



TREASoURcE

Circular systemic solutions: From demos to deployment

Parallel session • Plastics value chain

TREASoURcE Final Conference



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Agenda

Time	Title	Speaker(s)
13:00–13:10	Plastic key value chain introduction (10 min)	Ugur Kaya (Senior Scientist, VTT)
13:10–13:20	Challenges and Policy Recommendations (10 min)	Tran Ngo (Research Scientist, VTT)
13:20–13:30	Stakeholder engagement (10 min)	Jan Bakke (County authority of Østfold)
13:30–13:40	Sustainability assessment (10 min)	Alex Koch (Green Delta)
13:40–14:00	Optimizing Mixed Plastic Feedstocks for High-Efficiency Recycling (20 min)	Stephan Kubowicz (Senior Scientist, SINTEF) Ugur Kaya (Senior Scientist, VTT)
14:00–14:15	Coffee break (15 min)	
14:15–14:35	Chemical recycling for closing the loop of plastic waste (20 min)	Christian Lindfors (Senior Scientist, VTT), Juha Lehtonen (Research Professor, VTT)
14:35–15:00	Panel Discussion: Chemical recycling of the hard to recycle feedstocks (25 min)	Moderator: Juha Lehtonen (VTT)
15:00–15:15	Coffee break and coming back to plenary room (15 min)	



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Plastics key value chain introduction (13:00-13:10)

Ugur Kaya (Senior Scientist & Project Manager, VTT)



KVC-DEMOS: Circular plastics value chain

Objectives

- Efficient plastic collection, sorting and pretreatment.
- Mechanical recycling of targeted plastic waste streams.
- Chemical recycling technology to treat rejected plastic waste from mechanical recycling.
- Upgrading technologies to final valuable products.

Main activities

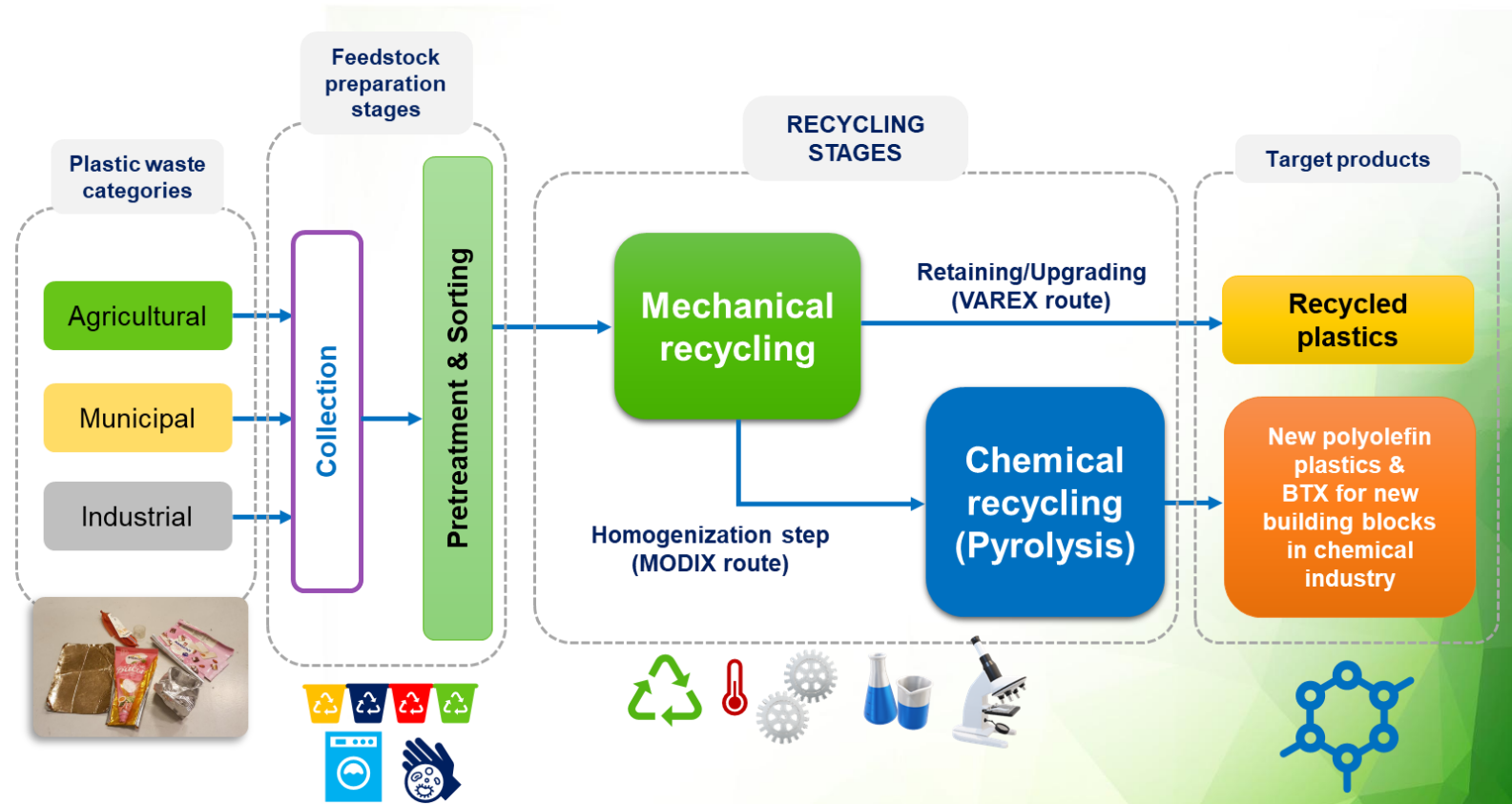
- Characterization and analyses of municipal, agricultural and industrial plastic waste.

- Classification of plastic waste for mechanical and chemical recycling.
- Determining and executing pretreatment steps before recycling for each waste stream.
- Advanced mechanical recycling (VAREX) for retaining and upgrading the properties of waste plastic.
- Mechanical recycling as pretreatment step (MODIX) before pyrolysis step.
- Chemical recycling (pyrolysis) to synthesize pyrolysis oil for new building blocks to produce new plastics/added value products.





KVC-DEMOS: Circular plastics value chain





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Plastics regulatory challenges and policy recommendations (13:10-13:20)

Tran Ngo (Research Scientist, VTT)

Legislative and regulatory mapping



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Desk research to map EU policies & identify its key drivers and barriers

Workshop & stakeholder engagement for practical validation

Policy recommendation formation

Plastics regulatory challenges and policy recommendations

1. Plastic waste collection, sorting, and logistics
2. The feasibility of recycled content requirement and bio-based plastics
3. Plastic recyclability, including design for recycling and advanced solutions
4. Economic profitability of circular plastic solutions
5. Plastics policy brief: Enabling complementary mechanical and chemical recycling



1. Plastic waste collection, sorting and logistics

Enhancing waste collection and separation

- Establish financial and policy incentives (E.g. through Emission Trading System (ETS) for reducing waste incineration and Extended producer responsibility (EPR) for handling waste collection and recycling)
- Enacting national and European plastic end-of-waste criteria

Eco-modulation for plastic recyclability by design

- Develop eco-modulation (recycling fees are determined by the recyclability of the product) to foster design for recycling



2. The feasibility of recycled content requirement and bio-based plastics

Gap between the recycled content requirement and recyclate quality management

- RDI funding and investment to advance knowledge and understanding of recyclate quality control and safety, e.g., in sensitive packaging applications like food contact.
- Update plastic recyclate regulations (EU 2022/1616) to facilitate alternative recycling options (mechanical and chemical recycling) that improve recyclate quality and safety, thereby enabling their use in contact-sensitive packaging.

Lack of regulatory framework for bio-based materials as alternative to plastic packaging

- Establish regulatory frameworks tailored to bio-based polymers covering production, utilization, quality control, and end-of-life management.
- Develop standards, technical guidelines, and labelling systems specific to bio-based materials to facilitate their integration into the packaging industry and end-of-life management systems.



3. Plastic recyclability, including design for recycling and advanced solutions

Lack of standardised plastic recycling practices and recyclate quality control

- Establish a stakeholder cooperation platform to develop industry-specific standards and certification schemes for plastic recycling and recyclate.
- Create flexible standards that adapt to the recyclate dynamic nature based on the feedstock composition.
- Periodically review standards to incorporate advancements and market demands.

Complexity of product and process design affecting the possibilities of effective recycling

- Enact ecodesign as well as material traceability to improve the sustainability and knowledge of the plastic waste feedstock, that further improves the safety and quality of the recycled plastics.
- Advancements in RDI are needed to improve mechanical recycling for processing more problematic waste fractions, complemented by chemical recycling to handle the most challenging waste fractions



4. Economic profitability of circular plastic solutions

Consumer acceptance and cost-effective circular plastic solutions

- Implement sanctions for virgin fossil-based solutions following the polluter pay principles.
- Implement consumer protection laws and develop sustainability labeling and certification schemes to ensure transparency and fairness in the marketplace.
- Invest in consumer education programs to empower individuals to make informed decisions.
- Establish a public procurement scheme to create demand for recycled plastic market.



5. Plastics policy brief: Enabling complementary mechanical and chemical recycling

- Mechanical recycling is well-established and energy-efficient
 - Preserves the polymer structure, making it the cornerstone of circular plastics systems.
- Complemented by chemical recycling
 - Enables use of recycled polymers in food contact and other demanding applications.
 - Feedstock focus on fractions difficult to mechanically recycle, e.g. mixed polyolefins, multilayer packaging and films.
 - New legislation is needed to approve as recycling method.

Policy brief TREASoURcE

Policy recommendations

Achieving a plastic circular economy requires further regulatory advancement beyond existing drivers such as recycling targets and recycled-content mandates. Current legal and technical barriers hinder the development of complementary mechanical and chemical recycling systems. To unlock the full potential of circularity in plastics, the following regulatory actions are recommended.

1 Develop harmonised End-of-Waste (EoW) criteria for plastic waste

The absence of EU-wide end-of-waste (EoW) criteria for plastics undermines market confidence, limit recycling uptake, and discourage investment in recycling infrastructure (EuRIC, 2023). It is recommended that the European Commission, through DG ENV and DG GROW, in close cooperation with Member States, establish harmonised EoW criteria under the Waste Framework Directive (Directive 2008/98/EC). This measure should clearly define the conditions under which plastic waste ceases to be classified as waste and becomes a secondary raw material, thereby promoting legal certainty and facilitating cross-border trade in recyclates.

2 Strengthen separate collection and sorting of plastic waste

Effective separate collection and sorting are essential to generate high-quality plastic feedstock for recycling. Robust source separation provides cleaner material streams, while advanced sorting of mixed waste increases recovery of recyclables. To this end, policymakers should reinforce the implementation of separate collection obligations and strengthen Extended Producer Responsibility (EPR) schemes, complemented by targeted consumer awareness initiatives. These measures should promote transparency, accountability, and widespread participation across the plastics value chain. Coordination should be led by the European Commission (DG ENV, DG GROW), with implementation supported by Member States, municipalities, EPR organisations, and industry stakeholders.

3 Recognise chemical recycling under the EU regulatory framework

The current definition of recycling under the Waste Framework Directive primarily encompasses mechanical re-processing, creating regulatory ambiguity for chemical recycling technologies. This uncertainty inhibits investment, slows innovation, and generates inconsistencies between Member States, where chemical recycling outputs such as pyrolysis oil are often categorised as fuels rather than recycled materials (Packaging Europe, 2023). The European Commission and Member States should formally recognise chemical recycling as a legitimate recycling operation where it demonstrably delivers material recovery compliant with circular economy principles. Furthermore, standardisation of chemical recycling processes and products should be developed, alongside a harmonised mass-balance accounting methodology to ensure traceability of recycled content when blending virgin and recycled feedstocks. Implementation should involve collaboration among the European Commission, Member States, relevant industry associations (e.g. Plastics Europe, EuRIC), and standardisation bodies (CEN, CENELEC).

4 Expand the scope of Food Contact Regulation to enable innovative recycling technologies

The current Food Contact Regulation (Regulation (EU) 2022/1616) primarily permits mechanically recycled PET within closed-loop systems, constraining the uptake of innovative recycling technologies for food-grade applications (European Commission, 2022). It is recommended that EU policymakers expand the Regulation's scope to include more advanced mechanical and chemical recycling processes capable of achieving safety levels equivalent to virgin materials. In parallel, harmonised assessment procedures under the European Food Safety Authority (EFSA) should be developed to expedite the authorisation of novel recycling technologies. These actions should be coordinated by the European Commission (DG SANTE), in cooperation with EFSA, national food safety authorities, and stakeholders from the plastics and packaging sectors.



Result documentation

- D1.3 Legislative and regulatory framework for targeted value chain was published in June 2024



- Plastics policy brief will be published in April 2026





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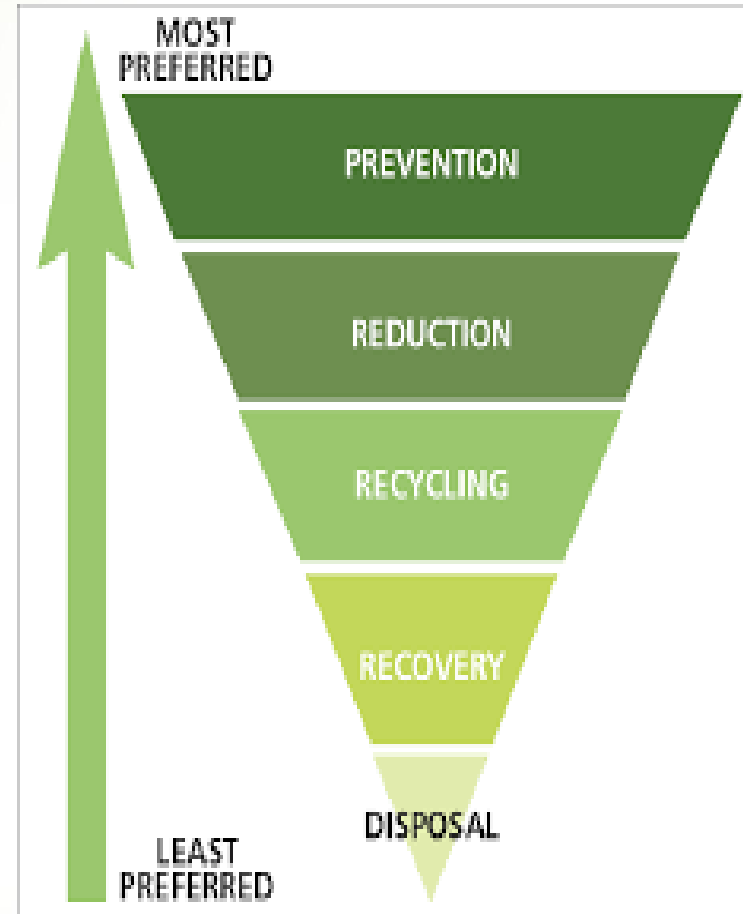
CE-smart procurement recipes for circular plastic (13:20-13:30)

Jan Bakke (County authority of Østfold)



Key elements of CE-smart procurement checklists

- Always do market inquiries
- If at least three (or all) suppliers confirm they can deliver – **minimum requirement**
- If fewer than three respond yes or inconclusive responses, consider using **award criterion**





Main elements

Category-based checklists

- Packaging
- Goods
- Textiles
- Construction
- Waste bags and containers

Do I really need it?



