Bio Energy
PowerON Hamburg 2023

Meet Ramboll Energy

RAMBØLL

Bright ideas.
Sustainable change.

Ramboll Energy

Ramboll's 18,000 experts work globally across nearly 300 offices in 35 countries

- Across the world, Ramboll combines local experience with a global knowledgebase to create sustainable cities and societies. We combine insights with the power to drive positive change to our clients, in the form of ideas that can be realised and implemented.
- We work multidisciplinary across our seven markets:

Transport

Buildings

Environment & Health

Energy

Water

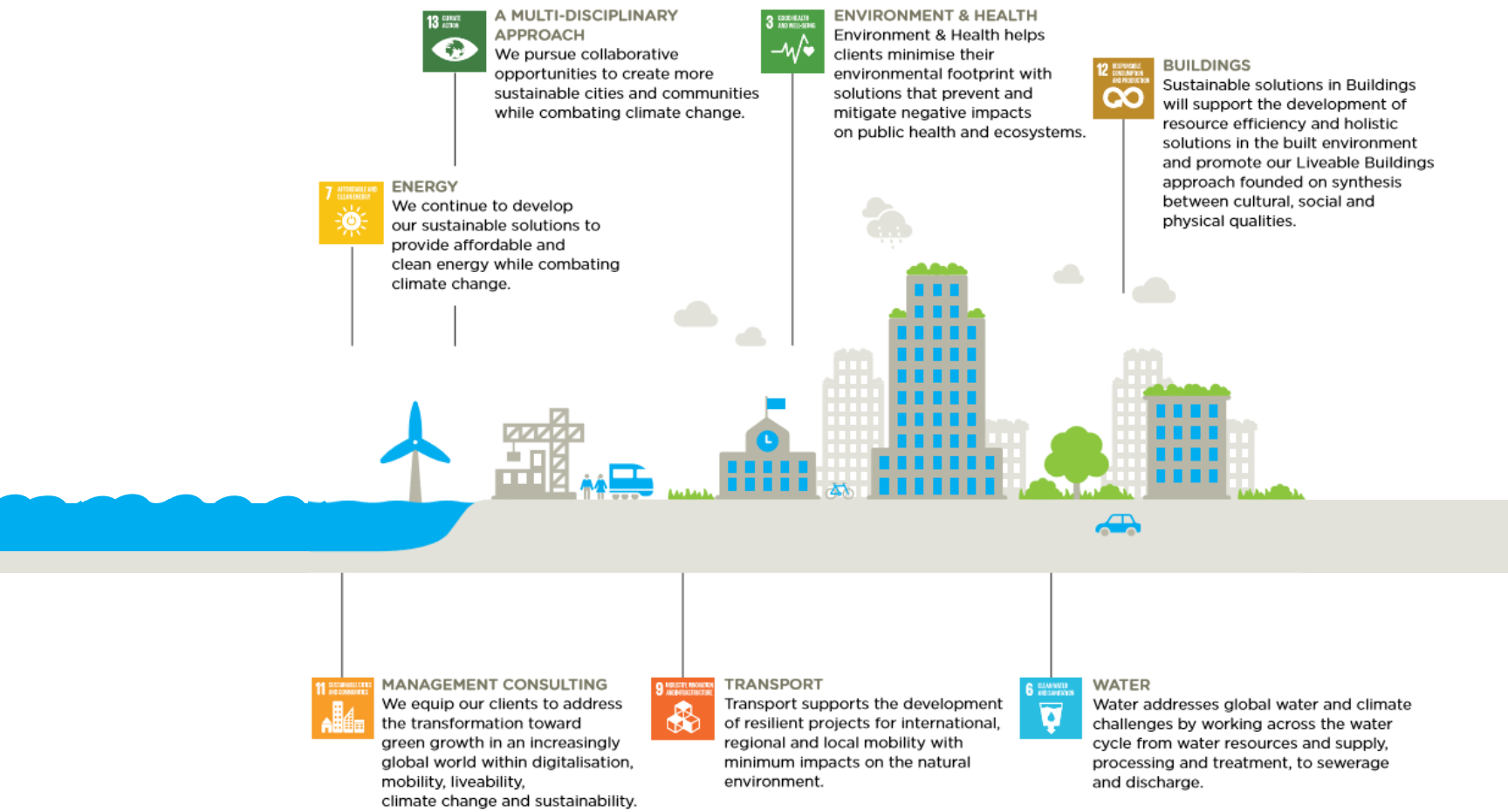
Management Consulting

Architecture & Landscape

Energy

- 50 years of experience in planning, design and implementation of energy solutions
- Expertise on full spectrum of technologies
- 13% of Group revenue
- 2,000 specialists
- 65 offices in 15 countries
- Among the top 10 leading energy consultancies in Europe

We embed sustainability into every project, and we walk the talk ourselves



- We are passionate green transition consultants with a high focus on decarbonisation. Our expertise is based on the latest insights as we advise key players across the value chain
- In addition to technical advisory on green transition, we are a trusted sustainability advisor for financial institutions, large corporations, energy agencies, international organisations and utilities and advise them on: GHG accounting, SBTi, sustainability reporting, decarbonization roadmaps, sustainable investments (SFDR etc.), EU Taxonomy and sustainable bonds

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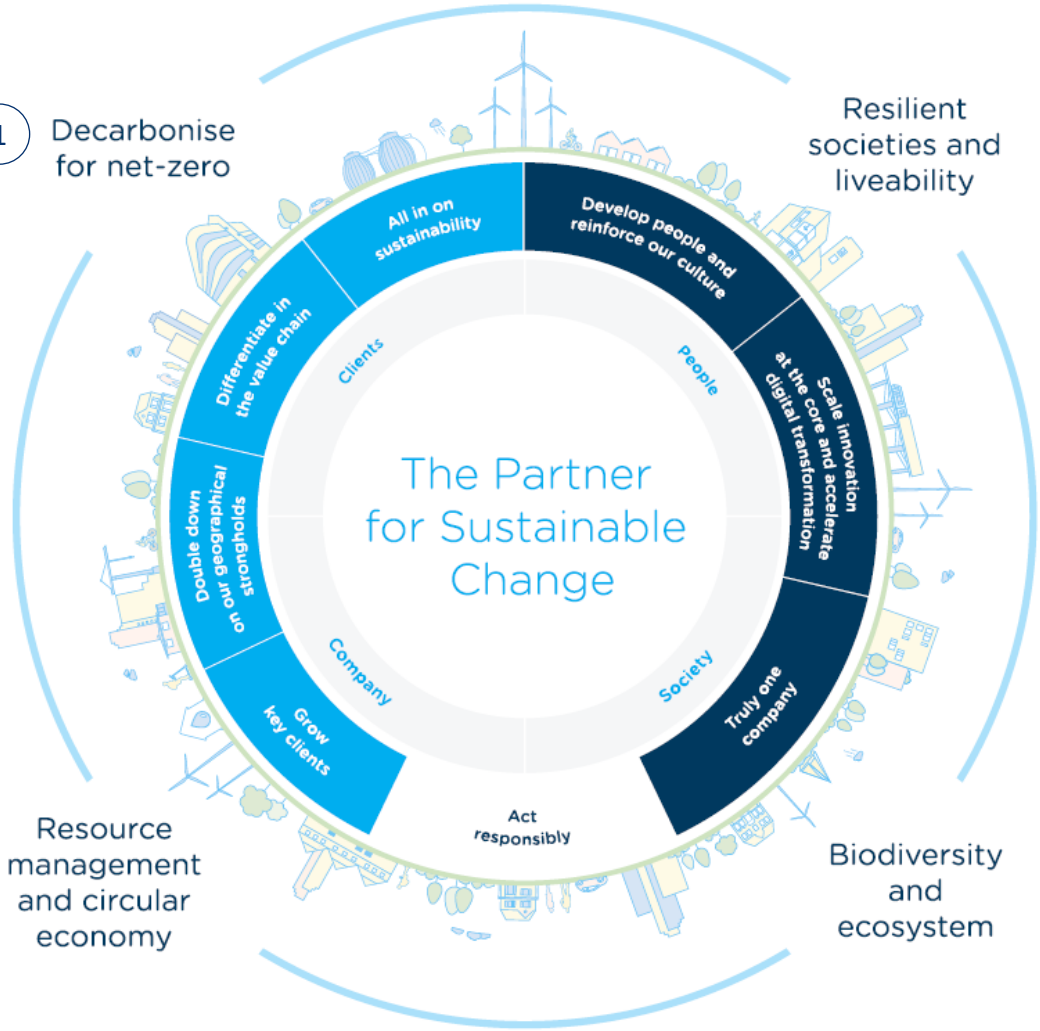
- In 2021, Ramboll's Science-Based Carbon Reduction targets were approved by the SBTi. We commit to contribute our fair share in limiting the global temperature rise to 1.5-degrees
- Ramboll commits that 80% of our suppliers by emissions covering purchased goods and services will have science-based targets by 2025
- And we commit to reduce absolute scope 1 and 2 GHG emissions 46.2% and scope 3 emissions from business travel 27.5% by 2030 from a 2019 base year

