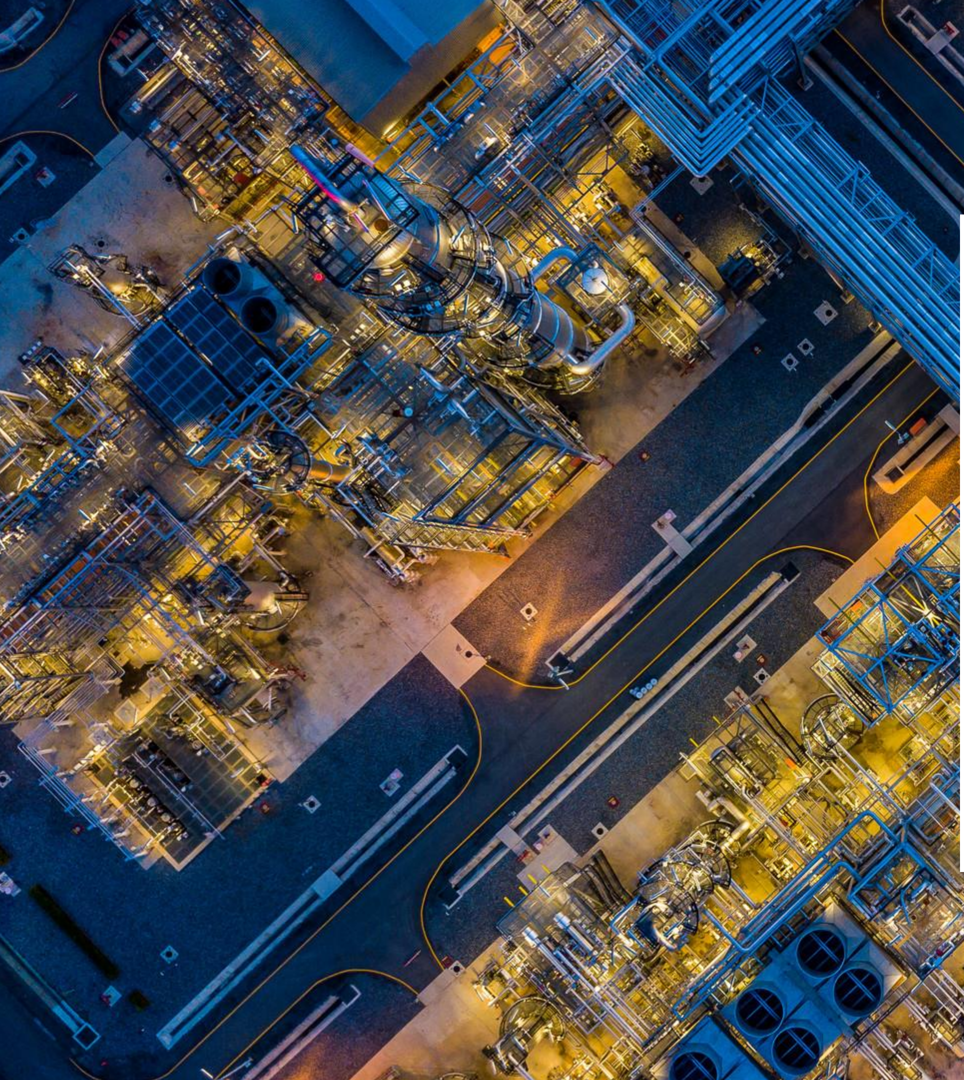

KEMIANTEOLLISUUS

VTT

The Chemical Industry Federation of Finland

Future directions through strategic foresight

2024 VTT – beyond the obvious

Introduction

This results report summarizes the findings and implications of comprehensive horizon-scanning analyses VTT has conducted for **The Chemical Industry Federation of Finland** in early 2024. It provides a comprehensive outlook on the industry's future, considering **sustainability, business, technology, and societal perspectives**.

The foresight-driven study examined **the chemical industry as a single entity** but also considered the perspectives of energy-intensive chemistry, reaction chemistry, inorganic chemistry, formulators, and converters. The objective was to provide insights into emerging trends, risks, and technologies expected to shape the future of the chemical industry.

The central element of the foresight report is **the Future Radar**, which provides chemical companies with a tool for conducting internal discussions on future opportunities and risks. It also offers tools for collaborating with stakeholders to build the future together.

Following the presentation of the Future Radar results, the report offers guidance on using foresight information and continuing the foresight journey.

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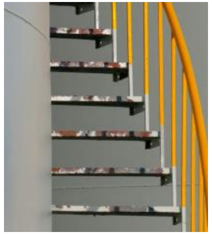
Executive Summary

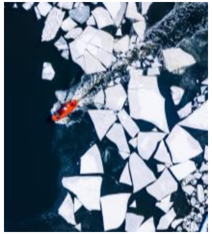
From Megatrends to Shaping Our Futures



Future Radar of Finnish Chemical Industry

From Insight to Action

Conclusions by Radar Dimensions



Future Radar Methodology

Authors and Contributors

Selected Literature Sources

Executive Summary

Executive Summary

This study aimed to identify the building blocks of **a desirable future** for Finnish chemical companies. The following signals summarize findings from the Future Radar, used for horizon scanning.

More **efficient recycling, CO2 capture and reuse, and bio-based feedstock** are driving the development of a more sustainable chemical industry. These technologies offer promising technological opportunities but also require **restructuring the chemical value chain**.

Quantum computing and AI will profoundly affect the future development of new materials. **In silico R&D** can ultimately change the basic requirements of R&D, shifting away from traditional labs.

The **talent availability crisis** is already acute and will be increasing in the future. The ageing population diminishes the talent pool, and technological development intensifies the need for sophisticated expertise. Adaptive and agile educational models help transform the skills of the workforce. Societally, a stronger emphasis on STEM education is acute.

Geopolitical tensions and competition over critical resources have intensified in several regions. **India** is becoming an increasingly important chemical manufacturing hub. **Africa** has abundant resources and the largest and youngest working-age population in the future. As the polar ice is melting, a "gold rush" for minerals, oil, and gas is emerging in the **Arctic**. In addition, actors such as NASA have initiatives to harvest raw materials from space. The sustainability issues related to these developments can be drastic.

Decoupling economic growth from the use of virgin raw materials is a fundamental theme in European policies now and in the future. It also drives the development of circular business models, localized value chains, and new materials in the chemical industry.

The **capability to partner with customers**, understand their business, and be more than a raw material supplier becomes integral. **Business models such as CaaS** and chemical leasing are supporting this transition.

From Megatrends to Shaping our Futures

From Megatrends to Shaping Our Futures

From the Finnish chemical industry's viewpoint, several significant megatrends are challenging current business processes, value chains, products, and markets. These trends include shifting to renewable and recycled feedstock, embracing AI and data as a transition accelerators, talent availability, and geopolitical tensions. Often trends seem too overwhelming to grant us a say on the future. **Strategic foresight provides tools and the mindset** to harness the momentum of these driving forces to create new business opportunities and shape the future. It empowers those who want to be proactive rather than reactive.

Shifting to renewable and recycled feedstock

AI and data as transition accelerators

Talent availability crisis

Geopolitical tensions

TIP. Adam Gordon's DEFT framework helps identify the underlying factors behind a trend. The framework comprises four main components: Drivers, Enablers, Frictions, and Turners. Drivers are the forces that initiate and sustain a trend, while Enablers are the catalysts that support these drivers. Friction represents the resistance that impedes a trend, and Turners are the events that actively block a trend. This framework helps to organize, analyze and dissect factors that underlie the often too vague or lofty megatrends and contribute to or hinder success on the business-level.

