ROADMAP TO REACH CARBON NEUTRAL CHEMISTRY IN FINLAND 2045

FINAL REPORT – EXECUTIVE SUMMARY

Vasara / Nyman / Lehtinen / Aktüre / Laukkanen
06/2020

THE STRONG FOUNDATION

Progress is only possible, if …

The basic condition for success in all scenarios and all chemical industry sectors in Finland is a competitive, viable industry.

KEY MESSAGES

In this work, the focus has been on the reduction of direct, energy-related and feedstock-related indirect greenhouse gas (GHG) emissions of the chemical industry in Finland. The study has been commissioned by Kemianteollisuus ry / The Chemical Industry Federation of Finland.

No silver bullet, but a mix of solutions

- The largest companies in the chemical industry in Finland are very energy and capital intensive, yet there are also many specialty chemical companies with very different business dynamics.
  ➔ The key is to reduce reliance on fossil fuels as a source of primary energy. However, changes can be very process-specific, and extreme temperatures are required in many processes.

Availability and price of low-carbon electricity

- To reduce the direct and energy-related indirect GHG emissions of the chemical industry, there are many technical alternatives, but most rely on increasing use of low-carbon electricity.
  ➔ The availability and price of low-carbon electricity will play a key role in defining when and where possible emissions reductions are achieved. Intermittent electricity is a challenge, but also possibly an opportunity for new production dynamics.

Support for RDD&D

- The chemical industry in Finland is a powerhouse of innovation. However, climate targets require public support. For the most ambitious scenarios, the investment decisions must be made in 2020s.
  ➔ The people-intensive R&D efforts need to be extended to include demonstration and deployment (RDD&D) and cross-industry cooperation should be promoted. Most technical solutions are not competitive with current levels. Digitalisation both increases productivity – and has an impact on more conventional employment.

Feedstock importance

- The majority of the feedstock of the industry is still fossil-based. Recycling technologies, CO_2 as feedstock and biobased raw materials are alternatives of the future. Focusing on only the GHG emissions within national boundaries may be costly and yield suboptimal results concerning emissions reductions.
  ➔In analysing feedstock emissions, a global handprint considerably larger than the domestic emissions of the industry was found with key export potential.

Emissions will decrease, but much depends on enabling factors

- Given the average production volume growth of +0.75%/a, total GHG emissions are estimated to decrease by 17% in 2045 (vs. 2015). The most ambitious climate scenario decreases total emissions by 92% by 2045 (vs. 2015), resulting in total electricity demand of 31 TWh/a (4.5 x current levels) and 72% higher investment costs than the business-as-usual development (excluding energy infrastructure).

WHAT, WHY, HOW?

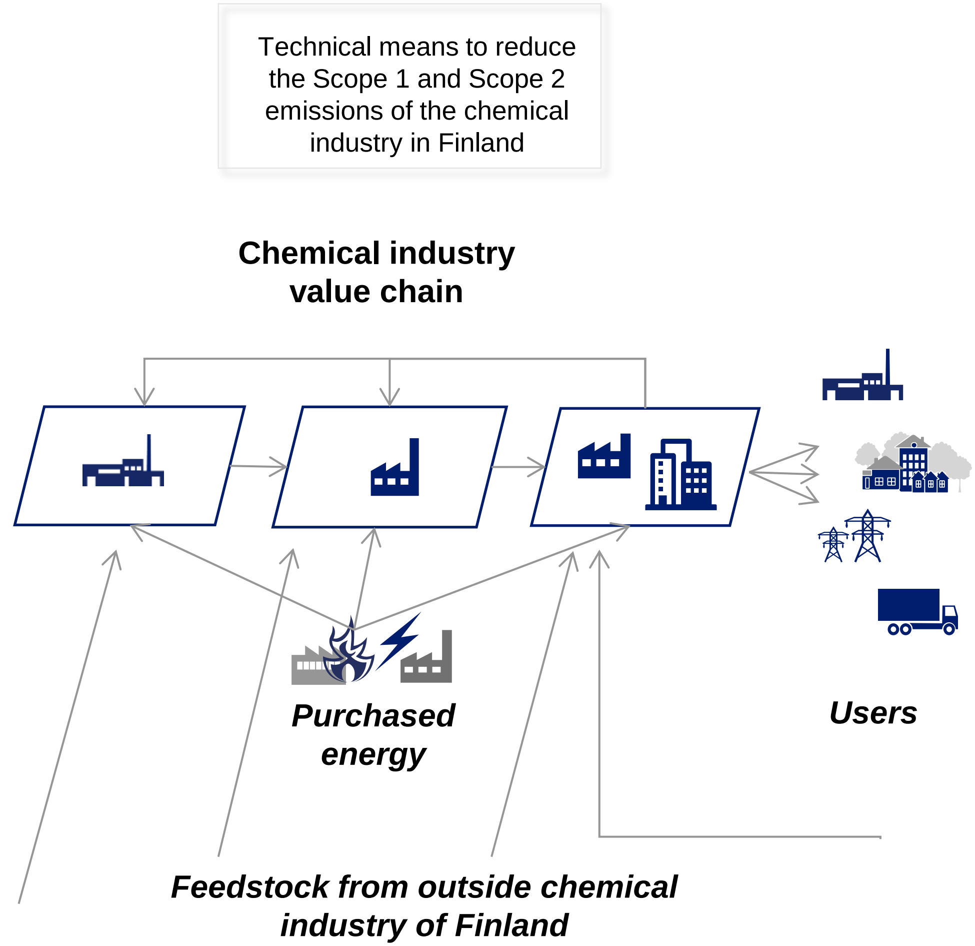
How can the project be condensed?

WHAT?	The goal is to identify the means and to provide a realistic roadmap towards carbon neutral chemical industry in Finland 2045.
WHY?	The background of the study includes the ambition of Kemianteollisuus ry / The Chemical Industry Federation of Finland and the climate targets declared by the Finnish government.
HOW?	In cooperation with other main manufacturing sectors (Technology Industries of Finland, Finnish Forest Industries Federation) and Finnish Energy (ET), a roadmap work where technology-driven scenarios, their requirements and costs iteratively meet the supply of low-carbon energy.

THE BOUNDARIES IN THIS ANALYSIS ARE WIDE – BUT RESTRICTIONS HAVE BEEN MADE

This is foremost an analysis of technical means for own direct emissions and purchased energy emissions

- In the first set of scenarios, the focus was on the technical means to reduce the own GHG emissions of chemical industry in Finland.
- In the primary scenario work, direct GHG emissions of chemical industry (Scope 1, process emissions and emissions from own energy production) and emissions from purchase energy (Scope 2) were accounted for quantitatively, while the impacts of feedstock on the emissions (Scope 3) were assessed qualitatively.
- In a separate chapter of the report, the impacts of feedstock on the emissions (Scope 3) are evaluated quantitatively.



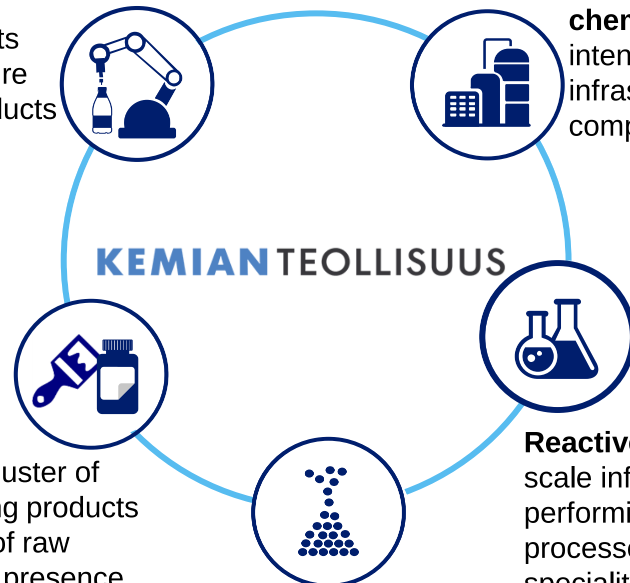
TO MANAGE THE COMPLEX WHOLE, A CLASSIFICATION OF COMPANIES OF CHEMICAL INDUSTRY IN FINLAND WAS MADE

Instead of 400 companies, 5 clusters of companies

- The chemical industry in Finland is a heterogeneous combination of companies which are often highly vertically integrated or may operate in completely different value chains.
- Many solutions, such as low-carbon fuels, are common to the whole sector, while some are very process-specific.
- Confidentiality of individual companies requires an anonymization of data. A division into five clusters was made to account for the heterogeneity while maintaining a holistic view.
- This classification is inherently flawed to a certain degree, as even a single company may have operations that could be placed in several clusters. However, this classification makes the results more specific and yet easier to generalize.

Converters: Cluster of plants that manufacture consumer products

Energy-intensive chemical industry: Capital intensive large scale infrastructures performing complex processes



Formulating: Cluster of plants formulating products by mixing a set of raw materials (in the presence of a reaction or not)

Reactive chemistry: Middle scale infrastructure performing complex processes, products including speciality chemicals and advanced materials

Inorganic chemistry: Cluster of plants specialised in inorganic chemical products

WHAT IS THE ESSENCE OF THE CLUSTERS?

Compressing the diversity into a few key essentials

Energy-intensive chemical industry

- Large chemical facilities comprise the backbone of the chemical industry. Typical energy intensive unit processes include distillation, reforming, polymerization. Products include transport fuels, petrochemicals, plastics, water treatment chemicals.
- Companies include Neste, Kemira, Borealis, etc.

Inorganic chemistry

- Inorganic chemistry is integrated to the metals and minerals sector. Energy intensive processes include crushing, grinding and electrolysis. Products include fertilizers, minerals, metals and salts and can be used in e.g. battery chemicals, pulp and paper industry, paints, construction industry and agriculture.
- Companies include Yara, Elementis, Freeport Cobalt, etc.

Reactive chemistry

- Middle scale infrastructure performing complex processes. Typical products include enzymes, dispersion polymers, resins, biochemicals, industrial gases to be used in various industries.
- Companies include Cabb, Linde Gas, Roal, etc.

Formulating

- Processes are primarily different types of mixing. Typical products include paints and coatings, pharmaceuticals, detergents, adhesives also in the customer product segment.
- Companies include Orion, Tikkurila, Kiilto, etc.

Converters

- Processes include molding and compounding. Typical products include plastic and rubber products.
- Companies include Exel Composites, Nokian Renkaat, ViskoTeepak, etc.

