

An aerial photograph showing a paved road that curves through a dense green forest. To the left of the road is a large, calm body of water with a deep blue-green hue. The road has a yellow center line and a white edge line. A small car is visible on the road, moving away from the viewer. The forest consists of many tall, thin trees, likely conifers, with a thick canopy.

Ramboll Energy

Engineering consultancy services

Green fuels

Jesper Knudsen
Head of Business, biofuels

October, 2023
Future of Biofuels
Copenhagen

RAMBOLL

Bright ideas.
Sustainable change.



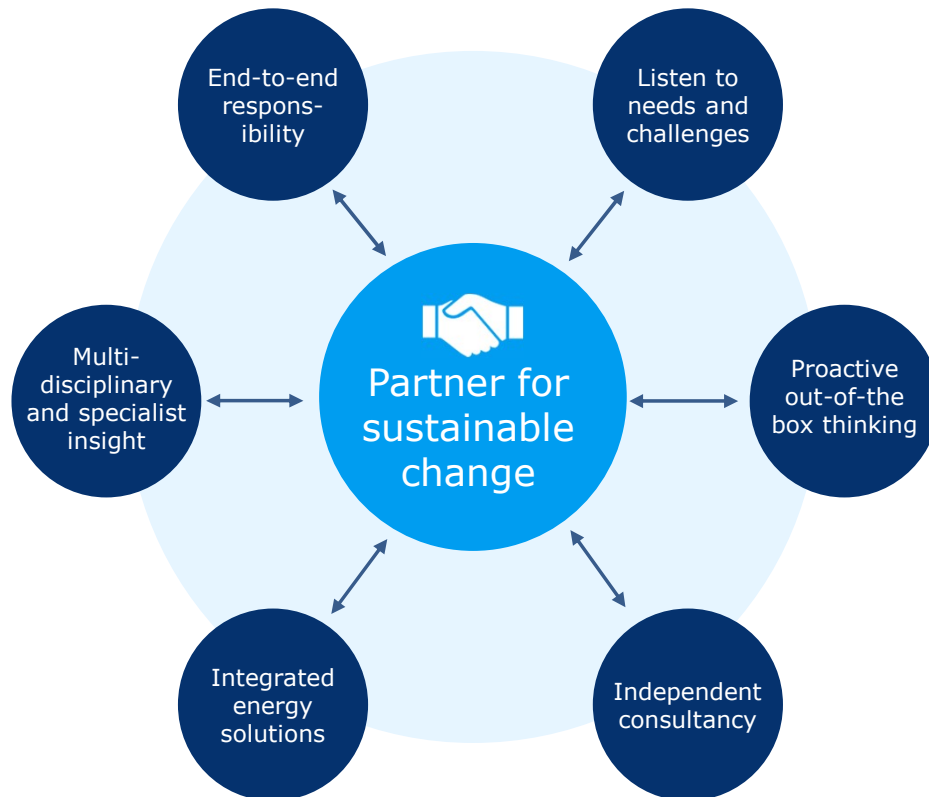
Ramboll in brief

- **Independent architecture, engineering and consultancy company**
- Founded 1945 in Denmark
- More than 18,000 employees
- Present in 35 countries
- Particularly strong presence in the Nordics, the UK, North America, Continental Europe, and Asia Pacific
- Creating sustainable solutions across Buildings, Transport, Energy, Environment & Health, Water, Management Consulting and Architecture & Landscape.
- EUR 2.2 billion revenue
- Owned by Rambøll Fonden – The Ramboll Foundation

Markets – Creating sustainable solutions



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

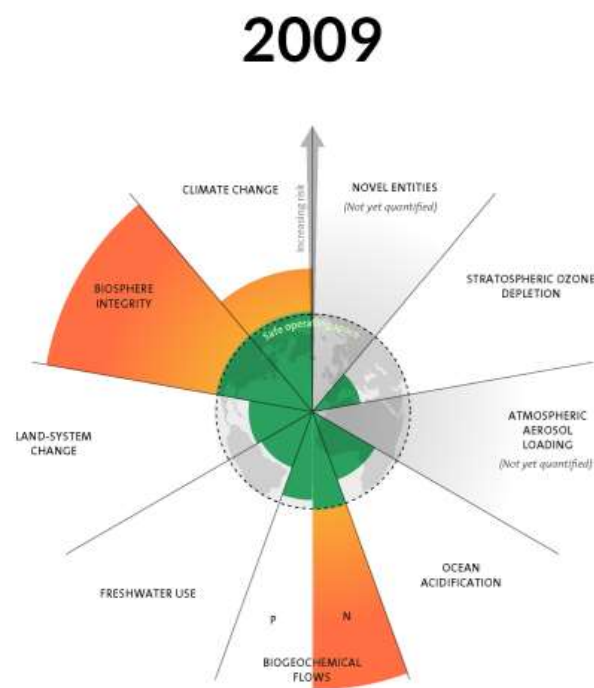


Helping our clients **reduce their carbon footprint, navigate the integrated energy system and innovate solutions** to improve it is at the centre of everything we do.

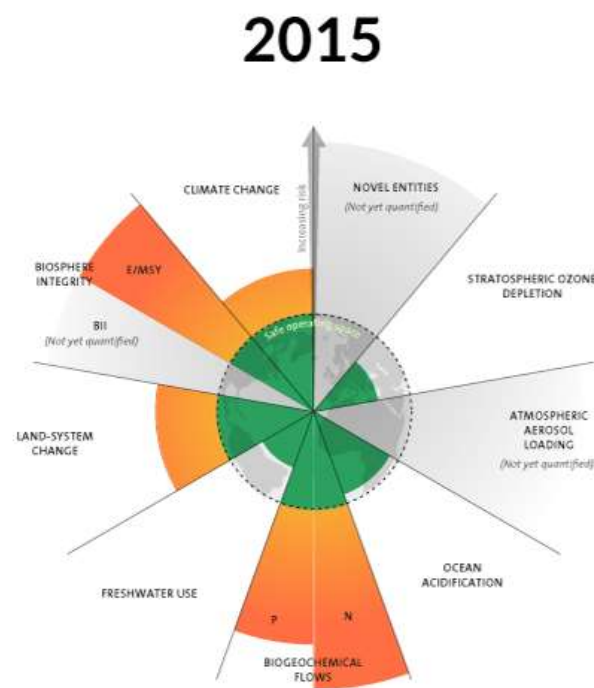
With our knowledge of the energy system, its elements and their interaction, we define the challenge and its complexity together with our clients.

What is sustainability?

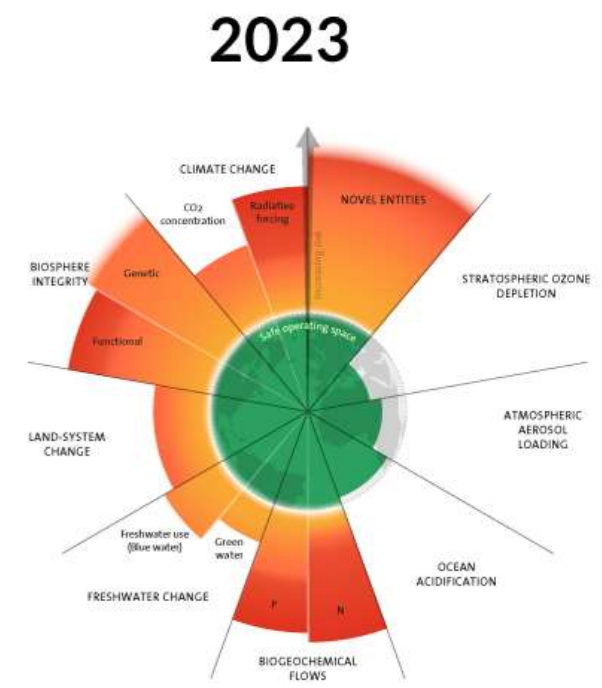
The earth has a problem...