Shifting to Renewable and Recycled Feedstock

The move towards renewable and recycled feedstocks involves substituting traditional fossil-based feedstocks with sustainable alternatives such as biomass, recycled materials, and captured carbon dioxide.

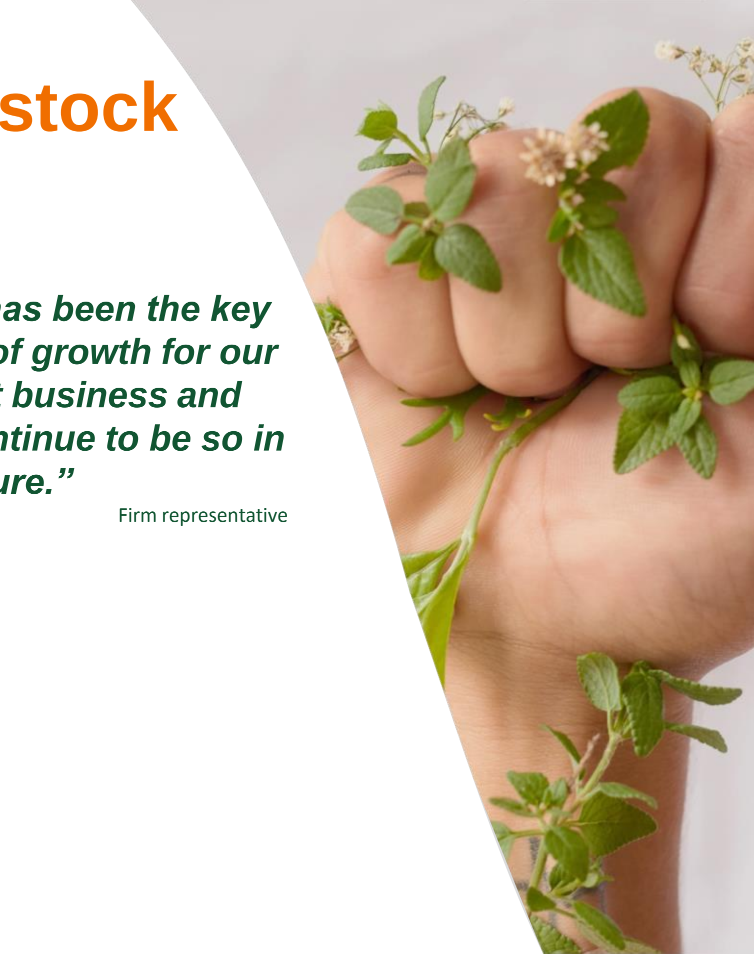
This transition is driven by the need to achieve climate goals, establish a circular economy, and decouple from oil. Advancements in technology, closed-loop supply chains, and the development of a hydrogen economy have facilitated it.

Although this shift presents challenges related to feedstock availability, legacy infrastructure, investment cycles, traceability as well as technology, funding, regulatory and business risks, it also **creates opportunities for innovation and collaboration.**

The chemical industry is leading in this transition, and several companies are already making significant progress. In fact, as part of many cross-industrial value chains, the chemical industry's progress is a crucial condition for the successful sustainability transition of numerous other sectors. Overall, the shift is crucial in achieving a sustainable and circular economy and mitigating the effects of climate change.

"This has been the key driver of growth for our current business and will continue to be so in the future."

Firm representative



AI and Data as Transition Accelerators

AI and data analysis rapidly accelerate the shift towards a more sustainable future. AI algorithms assist **in designing sustainable, often significantly improved materials and discovering alternative, eco-friendly chemical processes, products, and services**.

AI data analysis enables greater **transparency** and tracking within chemical supply chains, crucial for meeting regulatory standards. By analyzing vast chemical data sets, AI is boosting **production efficiency** and reducing overall costs for companies in the chemical industry. Both **work safety** and **quality** of production are improved as AI will support in creating early warnings via real time analysis of processes. Enabling **industrial metaverse** solutions and **automation**, AI is further expected to alleviate the looming **talent availability** crisis.

However, companies might face challenges investing in AI and hiring experts to work on and with it. Companies may also be hesitant to share their proprietary data, and ensuring data accuracy and security is crucial. While AI has immense potential to contribute to a more sustainable future, it must be used responsibly.

"Utilization of AI will most likely bring huge new opportunities beyond current imagination."

Firm representative

Talent Availability Crisis

The chemical industry faces a critical talent shortage driven by evolving skill demands, the accelerating pace of digitalization, and questions regarding the industry's overall attractiveness. Finding workers with multidisciplinary skills essential for the digital era is increasingly difficult, compounded by global talent competition and an ageing workforce.

This crisis necessitates retraining and upskilling existing employees, forming solid educational partnerships, and revamping employer branding to **attract younger generations passionate about sustainability**.

Potential solutions to promote sustainability in the chemical industry include rebranding the industry, reforming educational programs, expanding international talent acquisition, and leveraging automation and AI.

"To be a leader, which is the ambition of many Finnish companies, requires access to top talent."

Firm representative

Geopolitical Tension

Global development is facing **challenges and opportunities** due to rising geopolitical tensions, exemplified by Russia's invasion of Ukraine, China's assertive pursuit of technology and raw materials, India’s rise to influence and the growing rivalry between the US and China.

The conflict between Russia and Ukraine highlights the urgent need for countries to diversify their energy sources and adopt renewable technologies. China's pursuit of technological dominance and control over rare earth minerals shows a future economy reliant on technological supremacy.

The rivalry between the US and China drives rapid advancements in critical fields such as quantum computing, cybersecurity, and space exploration. Maintaining stable operations and supply chains for multinational companies is challenging but Finnish companies **can benefit from resilience strategies that drive localization** when their customers reorganize supply chains.

“Putin speeds up the EU green transition.”