ASPECTS TO CONSIDER WHEN INTERPRETING THE RESULTS

Global industry, global conditions

Only an economically successful industry can make the climate transformation happen

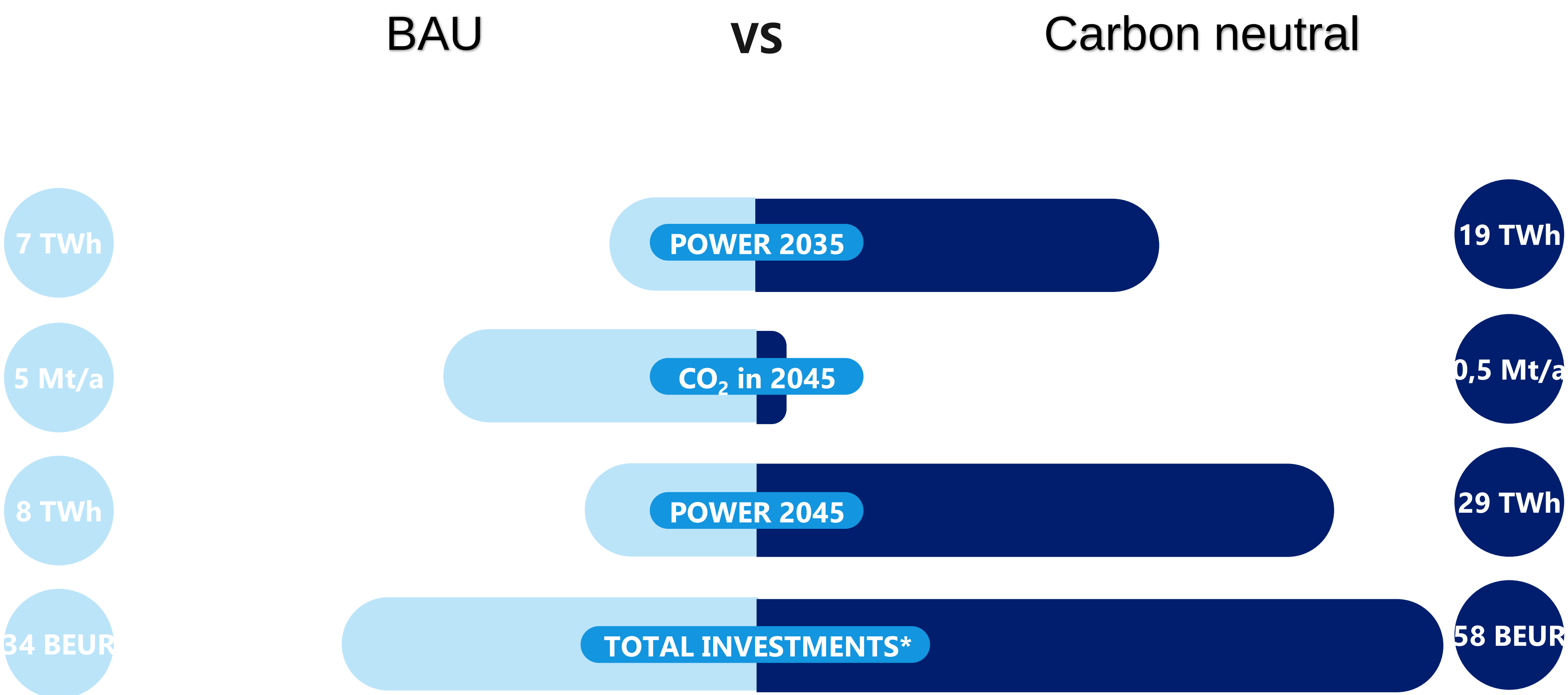
- It comes as no surprise that the transformation of chemical industry towards carbon neutrality requires tireless work in research and developing new products and processes, and significant investments in production assets, energy (production and infrastructure) and recycling infrastructure. Economic viability of the large investments, access to finance and new value chains will, to large extent, decide how quickly and to what extent the transformation will happen. *From an industry point-of-view, environmental sustainability necessitates economic sustainability, albeit new business opportunities are also numerous along the way.*

Global market, global players

- *Chemical industry operates in a highly globalized market*. Companies have production assets in many countries on different continents. Raw materials and products of the industry flow effortlessly across country borders. From a company point-of-view, focusing on national boundaries is not necessarily natural, whether it is a question of production investments or climate change mitigation, for example.
  - This is particularly true for the feedstock scenarios and GHG impact in scope 3 (indirect emissions). When interpreting the results, it is essential to keep in mind that *these scenarios (not forecasts!) are sensitive to a range of assumptions* and with a focus primarily on Finland. However, Finland will not be an island in the future, either, and the scenarios rely on continuation of imported raw materials.
- Keeping the above in mind, the following scenarios aim to depict a realistic, yet extremely ambitious transformation of what the chemical industry of Finland could look like in the future as a part of the national roadmap work of Finnish main industries.

BUSINESS-AS-USUAL (BAU) VS CARBON NEUTRAL SCENARIO

What are the extremes of differences between BAU and climate scenarios?

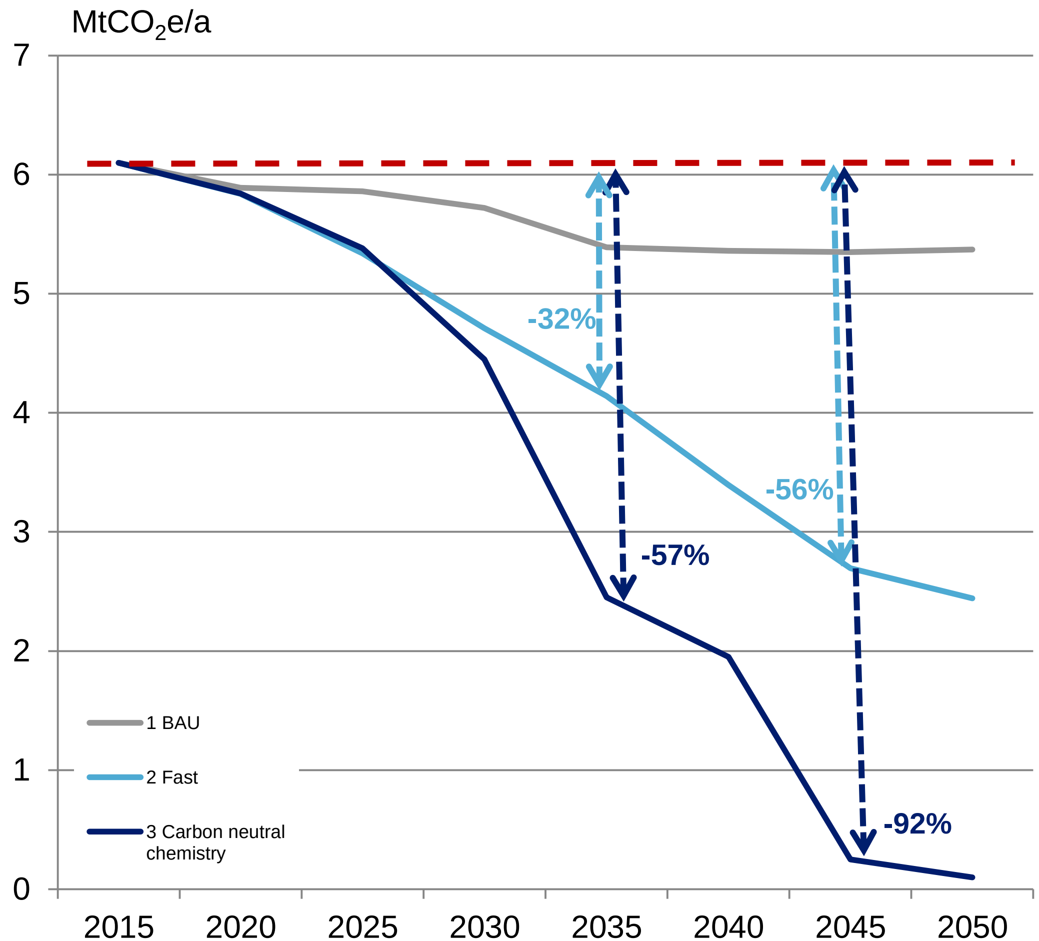


***) in addition, energy, see next page**

EMISSION REDUCTIONS FOR SCOPE 1 AND 2 ARE SIGNIFICANT

These are scenarios, where goals are reached

- Indirect GHG emissions reduce significantly in the *BAU scenario* and following scenarios due to development of power sector and energy efficiency measures.
- *Fast development scenario* reaches notable reductions in 2030s and 2040s, reducing the Scope 1 and 2 emissions by 56% by 2045 through new technology and investments. However, fossil energy and process emissions still remain in 2040s.
- *Carbon neutral chemistry scenario* reduces emissions by 92% in 2045, but requires breakthroughs in low-carbon technologies (and scale-up in the production) and wide utilisation of CCS & CCU in addition to a significant degree of electrification and fuel switches.



COMPARISON: TOTAL INVESTMENTS IN 2015-2050 EXCLUDING ELECTRICITY FOR SCOPE 1 AND 2 EMISSION REDUCTIONS

Even under business-as-usual (BAU) development, investments needs are high; in carbon neutral scenarios they almost double during the next decades

Current level as the baseline

- As the current level of investments is scaled up with the growth of production volume, the BAU investments (equal ca. 1 BEUR/year), including fixed assets and R&D. BAU development results in investment need of 34 BEUR in 2015–2050.

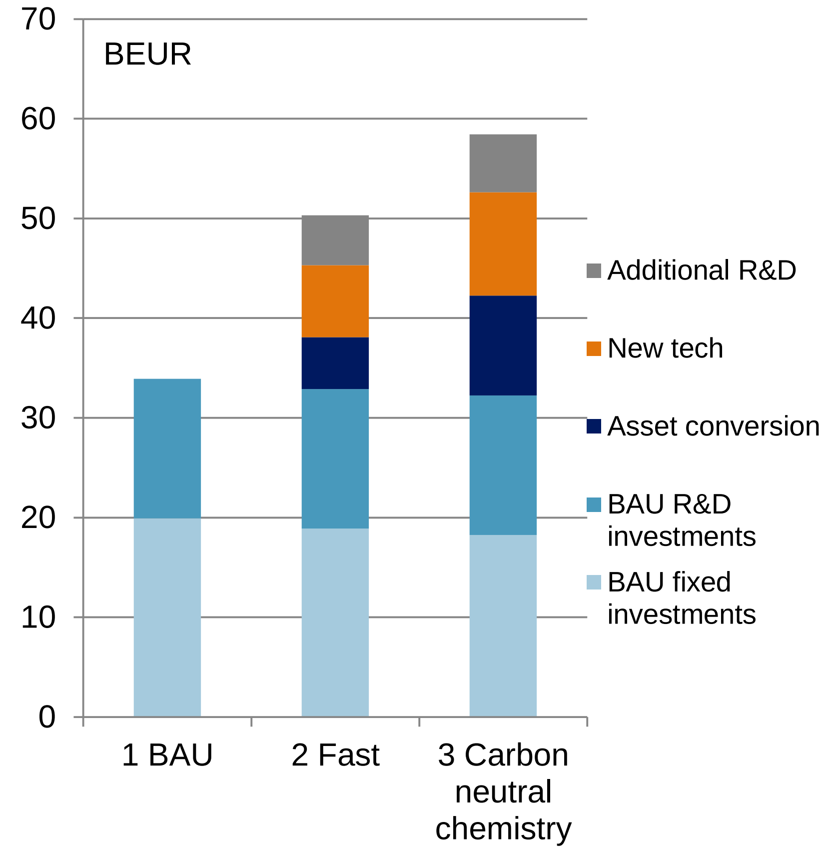
Additional investment need in the scenarios

- Total additional investment requirement (excl. energy) in the climate scenarios is 16-24 BEUR in 2015–2050, equal to 48-72% increase from current levels. Additional investments have to be for increased R&D, asset conversions and new technology.