Supporting the energy transition is at the core of Ramboll's strategic ambitions

Accelerate the Green Energy Transition: Renewables and new technologies



- Ramboll is the trusted partner for our clients, creating value by guiding them successfully through sustainable change, while understanding specific challenges and opportunities
- With an unmatched position in renewables as well as cutting-edge sector and consulting expertise, we aim to be the global leader in the professional services industry in the green energy transition

Ramboll offers a unique mix of technological, commercial and global expertise within green fuels

We know the **technology**

Ramboll is a world-leading advisor within a variety of green fuels and is at the forefront of the development of the technologies used today and in the future.

Our deep technical knowledge of systems and technologies within green fuels underpins our strong position in the market and allows us to help our clients make informed decisions.

Relating knowledge about green fuel technologies to our deep understanding of the green transition and the potential measures (incl. their limitations) makes our recommendations future-fit and highly accurate.

We work across the entire **value chain**

We embrace work across the entire value chain of sustainable fuels production from sourcing of biomass and renewable power, markets, logistics, process and operation, optimisation, to value creation and end-use.

We also work as a trusted technical and strategic advisor for stakeholders along all stages of the value chain, including various governmental bodies and regulators.

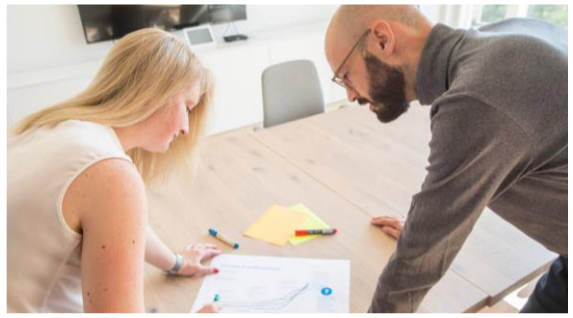
Consequently, we know and understand the key stakeholders, and know how to best plan, procure and manage the implementation and operations of alternative fuels[1].

We understand all the **commercial and environmental** aspects

We know and understand the waste and energy markets, including market trends, drivers, challenges, different business models and prerequisites for operational excellence.

We also have a comprehensive knowledge and understanding of the regulatory environment both globally and locally, and how it impacts projects commercially.

Moreover, our experts support clients with multimedia and multi-agency permitting and compliance support and are well-versed in the various environmental issues unique to renewable fuels, e.g. air quality, risk management, wastewater management, ESG strategy and across supply chain.



Our experience is **global**

Ramboll has global expertise combined with in-depth market insights and understanding through our strong local presence.

Our global footprint gives us in-depth “insider” knowledge about market conditions, sector connections and local industry dynamics and practices (incl. business cultural dimensions).

This further strengthens our knowledge-based and industry-specific recommendations, so they suit the unique goals of our clients.

[1]Ramboll has experience working with various kinds of feedstocks and energy sources including biomass, biofuels, biogas, sludge, RDF, plastic, municipal solid waste, PtX, hydrogen, wind, PV, geothermal energy, etc.

Some of our clients

Client satisfaction score: 4.3*

Scoring highest on our competencies and our understanding of client needs

One little mistake in the definition of the project may accumulate into a costly affair later on. Ramboll has the experience required to think many steps ahead.

– Klaus Wellington Hansen,
Vice Director, ARGO

Ramboll is excellent at understanding our needs.

– Jette Pedersen,
HOFOR – Greater Copenhagen Utility

Ramboll goes that extra mile in answering additional queries not necessarily covered by the scope.

– Andy Woodward,
Head of Business Development, RWE

If Ramboll's got an idea of something they think would be beneficial to us, they tell us about it.

– Donald MacBrayne,
Business Developer & Delivery Manager,
Scottish Water Horizons Ltd

The sense of ownership of my project has ben fantastic – I rely very much on Ramboll's support, and the assistance provided has been excellent.

