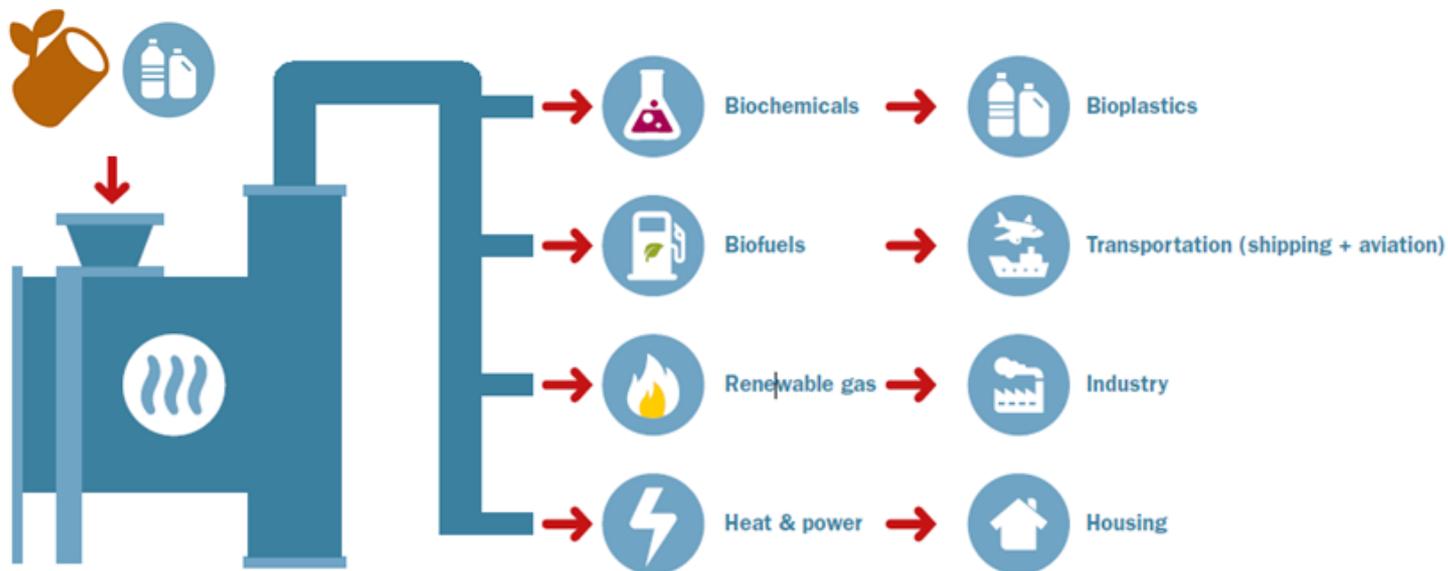


GASIFICATION FOR THE BIOECONOMY



› **TNO** innovation for life

FROM BIOMASS TO FUELS AND CHEMICALS

Gasification will play a mayor role in the energy transition by converting a wide range of organic and carbonaceous materials into a combustible gas, called product gas. This gas consists of H_2 and CO (syngas) and instant chemicals, such as ethylene and benzene. Product gas can be used for a variety of end- products ranging from fuels to high-value chemicals.

TNO has a long standing history in bio-energy research focusing on high efficient thermal conversion technologies, optimization of existing technologies and developing technology to pre-commercial readiness. Indirect gasification is one of these technologies that allow the production of green energy, green chemicals and biofuels.

MILENA – OLGA TECHNOLOGY

The MILENA OLGA technology has a long history at TNO. Both technologies were developed for high efficiency and maximizing the yield from any feedstock going into the gasifier. This has been successful, and as such the technology is now considered a standard platform, open for R&D activities.

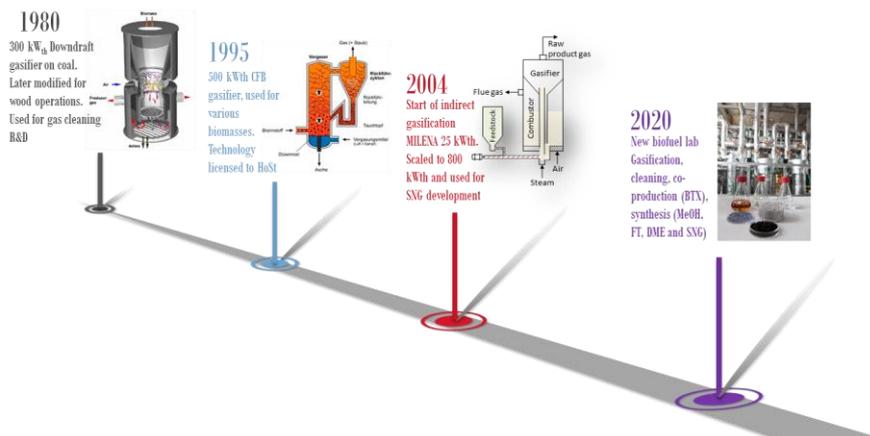
The MILENA-OLGA technology is commercially available at Synova (synovapower.com).