Interconnections of investments

- Through asset conversion, a part of BAU fixed investments will be avoided, as new assets will lower some of the maintenance costs, for example.

As a comparison:
Total cost of crude oil in 30 years: **195 BEUR**
(60 €/bbl, 15 Mt/a crude oil demand)



COMPARISON: TOTAL INVESTMENTS IN 2015-2050 INCLUDING ELECTRICITY FOR SCOPE 1 AND 2 EMISSION REDUCTIONS

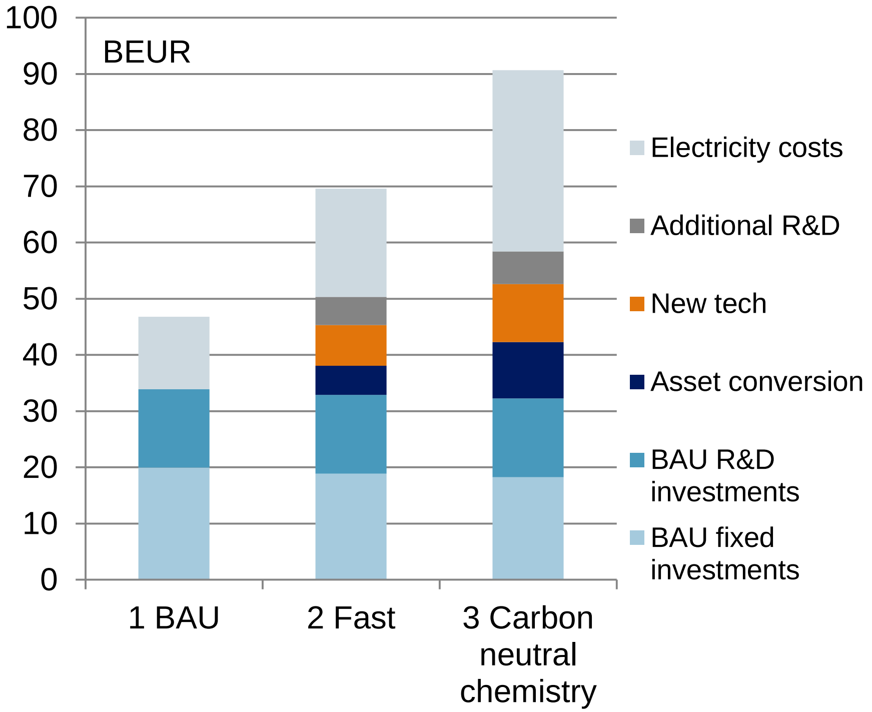
Costs of energy transition will also be borne at least partly by the chemical industry

Electricity costs

- Indication of the significant electricity costs in the scenarios is illustrated in the figure through the estimated cost of electricity procurement. The investments into low-carbon electricity generation (wind, nuclear, etc.) will also be performed by actors outside the Finnish chemical industry, and capacity must be built up prior to the consumption can increase. Electricity costs constitute the largest individual cost category in the three climate scenarios.

Additional investment need in the scenarios

- Total additional investment requirement (incl. energy) in the climate scenarios is 23-44 BEUR in 2015-2050, equal to 49-94 % increase from current levels.



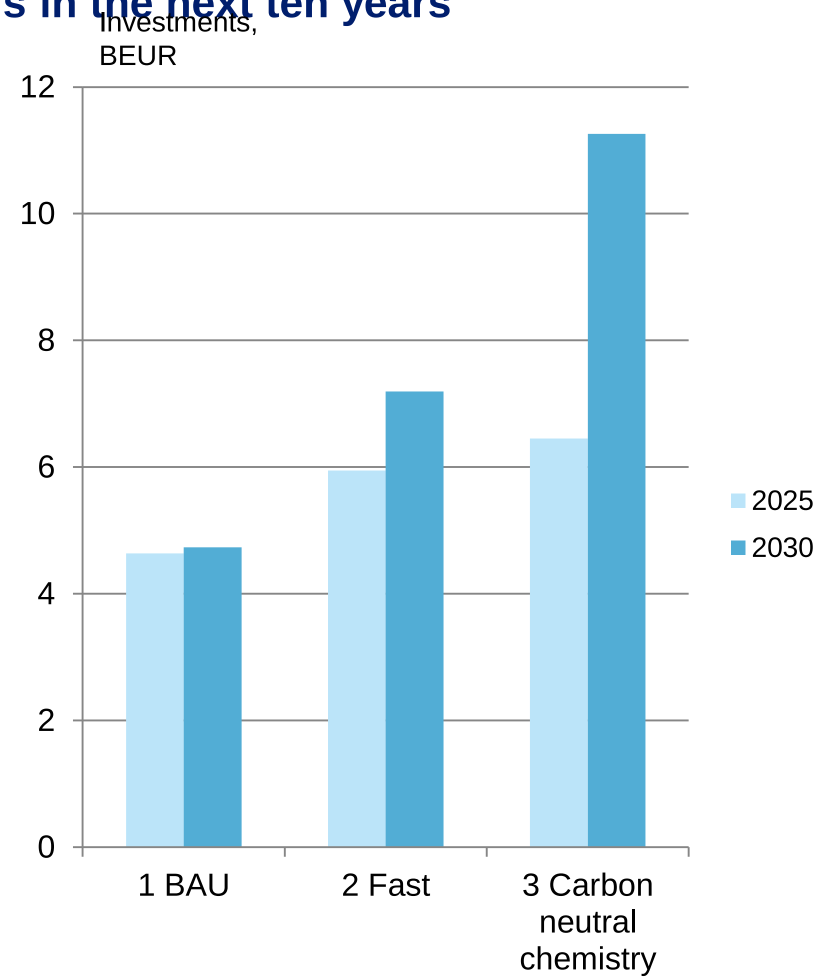
As a comparison:
Total cost of crude oil in 30 years: **195 BEUR**
(60 €/bbl, 15 Mt/a crude oil demand)

Electricity costs are based on the assumed price of 50 €/MWh for electricity and the cumulative electricity consumption of the scenarios. This is only a preliminary estimate of the energy costs, and it is sensitive to assumptions in the energy sector. Possible savings as a consequence of reduced use of fossil-derived heat are not accounted for in the calculation.

INVESTMENTS IN 2020-2030 SHOW THE INTENSE PILOTING SPEEDUP NEEDED

Investments into fixed assets, R&D, new technology and asset modifications require a doubling of total investment levels in the next ten years

- In process industry, major investments can be performed as a part of typical turnaround cycles.
- In the most ambitious carbon neutral chemistry scenario, the total investment levels **must more than double after the next five years** compared to BAU.
- The turnaround cycles in the industry are typically 4-6 years, which provide the natural window of opportunity for major investments for companies. Investments to be performed in 2025 are already under active planning.
- The heaviest investments need to be performed in 2025-2035. These include
  - New technology, such as pilots and industrial-scale production based new technologies: Power-to-X, CCU, electrification of heat, chemical recycling, fuel switches, etc.,
  - Major asset modifications to adapt the existing facilities to low-carbon production, e.g. to widen the feedstock base,
  - Increased levels of research and development (additionally 200 MEUR/year)

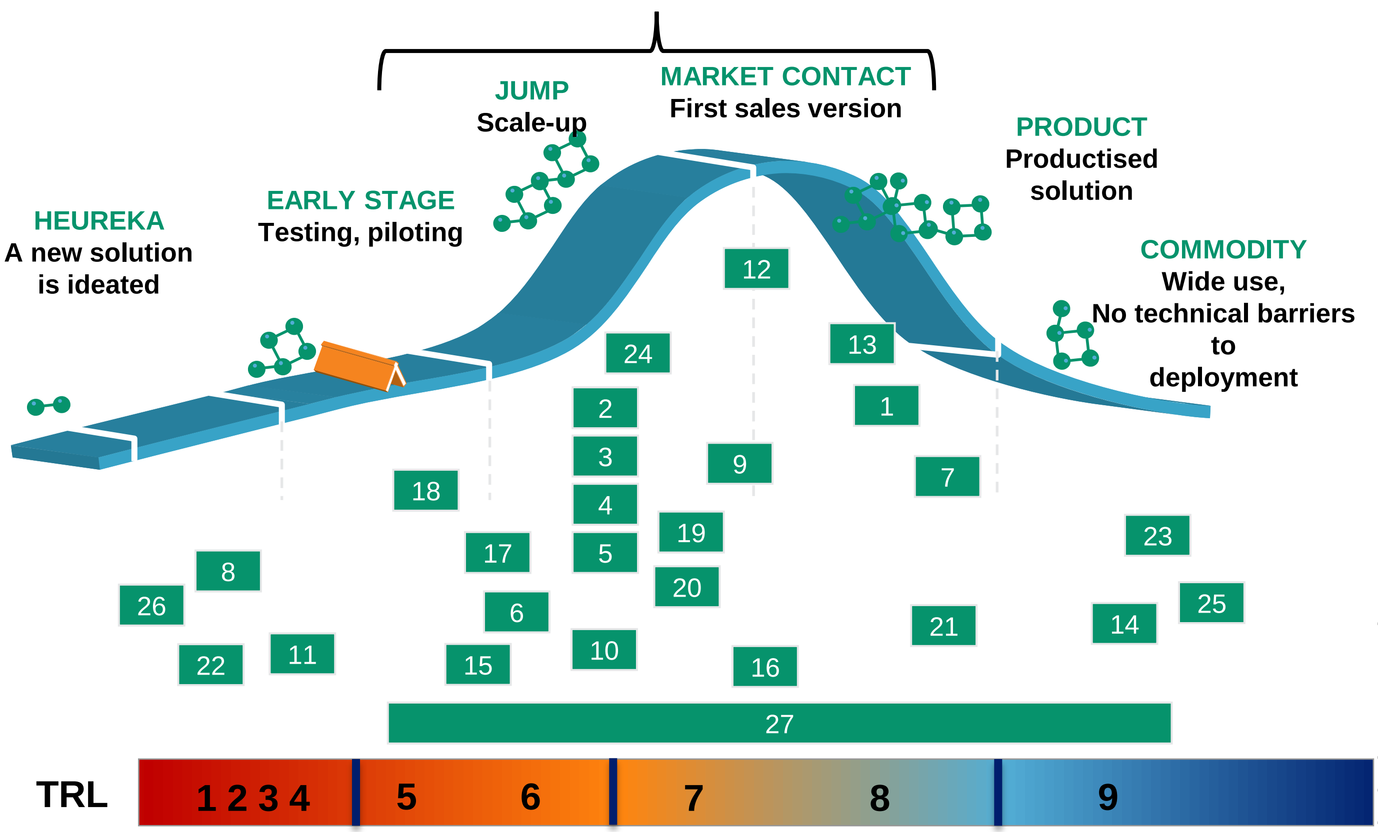


Each bar corresponds to the total investment need during the preceding 5-year-period. Possible investments into public infrastructure, energy infrastructure and cross-industry integration are excluded.

