2050
CLIMATE IMPACT	**13.6 $MtCO_2e$ avoided**	**54.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€5.8 billion cumulated investment** €0.6 billion yearly average (2020-2030)	**€23.2 billion cumulated investment** €0.8 billion yearly average (2020-2050)
JOBS	**9,000 total jobs**	**12,000 total jobs**

#36 [11]*https://ec.europa.eu/clima/sites/clima/files/transport/shipping/docs/swd_2020_82_en.pdf*
[12]*https://www.fertilizerseurope.com/fertilizers-in-europe/facts-figures/*
[13]*https://www.ft.com/content/2014e53c-531f-11ea-a1ef-da1721a0541e*

#37

SHIFT SHORT- AND MEDIUM-DISTANCE FERRIES TO HYDROGEN FUEL-CELL PROPULSION

Retrofit existing ferries to shift from fossil fuel combustion engines to H_2 fuel-cell propulsion engines

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** Hydrogen-powered engines for ferry shipping, although tested at pilot level, have yet to be deployed at a large scale
- **Solution:** Launch large-scale retrofit of hydrogen propulsion systems for ferries, and prove market readiness for hydrogen as a fuel and large-scale production
- **Key impacts:** 0.8 $MtCO_2e$, €0.3 billion total market, 4,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The first goal of the project is to launch the retrofit of 50% of European ferries into hydrogen-powered ships, each with a fuel cell power of 2 MW (in line with existing hydrogen-powered ferries[14]) by 2030. This will demonstrate the operational feasibility and commercial viability of the large-scale deployment of a zero-emissions propulsion system.

In line with this first objective, the project simultaneously aims at a yearly production capacity of 60,000 tons of green hydrogen fuel for short-distance ships, as the technology for GW-scale electrolyzers is developed in European projects. A deployment of green hydrogen production of this size will allow technical development, optimization of production processes and cost reduction, thus solving the main challenges currently faced by the technology.

- Identify five major ferry ports in the EU (such as Norway, the Netherlands, Spain, Greece or Portugal) with easy access to future facilities of green hydrogen production (emerging hydrogen clusters) and renewable energy supply (ideally from nearby offshore wind parks or PV solar plants).
- In each location, build a green hydrogen production facility, to drive forward electrolysis technology (accelerate the development of selected technologies with the strongest commercial potential and proven results for large-scale deployment).
- For 2030, launch the retrofit of 50% of the European ferry fleet (350 ships[15]) to 2 MW hydrogen fuel cell engines and produce 60,000 tons of green hydrogen dedicated to short-distance shipping fuel.
- Main stakeholders include public authorities, energy providers, port operators, ferry operators, maritime equipment manufacturers, fuel cell technology specialists and institutes of technology.

Projects that inspired this analysis: H_2SHIPS project, ZeFF project, Seashuttle project, Flagships project, ShipFC (ammonia-powered engine retrofit), 2x40 GW Green Hydrogen Initiative, HYPOS, HySynGas, Elekrolysefabriek.

Why this technology and project are needed to reach net-zero

Short-sea shipping, defined as the transportation of cargo and passengers with maritime transports on short distances (along the coast, from port to port, inland in small seas or rivers, without crossing an ocean), is a critical part of the freight chain in Europe as it is responsible for 37% of intra-EU trade[16]. This activity is complementary to road transportation (accounting for 45% of intra-EU trade), creating intermodal freight networks.

Retrofitting short-sea ships with LNG, as it has been attempted in Europe, is insufficient to decarbonize the sector, while hydrogen fuel cells are a viable solution (for short distance maritime transportation as well as for freight trucking).

Many European projects have already been launched to start the decarbonization of ferry transportation. Contrary to other zero-emitting fuels such as ammonia (for which no ship engine has been designed yet), hydrogen-fueled commercial ships exist since 2010, the offshore platform supply vessel *Viking Lady* being the first to use this technology. The H_2SHIPS project aims to pilot a hydrogen port-based ship in Amsterdam, a hydrogen station for open sea ships in Amsterdam and hydrogen ships on the Seine by 2022. Project ZeFF (Zero-emission Fast Ferry) received €1 million of public support in December 2018 to create hydrogen ferries in Norway. The Seashuttle project was also backed by the Norwegian government and targets 20% of zero-emissions coastal routes. Finally, the 2019 Flagships project received €5 million of funding from the EU to create two hydrogen fuel cell ferries in France and Norway.

95% of the world's hydrogen production is currently 'grey', using fossil fuels (natural gas or coal) in a cost-effective and technologically mature process[17], but with 10 tons of CO_2 emitted per ton of hydrogen produced[18]. 'Blue' hydrogen can also be produced in a process limiting the CO_2 emissions through carbon capture and storage. However, to reach a net-zero-emission economy, the production of hydrogen needs to be fully decarbonized, with electrolysis. This requires designing high capacity electrolyzers through technological development, and drastically reducing the price per kW installed capacity through large-scale deployment of facilities.

Impacts

	2030	2050
CLIMATE IMPACT	**0.8 $MtCO_2e$ avoided**	**1.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€0.3 billion total market** €1.2 billion cumulated investment by 2030, €0.1 billion yearly average (2020-2030) €0.1 billion turnover in 2030	**€0.3 billion total market** €2 billion cumulated investment by 2050, €0.1 billion yearly average (2030-2050) €0.2 billion turnover in 2030
JOBS	**4,000 total jobs** 2,000 construction jobs for investment 2,000 production jobs for turnover	**4,000 total jobs** 1,000 construction jobs for investment 3,000 production jobs for turnover

#37 [14]The 2 MW power target is coherent with existing hydrogen-powered ferries (https://www.uib.no/sites/w3.uib.no/files/attachments/fuel_cells_and_hydrogen_in_maritime_applications.pdf and https://www.oceanhywaycluster.no/member-area-hydrogen-vessels/hydrogen-vessel-1-68b62-g2dc4-2d4hx-8hgrc-544ls-99839-r8dbz and https://energy.sandia.gov/hydrogen-fuel-cell-funding-awarded-for-feasibility-study/)
[15]http://www.shortsea.fr/sites/default/files/fichiers/public/research_for_tran_committee-_the_eu_maritime_transport_system_focus_on_ferries.pdf
[16]https://www.ecsa.eu/sites/default/files/publications/ECSA_SSS_Download%201_0.pdf
[17]https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf
[18]https://www.hydrogen4climateaction.eu/2x40gw-initiative#:~:text=Improving%20the%20EU%20Climate,to%20the%20EU%20climate%20objectives

DEVELOP HYDROGEN USAGE FOR HEAVY-DUTY ROAD FREIGHT

Deploy hydrogen refueling stations along the key pan-European road corridors

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** Widespread implementation of H_2 in road transport is limited by poor infrastructure penetration and reliability
- **Solution:** Building a 'spine' based on high-utilization freight lays the foundation for expansion into passenger transport
- **Key impacts:** €4.8 billion cumulated investment, 7,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The project's goal is to pilot the deployment of freight hydrogen corridors in Europe. They will consist of large stations ensuring hydrogen refueling as well as production on site with small electrolyzers and photovoltaic panels. The stations will be located strategically along each corridor.

The aim is both to create the necessary infrastructure for an increased number of heavy-duty hydrogen trucks (as anticipated in Project #39), and to locally produce part of the fuel needs with renewable energy.

- Identify heavy-duty truck freight network corridors in Europe of 1,000 km, along the nine larger transport axes identified in the TEN-T (Trans-European Transport Network) program[19]. These nine core corridors had been previously identified by the European Commission in order to focus EU-backed infrastructure projects.
- Develop large hydrogen refueling stations along these corridors for heavy-duty trucks.
- Implement local hydrogen production in each Hydrogen Refueling Station with photovoltaic panels on roofs and electrolyzers, aiming at 1,000 kg of hydrogen production per day[20].
- Main stakeholders include developers and manufacturers of hydrogen generation and fuel cells products, companies specialized in trucking, shipping and rail freight, and renewable energy providers.

Projects that inspired this analysis: GIFT (intercontinental corridor selection), FCH ReFuel (hydrogen infrastructure), H_2ME 1 and H_2ME 2 (expansion of the European hydrogen vehicles fleet, fueling stations and hydrogen production techniques), $H_2$020 call for proposals: "Scale-up and demonstration of innovative hydrogen compressor technology for full-scale hydrogen refueling station".

Why this technology and project are needed to reach net-zero

Heavy-duty vehicles, such as trucks, buses and coaches, constitute a significant share of CO_2 emissions in the EU (~25% of CO_2 of road transport emissions, and 6% of total emissions within the Union)[21]. Between 65% and 70% of these emissions are produced by heavy-duty trucks[22], although new regulations (such as Euro I to VI) have been released to impose stricter emission standards.

Fully decarbonizing this mode of freight transport will have significant environmental benefits on a local and European level. However, widespread implementation of greener, hydrogen-powered heavy-duty trucks in Europe will require significant improvements to the infrastructure along the main commercial routes.

Although only 120 hydrogen refueling stations currently exist, the Hydrogen Roadmap for Europe expects this number to rise to 3,700 in 2030 (all sizes), for a cumulated investment of €8.2 billion, to accommodate an increasing volume of H_2 vehicles[23].

European projects are moving in this direction: the H_2Piyr project is one example of an EU-backed Hydrogen Corridor initiative, building six refueling stations along a 900 km long Spanish, French and Andorran corridor by 2021.

To accelerate the decarbonization of freight movement within Europe, an efficient green fueling infrastructure adapted for trucking needs to be put in place along these strategic corridors. The price of hydrogen must be kept at a low level to ensure competitiveness for long-haul transport (around €2.7/kg for trucks according to a 2019 study by the Hydrogen Council[24]). One solution is to implement local production at truck stations, with photovoltaic panels installed on roofs coupled with small electrolyzers, to guarantee renewable and cheap hydrogen sourcing.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in hydrogen trucks in circulation.*	*Counted in hydrogen trucks in circulation.*
ECONOMIC IMPACT	**€4.8 billion total market** €0.5 billion yearly average (2020-2030)	**€40 billion total market** €1.3 billion yearly average (2020-2050)
JOBS	**7,000 total jobs**	**20,000 total jobs**

#38 [19]The TEN-T network has a total length of ~48,000 km (https://books.google.fr/books?id=_WRnDAAAQBAJ&pg=PA149&lpg=PA149&dq=ten-t+europe+length&source=bl&ots=YL7xu9X4X3&sig=ACfU3U2QeGhaNS1nHi82pOFDdxtU64n55w&hl=fr&sa=X&redir_esc=y#v=onepage&q=ten-t%20europe%20length&f=false)

[20]Based on Hydrogenics HySTAT fueling stations with electrolysis-based production (https://www.hydrogeni cs.com/hydrogen-products-solutions/energy-storage-fueling-solutions/hydrogen-fueling-stations/)

[21]https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en

[22]https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/628268/EPRS_BRI(2018)628268_EN.pdf

[23]https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

[24]https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

SHIFT EUROPEAN TRUCK INDUSTRY TO HYDROGEN

Develop EU-based production of fuel-cell heavy-duty trucks, buses and waste vehicles

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** There is currently no large scale zero-emissions solution for the commercial transportation of goods by heavy vehicles
- **Solution:** Develop fleets of heavy-duty hydrogen-powered trucks across Europe
- **Key impacts:** 3 $MtCO_2e$, €7.2 billion cumulated investment, 11,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The project's goal is to launch an initiative in five countries to accelerate the development and testing of hydrogen heavy vehicles, leading to the production of 45,000 hydrogen-powered freight trucks by 2030. This is in line with the ambitious target of the Hydrogen Roadmap for Europe, anticipating 45,000 hydrogen-fueled heavy trucks and buses by 2030[25].

- Identify five countries (in Central (e.g. Germany), Eastern and Northern Europe).
- Create an initiative to stimulate the hydrogen and fuel cells industry. This can be done by funding the development of hydrogen-powered freight trucks, through partnerships between public authorities, institutes of technology and manufacturers.
- The project will lead to the production of 45,000 hydrogen freight trucks coming in to replace existing diesel vehicles.
- Main stakeholders include: national ministries of transport, local Institutes of technology, heavy-duty truck manufacturers (such as Daimler Trucks), freight transportation operators (such as DHL), logistic specialists (such as Schenker AG).

Projects that inspired this analysis: FuelCellsWorks Initiative, REVIVE (Refuse Vehicle Innovation and Validation in Europe), Fuel Cells and Hydrogen Joint Undertaking (FCH JU), Joint Venture between Daimler Trucks and Volvo Group JV.

Why this technology and project are needed to reach net-zero

Heavy-duty vehicles, such as trucks, buses and coaches, constitute a significant share of CO_2 emissions in the EU (about 25% of road transport CO_2 emissions, and 6% of total emissions within the Union)[26]. Between 65% and 70% of these emissions are produced by heavy-duty trucks[27], though new regulations (such as Euro I to VI, which do not cover CO_2 primarily) have been released to impose stricter emission standards.

