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December 2023

NORNER NEWS

Chemical Recycling Pilot

Circular Economy Case Studies

norner™
The Polymer Explorers

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Contents

Crisis after crisis – sustainable solutions are needed more than ever

Dear reader

For almost six years now, I have enjoyed working with my highly competent colleagues and excellent customers worldwide. We have grown fast with the need for more circularity in the polymer material business, particularly during the last 3-4 years.

The world and Europe are facing several crises at the same time. It has been an exceptionally long time since we have had such a troubled backdrop. It seems like one crisis follows the other these days. Post-pandemic, war and conflicts, and rapid climate changes are coming closer to everyone

We are the first generation to feel the impact of the climate crisis, and we are the last generation where only change counts. A shift in environmental focus and sustainability is needed. Changes are never easy. Even successful and profitable companies are reluctant to change, the same goes for developed societies. Either we are told that climate changes are not happening, that a change is not profitable, that the standard of living will be set back, or climate changes are not reversible, we should not listen to it. The shift is needed now, and it is needed fast.

Luckily, there are companies and organizations across the world that strive for change. Many of those are seeking to work with Norner, to develop and explore new sustainable solutions. Our employees are excited and engaged to work with forward-leaning companies, eager to innovate technologies and knowledge together with them that can make a difference in the polymer value chain.

For Norner, 2023 will be another memorable year. At the beginning of 2022, we moved into our new Polymer Exploration Centre (PEC I). 4600 square meters with laboratories, a pilot hall, and offices. In 2023 another large Polymer Exploration Centre II (PEC II) opened, with 1000 square meters with a pilot hall and machinery hall for larger equipment. PEC II is located next to our headquarters PEC I, in Porsgrunn, near the railway station with excellent connections to Oslo, as well as near Torp International Airport.

Norner has a stronger team than ever, with state-of-the art machinery, equipment, and knowledge to help our customers navigate out of crisis with sustainable solutions.

Enjoy the reading!

- Kjetil Larsen
CEO, Norner

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New employees at Norner

Our team is continuously growing and we are very proud to welcome our new colleagues who will bring valuable expertise across the Norner organization.

Petter Kjellemyr
Senior Engineer

David Laursen
Engineer

Manéa Lebrun
Principal Consultant

Janne Magnussen
Senior Communication Consultant

Bavan Mylvaganam
Principal Researcher

Morten Olsen
Engineer

Espen Selander
Engineer

Torbjørn Simonsen
Senior Engineer

Hilde Thorbjørnsen
Teamleader CAF

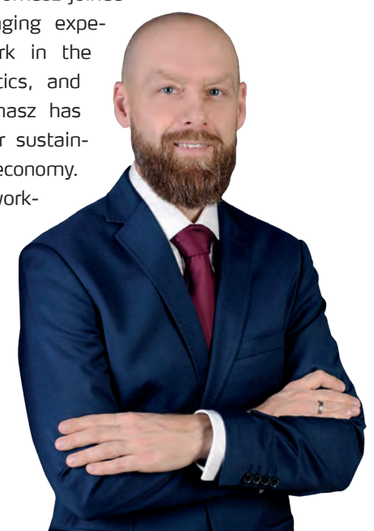
Thor-Erik Vartdal
Vice President Emerging Technology & Business

Norner in Europe

Tomasz Czulek is a mechanical engineer (MSc Engineer) by education, graduated from the Warsaw University of Technology at the Faculty of Power and aeronautical technology. In 2011 completed post graduate studies in Packaging Technology at Loughborough University in the UK. Having worked for the last 20 years for FMCG companies like Unilever, MARS, PZ Cussons, as R&D Packaging Manager in the local, region and global R&D structures, Tomasz gained knowledge on the circular economy, packaging development, packaging materials and plastic recycling.

Tomasz spent the last few years at Unilever as Global Technical Project Leader supporting ambitious sustainability goal of using 25% recycled plastic (PCR) in packaging by 2025. He successfully led a team of experts and developed and implemented the PCR R&D programme globally, what helped Unilever increase its use of recycled plastic to 21% in 2022.

In January 2023, Tomasz joined Norner team, bringing experience and network in the household, cosmetics, and food industry. Tomasz has a great passion for sustainability and circular economy. At Norner, while working remotely from Poland, he is managing projects and supports companies around the world on their journey towards the circular economy.



4 Four at Norner

Meet Heidi Houghton

Name: Heidi Houghton
Title: Senior Consultant
From, and lives in: Skien

Born and raised in Grenland, Heidi's journey to her current role in the Material Testing department at Norner was anything but ordinary. She initially set out on a path of a career in health, but quickly realized it wasn't her true calling. Her passion lies in researching and finding solutions, which led her to embark on a chemistry-focused journey at the University College of Telemark.

Heidi's Norner story began during the Borealis era, where she spent three years in a temporary position at the materials lab. After her initial three-year stint at Borealis, Heidi worked as a lab leader at SIC Processing, and RHI for several years. But Heidi's heart belonged to Norner, and in 2014, she returned to the company, drawing upon her invaluable experience from the Borealis days.

At Norner Houghton focuses on material testing, deciphering the mechanical and physical properties of plastic materials and products. Her content of work helps Norner's clients to understand their product's performance, strengths, and weaknesses. She is also an advocate for innovation and sustainability, thrives on collaborating with clients from concept to solution and values Norner's close-knit, knowledgeable team.

Outside work, Houghton is dedicated to training, encompassing everything from strength workouts to cycling and football. She enjoys the active outdoor life with her family, whether it is spending time out in their boat, kayaking or ice skating.

Meet Manéa Lebrun

Manéa Lebrun, originally from Siouville, Normandy, France, has travelled a diverse path to fulfil her engineering dreams.

Her father, an automation engineer, inspired her interest in engineering from a young age. High school reinforced her passion for science and set her on the path to becoming an engineer.

Manéa's educational journey took her across Europe, through France, England, and Sweden before she settled in Norway. With a degree in material engineering, specializing in polymers and composites, she combined her love for languages and travel.

She now works as a Principal Consultant at Norner, leading development projects, where each day brings diverse exciting challenges. Manéa is motivated and inspired by her colleagues' expertise and knowledge and is committed to reshaping perceptions of plastic materials. She believes the key is responsible and sustainable use, as plastic is an indispensable material.

In her spare time, Manéa enjoys training, outdoor activities, and spending quality time with her children, taking advantage of Norway's family-friendly culture.

Manéa is a dedicated engineer and advocate for responsible plastic materials. She aims to promote plastic's potential for sustainability and wishes to contribute to changing perceptions in the field of materials science.

Name: Manéa Lebrun
Title: Principal Consultant
From: Siouville in Normandy, France
Lives in: Stathelle

Meet Øystein Eksner

Name: Øystein Eksner
Title: Senior Engineer
From, and lives in: Porsgrunn

Growing up in Porsgrunn, Eidanger, Øystein's early years were filled with curiosity and a natural talent for finding solutions. From his school days in Porsgrunn, he loved ice hockey, showcasing his determination and teamwork through sports. He later on educated in economics, then moved on to his career as a commercial diver. It sounds exotic, he says, but it was not, it was hard work in harsh conditions.

Today, Øystein's role in the Processing Pilot Centre at Norner revolves around plastics processing equipment, where he explores the intricate mix between materials and production parameters. His passion lies in Machine Direction Orientation (MDO), a process enhancing material properties through alignment, and he's an advocate for making products more eco-friendly, with a keen interest in bioplastics.

Obviously, Øystein has a passion for the sea. He grew up by the coast and was educated as a diver, now he enjoys the sea as an avid windsurfer, often taking to the waters near his Stavern cottage.

Øystein's pursuit of broad knowledge and teamwork is a trait that meshes well with the dynamic environment at Norner. As he aptly puts it, "Two years at Norner is nowhere near enough to fully grasp the range of what we do, but I have a lot of supportive colleagues who assist me."

Meet Reza Rashedi

Reza's fascination with chemistry blossomed during his high school years, spurred by an internship at an oil refining company. This experience led him to pursue higher education, culminating in an engineering diploma, master's degree, and Ph.D. in Polymer Engineering from Tehran Polytechnic University.

His career commenced in the plastics industry, encompassing roles in a Polyethylene pipe manufacturing company and as a Polymeric Products Designer at SAPCO. Seeking fresh challenges, Reza ventured to the United Arab Emirates, where he played a pivotal role in designing polymeric compounds for diverse applications.

He made the decision to go to the head of the value chain and join Jam Petrochemical Company, one of the biggest petrochemical plants in the world. He participated in construction, commissioning, start-up, and operation of polyolefin plants. In the research and development department, he also worked on initiatives to create catalysts, new products, and process improvements from concept to commercialization stage.

Reza's journey eventually led him to Norner after a stint at the JAM Petrochemical Company. At Norner, he immerses himself in advanced polyolefin catalysts, polymerization systems, and sustainable material development.

Beyond his professional pursuits, Reza is a devoted family man. Norway's safety, family-oriented atmosphere, and natural beauty make it an ideal home for his family. On his spare time, he likes hiking, and appreciates seaside summers in Langesund with his children.

In Reza Rashedi, we find a blend of cultural diversity, a love for nature, and an unwavering commitment to sustainable innovation—a remarkable individual shaping the field of polymer engineering at Norner.

Name: Reza Rashedi
Title: Senior Researcher
From: Kangan, Iran
Lives in: Porsgrunn

World Cleanup Day 2023

400 kg less waste in nature

Each year we invite colleagues and families to join us to participate in the annual World Cleanup Day. In September our team organized a beach clean-up day outside our office.

Colleagues and their families put in a tremendous effort. Within an afternoon, we cleared away 400 kg of waste!

Discarded waste in the natural environment is a loss of resources, having numerous negative impacts. Our ambition is to make a difference, now and for future generations.

World Cleanup Day 2023

Announcing its best results in four years! Over 19 million participants from 91% of all UN-listed nations and a stunning 205,000 tons of mismanaged waste cleaned!

Sign up: worldcleanupday.org

PYROCO2 – EU research aim for plastics from CO_2

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We find polymers in all areas of society, and they will be part of our daily life for the foreseeable future. Today, polymers are made from fossil feedstock; oil, and gas. The fast transition toward a more circular economy puts new expectations on the feedstock for polymers.