Can I borrow, rent, or buy it used



How do I maintain and service it?



When I no longer need it, where do I take it?



Checklists on circular criteria for goods

1. Eliminate the need for new products
2. Buy second-hand items
3. Buy products as durable as possible and as environmentally friendly as possible
 - ❖ Eco-certifications
 - ❖ Materials they are made from and recyclability
 - ❖ Durability and long life-cycle
4. Disposal – reuse and repurpose products within organization



How to use the checklists

Question	Suggested follow-up action
<p>Can you offer products with recycled content for the plastic parts of the materials?</p> <p>If yes, what share of recycled plastic?</p> <p>Yes, for all Yes, for some</p> <p>No</p>	<p>If at least three responses of yes – make it a minimum requirement that the specified products contain recycled content</p> <p>Suggested requirement specifications below: «The plastic materials of – specify product – shall have a minimum content of x%</p> <p>If no – go to the next point</p>



Create market predictability

- Standardized requirements, evaluations and criteria
- If possible: avoid plastic materials which cannot be recycled
- Require or award recycled plastic
- **Requirements specification:**
“All plastic types should be recyclable, and all kinds of bio-degradable plastic categorized for residual waste should be avoided”
- **Verification requirements**



Combining circular concerns and economic thrift

- **Circular requirements and criteria**
- **Formal control functions:**
Routines to prioritize CE-choices
- **Accomodation:**
Repair and second-hand the default solutions
- **Communication and culture-building**
Money saved
Climate gas emissions reductions
Number/share of products with recycled plastic content



CE-procurement in circular strategies





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Thank you for your attention

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Ideas Are Recyclable.

Research and Replicate. This Handbook will guide you in making the right decisions and provide advice from your perspective.

Please Note! The site is in early development phase and we like to receive your feedback.

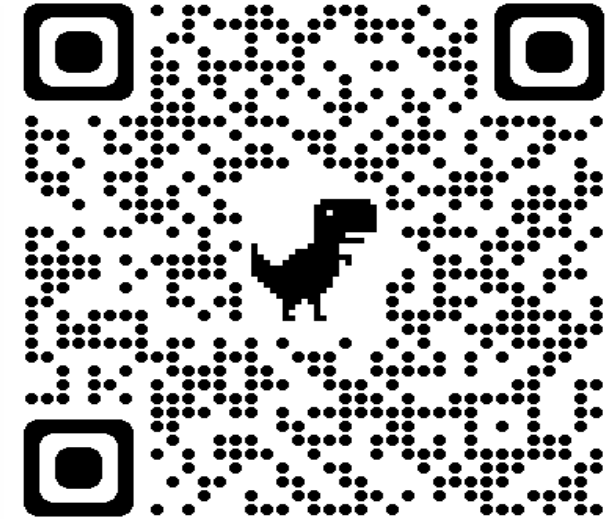
Circular Plastics
Capture the value: create added value from non-circulated plastic by optimising recycling technologies and collection.
[Explore solutions for plastics](#)

EV Battery Reuse
Evaluate possibilities and potential for use of second life electric vehicle (EV) batteries as building blocks for energy storage systems.
[Explore solutions for batteries](#)

Bio Streams
Power the local economies through new circular bio-economy investments and new business possibilities for rural producers.
[Explore solutions for bio streams](#)

[Home - Replication Handbook](#)

[Publications - TREASoURcE](#)





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Sustainability assessment (13:30-13:40)

Alexander Koch (GreenDelta)



Sustainability assessment of circular plastics

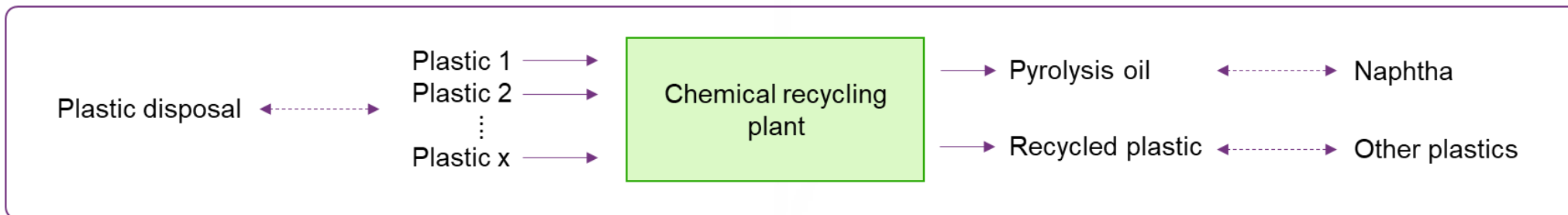
Goal: The goal is to assess the introduction of a chemical recycling plant in terms of its environmental impact. The recycling plant aims to increase the availability of recycled plastics, which can replace virgin materials on the market. Assessment results will act as decision-making support for policymakers.

Region: Gothenburg, Sweden

Material flows: Agricultural, industrial, and municipal plastics: high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP) and polyethylene terephthalate (PET).

System boundaries:

System: Chemical recycling in Gothenburg, Sweden





Method

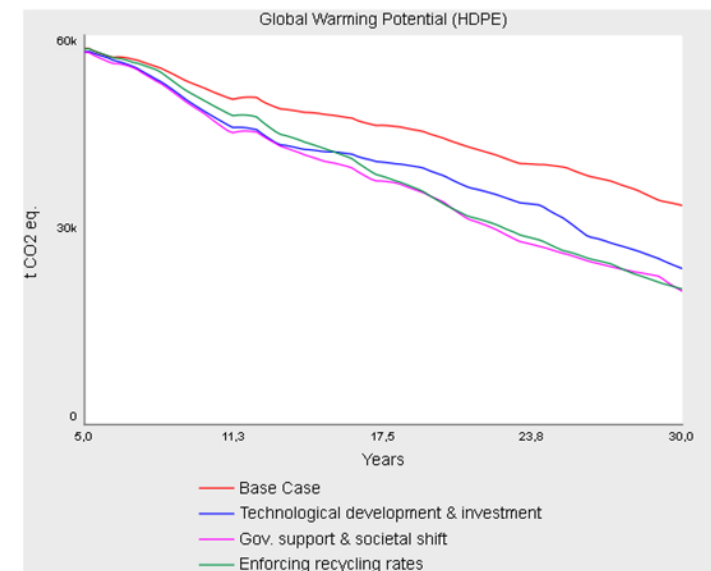
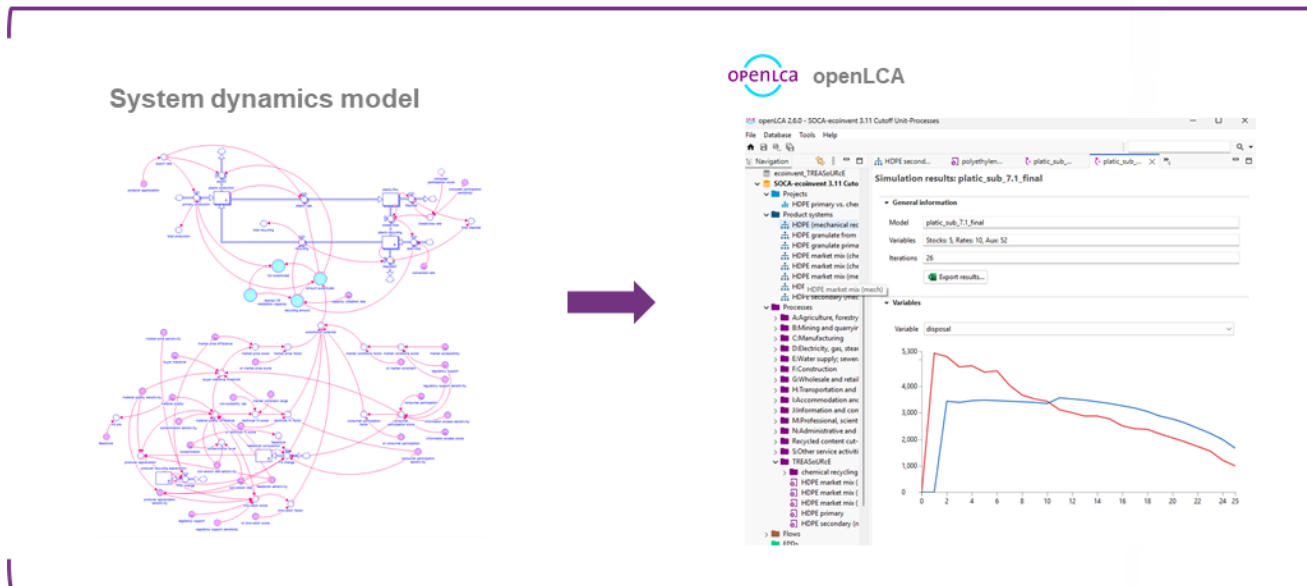


System dynamics

+



Context-specific sustainability assessment of different scenarios over time

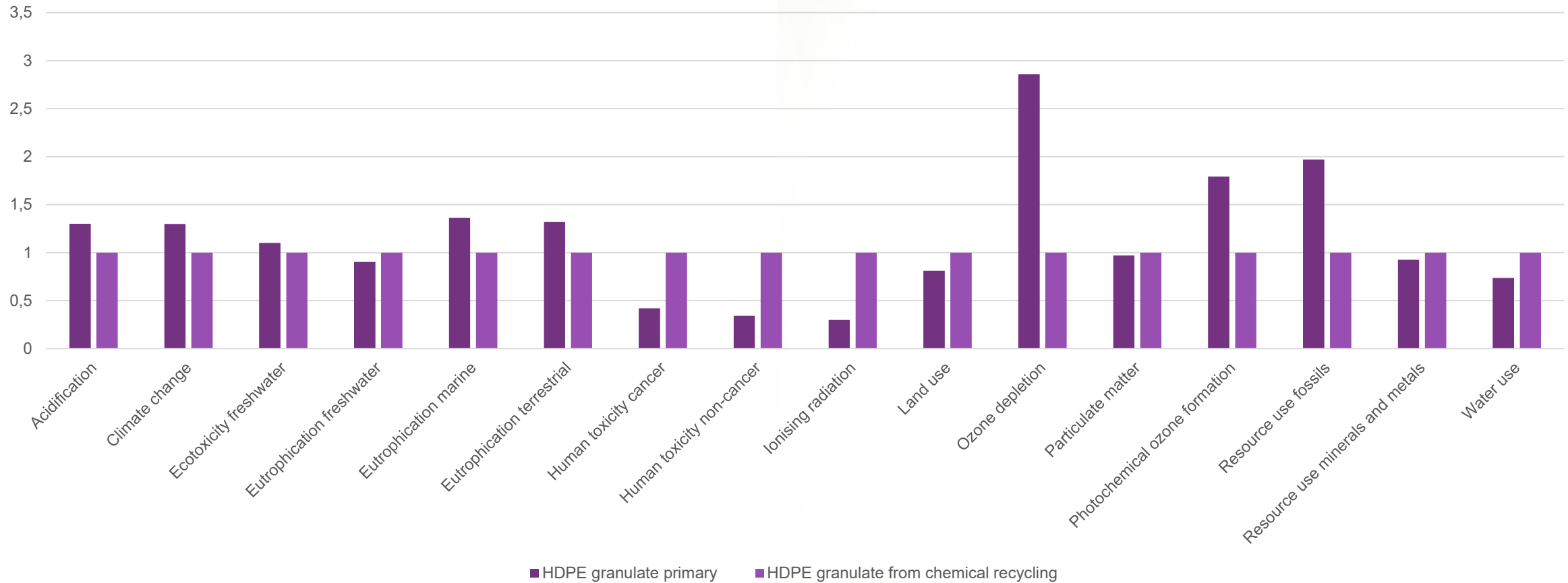


LCA results



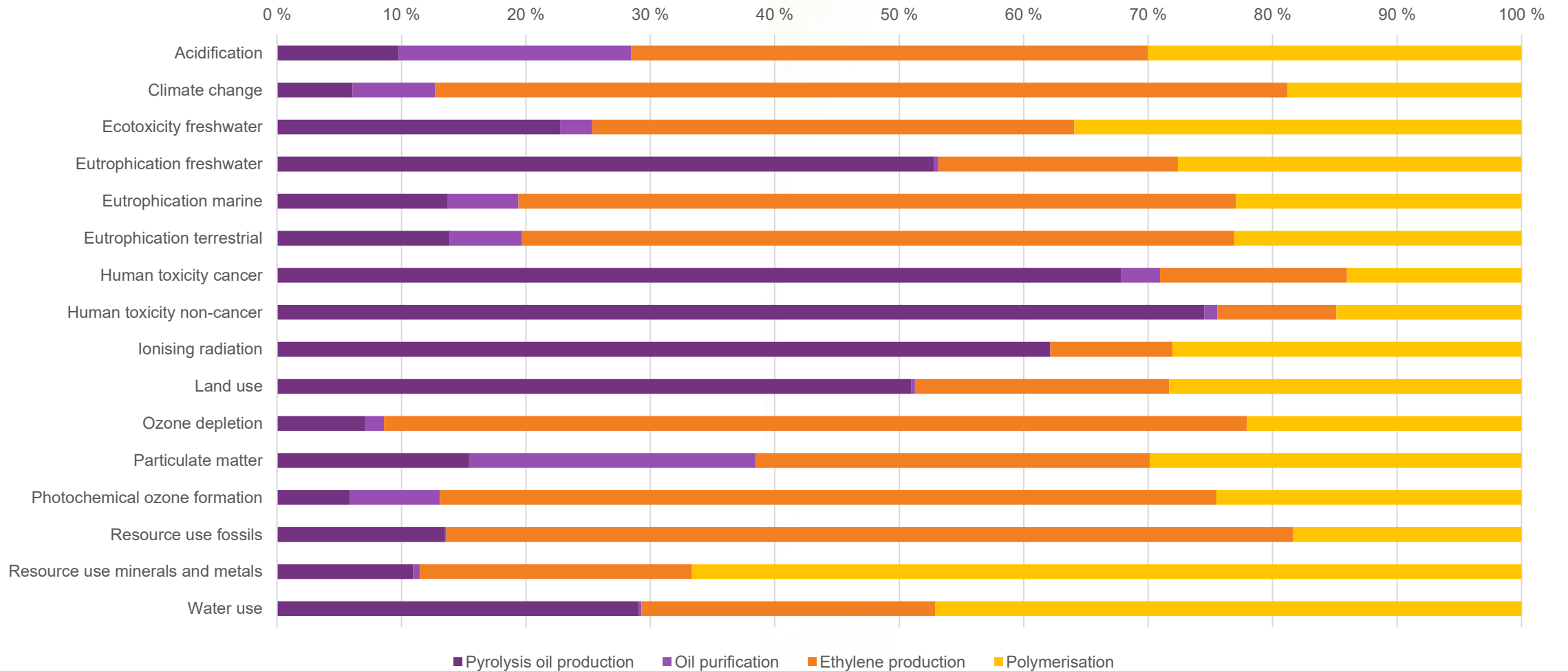
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Primary HDPE vs. chemical recycled HDPE