Unique features of this technology are:

- 100% feedstock conversion;
- No waste (carbon or tar);
- Instant Green Gas (~15 vol% CH_4);
- Instant Chemicals (ethylene and benzene);
- Fuel flexible, ranging from wood (residues), agro-residues, RDF to high plastic containing streams.



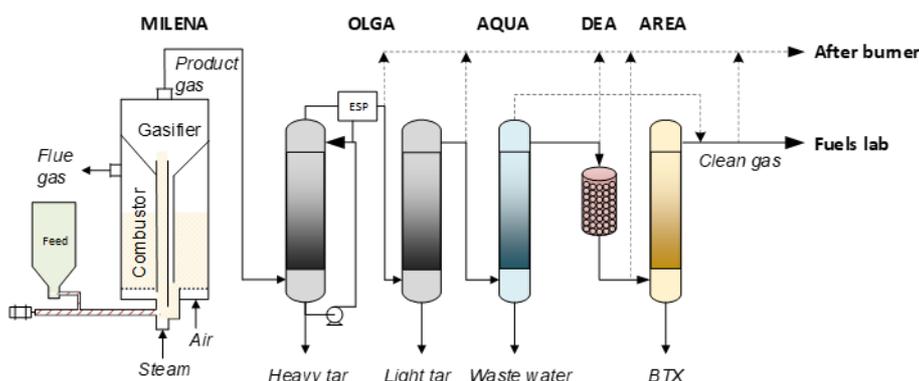
LONG EXPERIENCE IN GASIFICATION



The platform technologies were developed by learning from past technologies. For MILENA these are fixed bed-, BFB- and CFB- gasifiers. For OLGA these are, various scrubbers (water/oil), absorbents and cracking routes. This led to 8 patents on this gasification platform.

In 2020 a new laboratory for biofuels production from gasification became available at TNO. The new line up includes reforming, deep gas cleaning, compression and subsequent catalytic conversion facilities, enabling the cost efficient biofuel production with co-production of chemicals.

INDIRECT GASIFICATION AND PRODUCT GAS CLEANING AT TNO



Our gas cleaning facilities include one unit for the conversion of olefins to aromatics (DEA) in order to increase the yield of liquid products. It also contains a scrubbing technology to absorb the BTX fraction from the gas (AREA). These technologies allow co-production schemes, that can increase the overall efficiency and optimize the profitability of Green Gas or biofuels production.

The lab scale unit operates on 3 - 5 kg/h of feedstock and produces up to 8 Nm³/h of wet gas. The line-up shown above is on the complete flow and after this a split is made for the fuels production facility.

READY TO BE PART OF THE ENERGY TRANSITION?

Research lies at the heart of our organization and therefore, we dedicate our international expertise and years of experience to the improvement and optimization of our client's process development. We ensure our solution is suitable to your application.

- Support and design of thermochemical processes to optimize the valorization of biomass and waste streams;
- enhance valorization options;
- Collaboratively develop gasification based systems for energy, chemicals and biofuels from a variety of biomass;
- Convert biomass all the way to Synthetic Natural Gas, Methanol, DME, Mixed Alcohols or other biofuels via Fischer-Tropsch and wax upgrading;
- Performance optimization of existing gasification systems;
- Perform technical due diligence on gasification based technologies.

TNO.NL



CONTACT US

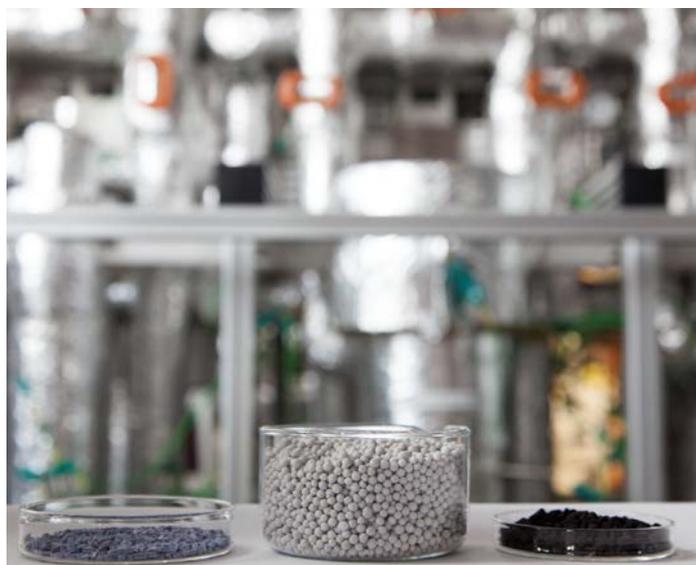
TNO Energy Transition
Westerduinweg 3
1755 LE Petten