Fully decarbonizing this mode of freight transport will have significant environmental benefits on a local and European level. Today, only hydrogen-fueled trucks can achieve this goal, as current battery technology is not economically viable for long-haul truck application in terms of size and weight[28].

Though individual fuel cell cars have recently been introduced to the market, a comparable zero-emissions solution for road freight is yet to be deployed at the European level. However, hydrogen applications for heavy duty trucks are steadily moving from first-generation proof-of-concept to pre-commercial and real-life prototypes, as several projects accelerate the development of this technology in Europe.

In October 2019, the German Federal Ministry for Transport and Digital Infrastructure announced €23.5 million of funding going to hydrogen mobility projects, including €8.1 million dedicated to the development of heavy trucks (a project jointly developed by Shell, MAN, Anleg GmbH and TU Braunschweig). In April 2020, Daimler Trucks and Volvo announced they would create a joint venture to design hydrogen-powered heavy-duty commercial vehicles. Anticipating a quick adoption of this technology, the Hydrogen Roadmap for Europe sets a target of 45,000 fuel cell trucks and buses for 2030 and expects hydrogen-powered vehicles to represent 40% of all heavy-duty truck sales in 2050[29].

Impacts

	2030	2050
CLIMATE IMPACT	**3 $MtCO_2e$ avoided**	**166.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€7.2 billion cumulated investment** €0.7 billion yearly average (2020-2030)	**€352.8 billion cumulated investment** €11.8 billion yearly average (2020-2050)
JOBS	**11,000 total jobs**	**176,000 total jobs**

#39 [25]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*
[26]*https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en*
[27]*https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/628268/EPRS_BRI(2018)628268_EN.pdf*
[28]*http://pan.ckcest.cn/rcservice/doc?doc_id=31115*
[29]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*

TRANSITION FOSSIL-POWERED INTERCITY TRAINS TO HYDROGEN

Develop and deploy urban/suburban hydrogen-powered trains

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** European fleets of diesel-powered intercity trains need to be replaced by zero-emission transport solutions
- **Solution:** Decarbonize intercity rail connections by deploying hydrogen-powered trains
- **Key impacts:** 0.2 $MtCO_2e$, €3.4 billion cumulated investment, 5,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The project's goal is to pilot hydrogen intercity and commuter train projects in selected European regions to replace the diesel-powered locomotives they currently use, with minimal adaptation of existing railways. This project is in line with the ambitions of the European Hydrogen Roadmap, anticipating 570 hydrogen trains by 2030 and a share of 9% of all railway transports powered by hydrogen in Europe by 2050 under a 2-degree target scenario[30].

- Identify ten European regions currently using diesel-powered intercity trains.
- Assist the ten regions and/or the local railway operators in launching calls for intercity hydrogen train tenders by 2025.
- Ensure each call for tenders is comprised of 15 intercity hydrogen trains and one hydrogen refueling station, aiming at a total replacement of 150 diesel intercity trains.
- Key stakeholders include railway manufacturers with experience in hydrogen-powered trains (such as Alstom), European regions involved, railway operators (such as SNCF or RMV).

Projects that inspired this analysis: deal between Alstom and SNCF in France (15 hydrogen regional trains for 2021-2022)[31], deal between Alstom and LNGV in Germany (14 hydrogen trains for 2021)[32], deal between Alstom and RMV (27 hydrogen trains for 2022)[33].

Why this technology and project are needed to reach net-zero

Commuter trains are still commonly powered by diesel engines in Europe, but their replacement by hydrogen locomotives, advocated by the Hydrogen Roadmap for Europe by the Fuel Cells and Hydrogen Joint Undertaking[34], has started in 2019.

This solution was successfully launched in 2018 in Germany and additional hydrogen trains are already planned in several European countries such as France, which involves railway manufacturer Alstom and its Corafia iLint model.

In comparison to diesel, hydrogen reduces not only CO_2 emissions but also local pollutants and noise levels of trains, which matter in dense areas. The hydrogen alternative requires the implementation of additional infrastructure for hydrogen trains, which are more cost-effective and faster to install than to electrify lines and electric locomotives. This includes a limited number of hydrogen stations built along existing railways to ensure adequate refueling.

Impacts

	2030	2050
CLIMATE IMPACT	**0.2 $MtCO_2e$ avoided**	**1.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€3.4 billion cumulated investment** €0.3 billion yearly average (2020-2030)	**€24.3 billion cumulated investment** €1.2 billion yearly average (2050-2050)
JOBS	**5,000 total jobs**	**18,000 total jobs**

#40 [30]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*
[31]*https://www.lemondedelenergie.com/sncf-commande-15-trains-hydrogene-alstom/2019/09/06/*
[32]*https://www.alstom.com/fr/press-releases-news/2019/10/alstom-va-tester-son-train-pile-hydrogene-aux-pays-bas*
[33]*https://www.alstom.com/fr/press-releases-news/2019/5/fahma-une-filiale-de-rmv-passe-commande-alstom-de-la-plus-grande-flotte*
[34]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*

ELECTRIFY SHORT-DISTANCE TRUCK TRANSPORT, WASTE COLLECTION AND URBAN BUS FLEETS

Low-GHG, silent and clean air city transportation: last-mile logistics, public transport and services

TRANSPORT

Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** Over 70% of goods used daily are transported within and between cities via heavy duty trucks that are large CO_2 emitters
- **Solution:** Develop heavy-duty electric trucks, buses, waste collectors and demonstrate the feasibility of reliable deployment to gain scale and reduce costs
- **Key impacts:** 13.4 $MtCO_2e$, €99.5 billion cumulated investment, 149,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Electrify short and medium distance truck transport in Europe

- Pioneer electric truck transport along short and medium distances in Europe by incentivizing truck manufacturers to invest in electric technologies.
- Inspirational technology: Volvo FL truck with 16 tons capacity and 300 km range.
- The project aims at a share of 10% of electric vehicles in the EU truck fleet by 2030.
- The aim of the project is to scale up electric truck transport capabilities in Europe through public-private investment initiatives to unlock capital, i.e. take advantage of the European Investment Bank's transport lending criteria.
- It will reduce greenhouse gases and noise pollution created by trucks on short distance routes in Europe, while not jeopardizing the importance of truck transport in delivering goods.

Projects that inspired this analysis: Volvo LIGHTS initiative in the US: $90 million public-private investment partnership between California Climate Investments and Volvo to make electric truck transport a viable capability.

Project type 2: Deploy electric vehicles for public transport, waste collection, and postal deliveries in urban locations

- Bring together public and private stakeholders to electrify public transport, waste collection and postal services.
- The aim of the project is to mobilize national and European funds to act as financial support to cities and municipalities in replacing current vehicle fleets by electric fleets.
- Start with ten major EU cities by 2025 and identify implementation obstacles before scaling up in other European cities on a 2030 horizon.
- City entities including public transport, postal or waste services must initiate tenders to replace ageing fleets and incentivize vehicle manufacturers to increase supply.
- Main stakeholders: cities management to set up tenders, vehicle manufacturers to prepare and compete for large electric vehicle orders, European investment banks to provide financial support to city transport budgets via financial mechanisms like green bonds.

Projects that inspired this analysis: 1) Paris RATP plan bus 2025 with 4,500 new buses of which 80% will be electric; 2) La poste (French postal service) massive deployment of electric light vehicles for last mile delivery.

Why this technology and project are needed to reach net-zero

- Heavy vehicles, which include trucks and buses, account for 6% of EU total yearly CO_2 emissions i.e. over 300 million tons of CO_2.
- Deploying trucks will reduce heavy vehicle-related CO_2 emissions in the EU and boost job creation as a result of the need for innovative electric technologies and charging infrastructures.
- Urban centers suffer from noise pollution and fine particulate matter created by public transport and city vehicle-based services. Replacing fleets with EVs will allow cities to eliminate such noise and atmospheric problems.
- The replacement of city vehicle fleets can also revitalize European engine producers by creating activity for European manufacturers with tenders, motivating them to increase their cost-competitiveness and supply capacities.

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (trucking): 8 $MtCO_2e$ avoided** **Project type 2 (bus): 4 $MtCO_2e$ avoided** **Project type 2 (waste): 1.3 $MtCO_2e$ avoided** **Project type 2 (postal): 0.1 $MtCO_2e$ avoided**	**Project type 1 (trucking): 16 $MtCO_2e$ avoided** **Project type 2 (bus): 6.1 $MtCO_2e$ avoided** **Project type 2 (waste): 1.7 $MtCO_2e$ avoided** **Project type 2 (postal): 0.1 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**Project type 1 (trucking): €56.7 billion cumulated investment** €5.7 billion yearly average (2020-2030) **Project type 2 (bus): €37.1 billion cumulated investment** €3.7 billion yearly average (2020-2030) **Project type 2 (waste): €5.1 billion cumulated investment** €0.5 billion yearly average (2020-2030) **Project type 2 (postal): €0.5 billion cumulated investment** €0.05 billion yearly average (2020-2030)	**Project type 1 (trucking): €160.7 billion cumulated investment** €8 billion yearly average (2030-2050) **Project type 2 (bus): €123.8 billion cumulated investment** €6.2 billion yearly average (2030-2050) **Project type 2 (waste): €10.5 billion cumulated investment** €0.5 billion yearly average (2030-2050) **Project type 2 (postal): €0.9 billion cumulated investment** €0.04 billion yearly average (2030-2050)
JOBS	**Project type 1 (trucking): 85,000 total jobs** **Project type 2 (bus): 56,000 total jobs** **Project type 2 (waste): 8,000 total jobs** **Project type 2 (postal): 1,000 total jobs**	**Project type 1 (trucking): 120,000 total jobs** **Project type 2 (bus): 93,000 total jobs** **Project type 2 (waste): 8,000 total jobs** **Project type 2 (postal): 1,000 total jobs**

FOSTER PRIVATE EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY

Massively deploy charging points at private homes and offices

TRANSPORT

Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** With the declining prices of EVs, increasing variety of EV models and growing driving ranges, access to charging infrastructure will soon be the only remaining barrier for EV uptake
- **Solution:** Deployment of additional charging infrastructure at home and in offices is essential for accelerating EV market penetration
- **Key impacts:** 57.9 $MtCO_2e$, €80.2 billion cumulated investment, 120,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The program will focus on putting in place favorable financial conditions for individuals and private entities to facilitate investment towards installing their own charging infrastructure. The project will target one private charger per EV, with 40 million EV cars by 2030 and 80% of cars being EV by 2050[35].

- Rework current incentive programs across EU countries and propose a 'boosting plan' in the very short term (2020-2021), coordinated at EU and national levels, with new subsidies and tax reduction schemes to encourage the roll-out of private charging stations (at home or at work).
- Additionally, work on developing new business models with private companies to secure a rapid return on investment from the private charging point deployment. For example, installation of private charging in parking zones increases rent prices of nearby real estate.
- Rely on five countries to lead the implementation. These include Germany, France and the Netherlands, which together account for 20% of the European EV market[36]. From there, the goal is to get other EU countries on-board.
- Adapt financing schemes and implementation across countries and localities according to:
  - ◊ The urbanization heterogeneities of countries. For instance, in Germany, almost two-thirds of households have a garage or a parking space.
  - ◊ The status of the local EV ownership, charging infrastructure, consumer preferences and ability to finance (e.g. a single suburban house in a developing area vs. an apartment building in a major capital - how to drive adoption in both?).
- This can take the form of 'cash-back' on installation by certified electricians/installers or even providing capital for no-money-down installations.

Main stakeholders: Academics, knowledge and innovation centers (Delft University of Technology (NL), smartlab innovations GmbH (DE); Parking Energy, Finland); EU institutions for the funding, private companies to propose bundled offers (EV sale plus the charging infrastructure), or end-to-end energy solutions by energy companies or mobility providers.

Clusters: Netherlands, Germany, France, Italy

Why this technology and project are needed to reach net-zero

Despite persistent heterogeneity, standardization and technological progress have boosted the deployment of chargers, and EV uptake is closely mirrored by the spread of charging infrastructure. Indeed, charging accessibility is fundamental to improving the general acceptance of EVs. E-mobility therefore relies on a massive deployment of charging infrastructure, along with further technological standardization.

In 2017, the number of private chargers at residences and workplaces was estimated at almost three million worldwide, and the most widely used charging installations for electric cars were owned by households and fleets. Currently, private charging points account for more than 90% of installations in Europe[37].

Ubiquitous charging is locally labor-intensive, meaning it will have a strong impact on the overall economic recovery, and it is ready to be rolled out on short notice. In addition, the European Commission is also seeking to increase the level of home charging by requiring that charging stations be built into new residential buildings with over 20 parking spaces as of 2025[38].