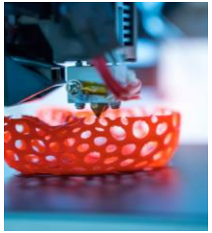
van der Leyen

Future Radar of the Finnish Chemical Industry

Content

Future Radar of Finnish Chemical Industry

Highlights of Sustainability Signals



Highlights of Technology Signals

Highlights of Society Signals

Highlights of Business Signals

Finnish Chemical Industry's Future Radar

Short Trend Descriptions

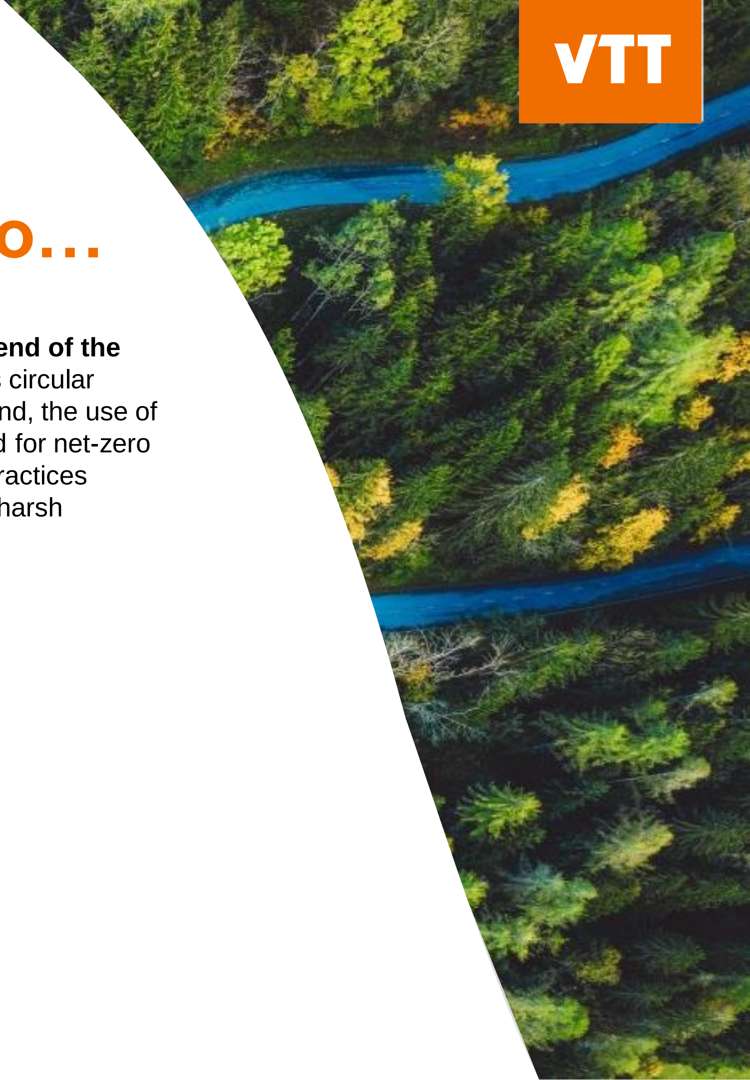

VTT
Sustainability

Sustainability highlights the needs and challenges related to…

The **capability to grasp holistic sustainability** through creating transparency across the value chain and tracking indirect emissions, designing and innovating sustainable and safe chemicals aligned with biodiversity goals, and building bridges for efficient use of raw materials and raw material independency.

Deploying new and more **sustainable feedstock opportunities** ranging from reuse of residues and harnessing the benefits of developing a hydrogen economy.

Transitions taking place **at the end of the chemical value chains**, such as circular battery ecosystems gaining ground, the use of sustainable fuels being prioritized for net-zero transportation, and agricultural practices transforming towards using less harsh chemicals.



Technology

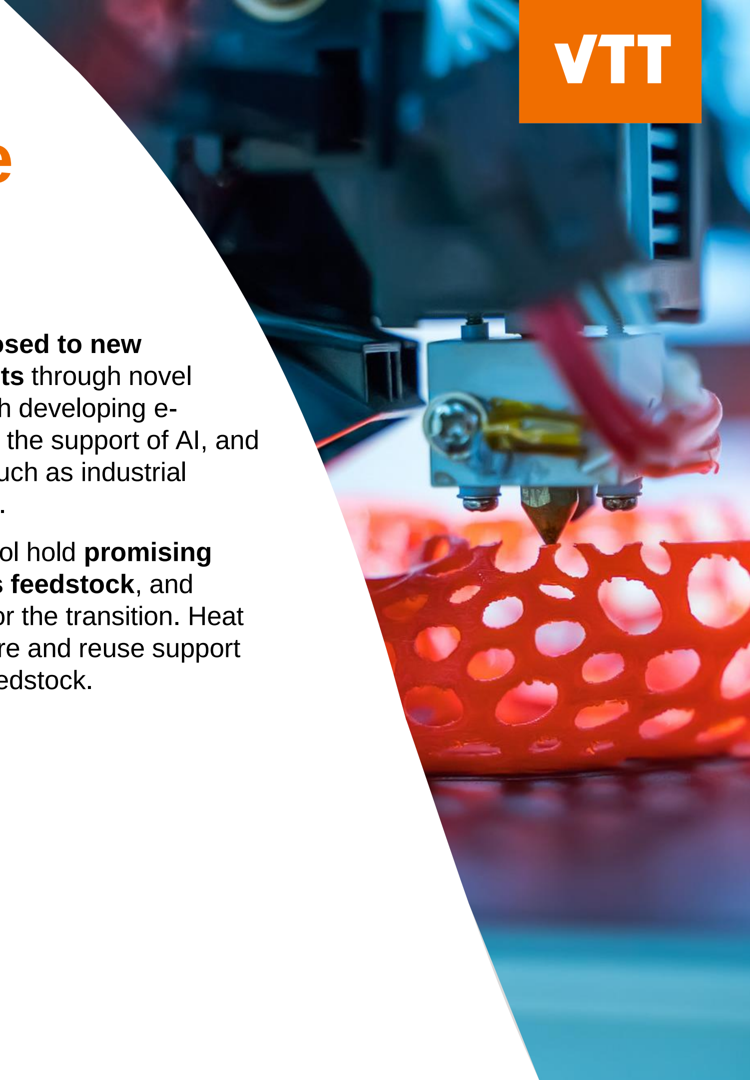
Technology guides through the transitions as…

New materials and innovative material development technologies are gaining ground. **New materials** such as graphene, metamaterials, programmable materials, and biodegradable electronics **are providing new advanced features** with potential new use cases.

Artificial intelligence and increasing quantum power hold **disruptive capabilities for research and development**. Similarly, synthetic biology, nanotechnology, and 3D bioprinting provide **innovative ways to engineer new materials**.

Chemical processes are posed to new technological advancements through novel catalyst technologies, through developing e-cracking technology, through the support of AI, and with assisting technologies such as industrial metaverse in factory settings.

Green ammonia and methanol hold **promising opportunities as chemicals feedstock**, and green energy is an enabler for the transition. Heat integration and carbon capture and reuse support creating more sustainable feedstock.



Society

Society describes the transitions within the operating field as…

The society sector encompasses transitions that relate to **demographic shifts, value changes, and systemic societal challenges**.

A shift towards **valuing environment and well-being over pure economic growth** can lead to stricter regulations and new expectations from emerging generations entering the workforce. **Aging populations in developed countries shift workforce compositions**.

Decoupled and “post-growth” economic models demand circular operations and smart resource use.

Political instability and a global trend towards authoritarianism will likely continue to cause tensions between nations and regions, resulting in trade wars, cyber-attacks, and military conflicts, increasing value chain fragility.

Business

Business provides ..

