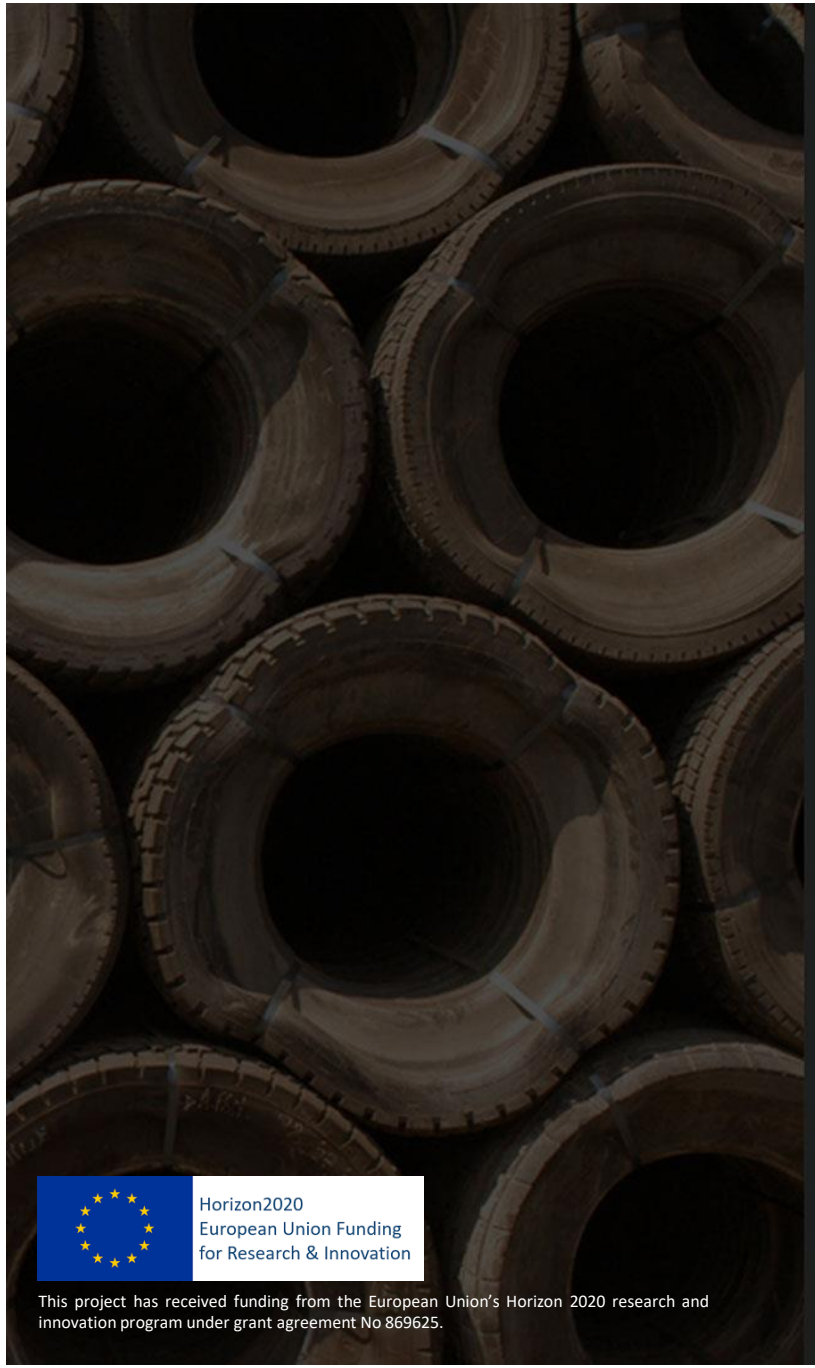
A MAJOR EUROPEAN PROJECT FOR RECYCLING END-OF-LIFE TYRES INTO NEW TYRES

BLACK CYCLE

Move to the green revolution

BlackCycle final workshop !

28th of May - SarrBrücken



Goals of the Blackcycle workshop

To share the final results of the Blackcycle project : technicological packages/environmental and economical assessment of the value chain

To review some actions to prepare its deployment

To create a connection between players in the tyre sector and beyond on the tyre Circular Economy

Horizon2020
European Union Funding
for Research & Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869625.

Day 1 : Plenary session

9: 00 *Welcoming notes*
Jean Michel DOUARRE , Pascal KLEIN – Pyrum, Simona MAASSEN - Orion

BlackCycle, enable massive and viable circular economy of tyres

9: 15 *Introduction Project Officer Blackcycle*
Floriana La Marca – HaDEA – European Commission

9: 20 *Context and value chain of the BlackCycle project*
Jean Michel DOUARRE, Margarita DORATO - Michelin

9: 40 *Innovative selective end of life tyre deconstruction*
Thomas SIMONELLI – Michelin, Alexander PROKEIN - Estato

10:00 *Optimized pyrolysis process and distillation*
Andreas KAPF - Pyrum, Ignacio de PASCUAL SAMPER - Sisener

Coffee Break & Networking

11:30 *Production of high quality secondary raw materials: Sustainable carbon black and plasticizer*
Celso MAGRI – Orion, Marion SERVEL - Michelin

11:55 *Closing the loop: secondary raw materials as direct replacement of fossil materials in new tyres*
Jean-Philippe WEBER, Magali HEURTEFEU - Michelin

12:20 *Viability of the value chain*
Christina PAPADIMITRIOU, Augustin MILLION – Quantis, Margarita DORATO - Michelin

Lunch Break & Networking

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Day 1 : Plenary session

Academic knowledge enhancement

13:45 *Introduction*
Jean Michel DOUARRE - Michelin

13:50 *Design and operation of a packed pilot scale distillation column for tyre pyrolysis oil: towards the recovery of value-added raw materials*
Juan Daniel MARTINEZ - CSIC-ICB

14:05 *Catalytic upgrading of the end of life tyre pyrolysis oil to increase the aromatic content*
Eleni PACHATOURIDOU - CERTH-CPERI

Making the tyre circular economy a success

14:20 *Introduction to the Blackcycle deployment*
Margarita DORATO - Michelin

14:25 *Achieving social acceptance while ensuring health, safety, and environmental compliance*
Jean-Philippe WEBER – Michelin, Cédric PERBEN – Eastman, Guy MALAIR & Céline DUPUIS - Ineris

15:05 *Unlock regulatory constraints and accelerate value-chain deployment*
Jean Michel DOUARRE- Michelin

Coffee Break & Networking

15:50 *Circular economy complementary initiative: WhiteCycle*
Thomas SIMONELLI – Michelin

16:05 *Advanced Materials for Industrial leadership*
Philipp RUNGE – DG Grow - European Commission

16:25 *Conclusion: We have moved to the green tyre revolution*
Jean Michel DOUARRE - Michelin

Dinner at the hotel

Join us at 18:30

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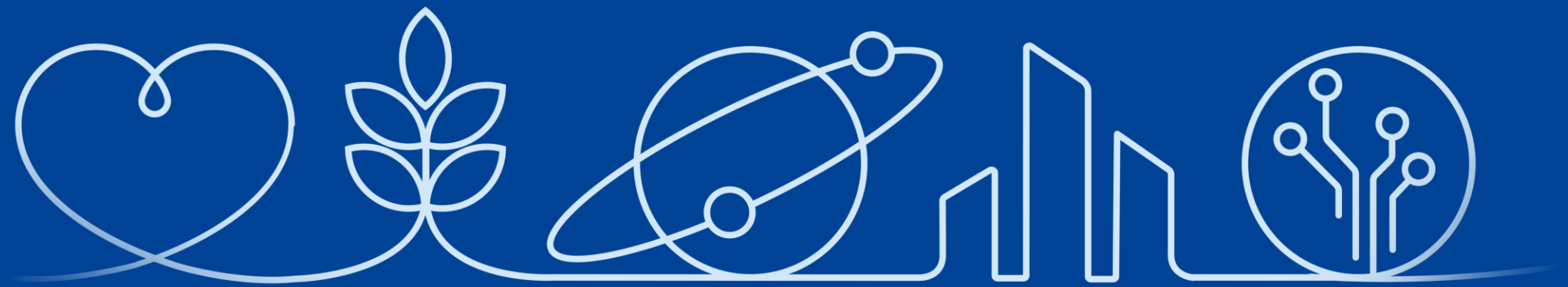
01

Introduction Project Officer Blackcycle

Floriana La Marca –Project Adviser, HaDEA
Unit B.3 - Industry

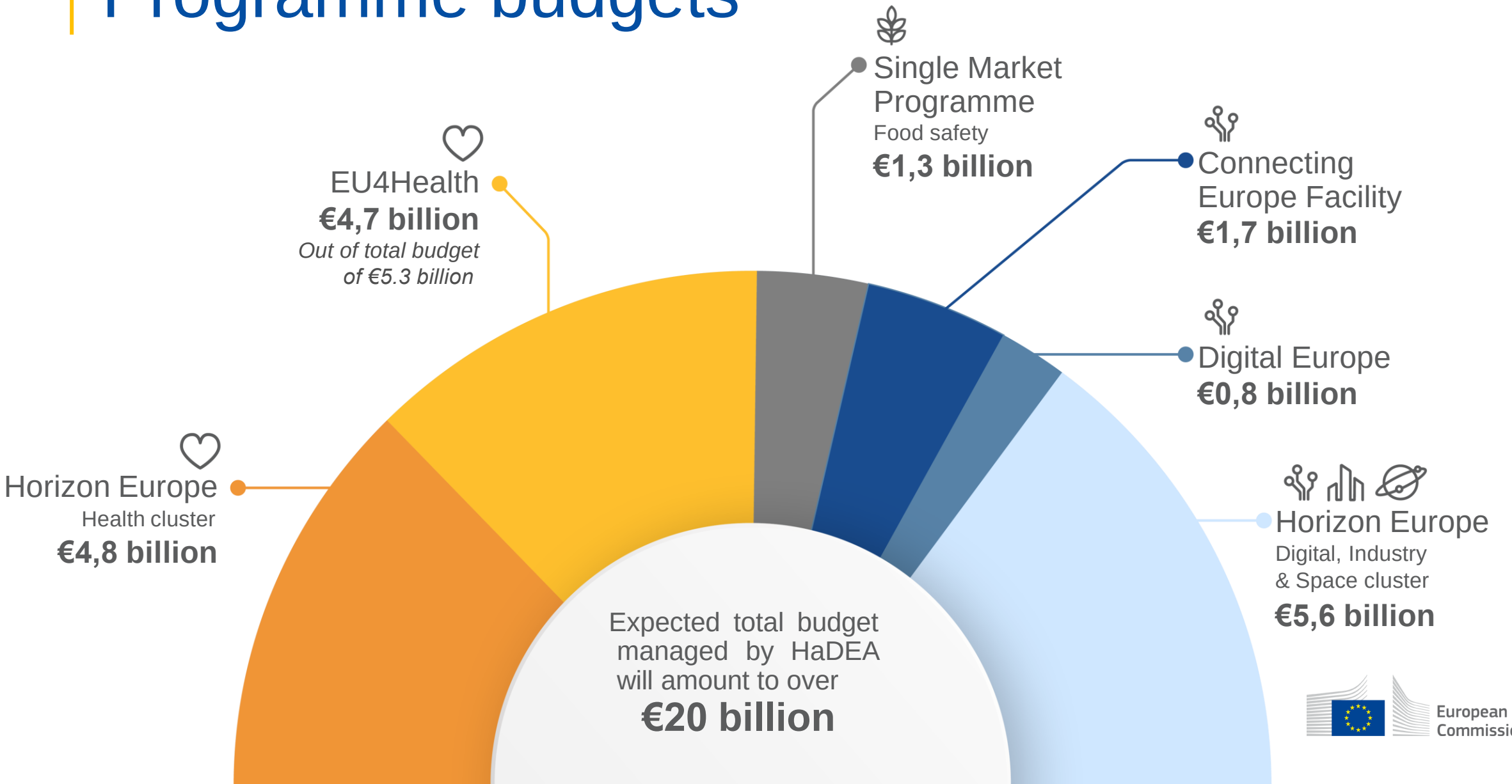
BlackCycle, enable massive and viable circular economy of tyres

Programme sectors



Health Food safety Space Industry Digital

Programme budgets



European Commission

Raw Materials in Horizon 2020 (2014-2020)

~ EUR 600 mln budget

Exploration	9 projects	EUR 55 mln
Extraction	15 projects	EUR 121 mln
Processing	19 projects	EUR 151 mln
Substitution	4 projects	EUR 19 mln
Reuse, recycling, recovery	6 projects	EUR 57 mln
Policy support	22 projects	EUR 43 mln

Raw materials innovation for the circular economy: sustainable processing, reuse, recycling and recovery schemes
TOPIC ID:
CE-SC5-07-2018-2019-2020

https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/ce-sc5-07-2018-2019-2020;callCode=H2020-SC5-2018-2019-2020;freeTextSearchKeyword=;matchWholeText=true;typeCodes=1;statusCodes=31094501,31094502,31094503;programmePeriod=null;programCcm2Id=31045243;programDivisionCode=31047972;focusAreaCode=null;geographicalZonesCode=null;programmeDivisionProspect=null;startDateLte=null;startDateGte=null;crossCuttingPriorityCode=null;cpvCode=null;performanceOfDelivery=null;sortQuery=submissionStatus;orderBy=asc;onlyTenders=false;topicListKey=topicSearchTablePageState

BlackCycle **Total costs 15,859,724.66 €**
EU Grant 11,919,385.64 € (75.16 % of total costs)

European Commission

Raw Materials in Horizon Europe (2021-2027)

1st Work Programme 2021-2022 ~ EUR 300 mln budget	**6 topics in 2021**	**EUR 159.5 mln**
	7 topics in 2022	**EUR 130.2 mln**
2nd Work Programme 2023-2024 ~ EUR 250 mln budget	**6 topics in 2023**	**EUR 118 mln**
	5 topics in 2024	**EUR 91,2 mln**

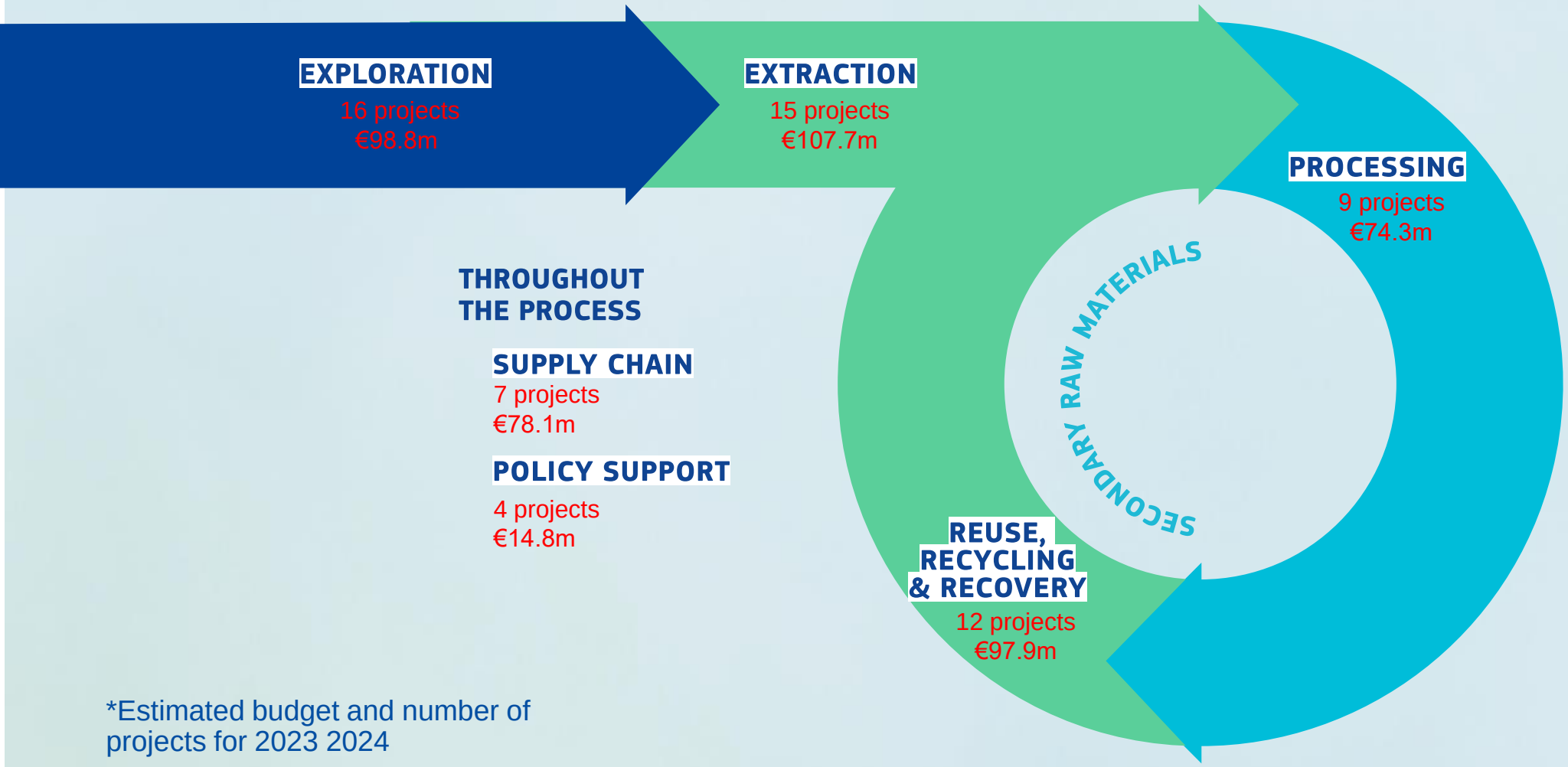
European Commission

Overview calls raw materials 2021-2024*

TOTAL BUDGET ALLOCATION FOR RAW MATERIALS

Research & innovation
€456.7m

Policy support
€14.8 m



*Estimated budget and number of projects for 2023 2024

European Commission

Stay in touch

HaDEA

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- @EU_HaDEA
- European Health and Digital Executive Agency

European Commission

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- European Commission
- EuropeanCommission
- europeancommission
- EUTube
- EuropeanCommission
- EU Spotify

European Commission

Thank you

02

Context and value chain of the BlackCycle project

Jean Michel DOUARRE
& Margarita DORATO - Michelin

BlackCycle, enable massive and viable circular economy of tyres

Annually, 1.6 Billion tyres become waste worldwide

31 Million Tons

90% Collected

Energy valorization

Material valorization

ELT management schemes in Europe

Today within the EU there are 3 different models for managing ELTs:

- 1- Extended Producer Responsibility (EPR)
- 2- Liberal system (Free market)
- 3- Tax system (Government Responsibility, financed through a tax)

Belgium	RECYTYRE
Czech Republic	eltma
Finland	SUOMEN RENGASKIERRÄTYS
France	ALIAPUR
Greece	eco elastika
Ireland	circol ELT
Italy	ecopneus
Netherlands	RecyBEM B.V. BAND & MILIEU
Norway	Norsk Dekkretur AS
Poland	CUO
Portugal	valorpneu
Romania	ECO ANVELOPE
Slovakia	eltma
Spain	SIGNUS
Sweden	Svensk Däckåtervinning
Turkey	LASDER

~3.5 Million Tons/y ELT

The number in the country refers to the year of publication of Extended Producer Responsibility Law

Source: https://www.etrma.org/key-topics/circular-economy/

Landfill Directive (EC Directive 1999/31)

A well-organized field

- EU Regulatory Framework Landfill Directive
- 95% Collected
- 40% Energy valorization
- 60% Material valorization

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Context of ELT valorisation in close loop recycling

Only **a limited amount** of secondary raw material that could be reused in the tyre industry in 2020 because of lack of SRM quality for a use in tyres

Possible ELT feedstocks exist:

- 50% ELT Exported outside Europe
- Recent Regulation constraints for granulates used for artificial turf, sports & children playground -Microplastic ANNEX XVII

Offering a **great potential for material recovery in tire**, if technologies are available to make high Quality SRMs

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CHALLENGES TO SUCCEED

Technological

The tyre is highly technological

Various performances at the same time

Supply chain creation

Large volumes, quality stability, worldwide coverage

Economical viability

of the overall value chain Vs. an optimized value chain , Customer's willingness

Environmental viability

>0 impact on LCA incl. waste avoïdance&Recycled Mat. use

Energy balance

No <0 environmental effects

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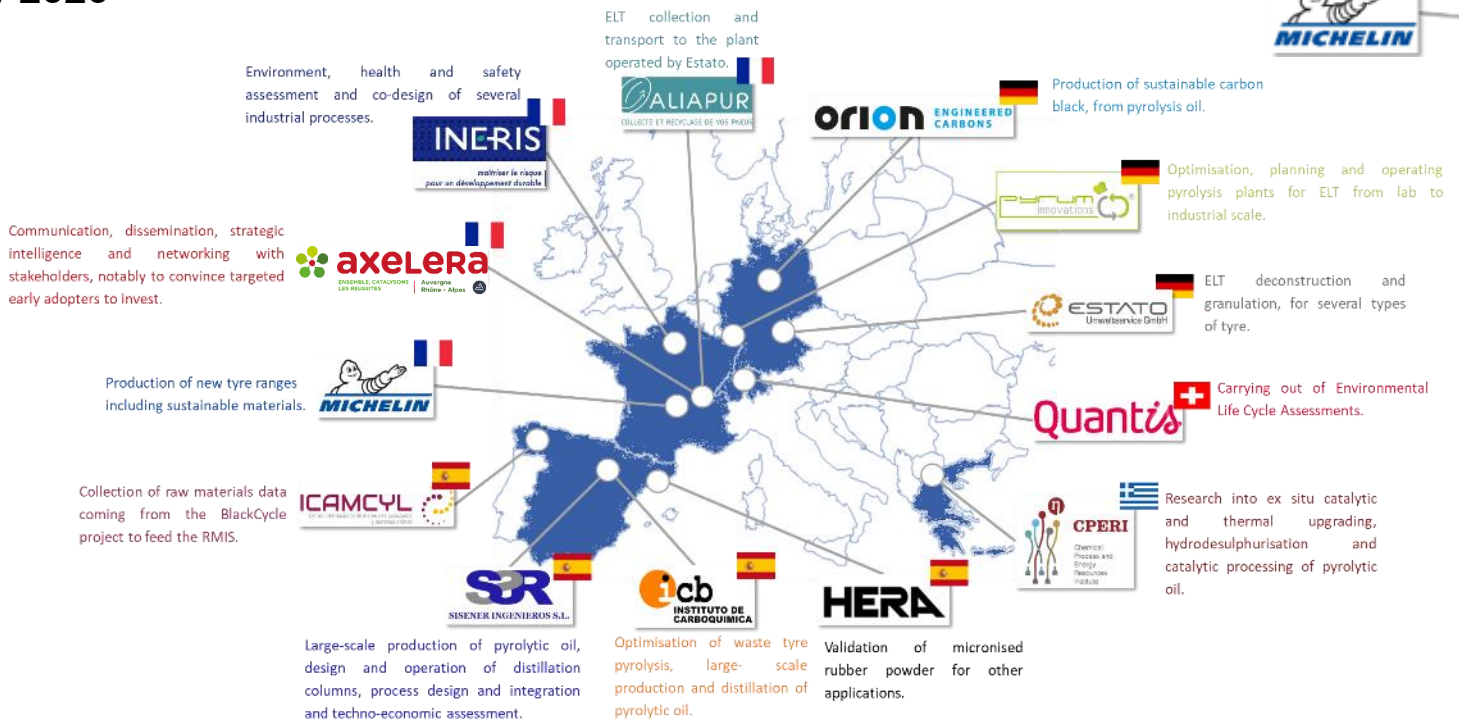
7 Industrial & Start up Partners, 5 Research Centers and an Innovation cluster gathered in a EU Consortium in 5 Countries

May 2020

June 2024



MICHELIN **BLACKCYCLE COORDINATOR**

- Waste Managers
- Technology Developers
- End Users and Validators
- Technology Providers and Manufacturers
- Environmental and HSE Experts
- Dissemination, Communication

TECHNOLOGICAL BARRIERS

NON-TECHNOLOGICAL BARRIERS

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ALIAPUR

French eco-company for collecting or recovering ELT

- **Main activity**

Aliapur operates as an eco-company and provides, a general interest mission that is defined and included in the French Environmental Code. Aliapur also invests in the future by devoting a significant part of its budget to industrial research, carrying out studies, in situ analyses and laboratory trials, and supporting innovative projects in the field of the recycling of end-of-life tyres.

- **Key achievement**

Since the start of its operations in March 2004, Aliapur has accompanied the key figures in the sector in developing and rendering sustainable a wide range of recycling solutions.

- **Level of outreach**

Aliapur operates on a national and European scale thanks to its involvement in consortiums and research and innovation projects.

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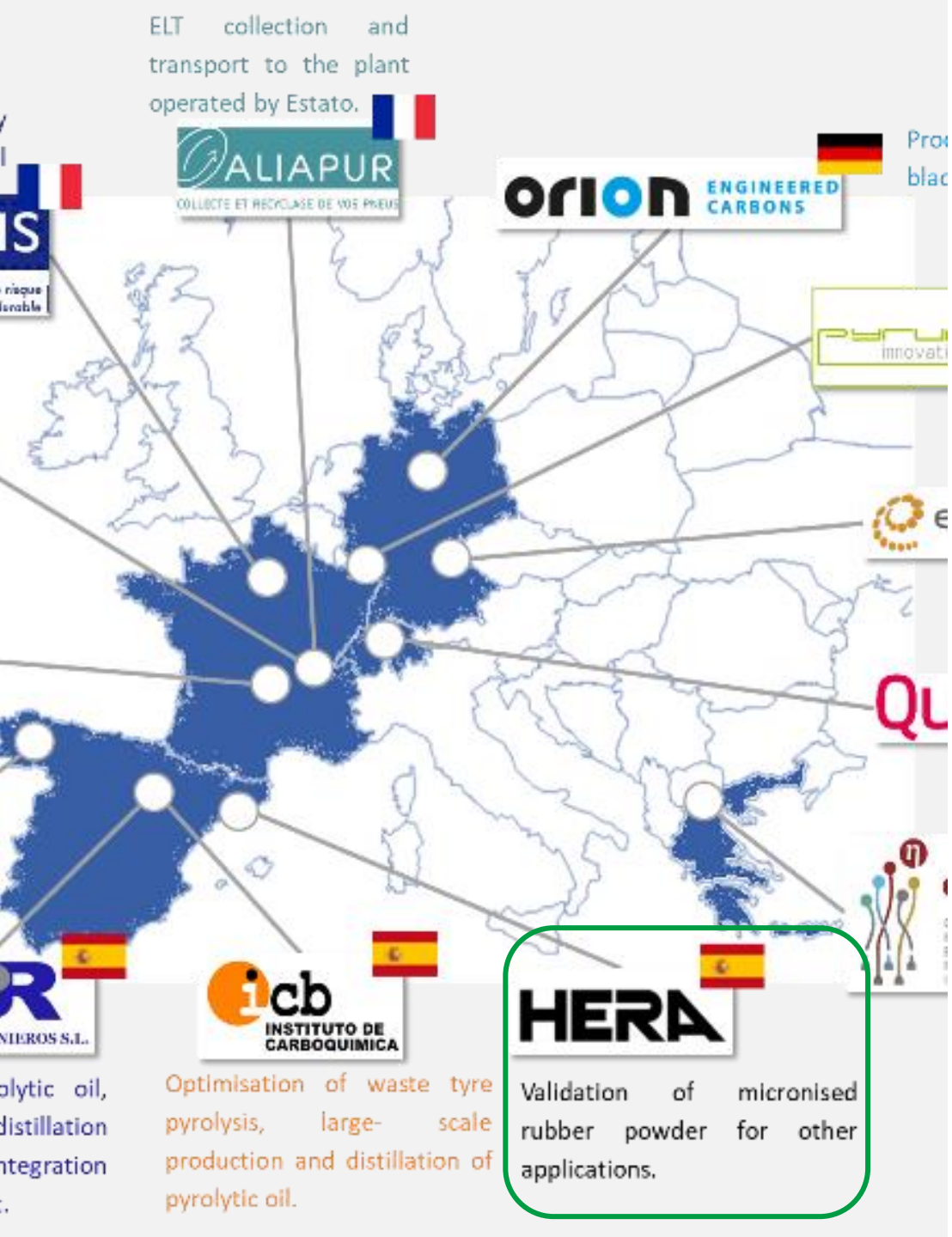

HERA

Spanish Process& solutions provider for Waste treatment and industrial recycling sites

- **Main activity**

The main activity is the environmental services with the management and the valorisation of waste to generate energy and secondary raw materials

- **Key achievement**

Main focus in waste to energy projects allowing customers companies to become energetically sustainable and self-suffcient biomas, solid recovered fuel and biogaz

- **Level of outreach**

Hera is a international company doing business across Europe, Latin-America and middle East

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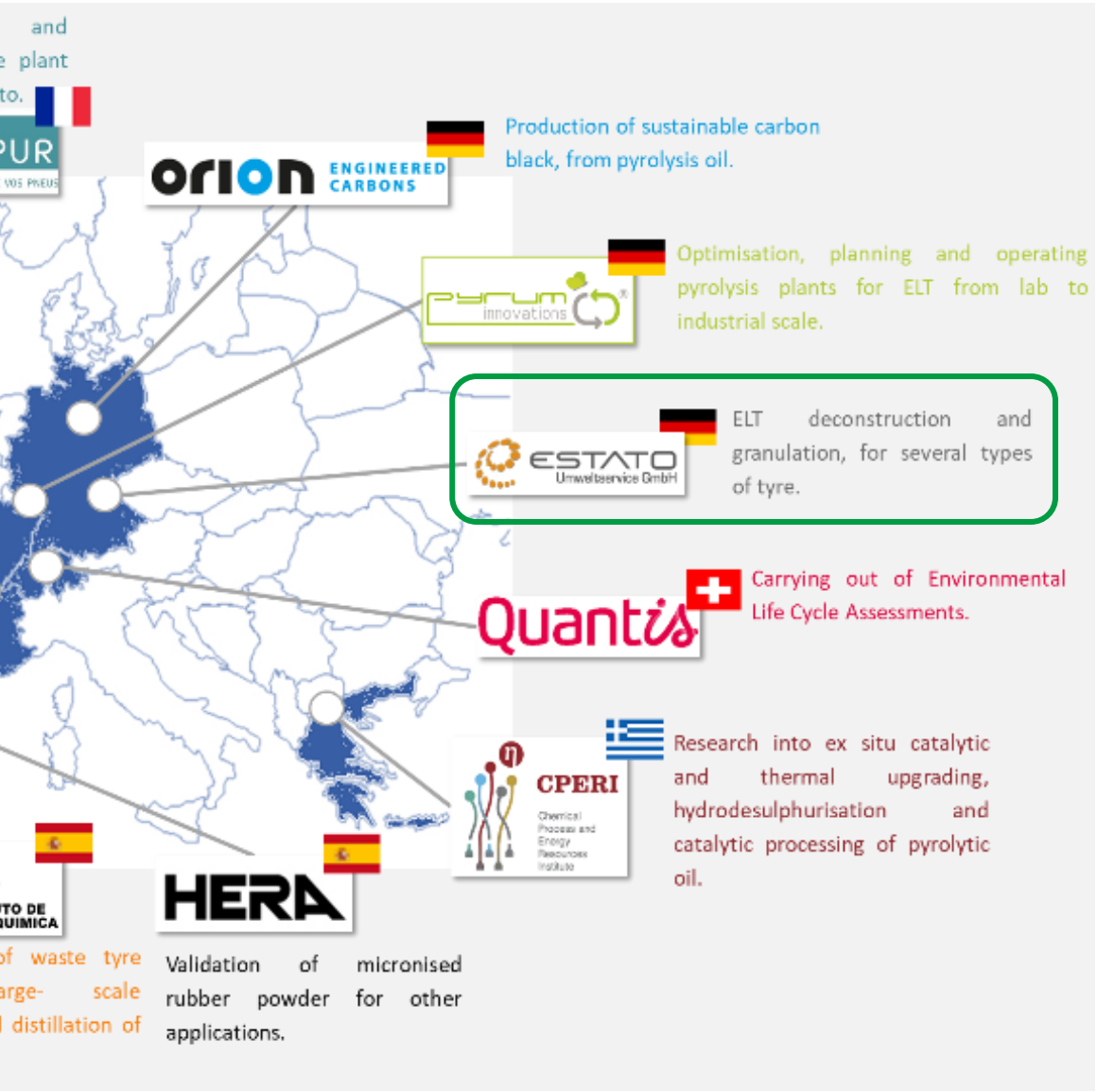

ESTATO

German entity : Workshop Collect/ Recycling& Waste disposal, ELT Granulates

- **Main activity**

ESTATO is one of the largest German full-service providers in the field of workshop disposal and waste collection. In addition to the general, advisory environmental service, the main activities include the collection, sorting, recycling and processing of various material flows in the two recycling centers in Germany as well as the marketing of the secondary raw materials resulting from the processes.