Impacts

	2030	2050
CLIMATE IMPACT	**57.9 $MtCO_2e$ avoided**	**297.1 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€80.2 billion cumulated investment** €8 billion yearly average (2020-2030)	**€656.9 billion cumulated investment** €32.8 billion yearly average (2030-2050)
JOBS	**120,000 total jobs**	**493,000 total jobs**

#42 [35]For 2050, in a study on the impact of EV on Europe's future emissions, the EEA envisioned two scenarios for the share of EV as part of the entire EU car fleet in 2050: 50%, or 80% (https://www.eea.europa.eu/publications/electric-vehicles-and-the-energy/download)
[36]https://www.statista.com/statistics/625795/eu-electric-vehicle-market-share-by-country/
[37]https://www.transportenvironment.org/press/only-5-percent-ev-charging-happens-public-charging-points
[38]https://bellona.org/news/transport/electric-vehicles/2018-01-newly-agreed-eu-buildings-law-to-require-buildings-readiness-for-electric-vehicles

FOSTER PUBLIC EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY

Slow to fast charging for urban areas and ultra-fast charging deployment projects along major transit routes

TRANSPORT

Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** Public chargers complement the role of private ones, are an important component of the EV supply infrastructure, but represent only 5% of total chargers
- **Solution:** Deployment of additional fast-charging public infrastructure along highways and transit routes
- **Key impacts:** €16 billion cumulated investment, 24,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

- In line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in passenger car fleet in 2050), deploy 8 million public charging points (one per 5 EVs[39], with both slow and fast charging capabilities) across Europe by 2030. It is that there currently are 175,000 public chargers in Europe[40], including the Netherlands, Germany, France and Norway, with more than 10,000 public charging points each.
- Make deployment of public charging points a core part of the motorway maintenance and expansion plans going forward, with spaces earmarked for future charging infrastructure.
- Deployment needs to be further accelerated via subsidy and regulatory initiatives as well as increased piloting of new charging technologies throughout Europe. Work to create a regulatory environment to support new technologies like vehicle-to-grid solutions (new regulatory frameworks to ease resell of energy to the grid, or innovative energy compensation models for customers who are part of V2G activities).
- Ensuring a low cost of renewable energy facilities is another key point. With technological evolutions, the price for purchasing and installing a bi-directional charger went from 10,000 down to 4,000-5,000 euros in three years (from 2017 to 2020). The project needs to establish strong links with existing smart charging initiatives, to ensure grid stability. New technologies will also decrease the maintenance cost of charging infrastructures.
- Inspiring company product: Tesla Supercharger network.
- Main stakeholders: TU Delft, The urban institute Hungary Zrt, Hungary; ElaadNL, Netherlands; Smartlab innovations GmbH, Germany; Delft University of Technology, Netherlands; Local Utilities (like Germany-based utility EnBW).
- Clusters: Netherlands, Germany, France, Spain and Italy.

Projects that inspired this analysis:

- *OSCD (Orchestrating Smart Charging in mass Deployment) lead by the TU Delft.*
- *UK initiative to install wireless public charging pads across residential streets, car parks and taxi ranks.*
- *E.ON x Clever and NEXT-E. E.ON has collaborated with Denmark's eMSP Clever to establish a network of 180 ultra-fast charging stations in seven countries connecting Norway to Italy.*
- *Mega-E is being implemented by Allego in partnership with Finland's Fortum, to develop a charging network of 322 ultra-fast chargers and 27 smart charging hubs across 20 central European and Scandinavian countries. It focuses on bringing multimodal charging hubs to metropolitan areas.*

Why this technology and project are needed to reach net-zero

Limited existence of charging infrastructure and long charging time compared to refueling at petrol stations are the main barriers for EV adoption in long distance travel. The EU had 175,000 public charging points in 2019[41].

- Slow public chargers are commonly found in urban areas where they can be used with other options including private off-street parking. The number of slow public chargers varies across cities depending on availability of off-street parking and the number of cars among other factors. The Netherlands has the highest number of slow chargers at 36,000[42]. Fast chargers only represent a small proportion of total EVSE in Europe, although the continent is emerging as one of the most popular destinations for DC fast charging stations deployment.
- Mass deployment of public EV infrastructure is needed, especially in vehicle-dense urban locations. Increasing the affordability of EV travel between major cities across Europe is also necessary. Most publicly accessible chargers are slow charging outlets, always complemented by publicly accessible fast chargers. Fast chargers are especially important in urban environments due to land availability constraints in densely populated European cities. In addition, fast chargers are essential to increase the appeal of EVs by enabling long distance travel.
- EVs are also assets for storage and renewable energy integration. Smart charging is an emerging business model to fasten EV adoption and allowing EV drivers to benefit from renewable energy sources. However, to enable this, either charging stations or the vehicle must communicate with smart grids. Currently, installed EV chargers are mostly unidirectional, preventing a roll-out of different technologies like Vehicle to Everything (V2X).

Ubiquitous charging is key in incentivizing rapid EV adoption. It is locally labor-intensive and ready to be rolled out on short notice. The Trans-European Transport Network (TEN-T) regulation – particularly the Innovation and New Technologies section – facilitates the deployment of low carbon transport infrastructure, while the Connecting Europe Facility (CEF) provides funding. As an example of EU funding programs, the Green Vehicles program supports road transport innovation including research on the interface between vehicle and charging infrastructure[43].

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**€16 billion cumulated investment** €1.6 billion yearly average (2020-2030)	**€131.4 billion cumulated investment** €6.6 billion yearly average (2030-2050)
JOBS	**24,000 total jobs**	**99,000 total jobs**

#43 *[39]https://www.transportenvironment.org/press/only-5-percent-ev-charging-happens-public-charging-points*
[40]https://www.transportenvironment.org/sites/te/files/publications/01%202020%20Draft%20TE%20Infrastructure%20Report%20Final.pdf
[41]https://www.transportenvironment.org/sites/te/files/publications/01%202020%20Draft%20TE%20Infrastructure%20Report%20Final.pdf
[42]https://nederlandelektrisch.nl/charging-infrastructure
[43]https://ec.europa.eu/inea/sites/inea/files/green_vehicles_brochure_2018.pdf

DEVELOP FASTER, CHEAPER, MORE CONVENIENT TECHNOLOGIES FOR EV CHARGING

Lever European R&D to invent disruptive charging solutions that will be highly competitive on global market

TRANSPORT

Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** The EV charging experience complicates customers' e-mobility journey and slows down EV uptake
- **Solution:** Accelerate R&D on wireless charging and electrified road technologies to enable a faster, cheaper, and more convenient charging experience
- **Key impact :** €18.2 billion cumulated investment, 27,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

Project type 1: Develop and scale static wireless charging technology

The goal of the project is to develop a new generation of wireless EV charging technologies with the aim of decreasing technology costs (go-mainstream) and supporting the development of common EU wireless charging standards.

- Identify stakeholders (OEMs, academies, cities, and others) currently working on wireless charging technologies. As an example, international German OEMs are already investing in this technology.
- Fund their R&D activities via public-private investment partnerships with consortia of private companies.
- Identify pilot cities for wireless charging deployment and support/subsidize their initial construction phase.
- After the initial development phase, work on scaling-up this solution across EU countries through public-private partnership models.
- Main deployment stakeholders: Europe based international OEMs (such as BMW, Renault), European regions (start with France and Germany), academies and research institutes, European e-mobility associations (such as Avere).

Projects that inspired this analysis:

- *As part of the INCIT-EV project, together with 32 partners across Europe, Renault will launch an initiative: dynamic induction-charging system (wireless chargers) integrated into road networks will be installed in Paris to allow EVs to charge while on the move, giving vehicles freedom and a greater range.*
- *Pilot project of new EV taxis wireless charging in Nottingham in 2020, financed by the UK transport department with a €4 million investment.*

Project type 2: Research and Development in the area of electrified roads technology

The goal of the project is to accelerate R&D activities on electrified technologies and identify the best business model to deploy and scale-up this technology.

- Identify stakeholders (see 'Main stakeholders' below) currently working on electrified road technology.
- Accelerate R&D investments via public-private funding partnerships and find the adequate business model for deployment (i.e. financing model).
- Identify one to two target countries and roll out further pilot projects like the Swedish '2 km pilot road' started in 2018: 50 km of electrified roads in Europe by 2025, scaled up to 100 lines of 20 km each by 2030.
- Main stakeholders: transport research labs, private companies (such as Europe-based OEMs, construction companies), energy companies and grid operators (DSOs, TSOs).

Projects that inspired this analysis: First European project launched in Sweden in 2018 with a cost of €1.1 million per km of electrified roads. Sweden aims to electrify 20,000 km out of its 500,000 km of roads.

Why this technology and project are needed to reach net-zero

Limited coverage of charging infrastructure and long charging times are the main barriers to EV adoption. The charging experience is another key issue as the lack of standardization, unclear pricing schemes and insufficient interoperability between charger providers further complicate customer journeys[44]. Further differences exist as chargers can be equipped with different sockets, which complicates charging and constrains automakers to equip their EVs with several types of plugs.

Wireless EV charging via magnetic resonance technology enables charging without connection[45]. This type of charging delivers the same power, efficiency level and charge speed as conventional plug-in charging methods[46]. Wireless EV charging technologies can operate with similar efficiency range – at 90% to 93% efficiency, with Plug-in EV Chargers, 88% to 95% efficiency range end-to-end, from grid to battery[47].

Rolling out electrified roads can be the fastest way towards full EV adoption: the batteries of electric cars and trucks are recharged by two tracks of rail in the road, transferring energy, recharging the batteries of electric cars and trucks[48]. EVs profiting from this technology, referred to as 'dynamic charging', will have relatively smaller chargers, eventually decreasing total cost of ownership[49].

Furthermore, dynamic charging will improve the flexibility of EVs especially over long distances, facilitating and encouraging long-haul vehicles such as heavy-duty trucks or regional buses to switch to electric batteries[50]. As heavy-duty vehicles, which are large motorway users, represent 6% of all EU CO_2 emissions each year[51], implementing electrified roads will thus contribute to reduce overall carbon emissions.

Charger deployment is locally labor-intensive, ready to be rolled out at short notice, so the benefits can be reaped when they are most needed. The Trans-European Transport Network regulation - in particular, the innovation and new technologies section - facilitates the deployment of low-carbon transport infrastructure, while the Connecting Europe Facility provides funding. As an example of an EU funding program, the Green Vehicles program has a total budget of €56 million and supports road transport innovation including research on interfaces between the vehicle and the charging infrastructure.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**Project type 1 (wireless): €16 billion cumulated investment** €1.6 billion yearly average (2020-2030) **Project type 2 (roads): €2.2 billion cumulated investment** €0.2 billion yearly average (2020-2030)	**Project type 1 (wireless): €131.4 billion cumulated investment** €6.6 billion yearly average (2030-2050) **Project type 2 (roads): €6.7 billion cumulated investment** €0.3 billion yearly average (2020-2050)
JOBS	**Project type 1 (wireless): 24,000 total jobs** **Project type 2 (roads): 3,000 total jobs**	**Project type 1 (wireless): 99,000 total jobs** **Project type 2 (roads): 5,000 total jobs**

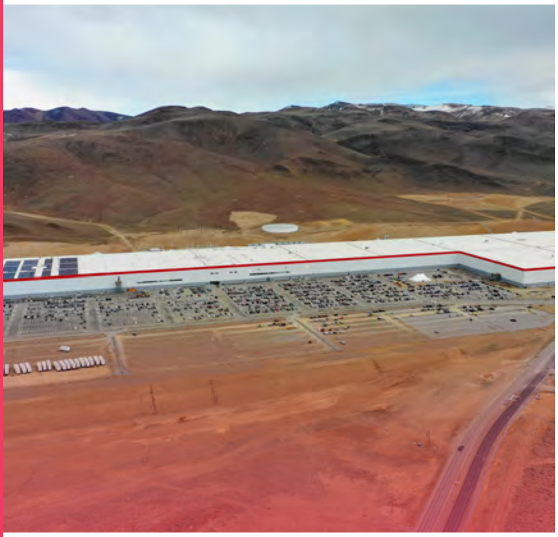
#44 [44]Key Factors Defining the E-mobility of Tomorrow, Capgemini Invent, 2018
[45]Could Wireless charging play a role advancing EV adoption? https://electricautonomy.ca/2020/02/26/wireless-ev-charging-advancing-ev-adoption/
[46]Ibid.
[47]Ibid.
[48]World's first electrified road for charging vehicles opens in Sweden https://www.theguardian.com/environment/2018/apr/12/worlds-first-electrified-road-for-charging-vehicles-opens-in-sweden
[49]Ibid.
[50]https://www.iea.org/reports/global-ev-outlook-2020
[51]https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en

SUPPLY THE EUROPEAN AUTOMOTIVE INDUSTRY WITH 'MADE IN EUROPE' LI-ION BATTERIES

Li-ion battery gigafactories to serve the increasing e-mobility market and develop jobs and know-how in Europe

TRANSPORT

Cheaper, cleaner and more efficient batteries made in Europe



IN A NUTSHELL...