THE SPEED AND STATUS OF TECHNOLOGY SOLUTIONS FOLLOWS NORMAL DEVELOPMENT PATTERNS

R&D (Research and development) must be expanded to RDD&D (Research, development, demonstration and deployment) to speed up commercialisation of new technologies

Focus: Commercialization and large-scale deployment of low-carbon technologies



Power-to-chemicals
1. Power-to-H2
2. Power-to-methanol
3. Power-to-olefins
4. Power-to-BTX
5. Power-to-ammonia

Raw material and product portfolio changes

6. Biomass to methanol
7. Biomass to bioethanol
8. Biomass to BTX (lignin-based)
9. Bionaphtha to olefins
10. Biomass to olefins
11. Hydrogen via methane pyrolysis
12. Biohydrogen
13. Biobased diesel (HVO)
14. **Energy efficiency**

CCU/CCS

15. Pre-combustion
16. Post-combustion
17. Oxyfuel combustion
18. CO2 mineralisation

Electrification & fuel switch

19. Steam production by electric/hybrid boilers
20. Steam production by electric furnaces
21. Coal to natural gas to biogas
22. **Synthetic biology & biochemistry**

Circular economy

23. Mechanical recycling
24. Chemical recycling
25. **Process development**
26. **Bubbling under technologies**
27. **Digitalisation**

FEEDSTOCK SCENARIOS PROVIDE PATHWAYS TO COMPLETE TRANSFORMATION OF THE INDUSTRY

A very significant defossilisation analysis of raw materials was also done, with three scenarios

1 BAU

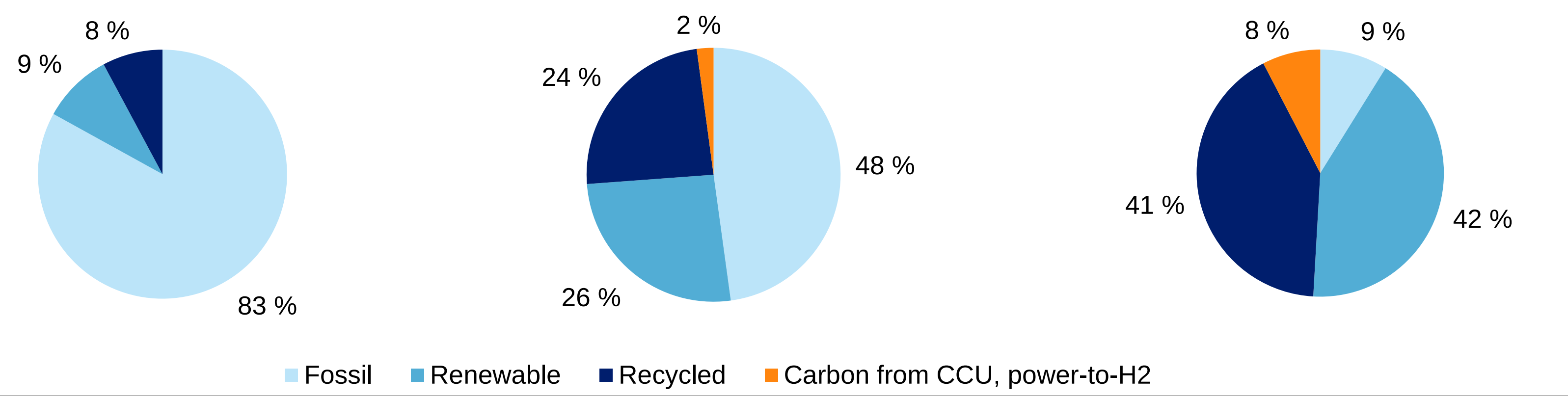
- No changes to current composition
- Amounts grow due to volume growth
- Fossil remains the major source of feedstock
- No additional investment, electricity or biomass demand

2 Fast development

- Recycled and renewable feedstock streams grow significantly
- Additional investments
- Significantly reduced GHG impact for Scope 3 emissions

3 Carbon neutral 2045

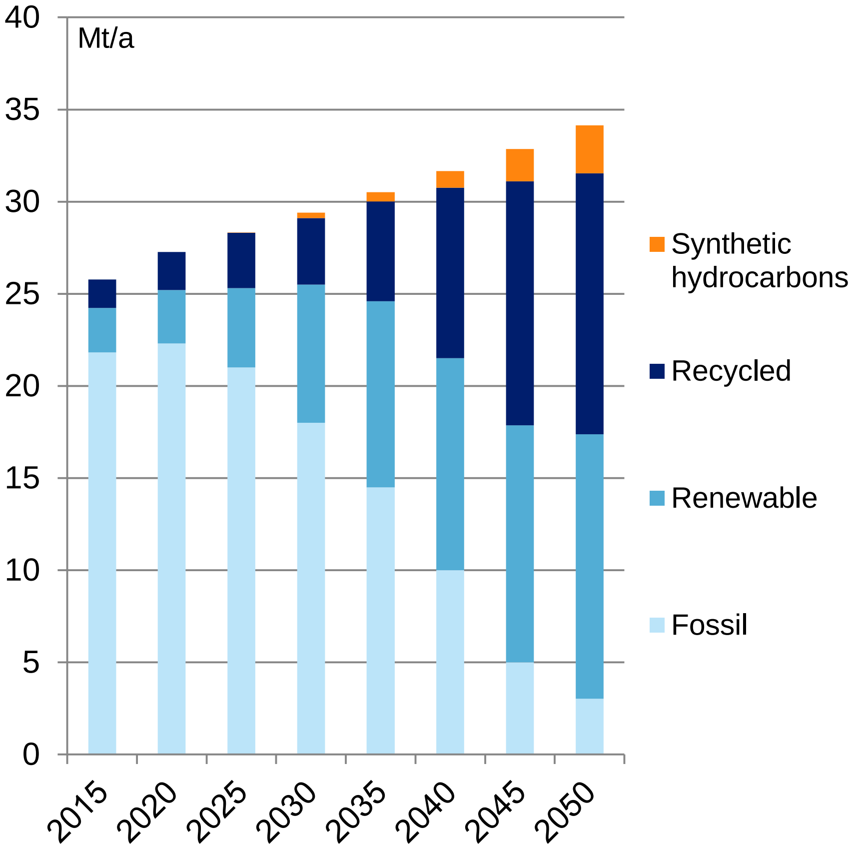
- A complete transformation of the feedstock portfolio by 2050
- Chemical industry could become carbon-negative
- Significantly increased demand for recycling infrastructure, energy demand and investments



IN FEEDSTOCK ANALYSIS, CARBON NEUTRAL CHEMISTRY 2045 SCENARIO HAS AN INCREASING DEFOSSILISATION

This admittedly very tough goal picks up speed after 2025 and accelerates

- Targeting a chemical industry with less than 10% fossil content in 2050.
- A rapid shift towards renewable and recycled raw materials starts after 2025.
- Quantities of novel raw materials are based on actual estimates for their availability. Imports would play a significant role in the future, as they do currently. A change of this magnitude is, however, conceived as possible (again, given many conditions fulfilled).
- The amount of recycled and renewable amounts grow 6-10 fold compared to current situation.
  - A large part of the feedstock is completely novel to chemical industry. Adding complexity and flexibility into process operations would enable using new raw materials and producing a wider array of products.
  - Synthetic hydrocarbons estimated to require 7-8 MtCO_2/a captured in 2050.
- As a comparison, the amount of renewable materials is equal to twice the current pulp production in Finland, albeit the largest part of renewables come from algae oil production.
- **It is imperative that entire value chains and dynamics of key material flows of modern society get transformed for this scenario to come true.**
  - Preconditions: recycling infrastructure, deep sector integration, strategic and synergistic locations, supporting legislation, large-scale investments, technology advancement and changes in consumer behaviour.

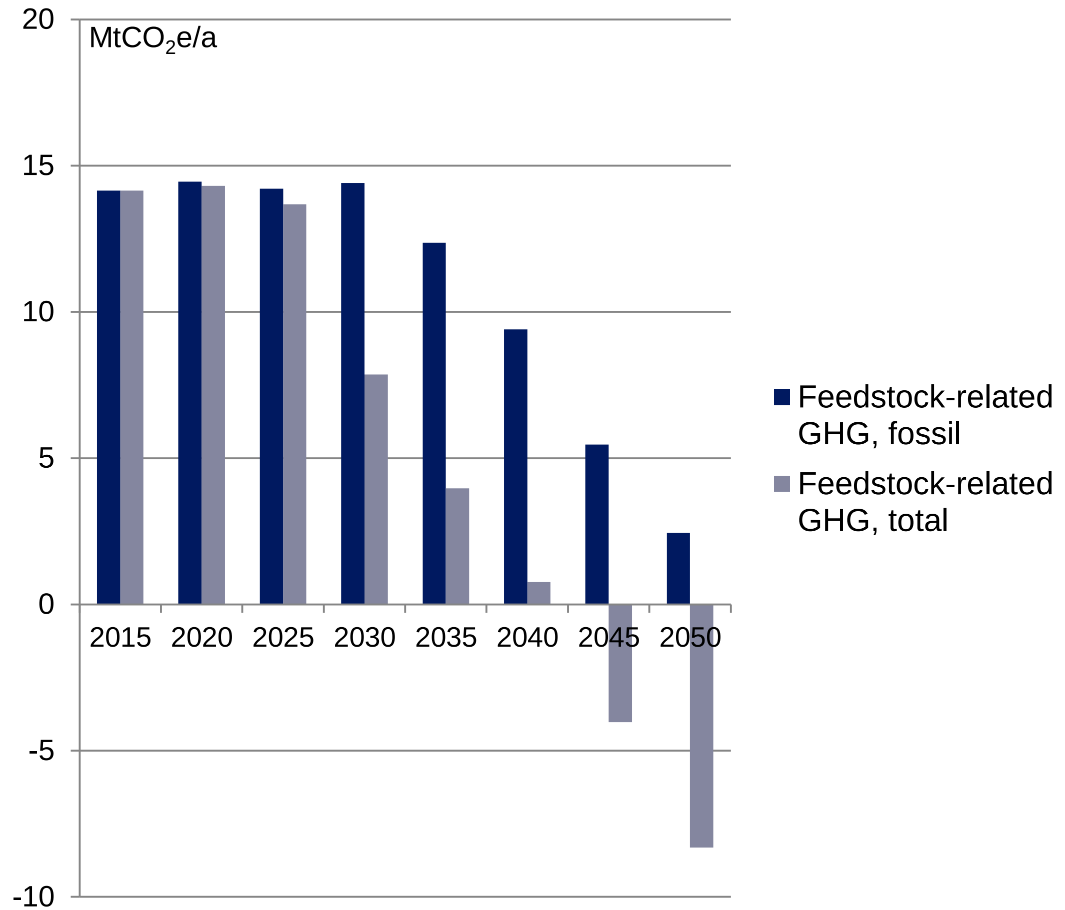


PÖYRY

IN FEEDSTOCK ANALYSIS, CARBON NEUTRAL SCENARIO 2045 REACHES CARBON NEGATIVITY FOR FEEDSTOCK EMISSIONS

A tough goal, and dramatic impacts, from 14 to -8 MtCO2

- This analysis is a comparison of GHG emissions related to feedstock up until the inbound gate of chemical industry.
- Total GHG impact includes fossil and (biogenic) CO_2 intake of renewable materials.
- Increasing the share of renewable and recycled raw materials starts decreasing the feedstock GHG emissions fast after 2030.
- By 2050, with current GWP data and estimates of the feedstock,
  - annual feedstock-related fossil emissions would be decreased from ca. 14 to 2 $MtCO_2$ and
  - annual total emissions (accounting for biogenic carbon) would decrease from 14 to ca -8 $MtCO_2$.