- **Key achievement**

One of the core businesses is the recycling of used tyres; ESTATO operates a total of six granulation lines and thus has a capacity of around 60,000 tons.

- **Level of outreach**

The trading area is limited to Europe with many industrial customers in Germany; around 100 well-trained employees are currently employed in the processes.

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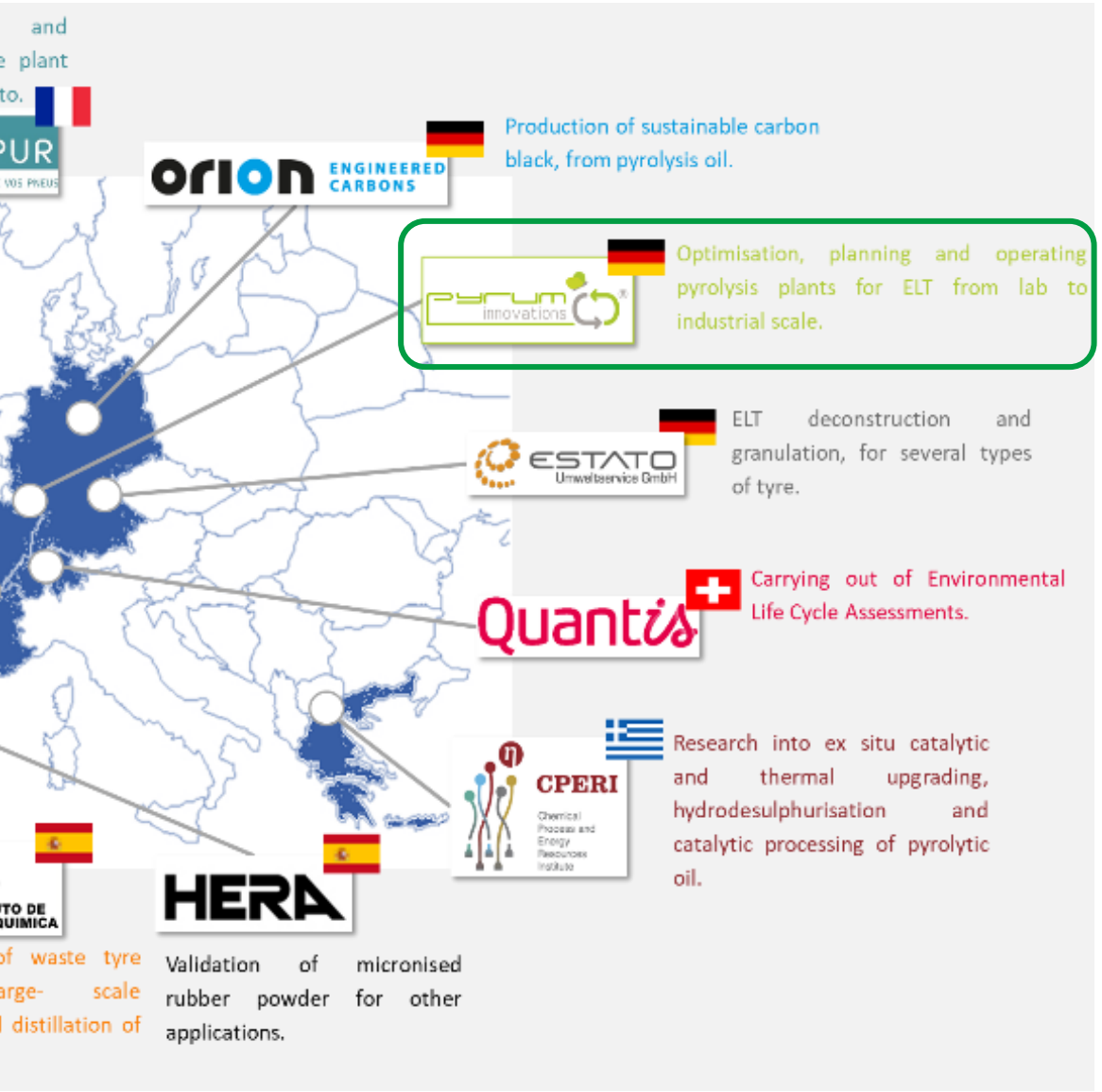

PYRUM

German engineering and recycling company for planning and operating thermolysis plant

- **Main activity**

The main activities are the development, sale and operation of recycling plants for used tyres to achieve the most holistic recycling possible in terms of material utilization and the Closed Substance Cycle Waste Management Act. Also, services for feasibility studies and consultancy of other waste materials and the development of new recycling technologies for problematic waste streams

- **Key achievement**

On of the key achievement at Pyrum is commissioning of two new production lines for tyre recycling in Dillingen. They have various new projects for new tyre recycling plants all over Europe and also the establishment of the world's first recycling system for bicycle tyres together with Schwalbe (Ralf Bohle GmbH)

- **Level of outreach**

They have currently 73 employees in Germany, for subsidiaries please see annual report in annex.

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SISENER

- **Spanish Consultancy/engineering firm (energy sector)**

- **Main activity**

Sisener is a reference engineering for the main electricity generation, transmission, and distribution companies, for the main EPCists and installers, and some of the main manufacturers and technologists.

- **Key achievement**

Projects such as electrical substations, high voltage lines, hydroelectric, wind farms, solar plants (photovoltaic, Stirling, thermosolar), biomass, geothermal, treatment and recovery of waste for energy production (WtE) or Fuel (Waste to Fuel), cogeneration, Industrial processes and large thermal power plants, as well as technological developments are part of the activities that we carry out at SISENER together with the different companies that are part of its group.

- **Level of outreach**

Internationally established, in Spain, Romania, USA, Mexico, Ecuador, Peru and Chile and Sisener has experience in many countries .

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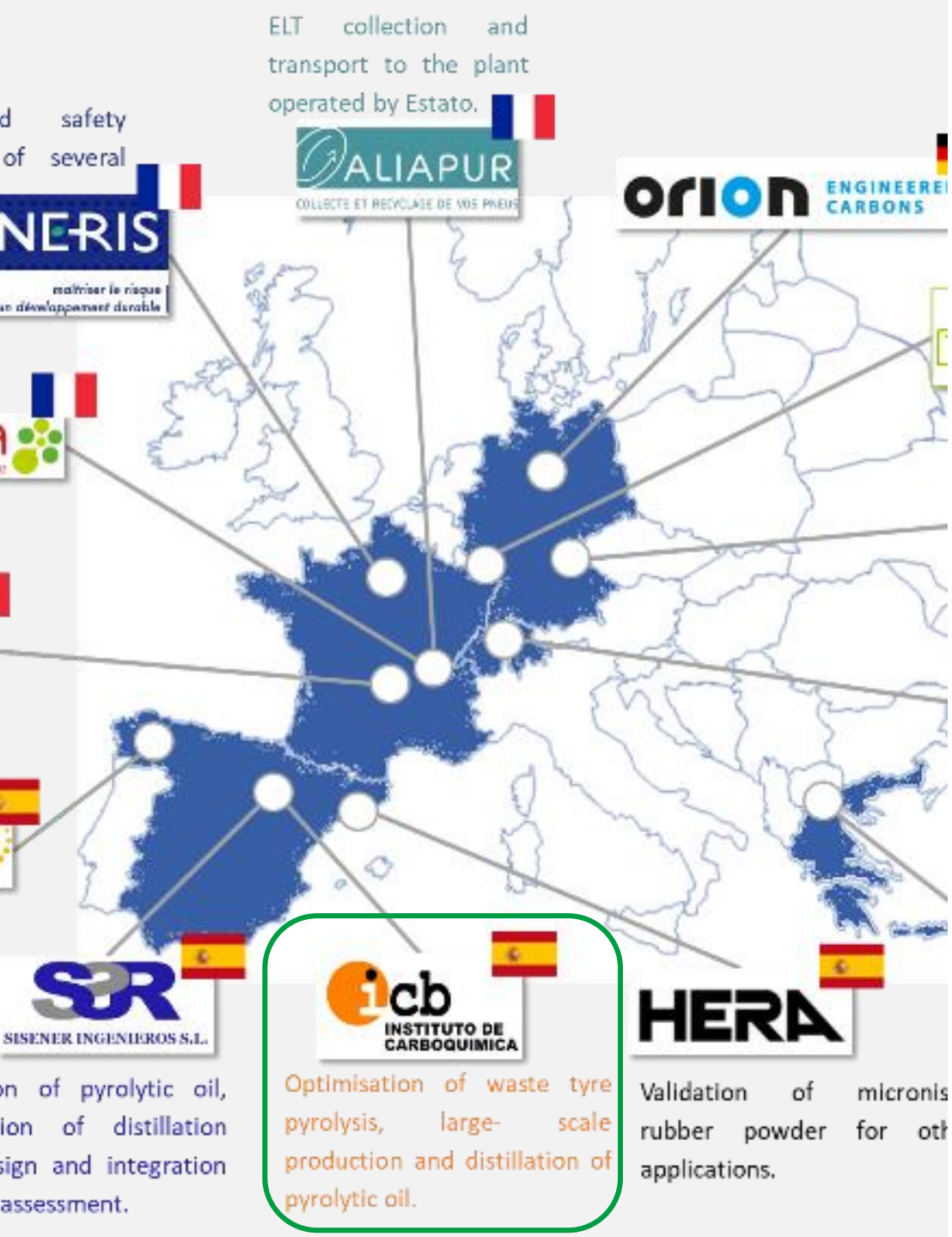

CSIC- ICB -

Spanish National Research Council – Institute of Carbochemistry

- **Main activity**

The Spanish National Research Council is a State Agency for scientific research and technological development. The Instituto de Carboquímica is one of the 120 centers of the CSIC. ICB has experience in thermochemical processes such as pyrolysis for the chemical recycling of complex wastes such as scrap tyres.

- **Key achievement**

ICB is recognized worldwide not only for the pyrolysis of ELTs, but also to advanced thermochemical processes such as sorption-enhaced gasification for syngas production, methanization, and also on chemical looping processes.

- **Level of outreach**

CSIC leads the scientific production in Spain, with an annual average of 13,000 publications. The qualification of the research of CSIC stands out nationally and internationally, as evidenced by its leadership in national and international projects, as well as in the activities of technology transfer and scientific culture.

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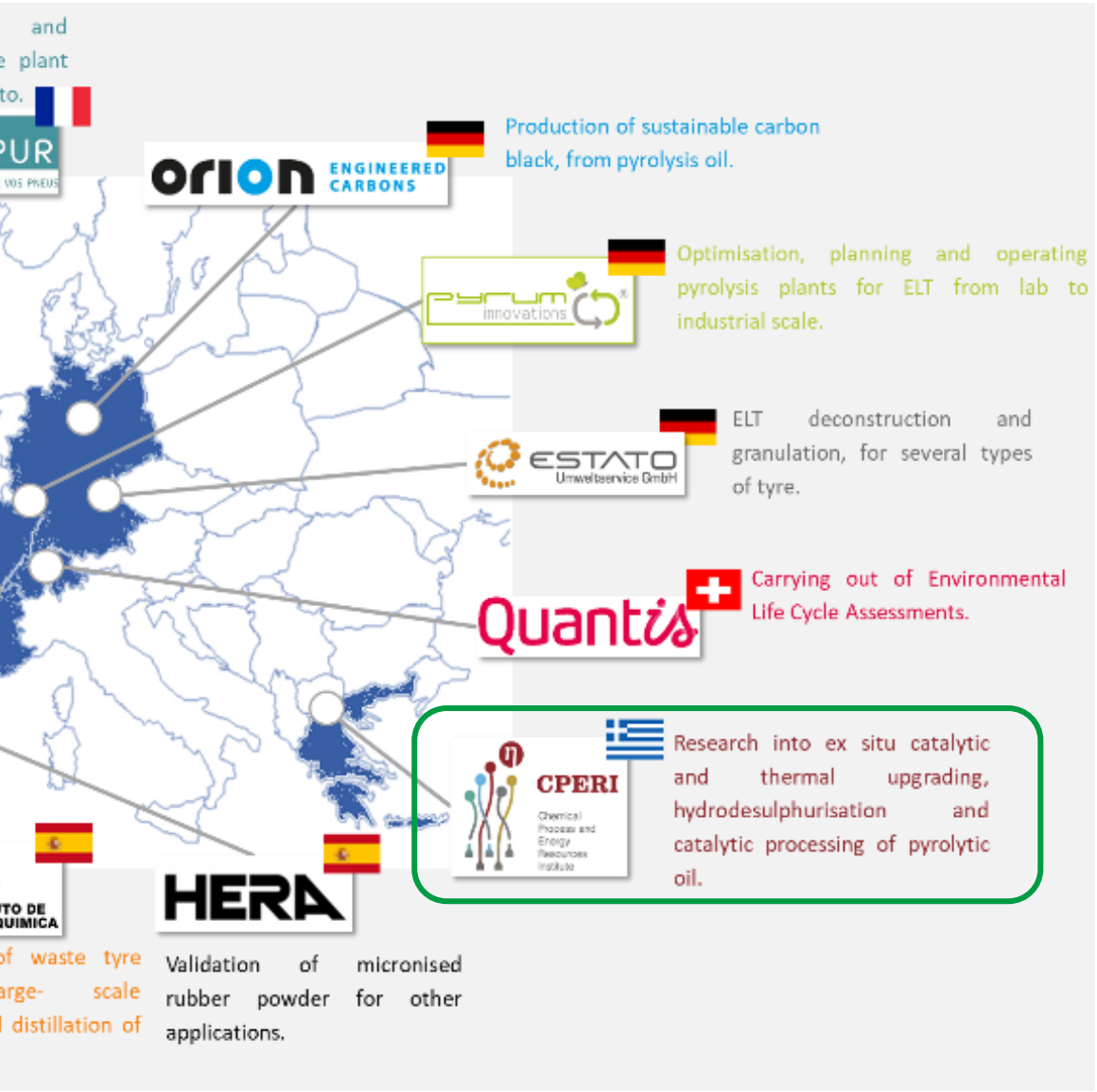

CPERI - CERTH

Greek Center for Research and Technology: Chemical process and Energy resources Institute

- **Main activity**

Laboratory of Environmental Fuels and Hydrocarbons (LEFH) is a catalytic reaction engineering laboratory of the Chemical Process and Energy Resources Institute (CPERI)/CERTH that carries out fundamental and applied research in the area of refining and biorefining catalytic technologies.

- **Key achievement**

Emphasis is given on the development of catalytic processes for the production of fuels and chemicals with low carbon footprint according to the principles of circular economy.

- **Level of outreach**

LEFH has over 100 collaborations with refining and biorefining companies worldwide and participates in European projects.

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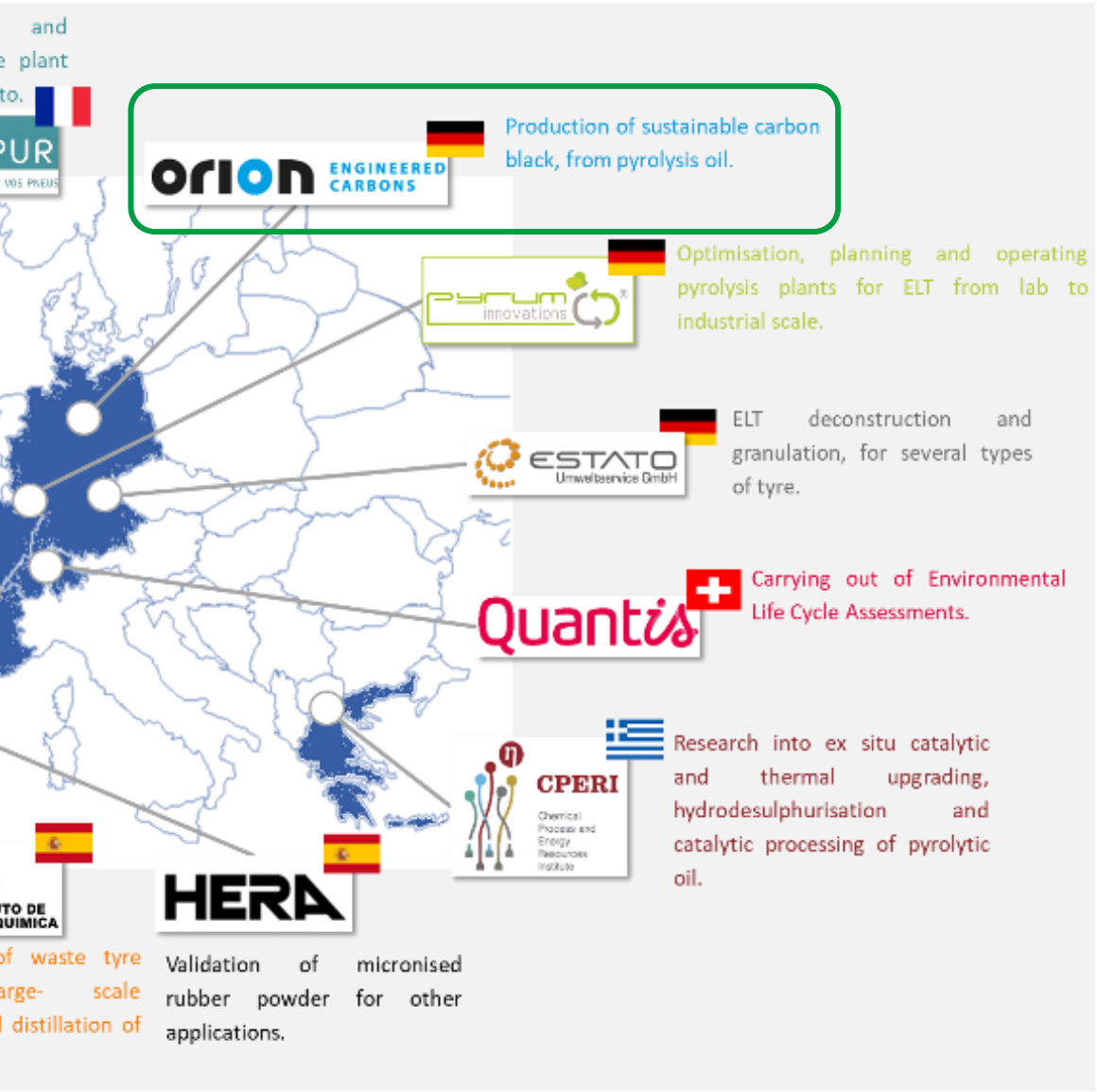

ORION

German leading global producer of carbon black

- **Main activity**

Orion S.A. is a global specialty chemicals company that makes carbon black, a solid form of carbon produced as powder or pellets – an essential material in everyday products.

- **Key achievement**

The company's corporate lineage can be traced back more than 160 years to Germany, where it still operates the world's longest-running carbon black facility.

Orion is a leading innovator, applying a deep understanding of customers' needs to deliver sustainable solutions.

- **Level of outreach**

Orion has innovation centers on three continents and produces carbon black at 15 plants worldwide, offering the most diverse variety of production processes in the industry.

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INERIS

French National institute of industrial environment and risks

- **Main activity**

Ineris is a well-known National Institute working under the umbrella of the the French Ministry in charge of the environment, core missions are to contribute to prevention and mitigation risks that economical activities may induce to health, safety of people and properties and to the environment in support of stakeholders.

- **Key achievement**

Applied research recognition and impact is notably reflected by contributions to 13 EU-funded research projects, 1 US-funded project, approximately 90 papers published annually in peer-reviewed scientific journals, and the supervision of 28 PhD students.

- **Level of outreach**

With around 500 employees, main labs in Verneuil-en-Halatte, France, and 5 other operational national sites, our activities extend to the national, European, and international levels.

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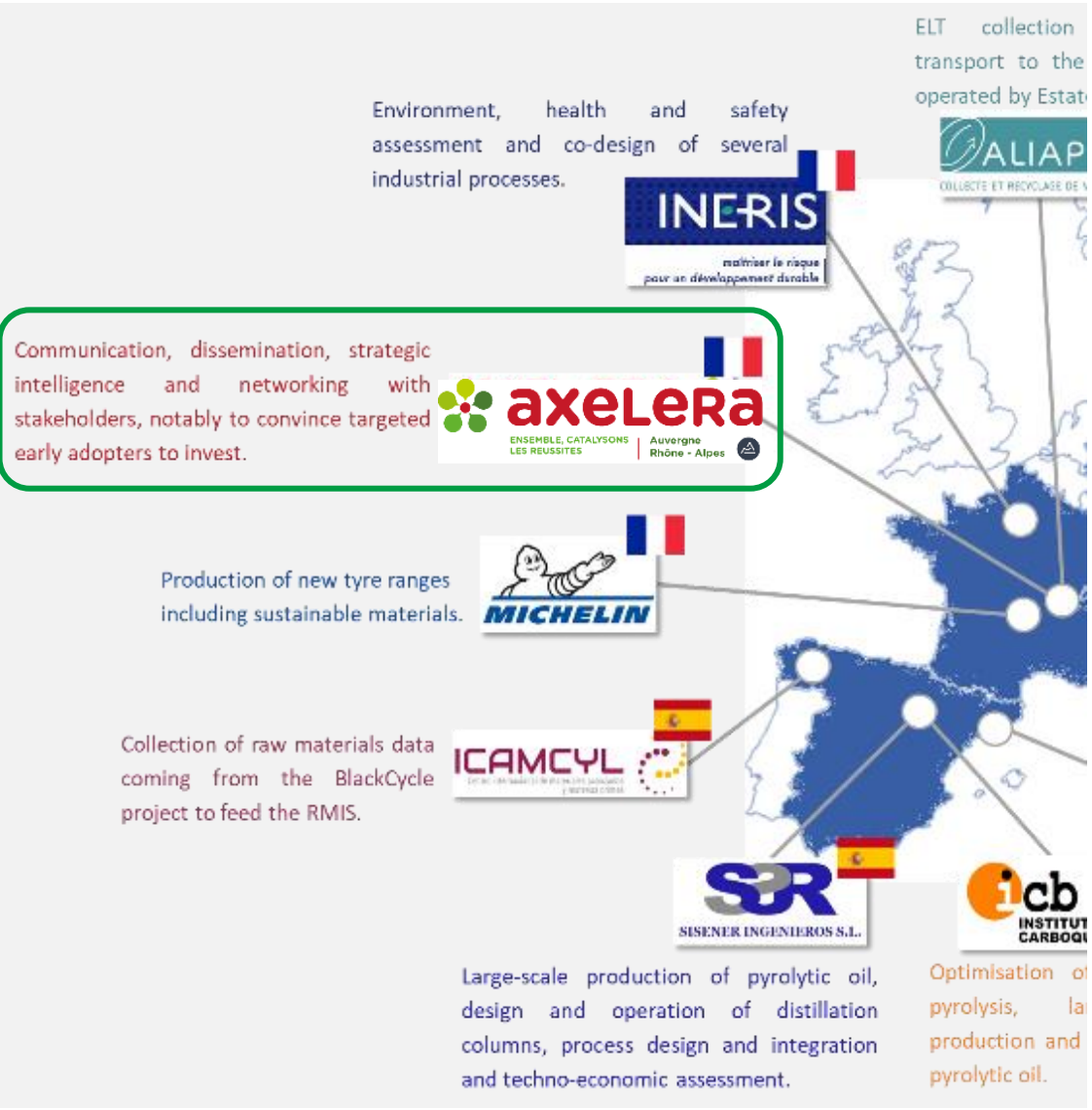

AXELERA

French Chemistry-Environment innovation Cluster

- **Main activity**

Axelera is the French cluster at the crossroads of the chemical and environmental sectors. Axelera is committed to their 400 members to developing sustainable, efficient, circular and clean solutions for industry.

- **Key achievement**

Using more renewable raw materials, having cleaner manufacturing processes, consuming less energy, developing more sustainable products, recycling all materials at the end of their life... these are the challenges tackled by AXELERA.

- **Level of outreach**

We bring together, in France and internationally, the stakeholders involved in the controlled management of materials and resources (water, air, soil, energy) for sustainable development of territories.

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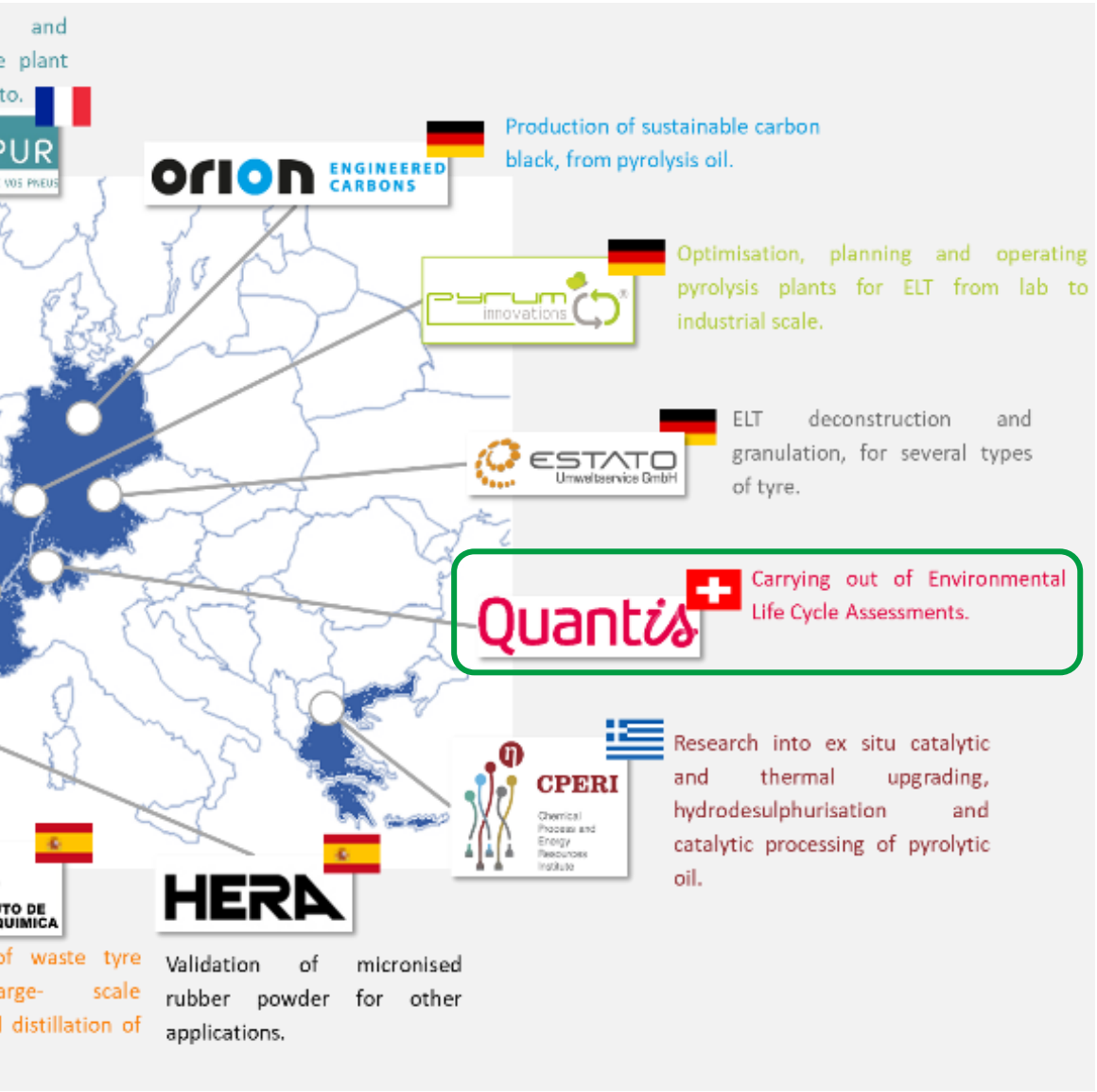

QUANTIS

Sustainability and life cycle assessment (LCA) Swiss consultancy

- **Main activity**

Quantis was established in 2006 as one of the first environmental sustainability consultancies of its kind. Over the years, they have been at the forefront of shaping the industry and leading the dialogue around sustainability-driven transformation. Environmental sustainability is their main focus (biodiversity, climate, water, plastic and agriculture areas)

- **Key achievement**

We unlock science-driven transformation by leveraging the best available data and metrics to shape actionable strategies to align businesses' operations within planetary boundaries. When it comes down to it, science is our compass, pointing the way toward the opportunities for innovation and true sustainable transformation.