Market demand
The global brand owners and customers expect polymers to be made from non-fossil feedstock. This is particularly needed for the world's largest volume polymers: polyethylene (PE) and polypropylene (PP). These polymers are produced from the monomers like ethylene, a two-carbon chemical, and propylene, a three-carbon chemical, respectively.

Non-fossil options
Three options for non-fossil feedstock are available:

- Chemical recycling of plastic waste
- Biomass
- Carbon dioxide (CO_2)

Of these options, CO_2 attracts high interest. CO_2 could originate from a variety of industrial emission points as well as from direct air capture. It is important that hydrogen is needed to convert CO_2 to ethylene or propylene.

CO_2 conversion
A variety of technologies to convert CO_2 to a range of chemicals and materials already exist, and new ones are currently being developed. No matter the technology, the first challenge is to convert CO_2 to ethylene and propylene as the major products in a high-yield process. The second challenge is to purify these two monomers, to meet the strict requirements of "polymer grade" quality to maintain high catalyst yield. Once this is in place, the CO_2-derived ethylene and propylene can be used in all current industrial plants with state-of-the-art catalysts to manufacture any PE and PP.

In other words, they are drop-in monomers in the current value chain. The origin of the PE and PP polymers is decoupled from fossil feedstock, with no changes to the product quality and/or existing infrastructure. The fully CO_2-derived PE and PP have exactly the same polymer identity, properties, and performance and are identical in every way to the fossil-based versions.

Research and pilot
Norner contributes to the development of propylene and PP made from CO_2 in the PYROCO2 project. The project will develop novel technology to produce the three-carbon platform chemical acetone from CO_2 in an energy-efficient thermophilic microbial process. This technology will be demonstrated in a 4000 tons/year pilot to be constructed and built at Herøya, Norway. The CO_2-derived acetone produced by the PYROCO2 processes will further be used as a drop-in chemical in a range of different processes to produce CO_2-derived chemicals and materials.

Norner role
Norner will be the off-taker of CO_2-derived propylene in PYROCO2. Norner will carry out a side-by-side analysis of the CO_2-derived propylene and of conventional fossil-derived propylene to demonstrate that they are chemically equivalent. At Norner, we will carry out extensive polymerization tests in our industrial standard, semi-continuous bench-scale reactor to produce fully CO_2-derived PP. Again, a side-by-side comparison will be done between CO_2-derived and fossil-derived PP to demonstrate identical polymer properties.

Norner polymerisation laboratory
Norner operates bench-scale reactors capable of using CO_2-derived propene as feedstock. Norner's Application Centre has advanced facilities to produce demonstration items for multiple applications like thermoforming, injection moulding, and blow moulding, where we can convert the PP from PYROCO2 into 100 % CO_2-derived products like films, cups, and bottles.

Norner's competence covers many areas of the polyolefin value chain essential for the development and validation of alternative feedstocks.

These include:

- Raw material analysis and purification
- Catalyst selection, development, and optimisation
- Polymerisation and process studies
- Process development and upscaling
- Additive formulations prepared for recycling
- Product conversion and development
- Plant optimization

About PYROCO2
The PYROCO2 project is funded in the frame of the Horizon 2020 programme (Topic LC-GD-3-1-2020 - Closing the industrial carbon cycle to combat climate change - Industrial feasibility of catalytic routes for sustainable alternatives to fossil resources). The project has a largely industry-driven consortium of 20 partners, a budget of 43 million Euro, and a duration of 60 Months. Norner has responsibility in WP3- From acetone to marketable products and WP5- Process integration and sustainability assessment.

Grant agreement ID: 101037009

More circularity with **chemical recycling**

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It is the right time to embrace the opportunities of chemical recycling to further improve the circularity of the plastics industry. It will be key to recycling waste that does not fit well in mechanical recycling.

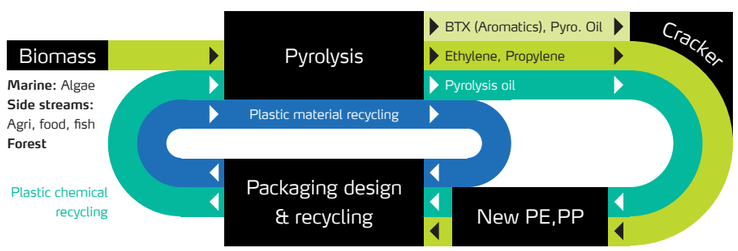
All in for circularity

Not a day goes by without new press releases, articles, and posts broadcasting circular initiatives from companies in the polymer industry. The ambitions of the major polymer producers are impressive within new sustainable feedstocks, chemical recycling, and mechanical recycling. EU is leading the way, and it is expected that the new Packaging and Packaging Waste Regulation (PPWR) will come into effect in 2025. This document partly reflects the growing understanding that without a significant contribution from chemical recycling, the EU targets for recycled content by 2030 and 2040 will be out of reach.

Complex packaging

Back in 2016, Norner was one of the partners in FuturePack (Figure 1), a collaborative project funded by the Research Council of Norway. The objective was to better understand the complexity of waste from plastic packaging to develop better solutions for the future. Multilayer barrier packaging with polyolefins in combination with PA or PET stood out as a challenge to recycle at the same time as it provides excellent protection of food which is difficult to fully replace by mono-material solutions. This challenge inspired Norner to develop a technology specifically designated for chemical recycling of these material combinations, to enable continued sustainable use of lightweight and high-performance packaging solutions.

Figure 1 The target of the FuturePack project was to investigate recycling options for plastic packaging and various materials.



> As the project manager for FuturePack, I am very pleased that we are now able to demonstrate our new pyrolysis technology package in a continuous pilot.
>
> **Siw Fredriksen**, Strategic Advisor at Norner.

A novel pyrolysis technology

Thanks to Pointbreak, the above inspiration and ideas materialized in a sophisticated chemical recycling pilot which was inaugurated at Norner in Q1 2023 (Photo 1).

Pointbreak's technology proved to be successful already few weeks after the inauguration of the pilot with continuous operation over several days, partly via remote monitoring. After testing various model waste simulating complex packaging materials, also demanding real waste has been tested successfully in the pilot. Although the waste composition covered PE, PP, PA, PET, and PVC as well as inorganic substances, the quality of the pyrolysis oil produced was even better than expected (Figure 2).

Industrial strategy

In contrast to most other players within chemical recycling, Pointbreak will take a role as a global technology provider, licensing and building plants to companies who will turn plastic waste into valuable high-quality pyrolysis oil and other chemicals reducing the need for new fossil feedstock to polymer production. Pointbreak has secured a strategic partnership with Hitech Products having construction and building competence as a supplier of module-based systems to the O&G industry for many years, and with Norner as their exclusive R&D partner. The investment in a pilot has already produced valuable data for scale-up, and Pointbreak plans to build a semi-commercial plant in 2025/-26.

Figure 2 Photos of fluffy plastic waste and resulting pyoil

> We are contacted by companies who want us to verify chemical recycling as an end-of-life solution for their products.
>
> **Sara Ronasi**, Director for Catalyst & Polymerization Technology at Norner.

Sara is also managing the technology development in the chemical recycling pilot and as such closing the loop from polymerisation to generation of new future polymer feedstock.

For such customers, Norner's offerings include:

- Suitability verification of plastic waste for chemical recycling
- Sample production of pyrolysis oil from selected plastic waste
- Quality analysis of pyrolysis oil and other side products

Pointbreak is also positive to make the pilot available for such work and to tailor its technology to solve any challenges seen.

> We want to adapt the technology to find the optimal balance between energy spent on sorting/cleaning the waste upfront vs flexibility for the presence of non-polyolefin/non-polymer substances in the process. We are very happy to have Norner as a partner in this technology development and look forward to contributing to increased circularity in the polymer industry together with them.
>
> **Rune Johansen**, COO/Project Manager at Pointbreak.

UHMWPE - The sustainable lightweight solution

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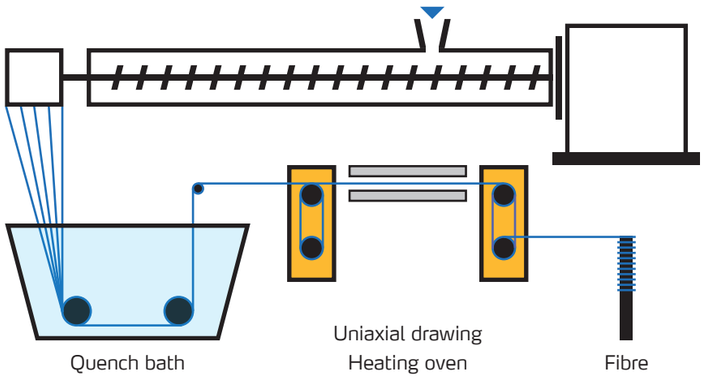
In recent years ultra-high molecular weight polyethylene (UHMWPE) has been the buzz of the polyolefin industry with high annual growth rates, forecasted above 8-9 % between 2020-2027. But how is it made and how does Norner support such developments?



High growth rate drivers
The growth is fuelled not only by the outstanding and well-known properties but also the accelerated penetration of high-value applications due to global trends such as prosthetics for an aging population, Li-Ion battery separator films for electric vehicles, and the growth of UHMWPE super high strength fibre segment. Also, the new regulation to replace perfluorinated (PFAS) materials like PTFE is promoting this growth.

Figure 1 Schematic for solution (gel) spinning process - reproduced from Lemstra, P.; Bastiaansen, C.; Meijer, H. Chain-extended flexible polymers. Die Angew. Makromol. Chem. 1986, 145, 343–358.

Applications Hip prosthesis, Armoured police, Ropes and moorings

Property benefits
Some of the excellent properties of UHMWPE are:

- High tensile strength.
- Abrasion resistance.
- Low friction.
- High impact strength even at low temperatures.
- High wear resistance.

The high crystalline, highly oriented UHMWPE materials are demonstrating outstanding features such as steel-like stiffness, which is remarkable for the low density of PE at 0.97 g/cm³.