- **Issue:** Scaling EVs requires massive quantities of lithium-ion batteries, currently mostly manufactured in Asia
- **Solution:** Multiple li-ion battery production gigafactories in locations where batteries can be most sustainably produced
- **Key impacts:** €33.2 billion total market, 223,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

New Li-ion battery gigafactories of 30 GWh capacity each in Europe by 2030

- in line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in passenger car fleet in 2050), the project aims to cover two-thirds of EU's EV market demand through European supply by 2030 (including production capacities already planned on the EU territory by Asian players such as SK Innovation, CATL, …) with the lowest environmental impact possible. The remaining one-third of the EV fleet will be powered with next-generation battery tech (see Project #47).
- 305 GWh additional li-ion battery production capacity will be needed by 2030 (to which must be added the demand for the stationary market, not considered in this analysis), i.e. 10 additional gigafactories of 30 GWh capacity each.
- To ensure low CO_2 impact of production, the four gigafactories must be set up in countries with the lowest power sector carbon intensity (max ~200 gCO_2eq/kWh[52]) and close to passenger car assembly lines[53]: This includes Northern France, Eastern Austria, Northern Slovakia, Northern Spain.
- *Projects that inspired this analysis: Northvolt's Gigafactory in Sweden is an excellent example of what the EU battery value chain ambition will look like:*

◊ *Large scale production plant (32 GWh) with auxiliary firms and JV in several countries.*

◊ *100% supplied by renewable power which is relevant considering amounts of energy needed.*

◊ *Fully automatized.*

◊ *Integrated with a recycling facility to support a circular approach.*

◊ *Located near centers of raw material supplies.*

◊ *Able to manufacture not only cells but the whole integrated system including the BMS, to target various markets, including the stationary one.*

Why this technology and project are needed to reach net-zero

Transport is responsible for nearly 30% of Europe's carbon emissions, or about 1.1 $GtCO_2e$ in 2018. Individual road transportation accounts for half of this. Meanwhile, the EU's emissions target for 2030 is about 100 $MtCO_2e$ below that, and emissions from this sector must drop to 340 $MtCO_2e$/year by 2050[54].

The stakes for developing technologies able to massively cut emissions from this sector are high. Among the range of technical possibilities, Li-ion batteries are gradually taking the lion's share of the new "clean" vehicles market, and demand is expected to soar.

In the EU Commission's scenarios to net-zero by 2050, about 80% of the passenger car fleet is electric. Batteries will thus be a key enabler for clean mobility and an important tool to increase renewable energy integration. While the battery accounts for 40% of the cost of an EV, only 3% of manufacturing capacity is currently based in Europe[55], while more than 75% of it is located in Asia.

The challenge is both environmental and industrial: Not only do batteries produced in Asia have a significant CO_2 footprint due to the high carbon content of the power sector, but if Europe fails in riding this new wave of industrialization, its automotive sector will strongly suffer from the shift to electric mobility.

The urgency is to create a competitive manufacturing value chain in Europe, centered around sustainable battery cells production. About 12 Li-ion battery gigafactories have been announced for construction in Europe by 2030, among which half are planned by foreign players, for a total production capacity of ~283 GWh.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**€33.2 billion total market** €26.8 billion cumulated investment by 2030, €2.7 billion yearly average (2020-2030) €30.5 billion turnover in 2030	**€106.6 billion total market** €114.2 billion cumulated investment by 2050, €5.7 billion yearly average (2030-2050) €106.6 billion turnover in 2050
JOBS	**223,000 total jobs** 40,000 construction jobs for investment 183,000 production jobs for turnover	**691,000 total jobs** 86,000 construction jobs for investment 605,000 production jobs for turnover

#45 [52]https://www.eea.europa.eu/data-and-maps/daviz/CO2-emission-intensity-5#tab-googlechartid_chart_11 and https://www.electricitymap.org/map
[53]https://www.acea.be/statistics/tag/category/european-production-plants-map
[54]https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12
[55]https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0176&from=EN#footnote8

CREATE A 100% CIRCULAR BATTERY ECONOMY IN EUROPE

Establish an extensive network of battery collection and recycling facilities to lower the GHG footprint of batteries and re-use precious resources

TRANSPORT

Cheaper, cleaner and more efficient batteries made in Europe

IN A NUTSHELL...

- **Issue:** Recycling EV batteries will reduce the environmental impact of the production of new batteries
- **Solution:** Create large scale battery recycling facilities across Europe to ensure reuse of these components and limit environmental impacts
- **Key impacts:** 11.3 $MtCO_2e$, €13.9 billion total market, 87,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

In line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in the EU passenger car fleet in 2050), the project aims to create an additional annual recycling capacity of 3.6 million tons of car batteries in major European regions by 2030 (compared to a current capacity of ~46,000 tons[56]). The project aims to do so by building 360 recycling factories with a 10,000-ton capacity each. The topic can later be extended towards a 2050 horizon, with the aim of 18.5 million tons of EV batteries recycling capability.

- Identify strategic locations across Europe, in countries with the lowest power sector carbon intensity and close to passenger car assembly lines (Northern France, Eastern Austria, Northern Slovakia, Northern Spain, Northern Europe).
- Deploy EV battery recycling factories per location of 10,000 tons annual recycling capacity.
- Key stakeholders include battery collection and recycling specialists such as G&P Batteries, battery manufacturers (such as Northvolt or Wamtechnik), aluminum companies (such as Norsk Hydro) and international organizations promoting battery recycling (such as ICM AG).

Projects that inspired this analysis: Frederikstad recycling factory project in Norway by Northvolt and Norsk Hydro and SungEel MCC Americas battery recycling facility project in New York.

Why this technology and project are needed to reach net-zero

Lacking large supplies of rare-earth metals and lithium supply sourcing, and having limited local production of batteries, Europe can mitigate these strategic weaknesses by becoming a leader in recycling and repurposing technology. Recycling EV batteries decreases the need for extraction of valuable raw materials (lithium, cobalt, manganese, nickel), reducing the cost and the environmental impact of their extraction for the manufacturing of future batteries and avoiding the pollution of landfill.

Currently, Europe only has a 46,000 tons EV battery recycling capacity. This is distributed between France with (21,000 tons), Finland, Norway, Denmark, and Belgium with a cumulated capacity of 25,000 tons.

Existing projects help drive the commercial supply: for instance, battery maker Northvolt, and Norwegian aluminum and renewable energy company Norsk Hydro, are planning to create a new recycling facility in Norway by 2021, to process and recycle 8,000 tons of batteries yearly.

Nevertheless, additional demand-side policies and technology measures are also required to sustain the market development. These can include requirements or additional taxes levied on high carbon emitting vehicles. Furthermore, imposing standardized battery design to enable simpler and/or automated disassembly can improve the cost competitiveness of batteries.

Impacts

	2030	2050
CLIMATE IMPACT	**11.3 $MtCO_2e$ avoided**	**57.7 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€13.9 billion total market** €4.2 billion cumulated investment by 2030, €0.4 billion yearly average (2020-2030) €13.5 billion turnover in 2030	**€49.2 billion total market** €17.9 billion cumulated investment by 2050, €0.6 billion yearly average (2020-2050) €48.6 billion turnover in 2050
JOBS	**87,000 total jobs** 6,000 construction jobs for investment 81,000 production jobs for turnover	**300,000 total jobs** 9,000 construction jobs for investment 291,000 production jobs for turnover

#46 [56]https://www.transportenvironment.org/sites/te/files/publications/2019_06_Element_Energy_Batteries_on_wheels_Public_report.pdf

STIMULATE THE DEVELOPMENT OF NEXT-GENERATION BATTERY TECHNOLOGY FOR MOBILITY USE

Lever European R&D to invent disruptive alternative battery technologies to Li-ion and invest in gigafactories to manufacture these new solutions

TRANSPORT

Cheaper, cleaner and more efficient batteries made in Europe

IN A NUTSHELL...

- **Issue:** Battery research is fragmented. As many different potential technologies are studied simultaneously, there is no clear commercially viable alternative to Li-ion
- **Solution:** Establish a cross-EU research and implementation initiative, incentivizing both breakthrough battery research and manufacturing at scale
- **Key impacts:** €16.4 billion total market, 110,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

Project type 1: Research and development on next generation battery technology

The project's goal is to create three centers to stimulate R&D activities on next-generation EV batteries across the EU by 2025, while at the same time building the standards, regulations, and commercial instruments to accelerate the deployment of successful technologies with a clear path to commercial viability.

The project takes inspiration from the EU-wide research and innovation project in all segments of the battery value chain (including the development of environmentally sustainable alternative technologies), backed by a €3.2 million public investment approved in December 2019 by the European Commission[57].

- Accelerate R&D on next-generation battery technologies and find the most adequate business model for large-scale deployment, by creating research centers in three European countries.
- Each center can be dedicated to a different battery technology. Technologies that enable upstream value chains entirely within the EU (e.g. reducing Cobalt/Lithium consumption), as well as technologies with specific advantages for non-automotive use cases (such as large-scale low-cost seasonal electricity storage) must be prioritized.
- Main stakeholders include public authorities, battery research laboratories, institutes of technology, electric vehicle companies, Europe-based OEMs.

Projects that inspired this analysis: IPCEI on batteries in Europe, ARPA-E's projects on battery in the US.

Project type 2: Develop and scale next-generation battery production

Once the research centers created under Project type 1 have demonstrated the feasibility of next-gen battery technologies and have identified a clear path towards large-scale implementation, project type 2 will aim at accelerating the development of production facilities.

In line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in passenger car fleet in 2050), the project aims to cover one-third of EU's EV battery demand through European supply by 2030 (including production capacities already planned on the EU territory by Asian players such as SK Innovation, CATL, and others) with the lowest environmental impact possible. The remaining two-thirds of the EV fleet will be powered with lithium-ion batteries (see Project #45).

About 150 GWh next-generation battery production capacity will be needed by 2030, i.e. 38 gigafactories of 4 GWh capacity each.

- Identify strategic locations in Europe (ideally the locations of the Project type 1) and build a total of 38 4-GWh production capacity factories.
- To ensure low CO_2 impact from production, the three factories will be set up in countries with the lowest power sector carbon intensity (max ~200gCO_2eq/kWh[58]) and close to passenger car assembly lines[59]: this includes Northern France, Eastern Austria, Northern Slovakia, Northern Spain.
- Main stakeholders include public authorities, battery research laboratories, institutes of technology, electric vehicle companies, Europe-based OEMs.

Projects that inspired this analysis: Northvolt's gigafactory in Sweden.

Why this technology and project are needed to reach net-zero

Lithium-ion, the only commercially viable EV battery solution today, is not without drawbacks. Lithium resources are unevenly distributed across the world and extracted through a polluting process. The technology also requires cobalt, which again is a precious resource, mainly mined from the Democratic Republic of Congo, creating significant CO_2 emissions. Additionally, lithium is limited in terms of performance, as some applications (other than for EV batteries) are too expensive. For large-scale, long-term energy storage, such as seasonal grid storage, alternative solutions are needed.

Numerous next-generation technologies are studied simultaneously across the world to develop alternatives to lithium-ion batteries. Some technologies aim primarily at outperforming Li-ion tech (longer life cycles, higher energy density, etc.): solid state batteries for instance introduce a solid compound instead of a liquid electrolyte to improve safety. Other technologies aim at reducing the environmental impact of battery production. Lithium-sulfur batteries (Li-S) rely on sulfur, a much more accessible resource with smaller environmental impact than lithium; however the cycle life of this battery remains inferior to li-ion as of now. Likewise, sodium batteries (Na-ion) would use sodium (an extremely abundant material, extractable from seawater) instead of lithium, while also withstanding more charge cycles than Li-ion batteries.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**€16.4 billion total market** €13.2 billion cumulated investment by 2030, €1.3 billion yearly average (2020-2030) €15 billion turnover in 2030	**€53.4 billion total market** €63.2 billion cumulated investment by 2050, €3.2 billion yearly average (2030-2050) €50.2 billion turnover in 2050
JOBS	**110,000 total jobs** 20,000 construction jobs for investment 90,000 production jobs for turnover	**349,000 total jobs** 47,000 construction jobs for investment 301,000 production jobs for turnover

#47 [57]https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705
[58]https://www.eea.europa.eu/data-and-maps/daviz/CO2-emission-intensity-5#tab-googlechartid_chart_11 and https://www.electricitymap.org/map
[59]https://www.acea.be/statistics/tag/category/european-production-plants-map

BUILD NEW URBAN MULTIMODAL TRANSPORT SYSTEMS FOR EASY DOOR-TO-DOOR JOURNEY PLANNING, EXPERIENCE AND PAYMENT

Public-private platforms leveraging AI, data and end-to-end payment business models, and reinforcement of physical mobility equipment and infrastructure

TRANSPORT

New forms of urban mobility

IN A NUTSHELL...

- **Issue:** Cars in urban areas represent 40% of road transport CO_2 emissions, and contribute to air and noise pollution. Public, shared and free-floating transport needs to be competitive against private car ownership in terms of door-to-door flexibility, reliability and convenience
- **Solution:** Establish streamlined mobility platforms offering multiple modes of shared transportation in European groups of cities
- **Key impacts:** 9.7 $MtCO_2e$, €12.4 billion total market, 187,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Contribute to define and illustrate the model of a city where all inhabitants can travel easily, efficiently, and conveniently from door to door, whether they live downtown or in the suburbs.