- **Level of outreach**

Internationally established, Quantis are committed to their 5000 clients around the world.

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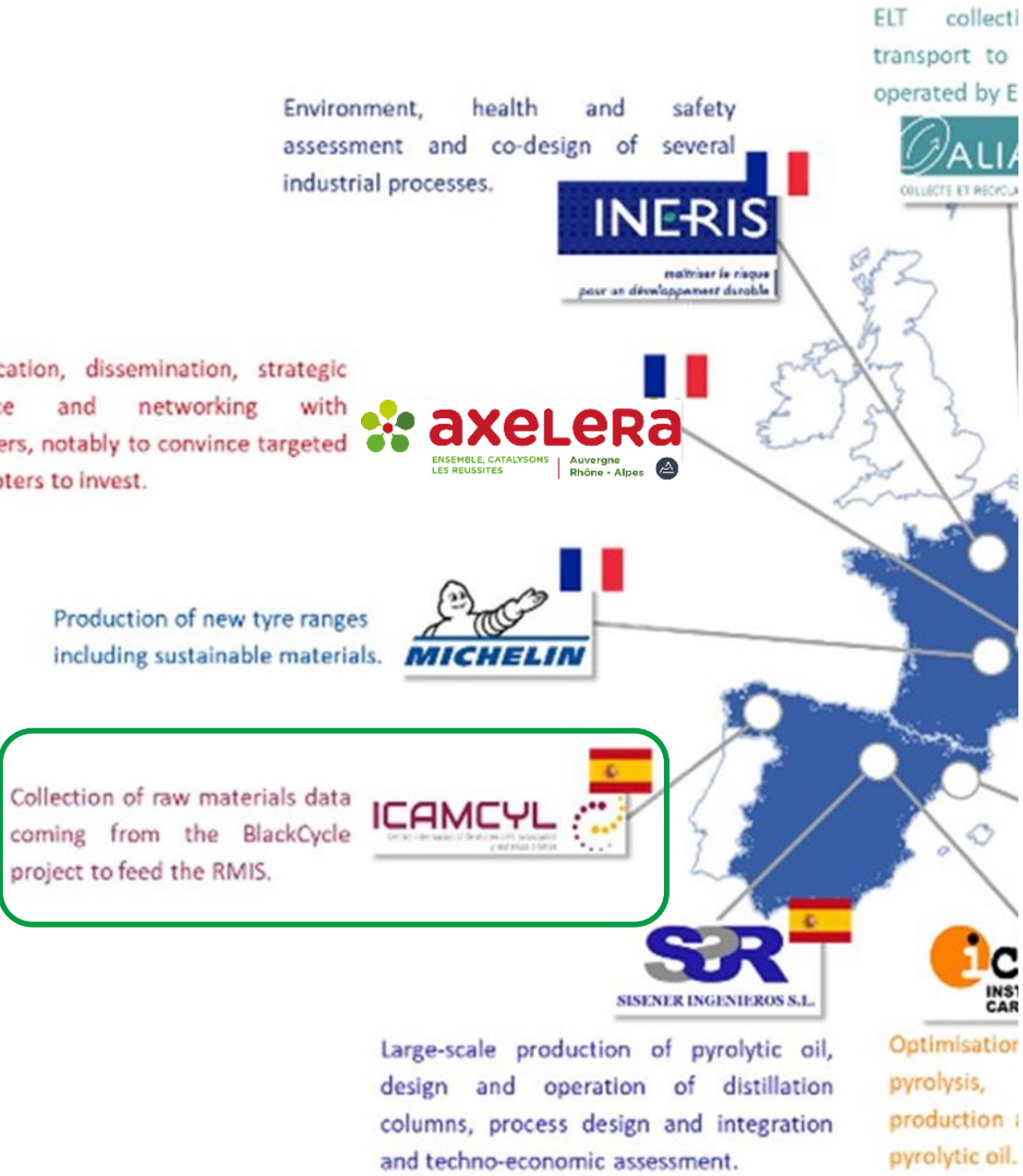

ICAMCYL

Spanish International Center in Advanded Materials and raw Materials (foundation)

- **Main activity**

The International Center for Advanced Materials and Raw Materials of Castilla y León, is a private non-profit foundation and competence center. Our main activities focus on promoting the development of advanced materials for the regional industrial network and enhancing the wealth of raw materials and endogenous resources.

- **Key achievement**

One of their most notable achievements is facilitating and building international projects. This highlights their expertise in coordinating large-scale initiatives and fostering collaborations.

- **Level of outreach**

ICAMCyL is recognized as an expert partner in preparing and launching international projects. Their efforts are dedicated to providing companies with cutting-edge technology and identifying opportunities that strengthen the region in strategic sectors.

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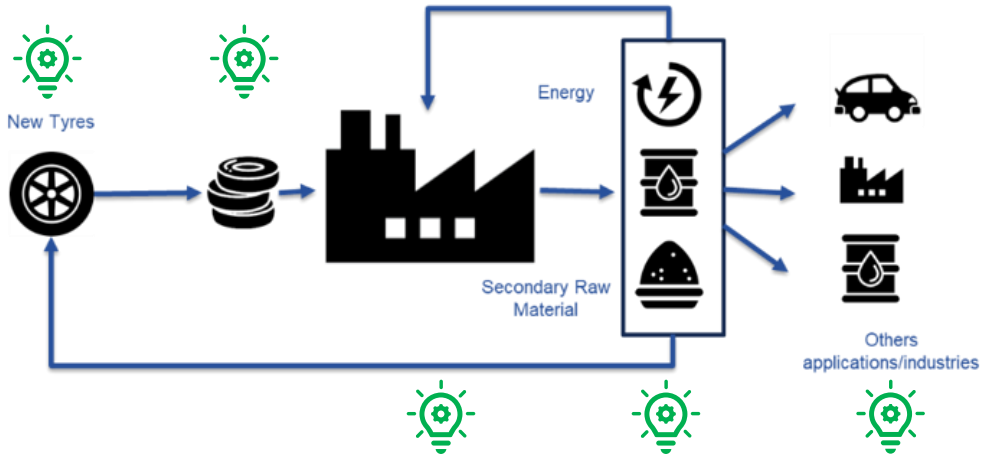
Jean-Michel DOUARRE – Consortium Director (MICHELIN)

BLACKCYCLE project aims to enable a massive circular economy of tyres by developing the technologies to make high quality SRM from ELT for New Tyres



More than **10** innovations along the value chain

The BlackCycle project aims at creating, developing, and optimising a full value chain :

To valorize **100%** ELTs selected

To increase up to **10 times** SRMs rate into a new tyre

To decrease **CO2** emission at least **50%**

By Offering An **Economically** And **Environmentally** Viable Alternative

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

BLACKCYCLE aims at creating, developing and optimising a full Value Chain

TRL : 4 to 7

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

The project aims to develop pilot plants recycling ELT on high-technical SRMS for new tyres and other to applications

Delivering validated high quality SRMs

Delivering technological packages

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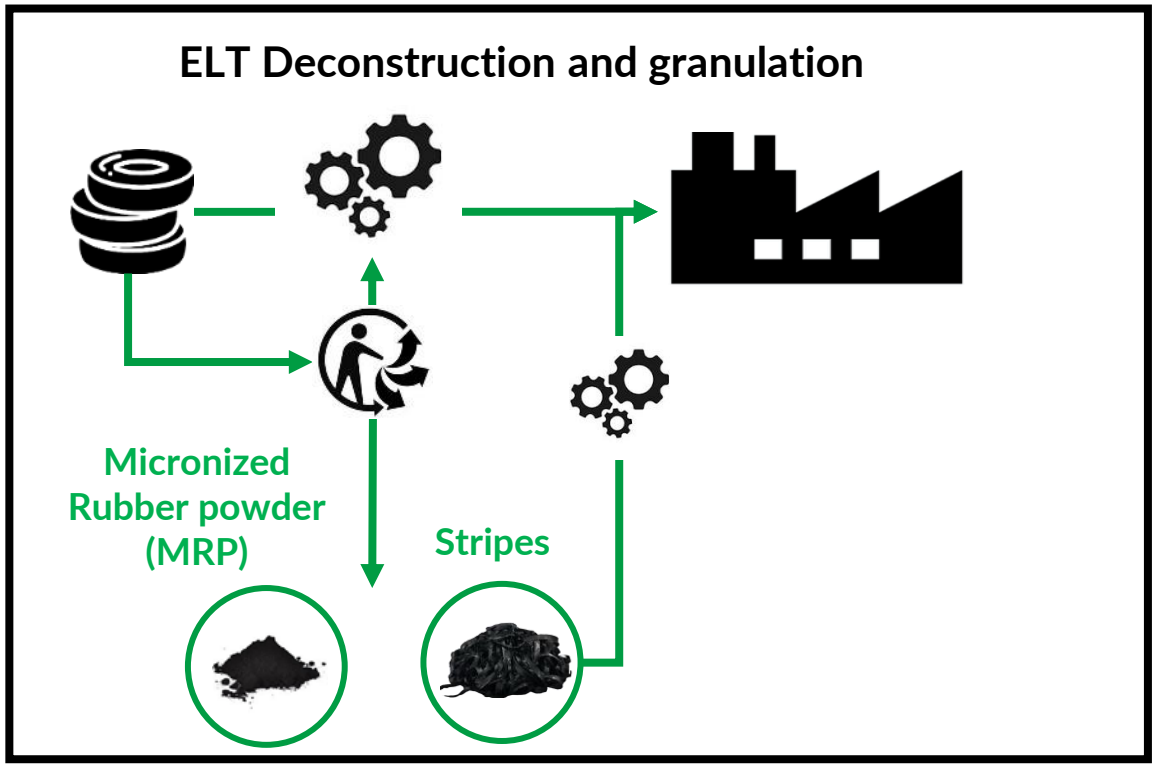
BLACKCYCLE aims at creating, developing and optimising a full Value Chain

ELT Deconstruction process to produce specified rubber granulates composition for MRP and pyrolysis application



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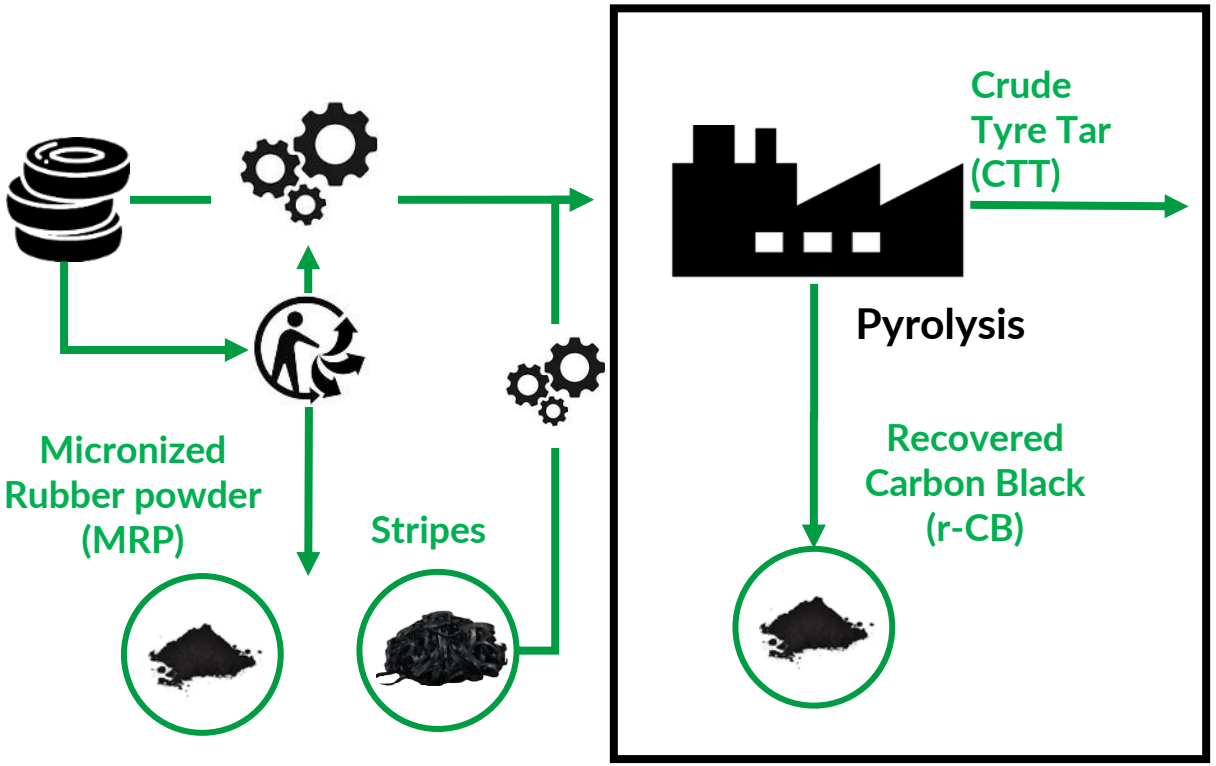
BLACKCYCLE aims at creating, developing and optimising a full Value Chain

Optimized pyrolysis process to produce high quality r-CB and optimized pyrolysis oil



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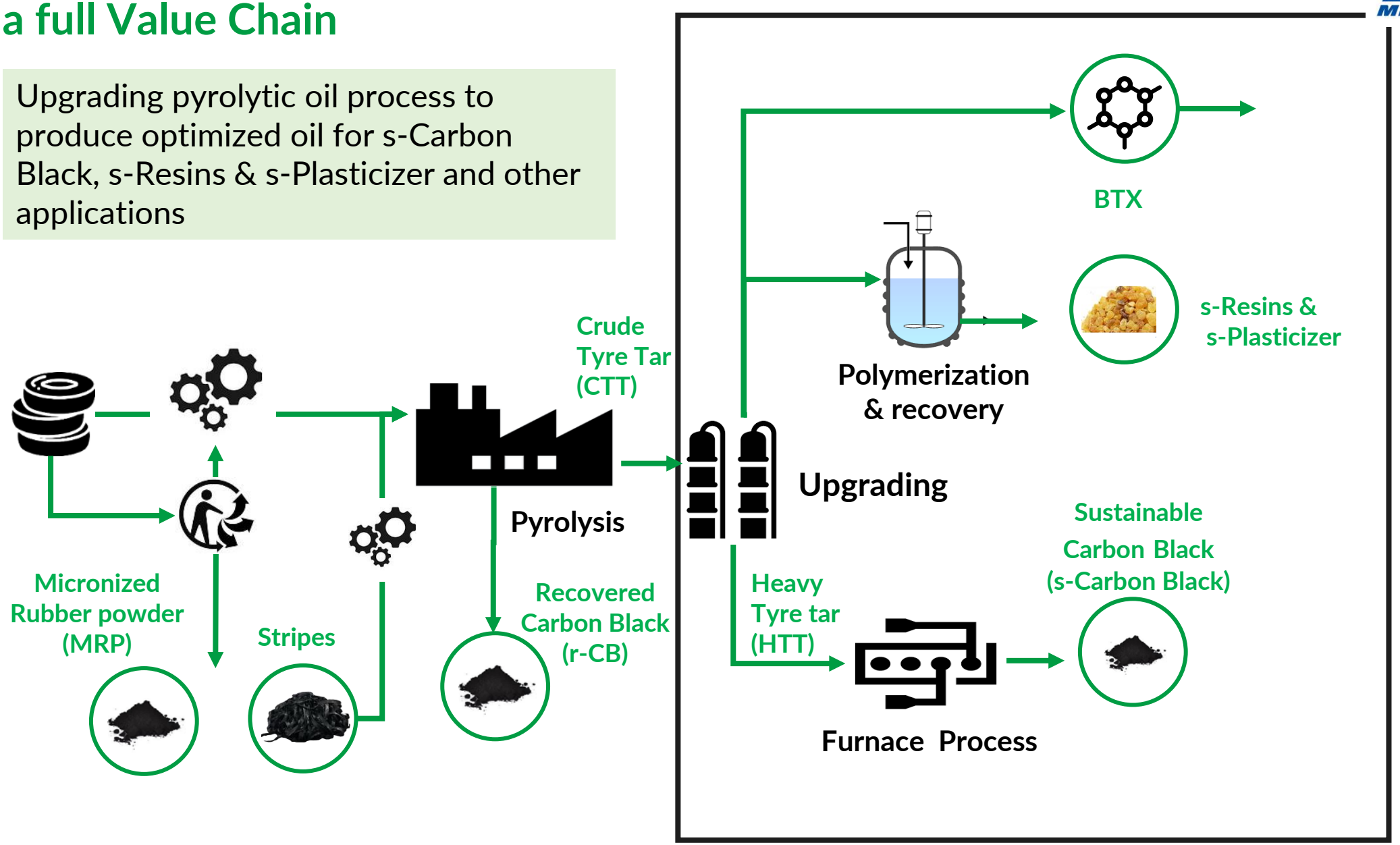
BLACKCYCLE aims at creating, developing and optimising a full Value Chain

Upgrading pyrolytic oil process to produce optimized oil for s-Carbon Black, s-Resins & s-Plasticizer and other applications



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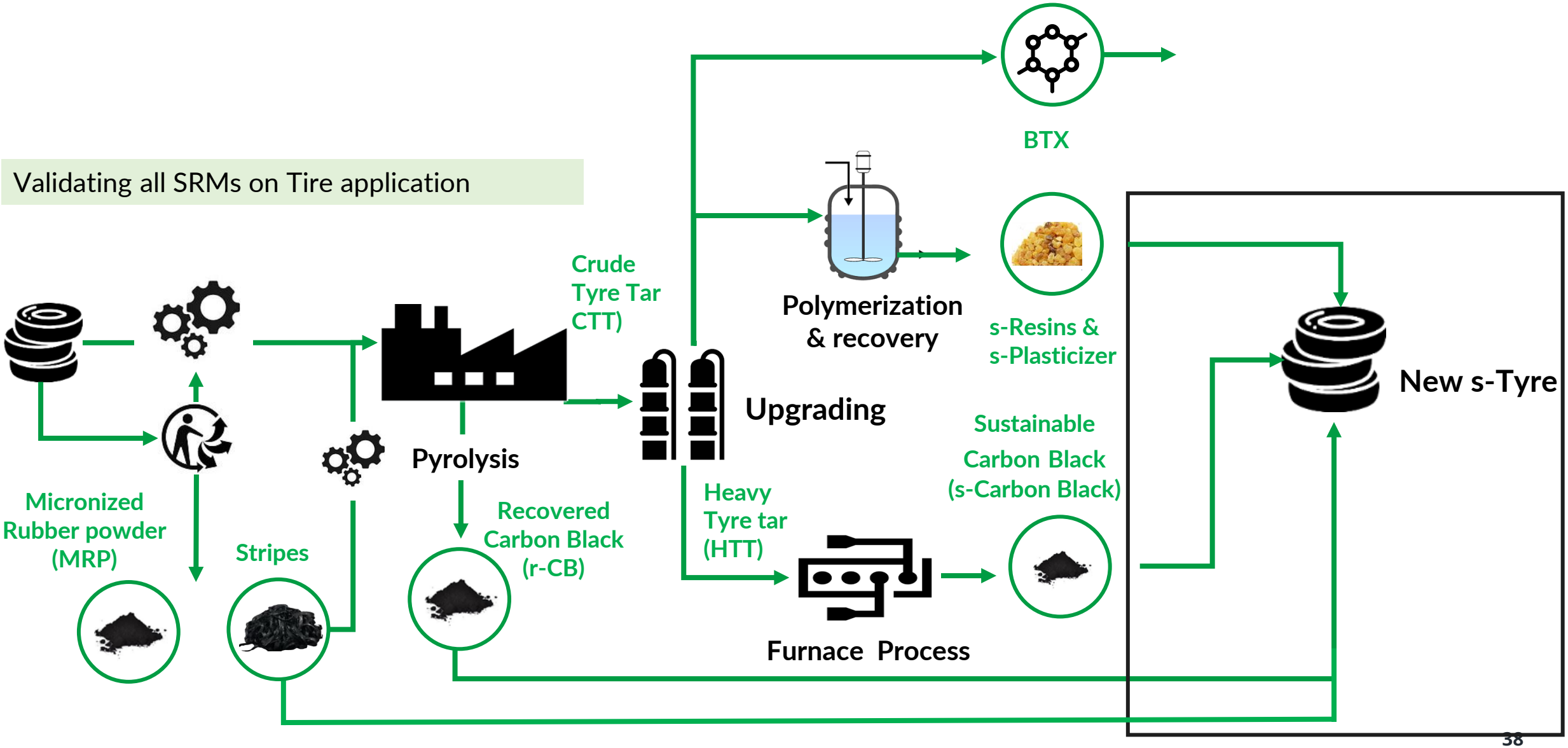
BLACKCYCLE aims at creating, developing and optimising a full Value Chain

Validating all SRMs on Tire application



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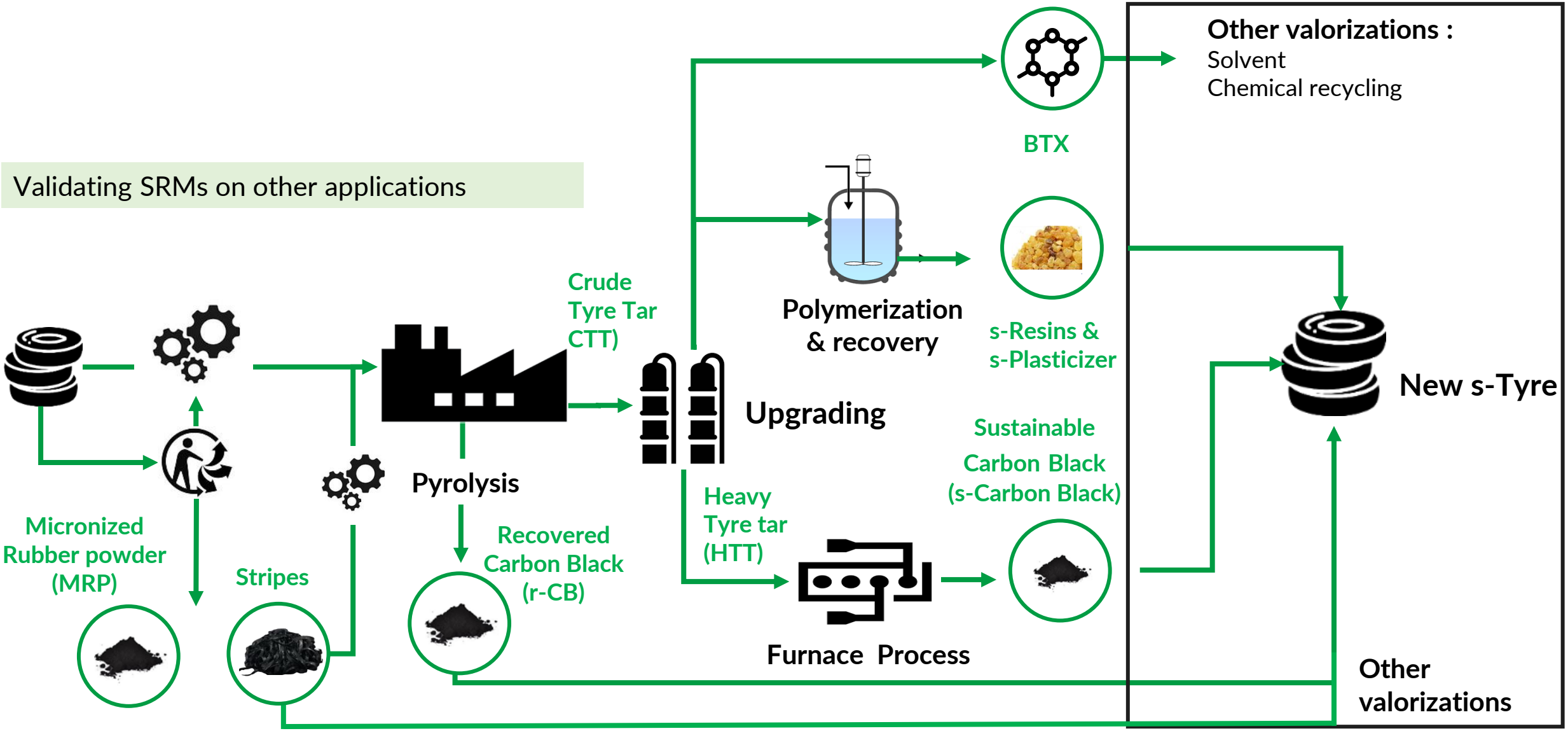
BLACKCYCLE aims at creating, developing and optimising a full Value Chain

Validating SRMs on other applications



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03

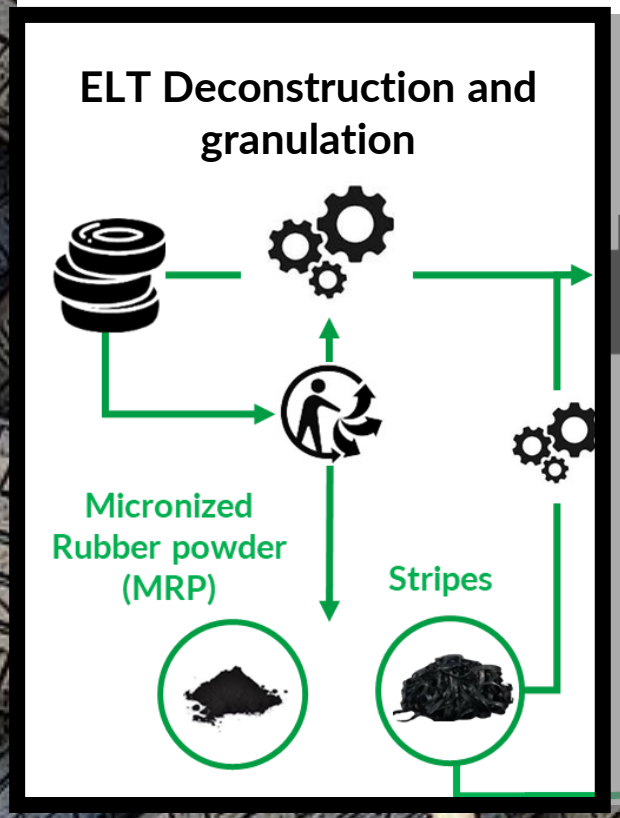
Innovative selective end of life tyre deconstruction

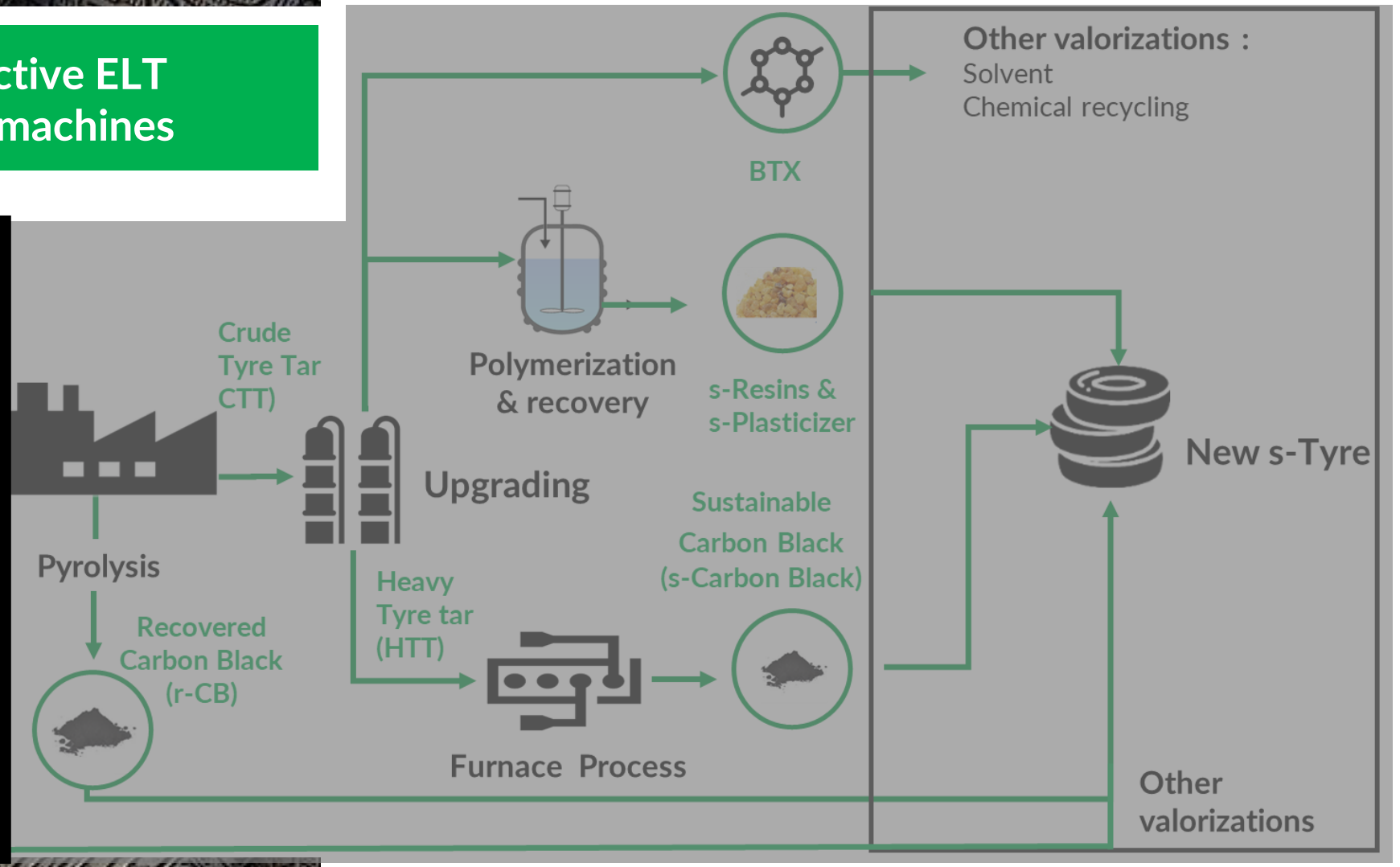
Thomas SIMONELLI – Michelin,
Alexander PROKEIN - Estato