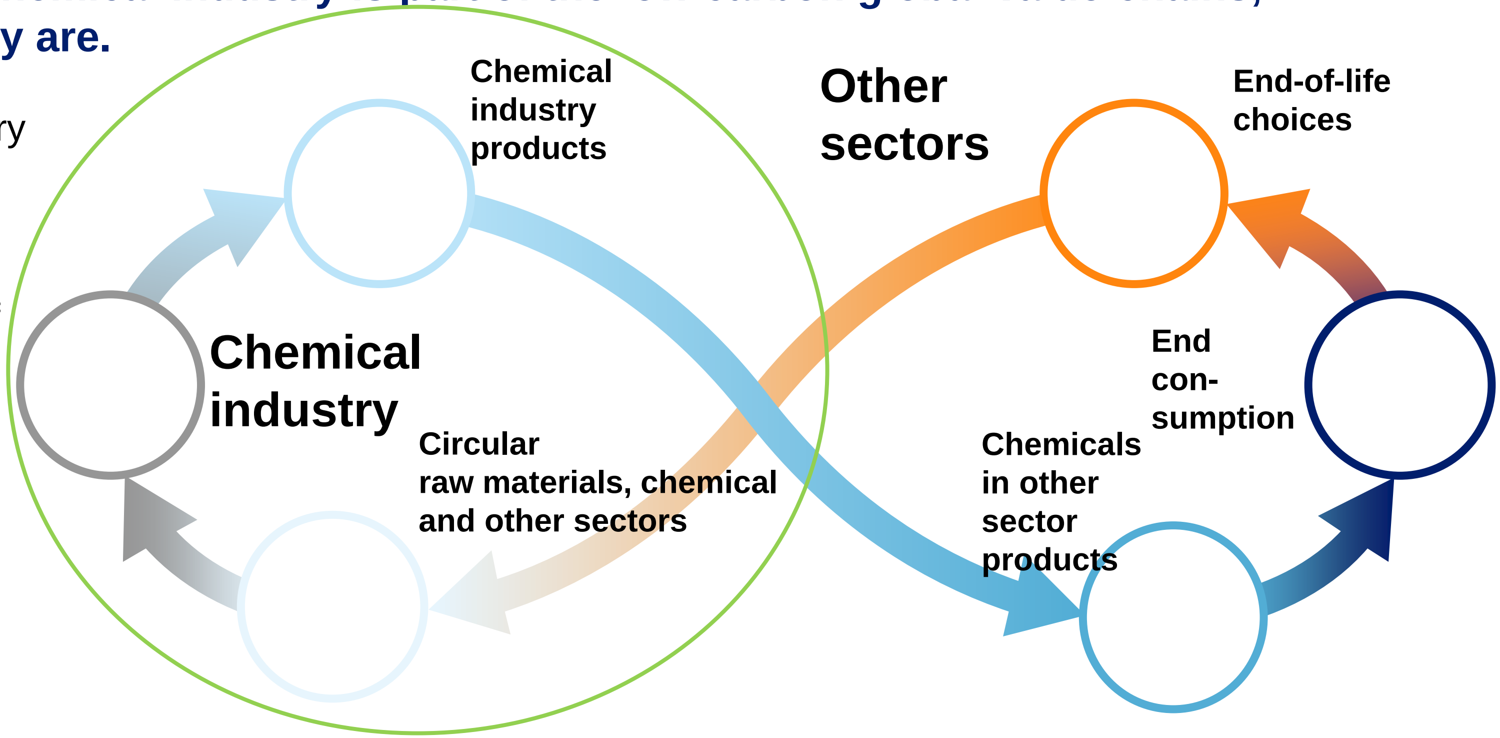


Results are estimates based on published LCA information.

THE CIRCULAR CHEMICAL LOOP IS EVERYWHERE

The products of the chemical industry are present in practically all other sectors. A low carbon chemical industry is part of the low carbon global value chains, whatever they are.

- Chemical industry products are present everywhere.
- The handprint of the chemical industry also includes the flow of raw materials from other sectors – and chemical sector circularity.



No notable sector is independent of chemical industry solutions.

HYDROGEN ECONOMY AND SYNTHETIC HYDROCARBONS

H_2

General description

Hydrogen economy became a "thing" due to energy considerations – from fusion reactors to low carbon fuels. However, the lightest element is not just a fuel or a storage, it is an important raw material for chemicals, for new compounds – and possible to produce in large quantities.

Fossil-based hydrogen can be produced from fossil fuels through e.g. steam methane reforming (SMR) or auto thermal reformation (ATR), which remain the cheapest options. Low-carbon options include blue hydrogen and green hydrogen. Blue hydrogen refers to methane use coupled with CCS or pyrolysis, while green hydrogen is produced by utilising low-carbon electricity for the electrolysis of water.

For hydrogen economy to truly realize 1) commercial and technical challenges must be solved, 2) cost competitiveness reached and 3) end use applications found.

Work is well under way through learning-by-doing and scale-up projects in Europe and beyond.

Applicability – spearheads for hydrogen:

- Climate impact through use

Low carbon fuel, no CO_2 emissions, possible transport and storage infrastructure needed.

- Flexibility in the production

Being able to adapt and adjust between energy (storage) and chemicals production. Opportunities to use as synthetic raw material of hydrocarbons and links to carbon capture and utilisation (CCUS) processes.

- New markets

Hydrogen – future end use sectors of hydrogen in addition to chemicals include other industries (e.g. new steel manufacturing technologies), transportation and potentially others.

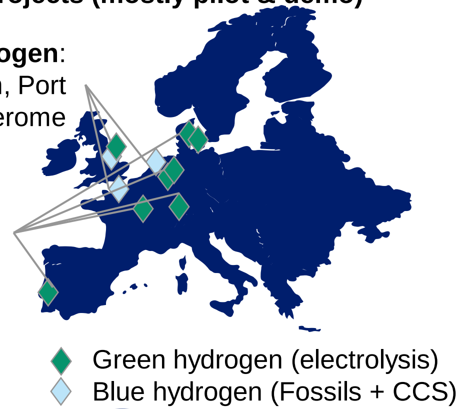
Examples of existing low-carbon hydrogen projects (mostly pilot & demo) are numerous

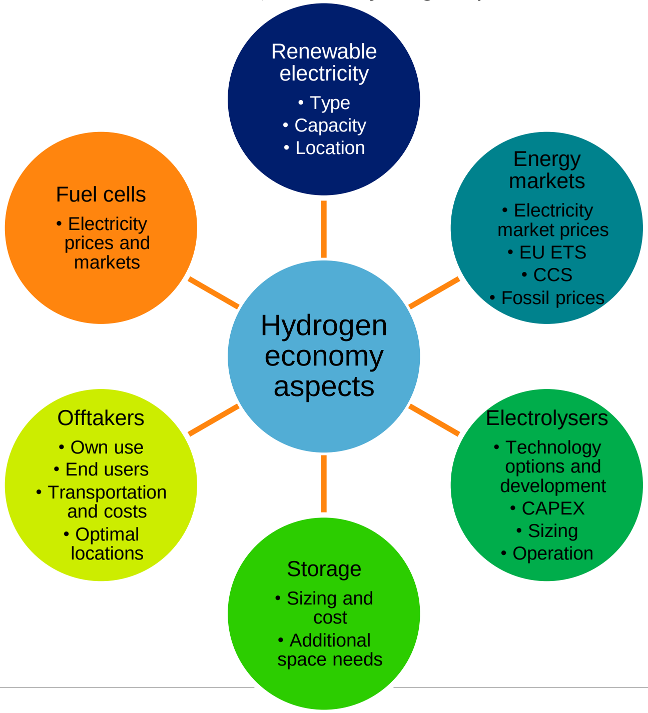
Interest in hydrogen is currently extremely intense. Several commercial projects are under planning and being performed, as new value chains and business models are sought, sometimes across new wide industrial consortia.

Several EU countries, such as Germany, the Netherlands and Portugal, have outlined their hydrogen strategies, envisaging significant growth in the 2020s. In Central Europe, hydrogen is seen to hold potential for sector integration through existing gas infrastructure much in a similar manner that integration through electricity networks holds in the Nordics.

Blue hydrogen: HyNet NW, Magnum, Port Jerome

Green hydrogen: Fredericia, H2RES, NorthH2, Hybridge, REFHYFNE, H2 Energy, H2V, Gigastack, Sines





INTERLINKAGES OF HYDROGEN, BIO AND CIRCULAR ECONOMY

Importance of new business models and value chains

- All new commercial activities in the fields of bioeconomy, hydrogen economy and circular economy share the need for completely new value chains to emerge. The problems are not simply technical or related to resources of individual companies. Knowledge (in the development phase) and money and products (in the execution phase) must start switching hands for the sustainable solutions to be sustained.

Importance of RDD&D and scale-up

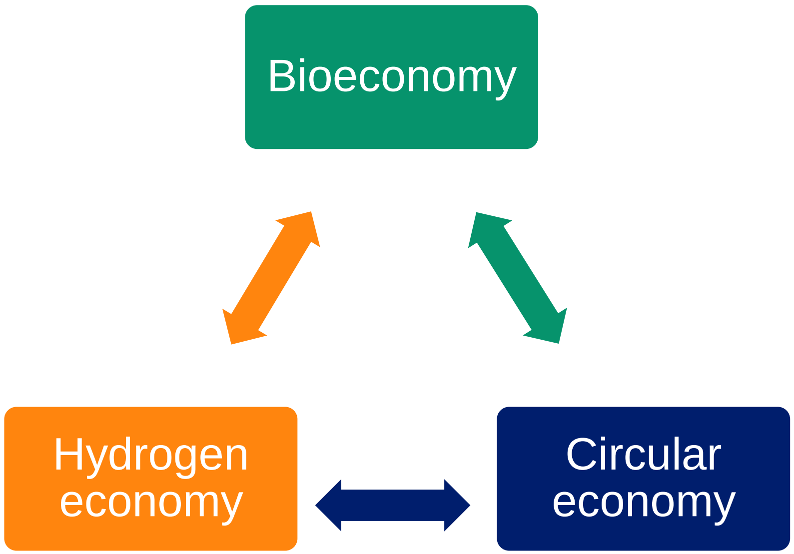
- Many of the new raw materials of tomorrow's economy have to intensively researched to clear the remaining technical barriers. Learning-by-doing in the pilot and demonstration projects and scale-up is absolutely essential for industrial-size operations to emerge.