Stephan Janbroers
Senior Business Developer
Biomass & Energy efficiency
E stephan.janbroers@tno.nl
M +31 610 95 69 64

BIOFUELS FROM GASIFICATION

SYNGAS CONDITIONING AND CATALYTIC CONVERSION



THERMOCHEMICAL BIOMASS CONVERSION TO FUELS AND CHEMICALS

Gasification will play a mayor role in the energy transition by converting a wide range of organic and carbonaceous materials into a combustible gas, called product gas. This gas consists of H₂ and CO (syngas) and instantly produces chemicals such as ethylene and benzene. Product gas can be used for a variety of end- products ranging from fuels to high-value chemicals.

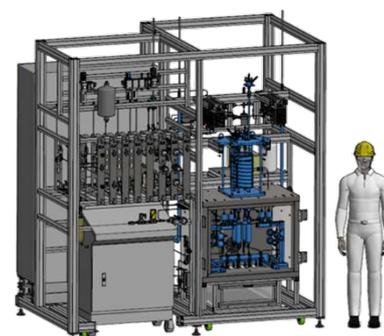
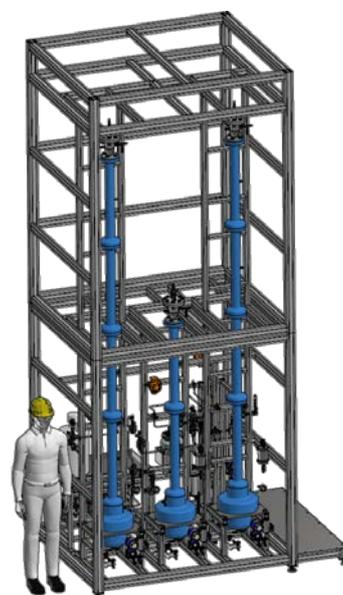
TNO has a long standing history in bio-energy research focusing on high efficient thermal conversion technologies. We optimize existing and develop new technologies to pre-commercial readiness. Indirect gasification is one of these technologies that allows the production of green energy, green chemicals and biofuels.

TNO BIOFUELS PRODUCTION LABORATORY

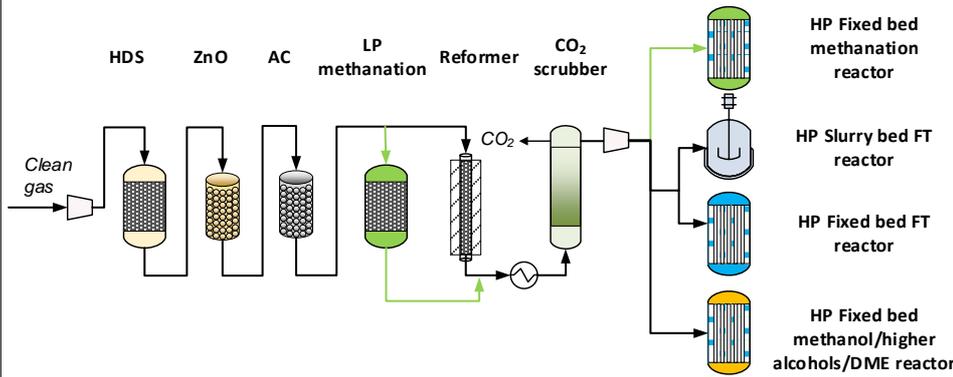
Government, research institutions and industrial partners all have an interest in adding “green “value to their production value chains. TNO’s biofuels lab consists of state-of-the-art facilities where experts work on affordable biofuels.

In our new laboratory, gasification of various types of biomass and plastic waste is one of the main conversion technologies. This thermochemical process operated at relatively low temperatures and in absence of oxygen allows the production of producer gas that can be processed downstream into Renewable Natural Gas and/or liquid fuels. The extensive facilities at TNO are unique in the world and allow show-casing of complete value chains.

› **TNO** innovation for life



GAS CONDITIONING AND CATALYTIC SYNTHESIS AT TNO



In 2020 a new laboratory for biofuels production from gasification became available at TNO. The new line up includes deep gas cleaning (HDS, Sulphur removal) reforming, compression and subsequent catalytic conversion facilities, enabling the cost efficient biofuel production with co-production of chemicals.