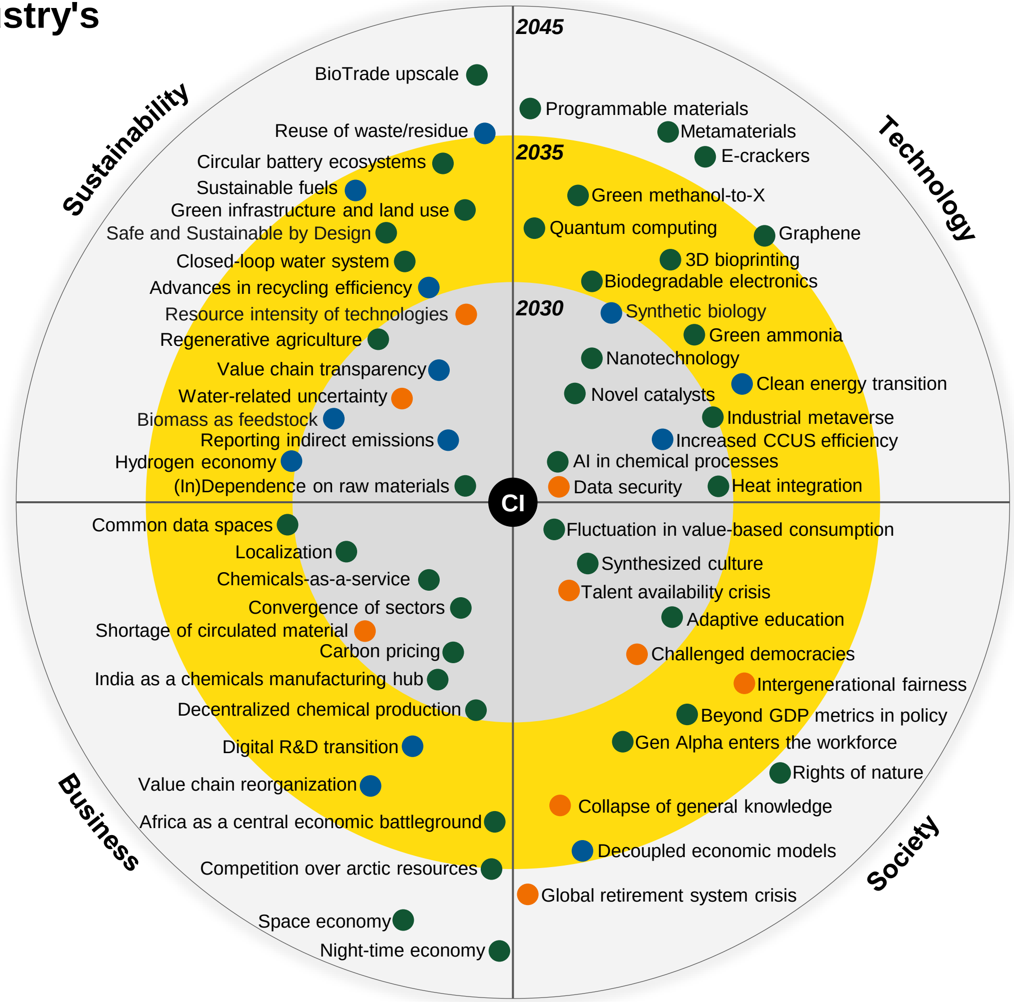
The business sector transitions point towards changes in the **economic landscape, industry dynamics, and operational models**.

The shift toward chemicals-as-a-service and decentralized chemical production points to a need for the chemical industry to adopt more distributed, customer-centric business models that provide not just products but also services and solutions.

Africa's emergence as a central economic battleground and competition over arctic resources suggest that the chemical industry must be prepared to operate in a globally interconnected and politically sensitive resource market

The digital R&D transition indicates a move towards leveraging digital tools and data analytics for research and development, which requires next-gen laboratories, startup collaborations, and participation in the innovation ecosystem.

Finnish chemical industry's Future radar



Trend
High-priority trend
Risk

The **placement** of a trend is an estimation of its mainstream adoption.

The **priority** is based on the assessment of a trend's impact and probability for the chemical industry.

Sustainability Trends - Short Trend Descriptions

Advances in recycling efficiency: Chemical recycling is an integral part of the circular economy, tackling the challenges that mechanical recycling poses. The field holds many promising technological developments, e.g., in terms of lowering the energy needed in the process or bettering plastic quality. In addition, AI can provide developments in recycling.

Biomass as feedstock: Biomass and even second-generation biomass can be used as feedstock for the chemicals industry. Attention must be steered towards sustainable sourcing of biomass.

BioTrade upscale: BioTrade refers to the sustainable collection, production, transformation, and sale of goods and services derived from biodiversity. It was thus created to promote the trade of biodiversity-derived products and services. It's considered emerging as the new fair trade.

Circular battery ecosystems: The automotive sector is one driver, but stationary applications such as local energy storage systems also increase the need for batteries. As battery production stages rely on precious metals (e.g. lithium, copper, catalysts), increasing the recycling efficiency of battery materials and intensifying the ecosystem around the recycling and reuse of batteries becomes highly important.

Closed-loop water system and management: Water scarcity is driving more efficient water management, and regulations are setting guidelines for this. Companies can take action by paying attention to efficient water consumption and reuse. Innovations are required, e.g. in identifying new, more efficient ways to produce fresh water for hydrogen production.

Green infrastructure and land use: Infrastructure (e.g. microgrids, biorefineries, etc) is paramount in securing chemical industry's access to energy and feedstock. Chemical companies can also support nature conservation and restoration by developing green infrastructure, like wetlands.

Hydrogen economy: The European Clean Hydrogen Alliance is supporting the large-scale deployment of cleantech by 2030. Low-CO2 hydrogen has a vital role as a sustainable fuel and as a decarbonized feedstock.

(In)Dependence on raw materials: The chemical industry relies heavily on raw materials. While measures are taken to ensure secure access and supply of raw materials (EU's Critical Raw Materials Act), actions must also be steered towards reducing dependency on them altogether through innovation and substituting materials (e.g., biomass).

Resource intensity of technologies: Modern technology solutions that support sustainable and digital transition, are also increasing the demand for critical raw materials. Fields that are growing the demand are for example, chip manufacturing, battery technology, and renewable energy transition.

Regenerative agriculture: Farming practices that rebuild soil and restore degraded soil biodiversity. It reduces, for example, the reliance on harsh chemicals and improves land use efficiencies.

Reporting indirect emissions: Companies in Europe must report their indirect emissions across their value chain, known as scope 3 emissions. This requires transparency across the value chain.

Reuse of waste/residue: Waste and other residues can be used as alternative feedstock. Even though processes already lean on waste as secondary raw materials (e.g. biofuels), the overall rate of scaled initiatives could be higher, and many challenges remain related to the quality and usability of waste as feedstock.

Safe and Sustainable by Design: The shift towards safe and sustainable design is driven by heightened environmental and health awareness, reinforced by data availability, research, regulatory pressure and evolving markets. EU's voluntary approach for promoting innovation for safe and more sustainable chemicals and materials takes a holistic view on sustainability.

Sustainable fuels: Processes such as turning plastic waste into fuels and using solar energy to drive fuel creation are ongoing developments in the field.

Value chain transparency: Supply chain, product and raw material traceability is an increasing end-customer demand. Pressure for transparency also originates from policies. Transparency can be supported with technologies such as blockchain.

Water-related uncertainty: The global mean sea level reached its highest value in 2022, and flooding is already threatening chemical factories. Increasing water scarcity, another water uncertainty posed in the current state, can increase competition over clean water resources and the cost of clean water.

Technology Trends - Short Trend Descriptions

AI in chemical processes: Artificial intelligence could be used to speed up the discovery of new materials. It can also enable predictive models to optimize chemical operations, and sales processes.

Biodegradable electronics: The increasing integration of technology into human body is driving the need for organic, toxin-free, and safe devices.

Clean energy transition: Electrification is an integral enabler in the chemical industry's decarbonization. Developments in sustainable energy sources (e.g., wind, fusion), decentralized solutions, and energy storage systems are driving the transition. For example, chemical parks can have the potential to enjoy economies of scale for self-produced green energy.