Public authorities and private operators must build the business model for open data (required data, who pays and how, and the payment flows). Payments need to be a part of the scope. To give up car usage, trips with any conventional and new free-floating decarbonized vehicles must be easy to use, plan and pay.

The project takes the form of a publicly-led public-private partnership. The urban areas covered by the project will share experiences to learn at each stage of their roll-out.

- Select groups of one-million-inhabitant urban areas (city including surrounding urban periphery) in Western, Eastern, and Southern Europe and Nordic countries.
- Gather public and private players specialized in shared transportation, AI, navigation and public transportation.
- Achieve a 50% reduction in use of individual cars, with special attention to peri-urban areas.
- Scale up green shared vehicles (electric cars, electric mopeds, electric kick-scooters, electric bicycles, other shared mobility), including peri-urban, to facilitate public transport access.
- Scale up the existing public transport networks to accommodate an increased number of users, following the 50% shift from private vehicles.
- Build the data, economic and payment frame enabling an inter-related ecosystem of public and private mobility services platforms: smoothen the flow of data and payments, establish clear data business model for operators and citizens.
- Regulatory sandbox: free innovation during the pilot phase in selected cities. In 2025, based on learnings, adapt European and national laws to enable seamless door-to-door mobility.
- Key stakeholders include public authorities (adapting the regulations to accommodate multimodal mobility platforms), urban mobility authorities, public transport operators (metro, buses, tramway, train), digital platform operators, navigation service providers (such as Vulog, Moovel, Google Maps or Free2Move), new mobility services (such as new European operators, Uber, Lyft, Google, Lime, Bird, etc.), future operators of autonomous vehicles and operators of charging infrastructures.

Projects that inspired this analysis: Vulog-powered multiple-city and multimodal shared mobility platforms Aimo in Stockholm and Poppy in Brussels and Antwerp.

Why this technology and project are needed to reach net-zero

Cities account for over 70% of CO_2 emissions in the world[60] and urban traffic contributes to 40% of all CO_2 emissions linked to road transportation in Europe[61]. Implementing more sustainable and fluent mobility solutions in European urban areas is crucial to reach a net-zero economy.

To reduce CO_2 emissions of passenger cars used for multi-city travel, public transportation needs to offer price competitiveness, flexibility and reliability, not only in densely populated cities but also in the nearby urban periphery. Aggregating on-demand and green mobility services on a single, streamlined application is one solution to reduce the dependence on passenger cars.

This end-to-end solution can guide users across the different urban transport options, identifying in real-time most optimal modes by comparing prices and timeframes. The project requires coordination of public and private operators to manage customer data collection and analysis. The application must be a one-stop payment platform, receiving and managing payments for all types of daily transportation.

In addition to public transport (including metro, buses, tramway, and trains), introducing on-demand light green vehicles, such as electric mopeds or kick-scooters, can also improve flexibility of shared transportation. Users would be able to use several transport options, each adapted to different lengths of journey (from a last-mile ride to a daily commute) over a single day.

Such multiple-city, multimodal and zero-emission mobility platforms have been successfully deployed in Northern Europe over the past years, through projects such as Whim (offering public transport as well as bikes, cars or e-scooters) and Aimo in Stockholm, or Poppy in Antwerp and Brussels.

Impacts

	2030	2050
CLIMATE IMPACT	**9.7 $MtCO_2e$ avoided**	**19.5 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€124.3 billion cumulated investment by 2030** €12.4 billion yearly average (2020-2030)	**€336.4 billion cumulated investment by 2050** €16.8 billion yearly average (2030-2050)
JOBS	**187,000 total jobs**	**252,000 total jobs**

[60]https://www.c40.org/why_cities#:~:text=Cities%20consume%20over%20two%2Dthirds,levels%20and%20powerful%20coastal%20 storms.
[61]https://ec.europa.eu/transport/themes/urban/urban_mobility_en

LEVER SHARED AUTONOMOUS VEHICLES TO REDUCE THE NUMBER OF CARS IN AN INCREASING NUMBER OF EUROPEAN CITIES BY 30%

Large scale deployment of automated vehicles in shared fleets and public transport

TRANSPORT | New forms of urban mobility

IN A NUTSHELL...

- **Issue:** Promote the use of shared autonomous mobility in medium and large cities
- **Solution:** Launch pilot projects of shared autonomous vehicles (taxis or minibuses) across ten one-million-inhabitant European cities
- **Key impacts:** 0.6 $MtCO_2e$, €18.7 billion cumulated investment, 28,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

The goal of the project is to launch several fleets of shared autonomous vehicles (either taxis or minibuses) in 10 large-size European cities by 2030. In addition to enriching the existing public transport systems and optimizing traffic, these fleets will contribute to a reduction of individual car use in urban environments, limiting CO_2 emissions.

- Select ten voluntary European cities with one million inhabitants, total ~10 million inhabitants.
- Deploy pilot projects of shared autonomous vehicles in real-life traffic conditions, aiming at a reduction of individual car use by 30% in 2030 (fleets of 18,900 vehicles, either taxi-sized or minibuses).
- Ensure the redesign of the urban scene necessary to reach the adequate safety standards for autonomous vehicles (local regulation, high-fidelity 3D mapping, optimized infrastructures and traffic rules).
- Key stakeholders include public transportation authorities, national ministries of transport, original equipment manufacturers (such as MAN, Daimler, Volvo).

Projects that inspired this analysis: FABULOS (Future Automated Bus Urban Level Operation Systems) conducting pilot projects in five European cities, Ruter AS project in Oslo, AVENUE autonomous bus testing in four European cities.

Why this technology and project are needed to reach net-zero

Cities are responsible for over 70% of CO_2 emissions in the world[62] and urban traffic stands for 40% of all CO_2 emissions linked to road transportation in Europe[63]. Implementing more sustainable and fluent mobility solutions in European urban areas is therefore crucial to reaching a net-zero emissions economy.

Shifting urban mobility towards public transport and decarbonizing available public transport are key levers to reduce urban emissions. Accelerating the adoption of zero-emission autonomously driving public vehicles is one such solution: they can replace CO_2 emitting passenger cars and increase the attractiveness of an enriched public transport system. This can decrease urban passenger car ownership, thus improving air quality.

The European Union has already communicated its interest in zero-emissions shared autonomous vehicles. In 2019, then EU Commissioner for Transport Violeta Bulc announced expectations of fully autonomous vehicle capability (level 5) by 2030. Additionally, three international consortia were selected by the EU funded project FABULOS in February 2020, to manage the implementation of autonomous buses in five European cities (Gjesdal, Helmond, Helsinki, Lamia and Tallinn)[64]. These pilot projects, already in place in Helsinki, will demonstrate the feasibility (ability to be monitored from a control center, adaptability to difficult terrain and obstacles) and the value of this technology.

Impacts

	2030	2050
CLIMATE IMPACT	**0.6 $MtCO_2e$ avoided**	**4.0 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€18.7 billion cumulated investment by 2030** €1.9 billion yearly average (2020-2030)	**€217.3 billion cumulated investment by 2050** €10.9 billion yearly average (2030-2050)
JOBS	**28,000 total jobs**	**163,000 total jobs**

#49 [62]https://www.c40.org/why_cities#:~:text=Cities%20consume%20over%20two%2Dthirds,levels%20and%20powerful%20coastal%20 storms.
[63]https://ec.europa.eu/transport/themes/urban/urban_mobility_en
[64]https://fabulos.eu/three-consortia-will-pilot-self-driving-shuttles-as-part-of-regular-traffic-in-five-european-cities/

FOOD AND LAND USE

BOOST SYSTEMIC CHANGE TO REACH NET-ZERO EMISSIONS FROM FARM TO FORK

Current situation and challenges

- European agro-sector from farm to fork generates 430.5 $MtCO_2e$:
  - 395 $MtCO_2e$ from agriculture (10% of the total European CO_2 emissions), mainly from three sources: soils nitrification and denitrification, enteric fermentation by ruminant animals and manure management.
  - 35.5 $MtCO_2$ from food and beverage industry.
- Agriculture, food and beverage dominate today's bioeconomy workforce, representing 13.7 million jobs.
- Major turnover is generated by the food and beverage industries, with €236 billion (20% of total turnover) generated by the meat sector.

> ***"We should take a holistic approach to deliver biodiversity and productivity through a series of pathways. Technology solutions must be incentivized for us to deliver the Farm to Fork vision."***
>
> **Alexandra Brand,** Chief Sustainability Officer, Syngenta

The main challenges are:

- Reducing the environmental impact of the whole agricultural value chain from farm to fork to cut down emissions by -20% in 2030 and -50% in 2050[1].
- Creating alternative sources of proteins to reduce our dependency on livestock production.
- Maintaining agricultural jobs thanks to changes in agricultural practices (for example conservation agriculture) and creating new ones to replace the losses triggered by technological development (for example synthetic meat, Agriculture 4.0)

> ***"We need to accelerate the whole agri-food bioeconomy, moving away from prototypes and front-runners, to a broad adoption of Agriculture 4.0 by 12 million farmers in Europe."***
>
> **Dr. George Beers,** Project Manager at Wageningen University

Solutions, projects and scale-up

Proposed projects will initiate sustainable changes to scale up in each part of the value chain to ensure the reach of overall net-zero objectives:

- Support the development of a sustainable agriculture:
  - Contribute to CO_2 reduction targets with actions both on soil fertilization to reduce the need for inputs such as nitrogenous ones (i.e., microbial fertilizer and bio-stimulants) and on global agricultural practices (i.e., conservation agriculture and Agriculture 4.0).
  - Scale up insect production to provide an alternative of fast-grow feedstock proteins while creating a new promising agricultural sector generating jobs, revenues and CO_2 savings.
  - Innovate to capture diffuse methane from cattle on-site as it is being done for CO_2 capture in industry.
- Change the dietary habits of Europeans by reaching respectively 20% and 10% market share for plant-based and cell-based meat products in 2030 while investing in synthetic milk technology development. Achieving this target will save up to 51 $MtCO_2$, while generating €40 billion turnover and supporting 596,000 jobs.

The first phase from 2021 to 2025 will be dedicated to innovation, launching of pilots and scale-up preparation:

- Carry out feasibility studies for breakthrough technologies and launch R&D projects and pilots for bio-stimulant and fertilizers, conservation agriculture and Agriculture 4.0.
- Scale up conservation agriculture and innovative livestock farming to 10,000 pilot sites for each technique.
- Launch regulatory discussions about an EU carbon credit program.

The second phase will prioritize new technologies from phase 1 and scale up to reach a 25% reduction of the emissions of the sector in 2030 compared to today's level.

- Multiply scope and scale and create bridgeheads in all European regions for new technologies.
- Scale up the pilots from 2021 to 2025 which have demonstrated the best technological and economic potential.
- Finalize the regulatory scheme for an EU carbon credit program.

Impacts

- **€66 billion total market (turnover + investments) per year in 2030.**
- **1.0 million permanent jobs in 2030.**
- **119 $MtCO_2$ avoided per year in 2030.**

Regional approach

Europe can lever:

- A strong agricultural R&D in Western Europe.
- A large variety of land across Europe, giving the opportunity to test innovations and regional specificities at European level.
- The Common Agricultural Policy frameworks and discussion groups must be involved to ensure consistency with current regulatory schemes.

List of projects – FOOD & LAND USE

Transversal

#50 - TRANSFORM EUROPEAN AGRICULTURE WITH SUSTAINABLE FARMING TECHNIQUES
Experiment and develop science-based conservation agriculture and sustainable farming systems to cut farming costs and emissions

#51 - HARNESS THE POWER OF AGRICULTURE 4.0
Boost the use of digital solutions to increase productivity while lowering GHG emissions, moving from 5% front-runner farmers to a broad application

Crop

#52 - REINFORCE PLANTS AND BOOST CROP RESILIENCE TO USE LESS EMISSIONS-INTENSIVE FERTILIZERS AND INPUTS
Customized microbial fertilizers production on-site and biostimulants to foster plant growth and carbon capture under abiotic stress

Livestock

#53 - TAP INTO THE POTENTIAL OF INSECTS FOR FAST-GROW FEEDSTOCK PROTEINS
Bring to commercial scale insect-protein production facilities and build routes to market

#54 - CAPTURE METHANE AND NON-CO_2 GHG EMISSIONS FROM CATTLE
Develop and test prototypes to capture methane and other gases emitted by cattle

#55 - PROMOTE TASTY, AFFORDABLE AND LOW-EMISSION ALTERNATIVES TO MEAT AND DAIRY PRODUCTS
Large scale production and receptive markets can massively cut greenhouse gas emissions associated with conventional animal products

[1]*Net-zero agriculture in 2050: how to get there: https://europeanclimate.org/content/uploads/2019/11/02-19-net-zero-agriculture-in-2050-how-to-get-there.pdf*

TRANSFORM EUROPEAN AGRICULTURE WITH SUSTAINABLE FARMING TECHNIQUES

Experiment and develop science-based conservation agriculture and sustainable farming systems to cut farming costs and emissions

FOOD & LAND USE

Transversal

IN A NUTSHELL...