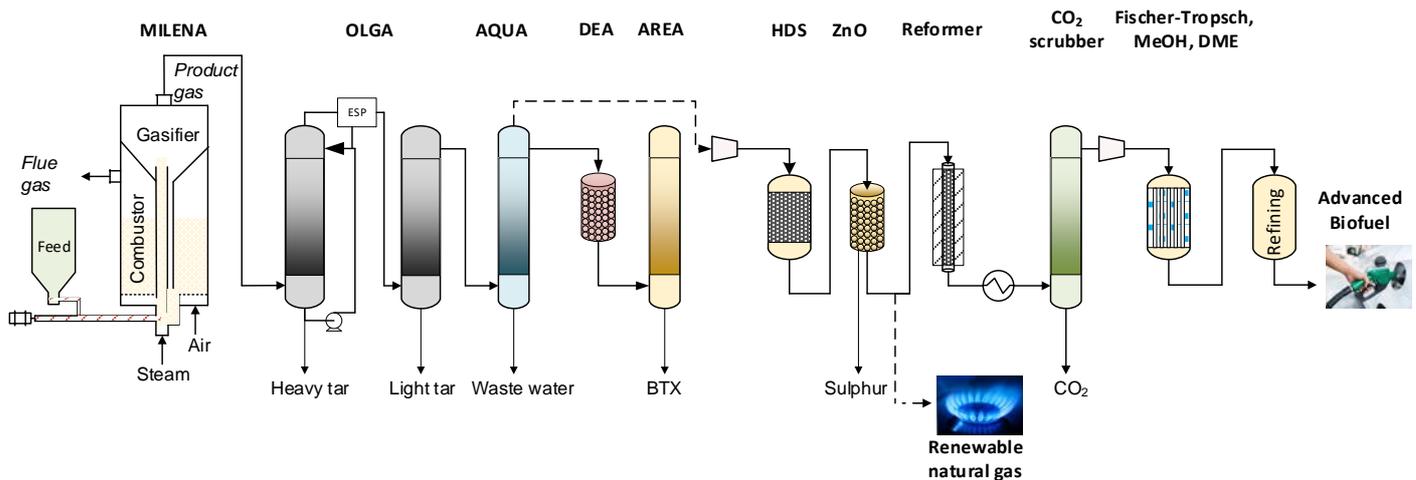
With two new high pressure catalytic fixed bed reactors and one slurry reactor, our facilities are able to process up to 1.7 Nm³/h of syngas and convert it to SNG, methanol and higher alcohols, DME or Fischer-Tropch liquid with high efficiency. The support facilities in our laboratory include a high pressure FT wax upgrading unit, a catalyst screening unit, a gas bottling system, as well as advanced analysis equipment.

READY TO BE PART OF THE ENERGY TRANSITION?

Research lies at the heart of our organization and therefore, we dedicate our international expertise and years of experience to the improvement and optimization of our client's process development. We ensure our solution is suitable to your application.

- Support and design of thermochemical processes to optimize the valorization of biomass streams;
- enhance valorization options;
- Collaboratively develop gasification based systems for energy, chemicals and biofuels from a variety of biomass;
- Convert biomass all the way to Synthetic Natural Gas, Methanol, DME, Mixed Alcohols or other biofuels via Fischer-Tropsch and wax upgrading;
- Performance optimization of existing gasification systems;
- Perform technical due diligence on gasification based technologies.

A COMPLETE SOLUTION FOR BIOFUELS PRODUCTION



Our gasification platform (MILENA OLGA) allows the development of various value chains, either towards chemicals or fuels. It can even operate on plastic rich waste for the production of olefins and BTX. We are ready to support you with your transition towards 2050.

TNO Energy Transition,
Westerduinweg 3
1755 LE Petten

Stephan Janbroers
Sr. Business Developer
E stephan.janbroers@tno.nl
M +31 610 95 69 64



COMBUSTION TESTING



TNO innovation
for life

Biomass combustion is widely recognized as one of the important options to contribute to the necessary CO₂ emissions reductions in the EU and World-wide on short term. Both large-scale (co-)firing of biomass in coal-designed plants, as well as dedicated stand-alone CHP units can deliver the necessary contributions to the reduction targets. This sustainable heat and power is even more important for fully “greening” of biofuels and biomaterials production.