– Isabel Brown,
Head of Infrastructure Support, Glasgow Life

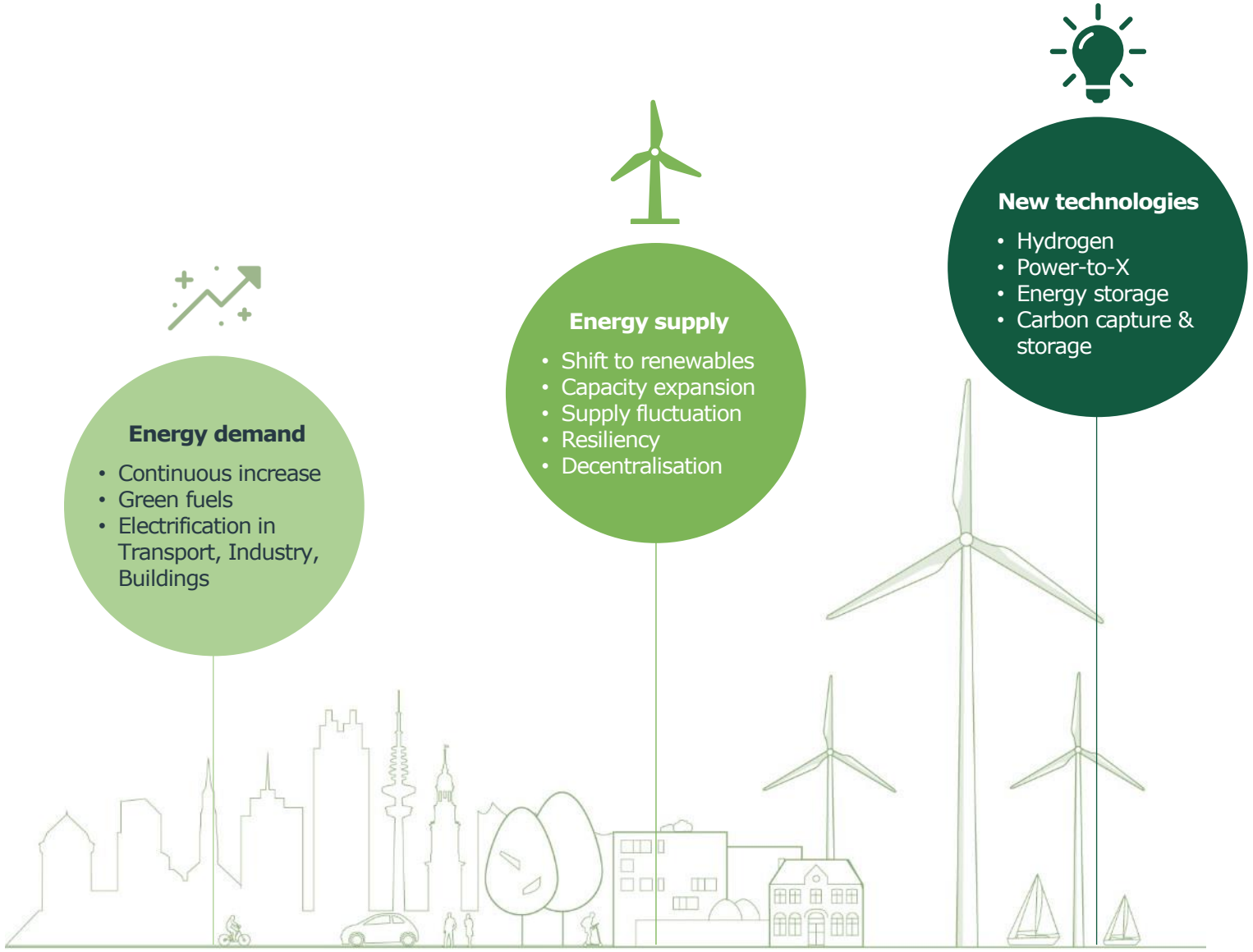
*On a scale from 1 to 5

How we work

The energy system will undergo massive changes

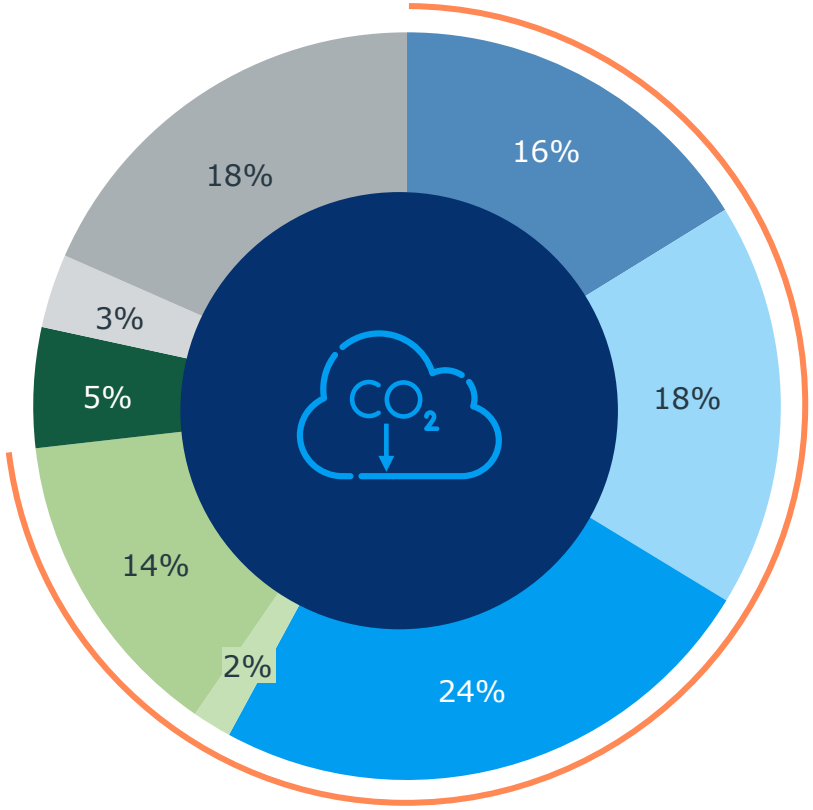
The **decarbonisation** megatrend coupled with **continuous increase of energy demand** will drive the transition to:

- Renewables
- Grid capacity expansion
- Enhanced balancing mechanisms



Decarbonisation is central to the future energy system

- IPCC: Global warming will exceed 2°C by 2100 due to greenhouse gas (GHG) emissions
- This will lead to natural disasters, water and food scarcity, climate migration, and massive economic impact
- Almost 75% of manmade GHG emissions relate to energy use



Breakdown of global greenhouse gas emissions by sector

Emissions from energy use: ~75%

IPCC…Intergovernmental Panel on Climate Change

Source: Climate Watch/World Resources Institute, 2020

We help our clients think, design and implement their green energy transition

Helping our clients **reduce their carbon footprint, navigate the integrated energy system and innovate solutions** to improve it is at the centre of everything we do.

With our knowledge of the energy system, its elements and their interaction, we define the challenge and its complexity together with our clients.

How we work with our clients

- Assisting clients from idea to operation
- Typical role: Owner’s / Developer’s Engineer or lead advisor
- Project management, technical expertise and engineering
- Both strategic advice and hands-on expertise
- Trusted advisor with long-term client relationships

Our approach

Transforming complex challenges into solutions that are:

- Future proof
- Energy efficient
- Cost effective
- Practical

Overall benefits to society:

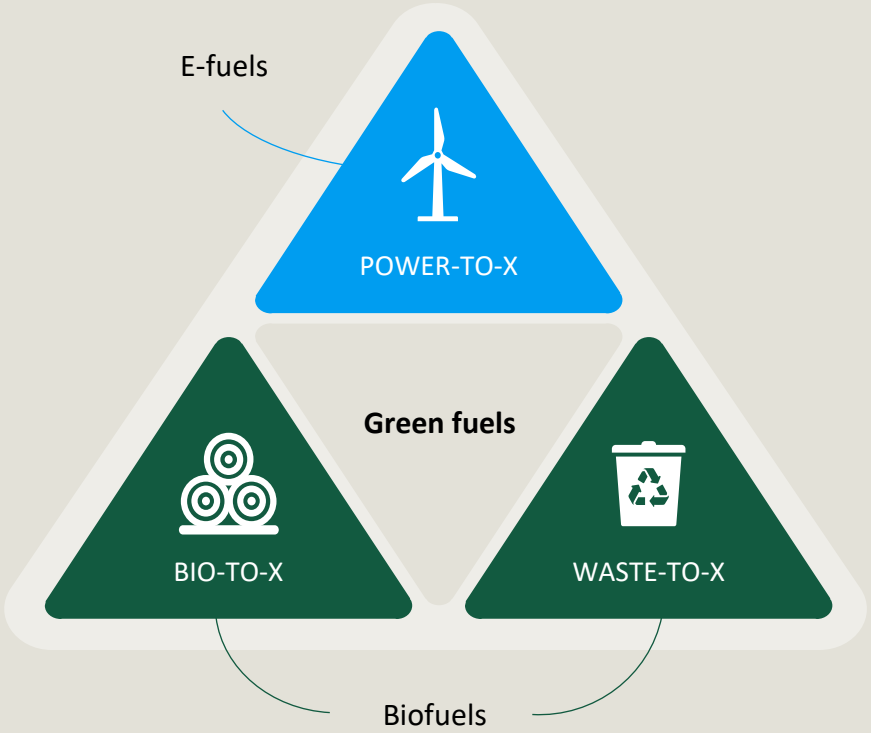
- Securing the supply of energy
- Reducing climate impact
- Improving energy efficiency
- Countering resource scarcity
- Reducing the cost of energy

Bioenergy

Ramboll is one of the most experienced engineering consultancies in the field of bioenergy. With more than 60 bioenergy plants in our portfolio, we have specialised in delivering high-efficiency rates, in some cases of more than 100%.