LCA results

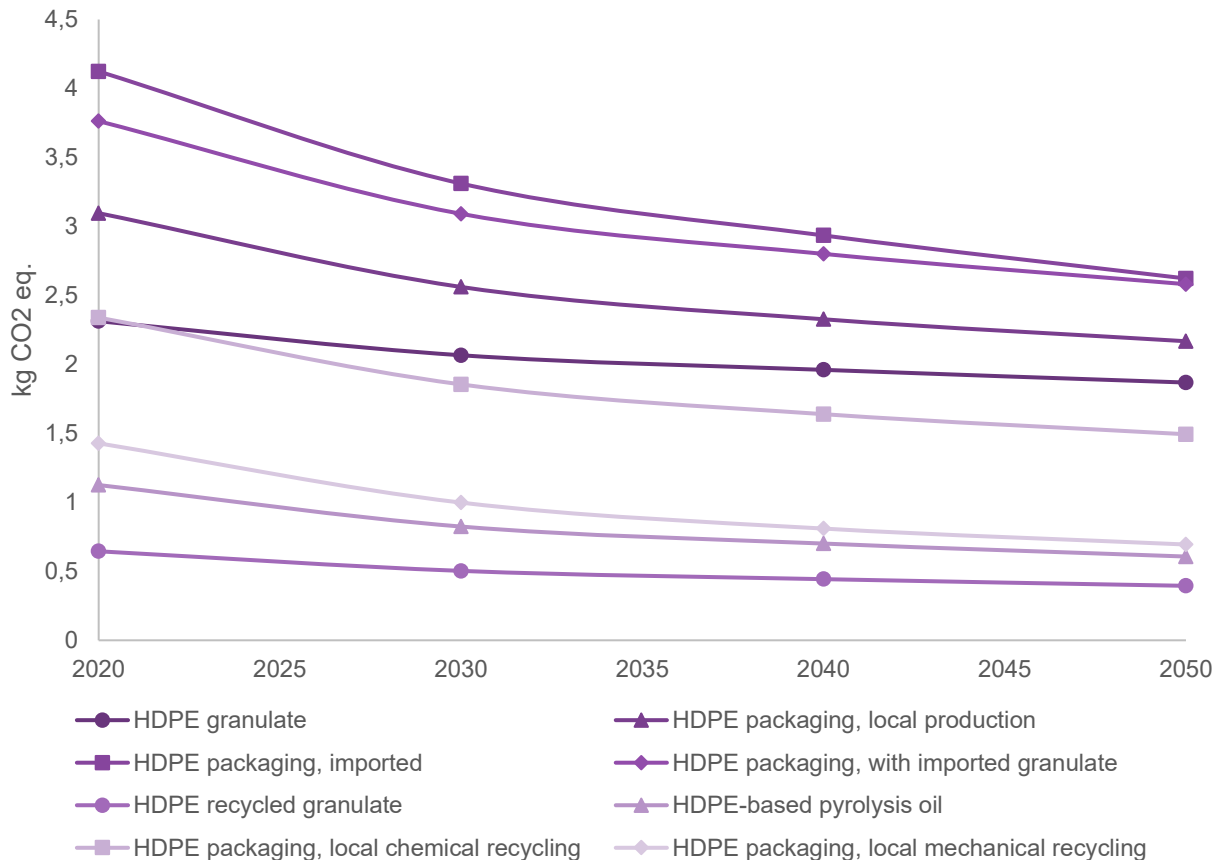
LCA hotspots of chemical recycling of HDPE



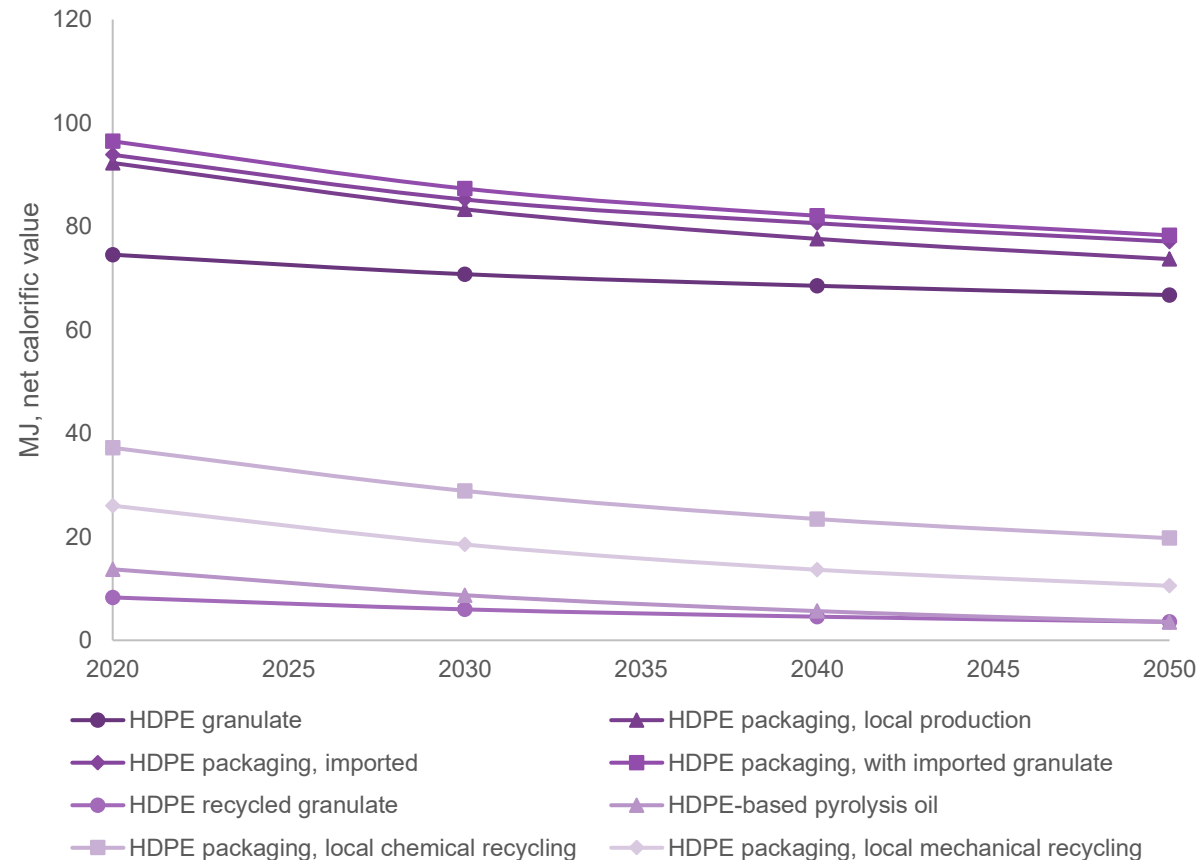


Prospective LCA results

Global Warming Potential



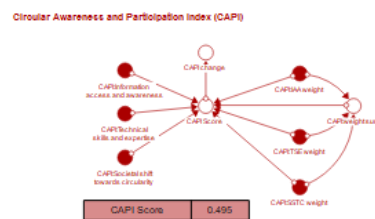
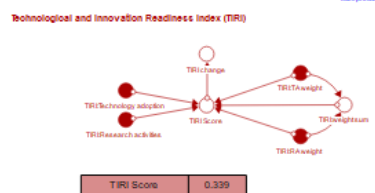
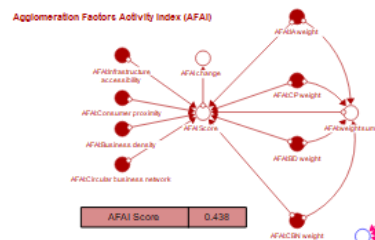
Resource use, fossil



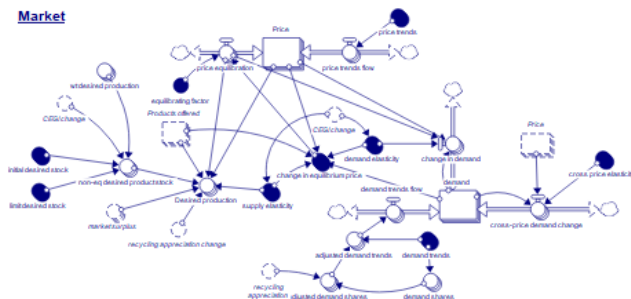


System dynamics model

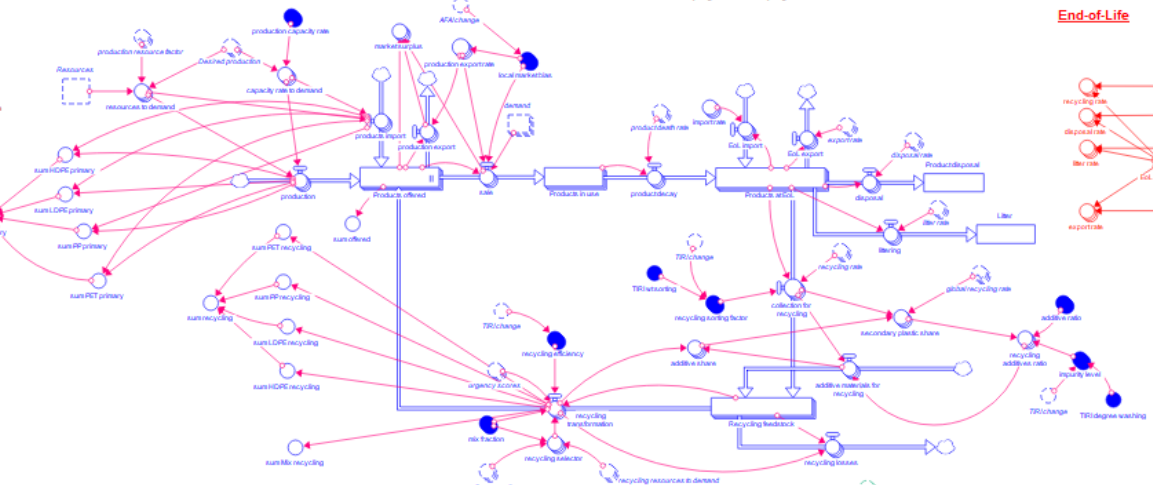
Context for Circular Economy



Market



Resources



End-of-Life



Environmental



Circular Economy Governance Index (CEGI)