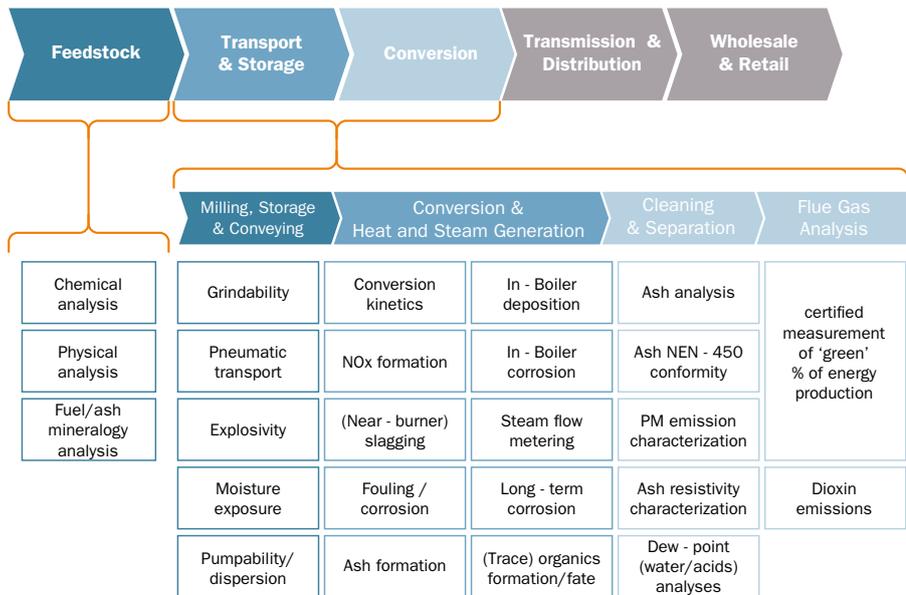
In such processes, utilizing the production residues is paramount to achieving acceptable sustainability levels. Thereby, swift adaptation of the existing designs to accommodate the fast-changing emission regulations and ever-broader portfolio of biomass and waste feed-stocks available on the market remains a critical skill.

COMBUSTION INSTALLATIONS

TNO owns and operates a variety of combustion test facilities, suitable for the simulation of nearly all state-of-the-art biomass combustion processes. This includes pulverized fuel, fluidized bed as well as grate-fired systems. Together with the advanced portfolio of sampling and analytical facilities, this enables widely-scoped and in-depth analyses of combustion-related problems.



Lab-scale Combustion and gasification Simulator (LCS) for Pulverised Fuel testing.

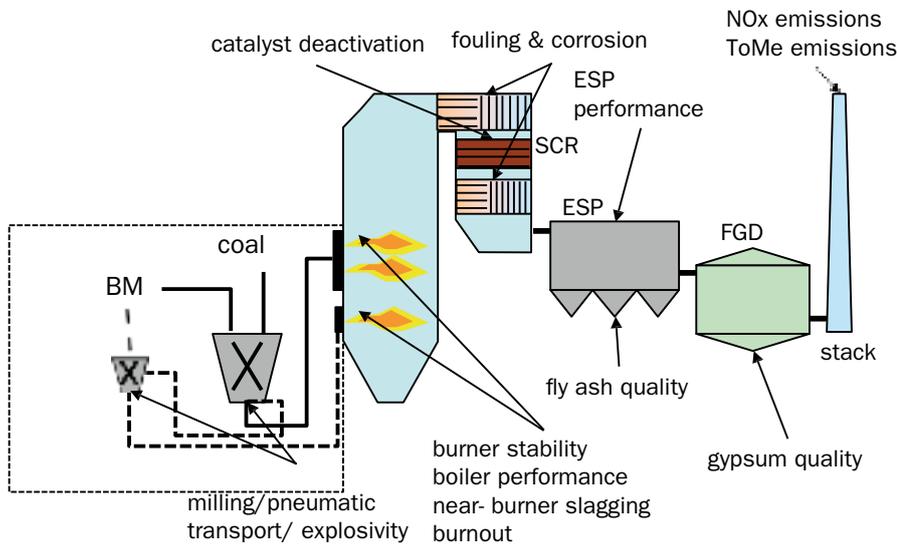


Overview of TNO biomass (and coal) conversion services.

THERMAL PROCESSES OPTIMIZATION CLIENT SUPPORT

TNO can help optimizing (co-) firing biomass in thermal processes. We have over 25 years of hands-on experience throughout the biomass-to-energy value chain. Our portfolio ranges from feedstock characterization, through grinding and feeding advisory services, to

complex analyses and simulations of combustion behavior of fuel blends, measurement and removal of regulated emissions from flue gases, measurement of the biogenic fraction in fuel blends in energy production. Also corrosion, erosion and mechanical stress-related material degradation monitoring and optimization is our strong point.



Technical bottlenecks in coal/biomass (co-)firing.

TNO.NL



TNO
Westerduinweg 3
1755 LE Petten

Stephan Janbroers
Senior Business Developer
Biomass & Energy efficiency

E stephan.janbroers@tno.nl
T +31 888 66 26 23
M +31 610 95 69 64

FROM BIOMASS WASTE TO A CLEANER, HOMOGENEOUS ENERGY CARRIER



TNO innovation
for life

In the Netherlands, roughly one and a half million tonnes of sludge end up in waste incineration plants, costing around 120 million euros. Sewage sludge is a waste stream produced at urban wastewater treatment plants and is largely being disposed of by truck transportation and incineration. With existing technologies sewage sludge can be dewatered up to 22 wt.% dry matter which is quite low and therefore makes current method of disposal inefficient and unsustainable.