Data security: As the chemical industry experiences transformational changes with integrated information technology systems, benefitting from improved operational efficiency and R&D, the risks related to cybersecurity also increase. Cybercrime risks range from production downtime to environmental contamination and worker safety risks.

E-crackers: Steam crackers produce basic chemicals. Electrically heated steam cracker furnaces could significantly reduce CO_2 in the process. In 2022, construction of the world's first demonstration plant for large-scale e-cracking started.

Graphene: Graphene has superior capabilities compared to many known materials. It's light, durable, and very translucent, and it also conducts heat and electricity well.

Green ammonia: Ammonia production is one of the most significant contributors to scope 1&2 emissions. Ammonia produced using renewable energy sources has multiple future use cases. One is a sustainable replacement for maritime fuel. Ammonia can also be used as a hydrogen carrier.

Green methanol-to-X: Green methanol is a new technological platform for synthesising olefins and aromatics using non-fossil feedstock.

Heat integration: Heat integration connects heat sinks and sources to use residual heat effectively. Due to the gas shortage, heat integration technologies have recently become more available.

Increased CCUS efficiency: A group of innovations increasing the speed and throughput of carbon capture, utilization, and storage systems. Development, e.g., in capture materials, in addition to DAC technologies and carbon scrubbers, enables using captured CO_2 as feedstock.

Industrial metaverse: The industrial metaverse has the power to profoundly change how chemical factories work. It refers to the combination of physical and virtual work environments, allowing work that isn't dependent on place and time.

Metamaterials: Metamaterials are artificial materials engineered to have properties not found in nature. They are created by arranging materials in a specific pattern or structure that alters how they interact with electromagnetic waves, acoustic waves, or other types of waves.

Nanotechnology: Nanotechnology manipulates matter on a near-atomic scale to produce new structures, materials, and devices.

Novel catalysts: Catalysts are used to speed up chemical reactions. As feedstocks become more complex and their quality varies (e.g., biomass, waste), novel catalysts are required. Innovation must be steered towards reducing the energy consumption and costs within the process.

Programmable materials: These are next-generation materials that can change their physical properties in a programmable fashion based on user input or autonomous sensing.

Quantum computing: Quantum computing has the potential to solve complex problems that would take years to solve using classical computing in just a few seconds or minutes. It enables chemists to understand molecular structures and interactions on a quantum level, which helps them design more efficient catalysts, materials, and chemical processes.

Synthetic biology: Syn-bio is a product and process disruptor. The disruptive impact is starting to become visible, e.g., in medicine and electronics, and it's steering towards chemicals, agriculture, and further fuel within the next ten years.

3D bioprinting: 3D bioprinting refers to creating functional structures that imitate biological tissues and organs. This technology can potentially disrupt industries such as tissue engineering and medicine.

Society Trends - Short Trend Descriptions

Adaptive education: Adaptive learning or education refers to the use of adaptive learning tools, such as AI algorithms, streaming video, gamification, and online collaboration, to personalize and enhance the overall learning experience.

Beyond GDP metrics in policy: Recent developments, such as climate change and the pandemic, have made it increasingly clear that GDP is incomplete as a measure of progress.

Challenged democracies: More countries are developing towards authoritarianism than democracy.

Collapse of general knowledge: The level of general knowledge may decline or even collapse. In the worst case, this will lead to the emergence of social bubbles within which there is hardly any knowledge about the lives of those in other bubbles.

Decoupled economic models: Decoupling economic growth from resource use will be the pivotal challenge for a new economic model. Europe has been successful in reducing CO_2 emissions substantially despite continued growth.

Fluctuation in value-based consumption: Value-based consumption, meaning values driving consumption decisions (over other attributes such as price, convenience, brand, etc.), is declining due to, e.g., inflation and the cost of living.

Gen Alpha enters the workforce: This generation will be permanently connected to the internet, socially aware, and more culturally diverse than the previous generation.

Global retirement system crisis: The increase in life expectancy and decline in fertility rates are increasing the dependency ratio and devastating the financial foundation for state pensions. Many developed countries find it challenging to provide pensions within a generation's time.

Intergenerational fairness: Young people are better educated yet have less disposable income than previous generations and are more likely to work in unstable forms of employment. Children born in 2020 will experience a two- to sevenfold increase in extreme weather events and the associated health risks compared with people born in 1960.

Rights of nature: The rights of nature are a compelling and evolving field that seeks to recognize the intrinsic value and rights of natural entities beyond their utility to humans. Recognizing the rights of nature represents a potential paradigm shift.

Synthesized culture: GenAI is creating cultural artefacts that result in a human-machine culture.

Talent availability crisis: Talent availability crisis is affected by industry appeal, working conditions, and requirements for new capabilities due to technological development.

Business Trends - Short Trend Descriptions

Africa as a central economic battleground: By 2040, Africa is expected to have the world's largest working-age population. The continent is also experiencing steady economic growth, and the area of Sub-Saharan Africa has rich natural resources.

Carbon pricing: According to Systemiq's report, carbon pricing is the most appropriate incentive to support the chemical industry's sustainable transition. It's the EU's instrument targeted at the economy's carbon footprint. Broadening coverage for carbon pricing will take place in 2027.

Chemicals-as-a-service: The CaaS business model shifts towards a value-based model focusing more on service provision with close supplier-customer relationships. By managing materials and chemicals' lifecycles, the CaaS business model can contribute to their circularity.

Common data spaces: Data spaces are about increased transparency and efficiency of processes. Many Common European Data Spaces are developing (e.g., in agriculture, health, and skills).

Competition over Arctic resources: The Arctic is home to various raw materials crucial to the chemical industry. As demand for these resources grows, competition between countries and companies to secure access increases.

Convergence of sectors: Aiming towards the chemical industry's decarbonization requires deeper engagement with adjacent segments (e.g., renewable energy providers, end-of-life disposal), which steers companies to expand horizontally and vertically.

Decentralized chemical production: Chemical production is becoming more capital-light, decentralized and located closer to the point of use. Decentralizing production away from fossil-based economies can also take place.

Digital R&D transition: Artificial intelligence and quantum computing can be significant catalysts in speeding up new material discovery and other industry research and development processes. Development process efficiency can also become visible in requirements for future laboratory settings.

India as chemicals manufacturing hub: India has been a global outperformer in demand growth and shareholder wealth creation. By 2040, India is expected to triple its global market share, with the speciality chemicals segment expected to be a net exporter.

Localization: Geopolitical conflicts and protectionism are driving the deglobalization of supply chains. For example, China's potential decoupling is steering companies to re-base supply chains closer to core markets.

Night-time economy: Night-time operations are increasing, e.g. in heat-stressed regions.

Shortage of circulated material: In a small market like Finland, the demand for recycled raw materials may exceed the supply. This can lead to a shortage of materials and the need to transport them long distances, which is expensive and unsustainable.

Space economy: The space market is expected to grow to $1 trillion by 2030. Space can offer suitable conditions for space-based production of certain products (e.g. pharmaceuticals), energy production, space agriculture and extraterrestrial mining.

Value chain reorganization: Value chains are being restructured to prioritize sustainable, biobased, and recyclable materials. To meet this demand, new industrial areas must be created where recyclable materials can be processed close to their source.

From Insight to Action

Content

From Insight to Action

How to use the results for action-oriented purposes and tangible impact?

From Insight to Action

Harnessing the Future Radar results to inform the development of purposeful actions with identifiable benefits

What are the recommended next steps in each chemical industry sector?