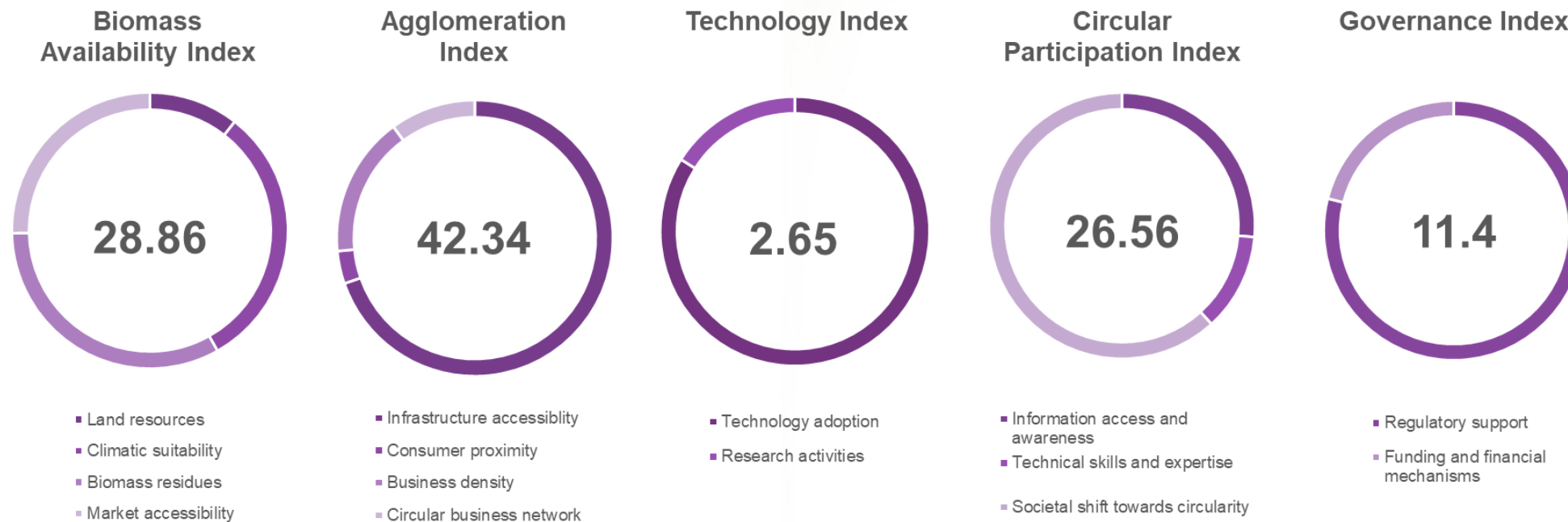


Circularity





Context score results



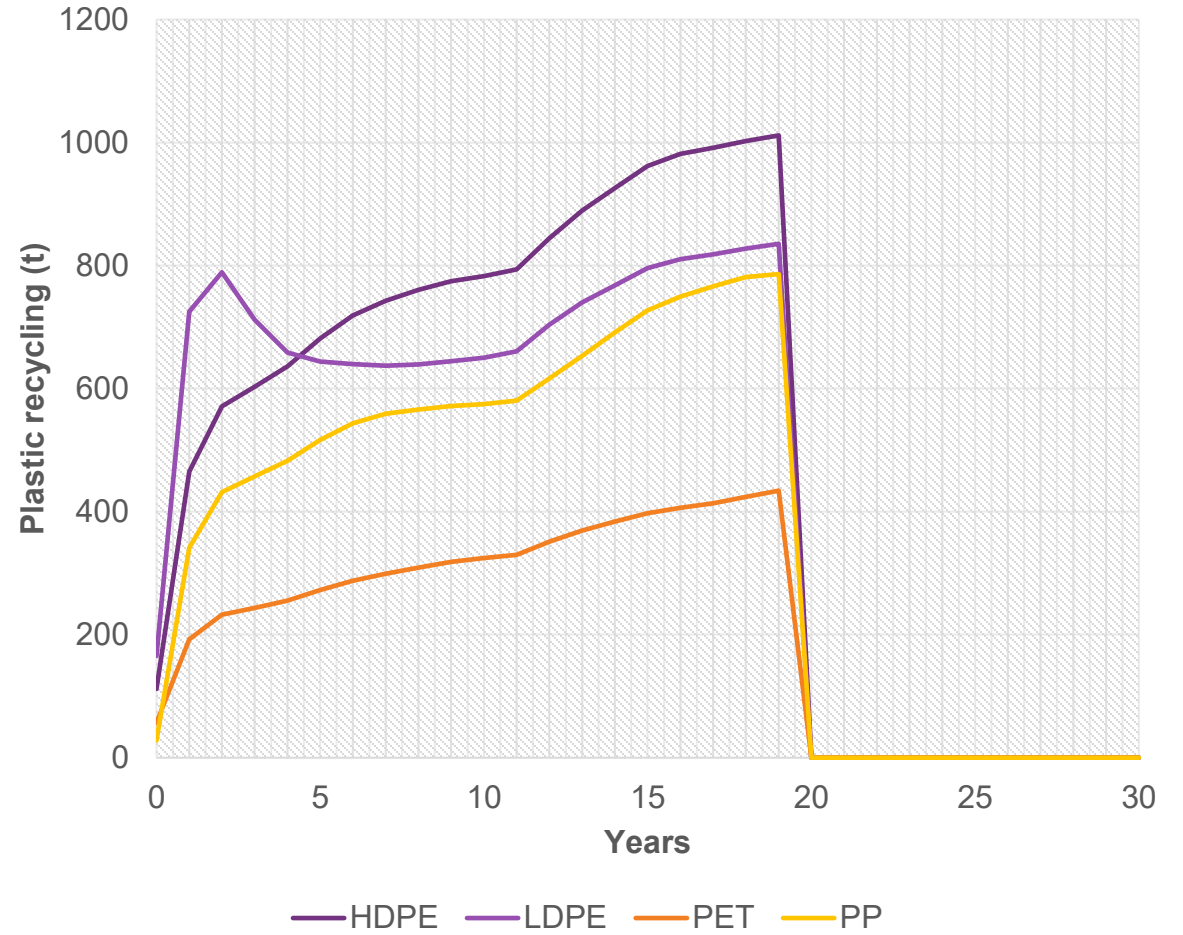
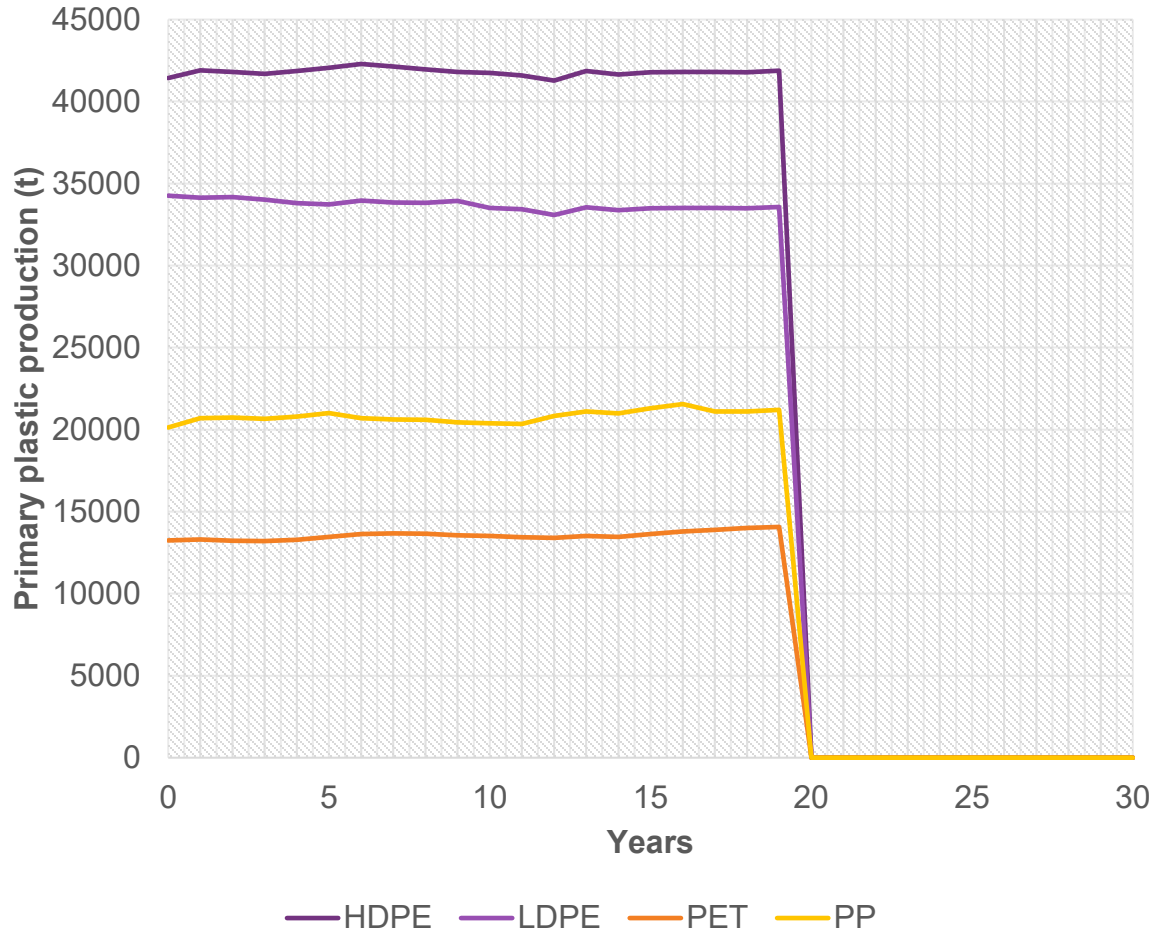


Assessed scenarios

1. Business as usual (BAU), where demand trends follow historic trends and there is only a minor increase of recycling rates over time.
2. Increasing chemical recycling (CR) capacity. This increases chemical recycling capacities of the region, thereby introducing new products to the market.
3. Increasing government support (GS) and funding, both for producers and consumers.
4. Increasing consumer awareness (CA) towards the benefits of waste prevention and plastic recycling.



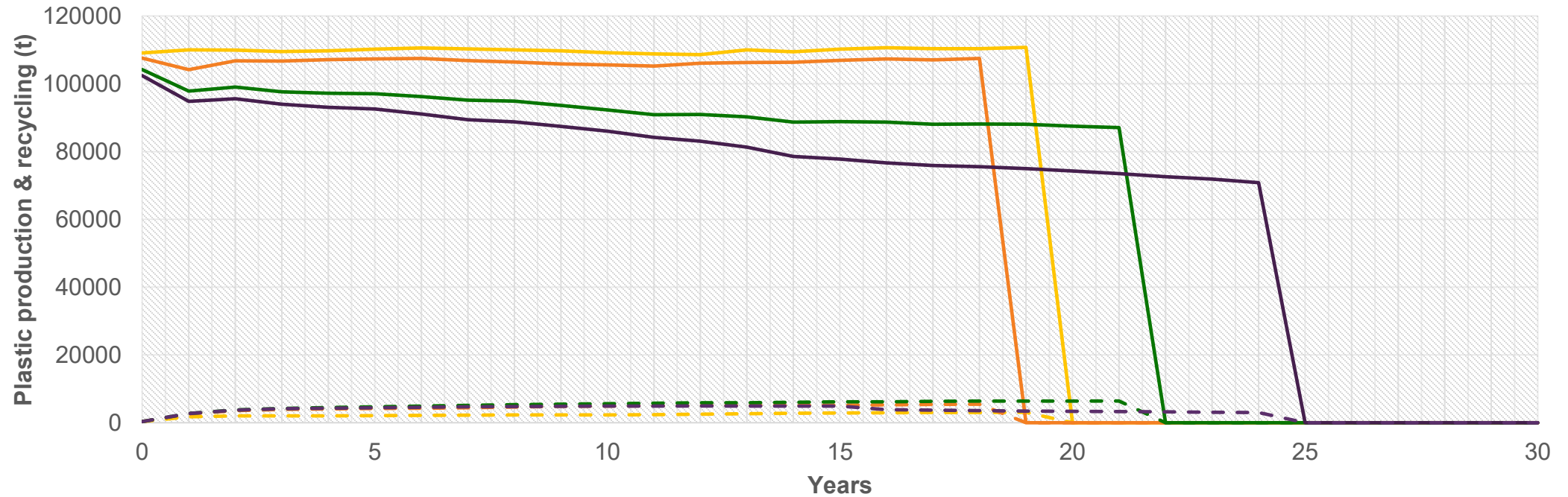
Change in material flows (BAU scenario)





Change in material flows

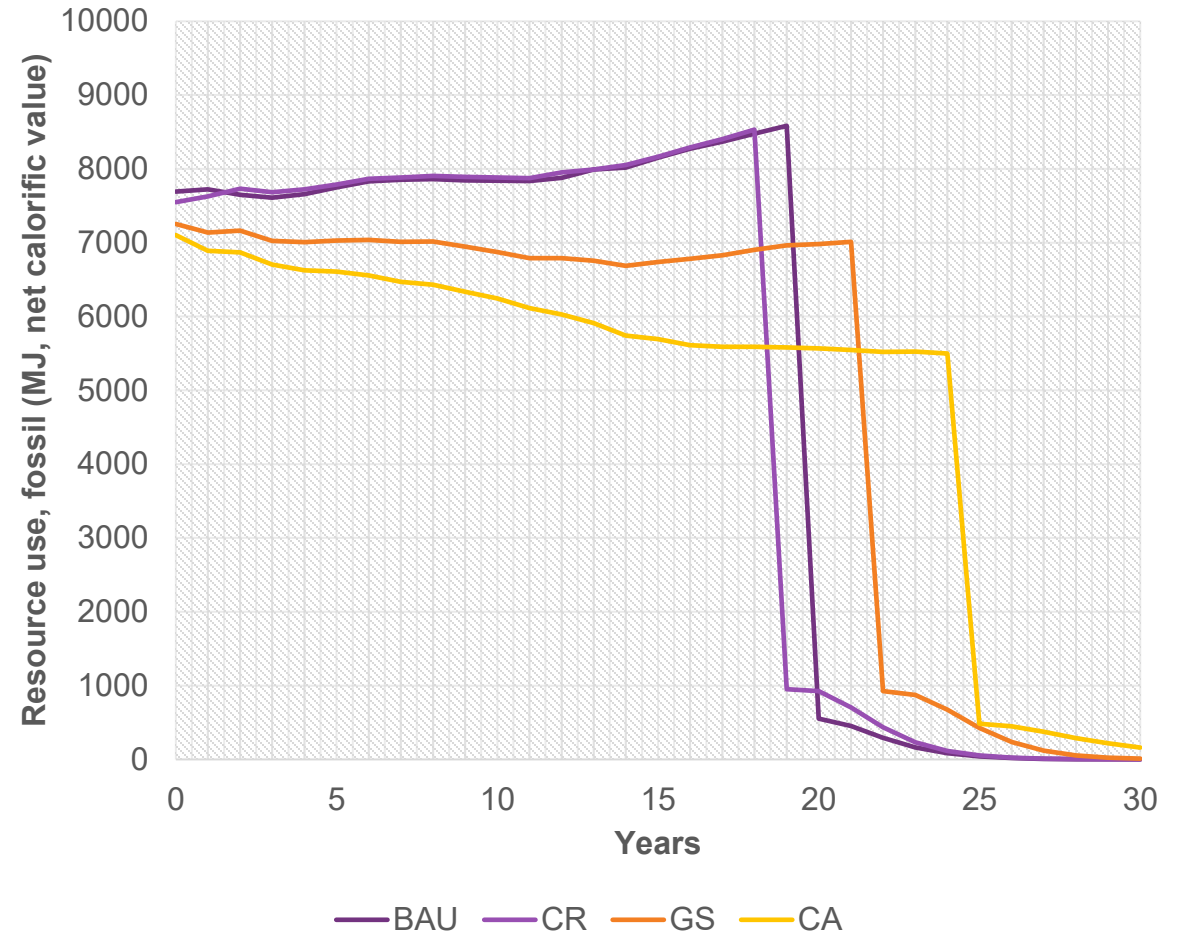
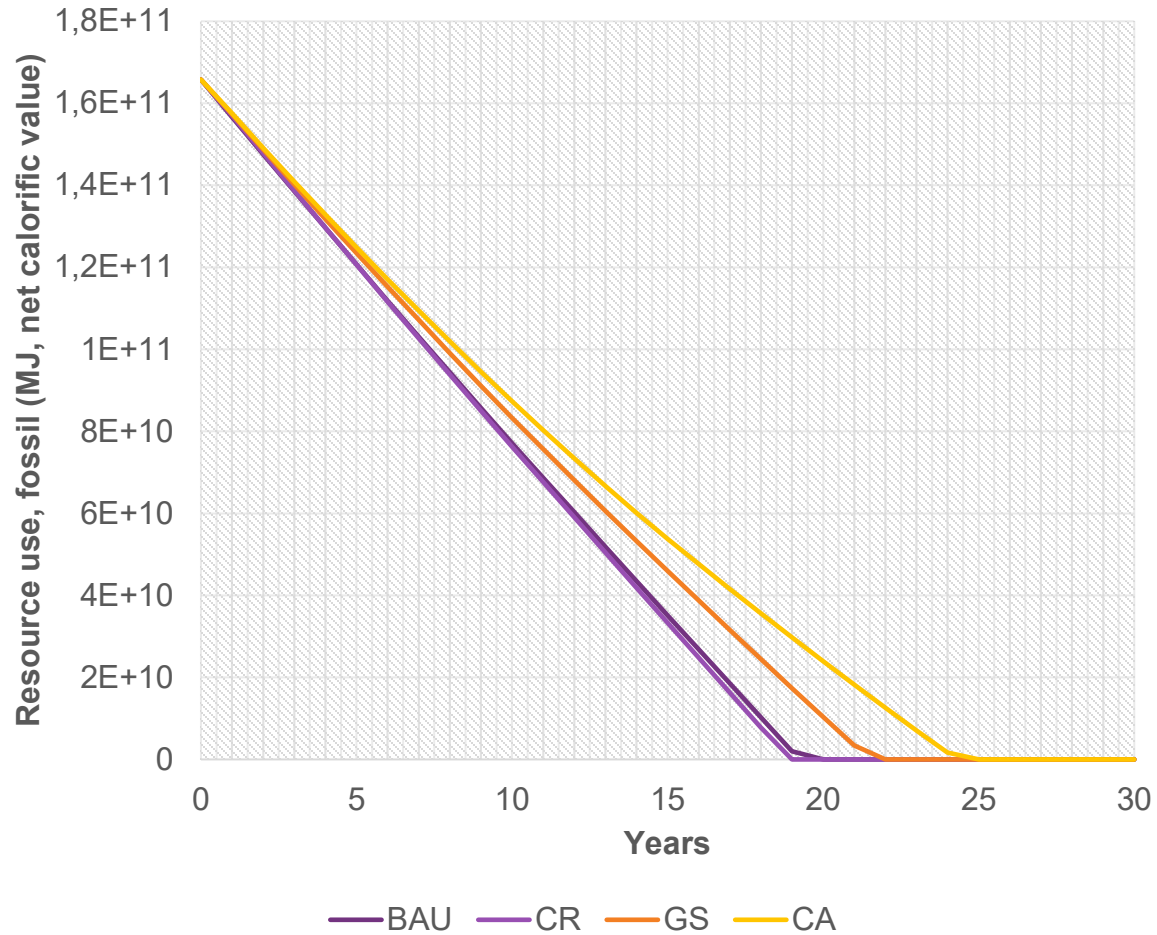
Total production and recycling across polymers for the different scenarios



Primary (BAU) Recycling (BAU) Primary (CR) Recycling (CR)
Primary (GS) Recycling (GS) Primary (CA) Recycling (CA)