Importance of trade, enabling regulation and new markets

- Materials must be able to flow effortlessly across the borders for new business to emerge, as scale is essential also in circular economy. New waste hierarchy implementation to ensure that "waste" becomes valuable feedstock and is utilised is crucial.
- Markets of conventional products can be regulated and government procurements used to promote the formation of new markets.

Complementary, but focus is needed

- None of the three entities can solve the climate crisis on its own, instead they complement each other even in the scope of chemical industry defossilisation and the scenarios in this work. However, focus is needed to estimate the core strengths and bottlenecks in each category from with viewpoint of single nation states. No country or company can perform the transformation on its own and sector integration much beyond energy is essential for all.



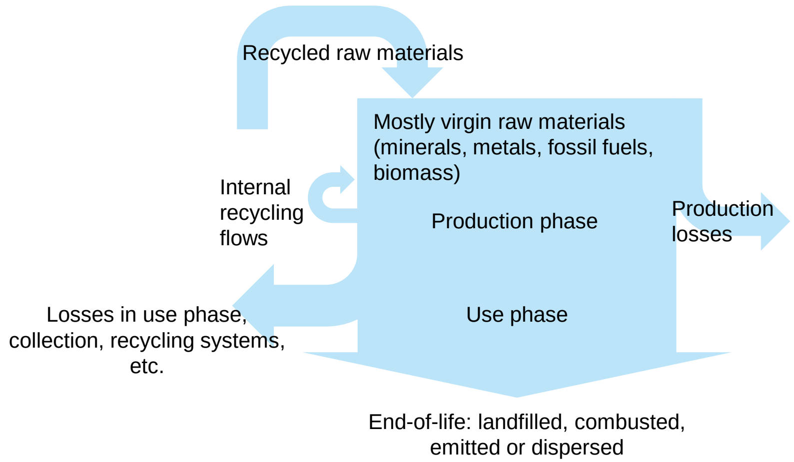
LINEAR AND CIRCULAR ECONOMY, WHAT'S THE DIFFERENCE?

More than 90 % of material inputs of global economy are virgin materials – circular economy would remove GHG emissions of most of feedstock and end-of-life

Reducing GHG impact in linear economy

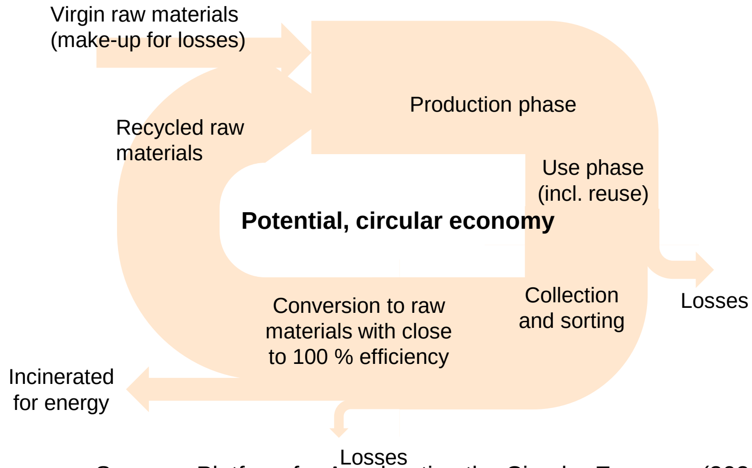
- GHG impact in scope 1 and 2 can be mostly mitigated through policies that advance low-carbon energy, as most of these emissions are related to energy. Some process emissions will be hard to abate and require novel technical solutions.
- But if the focus is only on scope 1 and scope 2 GHG impact (e.g. CO_2 emissions in Finland), a large part of emission reduction potential is neglected.
- Companies operating in a global world also seek solutions to their products across the entire life cycle, not focusing only on the direct emissions, even though those are the easiest to quantify.

Current, linear global economy



Reducing GHG impact by going circular

- GHG impact in scope 3 can be mitigated by closing the material loop. Material research and new production processes are needed to great extent.
- GHG impact in scope 3 incorporates the materials into the analysis. By using recycled and renewable raw materials, the overall GHG emissions are greatly decreased on a global level.
- In some cases, circularity may even increase emissions in scope 1 and 2, but the whole picture must be studied to determine the global impact.



Sources: Platform for Accelerating the Circular Economy (2020)

LINEAR AND CIRCULAR ECONOMY – POLICY IMPLICATIONS

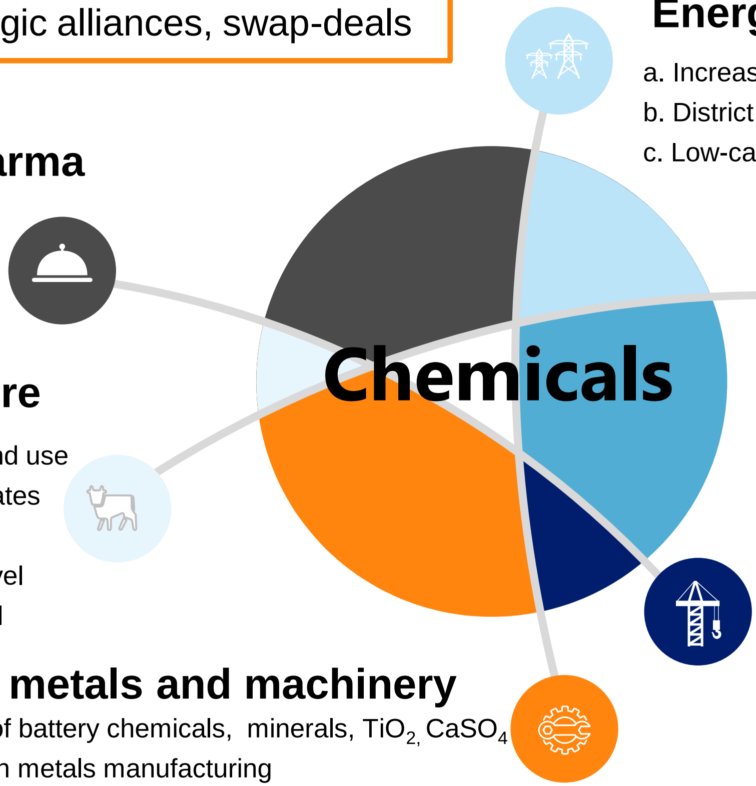
Question of reaching circular economy is fundamentally different from solely mitigating GHG emissions – and so are the answers related to measures and policies

	Linear economy point-of-view	Circular economy point-of-view
Goal	• Focus on reducing the GHG emissions in scope 1 (direct) and scope 2 (purchased energy)	• Focus on GHG emissions of entire lifecycle of products, accounting also for Scope 3 (indirect emissions)
Means	• Improvements in energy efficiency • Energy source changes • Mitigation of process emissions	• Improvements in material efficiency • Raw material source changes • Improvements for end-of-life: e.g. recycling • Strategic and synergistic locations for assets • (+ those related to energy, on the left)
Sectors in focus	• Energy production and generation and transmission • Industries with large energy consumption • Industries with large process emissions	• Sectors with large material flows (upstream and downstream), also end users of products • (+ those related to energy, on the left)
Conditions for mitigating the GHG impact	• Alternative low-carbon energy sources available reliably and at a competitive price • Investments into new energy assets (cooperation with energy sector)	• Changes in consumer behaviour • Recycling infrastructure • Completely new technology for production processes • Entirely new business models and value chains • (+ those related to energy, on the left)
Key aspects for policy	• How to incentivize companies to change main primary energy source? • How to catalyse energy investments (avoiding the chicken-egg problem of large energy producers and end users)	• How to make reusing and recycling the most attractive business? • How to incentivize considerable RDD&D and investments of forerunners? • How to catalyse deep cultural change across the society? • (+ those related to energy, on the left)

SECTOR COUPLING AND CROSS-INDUSTRY COLLABORATION

Business opportunities for chemical companies to reduce emissions extend far beyond the chemical industry

Possible forms of collaboration include JVs, public-private partnerships, collectives & cooperatives, strategic alliances, swap-deals



Energy

a. Increasing electricity demand + flexibility;
b. District heat + industry waste heat;
c. Low-carbon heat sources

Food and Pharma

a. Packaging solutions
b. Ingredients

Pulp and paper

a. Waste water + production of chemicals (PHAs, phosphates, nitrates)
b. CO_2 emissions as feedstock
c. Valorisation of biomass (cellulose, hemicellulose, lignin, tall oil, acetic acid)
d. Recycled fibers (also textiles)

Agriculture

a. Biogas production and use
b. Phosphates and nitrates recycling
c. Vertical farming, novel feedstock, e.g. algae oil

Construction industry

a. Recycling of construction waste (e.g. concrete)
b. New materials for construction: wind power, solar power, wave powers, low-carbon cement
c. Recycled materials for composites, composite recycling

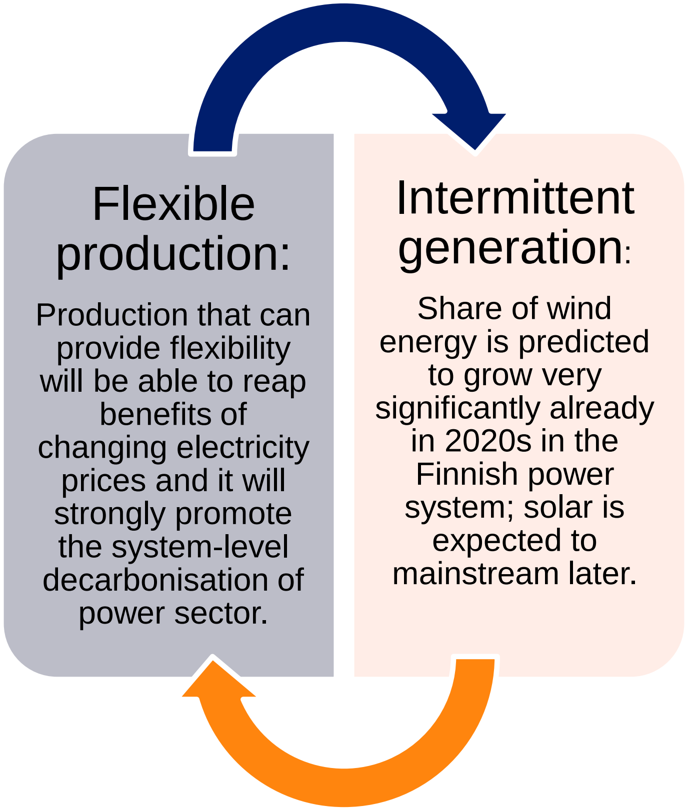
Mining, metals and machinery

a. Production and recycling of battery chemicals, minerals, TiO_2, $CaSO_4$
b. H_2 production to be used in metals manufacturing
c. Equipment manufacturers: hydrolysers, sorting equipment, biomass burners, flaring equipment, E-waste recycling, desalination equipment,

CHEMICAL AND ENERGY SECTOR AS THE ENABLERS OF DECARBONISATION OF EACH OTHER

Decarbonisation of the society depends on the phase out fossil fuels in the energy sector, which benefits from additional demand-side flexibility in the industry

- The profile of electricity demand is one of the decisive factors of feasibility of electricity system transformation.
- Some rules of thumb to consider
  - All production modes will benefit from higher number of operating hours per year
  - All production modes have a threshold value for the price of electricity, above which the production is not economically viable
  - BUT some production configurations may be able to provide flexibility for a specified duration and at a required speed without the economics of the whole facility being heavily affected.
- Possible sources of flexibility include:
  - Electrolysers, fuels cells and synthetic fuels
  - Mini-units capable to adjust production rate
  - Hybrid solutions combining fuel and electricity use
  - Power and heat storage solutions



WHAT CHARACTERISES THE GLOBAL CHEMICAL INDUSTRY?