TORWASH®

TNO has developed a hydrothermal treatment technology (TORWASH®) capable of converting low quality biomass feed-stocks, like agricultural residues or sludge from waste water treatment plants, Organic Fraction of Municipal Solid Waste (OFMSW), weeds, invasive water plants, sludges and even animal manure; splitting them into two usable streams, the valuable recovered product and a liquid effluent of the process without the use of flocculates.

The product recovered is a solid press cake that contains organic material and has a low salt content with a typical dry matter content of 60-70%. The press cake can be further densified through pelleting into high-quality black pellets that display chemical compositions that comply with wood pellet standards.

The second product is a liquid effluent that can be digested in a UASB-type digester to form biogas with a high methane content.

MINERAL RECOVERY

TORWASH® has a degree of flexibility in its operating conditions. Depending on the feedstock it is possible to control the distribution of certain elements between the solid fraction and the liquid effluent stream; particularly the fate of phosphorus can be manipulated. Potassium always dissolves in the liquid, while nitrogen is typically distributed evenly.

This effect leads to the possibility to concentrate phosphorous and potassium (and 50% of nitrogen) in the liquid effluent.



50-kg/h TORWASH® pilot plant

TNO AS SOLUTION PROVIDER

TNO has extensive experience in characterization and assessment of upgraded biomass: torrefaction, TORWASH®, steam explosion, hydro-thermal upgrading, biochar, etc. Our laboratory infrastructure is tailored to test upgraded biomass under conditions that are relevant for industrial-scale processes. Together with our in-depth knowledge of logistic chains and thermal conversion processes, this approach simultaneously provides solutions and mitigates risks at affordable costs.

PILOT TESTING IN ALMERE, THE NETHERLANDS

In 2018, a mobile pilot plant for the thermal processing of sewage sludge was built at a scale of 50-kg/h. The whole route from basic engineering to construction and functional testing took place in Petten at TNO's facilities. This pilot was



Dewatered cake after TORWASH®

transported to the wastewater treatment plant of Almere, The Netherlands in July 2018. There we proved that by thermally treating sewage sludge with our TORWASH® technology we can reduce this waste stream by 80%, and produce biogas. This means that the treatment of wastewater can become cheaper for citizens, and that wastewater treatment plants can become more sustainable by generating their own bio-based energy and materials.

READY TO BE PART OF THE TRANSITION?

Research lies at the heart of our organization and therefore, we dedicate our international expertise and years of experience to the improvement and optimization of process development. TNO ensures a tailor-made solution is suitable to your application.



TORWASH® pellets from sewage sludge

Please contact us to discuss:

- Assessment of biomass streams to provide dedicated upgrading solutions for production of high-quality bioenergy carriers
- Characterization of biomass before and after upgrading
- Jointly develop processes to upgrade biomass streams
- Assessment of upgraded biomass streams and mitigate risks during logistics, handling and conversion.
- Process consultancy and partnership

TNO.NL



TNO
Westerduinweg 3
1755 LE Petten

Levien de Lege
Sr. Business Developer
E levien.delege@tno.nl
T +31 888 66 25 39

STIMULATING A BIOBASED ECONOMY BY OPTIMISING THE SEAWEED VALUE CHAIN



TNO innovation
for life

WHY SEAWEED?

Growing under the sea and no requiring arable land, seaweed is one of the most promising and sustainable aquaculture crops of the future. Seaweed contains many valuable components such as proteins, bio-stimulants and carbohydrates and is capable to produce essential biocomponents used in the food industry, animal feed, cosmetics, pharmaceuticals, bioplastics and fuels.

Seaweed biorefinery concept can bring a significant contribution to a sustainable development by producing valuable raw materials to can accelerate the transition to a biobased and circular economy.

TAKING SEAWEED APPLICATION TO THE NEXT LEVEL

TNO experts have translated customer needs to potential applications for more than a decade by bringing experimental seaweed research combined with developing techniques to meet the continuous demand for specialized research and processing facilities on this subject.