BlackCycle, enable massive and viable circular economy of tyres

BlackCycle Value chain

Innovative selective ELT deconstruction machines





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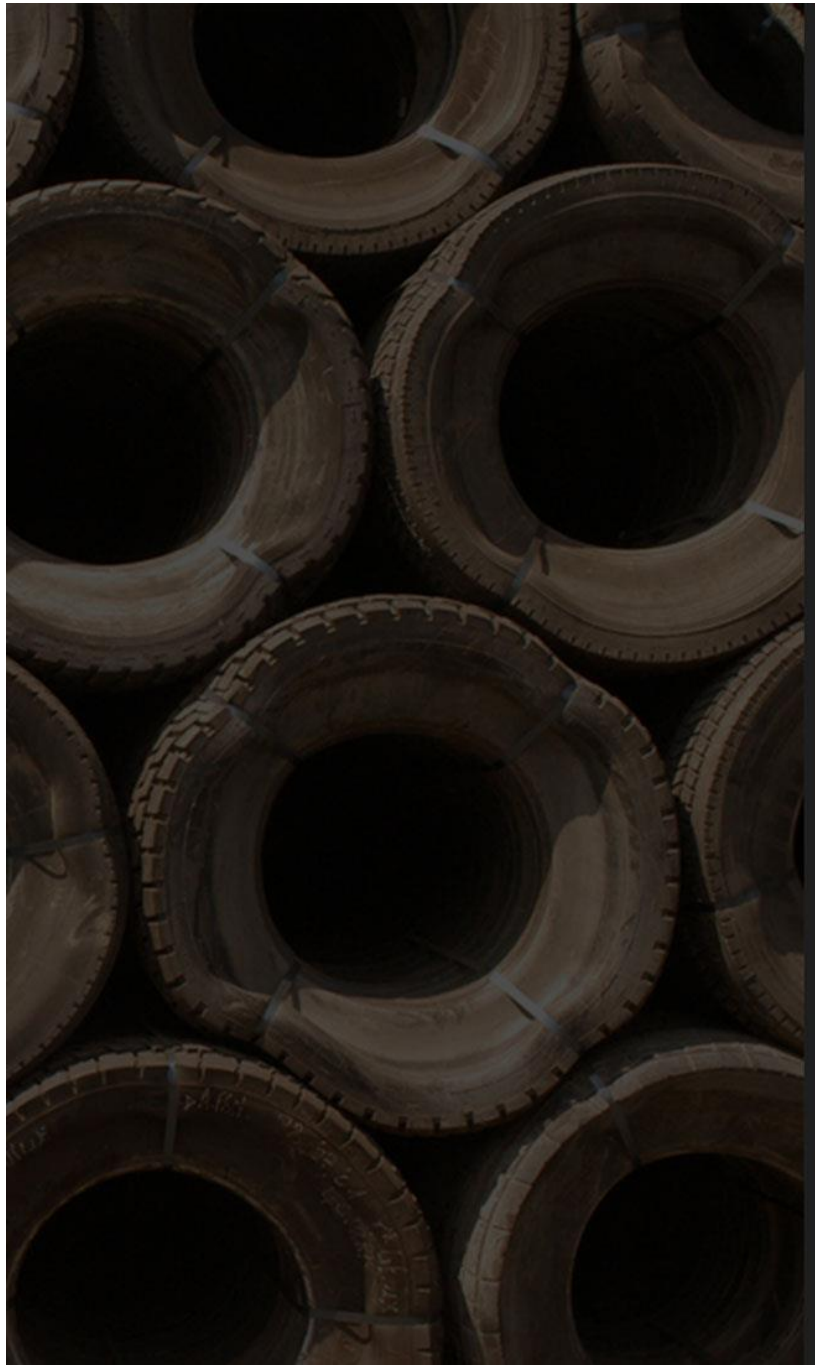


BLACK CYCLE

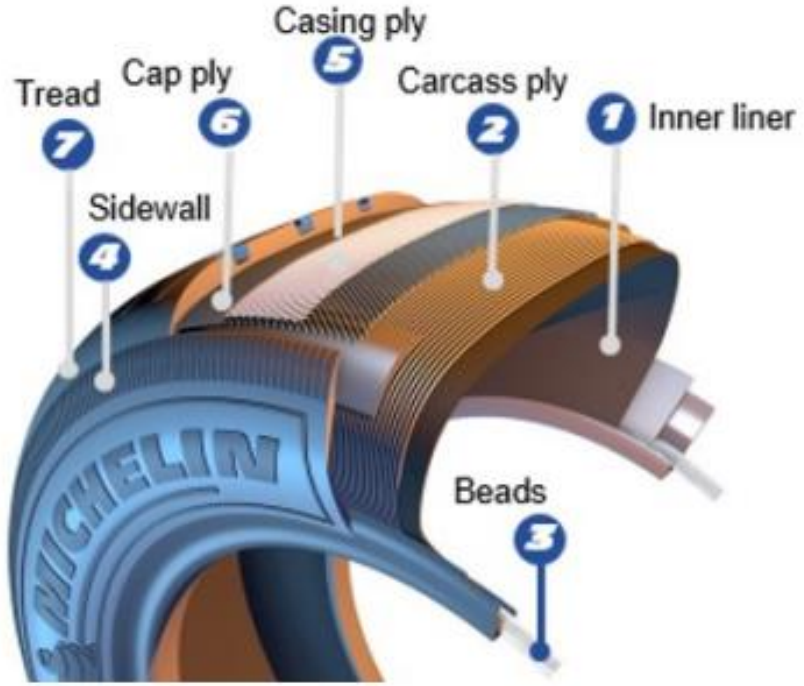
Move to the green revolution

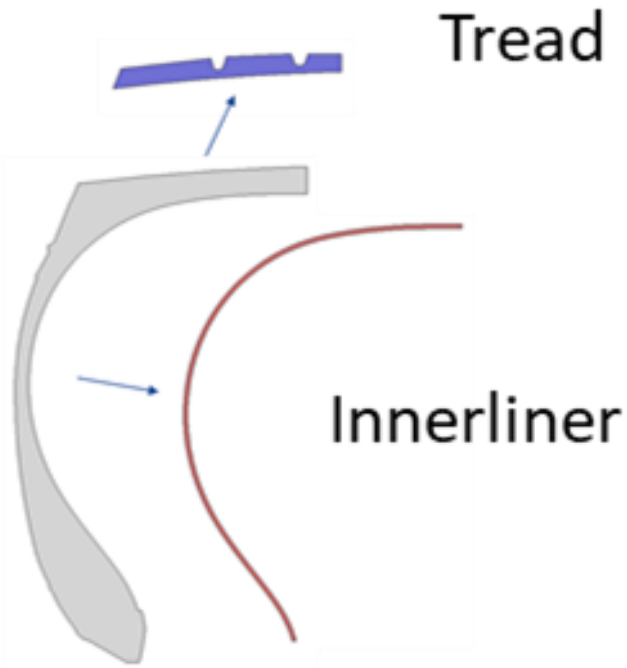
Innovative selective end of life tyre deconstruction

Alexander PROKEIN - Estato

Deconstruction principle & interest

-> Optimize the ELT valorization with higher value feedstocks





There are many different rubbers in tyres

Our choice : tread and innerliner recovery

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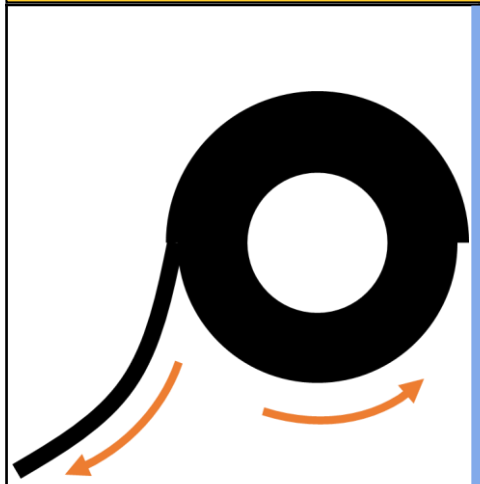
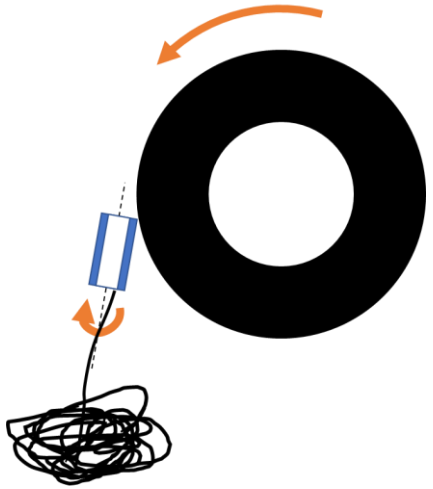
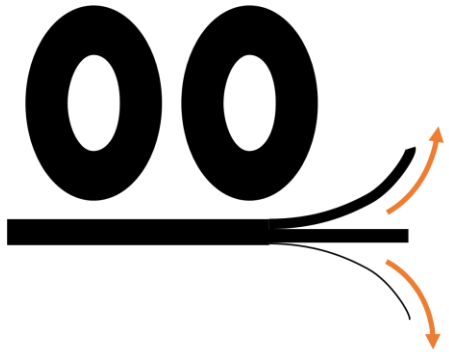
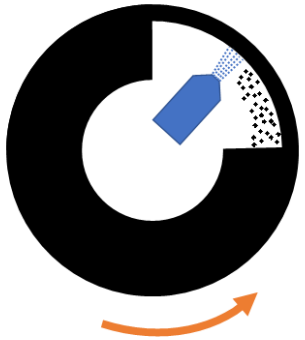
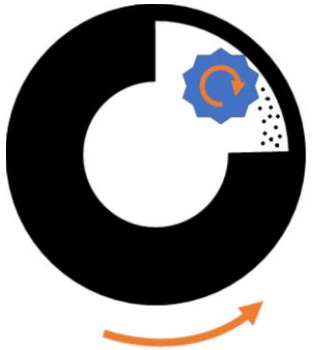
Deconstruction elementary tests

-> *Many different principles tested : 2 selected*

-> *Challenge : to stop the recovery automatically to get pure rubber*

TREAD RECOVERY		INNERLINER RECOVERY		
				
PULLING	CUTTING	SPILTTING	MILLING	GRINDING

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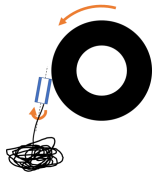
2 Innovative tyre deconstruction processes



Tread recovery : ORC (Outside Rubber Cutting)

Innerliner recovery : IRG (Inside Rubber Grinding)

New technologies developped :

- *Detection systems*
- *Fully automatic designs*
- *Special tools*

Proprietary technologies

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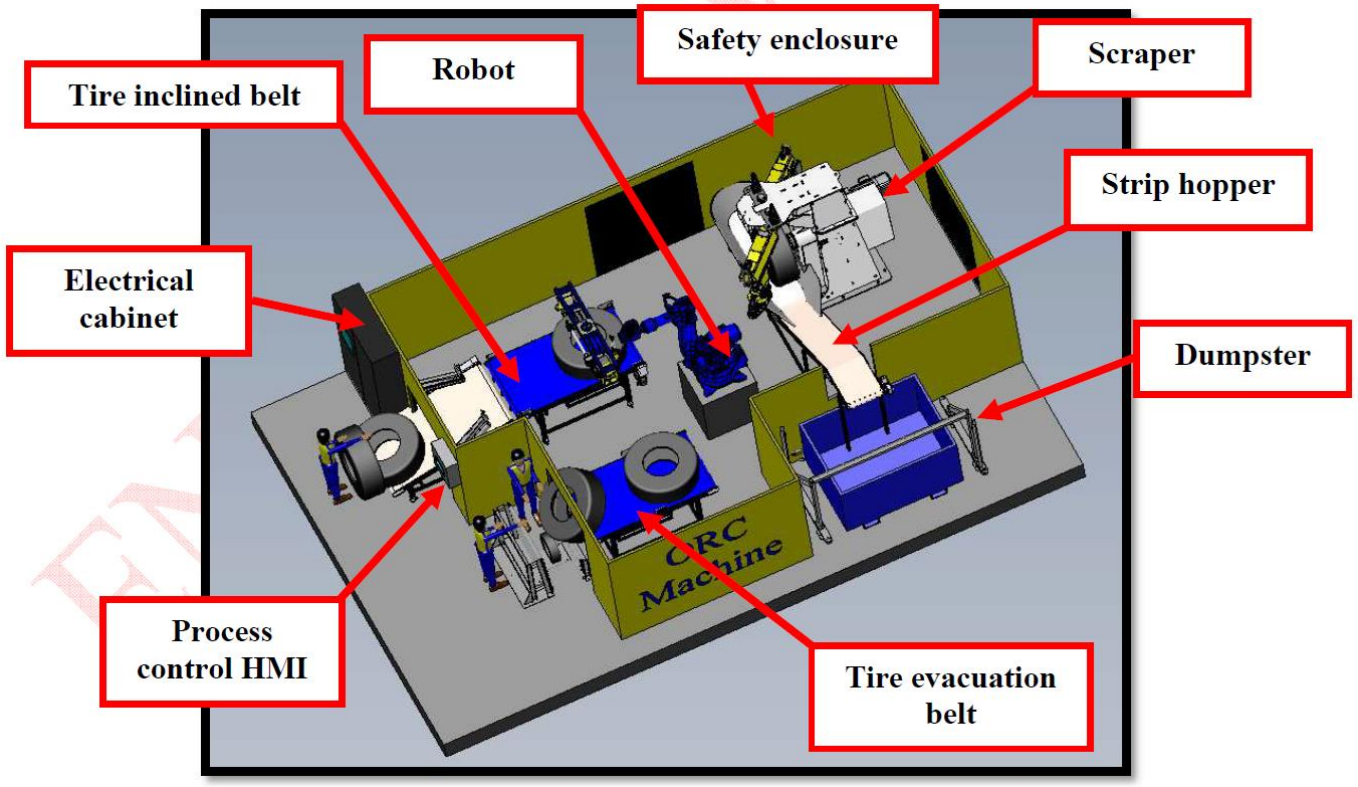
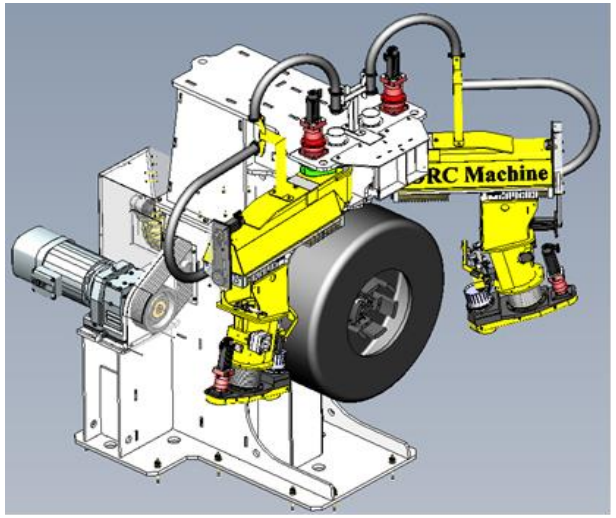
ORC Process : How does it work?



ORC global description



ORC cutting area

ORC in constructor facilities

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ORC Process TRL6 results

-> Innovative, robust, polyvalent & productive process

- Innovative : proprietary technology
- Robust : > 1 400 tyres processed
- Polyvalent :
  - For passenger car & truck tyres
  - All brands, all dimensions
- Productive :
  - Total timecycle : ~ 100s
  - Output : ~ 1kg (PCT), ~ 10kg (TT)

Passenger Car tyre **Truck tyre**

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ORC output adapted to the application

-> *Output : pure feedstock that can be used in different applications*
-> *A shredding step is necessary, size depending on the application*

Output : pure tread stripes

Shredding step

- *Pyrolisis*
- *Powder*
- *Other application*

Medium size

Small size

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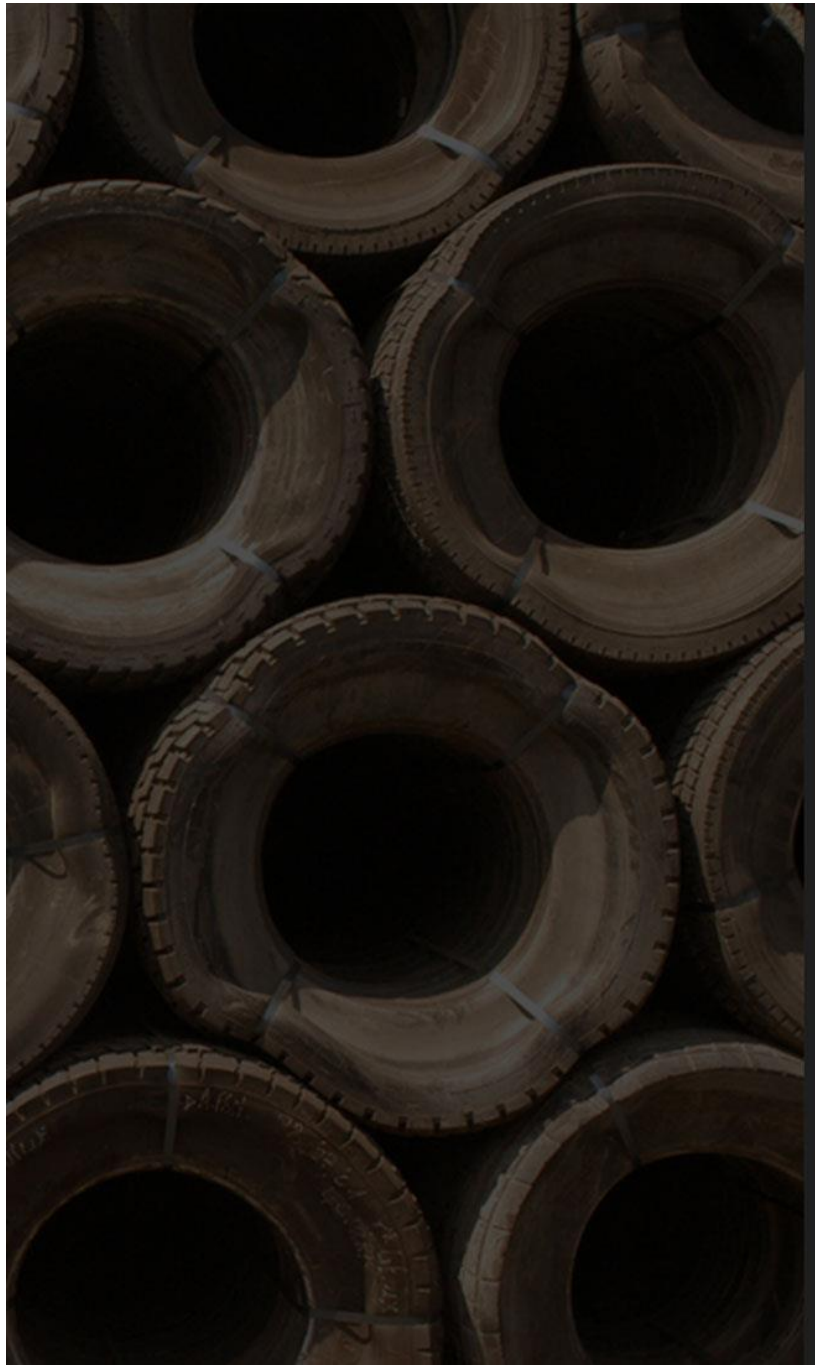


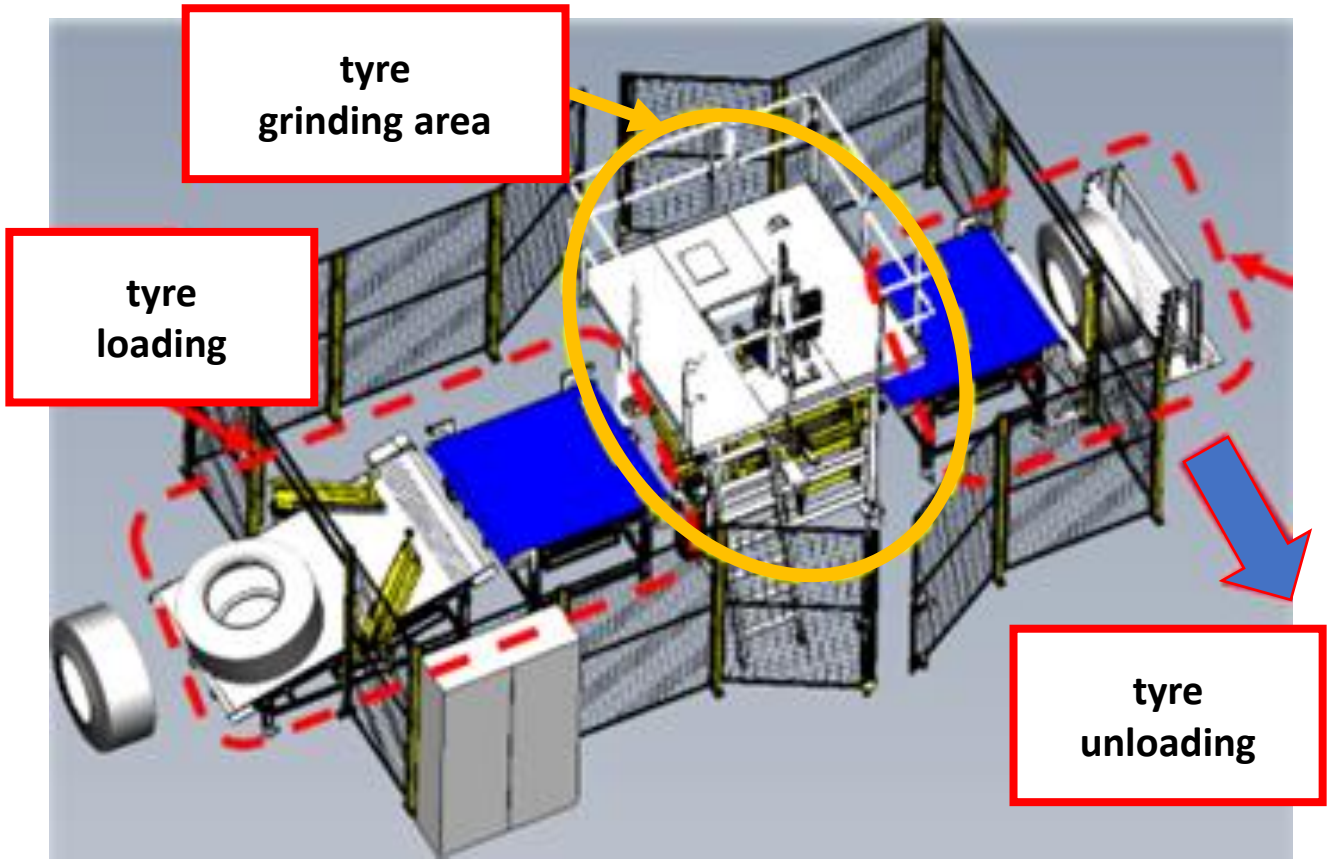
BLACK CYCLE

Move to the green revolution

Innovative selective end of life tyre deconstruction

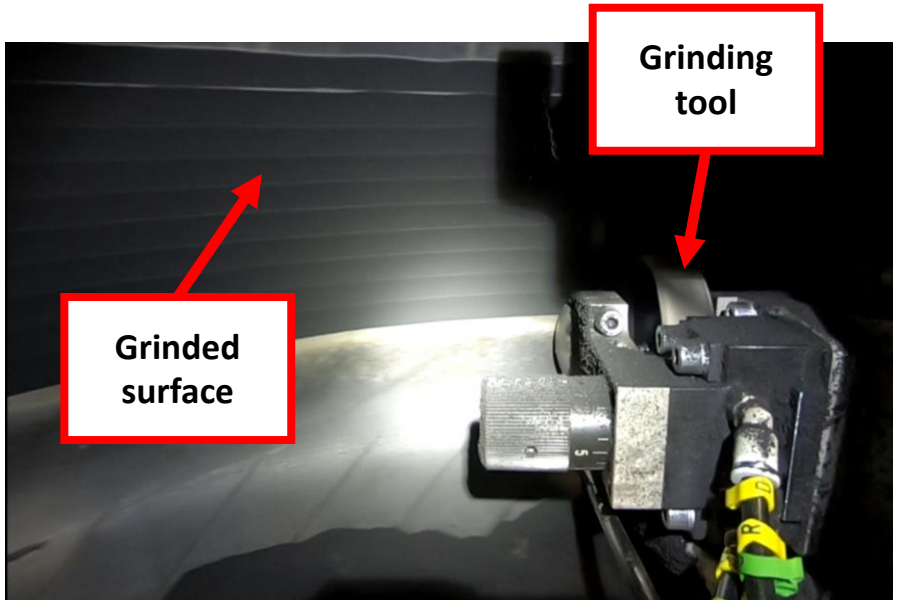
Thomas SIMONELLI – Michelin

IRG Process : How does it work?