Fibre applications
UHMWPE high-performance fibres such as the well-known Dyneema® product brand, "the world's strongest man-made fibre", represent the most important market segment along with prosthetics. These lightweight fibres can be found in anti-ballistic soft and hard armouring, ropes, and moorings as well as automotive and aerospace parts to name a few.

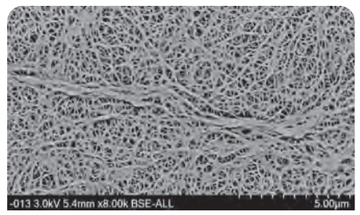
The processing of UHMWPE into high-performance fibres is based on the gel-spinning process (Figure 1). UHMWPE polymers are then dissolved and further isolated in a suitable solvent resulting in largely disentangled macromolecules. The resulting gel is further hot drawn and orientated after the extraction of the solvent. However, many hazardous solvents are utilized in current industrial gel-spinning.

Norner's investment
Norner is now investing in a pilot line for the production of UHMWPE fibres to facilitate product development for customers and conduct research to improve the environmental footprint of the process. The plan is to have this installation ready in Q1-2024.

Development support
We support clients, active in the development of UHMWPE products and applications with our tailored capabilities in catalyst synthesis, polymerization, polymer analytics, prototype production, and application testing.

Polymerisation and testing
In lab-scale polymerisations, the following has been achieved including polymerising large enough amounts for material testing and prototyping:

- UHMWPE with a Mw from 1-5 million g/mol.
- With heterogeneous Ziegler-Natta & Metallocene Catalyst.
- UHMWPE copolymers.
- Disentangled UHMWPE from homogeneous catalysts.
- Controlled powder morphology and porosity.



SEM photo of a Battery Separator Film

- Evaluation of UHMWPE catalysts at industrially relevant bench scale reactors ranging from 200 ml to 17 l in volume.

In a typical project, a range of catalysts will be screened with respect to polymerisation performance and ability to produce UHMWPE in 200 ml reactors. Then a suitable catalyst can be selected and the first scale-up tests in a 3 l reactor will be done to produce several 100 grams of material for testing. The specified targeted Mw (for example > 1 million g/mol) for the produced polymer materials will be confirmed by size exclusion chromatography (SEC).

Characterisation of UHMWPE
Laboratory methods for characterisation and analysis of UHMWPE powder samples by Norner are:

- Particle size distribution (Malvern).
- Degree of branching/comonomer by FTIR or C13 NMR.
- Specialised protocols for thermal properties by DSC.
- Light microscopy for homogeneity.
- Scanning electron microscopy.
- Dynamic rheology.
- Intrinsic viscosity.
- Compression moulded specimens & films.
- Creep, tensile, and impact properties.

We can help each other to increase circularity

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We found great motivation in developing a cross-industry collaborative project where we could help each other in developing circular solutions. The new project was started in 2022 and included 10 different Norwegian companies.

Norner is a shareholder in Future Materials, the Norwegian Catapult Centre, and applied for a grant from the foundation "Stiftelsen Teknologiformidling", for the project "Kickstart towards 2030 – recycled plastics". The purpose of the project is to increase the reuse of plastics that are recycled in Norway.

Through increased knowledge of materials and testing, the companies will increase the proportion of recycled plastic in their production. Each participating company received support from Norner according to the value of NOK 150,000 and had to provide a corresponding in-kind effort.

In November 2022 we gathered all participants to a kick-off meeting at Norner, where all companies presented their targets.

As part of the program, Norner took them around in the pilot facilities to see all our pilot machines and analysis instruments and gave introductory presentations on "EU requirements and targets" and "Sorting - washing - additives - odour removal - processing of used plastic".

Each company had a contact person in Norner with whom they worked closely. During the first month, a schedule of how to work and achieve the goal was made with Norner.

In the end, a final meeting was held where all companies presented very good outcomes of their cases and gave feedback on the collaboration with Norner.

The participants in the program have reported that the result of the project not only gave increased use of recycled material but that the company also has gained more focus on sustainability in general and what it means for them. The project has given them the expertise required to make progress towards the EU's climate goals for 2030. All the companies that participated were very satisfied and all had achieved their goals and more.

Photo The project group at the kick-off meeting

About the companies involved

Stiftelsen Teknologiformidling has a purpose to increase productivity, value creation, and competitiveness for Norwegian businesses and contribute to small and medium-sized companies in a successful transition to Industry 5.0.

Future Materials is a national development and testing centre for materials of the future with the aim to bridge the gap between the initial idea phase and pilot scale production in a way that makes it easier to develop advanced sustainable materials for Norwegian companies.

The companies and status of their projects are:

- **Rotostøp**

Business: Rotational moulding.
Target: Find suitable recycled material to be used in a roto moulding process, which was not yet commercially available. Rotagrosilo will now be produced in 100 % recycled material.

- **Form-Tek**

Business: Injection moulding
Target: Implement a recycled polyamide. Through Norner's connections we found a suitable material. The first product has been produced and is sent to customers for evaluation.

- **Grepi**

Business: Injection moulding
Target: Implement recycled ABS in a pipe-in-pipe cabinet. Through Norner's connections a suitable material was found. Successful first trials have been done.

- **Revixit**

Business: Recycling of cables.
Target: Find applications for the polymer, mainly PE, which is 50 % of the cable. We have tested materials and mapped potential applications. Today the most promising solution is expanded insulating mats.

- **Polyform**

Business: Produce buoys and fenders.
Target: Replace virgin with recycled material. A potential material has been found in the same region, evaluated by Norner and the first buoy has been produced in 50 % recycled material.

- **Herde Kompositt**

Business: Composite lifeboats.
Target: Recycling of PE hoses used in the vacuum moulding process.
Hoses and flexible material will now be sent back to the producer for recycling and hoses produced of recycled material have been tested out with success.

- **Hexagon Ragasco**

Business: Composite gas vessels
Target: Recycling of the casing, which until now has been burned. This material has been tested and shows good properties after use. This will now be recycled and used in pallet production.

- **Selstad**

Business: Filament and rope producer
Target: Use recycled rope back into the production. Several materials have been tested at Norner for evaluation of the material properties. 12 different recipes have been made and some fibres have been made in a pilot line.

- **Nordic Plastic Recycling with Pionerboat**

Business: Sorting and recycling returned plastic
Target: Use high-quality recycled materials in the production of new roto moulded Pioner boats. A different amount of recycled materials have been added to the virgin material and the initial testing shows promising results.

- **Industriplast**

Business: Profile and pipe extrusion
Target: Produce hoses for Herde Kompositt with recycled material. This was successful and Industriplast will now test recycled material in other applications with help from testing at Norner.

RecyClass – documentation and certification of recyclability

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EU authorities recently published a proposal for Packaging and Packaging Waste Regulation. This includes a target to achieve 100 % packaging recyclability by 2030, so we can be sure we must intensify the development of recyclable packaging.

Recyclable, what is that?
A recyclable plastic package is recyclable if it:

- Is made with a material which is collected for recycling.
- Is possible to recycle with commercially available processes.
- Is sorted and aggregated into a recycling stream.
- Contains a minimum amount of residual product.
- Becomes a new raw material for producing new products.

For plastic packaging, we strive for mono-material solutions of PET, PE, PP, or PS, which should be easy to empty for the product as well as have a reduced content of pigments, colours, adhesives, and inks.

About RecyClass
RecyClass is a non-profit, cross-industry initiative advancing recyclability, bringing transparency to the origin of plastic waste, and establishing a harmonized approach toward recycled plastic calculation and traceability in Europe. The RecyClass methodology was developed in collaboration with value chain stakeholders promoting the high standards that should improve the quality of waste in a way that helps to “close the loop” on plastic packaging.

This initiative aims to help the plastics value chain evaluate and improve the recyclability of their packaging through a systematic design for recycling approach. It also aims to contribute towards the standardisation of design for recycling guidelines and testing protocols across Europe in line with the proposed revisions of the Packaging and Packaging Waste Directive.

Design for Recycling
RecyClass has developed Design for Recycling Guidelines (DfR) which offer insights into how plastic packaging can be designed and assembled to be compatible with recycling, based on the principles presented above. This guideline is based on know-how from the industry and a scientific approach where factors of packaging are tested and evaluated. This has resulted in a detailed methodology for assessing recyclability.

The principle of DfR offers insight into how plastic packaging should be designed and how components of the packaging influence its recyclability.

RecyClass has transformed its guidelines into an online tool that is open to everyone. It is simple to register as a user and enter the details of the relevant package. The result will be a rating of the recyclability of that package composition.

Recyclability certification
"Design for Recycling Certification" is a process where the certification body needs detailed technical information for the package in question. It requires a contract and NDA between the company, RecyClass, and the certification body. The result can be a classification of:

- Technical recyclability, for the pack composition.
- Recyclability Rate, considering national collection.
- Letter of compatibility, for semi-finished packaging.
- All of these will come in categories of "Compatible" A or B, "Limited compatible" C, or "noncompatible" D, E, or F, together with a clear identification of the reducing factors.

The certification process is carried out on the unique RecyClass collaborative platform between the applicant, certification body, and RecyClass (Figure 1)

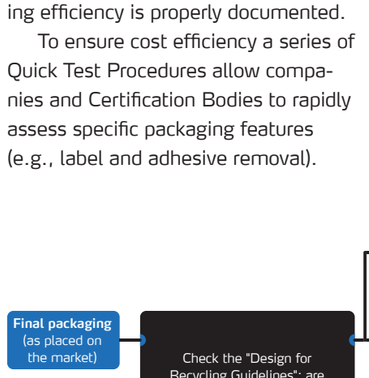

Figure 1 Recyclability certification process

Testing protocols
In the case where a material or composition (polymer, pigment, ink, adhesive, etc.) has not been included or tested, the producer can request testing according to RecyClass-specific recyclability evaluation protocols, at their own cost. The outcome of the testing will determine whether the composition will be approved or not. If it becomes approved, it will ultimately be included in the guidelines and the RecyClass Online Tool.

RecyClass has also developed a sorting evaluation protocol for plastic packaging which will ensure that sorting efficiency is properly documented.