3 boundaries crossed



4 boundaries crossed



6 boundaries crossed

Sustainable energy – areas to address

Renewable energy



New technologies



Sector coupling



Electrification



Integration of
renewable energy
in power system



Energy storage



Thermal technologies



District energy



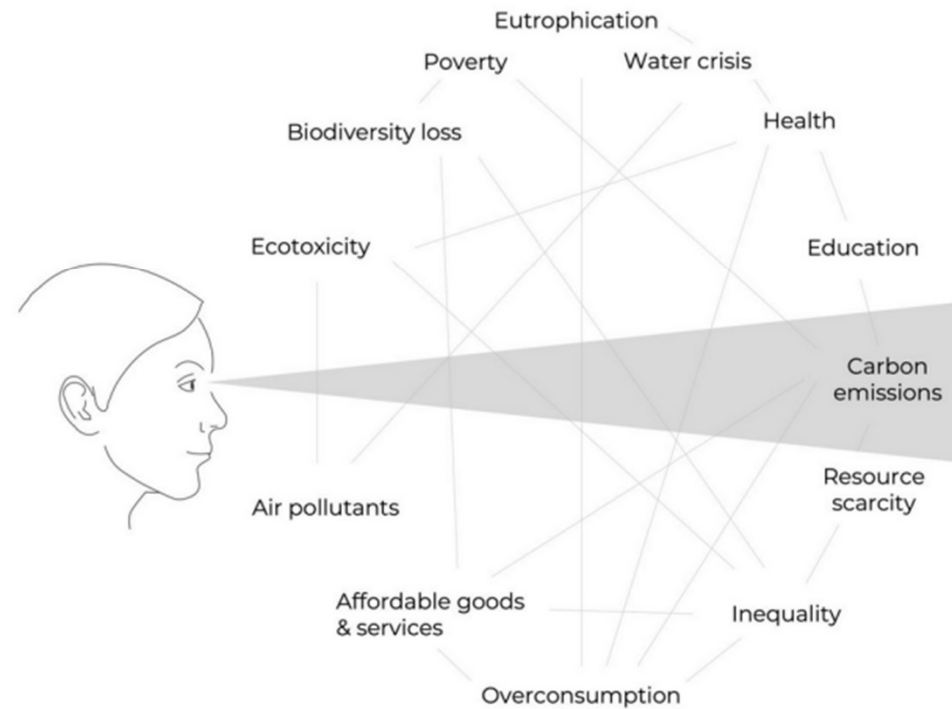


Sustainability Moment

The increase in carbon emissions is only one problem, and we must remember the other planetary and social boundaries

Ramboll

Carbon Tunnel Vision



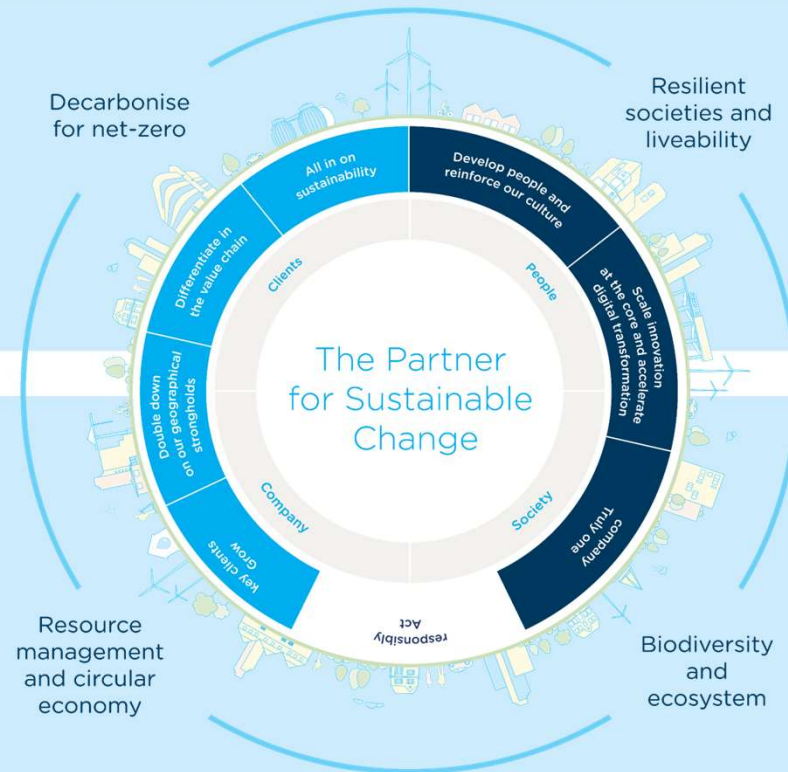
Sustainability transition

Graphic by Jan Konietzko

Ramboll's 4 unifying themes

Accelerating the **Green Energy Transition** by focusing on **renewables** and **new technologies**. We focus on the **decarbonisation** of the built environment in buildings, transport, water and energy-intensive industries via sustainable materials and reduced energy consumption

Resource management for a transition to **circular economy** design for re-purposing and re-use of natural resources, building materials, lifetime extension, end-of-life and reuse of secondary materials



Planning, designing, and retrofitting for **resilient, healthy, safe, inclusive** and **socially coherent societies, cities** and **communities** with attractive and accessible infrastructure and services, mobility, clean water and environment, and economic opportunities

Protection of **natural habitats** and **biodiversity**, restoration of **nature** and **ecosystems**, **bio-economy**, **biomaterials** and **natural carbon sequestration** in ecosystems.

Integrating sustainability in the project

Our multidisciplinary setup and profound understanding of the different disciplines will enable Ramboll to naturally integrate sustainability into the project, however the bar could be raised by including some of our additional sustainability services.

Activities

Methodology and prerequisites

1. Define sustainability

- Understand the client's sustainability priorities, vision and mission
- Define sustainability and create a common language on sustainability priorities, vision and mission of the client

2. Identify improvement potentials & sustainability measures

- Identify sustainability improvement potentials and measures for the specific project contributing to realizing the client's strategic priorities
- A sustainability workshop using our inhouse sustainability tools can help to identify and preselect sustainability measures

3. Focus where it makes most sense

- Quantify the sustainability impact e.g., net biodiversity gain, GWP in CO₂-eq, toxicity of the measures to identify focus areas as well as the economic consequence
- Prioritize most economic measures to meet sustainability ambitions

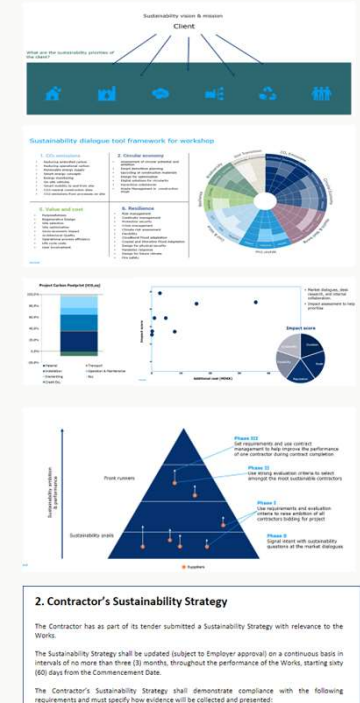
4. Work with the market

- Engage with contractors early and explore readiness to implement identified sustainability measures and ensure it towards client (e.g., is a technology provider able to use recycled steel in their products? If yes, is it possible to obtain a declaration proving recycled content of product or is only a self-declaration feasible?)

5. Implement sustainability in project (e.g., sustainability criteria in tender documents)

- Based on priorities and readiness of suppliers, define sustainability minimum criteria and evaluation criteria. Define weighting of sustainability evaluation criteria compared to other evaluation criteria (price, experience of project team, technical solution, etc.)
- Follow up on implementation of agreed sustainability measures

Examples of delivery





Sustainability
Reference



Image: Henning Larsen

Plastic to liquid fuel plant, Quantafuel, Denmark

The challenge

Establish a plastic to liquid fuel plant in Esbjerg for Norwegian-based company Quantafuel, which will use plastic waste to produce environmentally friendly chemical components for the plastic industry.

Our approach

We performed a FEED study, provided consultancy services on all engineering aspects and acted as a partner for industrialising Quantafuel's technology on a global scale. Furthermore, a sustainability workshop supported to define sustainability goals and find ways to achieve DGNB gold status for the building.

Result

The project is a showcase for ending wasteful and unsustainable handling of our planet's resources.

The plant will use a unique catalyst technology to recycle approx. 80,000 tonnes of plastic waste annually, making a significant positive impact on the environment.