IRG global description

IRG grinding arm



IRG grinding process

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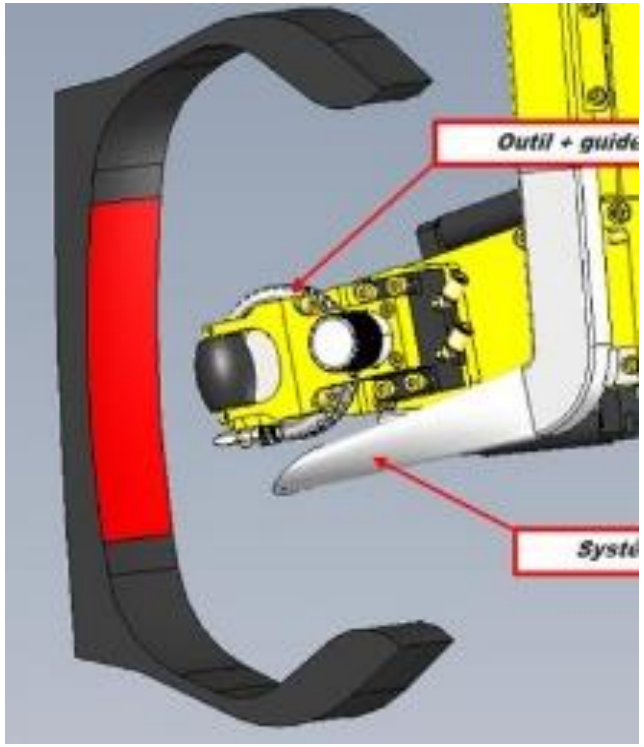
IRG Process TRL6 results

-> Innovative, robust, polyvalent & productive process

- Innovative : proprietary technology
- Robust : > 500 truck tyres processed
- Polyvalent : ~ 20 brands succesfully tested
- Productive :
  - Total timecycle : ~ 240 s
  - Powder output : ~ 1 kg per tyre
  - Powder size : ~ 250 µm



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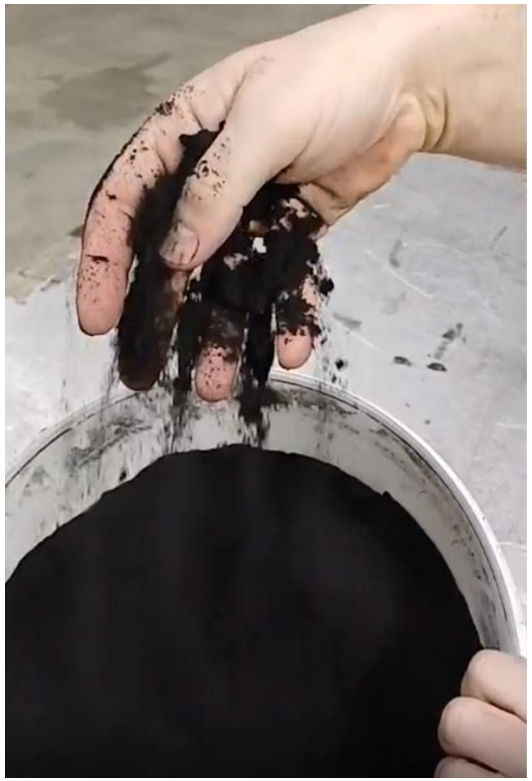
IRG Micronized Powder : many potential applications

-> Output : pure innerliner powder that can be used in different applications



Powder size

250 µm

500 µm

800 µm

Powder validated in tyre application

tyres

Inner tubes

Balloons

Curing bladders

Pyrolisis

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Deconstruction processes

-> Conclusions and perspectives

BlackCycle has successfully developed 2 innovative, fully automatic, robust and productive deconstruction processes at TRL6 to recover higher value pure feedstocks that can be used in many different recycling applications

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04

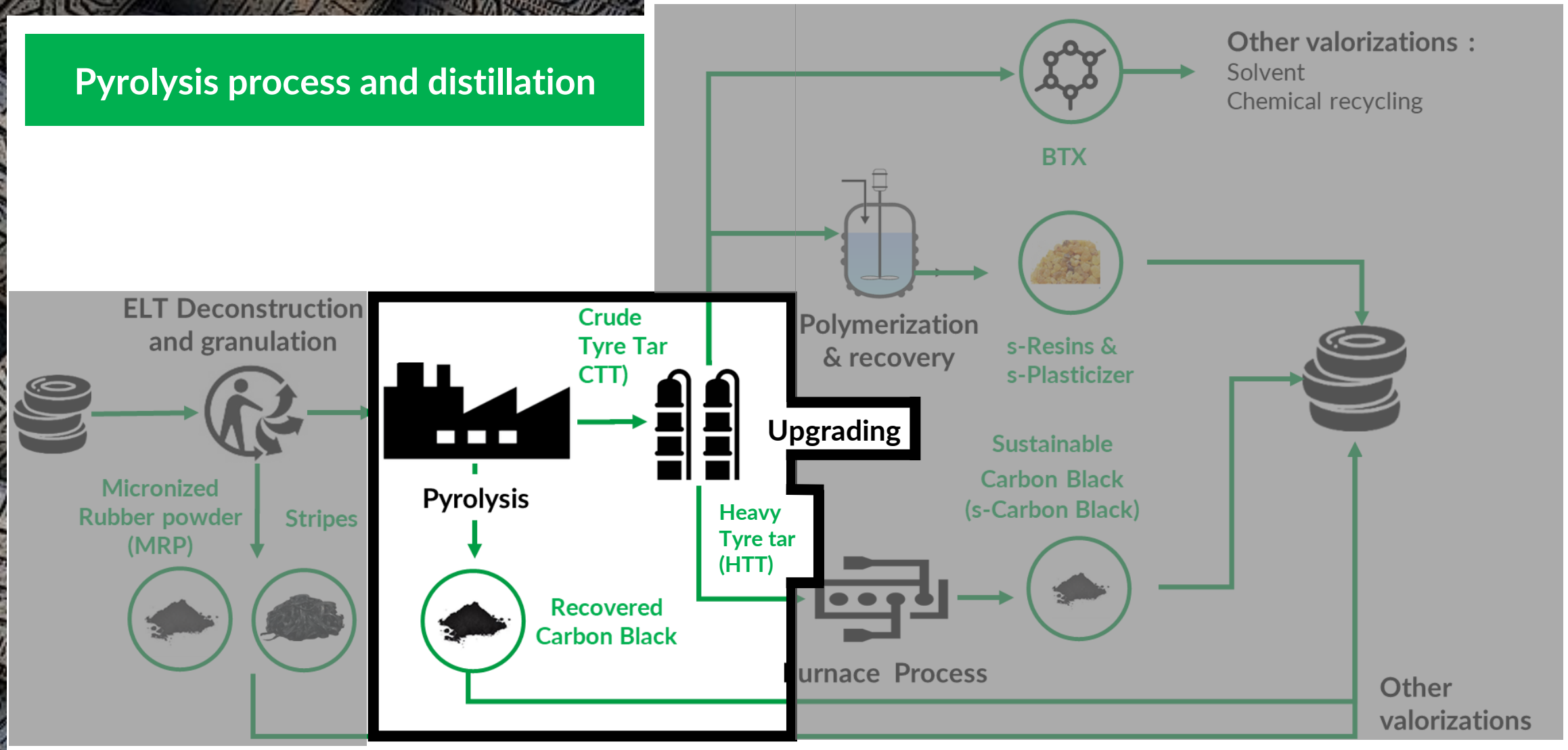
Optimized pyrolysis process and distillation

Andreas KAPF - Pyrum ,
Ignacio de PASCUAL SAMPER Sisener,
Juan Daniel Martinez - ICB

BlackCycle, enable massive and viable circular economy of tyres

BlackCycle Value chain

Pyrolysis process and distillation



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Develop 2 pyrolysis technologies to produce pyrolytic oil and r-CB

Depending on the quality of the of ELTs granulates and the operating conditions of pyrolysis

Moving Bed Reactor

TRL4
kg samples

TRL 9 dozens tons samples

Auger Reactor

TRL5
Hundreds kg samples

TRL7 - dozens tons samples

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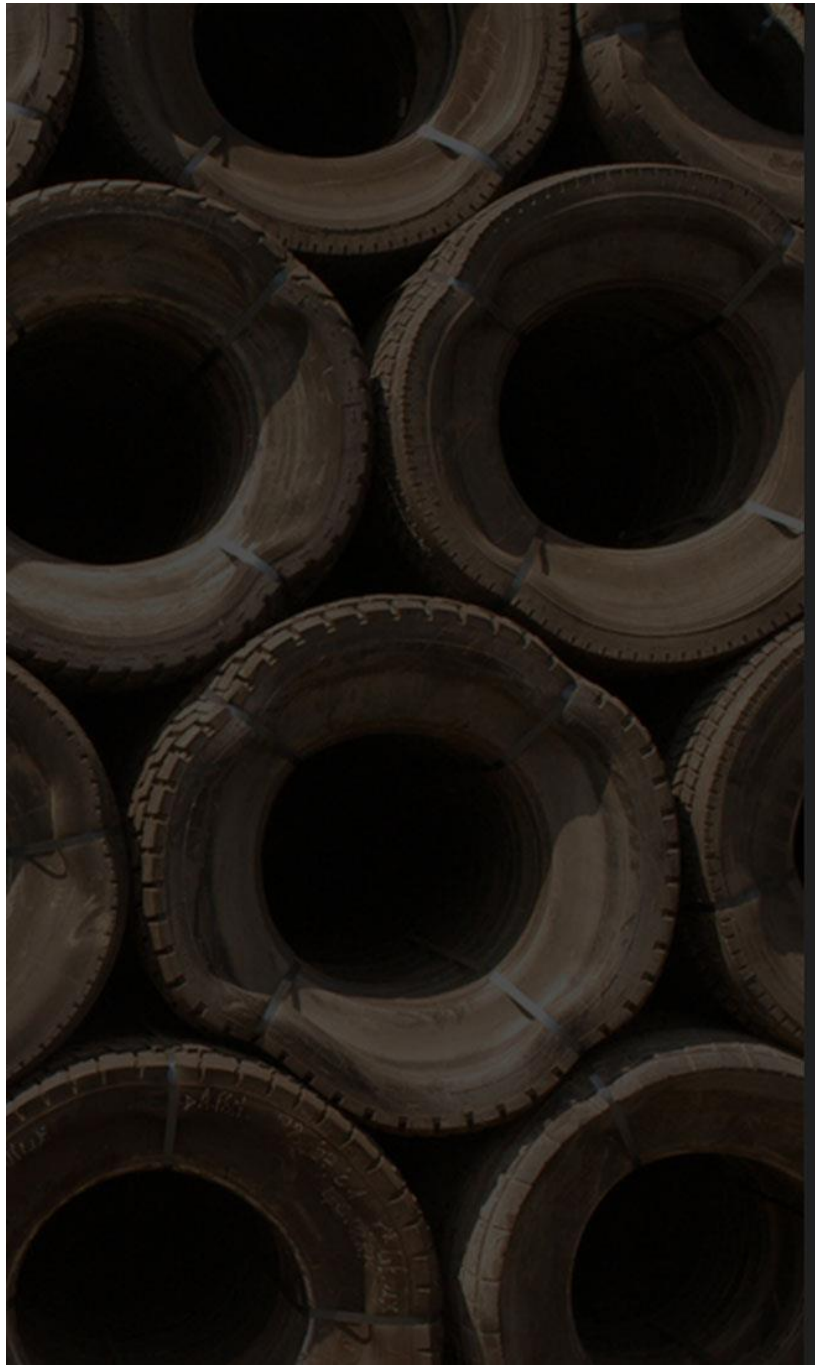


BLACK CYCLE

Move to the green revolution

Optimized pyrolysis process (moving bed reactor)

Andreas KAPF - Pyrum

Moving bed technology

Worldwide patented technology

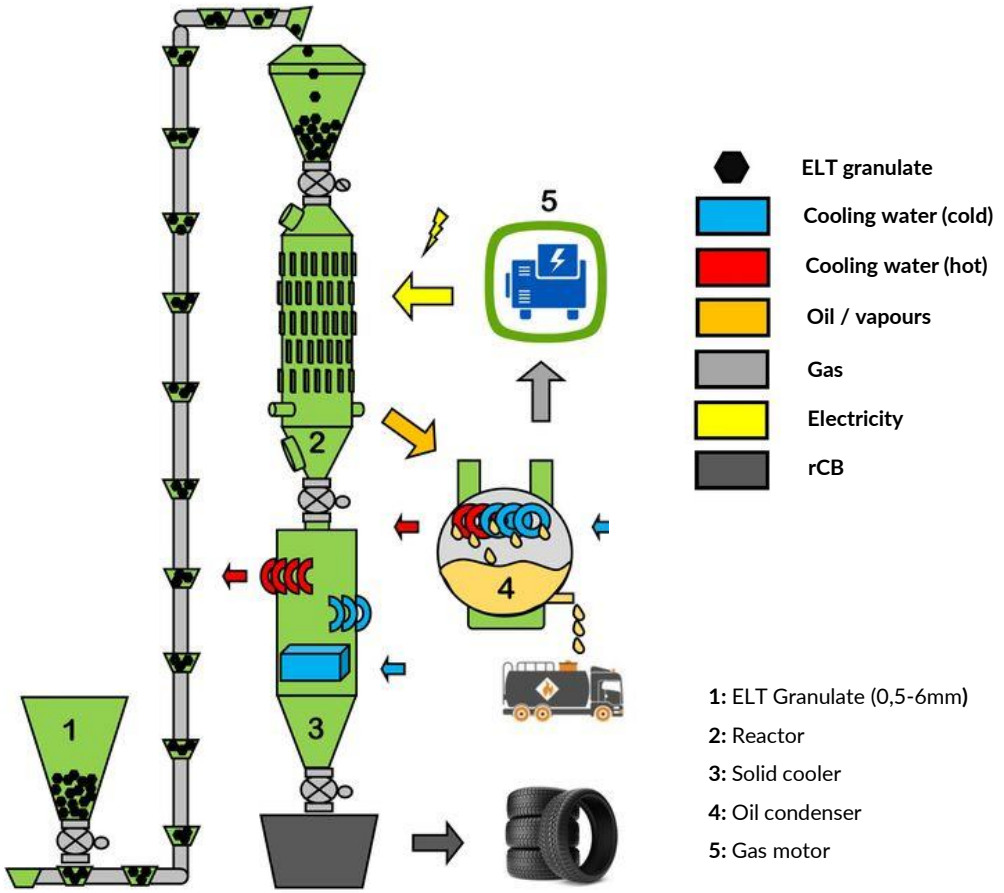
Advantages

1 ▸ **Proven concept**:
- In test operation since **2015**
- In 24/7 industrial production with commercial sales since **2020**

2 ▸ **Total control**:
152 electrical heating units distributed over 5 levels can be **individually** controlled to optimize the temperature input and product quality.

3 ▸ **Robust and safe design**:
The material is passing through the reactor just with **gravity**. The absence of moving parts and their sealings within the reactor results in low-maintenance and safe operation

4 ▸ **Energy self sufficient**
The electrification of the pyrolysis gas in the results in **more electrical energy** than the whole pyrolysis plant consumes



1: ELT Granulate (0,5-6mm)
2: Reactor
3: Solid cooler
4: Oil condenser
5: Gas motor

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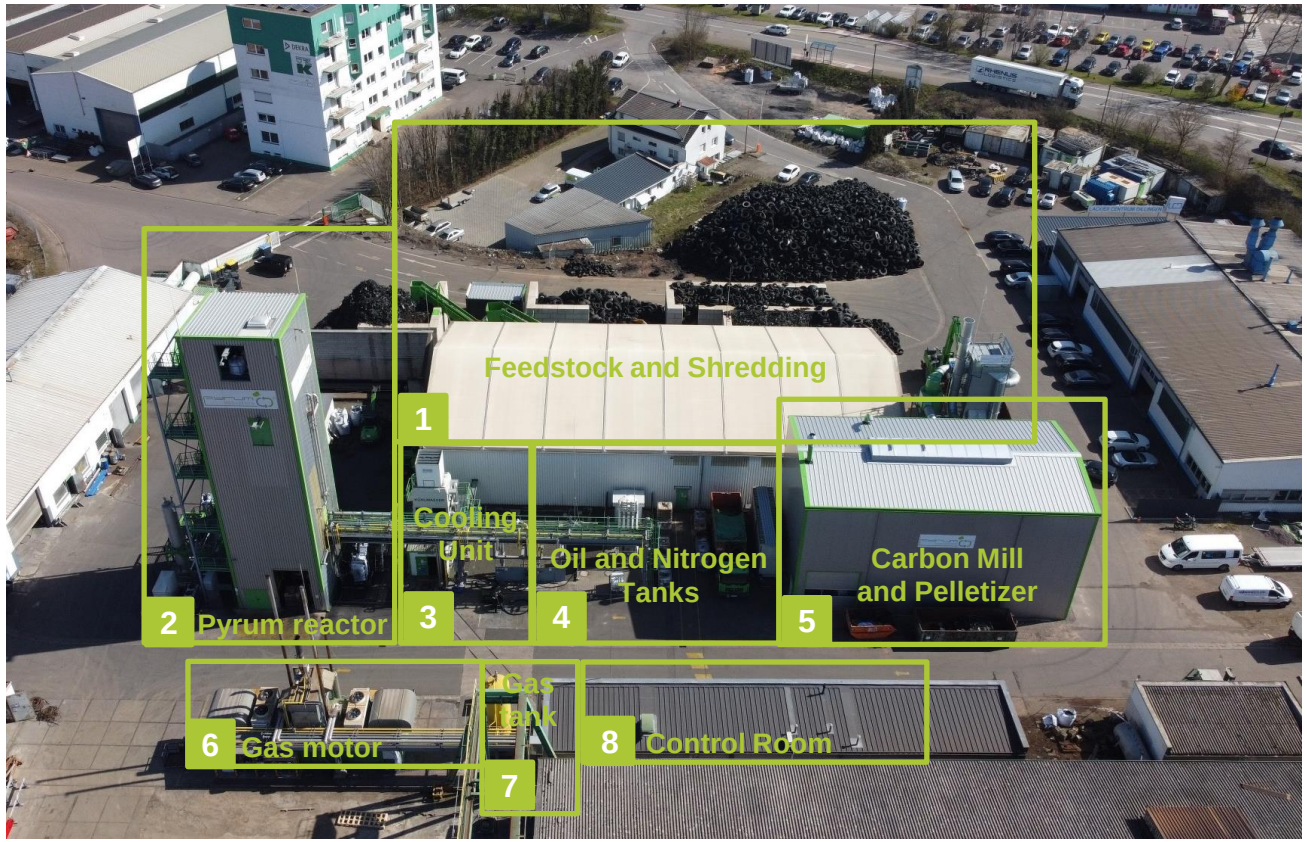
Overview: Plant side



1. **Feedstock (End-of-Life-tyres) and shredding unit**: granulating whole tyres and separating rubber from steel and textile fibers
2. **Pyrum reactor:** patented main part of the Pyrum process. 25-meter-high tower transforming rubber granulates into pyrolysis oil, carbon and gas
3. **Standardized cooling unit:** to cool the whole process and all end products
4. **Oil tanks (40,000 liters underground) and pumping station:** to fill trucks with Pyrum oil + nitrogen
5. **Carbon mill and pelletizer:** to transform raw carbon to commercial recovered Carbon Black (rCB)
6. **Gas generator:** creation the power for the Pyrum Plant thanks to the produced gas from the process
7. **Storage and cleaning of pyrolysis gas:** before it enters the gas generator
8. **Control room:** controlling the entyre plant with 2-3 persons only

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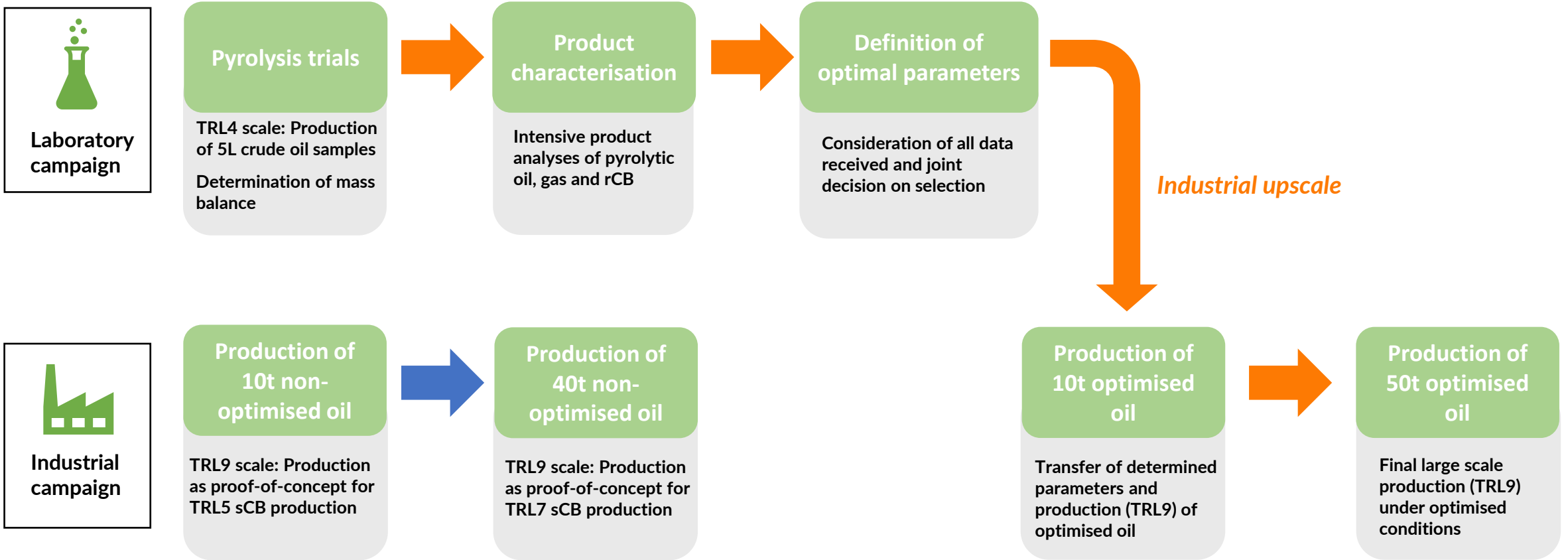
Overview actions within BlackCycle project
Optimisation of conditions on laboratory and scale-up



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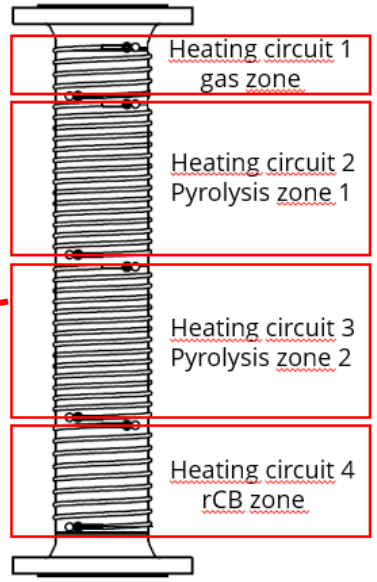
From laboratory to industrial scale

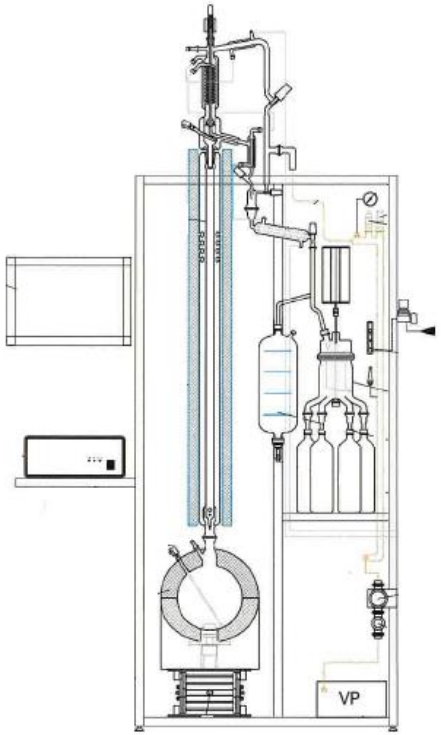
Pyrolysis

TRL4 laboratory pyrolysis plant



TRL4 reactor

Distillation



TRL4 laboratory distillation plant

The optimization of the pyrolysis not only based on crude pyrolytic oil, also in consideration of the final distilled product.

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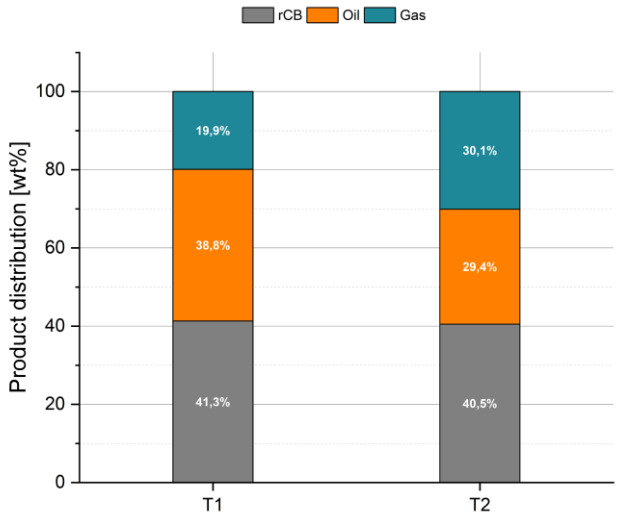
Influence of temperature

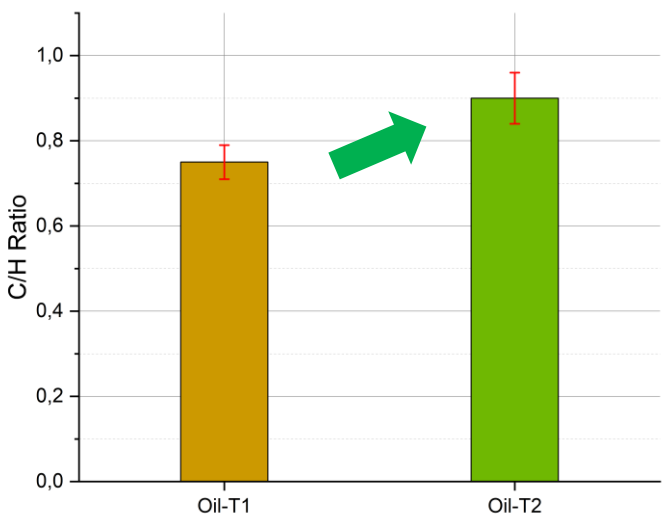
Pyrolysis trials at TRL4 performed at two temperature profiles: T1 < T2

Product distribution



- Higher oil yield and lower gas yields at lower process temperatures
- rCB yield is not effected

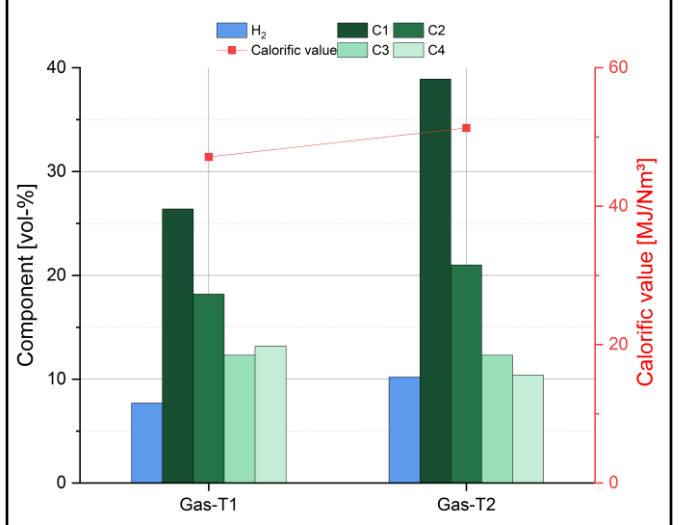
Pyrolysis oil



Higher content of aromatic molecules at higher process temperatures

→ Higher C/H ratio at higher process temperatures

Pyrolysis gas



- Higher H_2 content at higher process temperatures
- Lower C2-C4 content at higher process temperatures
- Higher calorific value at higher process temperatures

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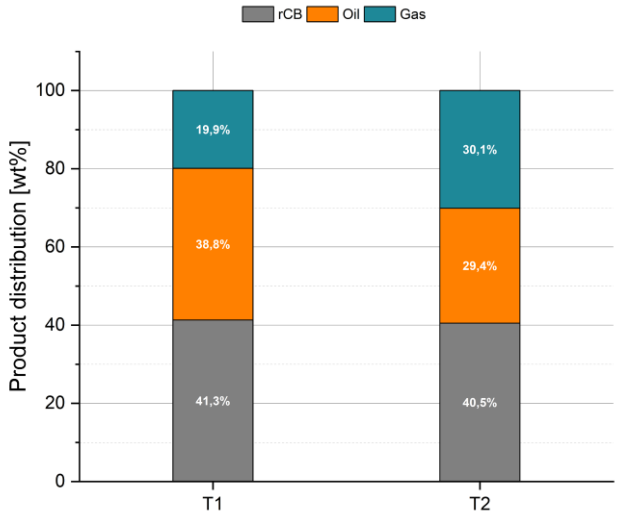
Influence of temperature

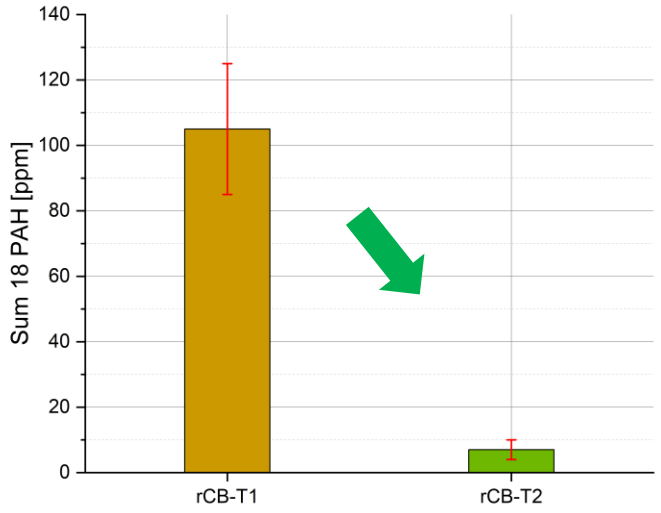
Pyrolysis trials at TRL4 performed at two temperature profiles: T1 < T2

Product distribution

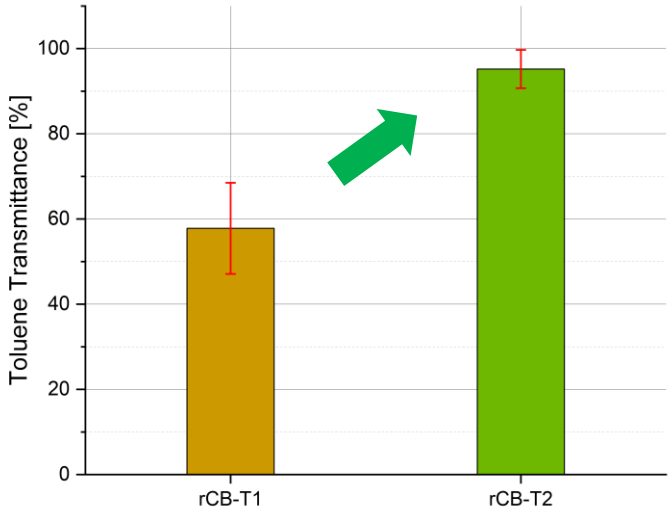


- Higher oil yield and lower gas yields at lower process temperatures
- rCB yield is not affected

rCB (untreated)



Higher process temperatures resulted in significant lower PAH contents in the rCB



Higher process temperatures increased the toluene transmittance and decreased the volatile content

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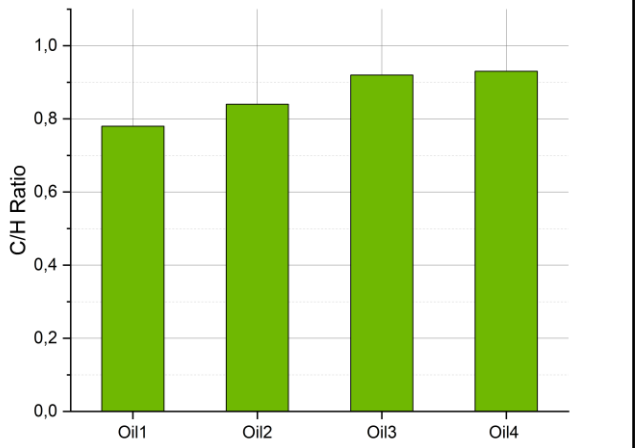
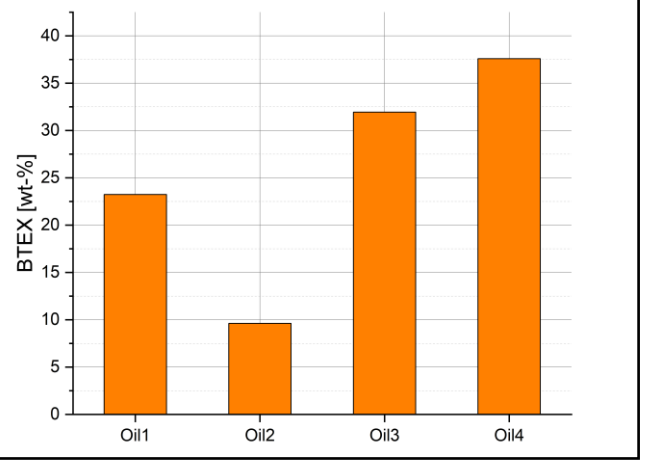
Influence of ELT feedstock