To ensure cost efficiency a series of Quick Test Procedures allow companies and Certification Bodies to rapidly assess specific packaging features (e.g., label and adhesive removal).

Norner RecyClass Certification
Norner is a RecyClass Certification Body for recyclability evaluation.

We provide certification services for three certification levels:

- Design for Recycling Certification
- Recyclability Rate Certification (Norway)
- Letter of compatibility

Norner is a recognized laboratory for RecyClass protocol testing for PE film, PP film, HDPE rigid, and PP rigid packaging.

Norner can also carry out quick test procedures.

Figure 2 Schematic overview of the recyclability assessment scenarios.

Development of packaging pouch for long shelf life

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The European Commission's target is that all plastic packaging will be recyclable by 2030. To reach this challenging goal, there is an urgent need for innovations within the field of recyclable flexible packaging solutions.

Need for innovation

Drytech AS is a family-owned Norwegian manufacturer and distributor of freeze-dried meals, snacks, and drinks, based in Tromsø. They are the owner and producer of well-known brands like Real Turmat and Real Field Meals. These products are recognized as premium, healthy, and lightweight food alternatives, and are packed in a stand-up pouch format. Drytech produces a significant number of portions annually. These are freeze dried, vacuumed, and prepared by adding hot water before eating. Real Turmat has a shelf life of 5 years and Real Field Meal has a shelf life of 7 years, which requires outstanding barrier performance from the packaging solution. The current pouch is a complex laminated structure with very high performance, but this is not recyclable according to current standards and recycling technologies.

The recyclability and re-use of materials are prerequisites for the transition to a circular economy, maintain market relevance, and fulfilling consumer requirements. This is a challenging task in general, and in particular for the packaging formats for Real Turmat and Real Field Meal with very high barrier and shelf life performance requirements for the freeze-dried and vacuum packed food products.

Project consortium

A new 3-year innovation project with Drytech, Norner Research, and partners from the whole value chain has been established to address this challenge. Other partners are MPack – a supplier of packaging solutions to the food industry, Skala Maskon – a supplier of tailor-made packaging machines to the food industry, Ragn Sells – a waste handling company and The Norwegian Defence Estates Agency, Forsvarsbygg (end-user). The Norwegian Research Council is supporting the strive for recyclable packaging solutions adapted to the circular economy and is funding the project.

Design for recycling

The new packaging solution(s) shall be a mono-material structure that is mechanically recyclable according to the classification system of the latest highly recognized RecyClass design for recycling guidelines. Recyclability classification in the RecyClass system is influenced by several factors such as the amount and type of barrier materials, printing and pigments, available recycling streams, compatibility, and Easy-to-empty and Easy-to-access indexes.

Solution development

The new solution must also have excellent functionality from production to end use. This will require significant material structure re-design and development. One of the most important challenges is to achieve the required long shelf life through sufficient barrier properties. The project will therefore address several major research topics, like barrier technologies and performance against oxygen, moisture, light, and aroma. Sealing technologies will be evaluated and food safety assessment by migration performance will also be addressed.

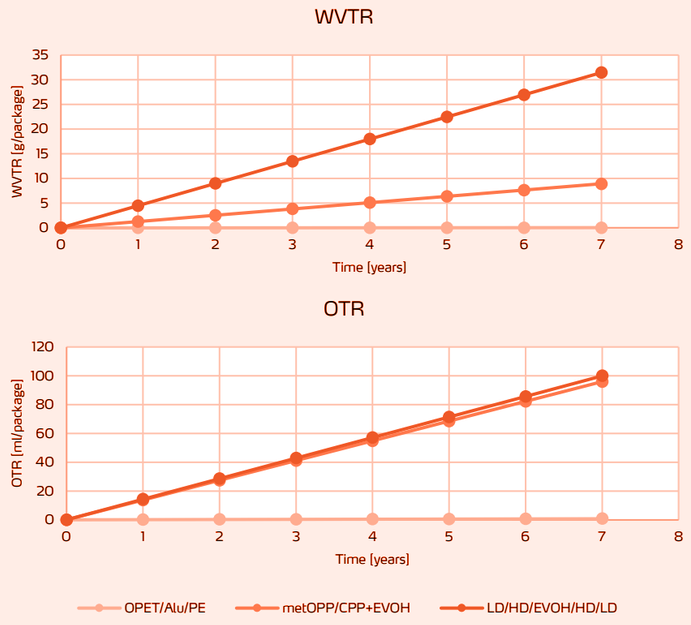
The project will further require considerable R&D efforts in the understanding of polymer structure-property relations, applied polymer research, polymer solution development, polymer processing technology, advanced characterization, and source separation of packaging waste. Research is also needed to understand and ensure that the packaging innovation fulfils the requirements for a RecyClass certification and is in accordance with EU legislation for Food Contact Materials.

Packaging prototypes will be produced and validated. Collection, source separation, and recycling of packaging to new raw material, in line with the circular economy principles, will also be demonstrated and evaluated according to defined evaluation protocols. The use of recycled material will also be demonstrated.

This project has major potential for sustainable value creation through a shift to recyclable and circular solutions.

A key challenge in the project is the shelf-life requirement, which depends on both permeability to oxygen and moisture. To illustrate this challenge and the superiority of an Alu foil laminate we have calculated the permeability with the Norner barrier calculator for some commonly available laminates, not related to Drytech, see below.

Figures Barrier performance calculations of current Alu/PE type laminate vs two available alternatives demonstrate the gap to close.



Performance uplift of recycled polyolefins

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Norner collaborates with Kraton to evaluate their CirKular+™ performance enhancement additives for plastics recycling. Kraton - A world-leading specialty polymer and biobased chemical solutions supplier has developed new innovative solutions that enable improved quality and a higher recycling rate of polyolefins.

Quality problems with rHDPE
Recycled HDPE is typically contaminated with some PP and Norner has seen that this has caused a reduction in the properties of rHDPE. Throughout multiple projects, Norner has documented strong variations in the quality of such recycled HDPE (rHDPE), compared to virgin HDPE. Several rHDPE suppliers have such quality issues specifically for the bottle market.

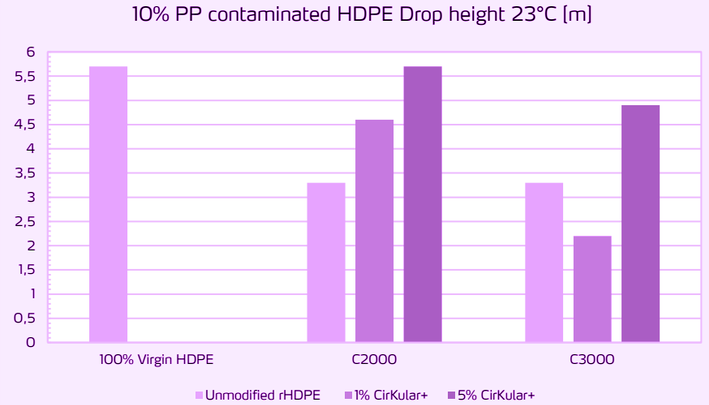
Given Norner's experience with EBM and PCR testing, Kraton approached Norner to perform multiple tests to evaluate rHDPE performance enhancement enabled by Kraton's CirKular+™ additives. A new fully electric EBM line at Norner with 3 extruders and flexible capability for materials and blends, which has proven to be a very good tool to evaluate the use of recycled material for end-uses within food, household chemicals, and personal care would be used in the trials.

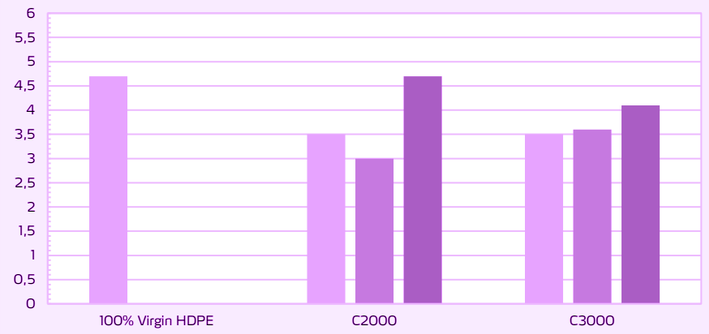
Kraton test program
Recycled HDPE was used for these tests with 5 or 10 % contamination of PP. The contaminated HDPE was processed while adding CirKular+™ additives in levels from 1-5 % by dry-blending the material and directly feeding it to the EBM machine.

We documented the possible enhancement by drop testing. The results show impressive numbers for the modification of the rHDPE blend with CirKular+™. It is important to note that it is typically difficult to achieve homogeneity for an HDPE contaminated with PP, and often large variations in drop performance are observed. The use of Kraton's CirKular+™ allows for bringing rHDPE drop performance back to the level of the original virgin HDPE while reducing the typically observed variability in the drop performance.

> "The performance testing results achieved by Norner further prove the value of Kraton CirKular+™ additives in solving the discussed challenges for the packaging industry. We value the pleasant collaboration with Norner and their expertise in the EBM and PCR testing.
>
> **Dr. Lennaert Klerk**, Regional Technical Manager Europe at Kraton Polymers."

KRATON™ CirKular™





Top load is another important property for bottles. Contamination of the stiffer PP can increase the top load. Modification with up to 5 % CirKular+™ has shown the ability to achieve the top load of a virgin HDPE level.

The trials also showed that the desired aesthetics can be achieved for the bottles containing CirKular™ in a conventional EBM machine. For further information contact Norner AS or Kraton Corporation.