The design will be standardised to build more similar plants across Europe.

Furthermore, sustainability was integrated into building and the site, e.g., by realizing the plant in DGNB gold standard, ensuring a healthy and safe environment or greening of site and roof.

Quantafuel

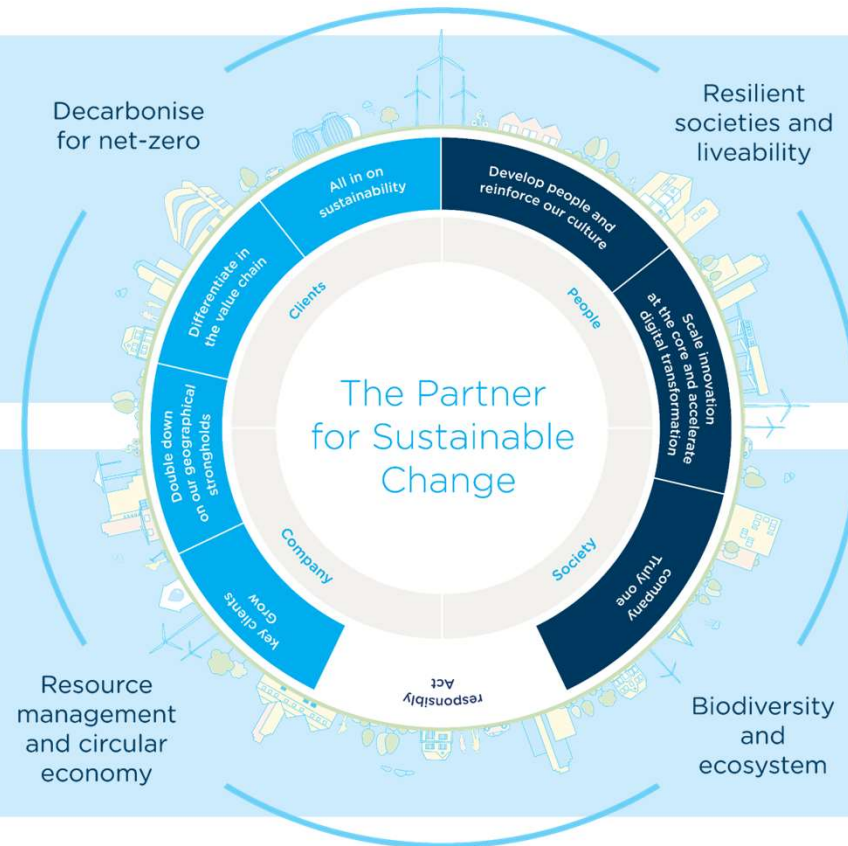
Pyrolysis plant



Sustainability
Reference

- Chemical recycling of plastic instead of incineration avoids CO₂-emissions from fossil waste streams

- Material selection and design to achieve DGNB gold standard for building / building façade
- Replacement of fossil resources for plastic reduces demand of fossil resources for plastic production
- Upcycling of plastic waste into petrochemical products – to be used as new plastics, substances or chemicals
- Maximise circular economy through additional recycling of metals, Tetrapak, etc. that is not suited for pyrolysis



- Sustainability workshop to develop sustainability vision and define sustainability goals
- Smart arrangement to optimize logistics
- Measures to ensure improved health & safety environment
- Increase of independency from fossil fuels from other countries

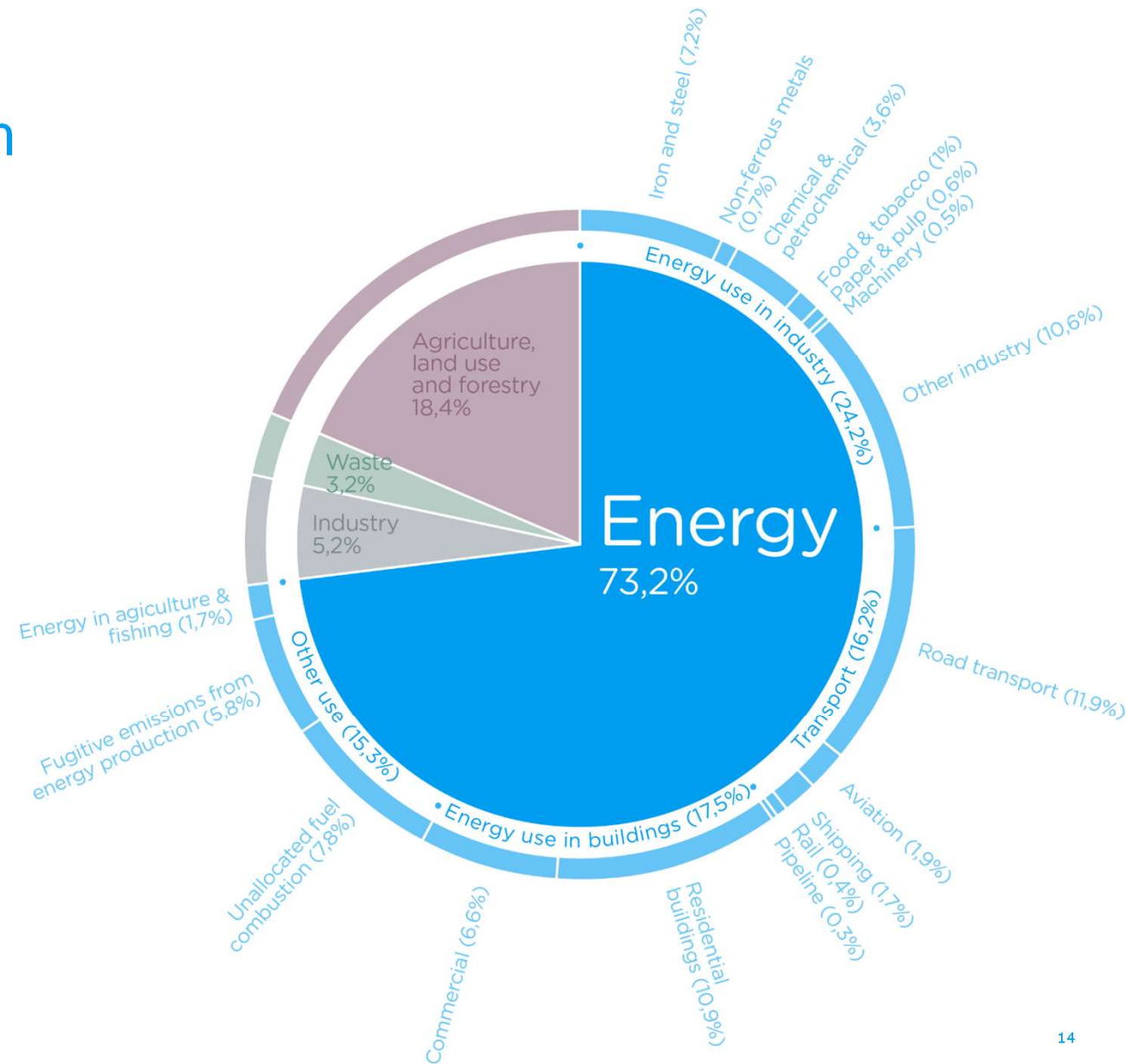
- Green roofs and greening landscape to integrate plant into nature
- Reduction of environmental impacts from crude oil extraction

Ramboll Energy

The energy sector is key in the green transition



Energy is the biggest GHG emission source



Ramboll Energy

- 50 years of experience in planning, design and implementation of energy solutions
- Expertise on full spectrum of technologies
- 14% of Group revenue
- 2,000+ specialists
- >90 offices in 16 countries
- Among the 10 leading energy consultancies in Europe