Taking the Next Steps

Developing sector specific implications based on the Future Radar results

How to use the results as a solid foundation for exploring the future further?

Foresight Journey

Using the Future Radar results as the fundamental building blocks of alternative futures and raw material for inspiring visions

From Insight to Action

FUTURE RADAR

Building blocks of the future

EARLY WARNING

Changing operating environment – Wild cards – Shifting technology – Societal change

FUTURE MARKETS

New markets - Evolving needs – Unforeseen competition – New partnerships

REDUCED UNCERTAINTY

RDI agenda – Industry dynamics – Societal trends

PRIORITIZATION OF ACTIONS

Relevancy of trends – Degree of urgency – Scale of impact

OPINION LEADERSHIP

Key stakeholders – Internal organization – Decision-makers

FOSTERING FUTURE ORIENTED CULTURE

Employer engagement – Forerunner mindset - Proactivism

Strategic Assessment of Trends in Business

It is recommended that you adopt a systematic approach to effectively exploring the presented trends in strategic and innovation management. Gather representatives from **different business functions** and analyze how each relevant trend could **impact your company**. Make a **gap analysis:** Are there trends that you haven't considered before? **Identify opportunities** and potential **challenges** within your business ecosystem related to them. Develop a **list of strategic measures** for exploiting the identified opportunities and making your organization resilient against the threats. **Prioritize the measures** and **start acting** on the top 1-3 **today**.

Opportunities

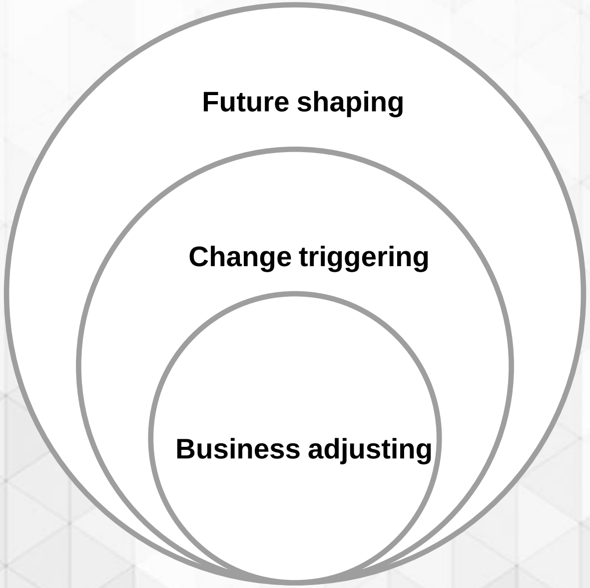
Threats

Strategic measures

Action

Building Futures Together

The chemical industry is moving towards sustainability through **systemic innovations** such as effective recycling, carbon dioxide capture and reuse, and the use of bio-based feedstock. Chemical companies need to collaborate with various stakeholders, including **in the field of foresight**, for the successful implementation of innovations. The chosen approach will depend on the company's specific goals and timeframe.



Anticipating and shaping the futures over industry borders through making-sense of dynamics in unforeseen circumstances

Triggering the change, and breaking the current path-dependencies with novel partners through knowledge building and identifying a variety of futures

Identification of business opportunities and developing offering with known partners through sharing knowledge and analysing future needs

Source:Valkokari, Paasi, Apilo, Nuutinen, 2023

Sector-specific implications

Taking the Next Steps
Converters

To remain vital in the supply chain, converters must adapt to meet the surging demand for sustainable products. They excel at transforming raw materials through various processes, but embracing eco-friendly practices and incorporating non-fossil and recycled materials will be crucial to their future success. Molding and compounding specialists must innovate with sustainable plastics and rubber alternatives.

- Promote comprehensive plastic recycling from product design to recycling, use of recycled and side stream as raw materials and diversified value chain building for resilient raw material access
- Increase investments in researching locally sourced bio-based and biosynthetic materials and monitor new material technology opportunities, e.g. self-healing materials
- Leverage AI and machine learning to improve production processes and raw material traceability
- Increase user centricity to anticipate preference shifts in still maturing future customer segments and generations
- Consider recyclability in product design and material selection

Highlights from the signals:
check at least these signals

- Reuse of waste/residue
- Biomass as feedstock
- Advances in recycling efficiency
- Clean energy transition
- Value chain re-organization
- Reporting indirect emissions

- Challenged democracies
- Shortage of circulated material

- Safe and Sustainable by Design
- Metamaterials
- Programmable materials
- Graphene

Taking the Next Steps
Formulating cluster

Sustainable formulating must prioritize developing formulations that incorporate renewable resources, biodegradability, and minimal waste to minimize environmental impact. They should also investigate innovative ingredients and formulations that maintain or enhance product performance to achieve a sustainable balance.

- Accelerate the journey towards digital R&D
- Develop products and processes for bio-based & recycled raw materials
- Explore the potential of synthetic biology to decouple from fossils
- Create a closed-loop water system
- Start preparing for quantum computing, especially in the pharmaceutical industry
- Reduce the share of raw materials affected by political tensions
- Promote meaningful jobs to get new talents
- Collaborate with users and customers to understand their future needs and requirements

Highlights from the signals:
check at least these signals

- Digital R&D transition
- Synthetic biology
- Reuse of waste/residue
- Biomass as feedstock
- Clean energy transition
- Value chain re-organization

- Talent availability crisis
- Challenged democracies
- Collapse of general knowledge

- AI in chemical processes
- Quantum computing
- India as a chemicals manufacturing hub
- Localization
- Fluctuation in value-based consumption

Taking the Next Steps
Energy-intensive chemical industry

Energy-intensive chemical industry companies can play an important role in reducing the industry's carbon footprint and advancing global climate goals.

- Actively prepare for and contribute to the hydrogen economy’s emergence
- Invest in CCU technologies that capture CO2cemissions and utilize them as input in product manufacturing
- Invest in valorisation of green ammonium
- Identify high-value-add new product opportunities
- Retrofit existing or build new e-cracking systems
- Leverage the potential of AI to improve energy efficiency in manufacturing processes
- Develop value-chain transparency and decrease dependence on natural resources from non-sustainable sources
- Create resilience by diversifying imports and increasing domestic capacity of raw materials
- Treat wastewater for industrial reuse to reduce the dependency on high-quality groundwater
- Explore the potential of synthetic biology to decouple from fossils
- Shift the focus of oil refining from fuel production to chemicals

Highlights from the signals:
check at least these signals

- Hydrogen economy
- Sustainable fuels
- Increased CCUS efficiency
- Green methanol-to-X
- Decoupled economic models
- Digital R&D transition
- Synthetic biology
- Clean energy transition

- Challenged democracies
- Talent availability crisis

- AI in chemical processes
- E-crackers
- Green ammonia
- Quantum computing
- Fluctuation in value-based consumption
- Closed-loop water system and management
- Adaptive education
- Rights of nature

Taking the Next Steps

Reactive Chemistry Industry

The future of **the reactive chemistry industry** is being shaped by the growing demand for sustainable products and technological advancements.