Green substitutes for fossil fuels can be produced from various renewable and biogenic sources and technologies

Ramboll's technical, commercial and environmental expertise covers all alternative green fuel types



POWER-TO-X

A range of technologies that transform electricity from renewable energy sources and water to hydrogen and through further synthesis to e-fuels.

1
"POWER"
Electricity from renewable energy sources and water

2
"TO"
Conversion through electrolysis and synthesis technologies

3
"X"
E-fuels such as hydrogen, ammonia, e-methane, e-methanol, e-kerosene (jet fuel)

BIO-TO-X & WASTE-TO-X

Conversion of sustainable biomass or residuals into a synthetic gas or liquid bio crude oil for further chemical processing in green refineries and chemical plants.

1
"BIO- & WASTE"
Sustainable biomass and residues or waste (e.g. plastic)

2
"TO"
Gasification, pyrolysis, AD, hydrothermal liquefaction, biochemical conversion, cellulosic conversion, etc.

3
"X"
Biofuels such as ethanol, pyrolysis oil, methanol, methane, sustainable aviation fuel, drop-in fuels and biochemicals

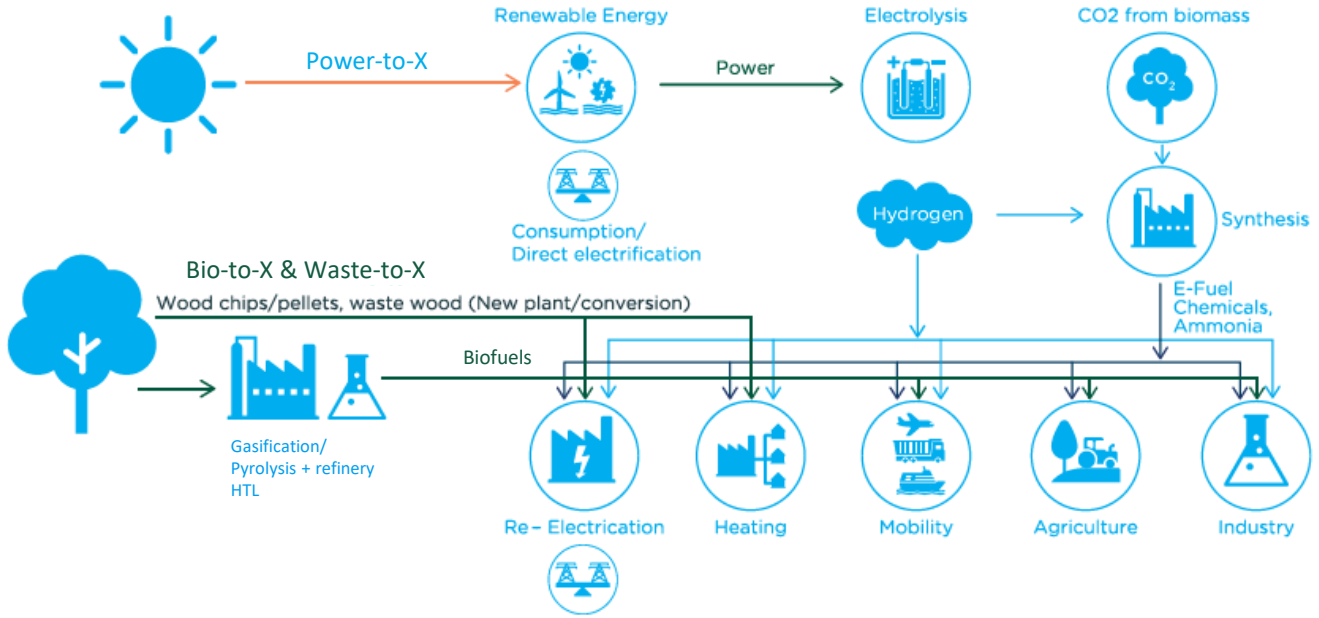
The effort to limit global warming calls for decarbonisation and new technologies in many sectors;

- Fossil fuel is being replaced by renewable energy such as wind, solar and hydro power
- In domestic heating, electricity can be applied directly e.g. in heat pumps which convert electricity to heat with high efficiency
- Similarly, most passenger transport may rather easily be changed from fossil-fuelled passenger cars to electric vehicles

However, some sectors cannot easily be electrified. For these applications, alternative fuels such as biofuels and e-fuels and will be the solution;

- Where high amounts of energy are required, batteries will not be sufficient for storing and transporting energy
- Heavy duty transport, shipping, and aviation all require a fuel in a liquid or gaseous form, as the weight of batteries makes it unsuitable for these applications

E-fuels and biofuels offer pathways for decarbonisation of hard-to-abate sectors

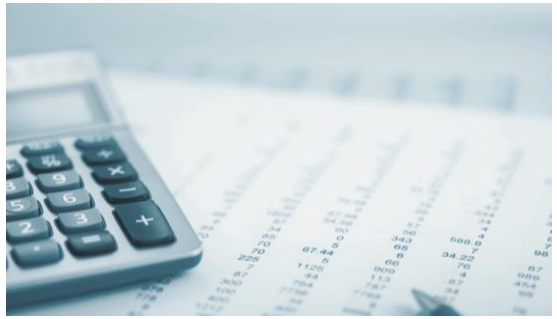


Ramboll provides studies of routes for possible combinations of feedstock, technologies and off-taker markets and a holistic understanding of each opportunity including:

- Technology options, flexibility, readiness and feasibility (technical and economic)
- Diversity and availability of applicable feedstocks
- End-product overview and associated market potential
- Regulatory and policy landscape and outlook

There remains a number of challenges to a successful scale-up of alternative green fuels production

Economic issues



- The commercial outlook for green fuels, in particular e-fuels, is closely connected to the ability to compete with conventional fossil fuels
- Today, alternatives to fossil fuels continue to be expensive, primarily caused by high technology costs for Power-to-X in particular
- Technology learnings will contribute significant to cost reductions that make alternative fuels more economically viable

Technological issues

- For the most part, the technologies needed to take us from Power to X or Bio to X already exist
- Many of the technologies are tried and tested and have a high level of market readiness as well as high market potential
- The challenges arise in finding solutions to connect the different technologies, and scaling them up
- Hence, the building blocks are in place, but how to build with them is still under development

Political issues

- Global commitments to reaching carbon neutrality is a key driver
- Yet, how ambitious will governments be in setting climate targets? And will those ambitions be matched sufficiently in actions and policies? How do we ensure that feedstocks for biofuels and e-fuels are sourced sustainably?
- The answers to these questions will greatly impact the potential and profits that can be realised in the coming years

Social issues

- While public support for the green transition is strong, the combination of industry and residential areas in close proximity continues to be a contested topic
- Involving local local stakeholders along the project and creating awareness is therefore paramount to securing social acceptance for the production of green fuels from e.g. smelly manure in biogas plants or solar power located nearby residential areas for Power-to-X

Engage with us: https://ramboll.com/energy

Thomas Palkovich
Director Business Development
Power Generation and Bioenergy
M +47 9820 8384
thomas.palkovich@ramboll.no

Jesper Knudsen
Chief Consultant, PhD
Biofuels / Bio-to-X
M +45 5161 2152
JKDN@ramboll.com

Jean-François Quillard
Business Development Manager
Power Generation and Bioenergy
M +49 1520 2534706
jeanfrancois.quillard@ramboll.com

Energy project cases

Bio- and waste fuel references – Technical support

A selection of projects

New Biogas Facility in Vordingborg to produce green methanol, Vordingborg Biofuels ApS, Denmark, 2022

Ramboll was commissioned as Owner’s Engineer of one of the world's largest bio-methanol plants to produce up to 200,000 tpa of bio-methanol, as well as a PtX that can produce a further 100,000 tpa of e-methanol.