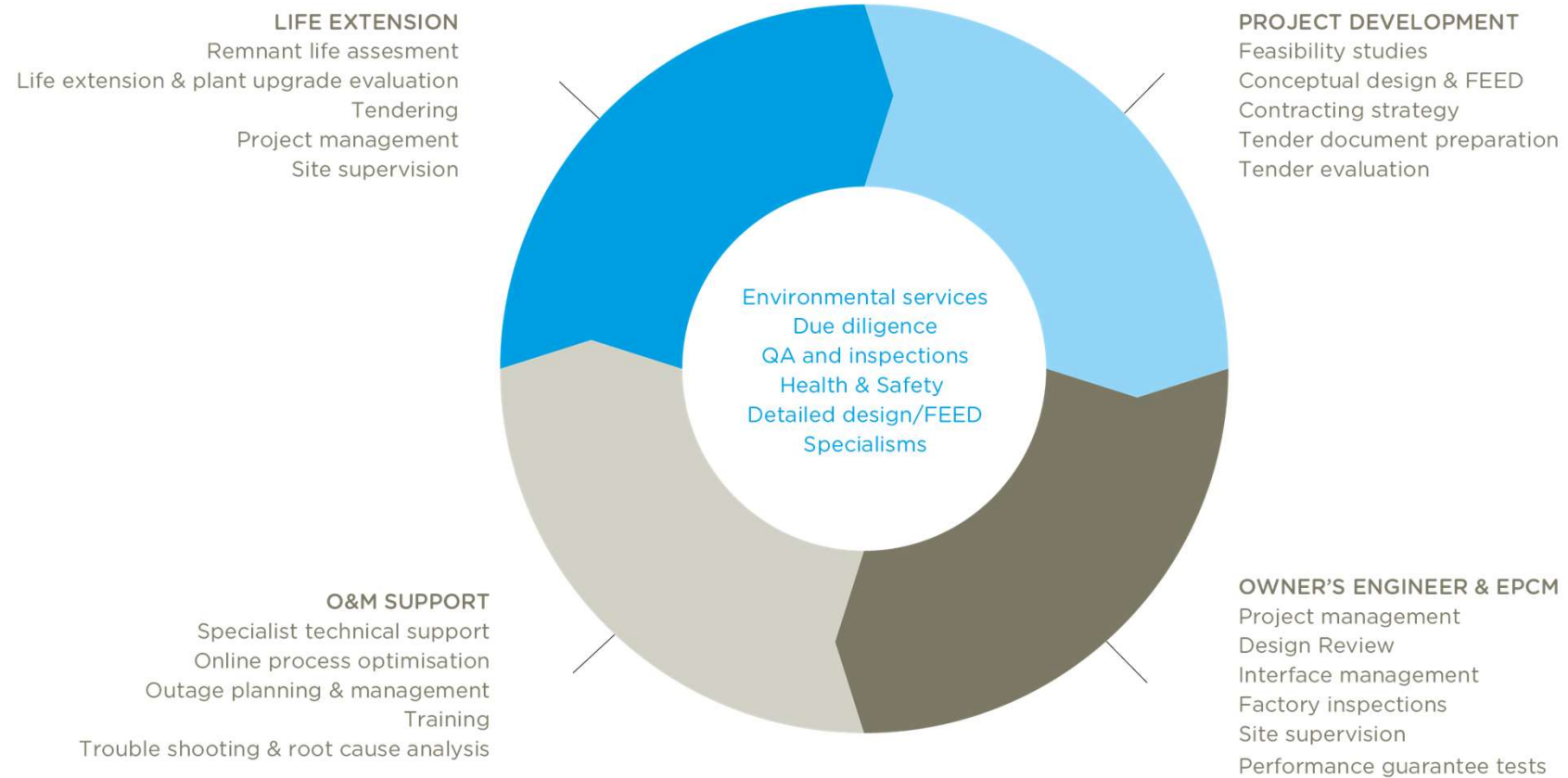


Fields of expertise

- Wind & solar
- Green hydrogen and Power-to-X
- Bio-to-X and Biofuels
- Biomass pretreatment, feedstock handling
- Carbon capture, utilisation & storage
- Energy infrastructure
- District energy
- Power generation, thermal bioenergy
- Biogas
- Waste-to-energy
- Energy-intensive industries

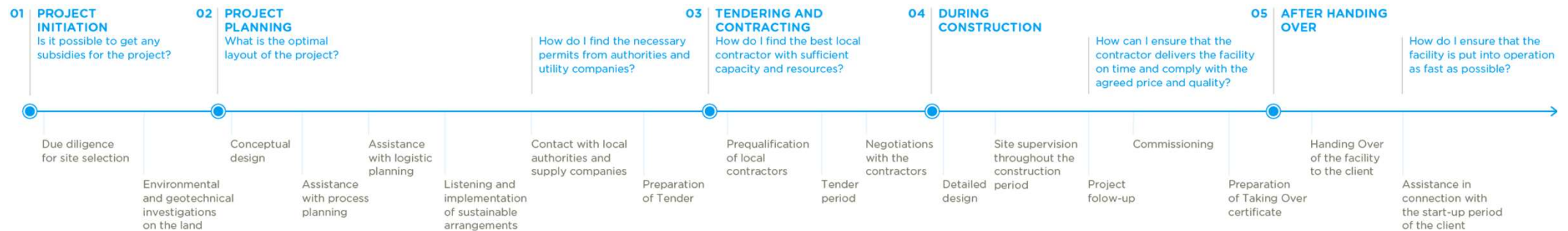
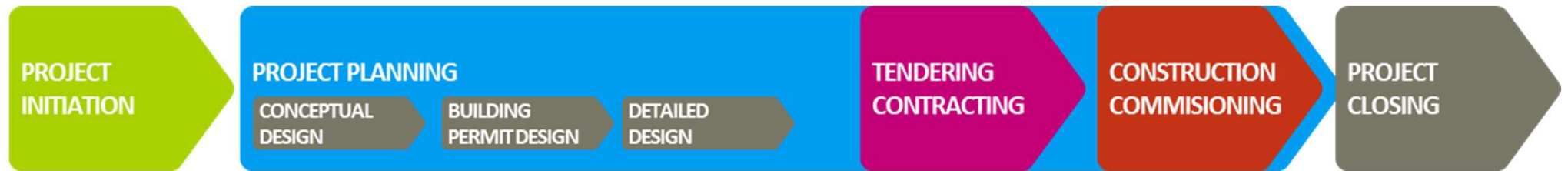