- Prepare for the hydrogen economy
- Invest in carbon capture and utilization (CCU)
- Develop recycling processes and infrastructure
- Develop closed-loop water systems
- Check whether synthetic biology can be an option for material and process disruption
- Consider chemicals-as-a-service business models
- Start investing in AI-based process control to boost the efficient use of resources, reduce waste, and increase product safety, quality and yield

Highlights from the signals:
check at least these signals

- Hydrogen economy
- Biomass as feedstock
- Reuse of waste/residue
- Digital R&D transition
- Synthetic biology
- Clean energy transition
- Talent availability crisis
- AI in chemical processes
- Green methanol-to-X
- Green ammonia
- Chemicals-as-a-service
- Quantum computing
- Safe and Sustainable by Design
- Closed-loop water system and management
- Adaptive education

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Taking the Next Steps
Inorganic Chemistry Industry

The inorganic chemistry industry can secure its future by recycling and reusing materials, lowering emissions, and developing efficient mineral extraction technologies.

- Increase circularity
- Build bridges through value chain transparency to battery manufacturers in the pursuit of creating circular battery ecosystems and reusing chemicals
- Green ammonia can enable self-sufficiency in fertilizer production for agricultural companies
- Prioritize sustainability and consider biodiversity in all operations and businesses
- Proactively address talent shortages by anticipating future skills requirements, exploring AI-driven automation and industrial metaverse applications for remote talent access
- Promote nutrient recovery in the product lifecycle

Highlights from the signals:
check at least these signals

- Reuse of waste/residue
- Biomass as feedstock
- Advances in recycling efficiency
- Clean energy transition
- Value chain reorganization
- Reporting indirect emissions

- Challenged democracies

- Circular battery ecosystems
- Green ammonia
- Closed-loop water system
- (In)Dependence on raw materials
- Rights of nature
- Fluctuation in value-based consumption
- Space economy

Foresight Journey - How to build on the radar

HORIZON SCANNING

What is happening in the future?

Finnish chemical industry's
Future Radar

Focus on specific viewpoints

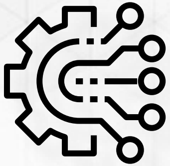
Your company's own
Future Radar

Create alternative futures

Shape the future

BUILD THE FUTURES LANDSCAPE

What alternative outcomes can be expected? What are the critical drivers behind the specific outcomes?

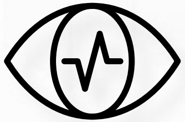


Scenario building
Use the building blocks identified in the Radar to layout the full landscape of possible outcomes

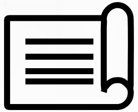
SHAPE PREFERABLE OUTCOME

Which future do we want to bring about?

Future customer
Understand your future customers' preferences



Vision building
Develop a concrete solution to meet your future customer



Roadmapping
Layout what to do today to reach your vision of tomorrow

Conclusions of Radar Dimensions

Sustainability
Technology
Society
Business

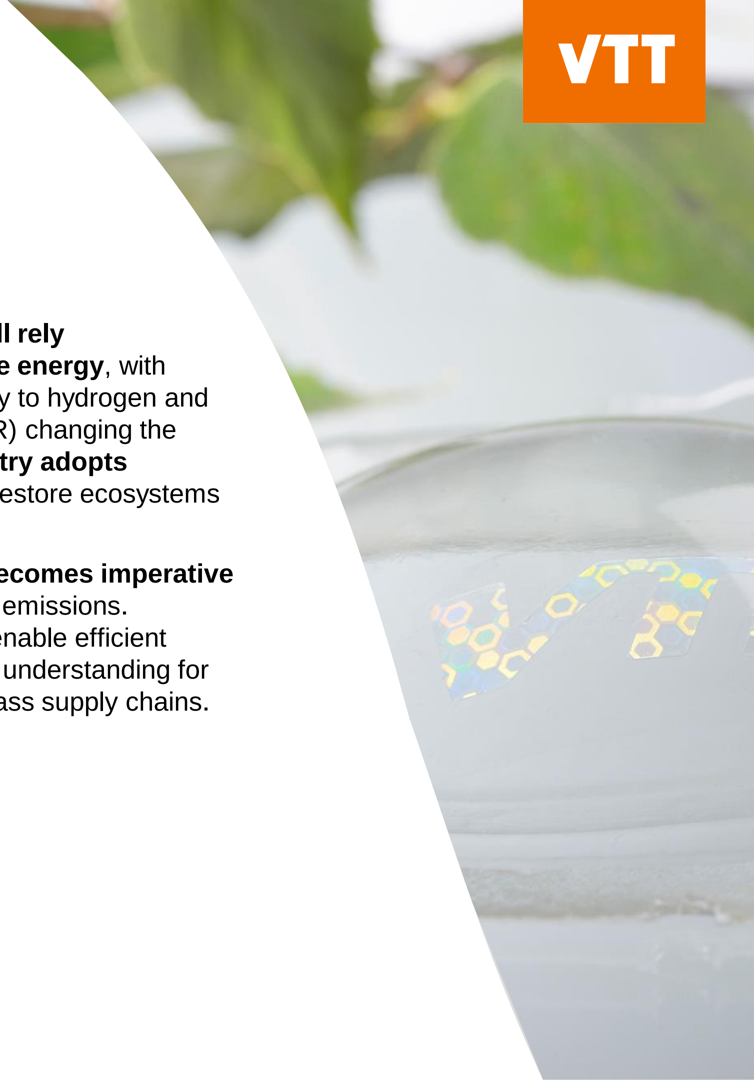
Future sustainability

Sustainability will be a core element of the industry. Closed-loop systems will increase significantly, and waste from one process serves as the raw material for another, making the concept of waste nearly obsolete.

Raw material scarcity is a fundamental consideration in the chemical industry's digital and sustainable transition. Digital technologies put pressure on critical raw materials, and at the same time, geopolitical instability is driving polarization between countries. These will pose questions about **who will govern the future raw material sources.**

Chemical manufacturing will rely predominantly on renewable energy, with innovations from fusion energy to hydrogen and Small Modular Reactors (SMR) changing the energy landscape. **The industry adopts regenerative practices** that restore ecosystems and improve biodiversity.

Value chain transparency becomes imperative to provide visibility on indirect emissions. Information is value and can enable efficient recycling and provide needed understanding for example on sustainable biomass supply chains.



Future technology

Sufficient availability of affordable green energy is a cornerstone in decarbonising the chemical industry. Chemical companies should **explore approaches to move upstream to self-producing energy to secure renewable energy sources**. Chemical parks can benefit from economies of scale.

Oil as a feedstock will likely not be removed completely at least during the next few decades. Oil can be suitable for applications with long life cycles. Similarly, applications with shorter life cycles benefit from renewable feedstock. Bio-based feedstock should be allocated to short-life-cycle and value applications.

AI-driven R&D speeds up the discovery of new chemical compounds and materials. **Launching innovation hubs and ecosystems dedicated to emerging technologies and collaborating with startups and established technology companies** allows to capitalize on advancements in materials, computing and AI.

Future society

New generations with different skill sets, values, and expectations enter the workforce but can’t directly replace the amount of retiring older generations. Agile training models, a culture of continuous learning, automation, and increasingly multicultural working environments become the norm in the industry.

Future economic models emphasize smart resource use. In addition, new workforce generations expect solid environmental performance and transparency.

Democratic systems and institution around the world face substantial pressures, and significantly more countries are moving towards authoritarianism instead of democracy. **Political polarization, disinformation campaigns, and societal volatility influence markets and trade relations – requiring increasingly resilient corporate structures.**

As AI systems become integrated in nearly everything, **a hybrid human-machine culture is emerging**. Cultural artifacts are increasingly a synthesis of AI-created and human-made elements.