Making HDPE bottles from discarded fish farming installations

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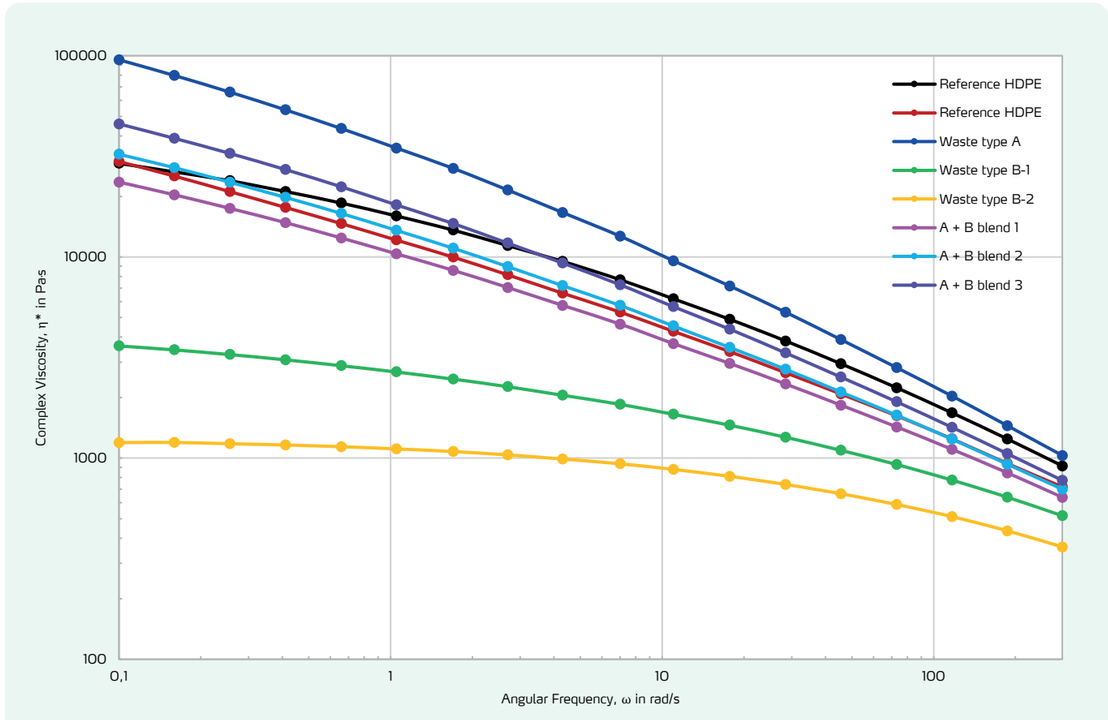
Orkla Home & Personal Care is evaluating how they could use locally sourced recycled materials for some of their products, like HDPE bottles. One alternative source of HDPE is PE waste from discarded installations in the fish farming industry produced with HDPE pipe type of resin. They engaged Norner in this challenging task and chose one of their soap bottles to be tested as a demonstrator.

First test - no success
Oceanize is a Norwegian company that collects and recycles various gear and installations from fishing and fish farming industries. Initially, some of the materials from Oceanize were tested for Orkla at a Norwegian blow moulding company without success. The HDPE recycled materials from discarded pipe was too difficult to use for small bottles due to the high viscosity.

Understanding the problem
Norner was invited as a project partner to investigate the material and the processability further. It soon became evident that the material fractions available at Oceanize at a large scale were not suitable for the blow moulding process of making HIC bottles. We used RDA rheology investigations to compare the recycled material with virgin HDPE bottle grades.

Solution development
To be able to match a material that can be run on an extrusion blow moulding machine, the materials needed to be modified. We needed to modify the rheology of the pipe fraction to be able to successfully produce bottles. Norner took this concept into the laboratories where we can analyse, test, and use one of our four laboratory compounders with excellent distribution and mixing for making blends. After performing a theoretical calculation based on the viscosity profiles of materials available at Oceanize, Norner made blends of 6 different recipes and compared these with a virgin HIC material. The RDA rheology analysis of the blends showed that one of the recipes had a similar viscosity profile like virgin HDPE blow moulding material.



We took this into our Magic blow moulding line and made trials to confirm the processability. The figure shows the viscosity curves of materials tested from Oceanize together with virgin HIC material and the table shows the key processing parameters of the optimised blend with a virgin reference, which confirm the similar behaviour.

Testing and verification
Mechanical properties like top load and bottle ESCR were also measured. Both were within spec but the top load was slightly lower and bottle ESCR was slightly higher than target.

The tests demonstrate that recycled materials can be used for high-quality products at Orkla.

Orkla Home and Personal Care are satisfied with the result and now have the tools to make future demonstrations or prototypes to check the market potential.

For further information please contact Ronny Ervik at Norner AS.

	Virgin HIC			rHDPE		
	RPM	AMP	Melt pressure	RPM	AMP	Melt pressure
Extruder 1	18,2	26,53	219	17,9	26,39	229
Extruder 2	18,4	23,6	175	18,3	23,62	187
Extruder 3	18,4	23,92	254	18,3	23,92	266
Cycle time(s)	18			18		

About the companies involved

Orkla ASA is a leading industrial investment company. Its scope of activity is brands and consumer-oriented companies. At present, Orkla has 12 portfolio companies.

Orkla has a long-term industrial approach to its portfolio companies and invests in companies where they can contribute to further value creation through their industry expertise, consumer insight, and experience in building leading brands.

Orkla's strategy focuses on Environmental engagement and innovation to protect the environment.

Oceanize is a Norwegian plastic recycler. They connect waste owners, the waste industry, and consumers of recycled plastic, as the foundation for the circular plastic value chain.

Efficiency in Collection:
A Green Success Story

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With impressive efficiency in collection and recycling, Norway is well on its way to achieving their ambitious goal of high usage of recycled Polyethylene Terephthalate (PET), even reaching 100 %. However, as with any journey, challenges pave the way to progress.

High collection efficiency

Norway's PET bottle collection system is a great model to replicate. Through effective deposit-refund systems, widespread awareness campaigns, and enthusiastic participation from citizens and businesses alike, the nation boasts one of the highest PET bottle recycling rates globally. Furthermore, an efficient recycling process adds to this success. This high efficiency has set the stage for a circular economy and has been a beacon for environmentally conscious nations.

100 % rPET – a challenging target

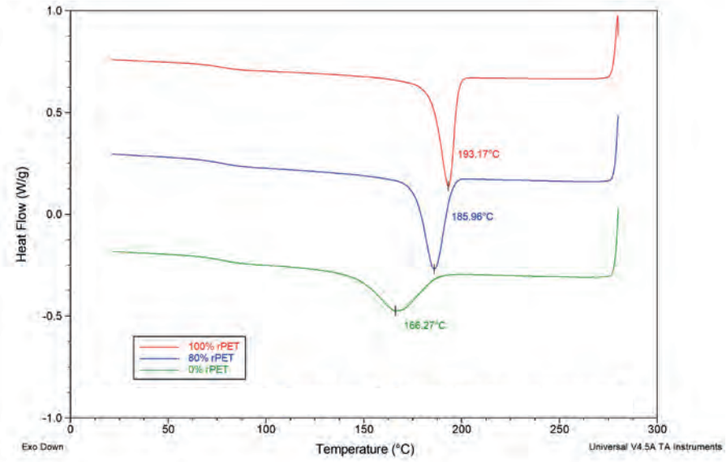
Yet, as Norway sets its sights on 100 % recycled PET, a complex challenge arises; mass balance. Achieving this lofty target necessitates meticulous calculations to ensure that the collected bottles can be transformed into the exact quantity of high-quality recycled PET needed, and as with any other industrial process, there are always some losses at every stage, which prevents truly achieving 100 % circularity by a single process such as mechanical recycling alone. Straying from this balance could also compromise the very sustainability the country and industry seek to uphold.

Drying challenges in recycling

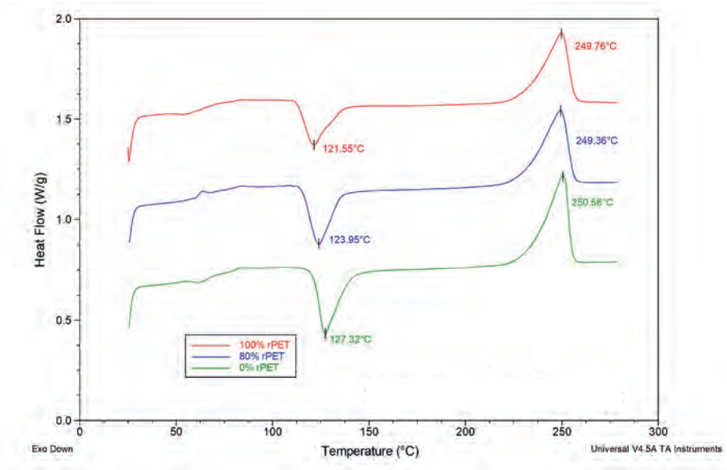
In the recycling journey, PET undergoes several stages including washing, grinding, drying, extrusion, pelletisation, recrystallization, and solid-state polymerization. It's during the drying step that a notable hurdle emerges. As PET is repeatedly recycled, it becomes more prone to absorbing more CO_2 from carbonated beverages. Norner's research in collaboration with Infinitum has shown that as the amount of recycled content increases in the bottles, the total amount of absorbed CO_2 increases, by TGA analyses (figure 2). Hence, during the drying process, a foaming type of phenomenon is observed, which increases the surface area of the flakes, allowing them to impinge on each other and get stuck to each other prior to surface crystallization. Furthermore, the rate of diffusion out of the bottles slows down with the increase in the amount of recycled content in the bottles. This behaviour is markedly observed in the finish (thread) region of the bottles, a consequence of the low crystallinity of that region coming from the injection moulding process of the preform. The major reason for this effect has been correlated to differences in crystal morphology of the PET materials with varying amounts of recycled PET content. This excessively absorbed CO_2 impacts both the material's properties and the recycling process. Managing this increased CO_2 absorption and its effects on the recycling process efficiency is a pressing concern.