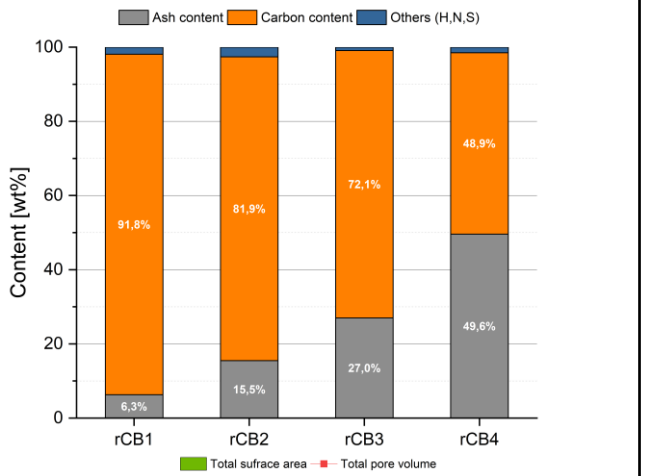
Pyrolysis trials at TRL4 performed with four different and pure ELT feedstocks with similar granulate properties

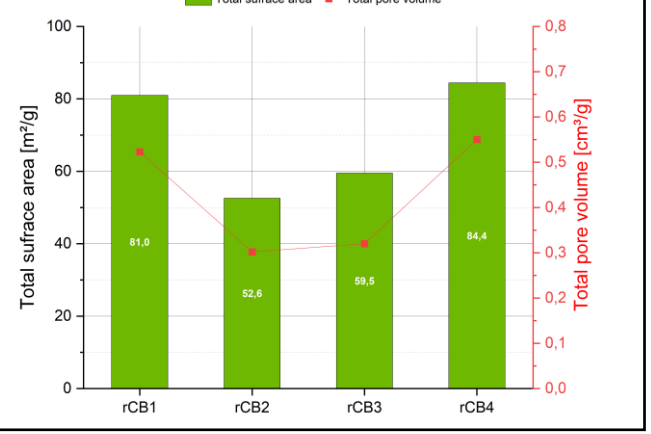
Pyrolysis oil



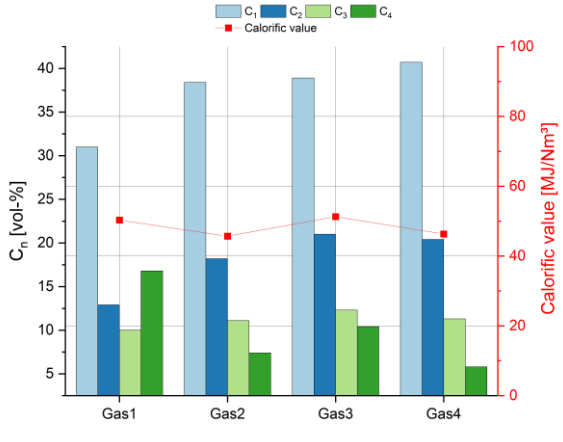


rCB (untreated)





Pyrolysis gas



Consideration of all obtained data of the influences of temperature and feedstock and selection of the settings for the industrial upscale

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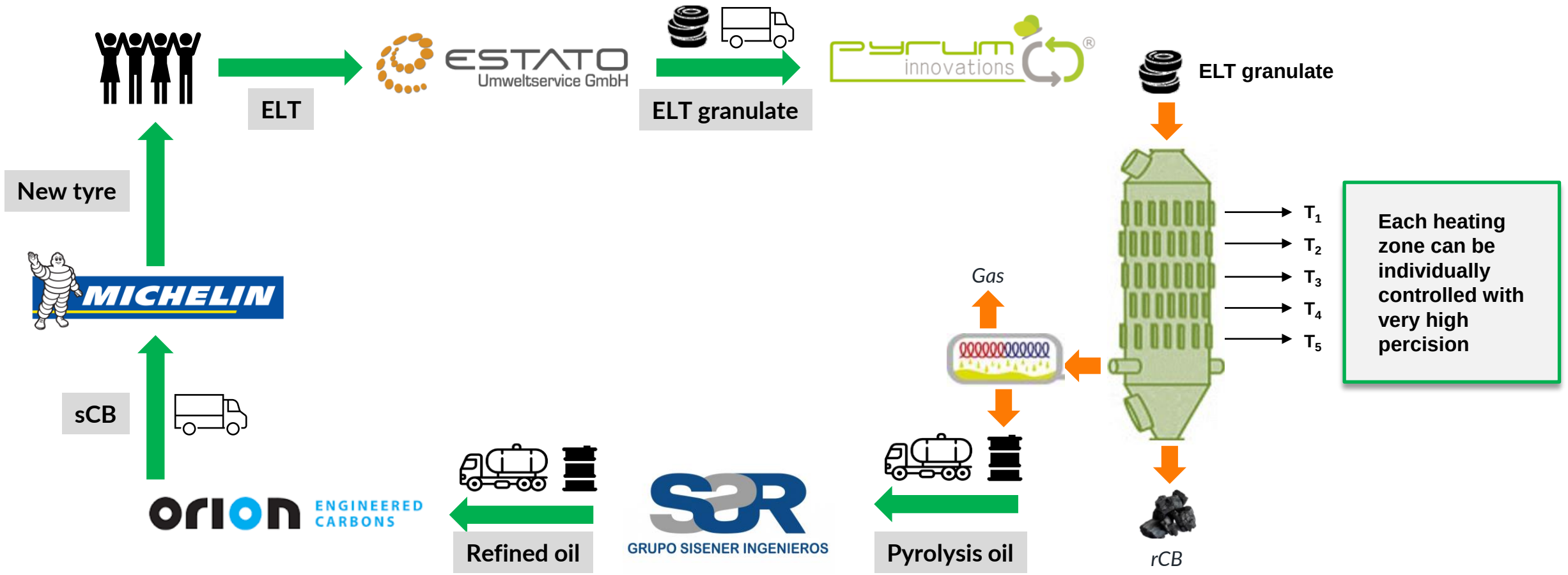
Industrial campaign



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Industrial campaign

Overview production data

	Name	Trial 1	Trial 2	Total
Input	ELT granulate	43,6 t	219,4 t	**263,0 t**
	Electricity	18,3 MW	91,5 MW	**109,8 MW**
Output	Pyrolytic oil	10,1 t	50,7 t	**60,8 t**
	Pyrolytic gas	9,8 t	69,6 t	**79,4 t**
	rCB	19,7 t	99,2 t	**118,9 t**
	Electricity	27,6 MW	138,0 MW	**165,6 MW**

In both trials a surplus of electrical energy was produced and was fed into net grid.

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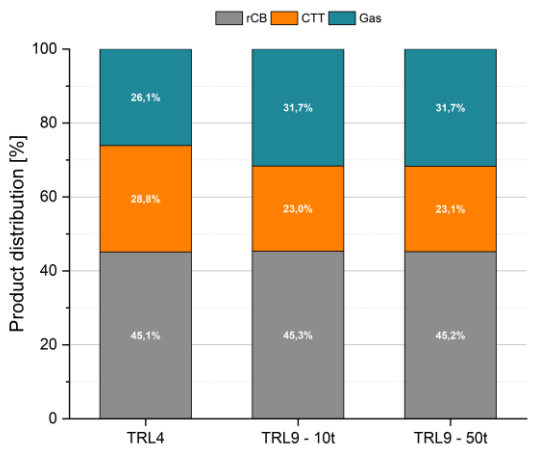
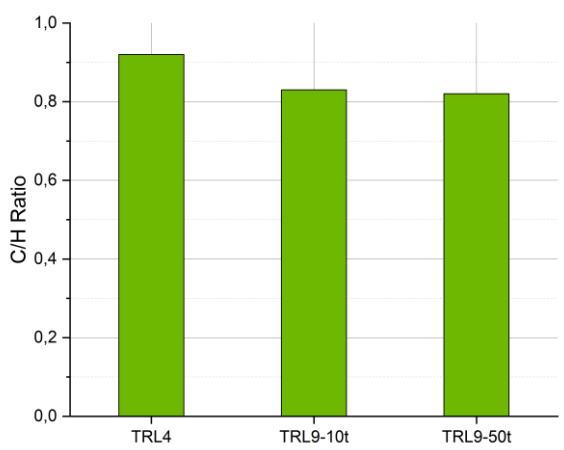
Comparison: Laboratory vs industrial campaign

Product distribution



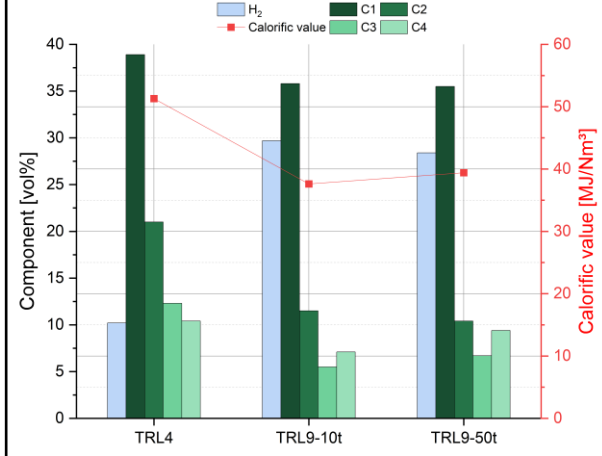
- Higher oil yield at TRL4
- Higher gas yield at TRL9
- Similar rCB yields

Pyrolytic oil



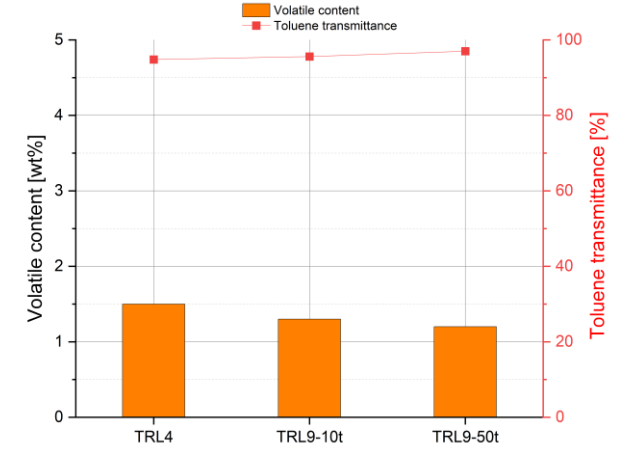
- Lower C/H ratio at TRL9

Pyrolytic gas



- Higher H_2 content at TRL9
- Lower content of C2-C4 at TRL9

rCB



- No significant deviations

1) Successful optimization of the industrial process and high quantity oil production
2) TRL4 trials give a detailed prediction of the product distribution and product quality of an industrial upscale → Highest similarity for rCB
3) Both TRL9 trials show close to identical product composition → Excellent process stability and repeatability

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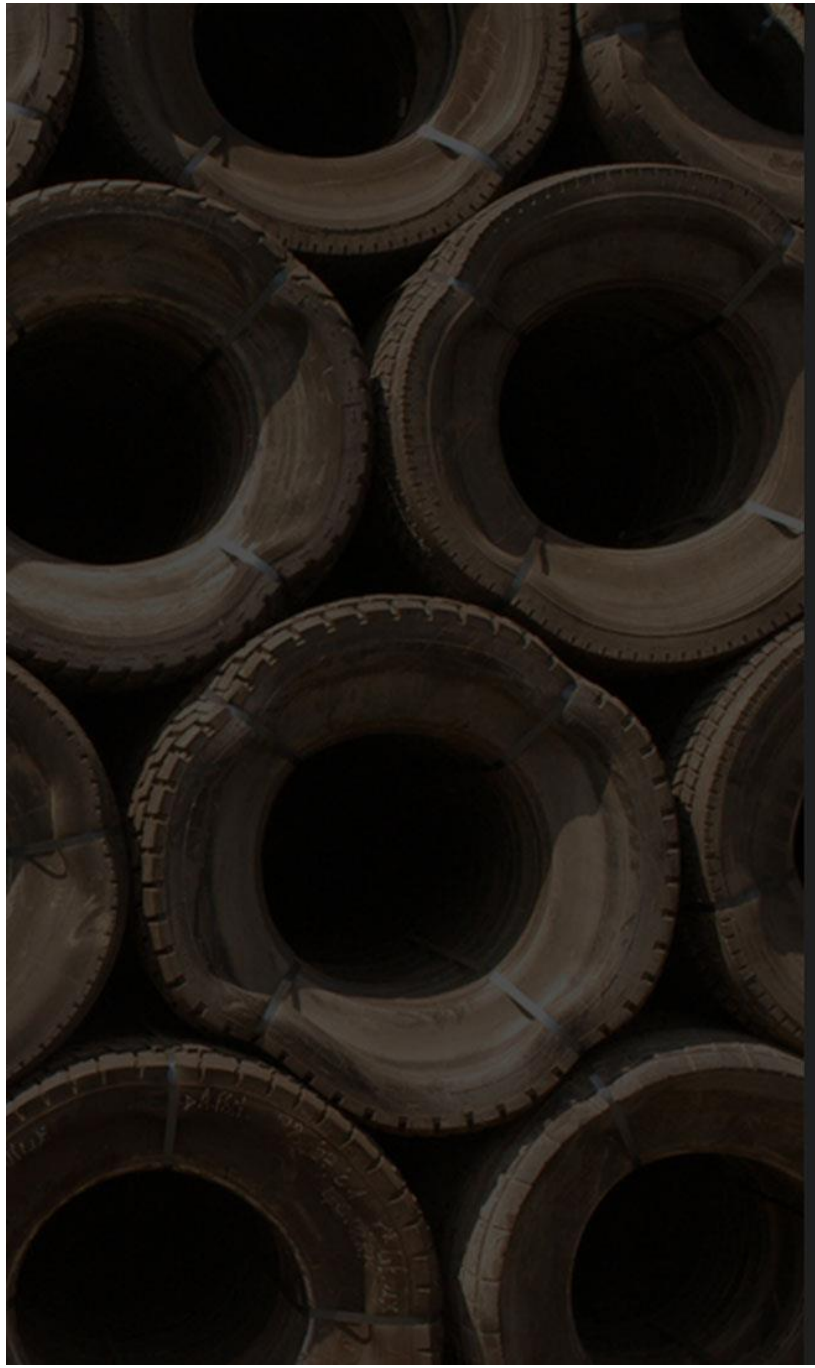


BLACK CYCLE

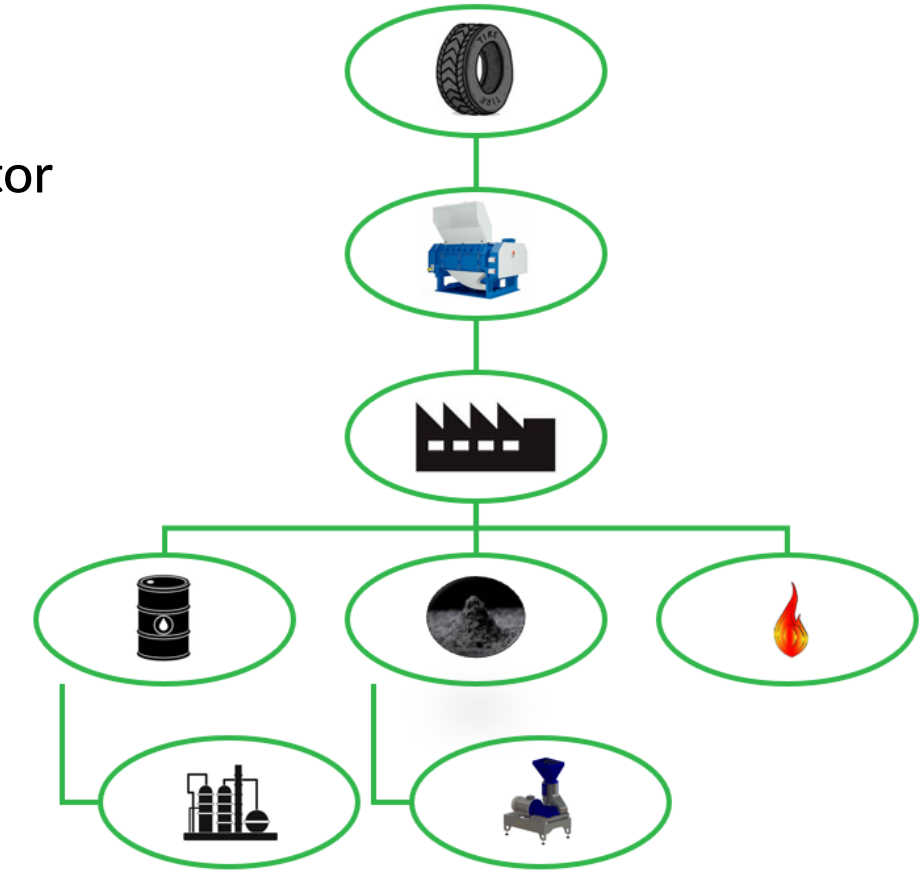
Move to the green revolution

Optimized pyrolysis process Auger Technology

Ignacio de PASCUAL SAMPER – Sisener

Optimized Auger Pyrolysis Process
INDEX

1. Auger technology: versatile continuous pyrolysis reactor
2. Facilities in Zaragoza
3. Pyrolysis scale-up with Auger reactor
4. Comparison between pyrolysis technologies
5. Conclusions



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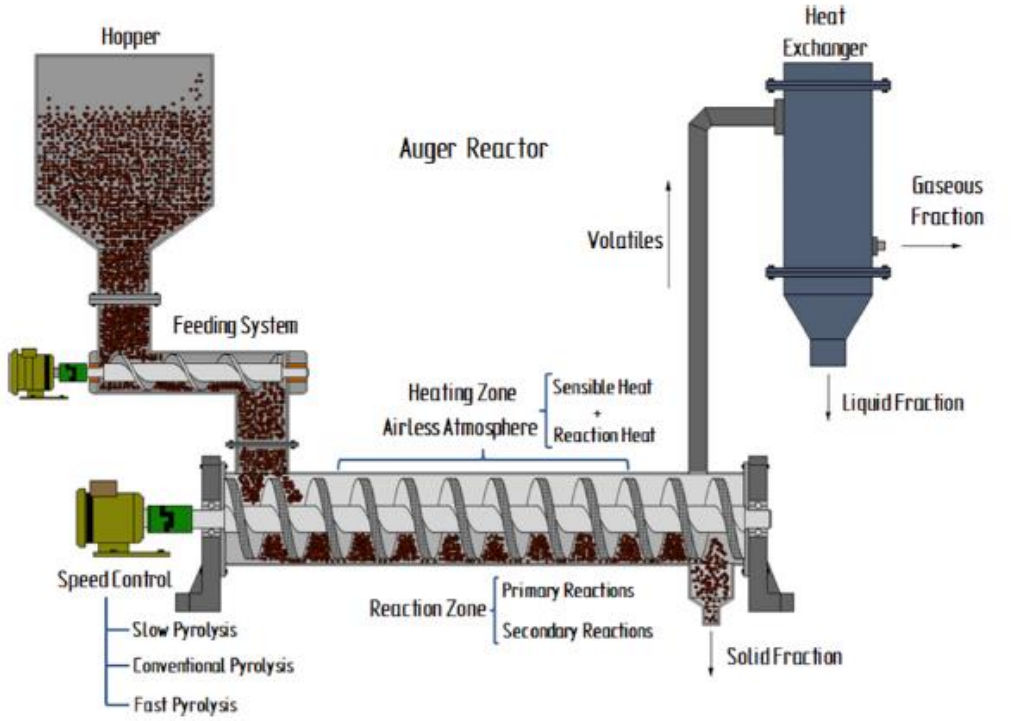
Optimized Auger Pyrolysis Process
A versatile continuous pyrolysis reactor



Source: Pyrolysis process scheme in a single-auger reactor. Adapted from [Auger reactors for pyrolysis of biomass and wastes. Campuzano et al 2019]

- Continuous operating reactor
- Absence of oxygen in the process
- Versatility in feedstock
- Versatility in operations conditions
  - 500-700 °C, favoured at low pressures, below 500 mbar
- Different products obtained:
  - solid, gas, liquid

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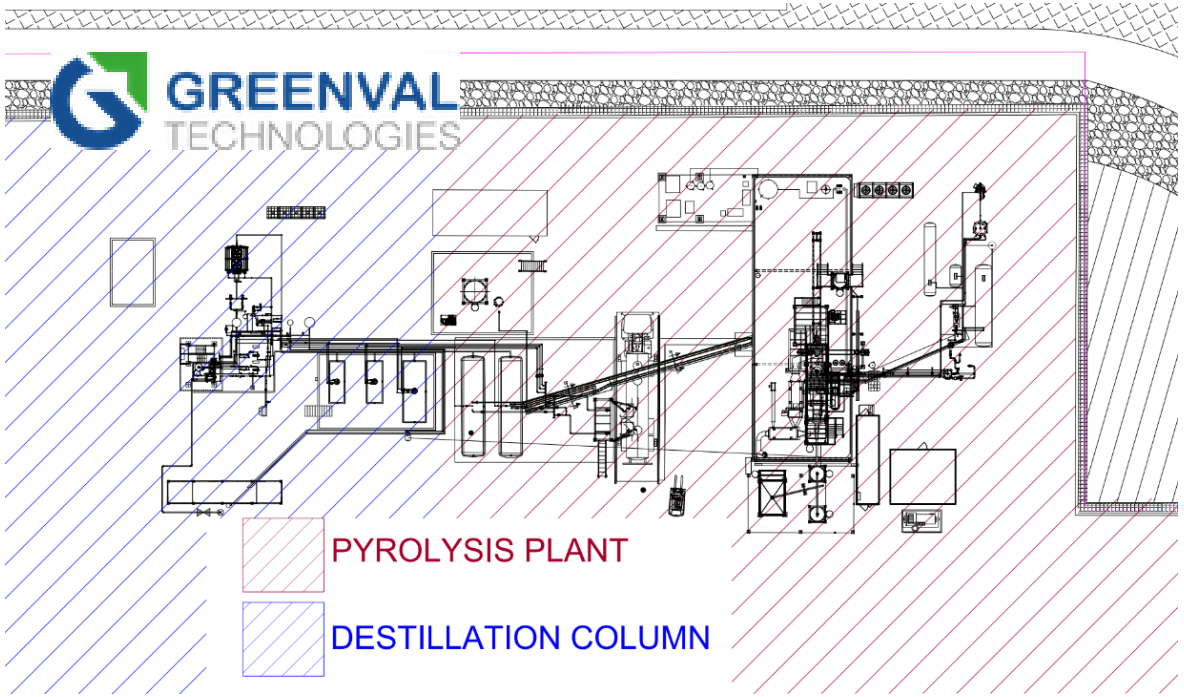
Optimized Auger Pyrolysis Process

Facilities in Zaragoza



- 5.000 tons/year of granulated rubbers
- Energy self sufficient
- Safe and reliable reactor
- Modulable
- Good quality products obtained

Greeenval Technologies S.L. is developing the Auger technology

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Optimized Auger Pyrolysis Process

Facilities in Zaragoza

Pyrolysis plant + distillation column

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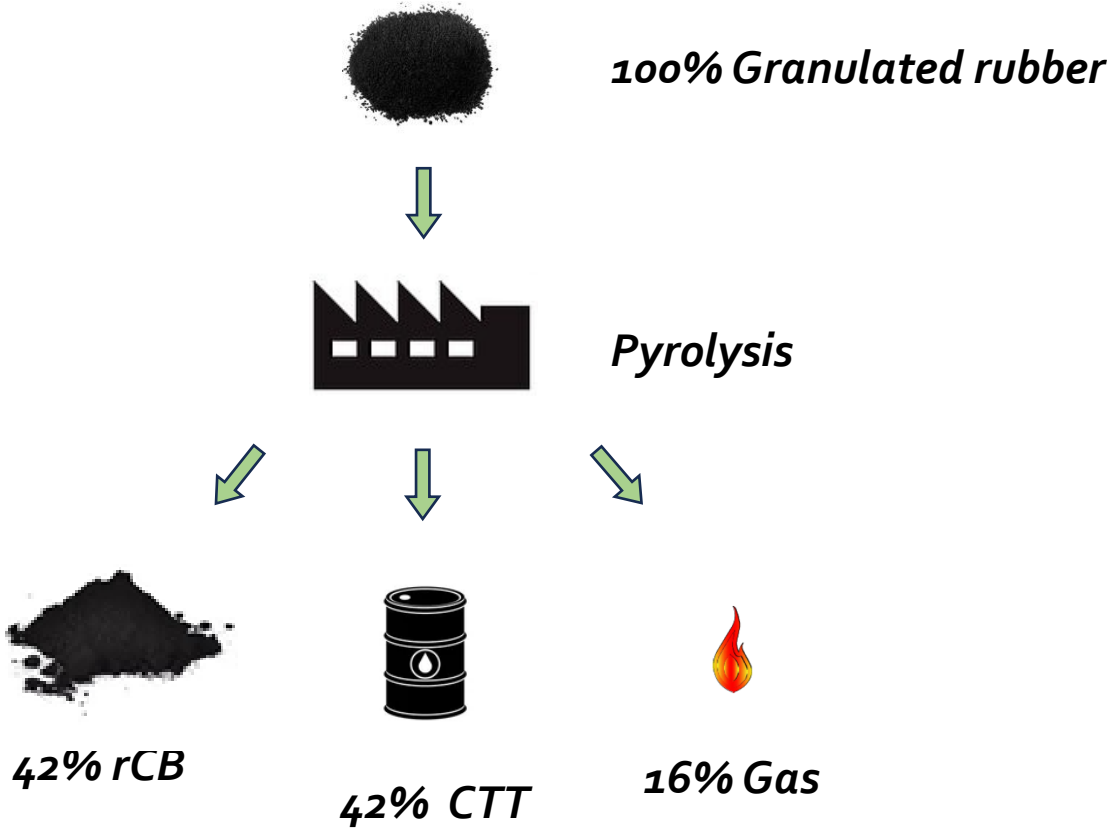
Optimized Auger Pyrolysis Process

Pyrolysis scale-up with Auger reactor : rCB/CTT/Oil production

TRL5 - Hundreds kg samples

TRL7 – Dozens tons samples



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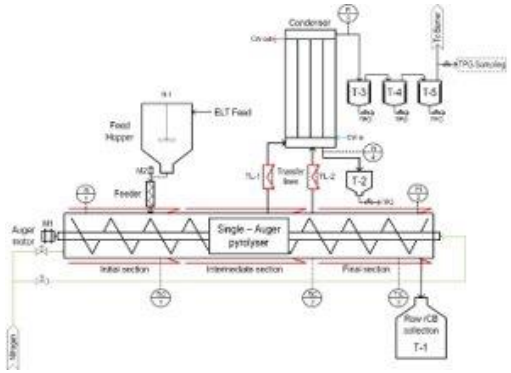
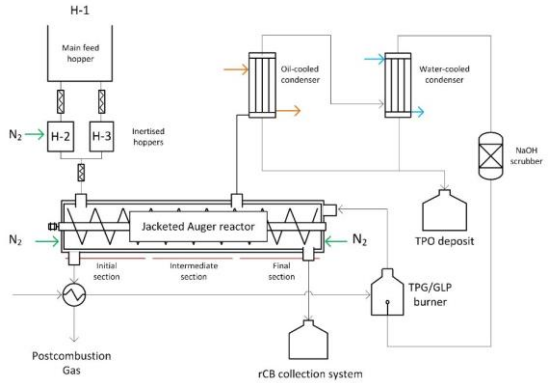
Optimized Auger Pyrolysis Process

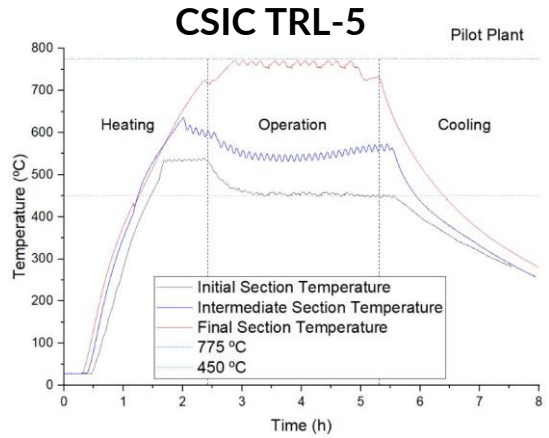
Pyrolysis scale-up : similar temperature profiles can be reached

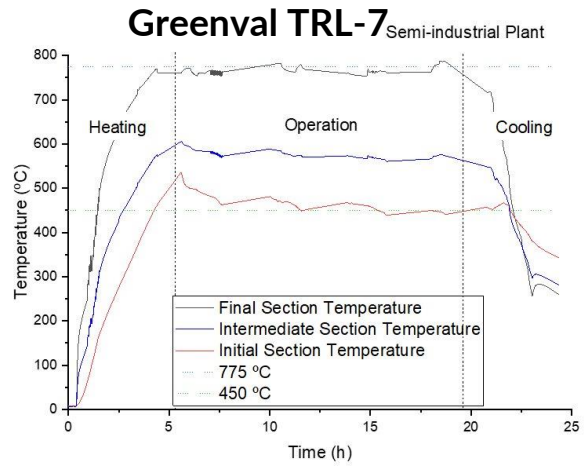


CSIC TRL-5



Greenval TRL-7





Validation of Auger reactor scale-up

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Optimized Pyrolysis Process

Pyrolysis scale-up : gas, r-CB and CTT characteristics at TRL 7

42% rCB

42% CTT

16% Gas

r-CB (% weight)	*TRL 7 (GREENVAL)*
Moisture	0,24
Ash	20,91
Volatile	1,62
Fixed carbon	77,23