The plant uses straw that is converted through a bio-fermentation plant into biogas, which is then converted into bio-methanol. For the entire process, mainly green electricity is used. Surplus heat from the plant is used for the plant's operation as well as for district heating.

Emission to air from Biofuels (HVO, FAME, bioethanol), Miljødirektoratet, Norway, 2021-2022

Ramboll has been commissioned by the Norwegian Environment Agency to update them on emissions of different air pollutants from the use of biofuels. To improve the emission inventory, specific emission factors for different biofuels and technologies are needed. The Norwegian Environment Agency has therefore announced a procurement to close knowledge gaps and enable them to calculate changes in emissions and the health effect of biofuel measures. The procurement is limited to the biofuels used in Norway.

Bio- and waste fuel references – Technical and environmental support

A selection of projects

Biogas plant running on organic waste collected from food factories in Hong Kong, Government of the Hong Kong Special Administrative Region, 2012-2013

Ramboll has consulted the Government of the Hong Kong Special Administrative Region in regards to a biogas plant for treatment of food waste from factories and restaurants. The following services were provided: feasibility study, process and technologies evaluation; conceptual design, technical specifications and project definition; preparation of tender documents and tendering business.

The biogas process includes: pre-treatment of waste, anaerobic digestion, separation, cleaning of waste water (end products are fertiliser and clean water) and composte. The biogas will be utilised for production of heat and electricity for the internal process and upgraded (by removal of H_2S and CO_2) for utilisation in the town gas grid. The end product - compost and fertiliser - will be used for agricultural purpose.

Technical study on introducing bioethanol (E10), Miljødirektoratet, Norway, 2017

Ramboll was commissioned by the Norwegian Environment Agency to map the opportunities and barriers associated with the introduction of bioethanol (E10) as an industry standard for petrol in Norway.

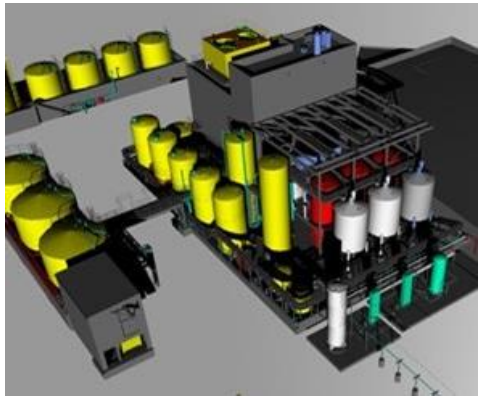
Ramboll described other European countries' experiences with the introduction of E10, and assessed the need for investments and the degree of security at Norwegian filling stations, e.g. through interviews with industry players. Both Norwegian, Finnish and German Ramboll resources contribute to this work.

Bio- and waste fuel references – Technical and environmental support

A selection of projects

Technical due diligence of biofuel production facility, Denmark 2019

Ramboll completed a technical due diligence of the Envergent Rapid Thermal Processing (RTP) technology on behalf of CWC Biofuels (CWCB) for the new application of treating straw instead of sawdust. CWCB are developing a straw-fired RTP-based plant at Vordingborg Port, Denmark to produce a biofuel that replaces fossil fuel oils. The continuous incoming streams to the RTP are sorted dried and shredded. Fresh sand is added to replace that which was removed with ash to produce a pyrolysis oil while non condensable gases are used to generate heat and power from combustion engines spinning generators.



Biodiesel production facility engineering, United States 2019

Ramboll provided engineering services for the development and design of a biodiesel production facility. The plant was an existing refinery retrofitted for biodiesel production. Modifications included repurposing of the existing equipment; development of the 3D piping models along with the pipe stress analysis that confirmed the efficacy of reusing of many piping systems. Ramboll also provided structural engineering and architectural support as well as equipment data sheets and procurement services. The result was an operating facility that was brought online for a fraction of the capital costs associated with a green field production plant.

Bio- and waste fuel references – Technical and commercial support

A selection of projects

Technical and commercial vendor due diligence of a biogas plants portfolio, Confidential client, Denmark, 2022

Ramboll has elaborated a Vendor Due Diligence (VDD) including technical, environmental due diligence, and ESG for an international client holding a portfolio of more than 10 operating biogas plants and more than 20 biogas plants in the pipeline. The due diligence includes establishment of an understanding of the business's approach to procuring feedstock, contracting biogas sales, operating their portfolio, and optimizing these plants, together with organizational structures and other assets such as transport. Further review of site performance and asset performance in terms of production vs capacity, use of consumables and energy, together with maintenance and CapEx costs have been carried out. Furthermore, a review of new technological developments within Power-to-X and a timeline for implementation have been reviewed.

Technical, commercial, and environmental advisory for a plastic to liquid fuel company, Quantafuel, Denmark, 2020-2022

Ramboll has been selected by Quantafuel, a European circular economy and waste recovery company, to perform a FEED study for a plastic-to-liquid plant in Denmark. The plant produces environmentally friendly chemical components from plastic waste. The ambition for this plant is to source plastic waste from local suppliers to produce environmentally friendly chemical components that will serve the plastic industry, and ultimately increase the recycled content in packaging plastics. Ramboll was also commissioned to conduct a feedstock and supply chain analysis of the plastic waste supply market. The key of the study is to quantify and forecast supply volumes and qualities as well as to describe and forecast the supply/demand situation and competitive outlook for plastic waste supplies. The analysis involved deep regulatory and policy analysis and impact assessment as well as industry interviews, sustainability assessment and analysis of publicly available data.

Bio- and waste fuel references – Technical and commercial support

A selection of projects

Commercial advise for upgrading Bekkelaget Biogas plant, Oslo Municipality, Norway, 2008-2010

Ramboll was invited to develop the complete gas upgrading facility at Bekkelaget treatment plant including an investment appraisal. Ramboll was involved in the procurement process and responsible for the evaluation of tenders including life cycle cost analysis. Upon approval of the project, Ramboll was commissioned to undertake construction management with overall technical control.

Norway's largest biogas upgrading plant - Bekkellaget WWTW - is set to deliver vehicle fuel. The plant utilises its biogas for heating the digestion process, on-site facilities and sludge drying, but with surplus gas available after this consumption, an upgrade facility was proposed. In the future a new biogas production facility using organic waste as the substrate will contribute to the biogas supply available for upgrade.

Market study and strategy development for the bio- and waste-to-x market, Confidential client, Europe, 2022

Ramboll was commissioned to identify strategic waste/bio-to-X opportunities in the United Kingdom and Spain for the client to invest in. The analysis consisted of a market analysis of feedstocks, technologies, and products and concludes with a high-level go-to-market strategy including strategic objectives for eight specific opportunities within the market with regional recommendations for where to enter.

The client was a leading supplier of specialist storage, handling, and transport for bulk liquids and gases, with one of Europe’s most comprehensive ranges of tankage. As part of its green-transitioning journey, the client wanted to understand which products and technologies are essential in the circular economy paradigm and how they, as a global infrastructure company, can address available opportunities to achieve its ambitious objectives for the future.