- **Issue:** Systemic approaches to lower GHG emissions from farms have proven efficient but are still not widespread across European farms
- **Solution :** Massively extend these practices while supporting continuous research will enable to reach 20% emissions abatement with no new inventions required
- **Key impacts :** 25.9 $MtCO_2e$ avoided, €9.4 billion turnover, 140,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Obtain quantified evidence on the economic and environmental benefits of Conservation Agriculture using 10,000 pilot projects across the EU

- Involve crop input manufacturers, researchers and local farmers in a five-year initiative.
- Evaluate solutions aiming to reduce soil disturbance, maintain vegetative cover on soils, increase pollinating species population, utilize appropriate rotations of diversified crops.
- Develop suitable measurement technologies for soil, crops, flora and wildlife indicators to justify and scale studied solutions supported by reliable data.
- Projects that inspired this analysis: Cross-country initiatives between Syngenta, farmers and researchers.

Project type 2: Test and extend innovative livestock farming systems in 10,000 farms to reduce emissions from meat and dairy industries

- Involve researchers, farmers and meat and dairy associations to assess the impact of several livestock farming techniques to reduce GHG emissions in 10,000 beef farms over a four-year period.
- Areas to test include cattle management, feed management, manure and land use, techniques to reduce fuel oil, electricity and water consumption.
- The goal is to sustainably transform livestock management in these farms, especially in countries where such practices are less widespread, e.g. Central and Eastern Europe.
- Projects that inspired this analysis: Life Beef Carbon, Life Greensheep.

Project type 3: Create an EU carbon credit program and other incentives to scale up sustainable crop and livestock farming systems

- Develop a common EU methodology to give certified carbon credits to farmers that reduce GHG emissions using sustainable farming techniques, thus enabling them to fund deep reductions below baseline.
- Encourage local farmers to adopt sustainable farming models by contributing to their initial investments (e.g. through loans or tax credit) or public finance.
- Test a set of incentives allowing farmers to adopt low-emission techniques while ensuring their financial security and business resilience.
- Projects that inspired this analysis: French CarbonAGRI methodology, certified under the Label "Bas Carbone" from the government, to issue tradeable carbon credits to incentivize GHG emission reduction.

Why this technology and project are needed to reach net-zero

These projects are necessary to respond to the three key challenges to ensure a sustainable food future, identified by the WRI report on global food[1]: the food gap, the land gap and the GHG mitigation gap. Closing these gaps will be required to manage the increase of world population (from 7 billion in 2010 to 9.8 billion in 2050), of food demand (to rise by 50%) and of the animal-based food demand (to increase by 70%).

Traditional farming techniques are not always optimized with regards to their climate impacts. For instance, only recently has it been realized that tilling soil is an emissions-intensive activity, as it was previously considered beneficial for crops. Avoiding it can reduce farming emissions by 20%[2].

Advanced farming models based on comprehensive approaches can unlock substantial reductions of GHG emissions from agricultural activities. Both crops and livestock management need to be considered.

Conservation Agriculture

CA is one of the pillars of the 4 per 100 global initiative launched at COP21 in Paris (along with other techniques such as Agroforestry)[3]. It focuses on minimum soil disturbance for establishing crops, maintaining vegetative cover on soils and utilizing rotations of diversified crops.

In Europe, successful cross-country projects are showing their benefits, with up to 50% decrease in GHG emissions and costs along with increased fauna population like birds and worms.

Sustainable livestock management

The Life Beef Carbon EU project promotes livestock farming techniques in France, Spain, Italy and Ireland (countries accounting for over 30% cattle emissions in Europe) which can lead to -15% GHG emissions. In addition, Life Greensheep, which is a similar project, is about to be launched.

It is crucial to study, test and spread sustainable agriculture techniques across Europe based on strong collaboration between researchers, industrials, producers and farmers. Once validated, sustainable farming techniques can be implemented in all EU countries, with support from public institutions. EU regulation and aligning subsidies are also important catalysts to promote sustainable farming across Europe.

Some countries, such as those in Southern Europe, would particularly benefit. These countries have a major need for soil restoration solutions due to a rapidly changing climate and high soil erosion together with considerable livestock numbers. Eastern countries like Poland or Romania are also starting to take interest resulting from the positive deployment of these techniques in Western Europe. Consequently, this is a trend to accelerate and promote.

Impacts

	2030	2050
CLIMATE IMPACT	**25.9 MtCO_2e avoided**	**60.5 MtCO_2e avoided**
ECONOMIC IMPACT	**€9.4 billion turnover**	**€21.8 billion turnover**
JOBS	**140,000 total jobs**	**328,000 total jobs**

#50 [1]https://research.wri.org/sites/default/files/2019-07/creating-sustainable-food-future_2_5.pdf
[2]https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975454/
[3]https://www.4p1000.org/

HARNESS THE POWER OF AGRICULTURE 4.0

Boost the use of digital solutions to increase productivity while lowering GHG emissions, moving from 5% front-runner farmers to broad application

FOOD & LAND USE

Transversal

IN A NUTSHELL...

- **Issue:** Innovative instruments such as robotics, IOT, satellites, AI offer great, yet under-exploited potential in the agricultural sector
- **Solution:** The accelerated development and uptake of these tools will help deliver more environmentally friendly practices
- **Key impacts:** 18.4 $MtCO_2e$ avoided, €4.4 billion total market, 67,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Inspired by the "Smart Agri Hubs" and "IoF2020" initiatives, this project is designed to push collaboration between key players (see “Major stakeholders”) to bridge the gaps in digital innovation for the agri-food sector.

The project will:

- Identify the gaps between real needs on the ground, ongoing projects and existing tools in the field (in terms of geographies, technologies, methodologies, integration needs, interfaces with other sectors such as transport and logistics).
- Derive 100 concrete experimentations to bridge this gap, based on real use cases and considering all existing learning.
- Conduct these experiments over four years and assess and optimize the impact of all digital components relevant for the agri-food sector (see below the list of technology areas).
- Build a unified reference network, that gathers dispersed initiatives across Europe to apply through local hubs and multiply their benefits.

It will deliver a portfolio of 100 use cases with details on:

- Technology and innovations tested, experiment protocol, involved stakeholders and geographies covered
- Results of the experiment with analysis on how to increase economic viability and market share of the technologies.
- Potential for replication across Europe, including proposed levers to increase end-user and farm adoption.

The project will cover the following areas of developing Agri 4.0 technology:

- Satellite images and their exploitation.
- Robotics, IoT and sensors.
- AI and Blockchain.
- Digital platforms.
- Transversal enablers, such as integration (authentication, fireware, connection and others), 5G infrastructures, standardization requirements.

Main stakeholders: Farmers, digital-based agrotech startups and SMEs, IT companies, telecom operators, universities, EU professional associations; The project will cover: fruit, vegetables, arable crops, livestock (meat and dairy), aquaculture, forest and other land use, as well as interfaces with other sectors: health, mobility, logistics, and education.

Regional Clusters: aim for EU27 balance, however the 400 targeted regional clusters of smart Agri hubs will be taken as a reference, to not create unnecessary inefficiencies.

Why this technology and project are needed to reach net-zero

Agriculture 4.0, in comparison to Industry 4.0, stands for the integrated internal and external networking of farming operations, relying on digital information, electronic communication, automated data transmission, processing and analysis[4]. It encompasses precision farming, smart farming and digital farming. Typical applications involve robotics, sensors, IoT, satellites, data analytics and decision support, digital apps and platforms.

These tools enable substantial savings on inputs (water, fertilizers, pesticide and others)[5], reduction of farm-related CO_2 emissions, soil compaction, optimized yields and quality in agricultural production.

Yet, according to the European Agricultural Machinery Association (CEMA), "Uptake of these technologies is currently lagging behind the pace of digital technology uptake in other sectors, due to agricultural product margin constraints and associated investment capability"[6]. Therefore, Europe must accelerate the development and deployment of these technologies, in order to consolidate a leading position in the digital area, and at the same time contribute to the attractiveness of the sector for younger generations of farmers.

Key challenges include the integration of solutions, standardization skills and attractiveness of rural territories to make business cases work for telcos, reconciliation of projects and funding levels (EU, national, regional). The exploitation of European satellite data is also a key challenge, as Copernicus satellites provide free and open data, based on which non-European firms (e.g. Google) can also provide services, with higher development means and better marketing. The EU must therefore strongly support promotion and development of usages in this field, e.g. through the DIAS (Data and Information Access Services)[7]. Agriculture is one of the most promising fields of application of Copernicus data[8].

Impacts

	2030	2050
CLIMATE IMPACT	**18.4 $MtCO_2e$ avoided**	**18.4 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€4.4 billion total market** €8.1 billion investment by 2030, €813 million yearly average (2020-2030) €3.6 billion turnover in 2030	**€9.8 billion total market** €20.3 billion investment by 2050, €680 million yearly average (2020-2050) €9.1 billion turnover in 2050
JOBS	**67,000 total jobs**	**146,000 total jobs**

#51 [4]*https://www.cema-agri.org/images/publications/position-papers/CEMA_Digital_Farming_-_Agriculture_4.0__13_02_2017_0.pdf*
[5]*Example of PepsiCo: -26% water input in http://breakthrough.unglobalcompact.org/disruptive-technologies/digital-agriculture/; example of Greece: -19% consumption of water, fertilizers and pesticides, and +10% production through Earth Observation-based smart farming services: https://www.copernicus.eu/sites/default/files/PwC_Copernicus_Market_Report_2019.pdf*
[6]*https://www.cema-agri.org/images/publications/position-papers/2019_CEMA_Agritech_2030_web.pdf*
[7]*https://www.copernicus.eu/en/access-data/dias*
[8]*https://www.copernicus.eu/sites/default/files/PwC_Copernicus_Market_Report_2019.pdf*

REINFORCE PLANTS AND BOOST CROP RESILIENCE TO USE LESS EMISSIONS-INTENSIVE FERTILIZERS AND INPUTS

Customized microbial fertilizers production on-site and biostimulants to foster plant growth and carbon capture under abiotic stress

FOOD & LAND USE

Crop

IN A NUTSHELL...

- **Issue:** Ammonia-based fertilizers rely on an energy-intensive production and environmentally harmful operations, and reduce soil quality
- **Solution:** Microbial fertilizers, combined with a better use of mineral fertilizers, offer a desirable alternative that can be rapidly developed and deployed at farm scale. In addition, biostimulants strengthen plants and allow for lower use of fertilizers
- **Key impacts:** 6.6 $MtCO_2e$ avoided, €1.4 billion total market, 20,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Test and commercialize solutions for on-site production of microbial fertilizers on 50 farms.

- The main ambition is to validate the feasibility of producing on-site soil specific microbial fertilizers at large scale, in 50 pilot European farms, with a robust, convenient, easy-to-use process, and at a competitive price.
- Ensure testing on several types of farms in terms of size, soil and crop.
- Results should clearly show each technology's versatility to fully commercialize and become substitutes to traditional fertilizers from 2022.
- Build and lever partnerships with large European crop input manufacturers to provide testing facilities and distribution capabilities.

In parallel, accelerate R&D in the field of biostimulants and increase the market penetration of these products through farm-scale research initiatives working on:

- Experimenting with new types of biostimulants.
- Increasing the efficiency of existing types.
- Demonstrating and quantifying the effectiveness of several biostimulants in practice.

Main stakeholders: Agritech startups, academic researchers, competence centers (like German Center for biobased solutions - CBBS), consortia such as EBIC (European Biostimulants Industry Council), major fertilizer and biostimulants manufacturers, farmers.

Regional Clusters: DACH countries (Germany, Austria, Switzerland) gather a considerable cluster of crop input companies acting as catalysts for startup-based innovations in this field.

Projects that inspired this analysis: Slovak startup Nitroterra has developed a less energy-intensive production unit for farmers to generate their own tailored biofertilizers. The project recently obtained funding to start the testing phase with a corporate partner. In the field of biostimulants, EU-funded research projects have resulted in cutting-edge companies levering on corporate and academic collaboration (e.g. Fyteko, AlgaEnergy).

Why this technology and project are needed to reach net-zero

Fertilizers

Around 1% of global GHG emissions come from the energy-intensive production of ammonia for use in fertilizers. Moreover, N_2O from inorganic fertilizer applications and end-use accounts for 50 $MtCO_2e$ emissions alone.

Biofertilizers provide a net-zero emission alternative to both issues, as they consist of natural micro-organisms. However, they are neither technically mature nor economically competitive today. To this end, it is important to upscale research in this field (only 1% of the fertilizer industry's total revenues are spent in R&D) while looking for solutions to grow production of available biofertilizers.

On-site versatile production units are critical to address these challenges. They enable the production of different microbial fertilizers at the farm, depending on climate, soil condition and crop requirements, while no longer having to rely on major distribution networks for continuous supply.