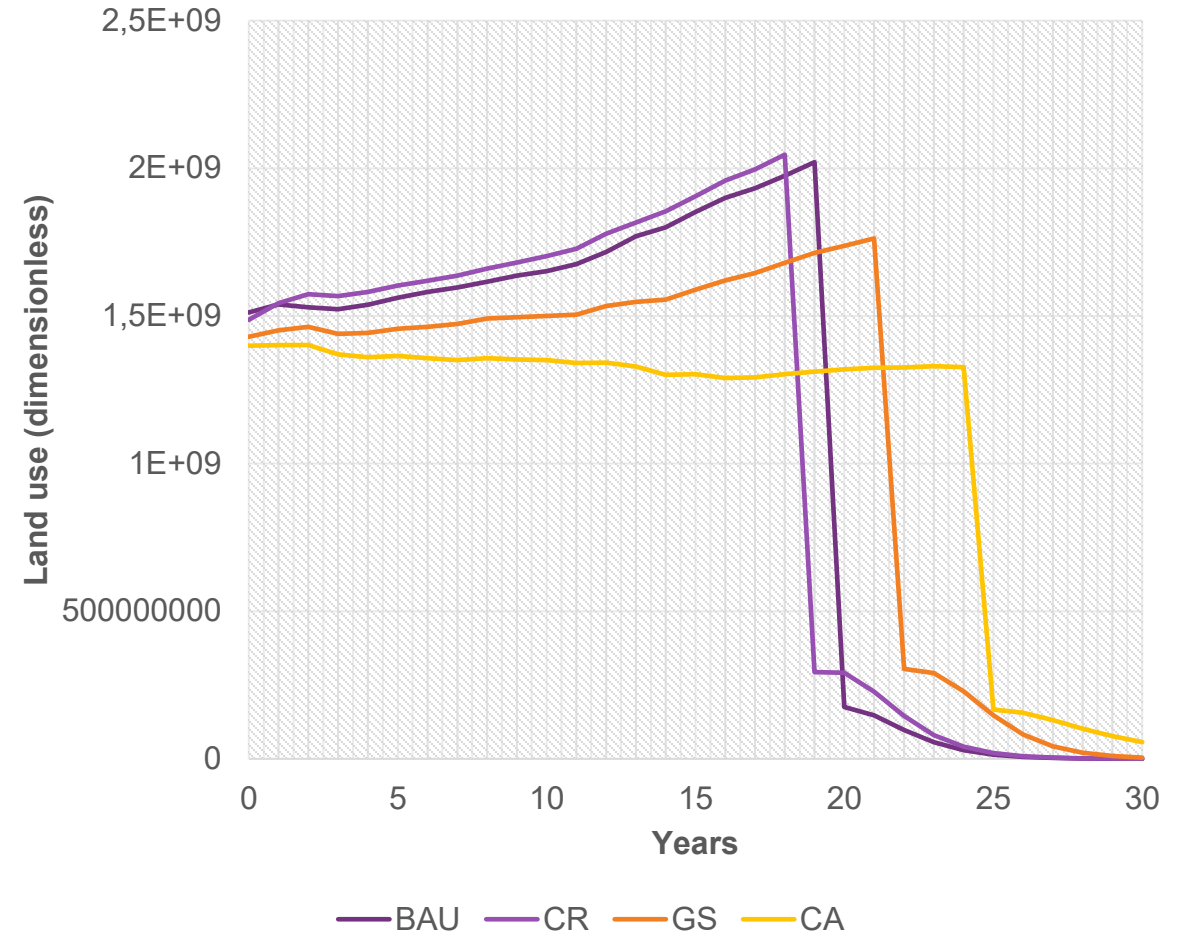
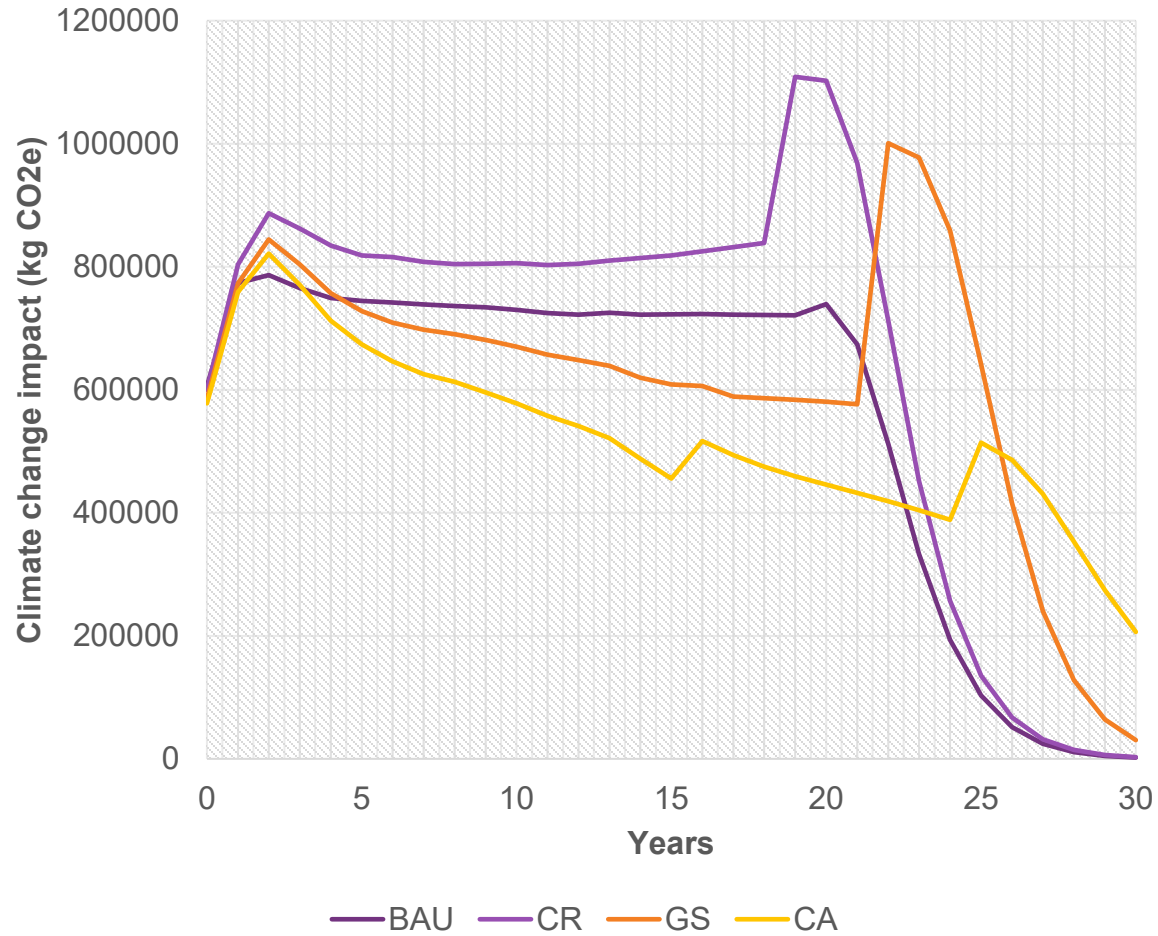


Regional impacts over time





Regional impacts over time





Conclusion

- LCA results show a decrease in impact for recycled plastics in several impact categories
- But chemical recycling is not necessarily better when considering the wider system
- Competes with mechanical recycling, resulting in a rebound effect, as more virgin additives are needed
- Improvements only with additional strategies, such as technological development or raising consumer awareness
- Yet, study is based on secondary data and validation of the model was not yet done



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Optimizing Mixed Plastic Feedstocks for High-Efficiency Recycling (13:40-14:00)

Stephan Kubowicz (Senior Scientist, SINTEF)

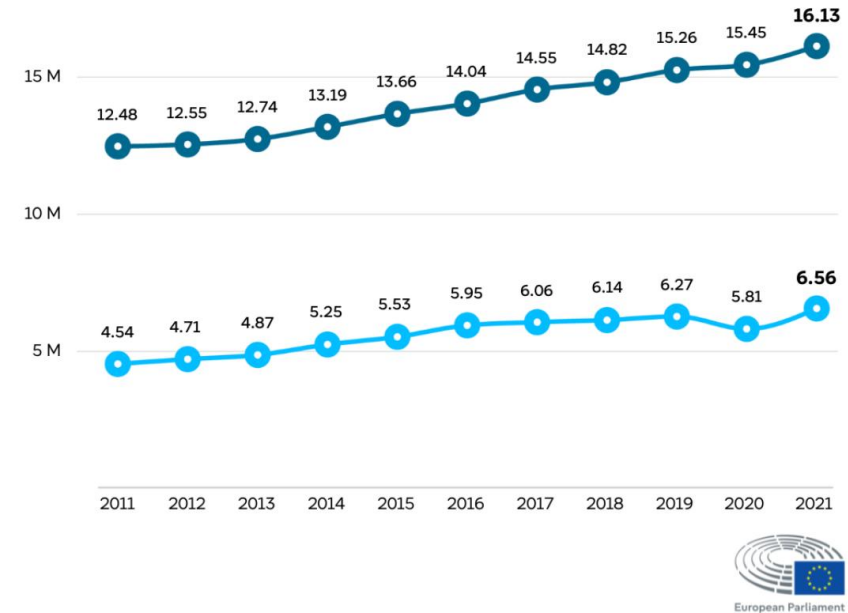
Ugur Kaya (Senior Scientist, VTT)



Why this matters?

- Plastic waste is growing; recycling rates remain low.
- Mixed plastic feedstocks are abundant, but difficult to recycle.
- 70% still landfilled or incinerated → value lost from circulation
- Efficient pre-treatment enables high-quality mechanical and chemical recycling.
- Policy push: 55% recycling target for plastic packaging by 2030

Plastic waste produced and recycled in the EU, in million tonnes (2011-2021)



Source: Eurostat [env_waspac] - most recent data available (2021)



What TREASoURcE Demonstrates

Regional Demonstrations Across Waste Streams

- Underutilized waste streams targeted:
 - Municipal mixed plastics (Norway, Finland)
 - Agricultural plastics (Finland)
 - Rigid plastics from households (Finland)
 - Reject streams after automated sorting (Finland)
 - Industrial waste plastics
- Development of upgraded mechanical & chemical recycling route
- Combined evaluation of collection → pre-treatment → recycling → product uptake

Project Regions: Norway & Finland



Key Waste Streams Demonstrated



Municipal Plastics

Mixed household
packaging & films



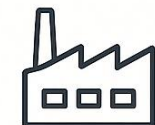
Agricultural Plastics

PE-based films,
silage wrap



Municipal Rigid Plastics

PP/HDPE items,
bulky waste



Industrial Plastics

Production scrap
& mixed polyolefins

AI generated



Plastic Waste Feedstocks in TREASoURcE

Nr:	Country of Origin	Company/ region	Plastics KVC	PCR/ PIR	Content of waste	Suitability for mechanical/ chemical recycling
1	Norway	Fredrikstad	Municipal	PCR	Mixed (Polyolefin-rich)	■
2	Finland	Tampere/ Pirkanmaa	Municipal	PCR	Rigid plastics, mixed, manually collected, sorted & pretreated (Polyolefin-rich)	● ■
3	Finland	Fortum	Municipal	PCR	Mixed reject after sorting (Polyolefin-rich)	■
4	Finland	Fortum	Municipal	PCR	Mixed (Polyolefin-rich)	■
5	Finland	Cleanplastics	Agricultural	PCR	Sorted high quality grade (LLDPE)	● ■
6	Finland	Cleanplastics	Agricultural	PCR	Mixed reject after sorting (Grade-1) (Polyolefin-rich)	■
7	Finland	Cleanplastics	Agricultural	PCR	Mixed reject after sorting (Grade-2) (Polyolefin-rich)	■
8	Finland	Individual farm	Agricultural	PCR	Manually collected, sorted and pretreated (PE mixture)	● ■
9	Norway	Hydrovolt	Industrial	PCR	EV battery cases PE-silicon, carbon black	Not suitable
10	Turkiye*	Farplas	Industrial	PIR	Post-industrial automotive plastic waste (PP-based)	●

● : Suitable for mechanical recycling

■ : Suitable for chemical recycling

PCR: Post-consumer recyclate

PIR: Post-industrial recyclate

*Comparable to universal polyolefin automotive plastic waste



The Challenge: Mixed & contaminated feedstocks

- Mixed plastics = many polymers + labels/inks + residues
- Contaminants reduce product quality and recycling yield
- Sorting gaps remain a major barrier (cost, limited technology availability)
- High-quality recycling requires:
 - Good collection practices
 - Efficient sorting and washing
 - Understanding polymer composition & impurities

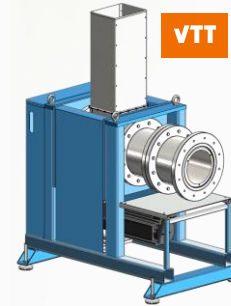


Mechanical recycling in TREASoURcE

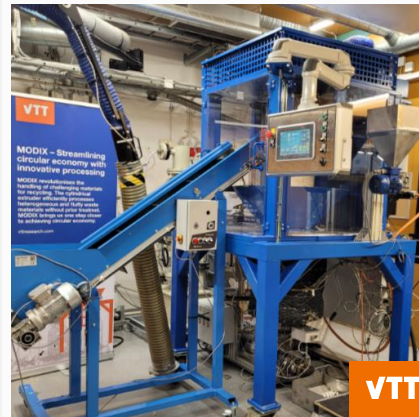
VAREX route (Mechanical recycling as the only recycling method)

In-line instrumented extrusion line for stabilizing and upgrading of the quality of recycled plastics:

- ✓ **Melting and filtering of recycled plastics**
- ✓ **In-line rheology measurement**
- ✓ **In-line spectroscopy:** Melt and gaseous phase (VOC) analysis by UV/VIS, NIR and FTIR
- ✓ **Smart process control** for rheology-controlled extrusion
- ✓ **Upgrading and homogenization** to reach to virgin-like material quality
- **Open piloting platform** for plastics R&D and development of new material formulations.



Scale-up



MODIX extruder route for plastic waste pre-treatment

- ✓ Compacting and homogenizing challenging feedstocks
- ✓ **At low-to-moderate processing temperatures:** Compacting and homogenizing of the feedstock.
- ✓ **At high temperatures:** Possible dehalogenation or removal of volatiles
- ✓ Heterogeneous feedstock:
 - Shredded plastic pieces (PP,PE,PS,HIPS etc.), w/ legacy additives & flame retardants
 - Foams (EPS etc.)
 - Bulky sheets, films
 - Textiles





Key Insight: Feedstock preparation drives recycling efficiency

Poor Input → Poor Output

- Agricultural plastics: heavy contamination but high PE/PP content
- Municipal rejects: 45–50% PE/PP, 5–20% PET, high ash
- Rigid plastics: mostly PP and HDPE - excellent recyclability

Cleaning, Sorting, Homogenizing → Plastics Become Valuable Feedstock

- Sorting (size, density, NIR sensor) reduces polymer variability
- Sink-float separates PE/PP from PET, PVC, stones, contaminants
- Washing removes soil, organic residues, labels



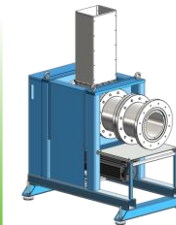
Demonstration results: Agricultural plastics

- High-quality PE-based agricultural plastics are excellent recycling feedstock.
- MODIX produced homogeneous material without pre-washing from mixed agro-plastic waste (rejects from mechanical recycling).
- VAREX improved tensile strength, modulus, and material homogeneity (well-collected/sorted, mono-polymer streams).
- Important practical insight: farm-level handling strongly affects recyclability (Sorting at source).