As intense as many of its processes – and as intensely needed

Diversity

Globally, it has been estimated that there are over 85,000 different chemicals produced commercially. Value chains, raw materials, production processes and markets are vastly different.

Chemical industry includes everything from the largest (petro)chemical plants in the world to family businesses producing niche chemicals and products in small facilities.

Energy-intensity

High temperatures (400-1000°C), pumping and drying are large energy uses in the chemical industry. High temperature heat is typically obtained through combustion of fossil fuels or other feedstock; electric furnaces to reach such high temperatures are expected to become widely available only in 2040s. The majority of GHG emissions (Scope 1&2) in the industry is energy-related; some CO_2 originates from chemical reactions (e.g. production of hydrogen through steam reforming of natural gas).

Capital intensity

Chemical industry is typically very capital intensive, and the investments are made with a time horizon of more than 30 years. Definitive indication of the direction of policy (market, RDD&D and other enablers) is needed in order to spark the investments, given the uncertainties of emerging technologies. Factories can suffer from technical lock-in effects, as incremental improvements throughout the years have made it hard to change the existing process without large stranded assets.

Global

Particularly in bulk chemicals, markets are global and value chains can be very large. In business-to-business, price and reliability are unfortunately often (the only) decisive factors, as bulk products are similar to each other. In specialized products, markets are small, driven by quality competition and higher margins. Price premium for environment-friendliness of products should be promoted.

Investment and RDD&D cycles

Large modifications to existing facilities are not possible without shutting down the plant. These turnarounds (maintenance breaks) occur typically every 4-6 years in a chemical plant. RDD&D projects may require 5-10 years of development before an investment decision is performed. From the investment decision, it may take another 5-10 years before the investment is fully operational. These characteristics emphasize the need for a stable, long-term operating environment and policies.

WHAT CHARACTERISES RDD&D IN CHEMICAL INDUSTRY?

It takes years to deploy new technology

Barriers of successful scale-up

- Long investment cycles, rare opportunities to change the underlying process
- Perception of risks associated with RDD&D projects
- Cyclical nature of business
- Technical lock-in in current processes as a consequence of incremental investments/improvements throughout the years
- Lack of customer-driven demand for low-carbon products
- Overcoming the *Valley of Death,* few opportunities to scale up; the most radical innovations become stuck in pilot phase

2020 (Now)

- Planning for 2025 is starting now / undergoing

RDD&D projects

- Research projects and process development may take 5-10 years even if technology is relatively mature before an investment decision is reached

Installing new technology

- Turnaround opportunities every 4-6 years to install major new technology
- Investments are made for an over 30-year time horizon

Scale-up and start-up

- Construction and commissioning of new production processes, particularly new locations, may take years

2035 (Day after Tomorrow)

- Target year of carbon neutrality of Finland
- Due to long deployment period of investments, decisions need to be made latest by 2025

FINNISH CHEMICAL INDUSTRY, PUNCHING ABOVE ITS WEIGHT GLOBALLY…,

Small country, big global handprint

Product solutions

- **PRODUCTS AND SOLUTIONS** Smart circularity, good processes and practices make winning solutions possible. Many products from different parts of the chemical industry form parts of very complex solutions – which opens possibilities for multiple categories of special knowhow with large impact.

Climate change

- **PROBLEM** Cutting to the core, climate change as a global problem is mainly due to humankind harnessing fossil-based technologies, especially in energy, with great impacts across the globe.

Technology solutions

- **ADOPTION OF TECHNOLOGIES** Starting from technologies instead of products, climate change prevention and mitigation are based on an as-fast-as-rational switch from fossil to low-carbon technologies. This is common for all sectors.

Finnish solutions

- **EXPORT** Finnish chemical industry's potential to combat climate change can fully be used by developing and exporting both solutions and parts of solutions (new business models, industrial processes, new raw materials, material efficiency and circular economy, energy efficiency, low-carbon energy, carbon capture storage and utilisation…).

Global scale-up

- **PUNCHING ABOVE ONE'S WEIGHT The** Finnish chemical industry is not the world's biggest heavyweight, but it punches far harder than it looks capable of. Finnish chemical industry solution potential for climate change far exceeds what can be seen with focus inside Finland's border. Greatly beneficial solutions on global scale may in some case in fact increase the national emissions (as a result of new economic activity in Finland), and the GHG emissions reductions materialize through product use.

THE POTENTIAL FROM SELECTED HANDPRINT SOLUTIONS FAR EXCEEDS CHEMICAL INDUSTRY FINNISH EMISSIONS

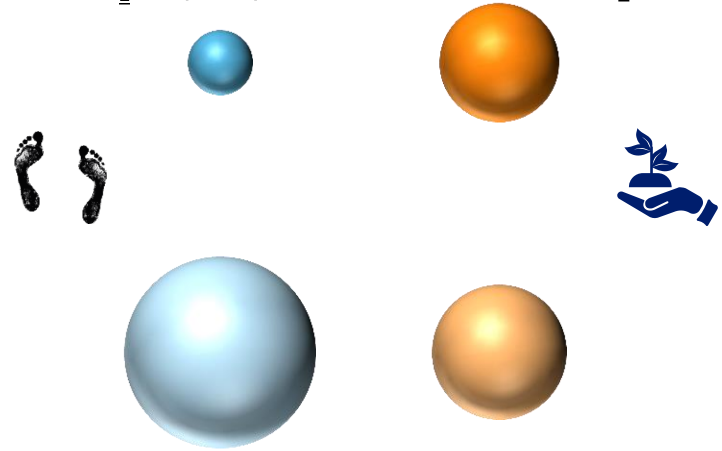
By estimating the handprint potential of key solutions, we can estimate a handprint of at least 4 times that of chemical industry CO_2 emissions in Finland

Outcome	Comparison

- The chosen, representative and varied key technologies and products represent both current and under-development products and technologies. Many of them still require scale-up for the handprint potential to be fully realized.
- The key solution sample's potential handprint is estimated at 26 $MtCO_2e/a$, of which 5 $MtCO_2e/a$ represents solutions further from market today.
  - Closer to market solutions refer to products and processes that are considered already commercial or close to commercialisation. Investments in Finland are primarily not constrained by technical immaturity.
  - Further from market solutions refer technologies that are still relatively immature but hold considerable potential for future.
- *The analysis represents only a very small part of the thousands of chemical industry products,* and in reality the impact is probably significantly greater. It should be noted that all estimates have uncertainties regarding e.g. market share, comparison solution and low-carbon impact.
- However, the estimate shows the great potential Finland has and which can be realised if innovative RDD&D is implemented and exported.

Chemical industry own CO_2-emissions in Finland (scope 1 and 2), 5.4 $MtCO_2e/a$ (2019)

Estimates for export solutions closer to market, potential global handprint of about 21 $MtCO_2e/a$

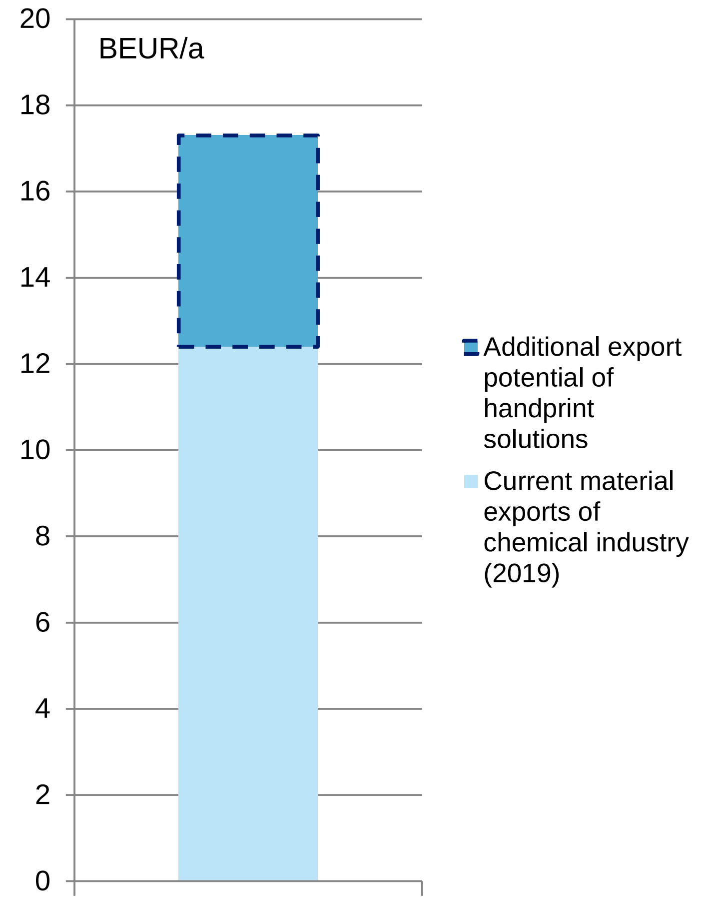


Finnish national GHG emissions, 53 $MtCO_2e/a$ (2019)

Estimate including solutions further from market, potential global handprint of about 26 $MtCO_2e/a$