Bio- and waste fuel references – Commercial support

A selection of projects

9

Market analysis of the global biomass/waste management market, Confidential Client, Global, 2019-2020

Ramboll was commissioned by a global energy company to undertake a comprehensive market analysis of the global biomass feedstock to energy market, including an assessment of the value chains characteristics, feedstock availability, underlying market drivers, and the overall market attractiveness. The analysed feedstocks comprise Municipal Solid Waste (MSW), Agricultural Waste (Animal and Agriculture residues), Forestry Waste and Energy Crops. The main focus of the market analysis was the Municipal Solid Waste (MSW) sector. The results of the assessment will better enable the Client to align strategic investments in biomass to energy with the Client's overarching development strategy and green transitioning.

10

Waste-to-X market study and business ideation, Confidential client, Germany, Sweden, UK, BENELUX, Russia, 2020-2021

A large energy and utility company had requested Ramboll's support to uncover innovative business opportunities within advanced biomass and waste-to-X to help with their green transition. The project's main activity was to conduct a market study within advanced biomass and waste areas and identify innovative business opportunities. The study consisted of an in-depth analysis of feedstocks (value chain, availability, sustainability, ease of transport, etc.), technologies, regulatory frameworks, end-products, and off-taker markets. The study focused on the client's current core markets Germany, Sweden, UK, BENELUX, and Russia. Ramboll's work provided the client with structured insights where business opportunities identified, described and assessed could be used as a basis for decision-making for the client on which opportunities to pursue.

Bio- and waste fuel references – Commercial support

A selection of projects

Market study & assessment of technology using paper sludge as biomass feedstock for biogas and upgraded to biofuels, Confidential client, Germany, 2020-2021

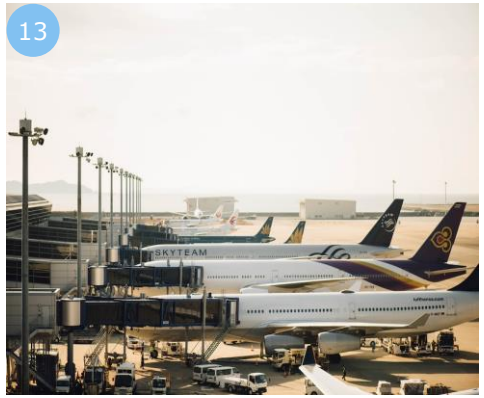
Ramboll was commissioned by a global energy company to assess a potential joint venture opportunity within biogas and biofuels production from paper sludge. The analysis comprised three parts; an investigation of the novel technology; market study on the availability of pulp and paper sludge (incl. sourcing and potential suppliers, feedstock volumes, qualities and prices, feedstock prices, market forecasts, regulatory requirements); and a market assessment of the off-taker products (biogas and fertilizer). The analysis outlined risks, dependencies and competitive features of the technology, volumes and quality requirements for paper sludge feedstock and the demand and market outlook for biogas and fertilizer products in Europe. The project delivery resulted in an overall attractiveness assessment of the opportunity incorporating a business case, providing a net present value.

Market study of the Waste-to-Energy market in the United States, Confidential Client, United States, 2017 & 2019

Ramboll performed an assessment of the Municipal Solid Waste (MSW) and Waste-to-Energy market in the United States. The study covered five overall themes, which outlined the fundamentals in the waste industry and detailed dynamics of the Waste-to-Energy market. The research and analysis presented in this report was completed in June 2017 and updated in 2019 based on Ramboll's existing market data, publicly available information/data, market reports, and interviews with regulatory and industry experts.

Bio- and waste fuel references – Commercial support

A selection of projects



Aviation Biofuel in Norway, 2nd edition, Avinor, Norway, 2017

The Norwegian Aviation industry, fronted by Avinor, has for a long time investigated sustainable aviation fuel (SAF) possibilities. In 2017, Ramboll conducted a study on SAF including multiple disciplines, resulting in a report with SAF status update and a policy instrument mapping.

The report outlines alternative procedures to achieve a domestic aviation biofuel market, mainly through either by implementing a blending requirement or through a fund, discussing various requirements, pros and cons, however, both solutions calls for increased usage of sustainable aviation biofuel which could stimulate Norwegian production.

Barriers and costs mapping for biofuels in the Norwegian transport sector, Miljødirektoratet, Norway, 2017

Rambøll carried out a study to identify the most important barriers and additional costs associated with increasing the use of biofuels in Norway. The report is limited to liquid biofuels, and assessments have been made of the development up to 2030. A distinction has been made between conventional and advanced biofuels, and assessments related to logistics have been a central part of the work. The work is presented in a report.

The commissioned survey is driven by the need of the Norwegian Environmental Directorate to update knowledge about costs associated with introducing more biofuels in Norway.

E-fuel references – Technical support

A selection of projects

CCU and PTX demonstration plant, Energipark Studstrup, Denmark 2021

Ramboll was commissioned by the owner of a biomass-fired power plant wanting to demonstrate CCU, including hydrogen production by electrolysis, and synthesis of green fuel. The project is a demonstration-scale project 1,750 t of CO_2 captured per year, resulting in 1,200 t distilled renewable methanol. The necessary 240 t hydrogen is produced using approximately 4 MW alkaline electrolyser technology (AET) or a Proton Exchange Membrane (PEM) technology operating on 100% renewable electricity. The plant will demonstrate full integration in the interfacing systems i.e., power plant, power transmission, district heating and water supply/discharge. Ramboll advised on all engineering aspects in Phase 1 and 2, including process design and integration, mechanical, electrical, civil, control system, risk assessment, and documentation for permits. The outcome of the project was engineering design, risk assessment, permission documents, and purchase documents which allowed the project to continue towards final investment decision.

1 GW hydrogen production plant, H2 Energy, 2021

Ramboll is assisting the client who wants to establish a 1 GW hydrogen production plant in Esbjerg for Swiss based company H2 Energy. The plant will produce green hydrogen for light and heavy duty vehicles, e-HRS (hydrogen battery charger for electric vehicle) or directed to other industrial application such as ammonia or green fuel production. Ramboll provided support for all project phases from early start-up of permitting activities, engineering, contracts and contract strategy development, construction planning and execution, and plant commissioning assistance.

The project will deliver the very first hydrogen plant in the GW class accelerating the transition from fossil fuels to green fuels generated from wind energy sources. The plant will use proven H2 technology in a scaled up plant configuration. The design will be standardised to build more similar or larger plants in Denmark and across Europe.

E-fuel references – Technical support

A selection of projects

Concept screening and study of 250 MW offshore hydrogen production, Confidential client, Germany, 2022

Ramboll performed a concept screening and study of centralised and decentralised hydrogen production from a site located approx. 150 km from shore. The technical focus for the concept study was on: Design of Offshore Wind Farm, Electrolyser concepts for WTG platform, Offshore platform concept for off-grid hydrogen production, Pipelines & cables both infield and export, Energy generation & transport, LCOH calculations (CAPEX & OPEX).

Based on Ramboll's concept screening and a workshop, the Client selected three concepts for more detailed study. Ramboll developed a new offshore platform concept capable of off-grid operation and optimised for operation and maintenance. Ramboll managed to address the challenge from electrolyser stack weight and create a flexible solution for the export pipeline enabling a 30 bar connection in 1st step with the opportunity to add compressor stages and step up to higher pressure levels when additional transmission capacity is needed.