Biostimulants

Climate change and human emissions have affected European agriculture. Highly volatile weather conditions and soil erosion have led to massive crop losses, especially in Southern regions[9].

Agricultural biostimulants have diverse formulations of compounds, substances and micro-organisms that are applied to plants or soils to improve crop vigor, yields, quality and tolerance to abiotic stresses. The product is applied as a seed treatment or foliar spray and is complementary to crop nutrition and protection. Typical biostimulants include marine macroalgae extracts (such as kelp), plant extracts (such as brassinosteroids), protein hydrolysates and amino acids, or humic and fulvic acids.

While some biostimulants products have been on the market for many years, the research-based biostimulants sector has emerged recently. According to the EBIC, the impacts reach +5 to +10% in yield and +5 to +25% in nutrient use efficiency, depending on the conditions and type of crop. Higher rates can be expected from the R&D projects.

EU regulation in the field of bioeconomy needs to ensure that there will not be any breaks in the sector's development.

Impacts

	2030	2050
CLIMATE IMPACT	**6.6 $MtCO_2e$ avoided**	**26.4 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€1.4 billion total market** €5.9 billion investment by 2030, €590 million yearly average (2020-2030) €770 million turnover in 2030	**€3.3 billion total market** €23.6 billion investment by 2050, €790 million yearly average (2020-2050) €2.5 billion turnover in 2050
JOBS	**20,000 total jobs**	**49,000 total jobs**

#52 [9]See European Environment Agency report No 4/2019 "Climate change adaptation in the agriculture sector in Europe" https://www.eea.europa.eu/publications/cc-adaptation-agriculture

TAP INTO THE POTENTIAL OF INSECTS FOR FAST-GROW FEEDSTOCK PROTEINS

Bring to commercial scale insect-protein production facilities and build routes to market

FOOD & LAND USE

Livestock

IN A NUTSHELL...

- **Issue:** Insect-based feeding potential remains untapped due to limited production
- **Solution:** Scale up production supporting new sites and R&D to reduce GHG emissions in the agri-food sector
- **Key impacts:** 12.5 $MtCO_2e$ avoided, €10.5 billion total market, 158,000 jobs in 2030

Innovation bet | **Acceleration and scale-up** | Drive to market scale

Project opportunity and ambition

Project type 1: Invest in R&D to scale up insect breeding processes to ramp up production efficiency

- The aim of this project is to tackle industrialization challenges to make insect-fed protein production a reality.
- Main issues to be solved are managing pathogens in large-scale breeding, increase insect feeding yield and use data analytics and automation to improve processes.

Project type 2: Build ten large-scale sites to increase insect-based feed production

- The production will target livestock and fish farming in Europe and will lever industrial symbiosis with food production facilities.
- The aim of the project is to build ten sites capable of producing at least 10,000 tons per year of insect protein feed using biowastes from nearby food production facilities as input for the insect breeding process, by 2025.
- Each of these facilities will individually avoid 25,000 tCO_2e per annum combining low-emission animal-feeding production with efficient biowaste utilization.
- Partner with major biowaste producers from the agri-food industry across Europe.

Main stakeholders: Insect-based feed companies (Protix, InnovaFeed, Ynsect and others), biowaste producers, livestock and fish farmers.

Regional Clusters: France and the Netherlands host some of the leading insect feed producers in the world.

Projects that inspired this analysis: Partnership between agri-food company Tereos and insect feed producer InnovaFeed in France. The latter has recently built its biggest production site (focusing on Hermetia Illucens insects for fish food production) combining their industrial processes by using agricultural byproducts as input for insect breeding. This company expects to further deploy similar plants by 2022.

Why this technology and project are needed to reach net-zero

Livestock consumes 20% of global proteins, in direct competition with humans. As a result, insect-based protein is a promising alternative for animal feed production since it has a high protein content, can be raised with almost no water, hundreds of times less land and with far fewer environmental impacts. Fish farming is the sector that benefits the most from this solution due to positive results shown by insect-fed fish on cost and quality. FAO data shows aquaculture supplies 50% of the fish destined for consumption and it is expected to reach over 60% by 2030. This sector can easily implement insect-based feeding to enable production to increase in the coming years.

Another key factor of this technology is its potential role in the circular economy. Insect-based feeding production uses biowaste as an input for the insect breeding process and produces other waste that can be used to generate biogas, also produced directly from biowaste. As such, there is an opportunity for regulation to create better market conditions by incentivizing the biogas industry to use waste that cannot be exploited by the insect farming industry while taking advantage of the outputs of insect-based feeding production processes.

Impacts

	2030	2050
CLIMATE IMPACT	**12.5 $MtCO_2e$ avoided**	**37.5 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€10.5 billion total market** €5.6 billion cumulated investment by 2030, €0.6 billion yearly average (2020-2030) €2.1 billion turnover in 2030	**€26.5 billion total market** €75 billion investment by 2050, €2.5 billion yearly average (2020-2050) €24 billion turnover in 2050
JOBS	**158,000 total jobs**	**398,000 total jobs**

#53

#54

CAPTURE METHANE AND NON-CO_2 GHG EMISSIONS FROM CATTLE

Develop and test prototypes to capture methane and other gases emitted by cattle

FOOD & LAND USE

Livestock

IN A NUTSHELL...

- **Issue:** Livestock produce significant amounts of methane as part of their digestive processes, which account for 40% of livestock emissions
- **Solution:** Capture CH4 and oxide to CO_2 using zeolites
- **Key impacts:** 3.7 $MtCO_2e$ avoided, €220 million total market, 3,400 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Launch five R&D projects to develop methane capture installations suited to livestock conditions:

- Test several materials and assess their efficiency and suitability to capture and transform CH_4 and N_2O. Nanoporous zeolites, as well as porous polymer networks (PPNs) are already identified and can transform CH_4 into CO_2 thanks to catalysts[11].They could also be used for nitrous oxide.
- Design installations (e.g. arrays) adapted to the spaces where livestock is the most concentrated, e.g. exhaust points of barns containing ruminant animals.
- Develop prototypes at industrial scale by 2023.
- Extend the research works to the economics of such installations, and derive recommendations in terms of carbon pricing, as well as business models.
- Propose a roadmap for the set-up of industrial production as well as deployment across Europe.

Main stakeholders: Public and private researchers, industrials and farmers to test solutions.

Regional clusters: Countries with high livestock density such as the Netherlands and Belgium can make the most out of methane capture technologies.

Projects that inspired this analysis:

- Stanford University research published in Nature.
- Similar technologies have been developed for CO_2 direct capture (e.g. Climeworks startup (CH) producing modular and scalable carbon capture units) allowing significant emission reductions at the source.

Why this technology and project are needed to reach net-zero

The agriculture sector constitutes more than 55% of non-CO_2emissions in the EU with 421.1 $MtCO_2e$/year in 2020[12]. In the 1.5TECH scenario, this total needs to go down to 276.9 $MtCO_2e$/year in 2050. These emissions come mainly from livestock, and especially ruminants, which release methane (CH_4) in the air as a result of their digestive process. Nitrous oxide (N_2O) is also released by the animal's manure. Both gases have a much higher global warming potential than CO_2: methane is 84 times more potent than CO_2 over the first 20 years and around 28 times more potent after a century. In the case of N_2O, it is 265 times more potent after a century[13].

Even after substantial efforts to reduce them, some methane emissions from meat production remain inevitable. Consequently, methane removal might counterbalance the most intractable emissions. The little research performed so far performed so far on this topic has focused not only on capturing methane but also on converting it into less harmful CO_2[14]. As methane is 200 times less concentrated in the air compared to CO_2, it is more difficult to capture. Therefore, catching it at some concentration points such as in barns where the ruminants are concentrated would enhance effectiveness.

Research is only at an early stage and shows promising results based on zeolites material. The process is said to be suitable to remove N_2O as well. Now, research needs to speed up in order to propose effective and scalable solutions which are economically viable before 2025.

The economic viability of such solutions will depend on the carbon price which will be set by European legislation.

Impacts

	2030	2050
CLIMATE IMPACT	**3.7 $MtCO_2e$ avoided**	**11.2 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€220 million total market** €370 million investment by 2030, €37 million yearly average (2020-2030) €190 million turnover in 2030	**€834 million total market** €1.6 billion investment by 2050, €50 million yearly average (2020-2050) €782 million turnover in 2050
JOBS	**3,400 total jobs**	**13,000 total jobs**

#54 [10]https://www.bloomberg.com/news/articles/2020-07-14/burger-king-s-climate-solution-is-a-limited-supply-whopper?cmpid=BBD071520_GREENDAILY&utm_medium=email&utm_source=newsletter&utm_term=200715&utm_campaign=greendaily
[11]https://www.nature.com/articles/s41893-019-0299-x
[12]Figure 12, https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[13]https://ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf
[14]https://www.technologyreview.com/2019/05/20/960/turning-one-greenhouse-gas-into-another-could-combat-climate-change/

PROMOTE TASTY, AFFORDABLE AND LOW-EMISSION ALTERNATIVES TO MEAT AND DAIRY PRODUCTS

Large scale production and receptive markets can massively cut greenhouse gas emissions associated with conventional animal products

FOOD & LAND USE | Livestock

IN A NUTSHELL...

- **Issue:** There are still only few alternative plant-based meat products and almost no cell-based alternatives. Market shares are low and, as well as dairy alternatives, they (until recently) have mostly failed to imitate original products
- **Solution:** R&D can break down the last barriers to go-to-market and cause the acceleration of alternative meat and synthetized milk products
- **Key impacts:** 51.5 $MtCO_2e$ avoided, €39.7 billion turnover, 596,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

Project type 1: Support mature plant-based products to achieve 20% market share by 2030

- Identify and invest in 100 promising startups that need resources to scale-up production and roll-out their plant-based products.
- Start-ups' agile nature allows them to rapidly commercialize newly-developed products.
- Alternative meat consumption will be encouraged in Europe by levering mature alternatives.
- Projects that inspired this analysis: Les Nouveaux Fermiers (FR), Vivera (NL) or Meatless (NL) have successfully started to commercialize plant-based products like steaks, sausages or nuggets.

Project type 2: Bring together industry stakeholders to launch production of low-cost cell-based meat before 2025

- Gather consortia involved in cell-based meat production across Europe (~5 pure players) to co-develop solutions.
- Identify synergies to promote research partnerships in order to boost progress and stabilize low-cost production processes.
- Make cultured meat prices competitive before 2025 and reach a market share of 10% on the meat market by 2030.
- Fund laboratories and startups to develop technologies and food producers to scale up promising solutions.
- Projects that inspired this analysis: Dutch startups Mosa Meat and Meatable have successfully developed cultured meat hamburgers.

Project type 3: Launch research to synthetize milk

- Validate the concept of casein imitation (protein found in natural milk) using a lab-grown plant-based substitute and precision fermentation techniques.
- Major Players: Besides startups, academic and private researchers for technology, food producers to scale-up production and policymakers to facilitate go-to-market and public acceptance.
- Regional clusters: The Netherlands has a startup cluster in the field of plant and cell-based meat. France and Spain are also making substantial progress in this area.
- Projects that inspired this analysis: Swedish start-up Noquo Foods has recently obtained funding to further research on a plant-based solution to produce casein. Ice cream startup Perfect day also works on this technology.

Why this technology and project are needed to reach net-zero

Livestock production produces 14.5% of all human-caused greenhouse gas emissions. Alternative sources of protein must be developed, especially replacing meat. Solutions like plant-based products or cultured meat can reach conversion rates of plant calories of 70-75%, compared to just 25% with conventional meat and will lead to significantly reduced deforestation.

Plant-based meat alternatives are already available but still need to ramp-up quality and production in Europe. These products are gradually increasing their market presence in some countries.

Cultured meat is the most innovative solution but has economic barriers to overcome before being competitive. Research can overcome the last barriers and develop European patented processes for affordable cell-based meat. Rapid progress in this field suggests that cell-based burgers will be sold for €10 in 2021.

Being able to synthesize milk in labs would enable creation of products with a similar taste as traditional milk. Solid proteins (casein and whey) account for 3.3% of the overall composition of milk and are the challenging ingredients to replicate. Synthesized milk could first be incorporated in products containing milk as an ingredient, such as desserts.

All these technologies will encounter issues with market acceptance to some degree. EU regulation and policymakers can play a critical role to help consumers get acquainted with ecological food alternatives.