Full range of project lifecycle services



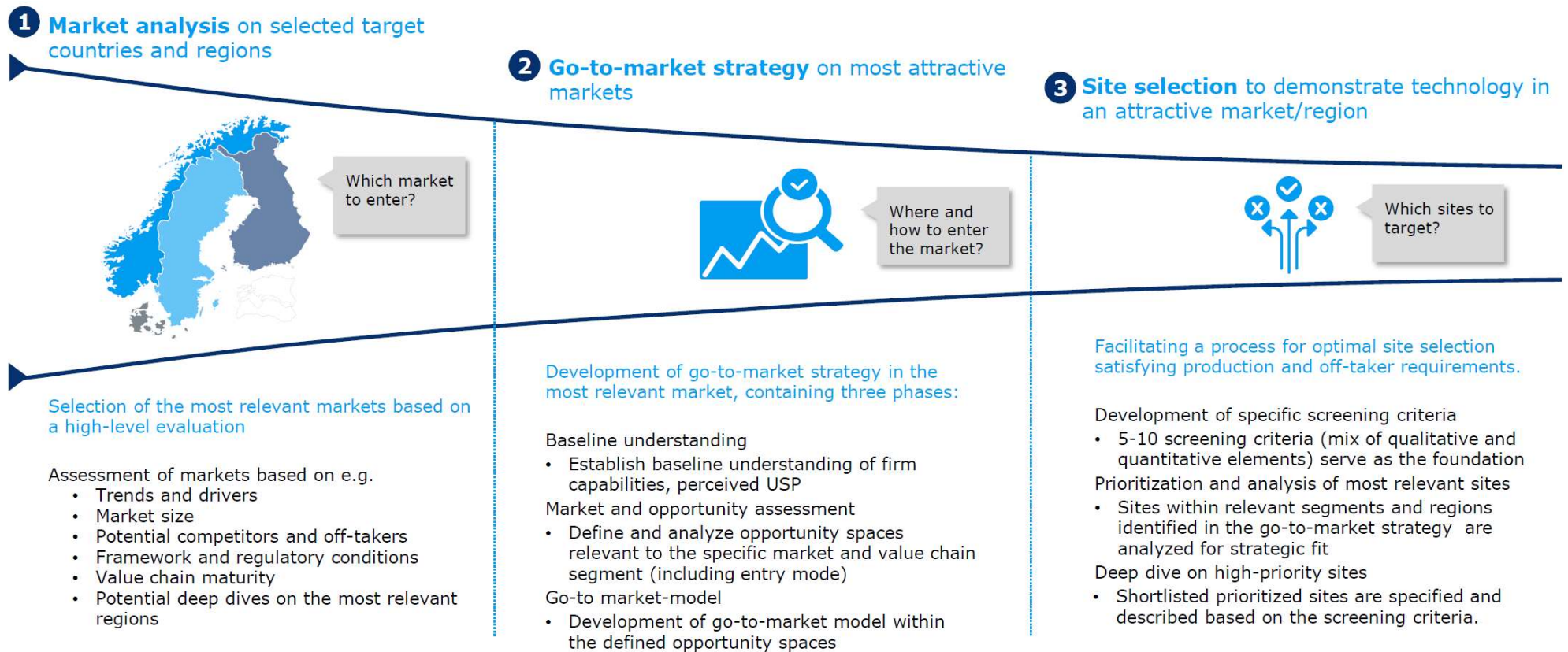
RAMBOLL

FULL-SERVICE PARTNER



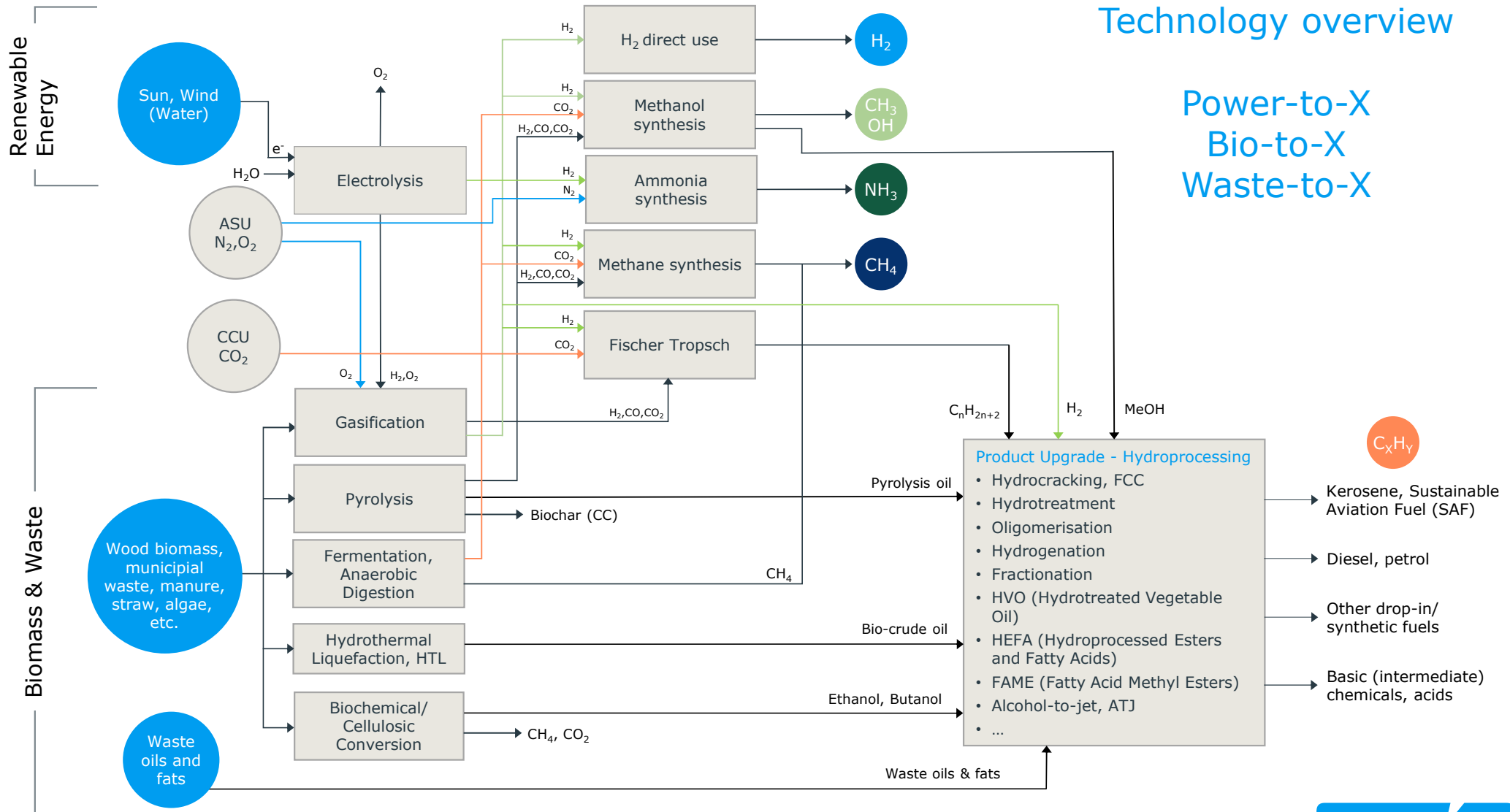
Management Consulting

Example - Market analysis



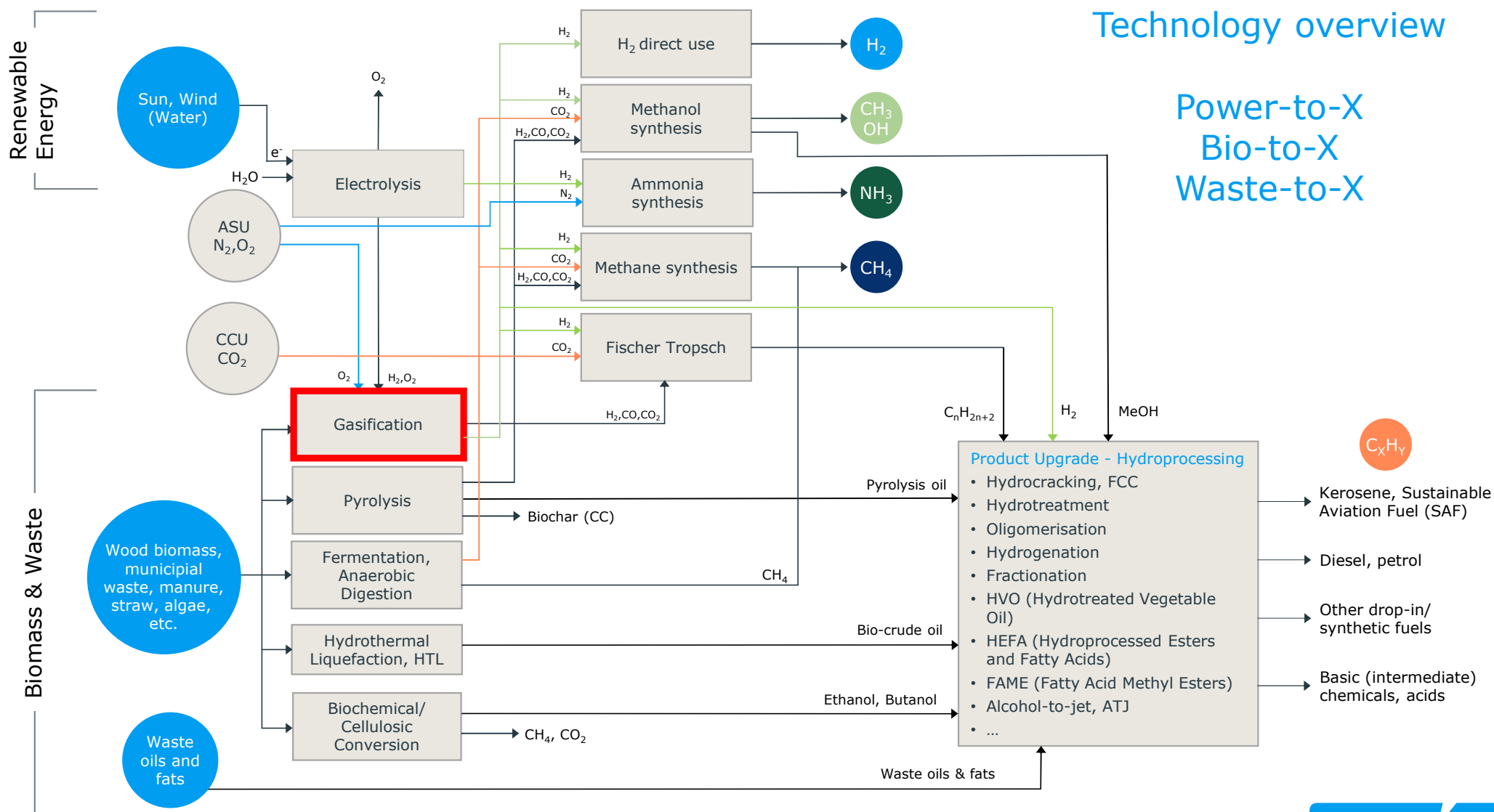
Advanced sustainable fuels Technology overview