The Colour and Haze Conundrum

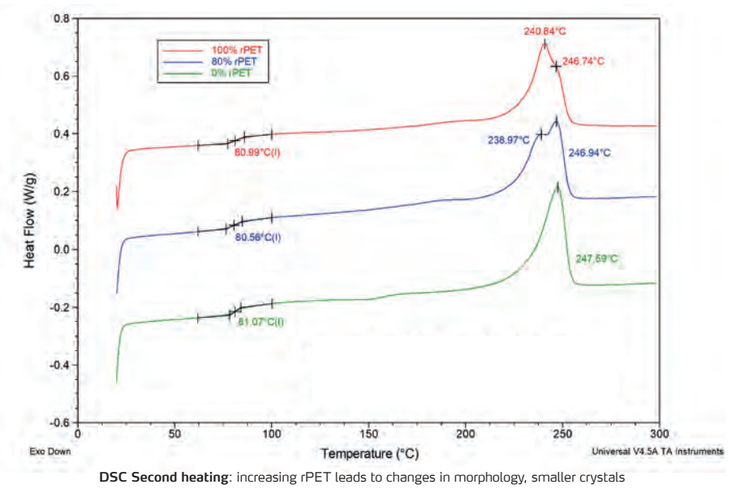
Ensuring product quality, particularly in terms of colour and haze, becomes increasingly intricate as the level of recycled PET in the production mix rises.



DSC First cooling: increasing rPET leads to higher crystallisation temperature.



DSC First heating: increasing rPET leads to higher crystallisation temperature.



DSC Second heating: increasing rPET leads to changes in morphology, smaller crystals

Figure 1 Effect of rPET amount on the crystallisation behaviour and crystal morphology of PET using DSC.

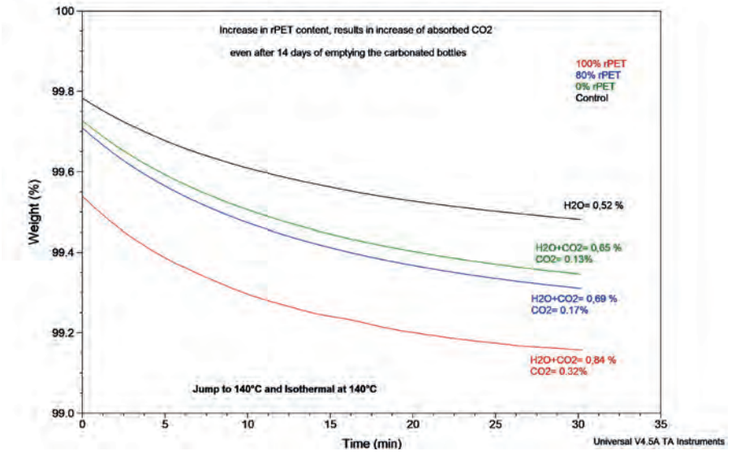


Figure 2 TGA isothermal analysis at 140°C

Despite advanced sorting and cleaning processes, variations in colour and clarity may occur due to impurities introduced during collection and particulate build-up during multiple cycles of the recycling process. This poses a challenge for manufacturers striving for consistent product quality.

Particle pileup, an intricate challenge
Particle accumulation during multiple recycling steps is another concern. These particles, originating from labels, caps, and other contaminants, act as nucleating agents. This affects the crystallization behaviour of PET, increasing crystallization temperature and hindering surface (cold) crystallization during drying, ultimately impacting the material's properties. This has been demonstrated by Norner and shown in Figure 1, where the effect of an increase in recycled PET content can easily be correlated with an increase in crystallization temperature and a change in crystalline morphology (shape of the melting peak) using Differential Scanning Calorimetry (DSC).

This reduced rate of (cold) crystallization also reduces the efficiency of drying, as the drying temperatures have to be reduced to compensate for slow crystallization behaviour, to prevent sticking of flakes and further leading to blocking of hoppers as the cold crystallization process continues, leading to a runaway exotherm, even leading to temperatures above the melting point of PET. This leads to line stoppages. Some of the lumps and degraded products retrieved from the drying hopper are shown in figure 3 and 4.

Figure 3 (Left) Popping and (right) lump formation (along with degradation) due to a combination of CO_2 absorption and slow cold crystallization due to the presence of high amounts of 100 % recycled PET.

Accumulation prohibits 100 % rPET
Attaining 100 % recycled PET presents unique challenges. Unlike a plateau, where material quality stabilizes, 100 % recycled PET would exhibit non-plateau behaviour due to particle accumulation and no way of mitigating this issue, due to the absence of any new virgin material being added to the recycling stream. These particles, acting as nucleating agents, disrupt the crystallization process and compromise the desired material properties. This is one of the major mechanisms which causes the issues discussed above.

Low drying efficiency hinders IV target
Furthermore, reduced drying efficiency can be problematic, even after prolonged periods of solid-state polymerization PET might not be able to reach the desired intrinsic viscosity, again limiting the possibilities of applications in carbonated beverage applications. The presence of particles as nucleating agents can slow down surface crystallization and increase crystallization temperatures, compounding the drying challenges.

CO_2 – Another migration challenge
As discussed above, due to an increase in the amount of recycled content of recycled PET, there is a higher absorption of CO_2 in the bottles, it marks a question regarding the result of this gaseous simulant in the migration of any small molecules from PET to the beverage or vice versa. This migration study, which includes the effect of CO_2, is currently not part of EFSA requirements and hence needs to be further studied to have a deep understanding of its implications on the safety of these high amounts of recycled PET-containing articles.

Norner is currently working with Infinitum to get an initial understanding of this possible migration mechanism.

Is a target adjustment needed?
Amid these intricate challenges, there's a compelling motivation for adjusting the target recycled content for PET bottles to fall between 75 % to 80 %. This adjustment would allow for the controlled introduction of virgin PET material into the recycling stream, thus stabilizing material quality parameters like the number of particles, colour, and haze. This balance ensures a more predictable and sustainable recycling stream, benefiting all bottle producers. Furthermore, there is a dire need to define a raw material specification, which would allow the recyclers, performer producers, bottling companies, and brand owners to control the quality of their products without damaging the PET recycling stream in Norway. Norner in collaboration with Infinitum has developed a first set of specification based on the observed material behaviour and the recycling process capability and continue to improve upon that as more data gets available.

Conclusion
In conclusion, Norway's remarkable journey toward a circular economy via PET bottle-to-bottle recycling is a testament to its commitment to sustainability. While challenges persist, the nation's proactive approach to adjusting recycled content targets offers a promising solution. By striking a balance between recycled and virgin PET, Norway paves the way for a greener future where material quality remains high, recycling is efficient, and sustainability is paramount. In doing so, it continues to inspire the world on the path to a more environmentally responsible tomorrow and Norner is proud to be part of this journey.

Figure 4 Amorphous PET bottle threads with 0% vs 100% PET demonstrate the increased tendency of popping/foaming with rPET

Photo Bottles of virgin and 100 % recycled PET showing greyness

Safe use of recycled plastics for cosmetics

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HDPE bottles for Personal Care and Cosmetic products (Cosmetics) are an attractive segment for the use of post-consumer recycled (PCR) materials. The availability is poor for materials that have good enough mechanical properties and purity. The latter can cause odour and migration of substances which needs safety documentation. Can a 3-layer structure be the solution?

Cosmetic regulation

In contrast to food contact applications, cosmetics do not have a defined process for signing off safety and regulatory compliance for the use of PCR materials. Instead, the EU Cosmetics Regulation (EC) No. 1223/2009 says that the cosmetic product made available on the market must be safe for human health when used under normal or reasonably foreseeable conditions of use. A safety assessment that involves information about the packaging material must be performed and included in the required Product Information File (P.I.F.).

Safety assessment

The introduction of PCR materials in the packaging increases the complexity of this safety assessment. Due to this, the qualification of PCR materials for use in Cosmetic applications is a high priority for packaging producers and brand owners.

The amount of PCR material that can be used in cosmetic packaging such as HDPE bottles depends on the material quality and purity. In single-layer bottles, it is common to use blends of PCR and virgin HDPE material to obtain a safe result. Another common method is to use PCR in the core layer in multi-layer bottles. Then there is a virgin food contact-compliant material in the inner layer of the bottle, in contact with the product.

Study of 3-layer bottles

Norner has made a large case study where migration testing and screening of non-intentionally added substances (NIAS) have been performed on 3-layer bottles intended for cosmetic packaging. The following paragraph presents the main results. The test bottles had PCR material in the core layer, a 400 µm inner- and a 100 µm outer layer. See Figure 1, which shows the layer distribution of the bottles.

Cosmetic products a have long shelf life (typically > 2 years). Due to this, it was decided to use 10 days at 60 °C as migration conditions. Two simulants were selected: 95 % and 50 % ethanol. NIAS screening is often performed with 95 % ethanol as a simulant, and it is well known that 10 days at 60 °C are tough conditions. 50 % ethanol is a milder simulant, and a lower level of migration could be expected. A commercial PCR grade and a virgin HDPE bottle grade were selected for the study. Reference bottles with 100 % virgin material was also tested. Migration from the raw material (pellets) were compared to the results from the bottle migration under the same conditions.

Migration test results

The migration tests were based on EN1186, and for the NIAS screening, Gas Chromatography with Mass Spectrometric detector (GC-MS) was used. See Figure 2, which summarises the results.

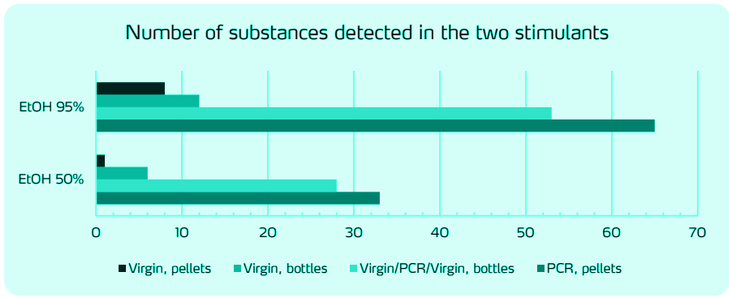


Figure 2 Number of substances found in the different samples and conditions.

A total of 69 different substances were detected in the analyses at concentrations ≥ 5 ppb, from the PCR pellets.