Mechanical recycling as pretreatment for chemical recycling (MODIX + Pyrolysis route)

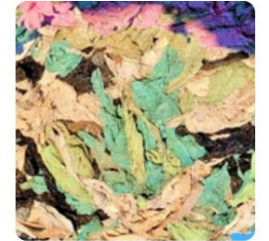


Homogenization with MODIX



Pyrolysis process

Mechanical recycling as only recycling method (VAREX route)



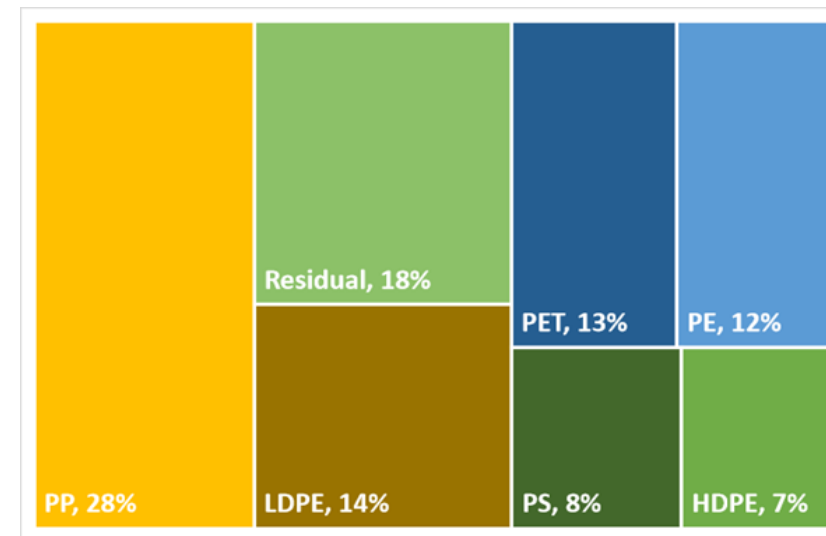
New applications



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Demonstration Results: Municipal Plastics (Norway & Finland)

- Municipal waste streams contain 45–70% polyolefins that is valuable for recycling.
- Manual/automated sorting revealed large shares of recyclable HDPE, PP, PS, PET.
- Density separation (float–sink) produced clean PE-PP polyolefin fractions suitable for:
 - Mechanical recycling
 - Chemical recycling (pyrolysis)
- Post-treatment mechanical properties close to virgin material.



HDPE



PP



PS



PET

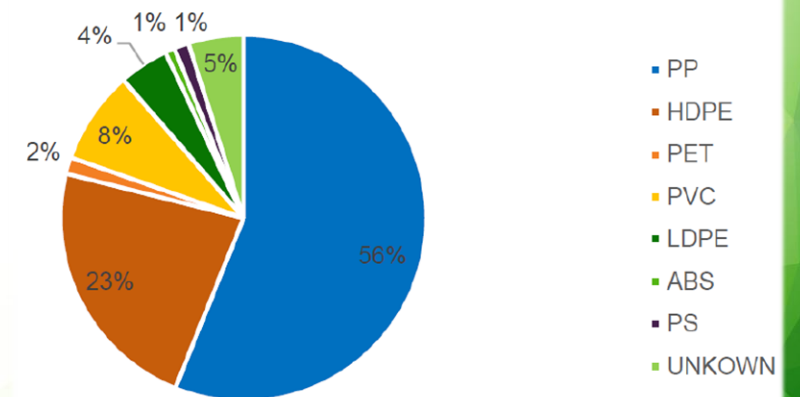


Rigid Plastics: A Missed Opportunity

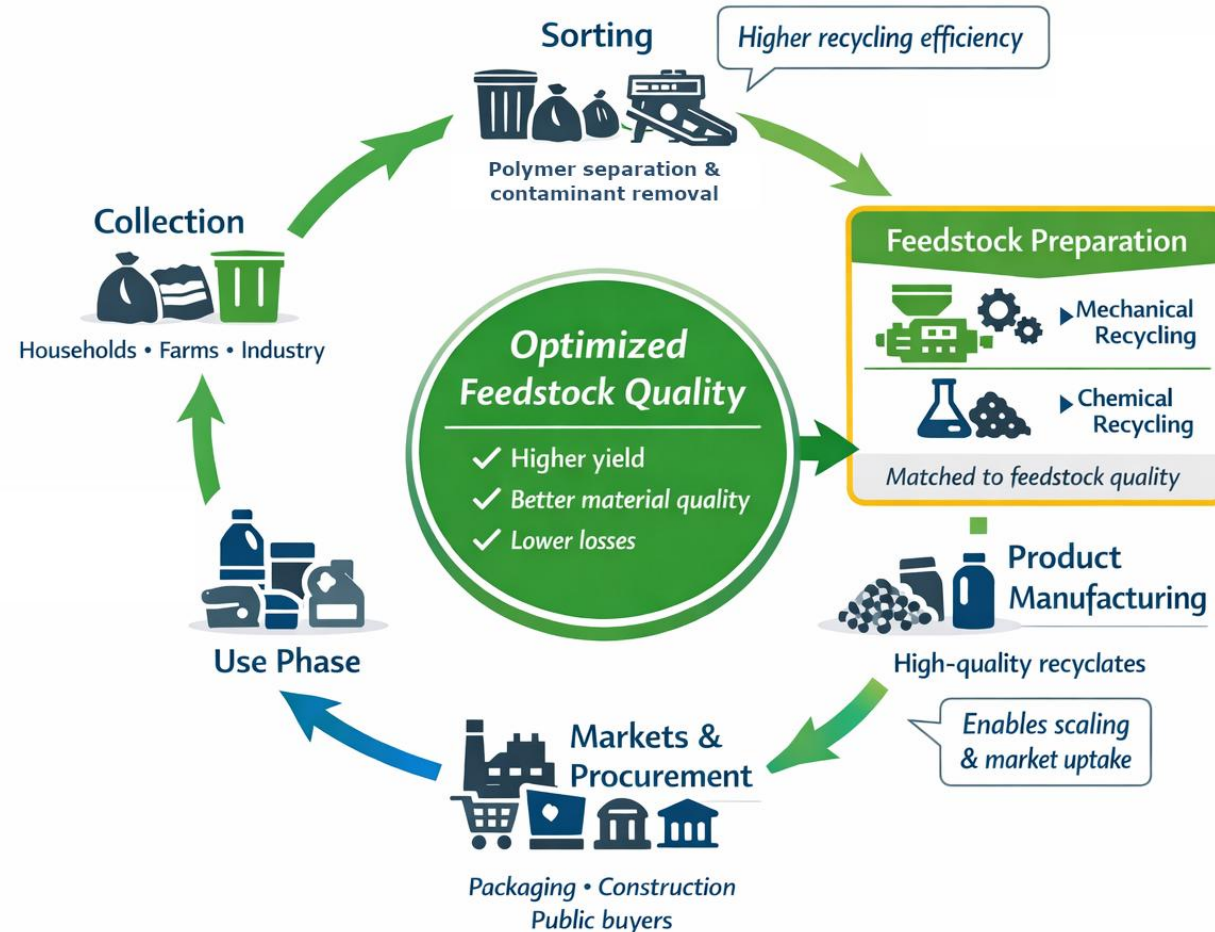
- Co-operation work between **Tampere University of Applied Sciences (TAMK)**, **Ekokumppanit** and **Pirkanmaa Waste Management Company**
- Rigid plastics recycling rates extremely low (<5% in Finland). PCR municipal rigid plastics (e.g., pipes, furniture, containers) are not systematically recycled in Finland.
- 1800 kg of plastic waste collected, manually sorted and shredded.
- TREASoURcE analyses show:
 - Stream is **dominated by PP and HDPE**. **~85%** of the composition is Polyolefins and PS which are **suitable for chemical recycling** as the main fraction.
 - Very low contamination by other polymers
 - High suitability for mechanical & chemical recycling
- Barrier: lack of dedicated collection & sorting solutions.
- For industrial scale, sorting stages to remove PET, PVC, ABS and others from the main fraction.



Weight of plastic types



Circular Value Chain Enabled by Feedstock Optimization





Scaling Potential & Practical Implications

What regions can take away?

- Mixed waste streams become usable with minimal pre-treatment.
- Mechanical recycling can tackle well-sorted and cleaned plastic waste feedstock.
- Chemical recycling has the potential to revalorize waste that mechanical recycling can not.
- Complementary usage of mechanical & chemical recycling increases overall recycling rate.
- Agricultural and municipal polyolefin-rich waste (flexible & rigid) are big potentials as plastic waste feedstock.
- Integrated systems can outperform standalone mechanical recycling.
- Regions can create new local markets for recycled feedstock.
- Subsidies at regions to facilitate ownership of the plastic waste.





Actionable Recommendations

For Policy Makers

- Harmonize collection systems (especially rigid plastics & films).
- Establish standards for chemical recycling inputs and pyrolysis oil.
- Strengthen EPR to incentivize design-for-recycling.

For Industry

- Adopt modular pre-treatment to expand feedstock range.
- Implement in-line quality control.
- Collaborate on specification-setting for mixed plastic feedstocks.

For Cities & Regions

- Improve local sorting infrastructure; support community collection events.
- Introduce dedicated rigid-plastic collection schemes.
- Use procurement criteria to boost recycled plastic markets.

For Researchers

- Advance detection, sorting, and digital traceability tools.
- Develop harmonized testing protocols for pyrolysis feedstock & oil.

For Civil Society

- Raise awareness of correct storage, cleaning, and sorting practices.
- Promote reuse and repair of rigid plastic items.



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Final remarks

- Mixed Plastics Are Not Waste; They're Feedstock
- With proper preparation, even "low-quality" plastics become valuable
- Smart collection and pre-treatment offers high-value circular pathways
- Regions can replicate these solutions today with existing technologies
- TREASoURcE provides a blueprint for scaling circular plastics systems



TREASoURcE

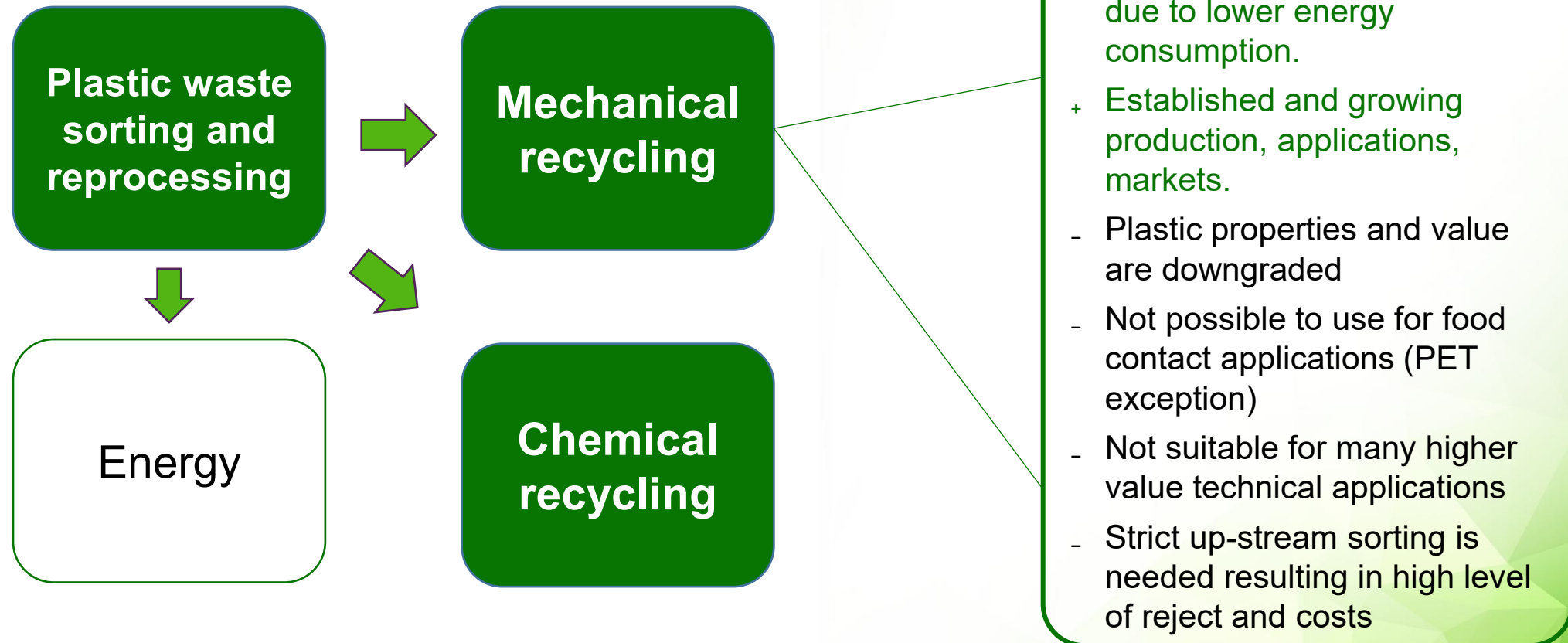
Chemical recycling for closing the loop of plastic waste (14:15-14:35)

Christian Lindfors (Senior Scientist, VTT)

Juha Lehtonen (Research Professor, VTT)



Mechanical recycling - preferred route with limitations



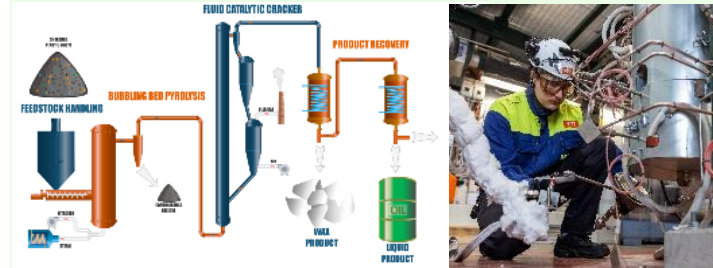
Pyrolysis-based recycling of plastics covers some essential process steps

PLASTICS WITHOUT RECYCLING PROCESSES



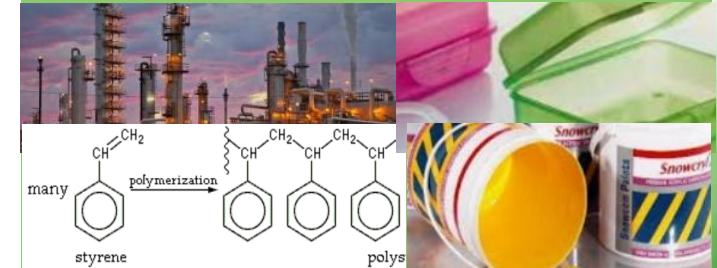
- **Consumer and industrial mixed plastics**, rejects of mechanical recycling, multi-layer plastics, composites
- **Feedstock pre-treatment** - removal of halogens, harmful polymers, additives, biowaste and other dirt.

ADVANCED PYROLYSIS TECHNOLOGIES



- **Thermal/Catalytic fluid-bed fast pyrolysis**
- Maximized yield and removal of impurities in pyrolysis.
- Minimized CO₂ footprint and energy consumption.
- Direct production of monomers.
- Pilot plant, scale-up, modelling.