Power-to-X
Bio-to-X
Waste-to-X



Advanced sustainable fuels Technology overview

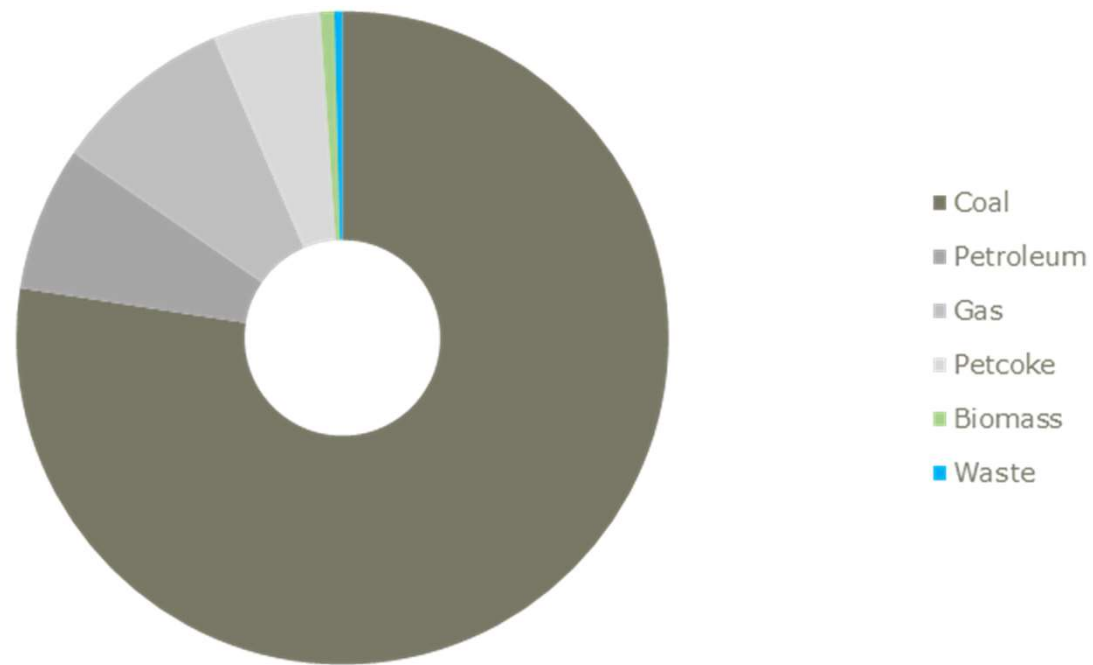
Power-to-X
Bio-to-X
Waste-to-X



Gasification

WORLDWIDE GASIFICATION FEEDSTOCKS

GASIFICATION SYNGAS CAPACITY 2018



[Global Syngas Technologies Council 2019]

Thermochemical conversion processes biomass/waste under controlled reaction conditions for a desired output

Thermochemical conversion processes are used to produce heat, solid, liquid, and gaseous products and a wide variety of each type depending on reaction conditions.

Degree of conversion

-

Pyrolysis

Feedstock is heated to high temperatures without adding air

Gasification

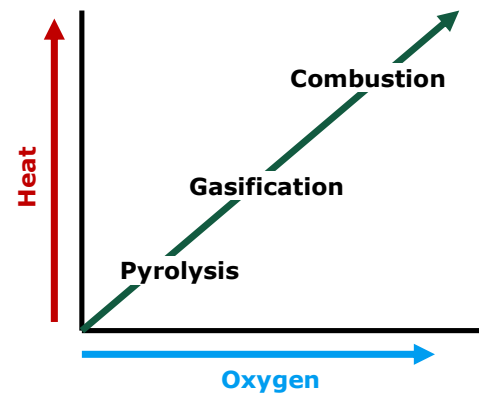
Feedstock is heated with the addition of small quantities of oxygen/air

+

Combustion

Feedstock is heated with excess air supply, causing total combustion

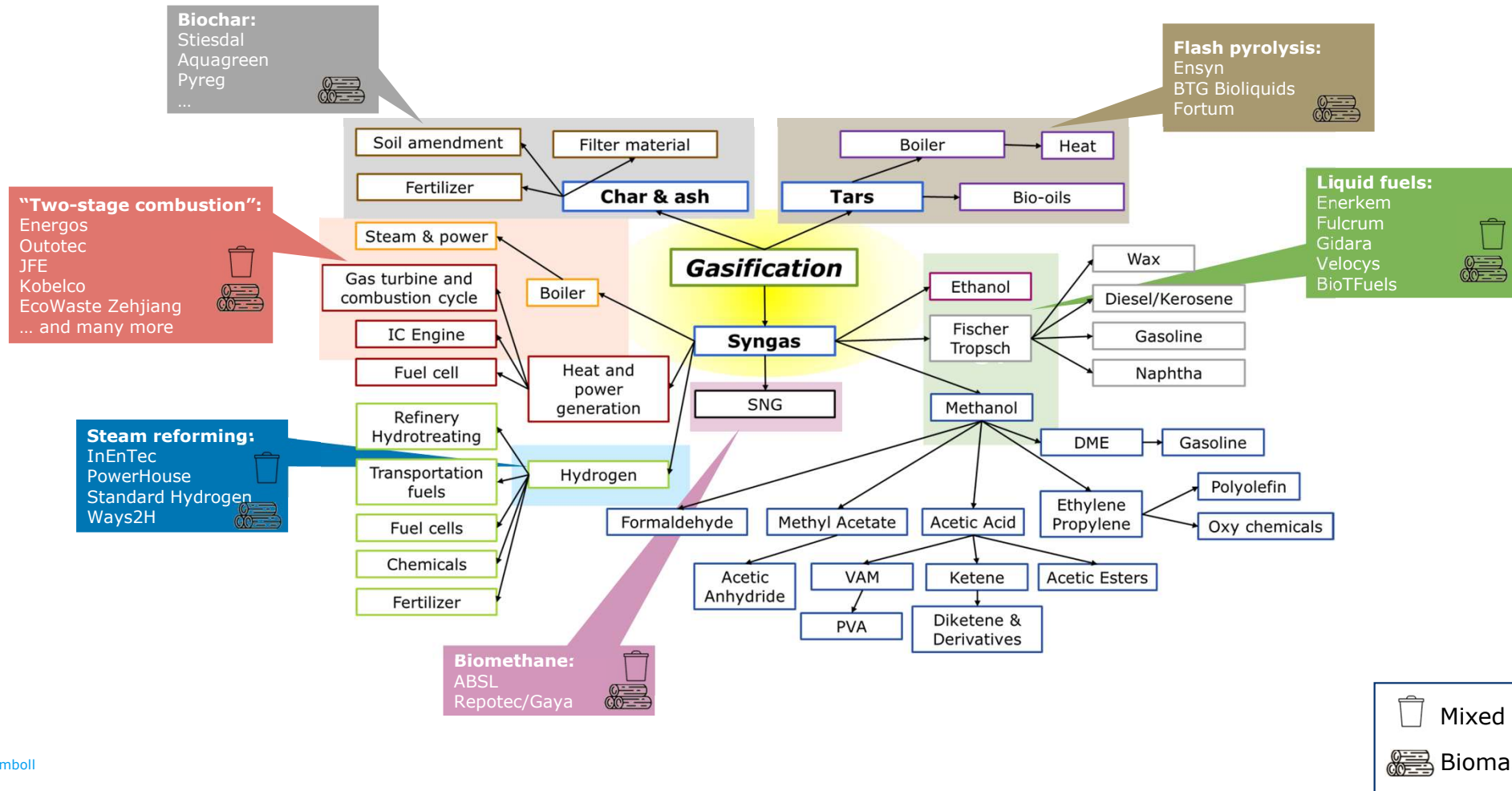
Heat and oxygen almost completely control what kind of thermal conversion will occur