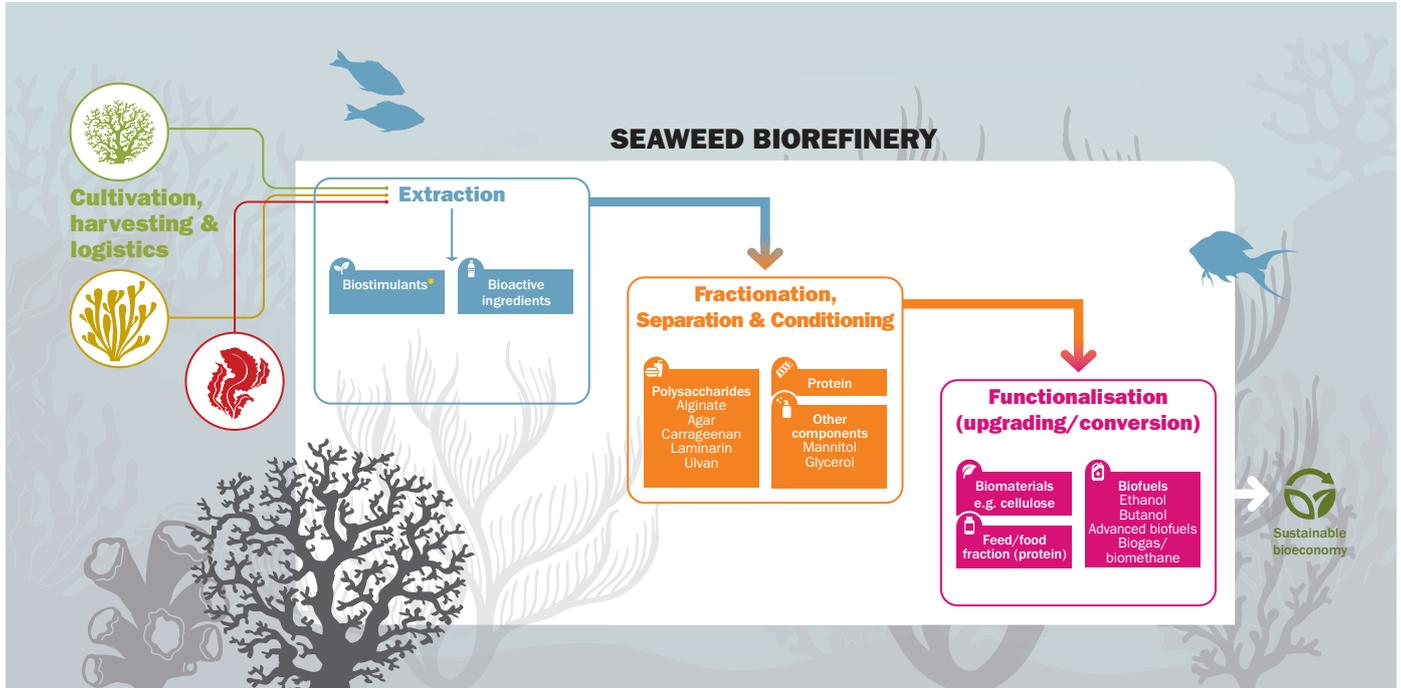
TNO has participated in national and international projects supporting the development and implementation of commercially viable and sustainable processes for the conversion of seaweed into biofuels, biochemicals, and biomaterials.

OUR COMMITMENT

TNO Energy Transition unit aims to accelerate the transition to a sustainable energy and raw materials society together with applied research institutes, industrial companies and governmental organizations.

The biomass expertise group focuses on the thermochemical and biochemical conversion of sustainably grown biomass into sustainable energy, chemicals and materials. Our state of the art and dedicated research facilities enable TNO, to support the research and development of innovative concepts for the production of biofuels and raw materials for the biobased economy.

FROM SEAWEED TO VALUABLE CHEMICALS, FOOD AND FUELS



RENEWABLE MATERIALS

Seaweed is a rich source of fine chemicals and performance polymers as such as well as the raw materials to produce them via environmentally benign processes, Examples are polyphenols, succinic and lactic acid.



AGRICULTURE

In our lab we develop, test and validate extraction methods for (in)organic bio active seaweed substances. The bio-activity of seaweed can be associated to its content of macro- and micro- nutrients, plant-growth regulators, phytohormones, and saccharides.

These compounds improve soil quality, stimulate root and plant growth, and activate defense mechanisms which help to drastically improve plant productivity in the agricultural sector.



FOOD AND FEED

Seaweed's popularity as an alternative and sustainable source of proteins for both food and feed applications is increasing. We are able to develop tailor made processes for the extraction and purification of protein and/or carbohydrate extracts for food and feed applications.



IMPROVING HEALTH AND BEAUTY

The beneficial effects of seaweed substances have been discovered by the beauty- and pharmaceutical industries and are used in various health improving applications e.g. in the prevention of diabetes, hypertension, cardiovascular diseases and mental degenerative disorders as well as in various cosmetic applications like anti-aging.



ADVANCED BIOFUELS

Seaweed, unlike terrestrial biomass, does not contain large fractions of recalcitrant non-sugar components. These features make seaweed particularly suitable as feedstock for the biorefining industry in the production of conventional biofuels, such as ethanol and butanol, and advanced fuel boosters, such as furan- based molecules.

OUR SEAWEED PROCESSING FACILITIES

Our seaweed biorefinery lab allows the development entire processing chain for the conversion of (fresh) seaweed into products such as carbohydrates, platform chemicals, plant stimulants or proteins; as well as the characterization and screening of seaweed composition simulating realistic processing conditions for producing samples so users can carry out relevant product tests.