HIGH - QUALITY SUSTAINABLE PRODUCTS

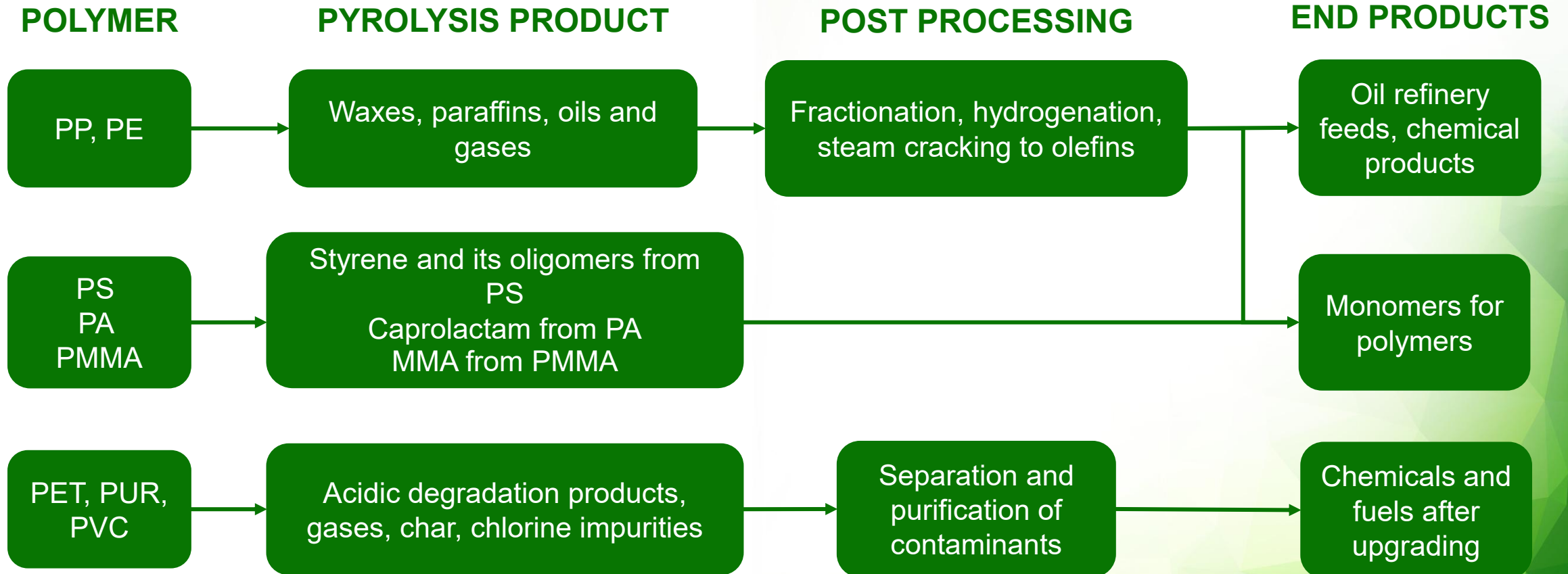


- **Pyrolysis product upgrading**, fractionation, heteroatom removals, hydrogenations, catalyst development.
- Steam cracker feeds
- Monomers, chemicals, e.g. BTX

Feedstock-Process-Product relation



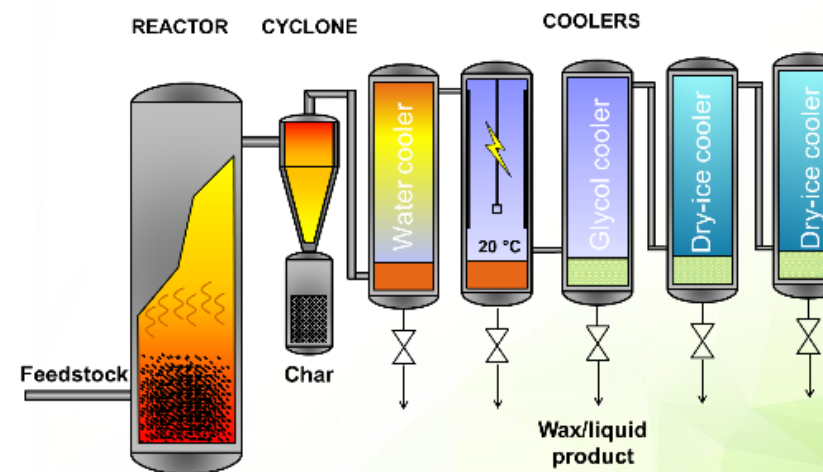
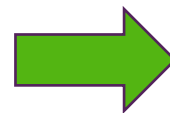
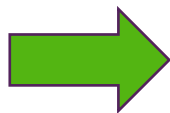
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Thermal and catalytic pyrolysis of agricultural plastic waste

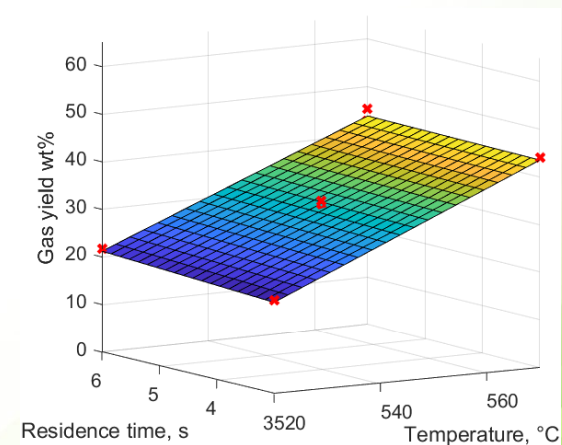
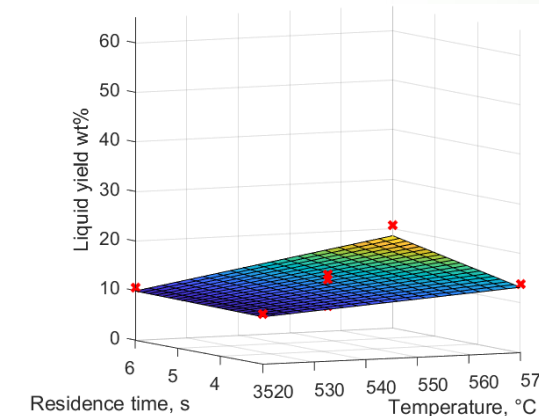
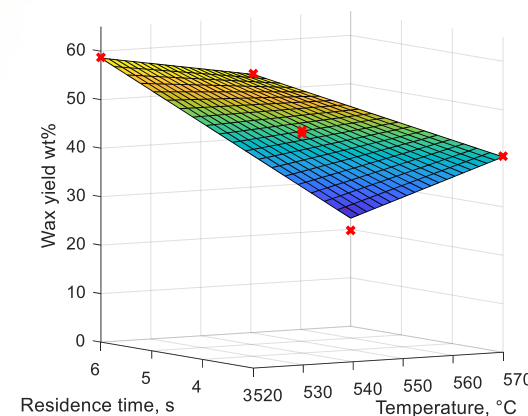
- Feedstock had been sorted during collection
- Small amount of PET is removed during washing
- Major plastic processed is LLDPE (Linear low-density polyethylene), but small amount of PE and PP are also included in the feedstock





Thermal pyrolysis of agricultural plastic waste into naphtha for steam cracker feed

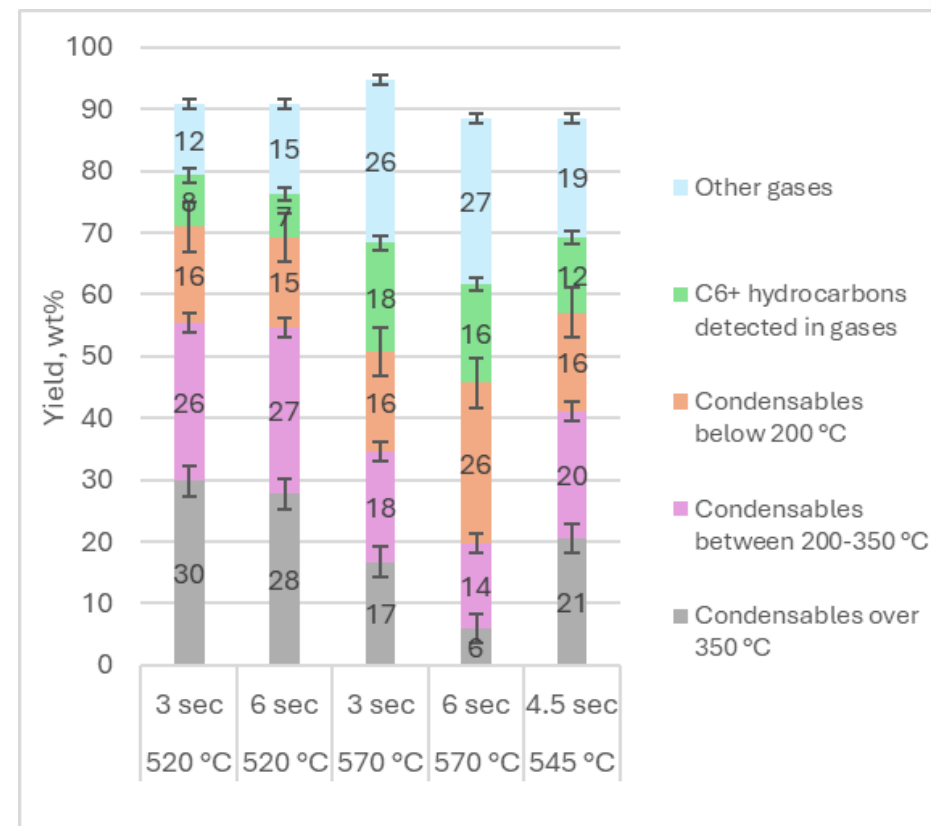
- Optimize the conditions for:
 - Liquid yield (BP < 350 °C)
 - Paraffin content in the oil
 - Reduce the hydrocarbon length
 - Temperature was varied from 520-570 °C and residence time from 3-6 s
- Smallest differences in liquid yield
- RT and T both has effect on wax yield. Higer RT and T decrease the wax yield
- Gas yield mainly dependent on T. RT has no significant effect.





Thermal pyrolysis of agricultural plastic waste into naphtha for steam cracker feed

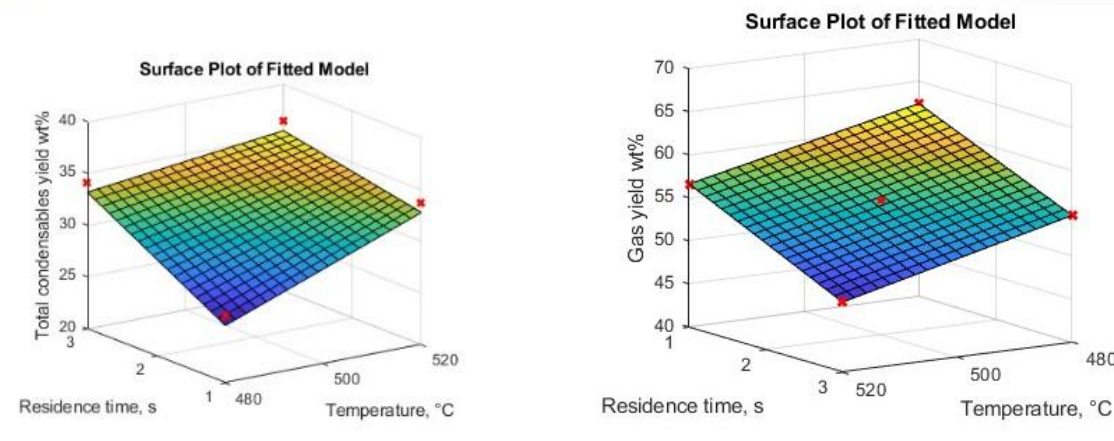
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-
- Smallest differences in liquid yield
 - RT and T both has effect on wax yield. Higer RT and T decrease the wax yield
 - Gas yield mainly dependent on T. RT has no significant effect.
 - Highest yield of target product at 570 °C and 6 s residence time





Catalytic pyrolysis of agricultural plastic waste into aromatics and olefins

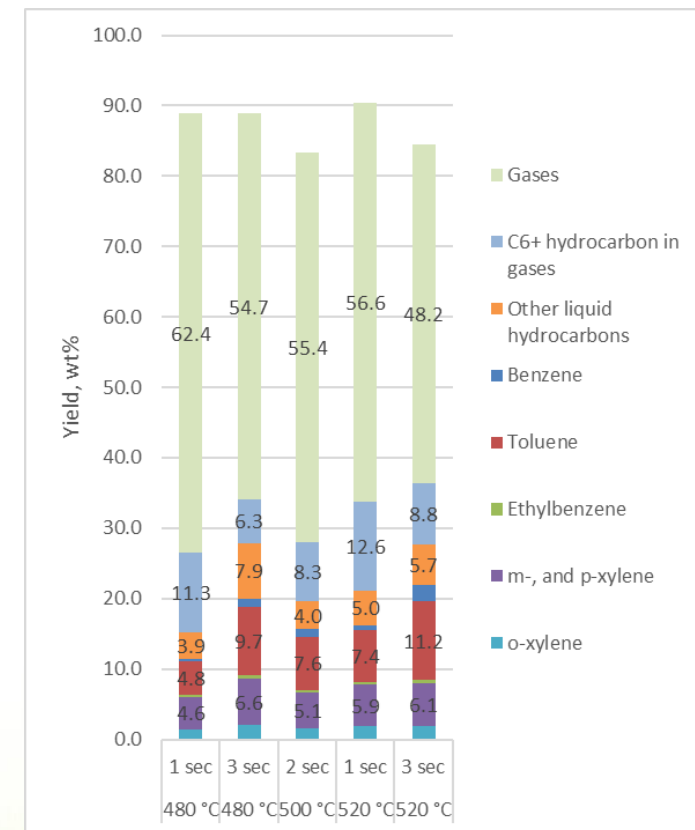
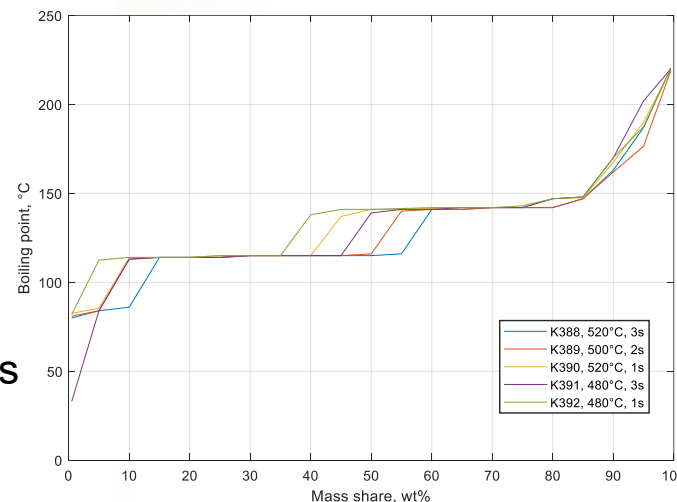
- Maximize the yield of BTX production by:
 - Varying the temperature from 480-520 °C
 - Residence time from 1-3 s
 - Utilizing a highly acidic HZSM-5 catalyst
 - SiO₂/Al₂O₃ ratio of 23
 - Surface area of 425 m²/g
- Gas yield increased, while yield of condensables decreased
- No wax formation
- Highest liquid yield with highest temperature and longest residence time





Catalytic pyrolysis of agricultural plastic waste into aromatics and olefins

- Maximize the yield of BTX production by:
 - Varying the temperature from 480-520 °C
 - Residence time from 1-3 s
 - Utilizing a highly acidic HZSM-5 catalyst
 - SiO₂/Al₂O₃ ratio of 23
 - Surface area of 425 m²/g
- Gas yield increased, while yield of condensables decreased
- No wax formation
- Highest liquid yield with highest temperature and longest residence time
- BP of product < 225 °C
- Highest BTX yield at 520 °C and 3 s residence time





Subtask 3.2.3. End product development upgrading



Objective: Hydrotreating the Municipal waste plastic pyrolysis oil with a hydrotreatment catalyst and H₂ at mid-high pressures to reach e.g., steam cracker specs. The catalyst should be active in:

- Hydrogenation of unsaturated compounds (primarily olefins and aromatics)
- Removal of impurities such as Cl, N, O and S.