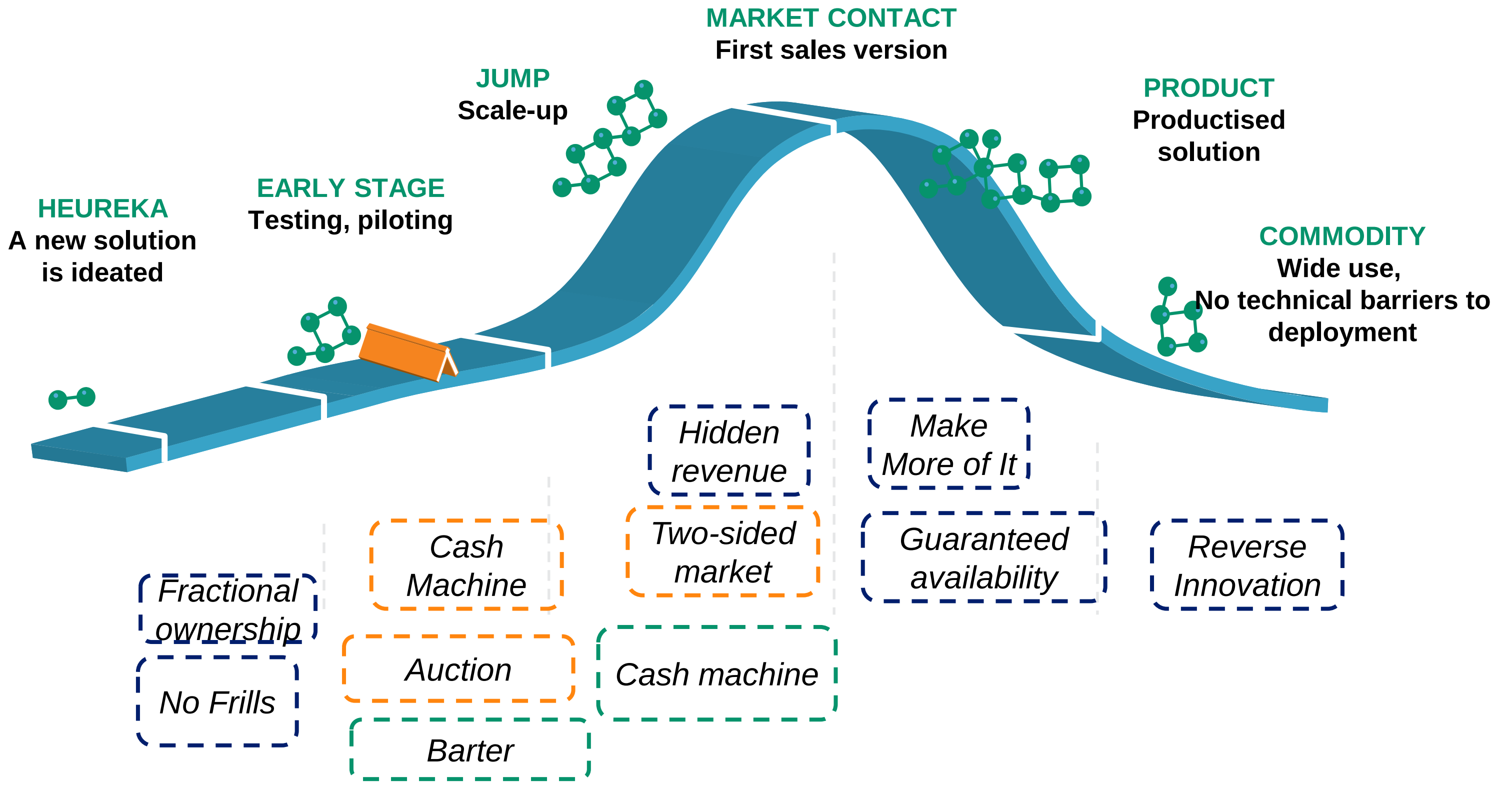
THE ADDITIONAL EXPORT POTENTIAL OF HANDPRINT THE SELECTED HANDPRINT SOLUTIONS IS CLOSE TO 5 BILLION EUROS ANNUALLY

- The additional export potential of the selected handprint solutions is ca 4.95 BEUR annually. This represents a potential 40% increase to the current exports of chemical industry.
  - Compared with the exports growth of ca. 2 BEUR/a between 2008–2019, this would mean a very notable increase compared to past trends.
  - The solution is based on current estimates of price premiums of handprint products. These premiums are still relatively moderate, as many companies and consumers have only in recent years become aware of the added value of low-carbon products. Therefore, the price premiums of low-carbon products may increase further compared to fossil products in the future through changes in consumer behavior and regulatory requirements.
- Additional potential benefits of the handprint cases include reduced imports, avoided incineration and waste treatment costs – and of course the very significant CO_2 mitigation in addition to other environmental benefits.



SPEEDING UP TECHNOLOGICAL DEVELOPMENT: INITIAL BUSINESS MODELS

In addition to conventional RDD&D-instruments, it might be useful to test new business models and incentives in a new situation. Below, business models placed along the timeline of development, explanations on the next page.



BUSINESS MODELS IN SHORT

Four categories of model goals

Differentiate/Fill gap

- **No frills**
  Instead of the fairly common tendency to over-engineer (because the technology is so beautiful), focus on filling a perceived market gap/planet saving gap with the minimum possible features, to get to the market quickly.

Commercialisation

- **Cash Machine**
  The whole estimated RDD&D sum, (or a significant portion) is paid up front to the developer. Liquidity crises that have overturned promising technologies are avoided.
- **Auction**
  Exactly what it sounds like: can be connected to Cash Machine. The developer commits to selling the whole/a part when the technology reaches a certain stage, and continues as support.
- **Hidden revenue**
  Alternative to Cash Machine: funder/investor acting as ”proxy” client, funding parts it finds interesting and of value to potential clients and thus steering development
- **Make More Of It**
  Know-how scaled up, so as to get additional income by using own resources also as e.g. development-for-hire.

IPR

- **Barter**
  Two developers need pieces of tech the other is evolving – a barter is agreed where parallel development without cash transfer gives both access to both – and the overall market readiness increases for both.
- **Two-sided market**
  A special ”marketplace” between multiple parts of chain, linking potentially to Cash Machine-Auction combination.
- **Fractional ownership**
  At early stage, when many parts of the chain have only limited interest in the concept, making possible a small fraction interest, possible as an option to invest in part of larger facility later in exchange for small funding.

Export

- **Reverse innovation**
  Using emerging market low-grade innovation (e.g. Indian ”jugaad”), ”making the simple idea just suitably more complex” and adapting to developed markets.
- **Guaranteed availability**
  Often key failure factor: no trust in secure access to new commodity. E.g. larger partner stepping in to guarantee that against relevant compensation.

UNCERTAINTIES AND CONDITIONALITIES

Preconditions and uncertainties related to carbon neutrality with a time horizon of 2050 are numerous

Technology availability

- All technologies that need to be deployed are not technically ready yet. Commercial availability may be decades away, and notoriously hard to predict. Competitiveness of low-carbon technologies compared to fossil ones (from company point-of-view) will be one of the deciding factors of the speed of transition. The more ambitious scenarios rely on an optimistic estimate of key technology availability.
- Scenario outputs (electricity demand, CO_2 capture demand, alternative feedstock demand) are *highly sensitive to choices of technologies*, which are partly over-lapping and interdependent alternatives to each other. In addition, results are very sensitive to assumptions about production volume growth and product portfolio.

Investments

- Investment levels in both RDD&D and new assets need to increase already in the next ten years. Impacts on business may become significant in the globally intensely competed market.

Energy market and use development

- Low-carbon energy-intensive industry of the future will (by definition) be located where there will be low-carbon energy available reliably in large quantities at a competitive price.
- Energy demand (both electricity and heat) is highly influenced by the extent and type of feedstock changes, which may significantly increase the energy demand. On the other hand, fundamental process changes may change how much excess heat (steam) there is from processes to be used elsewhere (other processes or district heating, for example).

Regulatory environment and politics

- New (national and EU) regulation can create incentives or hurdles for the transition.

Effects of climate change

- Direct effects of the root cause for the transition may already be felt across the industry (feedstock availability, extreme weather, market environment, etc.).

Unknown unknowns

- There is life beyond the efforts to carbon neutrality, and chemical industry in Finland will also in the future be exposed to global stormwinds.

IMPLICATIONS FOR THE NATIONAL FRAMEWORK…

Chemical industry can deliver decarbonisation reaching the core of modern societies, given the enablers are in place

Knowhow, innovations, RDD&D

- Additional resources into education, knowhow and interdisciplinary expertise targeted at climate solutions and low-carbon technologies are essential to be dealt immediately.
- Funding of research and development must be secured, while extending the channels of finance to cover demonstration and deployment phases, supporting industrial scale-ups and technology commercialisation.

Promoting exports

- Paths to commercialisation and to global markets will be ever more important in the future, as the industry scales up low-carbon solutions.
- Promoting a supporting international framework is a key aspect even from national perspective.
- All human activity comes with environmental impacts, which should not limit the most innovative sustainable solutions being manufactured in Finland.

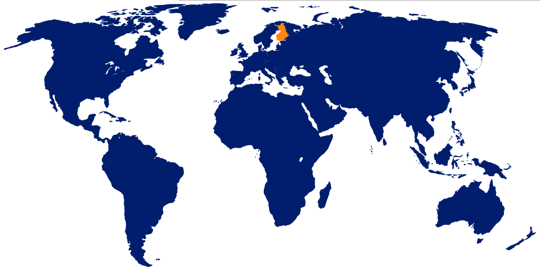
Industrial and technology policy

- Seeing the industry as a part of the solution or a part of the problem impacts the policy toolbox. Chemical industry embraces the Paris Agreement – how can domestic industrial and technology policy speed up the transformation, considering global competitiveness aspects?
- Reliable, inexpensive and low-carbon energy is key, as well as the necessary recycling infrastructure of materials.

New business models

- Handprint solutions are based on the use of the product or service.
  - Technology as an export product, licensing; need for enabling IPR environment
  - Piloting environment as a export product
  - Enabling sector integration through circularity

…EMPHASIZING THE GLOBAL LEVEL



Solutions must be reached on the global level

European Union level

- EU is the most significant channel of Finland to impact global affairs, while the decisions made in Europe also fix the operating environment of Finnish industry to a great degree.
- From the view point of climate initiatives in the industry, the core areas in EU include the Green Deal and Green Recovery, mechanisms to set the CO_2 price and development of the EU ETS and the taxonomy of sustainable finance.

Trade politics

- Trade policy is the tool to reach a level playing field for industry.
- The transformation of industry towards climate neutrality can only be performed if it is also sustainable economically to the participating companies.
- The global uptake of Finnish handprint solutions could be leveraged also through trade policy.

International climate politics

- International climate negotiations have a key role for reaching the Paris Agreement goals.
- Increasing the global coverage of strict environmental and climate regulation and their further development could be very beneficial from the viewpoint of European industry's competitiveness.

Broader Sustainability Agenda

- Climate change is only one (though a key) aspect of environmental problems, which also include e.g. loss of biodiversity, water scarcity issues and overuse of natural resources.
- Chemical industry provides not only environmental solutions, but also serves core societal needs in the fields of food and pharma, for example.
- Other aspects of sustainable development (economical, social, cultural) cannot be sacrificed on the altar of the climate change – rather, they must be considered absolutely essential for succeeding in global efforts to mitigate and adapt to climate change.

PÖYRY
The connected company

The leading advisor to the world's energy, forest and bio-based industries. Clients choose us for the sharpness of our insight, deep industry expertise and proven track record – because results count.

Pöyry Management Consulting