System Integration Innovation with offshore wind power, SSE Renewable, United Kingdom, 2022

Ramboll was commissioned by SSE Renewable to provide technical support for selection of technologies and concepts for system integration with offshore wind power. Potentials for hydrogen, other green fuels, energy storage and applications were investigated. Ramboll supported with the following analyses: idea generation and concept development, offshore hydrogen pipeline assessment, preparation for the hydrogen production plant, layout and risk assessment, identification and negotiation with vendors.

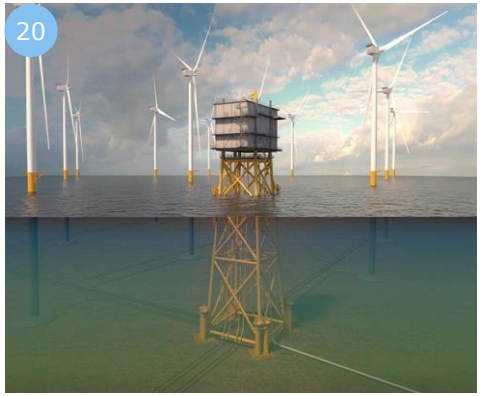
E-fuel references – Technical support

A selection of projects

Hydrogen feasibility study, Liberty Utilities, USA, 2021-2022

Ramboll is performing a feasibility study of a green hydrogen facility utilising hydroelectric power, in St. Lawrence, NY.

Ramboll reviewed the electrolyser technology and the possible electro fuels products and supported on determining the facility size order of magnitude for potential future expansion. Moreover, Ramboll supported on the permits and licensing documentation, site suitability, logistics, cost estimate and planning, water and power supply. Finally, commercial and legal advice was given.



Hydrogen pipelines and energy hubs as hydrogen interconnectors, TenneT, Netherlands, 2021-2022

Ramboll supported with the development of hydrogen pipeline transportation systems for the first offshore power to gas hub-and-spoke project. The scope of work includes various options for pipelines to shore and interconnecting pipeline between wind power hubs. Ramboll's services included: Selection of hydrogen pipeline route options including both new and repurposed existing pipelines; Assessment of restricted areas, environmental impact and achieving construction permits for new pipeline routes; Hydraulic and flow assurance studies including line packing; Assessment of repurposing existing gas and oil pipelines to hydrogen transport; Conceptual design of new pipelines; Tie-in to existing pipelines and wind power hubs; Conceptual landfall design; Input to selection of compressor station location and capacity; Cost estimation of optional hydrogen pipeline systems; Identification risks and preparing risk register.

E-fuel references – Technical support

A selection of projects

Retrofitting windpark with hydrogen production, Treurat und Partner, Germany, 2020-2021

Two concepts are being developed for the "Kremsdorf" wind farm near Oldenburg (Holstein) and are being technically, ecologically and economically evaluated and compared. One concept investigates the hydrogen production from the wind farm. The electrolysis plant is dimensioned, mass and energy balances are drawn up, the installation area is estimated and a suitable site is selected. The hydrogen is used by local consumers and alternatively by feeding it into the nearest gas grid. In the second concept, the electricity from the wind farm is used for heat generation in order to feed into a nearby heating network. Here, the system technology (including heat pump and electrode boiler) is also dimensioned and a suitable location selected. Both concepts are economically evaluated with regard to energy, operating and investment costs. We work in subcontracting with our project partner, through whom a legal evaluation of the two subsequent use concepts as well as the establishment of a business model suitable for banking purposes is carried out.

Dalmarnock Hydrogen Feasibility, Scottish Water Horizon, United Kingdom, 2020

Ramboll conducted a feasibility study to investigate the potential for hydrogen production from final effluent at the Dalmarnock Wastewater Treatment Works (WWTW) in Glasgow. The study sought to establish the viability of a pilot project and assess the potential wider economic and operational benefits associated with hydrogen generation. Scottish water has set a target to become a net zero emissions business by 2040, and hence the key driver for the project was reduction in carbon emissions from Scottish Water’s operations particularly in transport.

The project focused on hydrogen generation by electrolysis of final WWTW effluent. The main products of electrolysis are oxygen and hydrogen- it is proposed that the oxygen in this case would be used on-site in the existing WWTW aerators, while the hydrogen would be used as a transport fuel. A bespoke techno-economic model was developed to assess project’s economic performance.

E-fuel references – Commercial and technical support

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Assessment of the potential for PtX in Greenland, Nuuk Municipality, Greenland, 2020

The Ramboll study assessed if the production of e-fuel could be a way to put some of the country's hydro power resources to new use and at the same time reduce Greenland's CO2 footprint. The study looked at using spare capacity at the Nuuk hydro power plant "Buksefjorden" to generate an e-fuel using carbon from CO2 captured from the waste-to-energy facility in Nuuk.

At the waste-to-energy plant, where Ramboll is acting as the owner's engineer on the establishment of the new facility, capture of CO2 emissions from the stack would make the plant one of the most climate-friendly waste-to-energy plants in the world. In addition to the introduction of carbon capture at the waste-to-energy plant, the production of an e-fuel in Nuuk would be based on the implementation of current plans to extend the hydro power plant at Buksefjorden and the establishment of a plant for the production of e-fuel using hydro power and captured CO2.

PtX and associated business possibilities, Green Power Denmark (prev. Dansk Energi), Denmark, 2021

Rambøll was commissioned by Dansk Energi (now Green Power Denmark) to undertake an analysis of the benefits of increased requirements for use of green fuels in the transportation sector. Tightening the requirements for usage of green fuels and could potentially accelerate the development and thus enhance the capabilities of Danish companies, as it is estimated to increase further investment in PtX and thus increase experience and expertise of involved companies, while increasing their exposure to competitive technical solutions.

Ramboll provided development of energy balances and scenarios consistent with higher ambitions within shipping, air traffic and potential export of energy. For each scenario determination of the socio-economic gains in terms of employment, export of technology and earnings from energy export. The result of the project was identification of potential economic benefits and associated barriers in reaching each scenario.

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Management of Bunker Hub Consortium aiming to supply sustainable fuels in the Baltic Sea, Bornholm Bunker Hub, Denmark, 2021-

Ramboll is part of the Bornholm Bunker Hub consortium which launched a feasibility study to investigate the technical and commercial potential for supplying sustainable fuels in the Baltic Sea for the more than 60,000 ships that pass the island of Bornholm every year. The consortium consists of several large international companies from across the value chain, representing energy and fuel producers, distributors, off-takers and port infrastructure owners.

Ramboll has taken the project management lead and contributes with commercial and technical knowledge, in addition to reviewing and summarising analyses. The project is closely connected to other projects investigating the potential for local Power-to-X production of sustainable fuels.

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ESD & relief system and hydrogen interface piping for a hydrogen plant, Everfuel, Denmark, 2021

Ramboll developed, and matured the concept and detailed design of the Emergency Shut Down (ESD) and relief system, as well as the hydrogen interface piping for the HySynergy hydrogen plant in Fredericia. The detailed design covered piping & instrumentation diagrams, data sheets, including pressurised safety valve data sheets, 3D model, piping specs, and electrical & instrumentation work packages ready for purchase and construction. Ramboll also performed a series of risk and safety studies and offered support and advice in obtaining the required safety permits that were fundamental for starting construction activities. HySynergy is one of Europe's largest production plant for green hydrogen with a capacity of 20 MW and a long-term possible expansion to 1 GW.

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Market Analysis export of CCUS and PtX Technologies, Energistyrelsen, Denmark, 2021

Ramboll conducted a market analysis to highlight the potential for Danish exports of CCUS and PtX technology. The analysis describes the Danish competencies and strengths within CCUS and PtX technologies, the market for these technologies, as well as the potential for Danish exports in these markets, including what value export of these technologies can have for Denmark.