Catalyst selection:



- Self-made **Ni-Pd/Activated carbon** catalyst (developed in previous project):
 - Good saturation of olefins and removal of Cl from PPOs
 - Poor saturation of aromatics, moderate removal of N
- Commercial **1%Pt/γ-Al₂O₃**
 - Should perform better in the saturation of aromatics

Experimental plan:



- Evaluate commercial and self-made catalysts under identical hydrotreatment conditions for upgrading municipal plastic pyrolysis oil from PolyFuels to steam cracker feed quality.
- Study the use of guard bed (Cl removal) before HT catalyst bed

Subtask 3.2.3 - End product development upgrading



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Pyrolysis oil production from Fredrikstad municipality hand sorted waste plastics.

1. Fredrikstad municipal plastic waste was initially hand-sorted, revealing a heterogeneous mixture of PE, PP, PET, PS, films, plastic bags (Folie), and other mixed plastic fractions (Fig. 1).
2. Table 1 presents the wt% composition of the individual polymers prior to pyrolysis oil production for upgrading studies



Table 1: wt% composition of Fredrikstad municipal plastic waste.

	Bag 1 Kg	%	Bag 2 Kg	%	Bag 3 Kg	%	Average %
Folie	0,76	20	0,77	22	0,88	28	23,4
Mixed	0,95	25	1,09	31	0,8	26	27,2
Pet	0,56	15	0,38	11	0,37	12	12,4
PP	0,95	25	0,3	9	0,24	8	13,7
PS	0,2	5	0,25	7	0,28	9	7,1
Feil	0	0	0,2	6	0,23	7	4,4
PE	0,42	11	0,53	15	0,3	10	11,9
Total	3,84	100	3,52	100	3,1	100	100,0

Sorted by hand based on the recycling number labeled at the object.

Total amount used in the tests 19,2 kg

Hand sorted 10,5 kg

Fig 1: Hand sorted plastics from Fredrikstad Municipal plastic waste

Subtask 3.2.3. End product development upgrading



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Feedstock composition before hydrotreatment

1. The produced oil from Fredrikstad municipal waste plastic was clearly consisted of three distinct phases as shown in the Fig 2.

Around 5 L of oily phase was separated from these phases by using centrifugation process.

2. Before hydrotreating the oil, it is critical to know the contamination levels and also the composition of hydrocarbon of this feedstock.
3. Compositional analysis of the oil by GC-MS (Fig 3), showed the presence of about 29 wt% alkenes, 7.8 wt% aromatics and around 15 wt% alkanes. On the otherhand, CIC analysis indicated the presence of S (31 ppm), Cl (762 ppm) and Br (<1,1 ppm).



Fig 2: Feedstock received for catalytic hydrotreatment

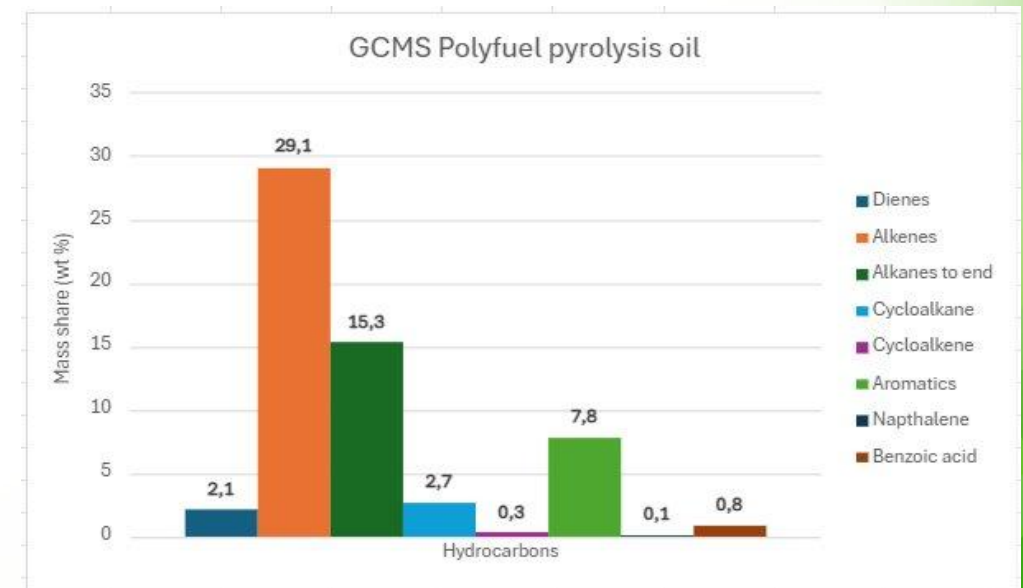


Fig 3: Composition of Municipal waste plastics pyrolysis oil produced by PolyFuels.

Subtask 3.2.3 - End product development upgrading

Hydrotreatment experimental plan

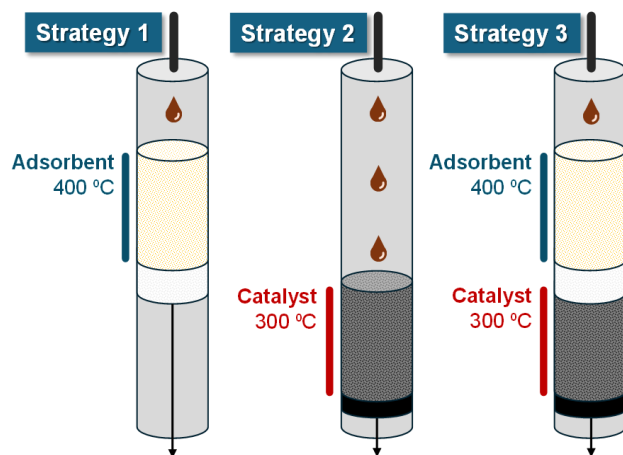
Run	Catalyst	Time, h)	T, °C	P, bar	PPO flowrate, g/h
#1	Pt/Al₂O₃ (commercial)	6	300	80	15
#2	Ni-Pd/activated carbon (AC) (made at VTT)	6	300	80	15
#3	With adsorbent before Ni-Pd/AC catalyst	6	400 (adsorbent), 300 (catalyst)	80	15
#4	With adsorbent before Ni-Pd/AC catalyst	18	400 (adsorbent), 300 (catalyst)	80	15
#5	Only adsorbent, no catalyst	10-12	400	80	15

- **H₂ flow rate** = 7.5 L/h; **mass of catalyst**: 5 g.
- **Adsorbent composition**: Na₂CO₃/Al₂O₃

Subtask 3.2.3 - End product development upgrading

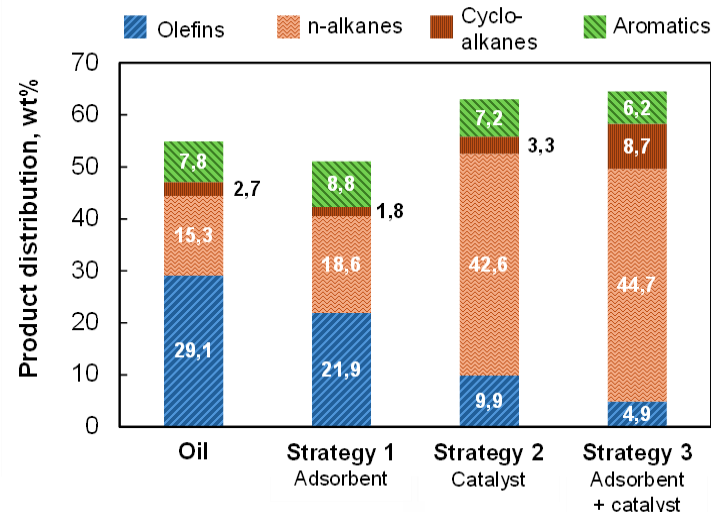
Process level strategies for PPO upgrading

3 different reactor configurations with adsorbent and/or hydrotreatment catalyst

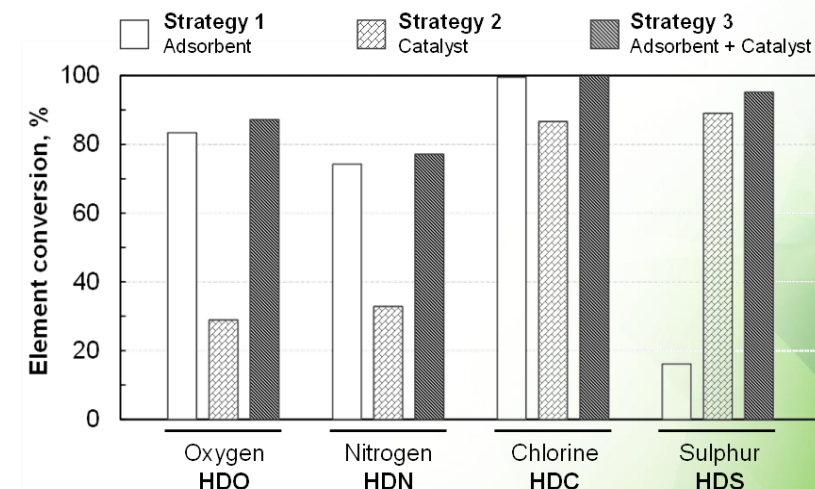


Catalyst: Ni-Pd/AC
Guard bed: Na₂CO₃/Al₂O₃

Product distribution after 6 h



Removal of heteroatoms (O, N, Cl, S)



- **Strategy 3** (adsorbent + Ni-Pd/AC catalyst) substantially improved the oil composition through extensive olefin hydrogenation (and partially aromatics) and efficient removal of heteroatoms (HDC > HDS > HDO > HDN).
- **Strategy 1** (only adsorbent) effective HDC, HDO and HDN (poor hydrogenation and HDS), while **Strategy 2** (only catalyst) achieved substantial olefin hydrogenation and efficient HDS and HDC, poor HDN and HDO

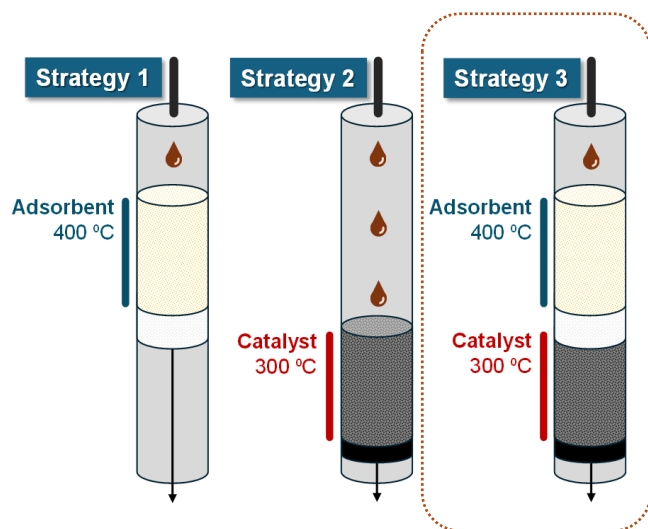
Subtask 3.2.3 - End product development upgrading

Stability test with Strategy 3 (adsorbent + catalyst)



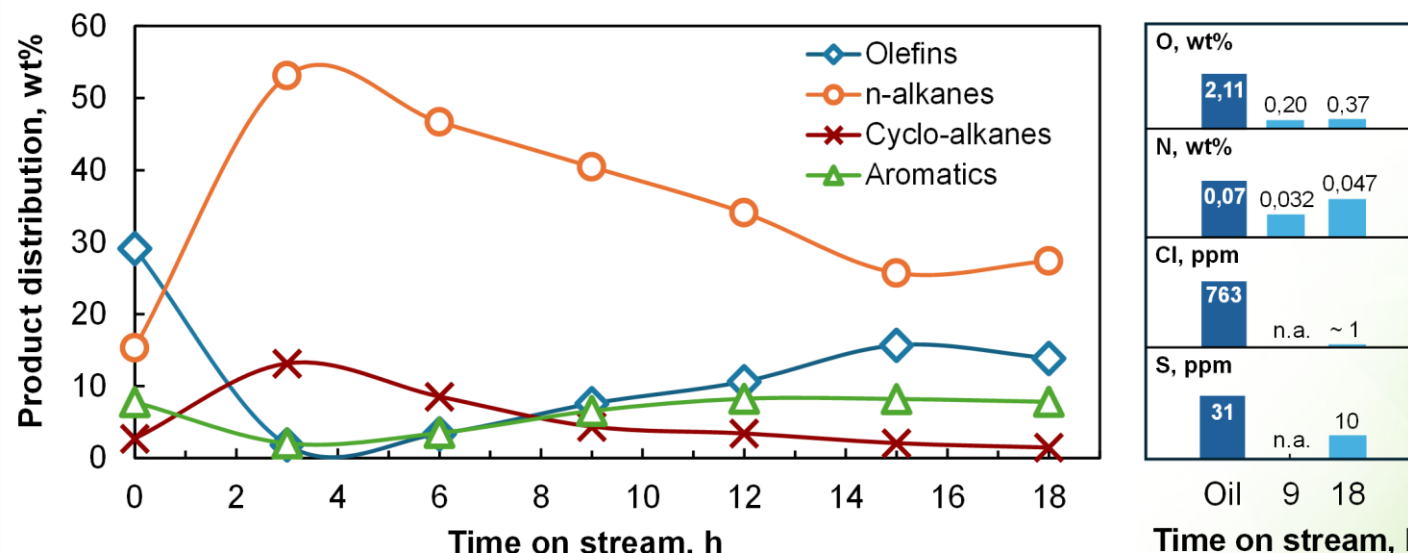
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Implementing Strategy 3



Catalyst: Ni-Pd/AC
Guard bed: Na₂CO₃/Al₂O₃

Evolution of hydrotreated oil and heteroatoms with time-on-stream



- The **adsorbent-catalyst** tandem exhibited **high initial hydrogenation activity** toward olefins and also aromatics, followed by a gradual decline in activity with time-on-stream.
- By the end of the experiment, **HDC and HDO remain substantially high/active**, while HDN (adsorbent-driven) and HDS (catalyst-driven) show moderate loss of activity.
- Overall, the tandem system has demonstrated promising performance in oil quality upgrading, however, much longer runs are needed in coming projects to verify the performance and a strategy how to regenerate the adsorbent needs to be developed.



Subtask 3.2.3 - End product development upgrading

Conclusion

- ❖ The guard bed - hydrotreating catalyst tandem **significantly upgraded the composition/quality of the plastic pyrolysis oil** (substantial reduction of olefins and, O, N, Cl and S). Given the stability limitations of the system, optimal bed volume and bed regeneration must be evaluated to ensure stable continuous operation.
- ❖ Strategy 1 (guard bed alone) effectively removed chlorine, oxygen, and nitrogen, while Strategy 2 (catalyst alone) achieved substantial hydrogenation and efficient sulphur removal.
- ❖ Strategy 3 (guard bed + hydrotreating catalyst) substantially improved the oil composition through extensive olefin hydrogenation and efficient removal of heteroatoms (O, N) and contaminants (Cl, S).
- ❖ Stability of the guard bed/catalyst tandem showed that the hydrogenation of olefins and aromatics reached a maximum at 3 h TOS and then slowly declined.
- ❖ By the end of the stability experiment, concentrations of O, N, Cl, and S were substantially lower than in the original oil, indicating moderate test activity of the tandem system.

Key take away:

Given the stability limitations of the system, bed regeneration must be evaluated to ensure stable continuous operation.



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Panel Discussion: Chemical recycling of the hard to recycle feedstocks (14:35-15:00)

Moderator: Juha Lehtonen (Research Professor, VTT)