Process comparison

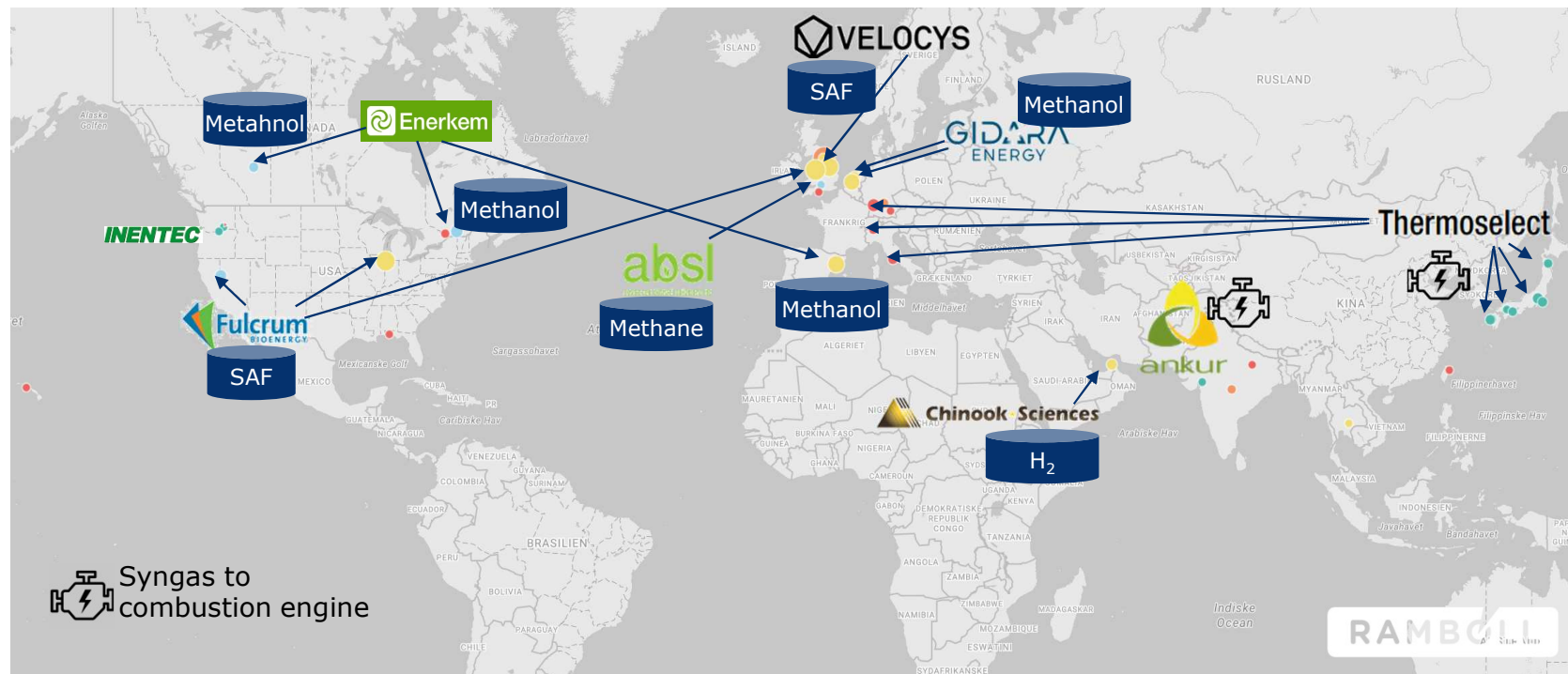
	Pyrolysis	Gasification	Combustion
Reaction environment	Zero oxygen	Reducing, low oxygen	Oxidizing, excess stoichiometric oxygen
Oxidizing agent	None	Air/O ₂ /steam	Air
Temperature	400-800°C	500-900°C (air) 1,000-1,500°C (other gasifying agents)	850-1,200°C
Main outputs	Liquids & solids	Gas	Heat
Produced gases	CO, H ₂ , CH ₄ and other hydrocarbons	CO, H ₂ , CH ₄ CO ₂ , H ₂ O	CO ₂ , H ₂ O
Pollutants	H ₂ S, HCl, NH ₃ , HCN, tar, particulates	H ₂ S, HCl, NH ₃ , HCN, tar, particulates	SO ₂ , NO _x , HCl, PCDD/F, particulates

Gasification can potentially produce a wide range of end products



Current biomass/waste gasification development projects are primarily based in Europe and North America

Global distribution of MSW/RDF gasification projects



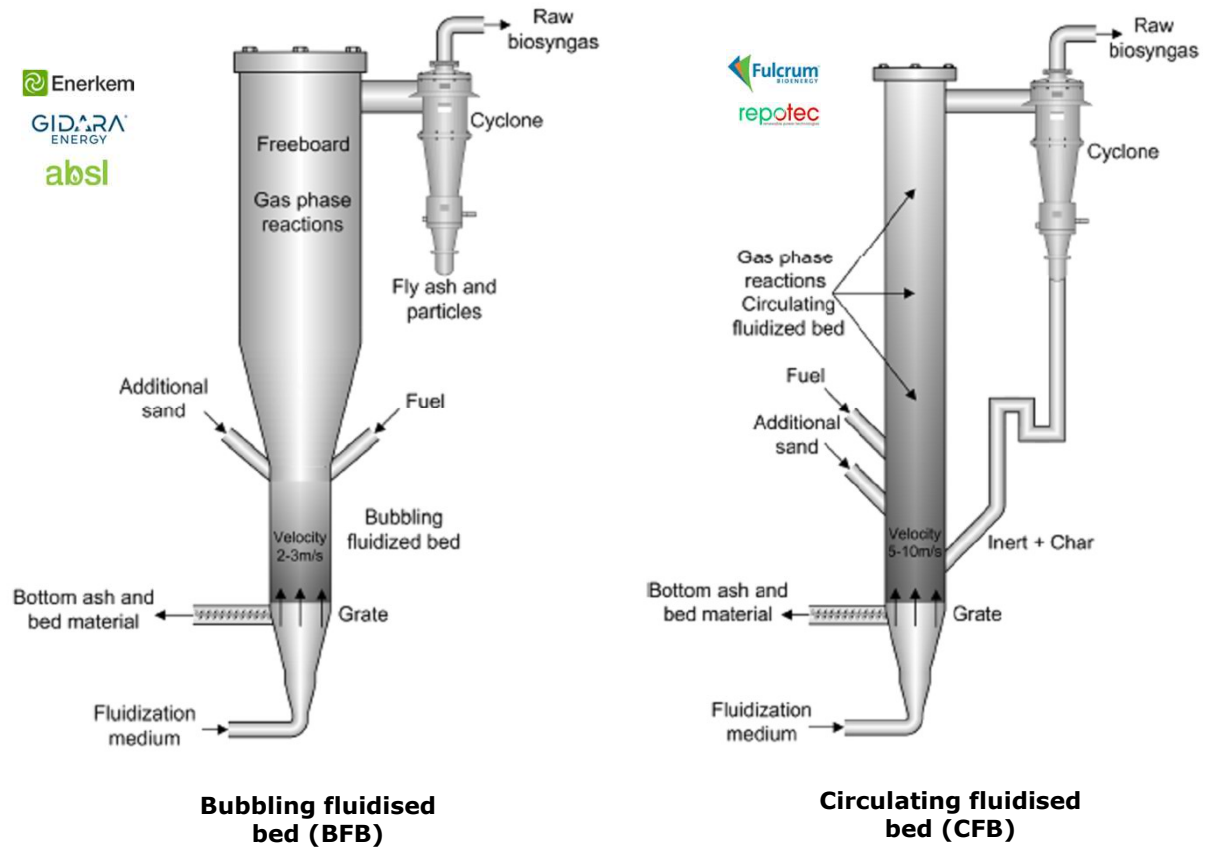
[Ramboll October 2023]

In Europe and US, no gasification or pyrolysis plant predominantly processing waste is known to have passed a successful commissioning demonstrating the expected functionality and performance.