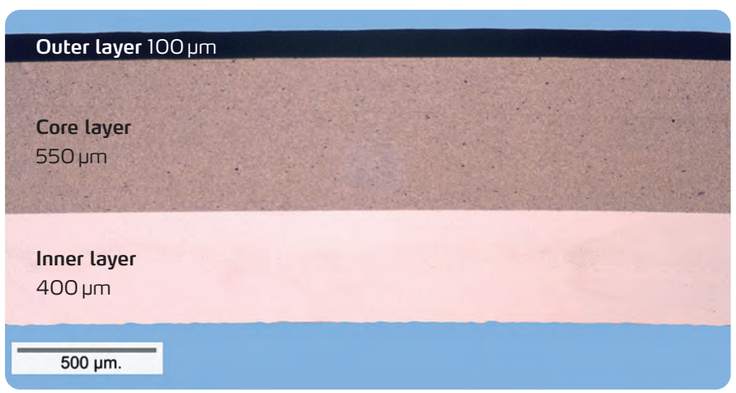
- This includes polyolefin oligomeric saturated hydrocarbons (POSH), which are shorter polymer chains always present in HDPE.
- Some intentionally added substances (IAS), i.e. additives, were identified.
- The main part of the substances was contaminants/NIAS.

From the virgin materials, very few substances were found. There were more substances from bottles than from pellets, in both simulants. For all materials, we found fewer substances with 50 % ethanol compared to 95 % ethanol. We found more substances in the bottles with PCR core layer than in the virgin bottles.

- With 95 % ethanol, more than 40 substances have migrated through the 400 µm virgin inner layer
- In 50 % ethanol, only half of these substances had migrated through the virgin layer.
- The amount of migration per substance was significantly less when the bottle had an inner virgin layer.

The number of substances was highest for migration from the PCR pellets. Some of these did not migrate through the virgin inner layer of the bottles.

Figure 1 Cross section of the bottle wall



Conclusion

Based on the results, we can conclude that a virgin plastic layer acts as an inhibitor to migration, and even if it is not an absolute inhibitor, it reduces the risk and increases consumer safety. However, in order to remain safe, the migration and safety assessments need to be made.

Strategic investments

To support the global transition from virgin fossil-based materials to recycled polymers for various applications, Norner has enhanced its competence and resources. We have invested strategically in people and equipment to provide required solutions for the circular economy goals set by the authorities, brand owners, and the industry, including:

- New analytical techniques for PCR purity assessment (GC/MS-ODP, GC/FID, LC/QTOF).
- Recycling Pilot for PCR upgrade by better extrusion
- 7-layer cast and blown film large pilot line
- 3-layer Extrusion Blow Moulding (EBM) commercial scale bottle production unit.

Increasing requirements on purity analyses of plastic

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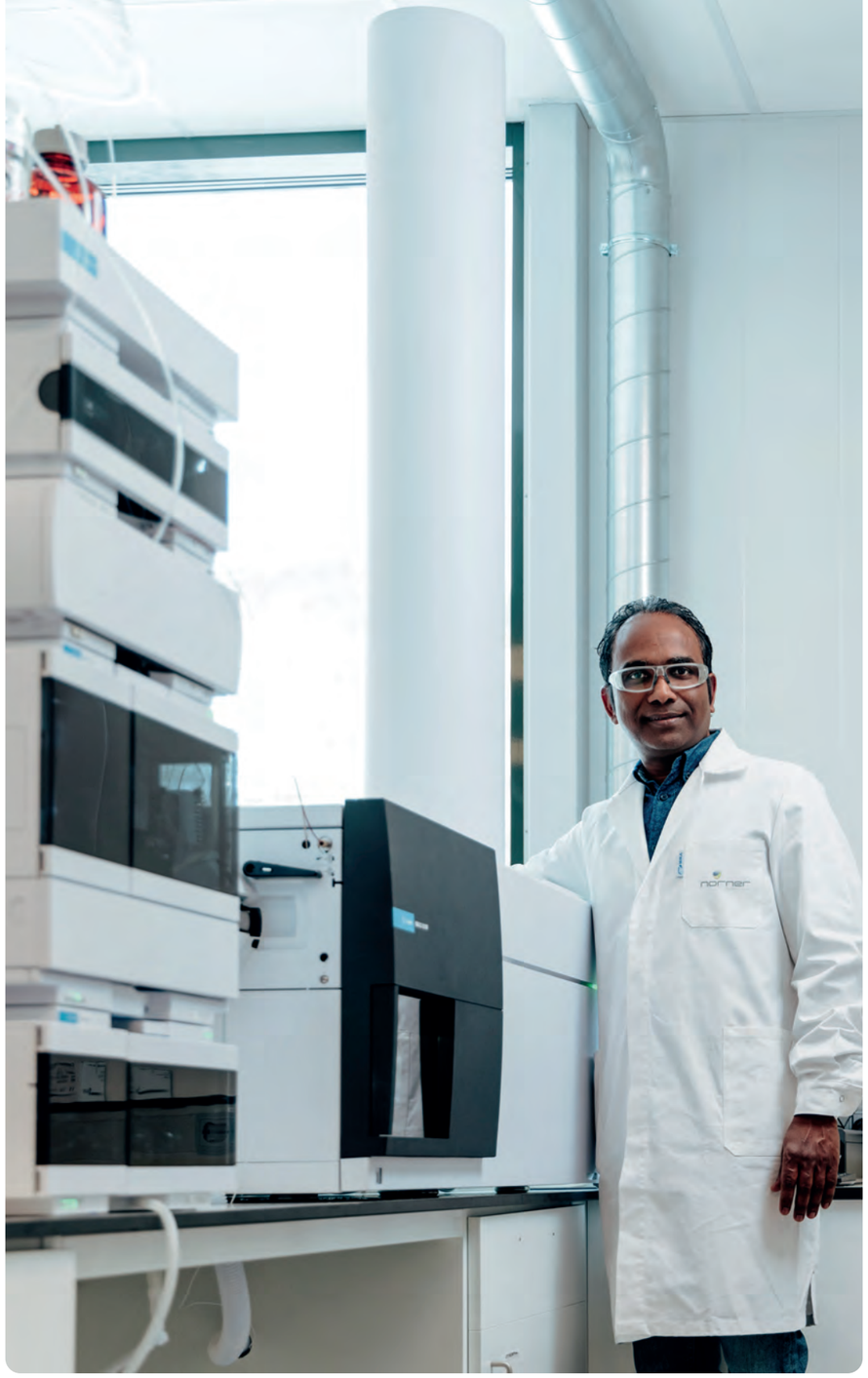
EU is introducing requirements to converters within packaging, building and construction, automotive, and several other applications where plastics are being used. The proposed Plastic and Packaging Waste Regulative (PPWR) states that by 2030, the minimum amount of recycled content of single-use plastic beverage bottles will be 30%, and the number will increase to 65% by 2040. Similar targets will be published for other applications, and these are tough requirements to meet for the industry. The race to build knowledge and competence within plastic recycling and characterization of the resulting products is at full speed.

Challenges with recycled plastics
Products containing mechanically recycled plastics have many challenges that limit their usage, especially in high-value applications such as food, cosmetic products, UN packaging, and plastic toys. Poor mechanical properties, unwanted odours, polymer degradation, colour inconsistency, and organic and inorganic contaminations are some of the challenges that need to be addressed.

Advanced characterization
The introduction of recycled plastics in contact-sensitive applications such as cosmetics, toys, and food contact materials needs to be made safe for consumers. Due to the potential risks of contamination, advanced characterisation and testing are required. A normal procedure so far has involved migration tests according to the food packaging regulation EU 10/2011 followed by GC-MS screening and specific target analysis. However, alternative techniques to detect more substances at even lower concentrations will be needed.

To meet these increasing demands, Norner has invested in state-of-the-art equipment and is developing methods for the separation, identification, and quantification of known and unknown organic compounds. The new techniques are based on Pyrolysis (PY) GCMS and Liquid Chromatography (LC) coupled with high-resolution mass spectrometry through a Quadrupole Time of Flight (Q-TOF) detection system. The new equipment and methods are complementary to Norner's other capabilities within purity analysis like migration and GC/MS, and we can now offer a comprehensive set of services as visualized in Figure 1.



Collaboration with academia
Norner is involved in various research projects related to additive and contaminant characterization with recycled plastics. In 2019, Norner initiated a collaboration with the Royal Institute of Technology in Stockholm, KTH, where the focus is to increase the knowledge around the purity of Post Consumer Recyclates (PCRS). The current research focus in this collaboration is studies of post-consumer recycled plastics in food contact.

Norner's research efforts
We have developments ongoing in various fields such as food, pharmaceuticals, automotive, and infrastructure:

- Identification of unknown peaks, large and small molecules (MW range up to 10,000 Da). The LC/Q-TOF has a mass accuracy that is 100 times better than conventional methods such as HPLC/MS. PY-GCMS does not have an upper MW limitation, and a very small sample amount can give a lot of relevant information.
- Extractables and Leachables (E&L) testing – detection of compounds at very low levels (ppb), with the use of an extensive library available at Norner
- Verification of 10 ppb food regulative requirement (ECHA)
- Target analysis with low detection levels for polyaromatic hydrocarbons (PAH) and polyaromatic amines (PAA)
- Improved identification and quantification of large molecules (> 700-800 Da) by combining FTIR, LC/Q-TOF, and PY-GCMS.

Pyrolysis-GCMS
Pyrolysis-GCMS is a powerful technique used to identify and characterize polymers. It involves the controlled heating of polymer samples to break them down into small components (pyrolysates), which are then separated and analysed using Gas Chromatography and Mass Spectrometry. This technique provides valuable information about the polymer's chemical structure, thermal stability, degradation products, and more.

LC/Q-TOF
LC/Q-TOF is a powerful analytical technique used for the separation, identification, and quantification of non-volatile components. It offers high resolution, sensitivity, and mass accuracy for reliable and precise analysis. It combines the capabilities of ultra-high liquid chromatography, which separates the non-volatile components with high-resolution mass spectrometry for accurate identification and characterization of the separated components.

Contaminations	DSC	FTIR	GC/MS	GC-O/MS	GC/FID	LC-MS-QTOF	HPLC	Pyrolysis-GC/MS	Ash-SEM-EDS	ICP/MS	XRF	Filter test SEM-EDS/FTIR/microscopy
General level of detection	%	%	PPB-PPM	PPM	PPM	PPB	PPM	PPM-%	PPM	PPB	PPM	-
Polymers contaminations	X	X						X				
Organic (<800g/mol)		X	X		X	X	X	X				
Organic (> 800g/mol)		X				X	X	X				
Odour substance			X	X								
Inorganic contaminations		X							X	X	X	
Solid contamination in melt-processing												X

Figure 1 Typical method selections for different classes of contaminations.