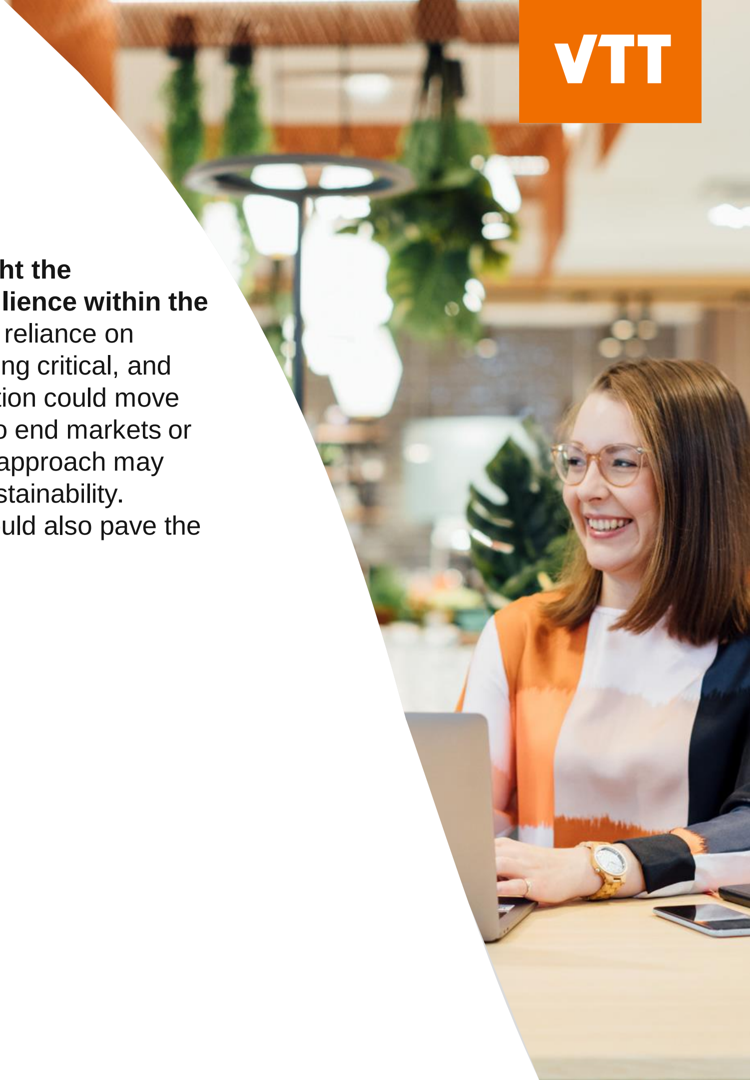
Future business

Collaborating with customers, understanding their business needs, and **going beyond the role of a raw material supplier** is increasingly crucial. For example, this can help overcome existing volume-based business models and facilitate the transition to circularity.

Due to its capital-intensive nature, the chemical industry may not offer substantial opportunities for startups. However, specific sectors like synthetic biology present potential for startup engagement. **Established actors in the chemical sector play a crucial role in accelerating development.**

Demand for bulk products (e.g., diesel) may shift towards more specialised, high-value requirements. Synthetic biology, for example, has the potential to disrupt processes, but its development is likely to originate from niche markets and bespoke solutions before advancing to large-scale chemical production.

Geopolitical tensions highlight the importance of bolstering resilience within the chemical industry. Assessing reliance on certain raw materials is becoming critical, and decentralised chemical production could move companies' operations closer to end markets or sources of raw materials. This approach may further enhance operational sustainability. Instability within the industry could also pave the way for new entrants.



Future Radar Methodology

A participatory foresight process

Trend scanning and analysis
Technology expert discussions

Trend analysis
Radar fine-tuning

Kick-off workshop
Orientation to foresight
Group work on DEFT pre-exercise
Scoping the radar work

Prioritization workshop
Prioritization of trends
Discussing the implications of the trends

Final seminar
Presenting results

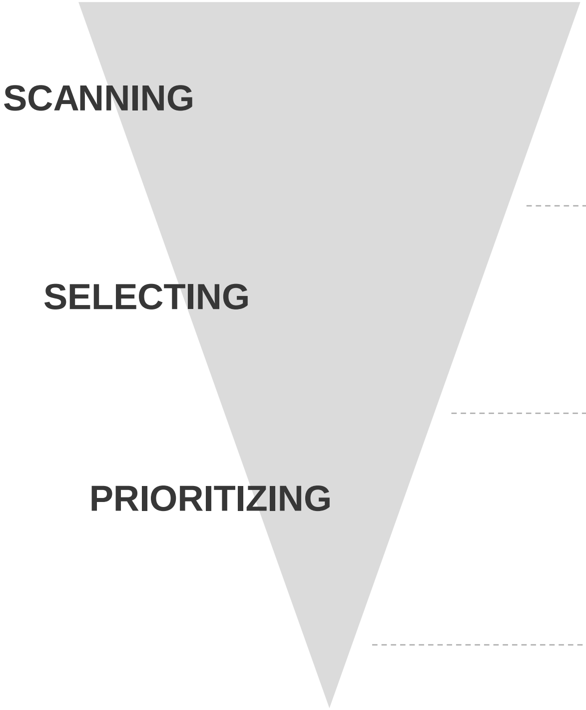
VTT conducted the foresight study by implementing a participatory strategic foresight process. The approach ensured that chemical industry companies' emerging technologies and changes in the operating environment were reflected in research needs and business opportunities.

The project included the creation of a Future Radar, where VTT identified future trends relevant to the chemical industry utilising an extensive amount of source material, such as industry reports, foresight reports, technology research, market research databases, and expert discussions.

VTT technology experts in various areas supported in evaluating the signals.

Companies from the Chemical Industry Federation of Finland participated in two workshops. These workshops helped to scope the radar work and prioritise preliminary results.

The Future Radar approach



A large signal base as a foundation
Collection of over 170 signals based on an extensive amount of source material, such as industry reports, foresight reports, technology research, market research databases, and expert discussions.

Trends to the Radar view
Selection of trends to the Future Radar view by:

- Grouping multiple trends to larger phenomena
- Evaluating trends within the foresight team and with VTT technology experts

Prioritising trends in the Radar view
Validating and fine-tuning the Future Radar view within the foresight team and with VTT's technology experts.

Prioritisation of trends with the Chemical Industry Federation and companies in the II workshop.

The Future Radar Structure

The **Future Radar** is a tool that collects signals in visual forms. There are three kinds of signals: trends, high-priority trends and risks. The chart is centred around the organisation or sector under focus, in this case, the Finnish chemical industry. The concentric circles represent different time horizons from now to **2030, 2035, and 2045**.

The chart's axes represent four categories of trends - **Sustainability, Technology, Society, and Business**. Specific trends or risks are placed on the radar as points, with their position determined by their timeframe and category.

The placement of a trend on the chart estimates its mainstream adoption, while its impact and probability for the chemical industry determine its priority.

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VTT is a visionary research, development and innovation partner for companies and the society. We bring together people, business, science and technology to solve the biggest challenges of our time. We advance the utilisation and commercialisation of research and technology in commerce and society. This is how we create sustainable growth, jobs and wellbeing and bring exponential hope.

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