The operating plants clustered in Japan are predominantly low-efficiency plants purposed for ash melting. Further details on the following slides.

- The FB reactor contains whirlpool of hot sand (600-900°C)
- Oxygen/air/steam added from below to "fluidize" the sand and keep sand hot by partial combustion of gas
- Fuel is heated instantly (pyrolysis)
- Pyrolysis char stays in reactor until gasified
- Main limitations:
 - Particle size (shredding/screening)
 - Ash composition (limits on Cl, K)
 - Inerts, glass, rock, metal... (feed system and removal from reactor)

Fluidized bed is the most common type for biomass/waste gasification



Why is biomass/waste gasification so difficult?

In fact not easy with biomass, but worse with waste/RDF

- **Tars!** Sticky/smelly/toxic aromatic compounds
 - Fouling pipes, heat exchanger, rotating equipment, ...
 - Serious trouble for most gas cleaning
 - In residuals and waste-water
- **Ash properties**
 - Ash can get sticky at process temperatures
- **Inerts**
 - Solids often handled in augers. Inerts can be difficult to remove from reactors.
- **Particle size**
 - Fluidized bed reactors have both narrow upper and lower particle size limits
 - Gasification kinetics are slower than combustion, thus large particles convert slower.
- **Sulphur and metals**
 - Catalytic synthesis requires low ppm levels in the syngas

Current trends in the gasification industry are towards:

- **Biomass** and **waste/RDF** as the feedstock
- From boilers/engines **towards synthesis into fuels/chemicals**

Green transition increases demand for green fuels and thus the resources and interest from investors

Thank you

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Bright ideas.
Sustainable change.

Selected project references

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.

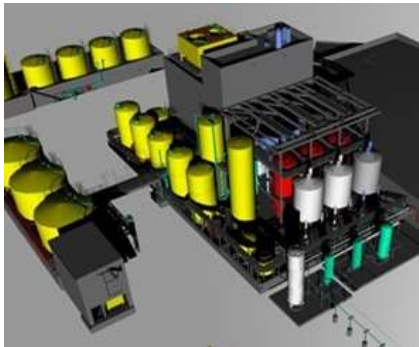
Bio- and waste fuel references – Technical and environmental support

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.

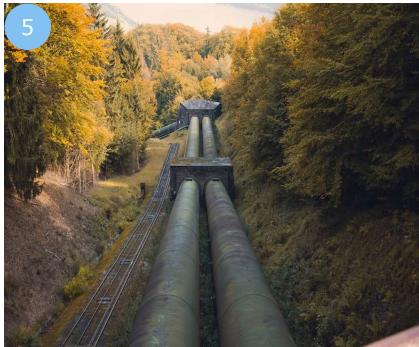


Biodiesel production facility engineering, United States 2019

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

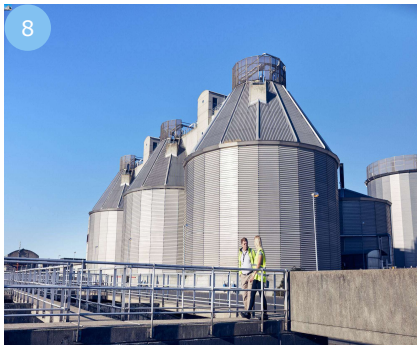
A selection of projects



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 - Bekkelaget 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



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.



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.

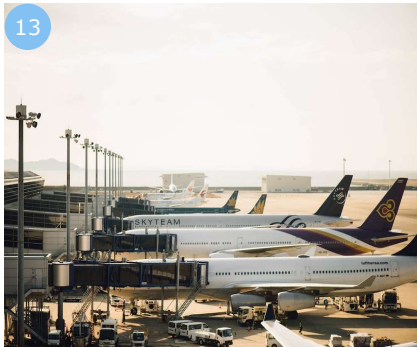


Market study of the Waste-to-Energy market in the United States, Confidential Client, United States, 2017 & 2019

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 CO₂ 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

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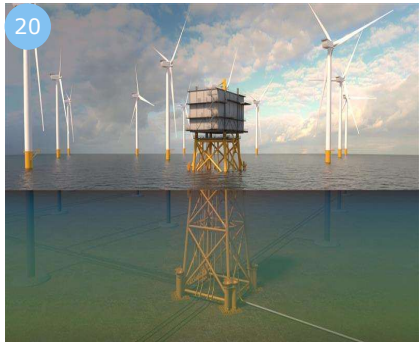


Hydrogen feasibility study, Liberty Utilities, USA, 2021-2022

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.

20



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

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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.

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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

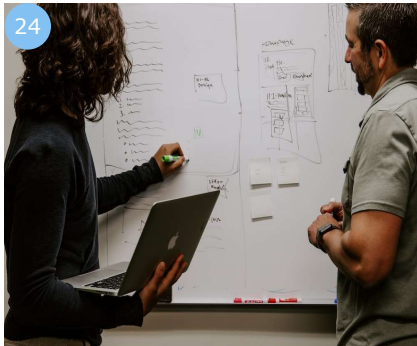
A selection of projects



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

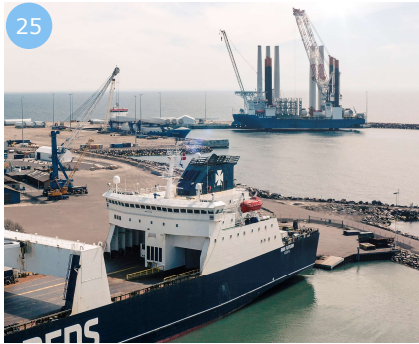
Rambøll was commissioned by Dansk Energi (now Green Power Denmark) to undertake an analysis of the benefits of increased requirements for use of green fuels in the transportation sector. Tightening the requirements for usage of green fuels and could potentially accelerate the development and thus enhance 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.

Rambøll 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.

E-fuel references – Commercial and technical support

A selection of projects

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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.

E-fuel references – Commercial and technical support

A selection of projects

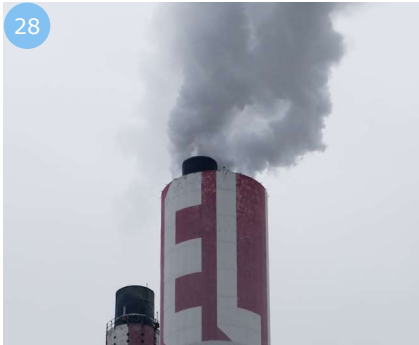
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Market Analysis export of CCUS and PtX Technologies, Energistyrelsen, Denmark, 2021

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.

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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-CO₂-reduction and generate economic growth and jobs for Denmark and Lolland.

E-fuel references – Commercial and technical support

A selection of projects



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.

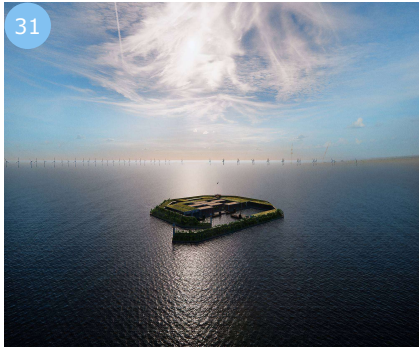


Market assessment for Power-to-X plant and bunker hub for carbon neutral fuels, 2020-2021

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.

E-fuel references – Commercial and technical support

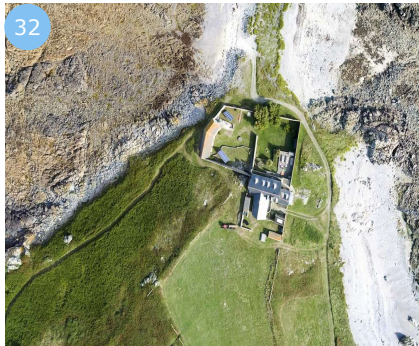
A selection of projects



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.

E-fuel references – Commercial and technical support

A selection of projects



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.