A notch is enough to break your plastic

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Product failures are costly. Still, it happens in most daily use of plastics. It seems like some principles are forgotten or ignored.

Consequences
Failures have serious consequences:

- Product liability and warranty claims
- Significant penalties
- Loss of brand credibility and competitive edge
- Expensive recalls
- Re-tooling
- Failure investigation costs
- Legal disputes or insurance claims

Causes for failures
Plastic failures are seldom caused by material weaknesses or process faults, but mostly related to human errors:

- Material misselection
- Poor specifications
- Poor design
- Poor processing
- Abuse and misuse

A reoccurring cause of failure is stress concentrations caused by sharp radii in moulding and welds. This has been documented by numerous failure analyses by Norner and is the main cause of failures.

Notch sensitivity
Plastics are notch-sensitive, and a significant reduction in toughness and strength can occur. This can be described as the susceptibility of a material to crack initiation and propagation at locations with stress concentrations, like sharp notches.

Sharp radii in corners must be avoided when designing plastic products. Such sharp radii may also have other origins such as improper masterbatch selection or mixing, voids, foreign particle contamination, or other geometric discontinuities such as in weld joints.

Test methods
The notch sensitivity of plastic materials is often tested by the Izod notched impact test ISO 180 or the Charpy notched impact test, ISO 179, often reported in product datasheets measured at different temperatures to differentiate materials. These impact tests consider a well-defined standard notched specimen.

A drastic decrease in impact strength will be caused by reducing the notch radius.

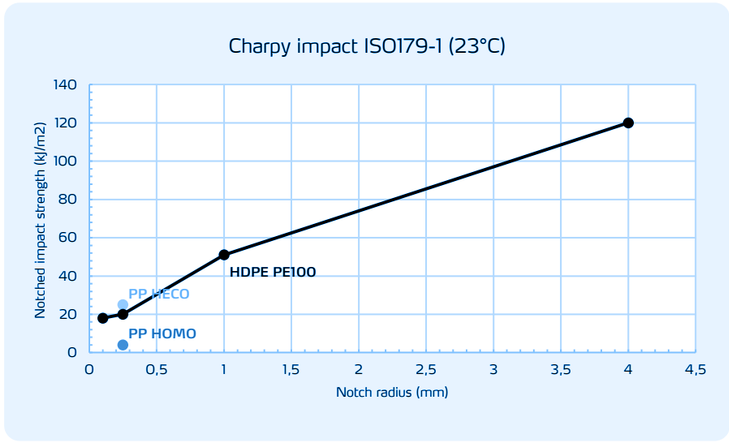


Figure 1 Charpy impact strength for HDPE PE100 at different notch radius demonstrate the sensitivity for sharp notches. The notch reduces the impact strength drastically to similar level as PP materials.

This is illustrated in Figure 1, where the notch depth is kept constant, while the notch radius is reduced. In this test series, a standard ISO test specimen is used in a Charpy impact test at 23 °C. It shows that by reducing the notch radius the impact strength of a durable and ductile polyethylene PE100 pipe material will become even less than polypropylene copolymer.

What does this mean?
The practical implication of such insight is highly important when designing plastic products and when securing quality through proper masterbatch selection, pigment distribution, and dispersion.

This is also of high importance when using recycled materials. Obtaining particle-free recyclate is challenging. Proper washing and melt filtration prior to extrusion and pelletisation will reduce the risk of undesired particles, and internal notch effects.

Failure in pipe welding
A failure type where the effect of notch sensitivity is frequently investigated by Norner is the quality of pipe welding joints.

Butt fusion is the most common technique for welding PE pipes, where the result should be a pressure-resistant and gas-tight joint, able to withstand both pipe installation, operation, and ground movements. During welding the pipe ends are heated and melted, followed by pressing them together. Some molten material will be pressed out of the welding zone, giving a weld bead both inside and outside of the pipe. If proper welding procedures are not followed, sharp notches might be generated. Mechanical testing of pipe welds and microscopy analysis at Norner often show that the conditions may cause sharp notches at the weld bead. The effect on mechanical strength is detrimental.

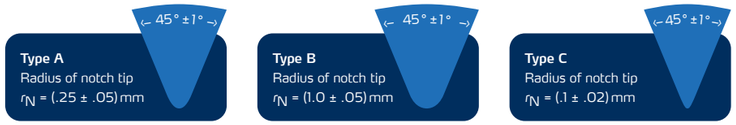


Figure 2 Bottom radius in Charpy test specimen.

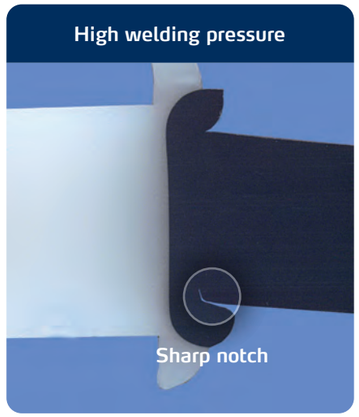
Example
The picture shows such a case, where our customer experienced that their structure cracked during lifting. Based on their experience they thought the weld itself was weak and therefore increased the welding pressure, which only worsened their problem. The facts were revealed by our microscopy failure analysis.

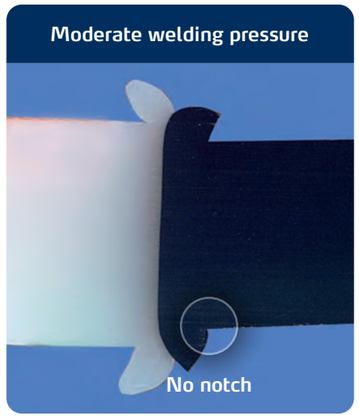
The high welding pressure led to a larger weld bead and caused a sharp but hidden notch. This was difficult to detect in the field and caused breakage.

Conclusions
It is important to carry out a failure analysis to find the root cause of breakage.

Sharp notches in combination with a high strain rate can cause brittle fracture even in very ductile and impact-resistant materials such as PE100 pipe grades.

Figure 3 A weld between two HDPE pipes with different holding pressure during welding.





Transforming aquaculture into a **circular economy** by 2030

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In December 2022, the Circular Solutions for the Aquaculture Industry project (SirkAQ) was awarded a grant of almost NOK 70 million from the government's Green Platform support scheme. The Green Platform is a national initiative to support research- and innovation-driven green restructuring in trade and industry.

Project ambition
The goal of the SirkAQ project is to promote the transition from a linear to a circular economy in aquaculture. The project will establish and implement sustainable circular value chains for plastics from discarded equipment from the aquaculture industry through reuse, repair, lifetime extension, and the use of recycled materials in new products. In addition to focus on eco-design, environmental documentation, and traceability systems throughout the value chain. The purpose is resource optimization as well as to reduce the environmental and climate footprint of aquaculture. The vision is "zero plastic waste by 2030."

The project has a strong consortium of partners throughout the value chain from producer, supplier, farmer to recycler. In addition, SirkAQ has strong R&D partners in relevant disciplines. Scale Aquaculture AS is the responsible company and heads the project.

Norner's role in SirkAQ
Norner Research is one of the R&D partners, and is responsible for a work package named "Technology for the increased use of recycled plastic from fish farming facilities". The purpose of this research work is to ensure material recycling of plastic equipment from the aquaculture industry. The work will develop, test, and establish suitable processes for high-quality mechanical recycling, lifetime extension, and upgrading of the technical material properties of discarded equipment.

> "This will be a positive boost for the required green transition in aquaculture, it will give us new knowledge and expertise. A more sustainable aquaculture ecosystem is also a precondition to creating even more jobs in this industry.
>
> **Hanne Digre**, project manager for SirkAQ."

Norner and Future Materials Catapult Center
Through several work packages, Norner AS is actively contributing through Future Materials, aiming to play an essential role in the success of SirkAQ using its extended know-how:

- Advanced microscopy analysis to enable in-depth materials, contaminants, and structural analysis.
- Fatigue and aging testing to ensure component durability.
- Additives and polymer expertise
- Recycling know-how and pilot lines for compounds with optimal material performances.

Norner's multifaceted knowledge and skills are crucial in achieving SirkAQ's sustainability goals efficiently.

Participants

- *ScaleAQ*, system supplier, and project owner
- *Hallingplast*, pipe, and profile extrusion
- *Sinkaberg-Hansen*, aquafarming
- Oceanize, recycler
- *Norner Research*, material research
- *OsloMet*, systems, and design
- *Sintef Ocean*, technology research
- *Future Materials Catapult*, processing pilot

Photo Kick-off for the project group at Frøya, March 1st, 2023.

About the Green Platform

The Norwegian government wishes to use the Green Platform Initiative to stimulate larger and more rapid investments from companies in green sustainable solutions and products.

The Green Platform Initiative is financed by the Norwegian Research Council, Innovation Norway, and Siva through different types of applications and policy instruments to ensure that users find the process easy.

The Green Platform Initiative provides funding for enterprises and research institutes engaged in green growth and restructuring driven by research and innovation to strengthen Norwegian exports and value creation by implementing the green transition and creating green growth.

The objective is to trigger opportunities for green value creation through major projects.

The Green Platform projects should comprise the whole value chain from research and knowledge production to testing, commercialisation, and industrialisation of sustainable, green products and services.

The projects accepted in the Green Platform Initiative are very competitive and have been through a thorough application process, where in-depth interviews have been conducted by an expert panel and the funding bodies prior to awarding grants.

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Norner online barrier calculator

At a lower cost than a single barrier test, you can use our calculator as a fast track to limitless estimation of the packaging barrier performance every month.

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The calculator has great flexibility in geometrical options, multilayer definition, material selection and environmental conditions allow our clients to tailor the calculations to their packaging cases. You can calculate the barrier at standard conditions or at the real in-use conditions or choose to simulate and compare what would happen if the package were exposed to high temperatures during transport or storage.

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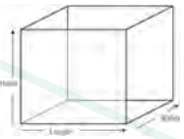


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