Our lab offers the flexibility to perform processing steps separately as well as in sequence by combining a unique and extensive seaweed biorefinery experience and lab infrastructure.



PRE-CONDITIONING

- **Wet cutter / Wet biomass processor:** Designed for size reduction and homogenization of large seaweed leaves and stems before further processing. Suited for fresh and ensiled seaweed.
- **Freeze dryer:** Reduces the moisture content from more than 80% to less than 10% at room temperature or lower, preserving the cellular structure and purity of seaweed.



SEPARATION AND PURIFICATION

- **Centrifuge:** Designed to separate solids and/or fibers after extraction, as well as carbohydrate fractions.
- **Spray dryer:** Purifies seaweed components e.g. sugars, mannitol, proteins and/or bioactive components.



CONCENTRATION OF ACTIVE COMPONENTS

- **Membrane unit:** Suited for the selective separation of different components e.g. carbohydrates, minerals; and for the increase of concentration of active components in extracts.



- **Rotary evaporator:** concentrates active components and platform chemicals e.g. furanics or bio alcohols in solution.



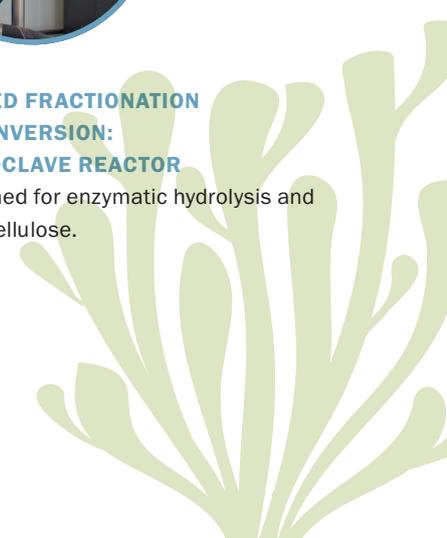
SEAWEED FRACTIONATION AND CONVERSION: 100L AUTOCLAVE REACTOR

- Designed to handle acids and bases, at operating temperatures up to 150°C and pressures up to 3 bar.
- Ideally suited for cold and hot water extraction e.g. for production of mannitol or bio stimulants, acid or enzymatic hydrolysis e.g. for sugar production, sugar fermentation, etc.



SEAWEED FRACTIONATION AND CONVERSION: 4L AUTOCLAVE REACTOR

- Designed for enzymatic hydrolysis and hemicellulose.





READY TO BE PART OF THE ENERGY TRANSITION?

Research lies at the heart of our organization and therefore, we dedicate our international expertise and years of experience to the improvement and optimization of our client's seaweed process development. We ensure our tailor-made solution is suitable to your application.

Please contact us to discuss:

- Scale-up, characterization and sample needs
- Consultancy by specialized experts
- Techno-economic analyses
- Technology development and integration of conversion routes to marketable bio-based products

OUR PROJECTS



MACROFUELS

MACROFUELS

(H2020, Grant No. 654010, 2016–2019)

MacroFuels produced the advanced biofuels ethanol, butanol, furanics and biogas, from seaweed or macro-algae. MacroFuels demonstrated the entire production train including road tests with advanced biofuels blends. The seaweed lab produced the sugar syrups from seaweed for the conversion to biofuels.



ZCORE

Seaweed Residues for Superior Bio-Coatings

The ZCORE project will positively contribute to CO₂ reduction goals and help to strengthen the chemical industry as well as the open innovation network in the south of the Netherlands. Fast-growing seaweed is used to produce high-value proteins. A by-product is non-edible sugars streams, a potential valuable raw material for the chemical industry. In this project, these sugars will be converted to biobased aromatics which will be tested in coatings applications.

OUR PARTNERS

We have strong collaborations with institutes and companies in academic, research and industrial sectors of the Netherlands and Europe, including Stichting Noordzeeboerderij, Wageningen University & Research, Deltares, the Maritime Research Institute of the Netherlands (MARIN), the Royal Netherlands Institute for Sea Research (NIOZ), SIOENIndustries, and Avantium.

CONTACT US

TNO Energy Transition

Westerduinweg 3
1755 LE Petten
The Netherlands

E biorefinery@tno.nl

T +31 888 66 24 65



MACROCASCADE

(BIC JU Grant No. 720755, 2016–2020)

MACRO CASCADE will prove the concept of the cascading marine macroalgal biorefinery i.e. a production platform that covers the whole technological chain for processing sustainable cultivated macro-algae biomass to highly processed value added products. Algae based products for food, feed, cosmetics, pharmaceutical will be tested and documented for their bio-activities and health properties. The lab is used to provide essential feedback for developing realistic process schemes.