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (plant-based): 22 $MtCO_2e$ avoided** **Project type 2 (cell-based): 11.3 $MtCO_2e$ avoided** **Project type 3 (dairy): 18.1 $MtCO_2e$ avoided**	**Project type 1 (plant-based): 44.1 $MtCO_2e$ avoided** **Project type 2 (cell-based): 22.6 $MtCO_2e$ avoided** **Project type 3 (dairy): 36.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**Project type 1 (plant-based): €19.5 billion turnover in 2030** **Project type 2 (cell-based): €9.8 billion turnover in 2030** **Project type 3 (dairy): €10.4 billion turnover in 2030**	**Project type 1 (plant-based): €39.1 billion turnover in 2050** **Project type 2 (cell-based): €19.5 billion turnover in 2030** **Project type 3 (dairy): €20.8 billion turnover in 2030**
JOBS	**Project type 1 (plant-based): 293,000 total jobs** **Project type 2 (cell-based): 146,000 total jobs** **Project type 3 (dairy): 156,000 total jobs**	**Project type 1 (plant-based): 586,000 jobs** **Project type 2 (cell-based): 293,000 total jobs** **Project type 3 (dairy): 312,000 total jobs**

#55 [15]Europe has three major actors in cell-based meat in Europe (Meatable, Mosameat, Cubiq Foods) against eight in the USA (https://www.gfi.org/non-cms-pages/splash-sites/soi-reports/files/SOI-Report-Cell-Based.pdf)
[16]ATKearney study: https://pdfs.semanticscholar.org/a9a1/016f0eb1074257f1418ab0d8f3078e6b76a3.pdf?_ga=2.224159707.1380060643.1594894475-1928829873.1594894475

7. APPENDIX

Methodology guiding the 55 Technology Quests and impact calculations

Each Technology Quest is presented in a double-page format with expected benefits described in terms of climate impact (CO_2 emissions savings), markets to be created (investment, turnover) and jobs.

Figure 16 - Structure of the Impact table of each Technology Quest

	2030	2050
CLIMATE IMPACT	tCO_2e saved per year	tCO_2e saved per year
ECONOMIC IMPACT	€billion Investment averaged per year[37] Turnover[38]	€billion Investment averaged per year Turnover
JOBS	#Jobs	#Jobs

An additional Excel spreadsheet contains the detailed calculations, sources and proxies laid out in a transparent way. The Quests propose investments at speeds which authors believe are both practical and commensurate with a net-zero emissions goal by 2050, readers are invited to make up their own minds on acceleration and targets proposed and use the spreadsheet to derive their own assessments as well.

General approach

Firstly, this report is bold by nature and the figures should be considered as "order of magnitude" correct, as opposed to precise. The general objective of the report is to underscore the role of technology innovation investments, and a supportive policy environment, in shortening the usual 25-year technology-to-scale maturity cycle to about 10 years, and to make significant progress and deliver impacts by 2030.

In terms of the double-pagers:

- 2030: The left column in the tables provides the direct benefits calculated and derived from the execution of each defined project in 2030 (example: launch 10 industrial pilots of a technology).
- 2050: The right column provides the benefits of driving that technology to "EU market scale" by 2050, imagining that the project can be replicated at the velocity which innovation will allow to deliver the timely emission reductions projected in the newly proposed climate and energy targets. Benefits cases are calculated using a bottom-up and top-down hybrid approach.

All presented figures come from recognized authors, or are based on specific experience from the consultants on projects, and have been challenged by experts using different sources. Figures are rounded in report writing to facilitate reading.

A large variety of trusted sources have been used. In many cases these have been referenced, and all of the references in the Excel spreadsheet have been cross checked. Sometimes to save space we may have omitted a source, the right assumption in case of doubt is that this is a Capgemini Invest estimate or is derived from the other sources. The bibliography of the Report is available in the "COM" worksheet of the Excel file. Our consultants have used their own judgement and expertise to make what we feel are appropriate estimates and appropriately ambitious suggestions in many cases, we do this at our own risk. Several transversal sources have been used to provide a baseline and set of consistent assumptions in emissions and costs and for the different technology deployments and applicability in energy, industry, buildings, transports, food and land use. These include:

» European Commission - In-depth analysis in support of the Commission's communication (2018)[40]
» European Commission – Clean Planet for All - 2050 long-term strategy[41]
» EUROSTAT database[42]
» ENTSO-E-G TYNDP scenarios[43]
» HYDROGEN COUNCIL publications[44]
» Heating & Cooling – HOTMAPS project[45]
» IEA, IRENA publications on volumes, costs and scenarios[46]

Each Technology Quest describes the actions needed illustrated by actionable projects, where available, and suggested programs to go to scale in the 2020-2030 period (or for 2020-2025 when technology readiness level is higher).

Climate impact (tCO_2eq)

CO_2e emissions savings are calculated starting with assessment of working units (projects) and use carbon intensities identified in the literature and trusted European sources, with rounded figures.

CO_2 emissions are calculated for a target base year (typically 2030). Depending on the technology, accounted emissions can be expressed in real physical CO_2 emissions, or CO_2 equivalent emissions if other of the six greenhouses gas emissions are involved, such as methane or refrigerant.

[37] "Investment" refers to a market where the payer is a business paying for an investment in an asset, that will in turn deliver products or services. Such spending contributes to the creation of national GDP.
[38] "Turnover" refers to a market where the payer is a final customer for a final good or service. Such spending contributes to the creation of national GDP.
[39] Capgemini does not maintain an integrated econometric model and uses external sources to ensure consistency.
[40] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf ; https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[41] https://ec.europa.eu/clima/policies/strategies/2050_en
[42] https://ec.europa.eu/eurostat/data/database
[43] https://www.entsos-tyndp2020-scenarios.eu/wp-content/uploads/2020/06/TYNDP_2020_Joint_ScenarioReport_final.pdf
[44] https://hydrogeneurope.eu/index.php/publications-0
[45] https://www.hotmaps-project.eu/
[46] https://www.iea.org/ ; https://www.irena.org/Statistics

Double counting of CO_2 emissions savings between Energy domain and end-use sectors

CO_2 emissions avoided in the Energy supply area are double counted in the four demand areas: Industry, Buildings, Transport, Food and Land Use. The following chart shows how this calculation works:

Figure 17 - CO_2 emissions double counting methodology

Economic area	2018 Emissions (Eurostat)	CO2e savings of 55 quests	Quests with potential double counting	CO2e savings on scope		Double counting estimate
Energy	2907	1565	PV & floating Offshore Wind (#1, #2, #3, #6) - does not include conventional offshore wind, onshore wind and other renewables, as they are not listed in the 55 quests.	813		
			Centralized Hydrogen (#4)	129		
			District Heating & Cooling DHC (#12)	299		
			Others	324		
			Total Energy - 100% is double counted with Demand	**1565**	100%	1565
As expected, the energy emissions savings are equivalent to the demand-side emissions savings:						
Total	**4032**	**2694**		**1943**		1576
Industry	1201	705	Processes with hydrogen or electrification (#17, #18, #19, #20, #21)	217	50%	109
			Heat - only heat coming from district heating or electrification (#22, #23)	259	30%	78
			Total (scope; probably double counted with Energy)	476		186
Buildings	1026	944	Renovation & Newbuild (#27, #29, #32)	280	50%	140
			Heating Pumps (#31). Double counting 100% scope but average COP 3, divide by a factor 3 the impact on electricity generation.	481	33%	159
			Total (scope; probably double counted with Energy)	761		299
Transport	1214	787	H2, C-liquids, N-liquids (#36, #37, #38, #39, #40, #41, #42, #43). Double counting 100% scope, multiplied by a factor 2 as producing a synthetic fuel requires twice the amount in green electricity*.	385	200%	770
			Electric mobility (#44, #45)	321	100%	321
			Total (scope; probably double counted with Energy)	706		1091
Food & Land use	471	257	No major double-counting identified			
Others	120					

Markets created (investment markets + final customer markets = total market)

Gross Domestic Product (GDP) in advanced economies is segmented into three accounting categories:

- Investment from businesses;
- Products and services to final customers; and
- Public administration spending.

Our 55 Technology Quests generate expenditure and markets mainly in the first two categories: Business Investments, and turnover from the sale of Products and Services. Depending on the Technology Quest, and on the type of project defined, the markets created are described using three forms:

1. Market size as turnover expressed for a typical year at the end of the execution period – usually 2030 – which is derived from the production of units of goods in that year:
   - ◊ Example 1: kg of synthetic meat consumed in Europe in 2030
   - ◊ Example 2: m² of new or renovated buildings in 2030
   - ◊ Example 3: units produced by gigafactories (Wp of solar modules, MW of electrolyzers, MW of heat pumps) in 2030

2. Investments in project-related infrastructure development and construction. These are calculated as a cumulative figure over the period, for example a decade (2020-2030) and then smoothed out as a flat average annual investment from which permanent jobs numbers can be derived more appropriately:
   - ◊ Example 1: construction investments for grids (electric, gas, H_2, CO_2, heating and cooling)
   - ◊ Example 2: construction investments in gigafactories
3. Total market size is the simple addition of annualized Investments and Market size (1+2).

Job Calculations

Permanent jobs generated by the Technology Quest are targeted for estimation. These are derived from the three economic market figures:

1. Production jobs: calculated from the market size (annual turnover or GDP, see below) using standard ratios.
2. Construction jobs: calculated from annualized investments in infrastructure construction and development.
3. Total permanent jobs is the addition of jobs deriving from annualized Investments and Market size.

To be consistent, construction jobs in the buildings sector are referred to as “production jobs” in the Quest descriptions: the building itself is a good, not a factory that produces in turn goods for use over several future years.

GDP to jobs ratios

Unless otherwise specified, the default jobs ratio is a conservative rounded standard ratio of 15 jobs for each €1 million investment or turnover. This is sufficiently close both to the European average and to the industry average (NACE C segment in the table below). Most of the jobs discussed in this report are related to technology deployment and are therefore by nature "manufacturing" or related.

Figure 18 - Jobs ratios per Eurostat NACE segment

Economic area	Eurostat NACE segments - EU 27 – 2017	Jobs	GDP	Jobs//GDP
		Thousands	€ billion	Jobs for €1 million
TOTAL European economy		203 840	11 665	17
TOTAL Industrial activities		64 122	3 618	17
ENERGY	D - Electricity, gas, steam and air conditioning supply	1 080	212	5
BUILDINGS	F - Construction	12 695	601	21
INDUSTRY	C - Manufacturing	29 920	2 002	15
TRANSPORTS	H - Transportation and storage	10 470	583	18
FOOD & LAND USE	A - Agriculture, forestry and fishing	9 958	221	45

In the table above, Energy refers to the conventional energy sector, which buys primary energy, coverts or transports it, and resells it to final customers through operating assets. This explains Energy's low ratio of just five jobs per €1 million. The jobs identified by this report for "energy" are mainly required for the construction of energy assets, grids and for manufacturing equipment, so we use our default "average" ratio of 15 jobs per €1 million for Energy. Similarly, most of the transport and the food sector Quests also relate to construction and manufacturing equipment or food.

Our main exceptions include gigafactories which, once built, are expected to be highly automated using the best 4.0 industry know-how. Public information suggests that direct permanent jobs in gigafactories are often as low as 0.5 to 2 jobs per €1 million of turnover. Nevertheless, other jobs around the factory and in the upstream value chain will increase this number. To reflect this, Capgemini Invent has selected a factor of six jobs per €1 million for gigafactories Quests, equivalent to 40% or 2.5 times less than the 15 jobs ratio for the average Quests.

These jobs ratios all include both:

- Direct jobs employed on site (or in plant); and
- Indirect jobs employed in providing services to the sites or upstream in the value chain.

We note that an additional 33% of "induced jobs" (those that are created by the very impact of economic activity itself) can be added to the global direct and indirect jobs, but that we do not include this ratio in this study, nor in its reported conclusions. This induced jobs ratio of 33% is derived from the following calculation and set of assumptions:

- 50% of GDP created by the Quests is spent in the gross compensation of workers.[47]
- 50% of the personnel gross compensation is net revenue that is spent in the economy by those employees (food, car, real estate, leisure etc.), generating an additional 25% (50% x 50%) of induced GDP and therefore jobs.
- This "first line" of induced jobs (25% of total) itself generates a second line of 25% x 25% induced jobs, which in turn generate a third line of 25% x 25% x 25% induced jobs, and so on ad infinitum.
- The sum of these lines of induced jobs is +33% of the initial direct and indirect jobs.

All the figures provided in the report are direct and indirect jobs (not including the induced jobs).

Turnover and Investment compared with Gross Value Added - Local activity vs. Imports and Exports

The default ratio of 15 jobs for €1 million is applied to GDP, which is the sum of the Value Added by each intermediate player in the economy until each product is sold to the final user (final user or investment). The 15 job/€1 million of GDP ratio can reflect several types of realities that can be found either at a global level or in specific sectors:

- The average balance in the current European economy where 50% of the Value Added is produced in Europe, 50% is imported, and the equivalent amount is exported, thus compensating imports; or
- In some specific or extreme situations, the 15 job/€1 million ratio could also reflect a situation where 100% of the Value Added is produced and consumed in Europe without any import and export.

In conclusion, our default 15 jobs/€1 million ratio includes a share of jobs in production devoted to exports, aligning with the current Import-Export structure of the EU economy. We feel that this is a neutral assumption which can be applied across all of the 55 Technology Quests.

[47] *Source Eurostat*

The analysis and conclusions of this report are those of Capgemini Invent.
It is solely responsible for its contents.

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