Market assessment and potential analysis for Power-to-X on Lolland, GATE 21 and REEL (REn Energi Lolland), Denmark, 2021

Ramboll has been assigned to analyse power-to-x options for Lolland, the largest island in Denmark. The project also aims to identify options for converting the existing natural gas pipeline to green gas as quickly as possible and ahead of schedule. The analysis serves as a knowledge base to assess whether Lolland is suitable as a potential location for Power-to-X and CCU in the context of the government's strategy and the planned, national investments in Power-to-X.

Power-to-X options will only be considered suitable for Lolland if they offer a technological readiness for deployment in the near future, a positive business case, improve rather than overload the local energy system, provide Net-CO_2-reduction and generate economic growth and jobs for Denmark and Lolland.

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UK Hydrogen Market Analysis and Strategy, Confidential client, United Kingdom, 2021

Ramboll conducted a high-level strategic analysis of the UK H2 market for one of Europe's largest engineering firms to be able to better position itself in the coming years.

The project involved a value chain description, competitor landscape assessment, identification of opportunities and a gap analysis for the client, ending with high-level strategic recommendations for how to better position in the market.

Market assessment for Power-to-X plant and bunker hub for carbon neutral fuels, 2020-2021

Ramboll conducted the initial analysis of the possibilities of establishing a plant of up to 1GW electrolysis in the Baltic Sea region. The first part of the analysis investigated technical options and constraints of the three key water electrolysis technologies: Alkaline, Polymer Electrolyte Membrane and Solid Oxide Electrolysis Cells. One technology was recommended based on projections of CAPEX, OPEX and TRL (Technology Readiness Level) considerations to maximize the likelihood for successful funding application. The economic part of the feasibility study analyzed the region's commercial and regulatory possibilities and challenges. The purpose was to identify and assess critical end-user markets and engage with potential value chain stakeholders who could participate in an industrial consortium.

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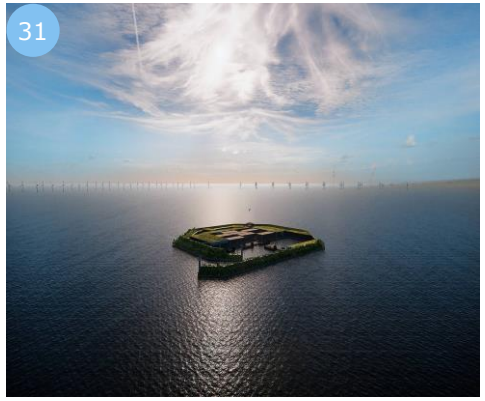

Master-planning the world's first artificial energy island, VindØ Consortium, Denmark, 2021

Ramboll provided high-level support to the consortium on sustainable and innovative solutions for the energy island, including the possibility of developing large Power-to-X facilities where power from wind farms is converted to products such as hydrogen and ammonia to be used in shipping and industry.

The planned energy island in the North Sea is a monumental project that not only plays a leading role in fulfilling Denmark's target for reducing greenhouse gas emissions by 70% by 2030, but also contributes to increasing renewable energy across Europe.

Technical advice for development of a leading circular bio- and e-fuels cluster, BioCirc Aps, Denmark, 2022

Ramboll has provided technical advice in the strategic acquisition of the Danish biogas producer Vinkel Bioenergi by Maigaard & Molbech and European Energy, which entered into a joint venture agreement. The new joint venture holding company BioCirc ApS will be a leading circular bioeconomic group with a focus on Recycling, Waste-to-Energy, Renewable Energy and Power-to-X.

European Energy can use the CO2 that would otherwise be released into the atmosphere from the production of biogas at Vinkel Bioenergi in the production of e-methanol, which is supplied to large companies.

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Fuel analysis in shipping by ship segment, Deutsches Maritimes Zentrum e V, Germany

Ramboll was commissioned by the client to carry out a study including an in-depth analysis of alternative fuel characteristics (for e. g. methanol, ammonia or LNG) as well as fleet details with information on e. g. fuel types, engine types and power, vessel age, region of operation and bunkering practices. The aim was to develop options for action and recommended measures for the targeted development of an alternative fuel portfolio. The results of the study contain ship type / shipping segment and operating region-specific recommendations on which fuel strategies are most sustainable and competitive in a well-to-propeller approach, which gaps in technology, regulation, etc. need to be closed and how the transition in the industry can be optimally supported.

Power-to-X concept and market study for a large European utility company in connection to an offshore windfarm, Confidential client, Baltics and Northern Europe, 2023

Ramboll was commissioned by a large European utilities company to perform a concept study for the development of Power-to-X in connection with the grid connection of an offshore wind farm. The concept study investigated PtX products such as green hydrogen and its derivative products, i.e., methanol, ammonia, SAF, and methane. The main purpose of the study was to provide the client with an overview of the opportunities, technical solutions, and locations for the proposed Power-to-X plant and reduce the number of concepts to investigate at later phases before offering a final selection of preferred concept/solution and sites. The project also included a high-level market analysis for the products of Power-to-X in a range of Northern European countries that estimated the expected demand and prices for these products in the future.

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Market assessment of energy storage and industrial decarbonization solutions in Europe and North America (2023)

Ramboll conducted a comprehensive market study with the primary objective of gaining a profound understanding of the global and regional market landscape for e-fuels and PtX within the Baltics, Northern Europe, and Central Europe regions. Ramboll conducted a PtX and E-fuel Market Study, including precise market segmentation, competitive analysis, and infrastructure benchmarking, as well as an in-depth analysis of market dynamics, including supply, demand, and pricing forecasts. Additionally, Ramboll undertook the PtX and E-fuel Regulatory Framework Analysis, diving deep into governing production, consumption, transportation, and dissecting complex regulations related to financial incentives and funding mechanisms.

Green Fuel Market Assessment for Infrastructure Fund Acquisition, Confidential Client, 2023

Ramboll conducted a comprehensive assessment of the green fuel market in the EU and North America, with a focus on supporting an infrastructure fund's acquisition process. The analysis covered several key aspects, including technology, regulatory landscape, market attractiveness, supply and demand, price considerations, and ESG considerations.

A thorough analysis of the market was conducted to identify the opportunities and risks associated with the acquisition. Ramboll examined the current and future market trends, evaluated the regulatory environment, assessed the technological landscape, and analysed the competitive landscape to determine the market's attractiveness.

The report provided the client with valuable insights into the green fuel market and assisted them in making informed decisions regarding the acquisition process. It also highlighted the importance of ESG considerations in the acquisition process, providing the client with a deeper understanding of the potential environmental and social impacts of their investment.

E-fuel references – Commercial and technical support

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Carbon sourcing and pricing strategy study for a Scandinavian energy company, Denmark, 2023

Ramboll was commissioned by a Scandinavian energy company to conduct a study on sourcing and pricing of biogenic CO2 for a planned e-fuel production site. The study covered the entire CCUS value chain. Its initial focus was on identifying key regulations, types of CO_2 source plants, and carbon capture and transport technologies to establish the suitable geographical scope for attractive sourcing opportunities. Based on these findings, the study evaluated and ranked numerous CO_2 sources to pinpoint the five most relevant sources for the company. Each source was then analysed for associated risks and opportunities. Additionally, the project involved a broad analysis of CO_2 pricing strategies and future price projections up to 2045 to provide insights for forthcoming negotiations and contracts for carbon sourcing.