CTT (% weight)	*TRL 7 (GREENVAL)**
Benzene	0,39
Toluene	1,33
Ethylbenzene	0,46
p-Xylene y m-Xylene	1,03
Styrene	0,57
o-Xylene	0
Limonene	5,1

Syngas (% mol)	*TRL 7 (GREENVAL)*
H_2	24,1
CH_4	34,5
COx	3,1
C_2	13,3
C_3	6,6
C_4	9
$>C_4$	8,9
COS	0,02
H_2S	0,5
CH_4S	0,02

**Greenval's data from the pyrolysis plant in April 2024*

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Optimized Pyrolysis Process Conclusions

- Auger technology developed by Greenval is a versatile continuous pyrolysis reactor
- Using Greenval facilities in Zaragoza, the scale up of the optimized operating conditions was validated producing specific CTT and rCB
- More than 40tn of optimized CTT oil produce for the project

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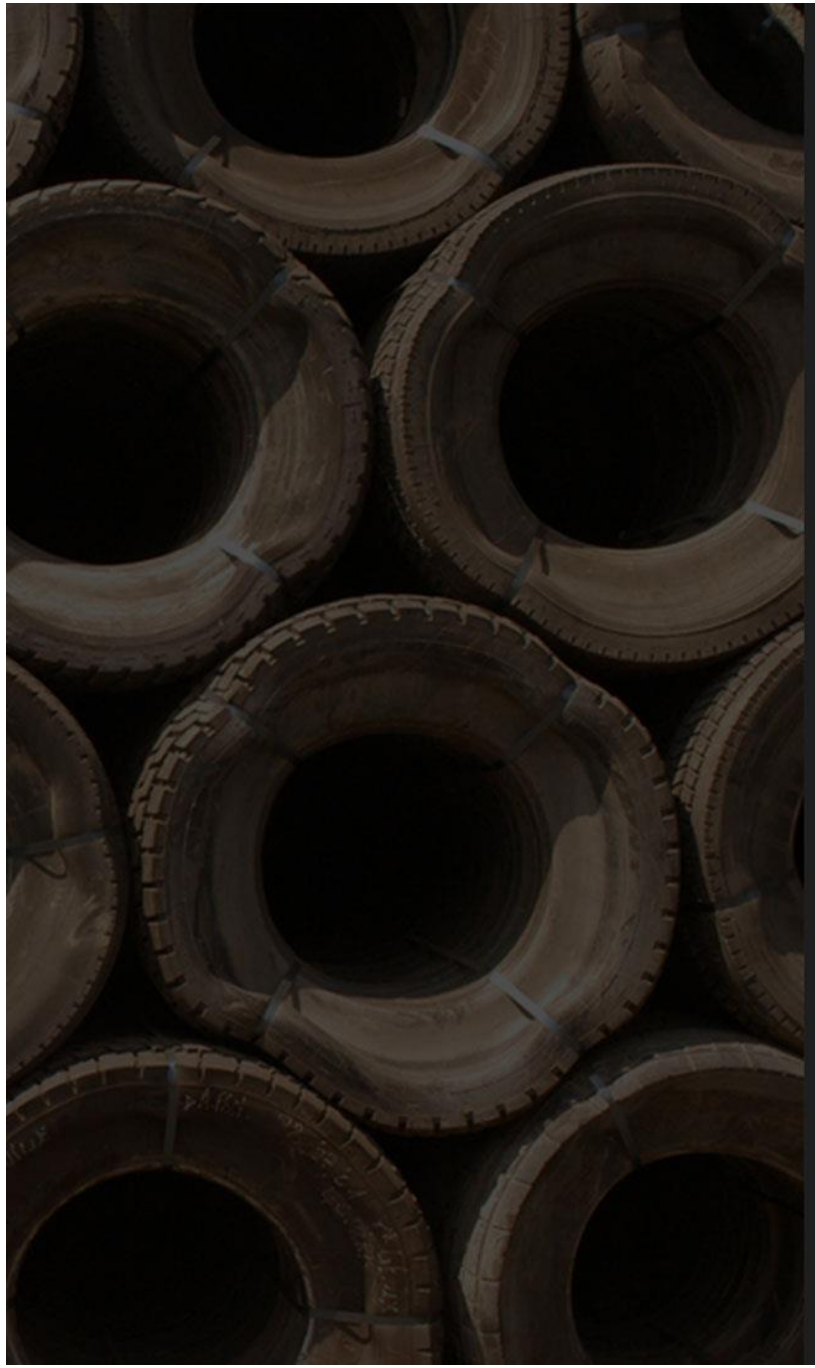


BLACK CYCLE

Move to the green revolution

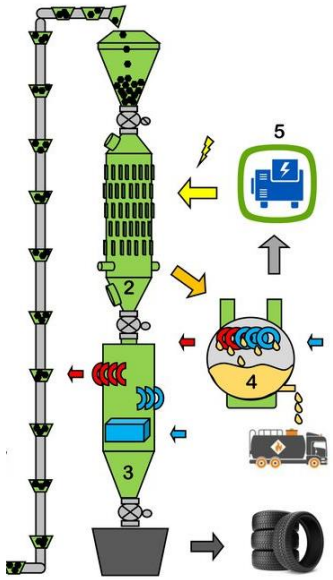
Optimized pyrolysis process

Comparison Auger vs Moving Bed

Ignacio de PASCUAL SAMPER – Sisener
Andreas KAPF - Pyrum

Comparison between pyrolysis technologies

2 validated pyrolysis complementary technologies producing oils for SRM and high-quality rCB



MOVING BED REACTOR

- High flexibility of temperature conditions
- No moving and Selling parts
- High C/H ratio
- High quality rCB

AUGER TECHNOLOGY

- High flexibility of residence time
- High flexibility on granulates diameter
- High limonene content
- High quality rCB

High flexibility on operating conditions to optimized the quality of the products

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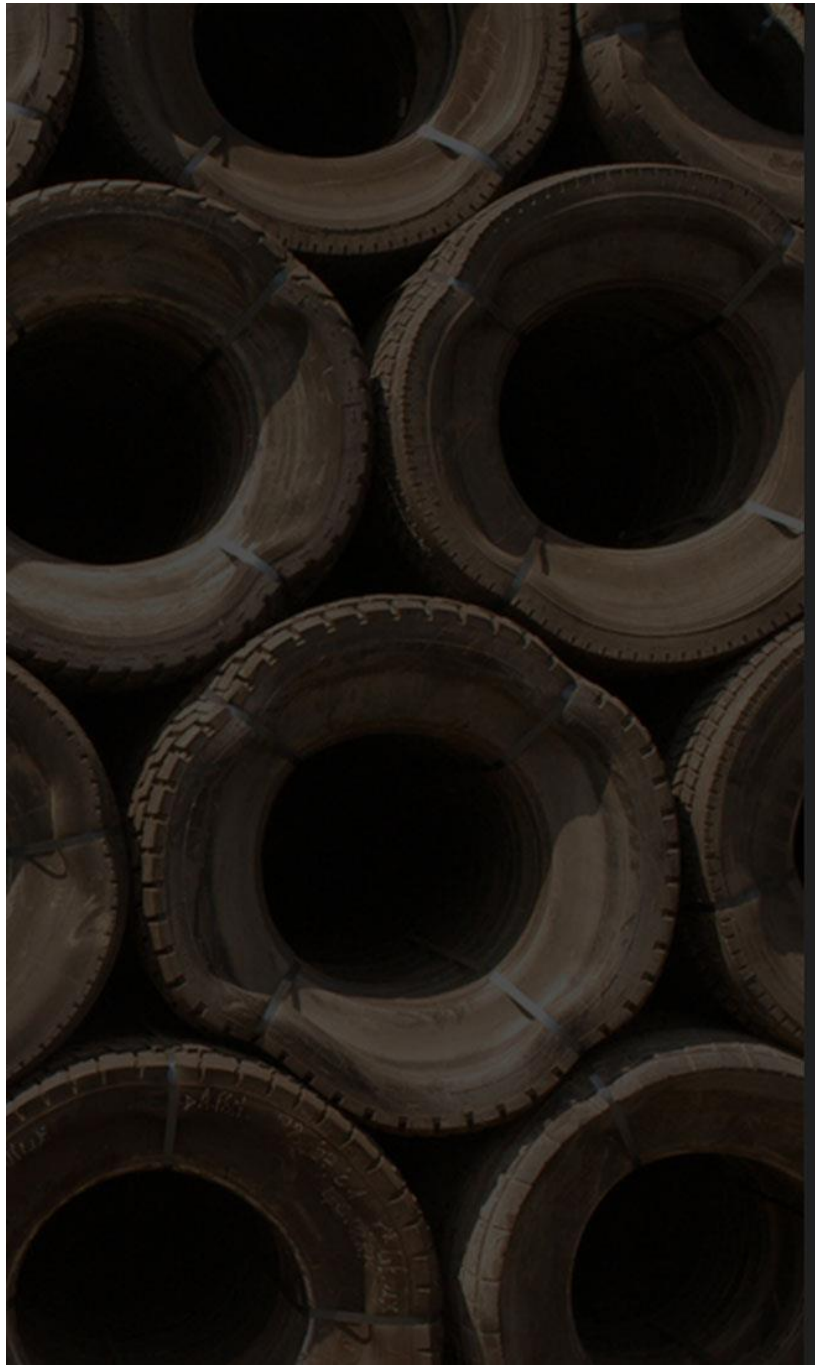


BLACK CYCLE

Move to the green revolution

Optimized distillation

Ignacio de PASCUAL SAMPER – Sisener

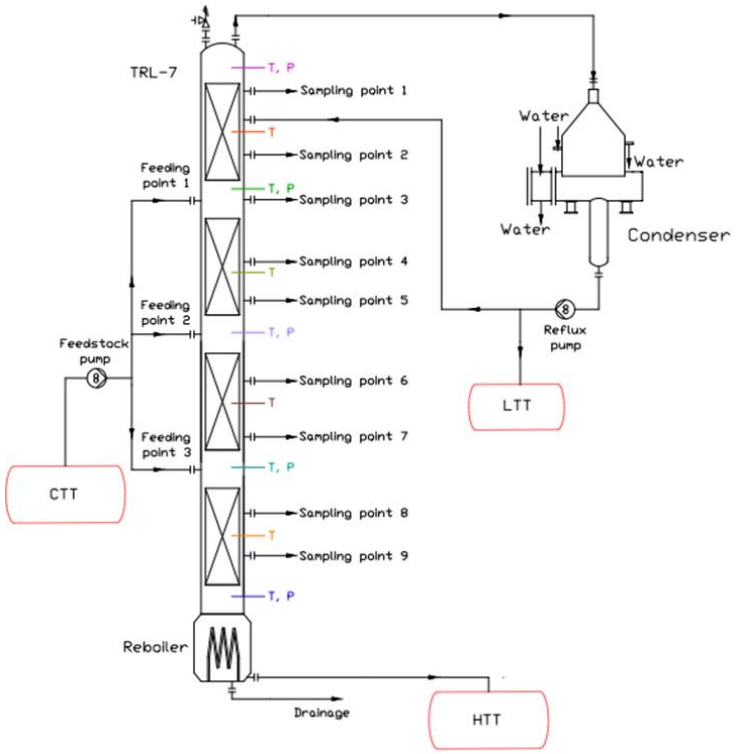
Optimized Distillation

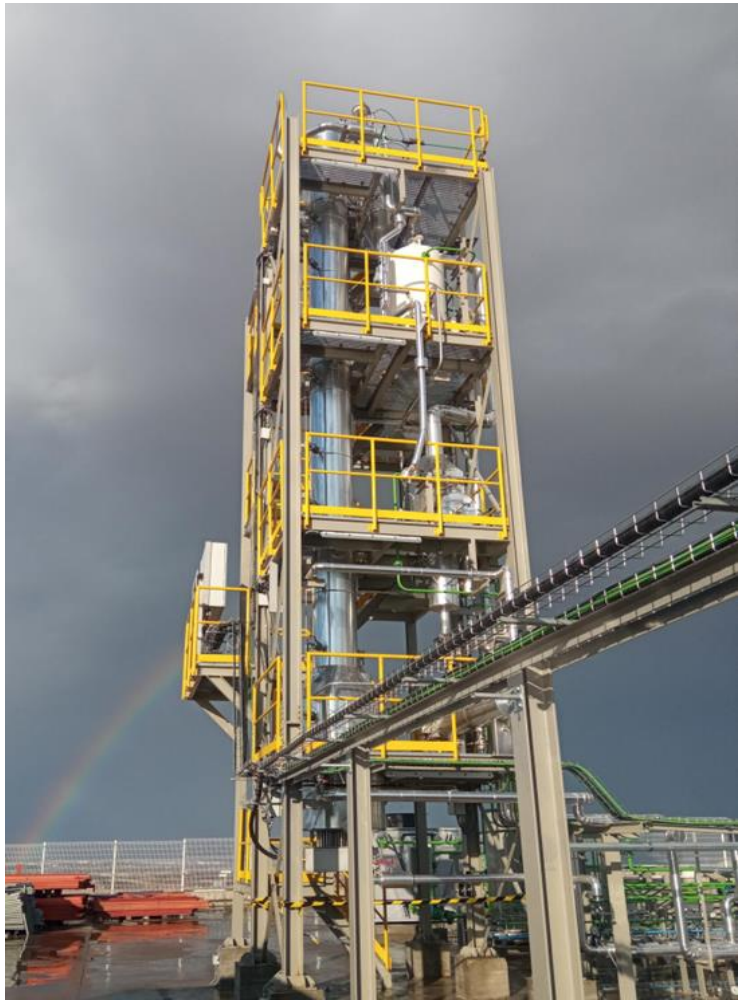
Works done by Sisener in the Blackcycle Project

Construction, commissioning and validation of the scale-up at the TRL7

Basic details of the TRL7 distillation column

- Nominal capacity: 500 kg/h
- Reflux ratio: 0-3
- Max. Pressure: 0.5 barg
- h: 12 m
- Øi: 343 mm
- Packing: 4 packs of pall rings 1"
- Total packing height: 6 m
- Equilibrium stages: 12





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Optimized Distillation

Works done by Sisener in the Blackcycle Project

TRL7 distillation column main equipment

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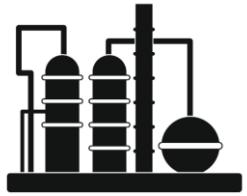
Optimized Distillation

Oil refining, valorisation and scale-up distillation column

TRL5 - Hundreds kg samples

TRL7 – Dozens tons samples

100% CTT



Refining

36% LTT

64% HTT

Validation of distillation columna scale-up

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Optimized Distillation

Oil refining, valorisation and scale-up in the distillation column

Successful production of significant quantities of HTT in-spec with PF > 65ºC and delivered to Orion
Validation of the scale-up distillation column with different CTTs

Production nº 1 – Pyrum optimized CTT		
CTT	59	tons
HTT distilled	33	tons
C/H ratio	0,87	-
LTT distilled	26	tons
BTEX (in CTT) TRL-7	23,25	%

Production nº 2 – Greenval CTT		
CTT	48	tons
HTT distilled	30,8	tons
C/H ratio	0,78	-
LTT distilled	17,2	tons
BTEX (in CTT) TRL-7	18,57	%

Note: Distillation carried out at 250 ºC without reflux

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Distillation is a key step in Blackcycle value chain valorizing the CTT by generating specific oil fractions

- Design & construction of a new key equipment for the project
- Scale up validation of the operating conditions to produce specific oil fractions
- Flexibility to distillate different CTT qualities
- Validation of production of significative quantities of in-spec HTT and LTT
- More than 60tn of HTT delivered to Orion

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Networking in room "Monnet" first floor

The sequence:

- 3 rounds of table discussions
- 10 minutes per round
- 10 tables
- 60 seconds to introduce yourself
- At the sound of the horn, switch groups!

What information to give in 60 seconds?

- Your name & surname
- Your position
- Your company
- The purpose of your presence at this event

Your table number for each round is written in the list that was given to you upon your arrival

Nom	Prénom	Structure	Tour 1	Tour 2	Tour 3
Ampère	André Marie	École polytechnique	2	3	5
Avogadro	Amedeo	Université de Turin	1	2	3
Becquerel	Henri	École nationale des ponts et chaussées	1	3	4
Boltzmann	Ludwig	Université de Vienne	1	4	5
Copernic	Nicolas	Observatoire de Frombork	1	5	6
Gauss	Carl	Université de Göttingen	3	8	2

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05

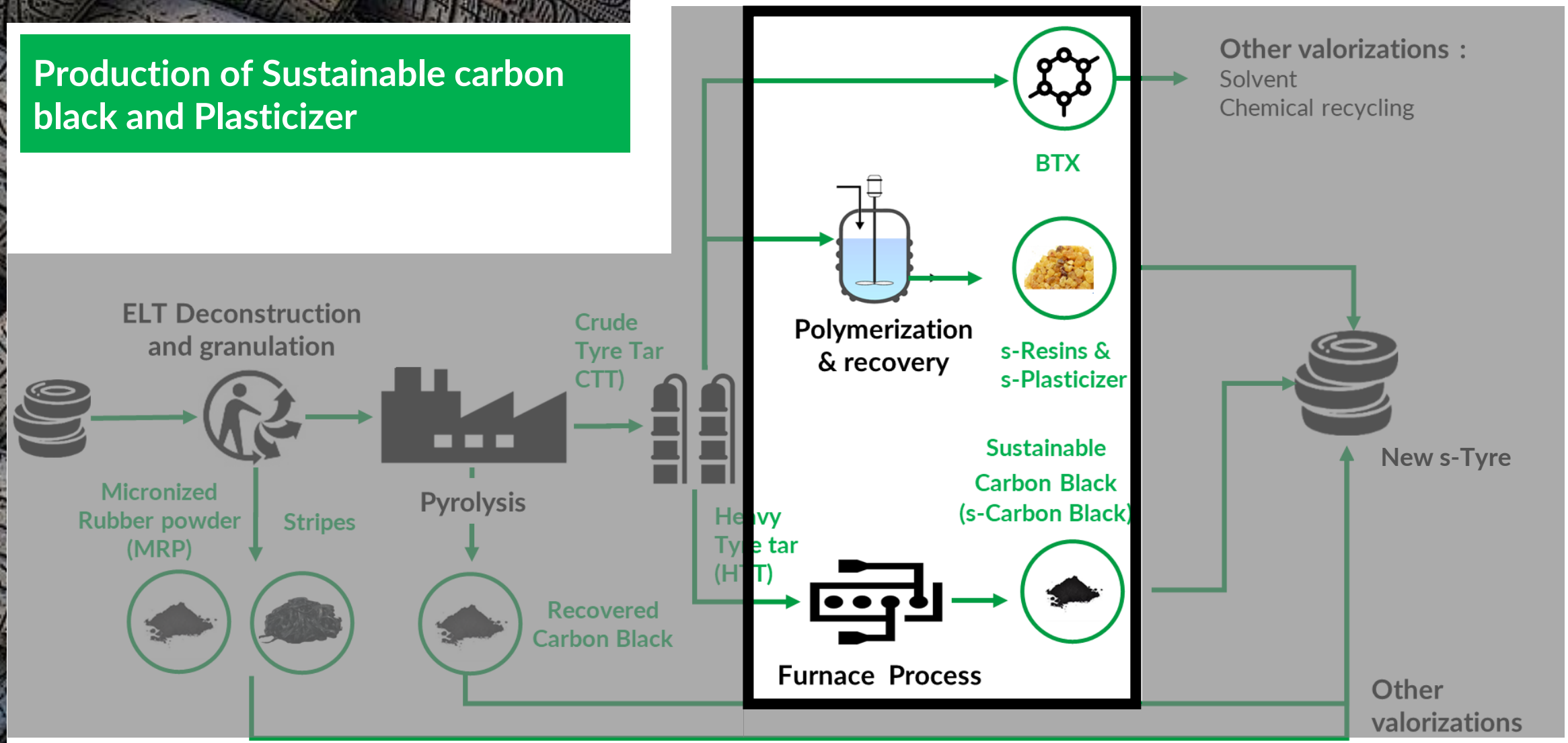
Production of high quality secondary raw materials: Sustainable carbon black and plasticizer

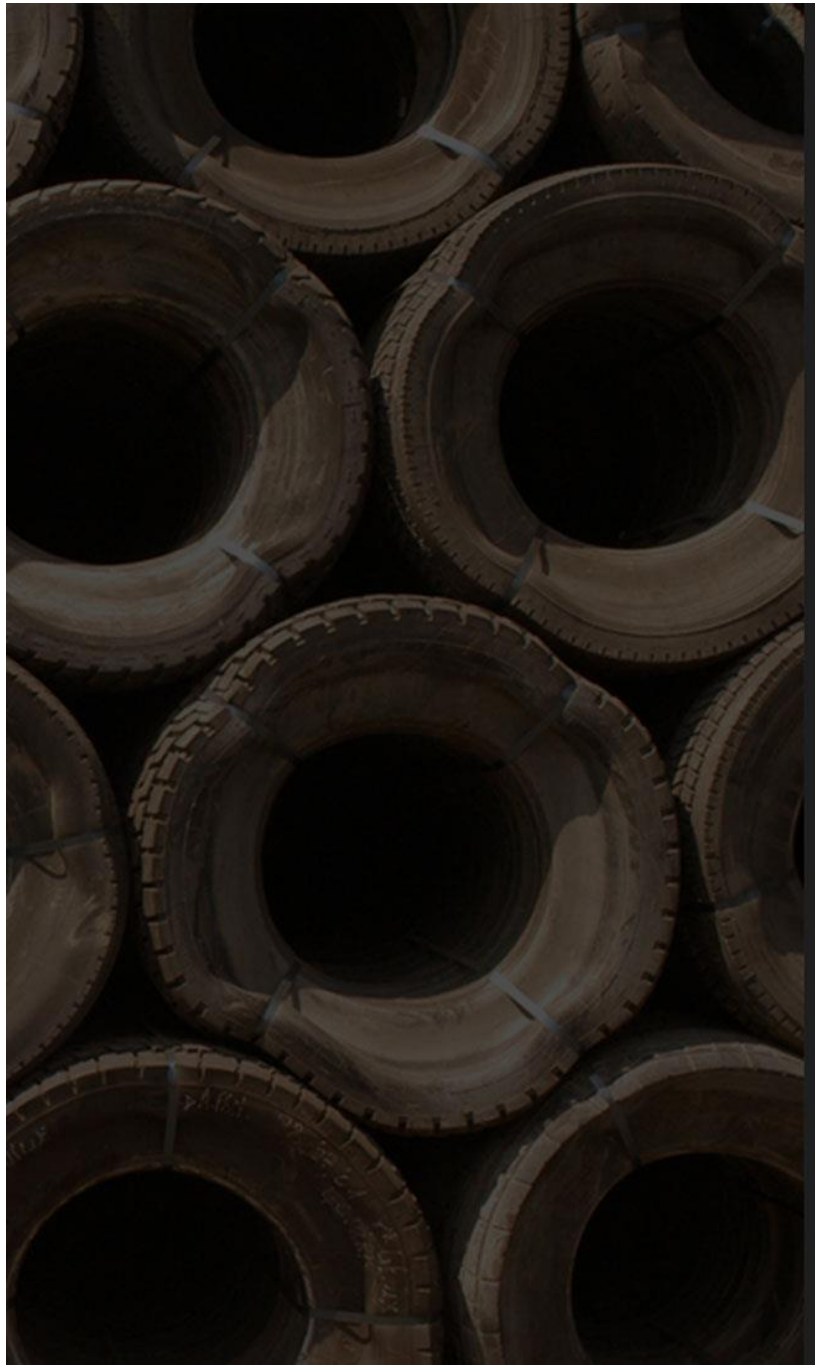
Celso MAGRI – Orion,
Marion SERVEL - Michelin

BlackCycle, enable massive and viable circular economy of tyres

BlackCycle Value chain

Production of Sustainable carbon black and Plasticizer





BLACK CYCLE

Move to the green revolution

Production of high quality secondary raw materials: Sustainable carbon black

Celso MAGRI – Orion

Carbon Black, an essential material made to customers' specifications

Huge variety of **applications**:

- **tyres** & rubber goods, Polymers, Adhesives & Sealants, Coatings, Ink, Batteries and numerous other high-performance Specialty applications





Carbon black is used to:

- **Reinforce**, Tint, Colorize, Conductivity, Increase durability, Add UV protection, Rheology

Market **demand approx. 14 mio tons** (2023)

- **tyres 73%,** other Rubber parts 19% and Specialty applications 7 %

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Sustainable Carbon Black (sCB) : 3 main activity areas

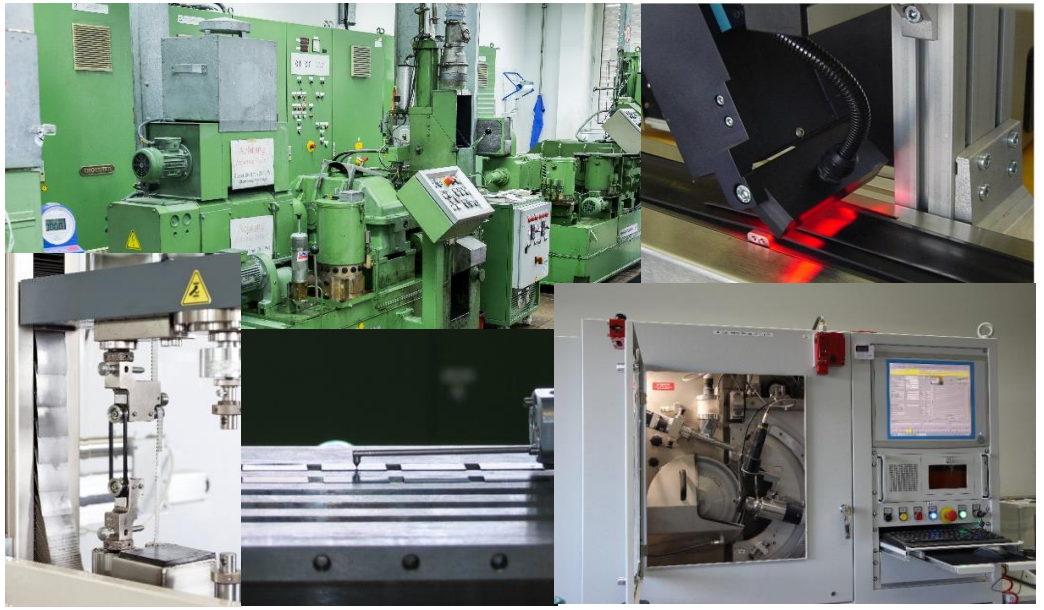
1. Analysis of tyre Pyrolysis Oil (TPO)

- Crude tyre Tar (CTT), Heavy tyre Tar (HTT), Light tyre Tar (LTT)

2. Production of 3 different sustainable CBs produced with 100% TPO up to TRL 7

- sN234, sN347 & sN550
- in TRL 5 (30 kg) & TRL 7 (> 1 to) scale

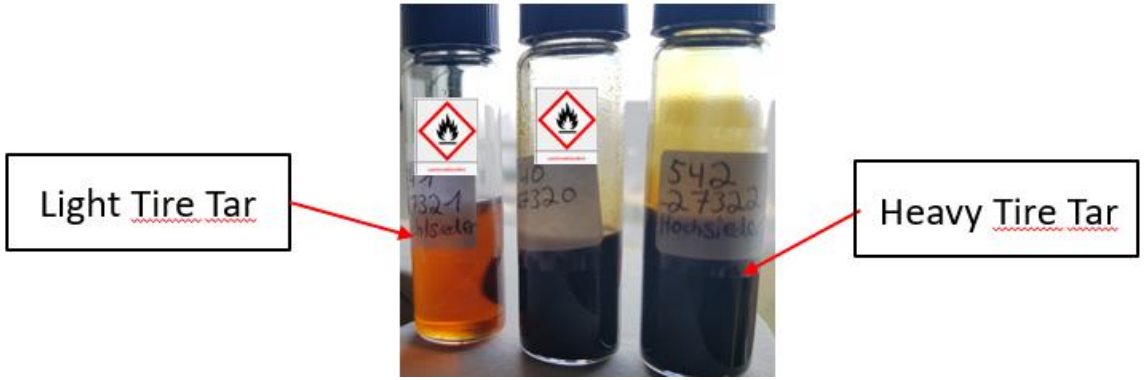
3. Evaluation of in-Rubber properties



BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Oil from tyre pyrolysis : Following distillation to meet safety requirements with good oil quality and production handling

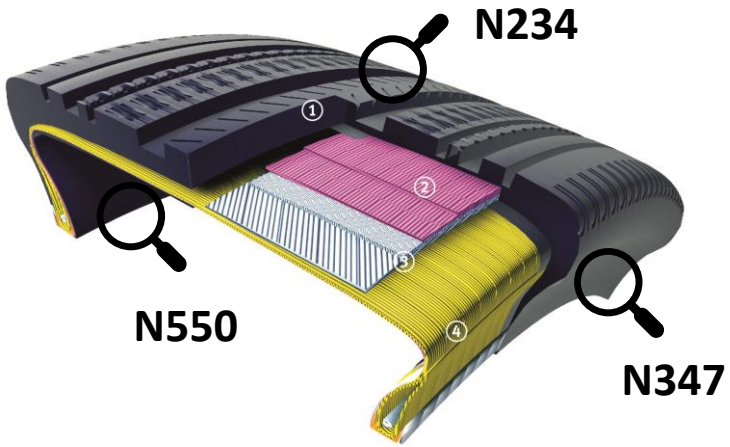
- **Quality:** very clean oil, low ash, low TI, QI and sieve-residue.
- **Processability:** oil is easy to operate, low viscosity, no heating in tanks required.
- **Productivity:** yield and throughput are lower than conventional oils.



BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Production in TRL 7 pilot plant (furnace process) All 3 selected sCBs met analytical specifications despite significant changes in oil feed

Selected full range of
CB types in tyres parts



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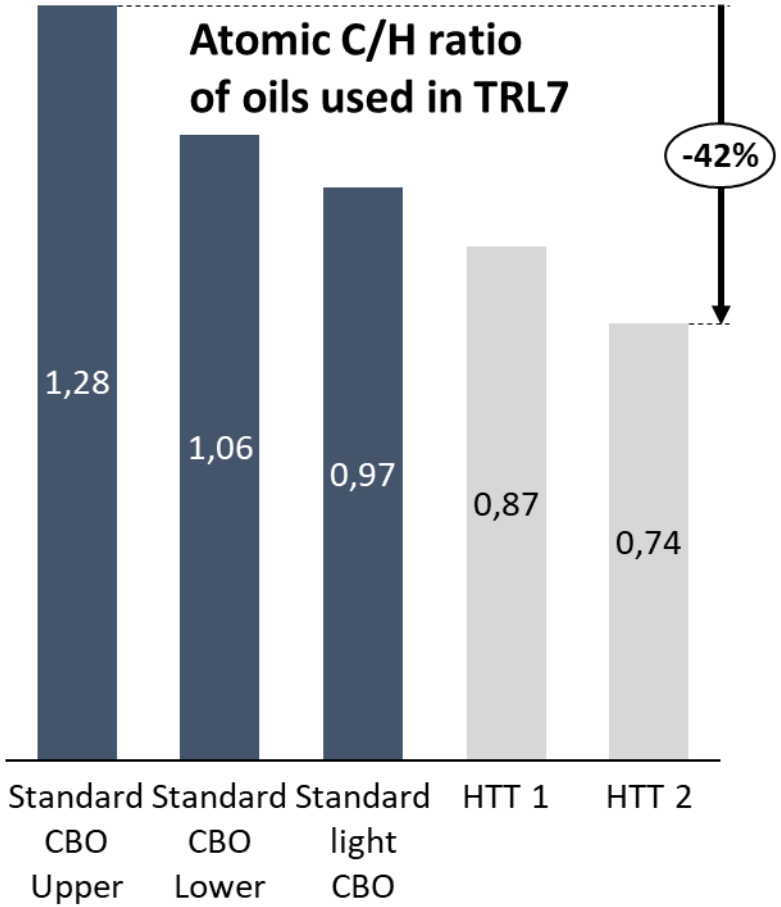
Production in TRL 7 pilot plant (furnace process) All 3 selected sCBs met analytical specifications despite significant changes in oil feed



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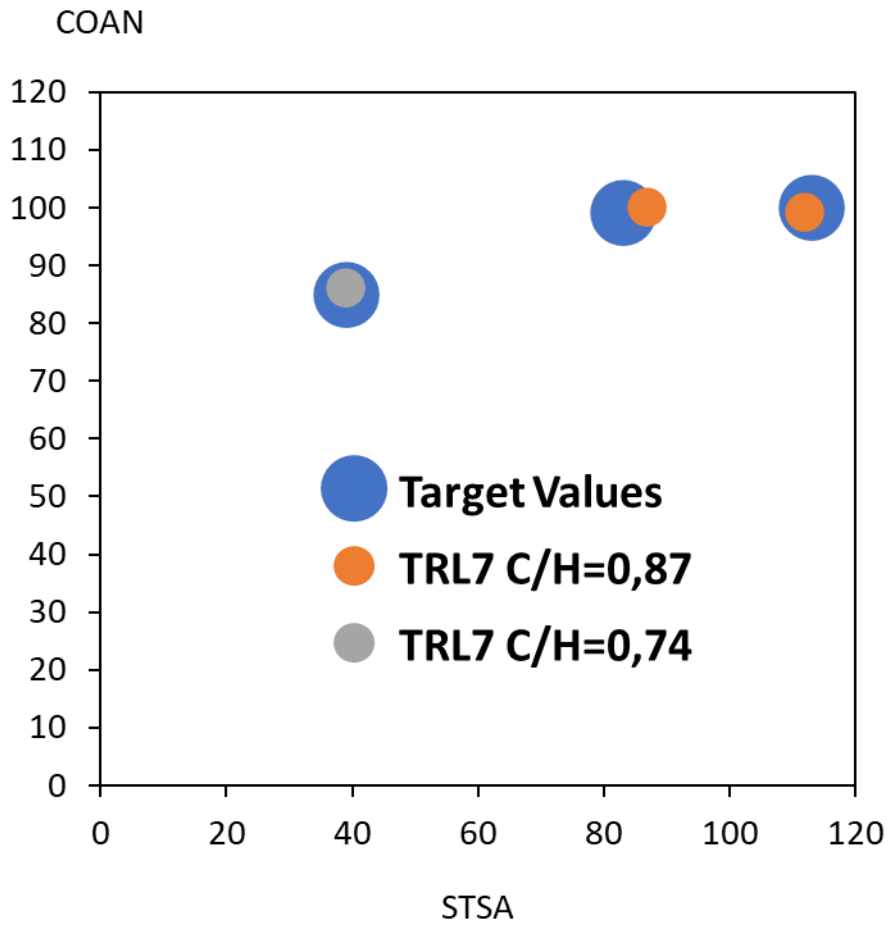
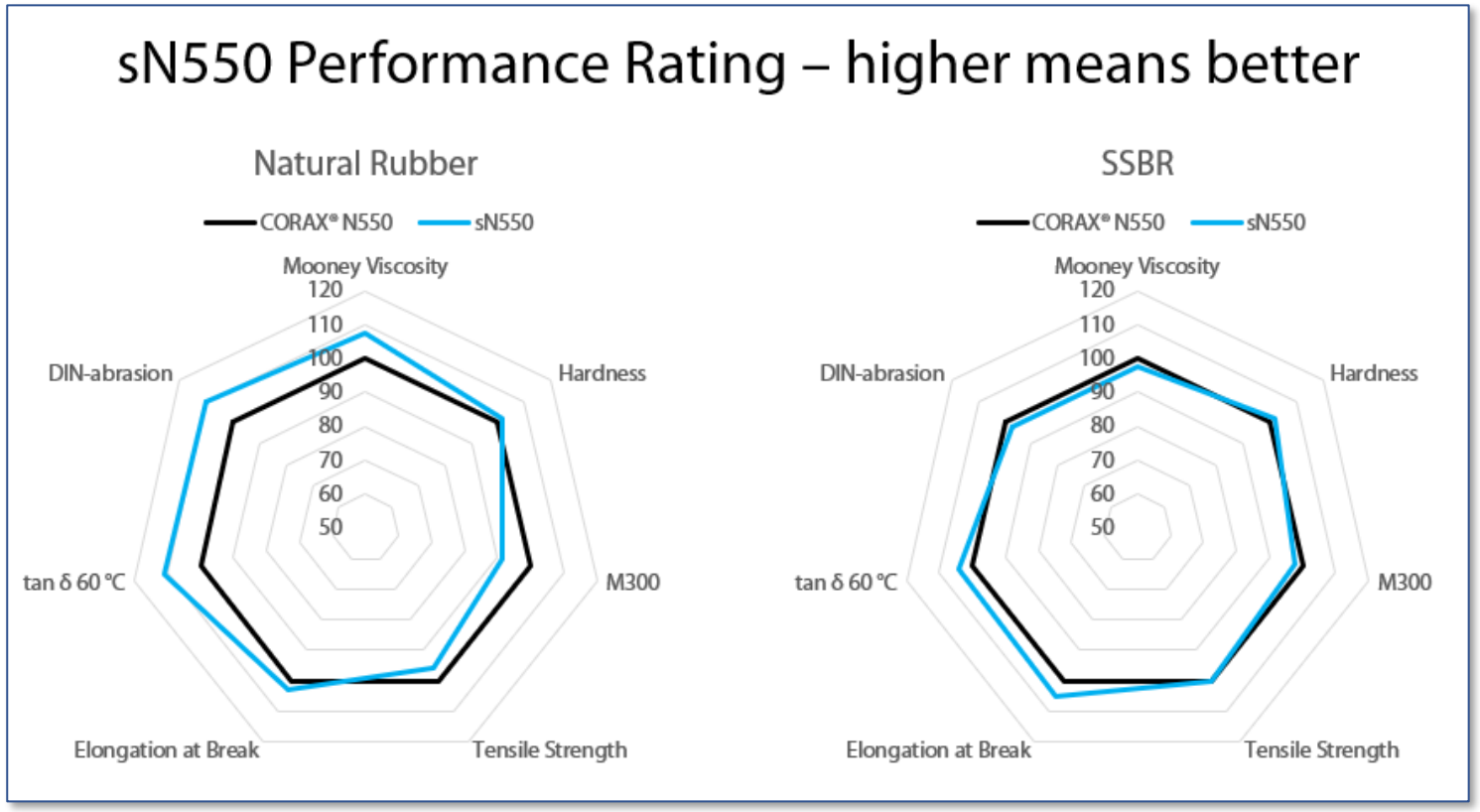
Production in TRL 7 pilot plant (furnace process) All 3 selected sCBs met analytical specifications despite significant changes in oil feed



BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

In-Rubber / tyre application performance
All 3 sCBs can completely replace conventional CBs



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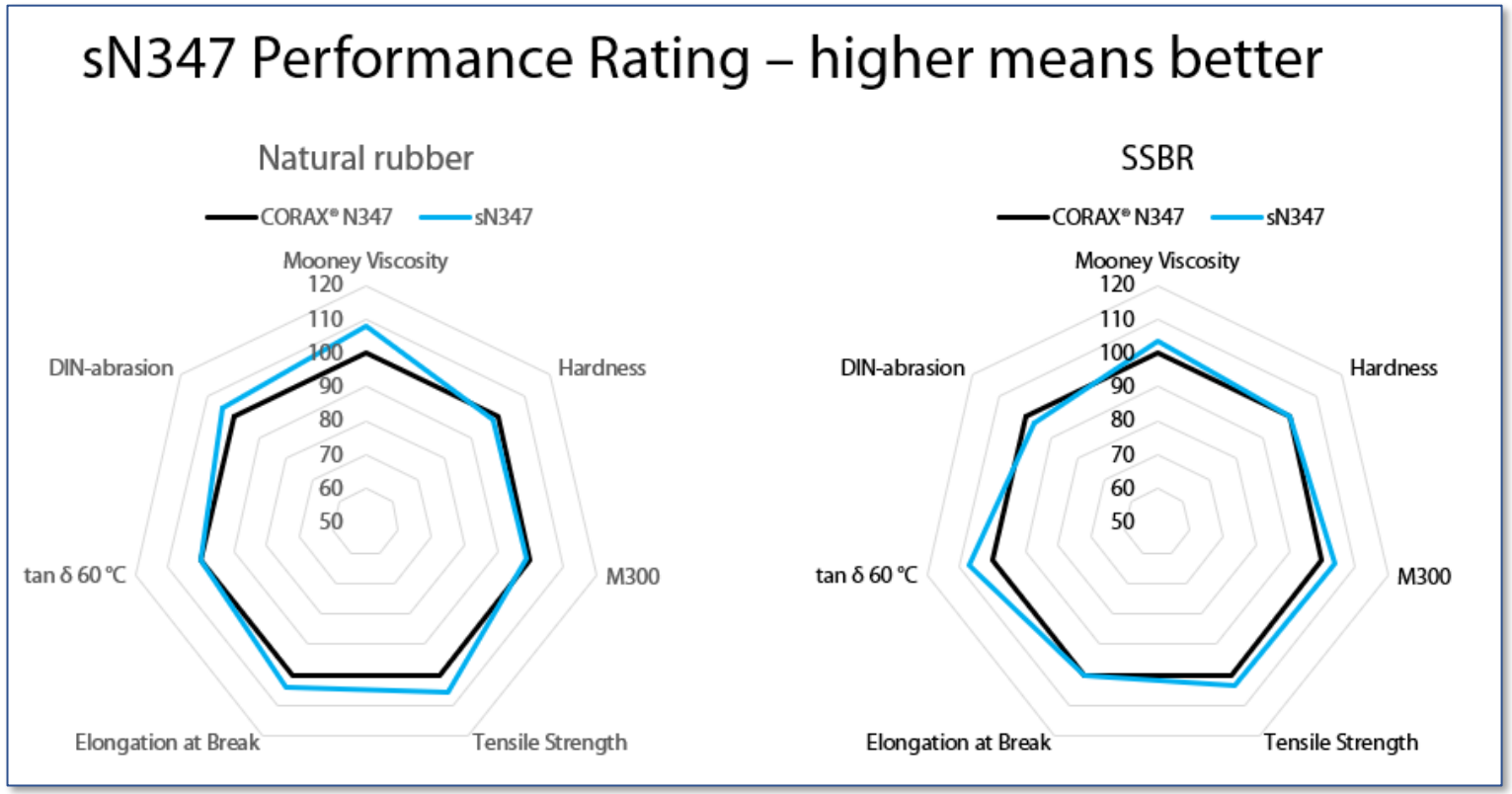

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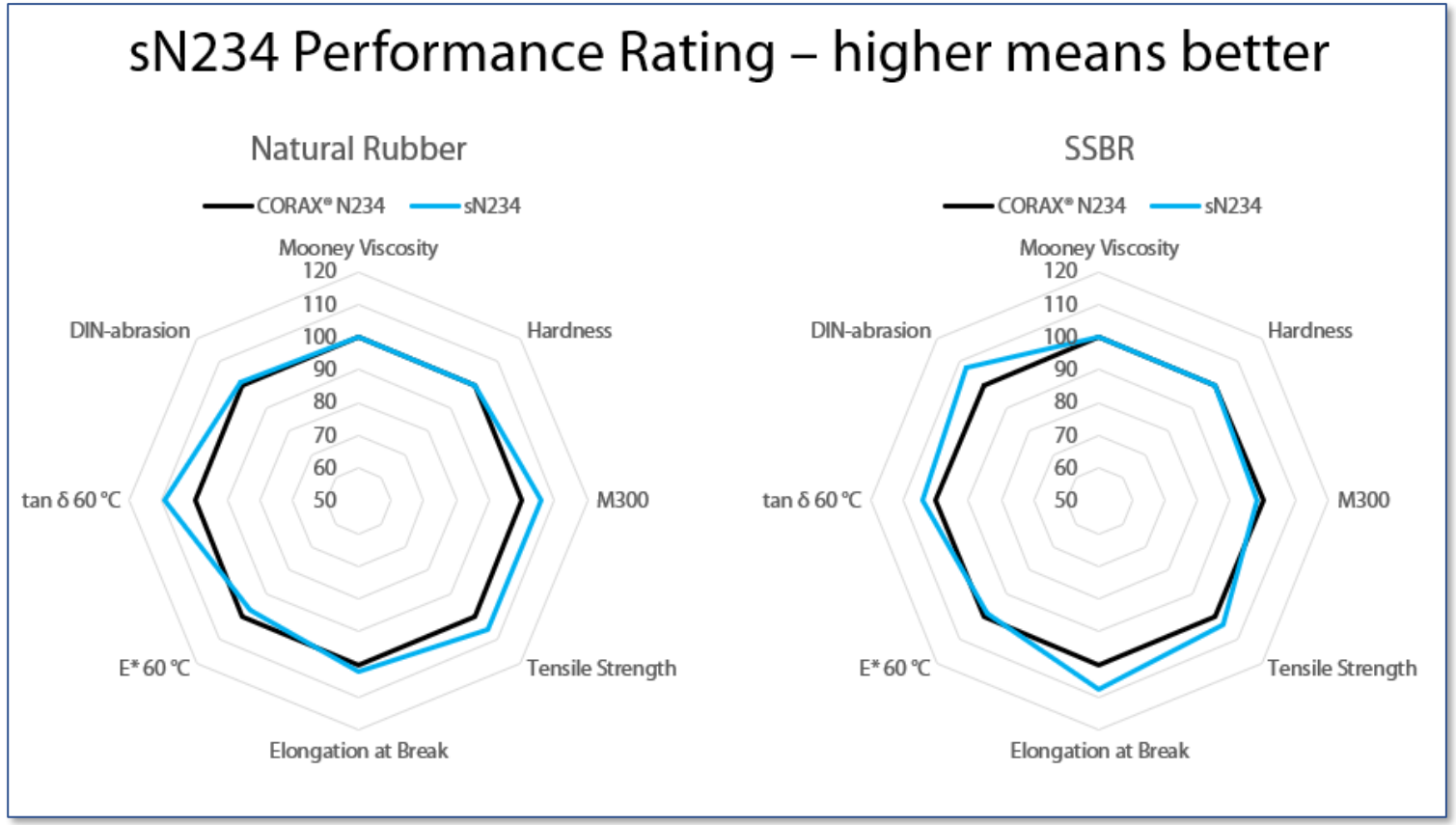
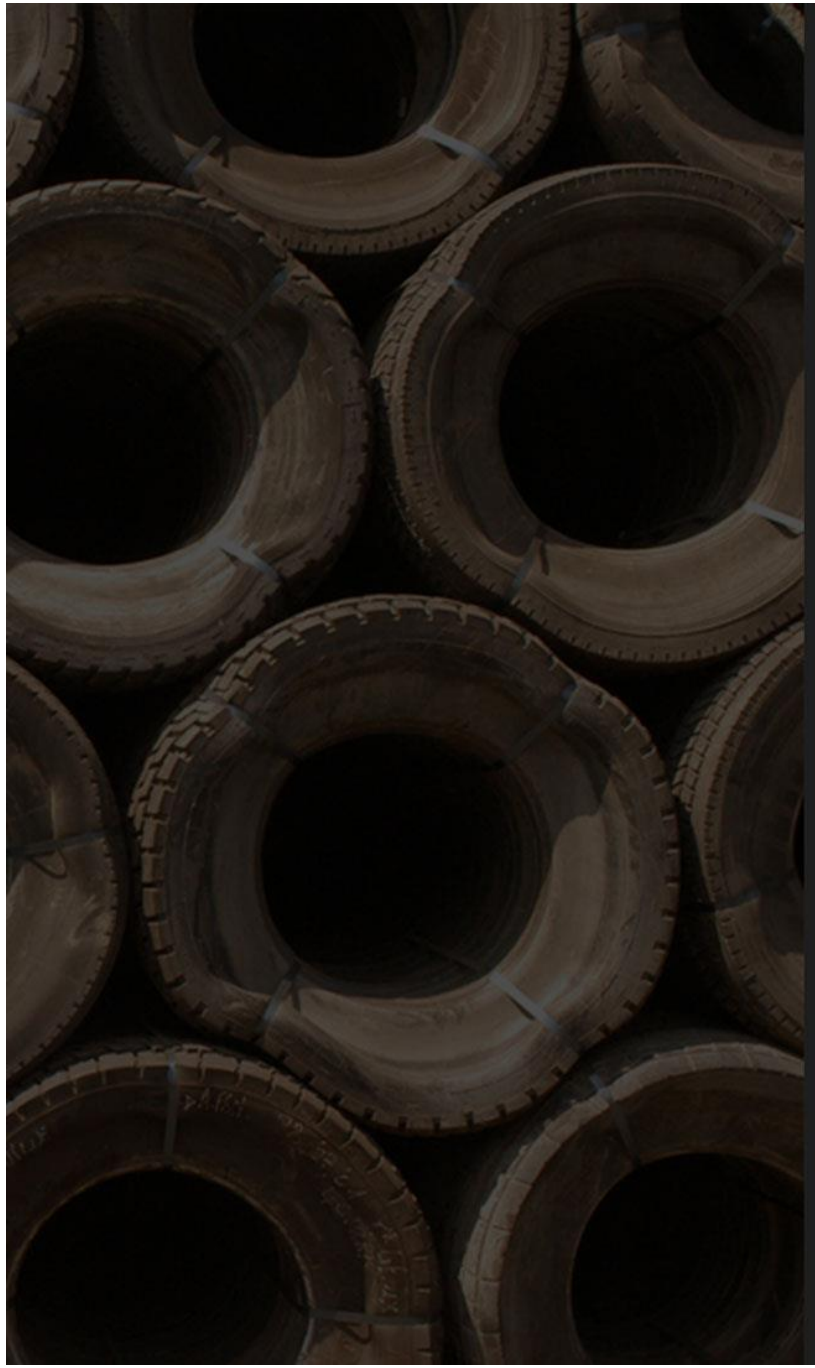


BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Conclusion :
sCB produced by Orion can completely replace conventional carbon black in tyres

- Following **distillation to meet safety requirements**, oil quality and handling are good
- **All three sCBs produced in TRL 7** pilot plant with Furnace process **met analytical specification** despite significant changes in oil feed
- In-rubber performance testing demonstrate that **all 3 sCB grades perform equally as conventional carbon blacks**
- **Beyond BlackCycle:** Orion has already started production of different grades at commercial plants and will continue to expand together with the value chain

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625



BLACK CYCLE

Move to the green revolution

Production of high quality secondary raw materials: Plasticizer

Marion SERVEL - Michelin

s-Resins at a glance

What ?

- Polymer defined by :
  - Low molecular mass
  - Microstructure
- The resin must have a sufficient Tg to activate formulation levers.
- Highly increase tyre performance : magic triangle -> rolling resistance/wear performance and Wet grip

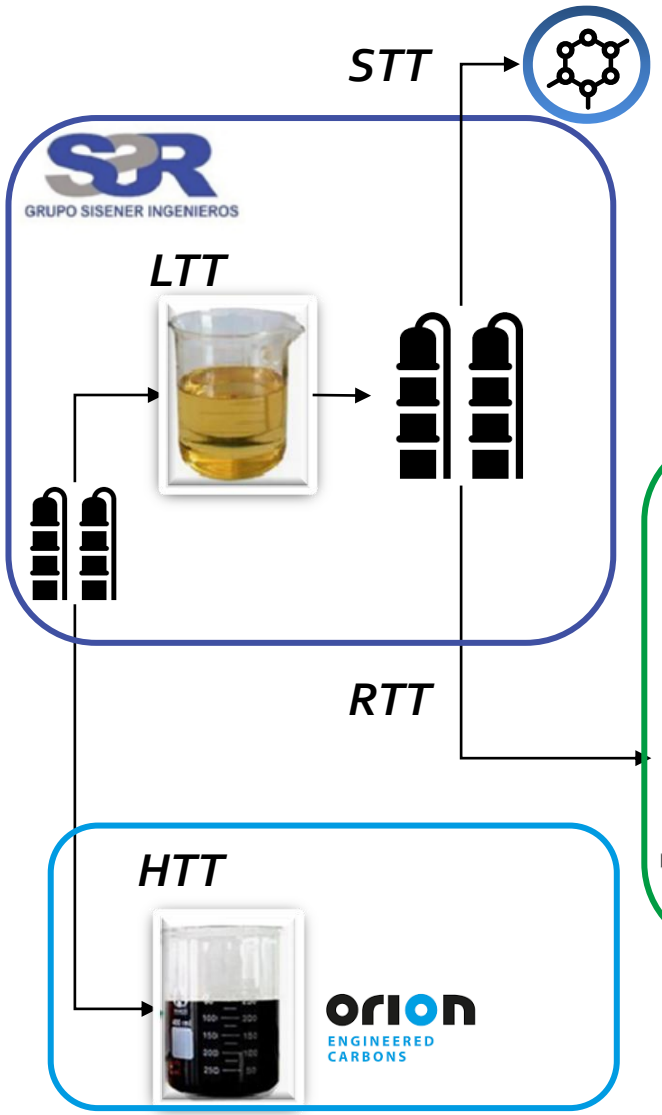
How ?

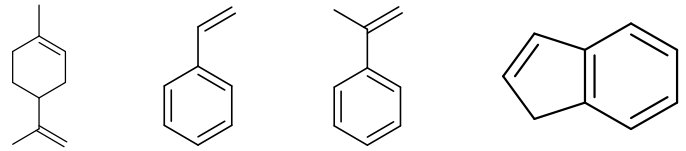
Upcycling of valuable monomers (Limonene) contained in the CTT (Crude tyre Tar)

Why ?

- Increase **secondary raw** material's rate
- **High know-how** in polymer synthesis & mix for tyres

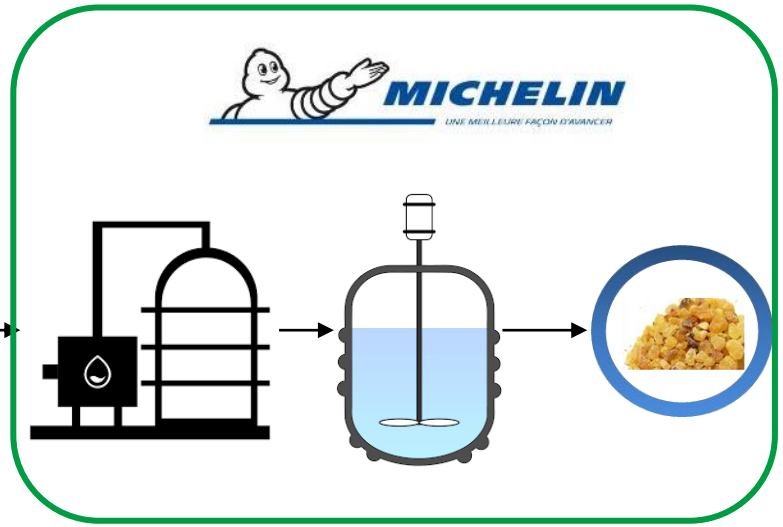
A succesfull partnership to produce a high quality s-Resins





HTT: High C/H ratio, up to 0,87

LTT: Limonene content > 8%



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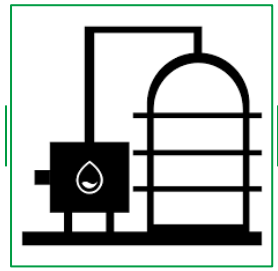
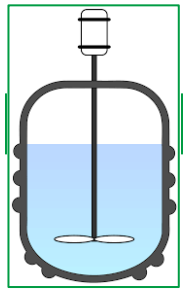
Strong ecodesign to develop a innovative process

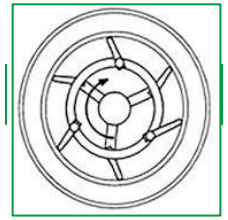
RTT
(> 20% monomers)



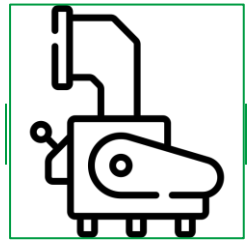
Purified RTT
(polar compound)



Diluted s-resin



Dry s-resin
(spec Tg)



shaped s-resin

Ready to be used downstream (Magali Heurtefeu)

Co-products

Purification solvent

Light solvent

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Process development steps of s-Resins production from ELT pyrolysis oil : A world's first !

TRL : 2

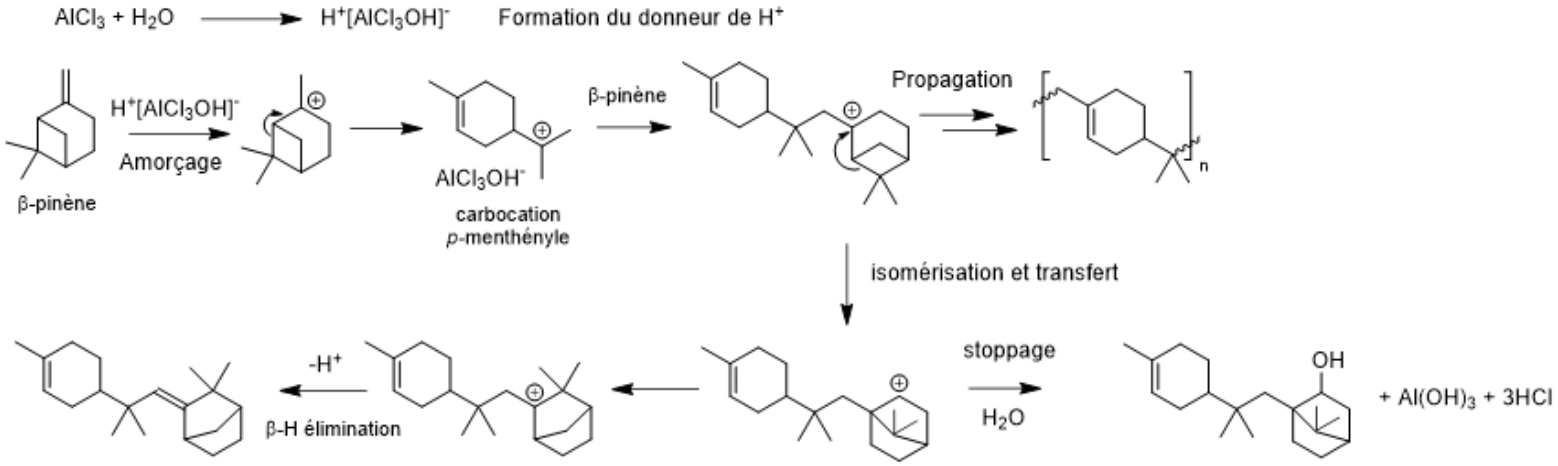
- **V = 25 mL**
- No reaction limitation
- Not representative of industrial unit
- Batch ~ g

TRL : 3

- **V = 2 L**
- 1st process issues
- Not representative of industrial unit
- Batch ~100 g

TRL : 4

- **V = 70 L**
- Process limitations
- **Representative of industrial unit**
- Batch ~ 10kg

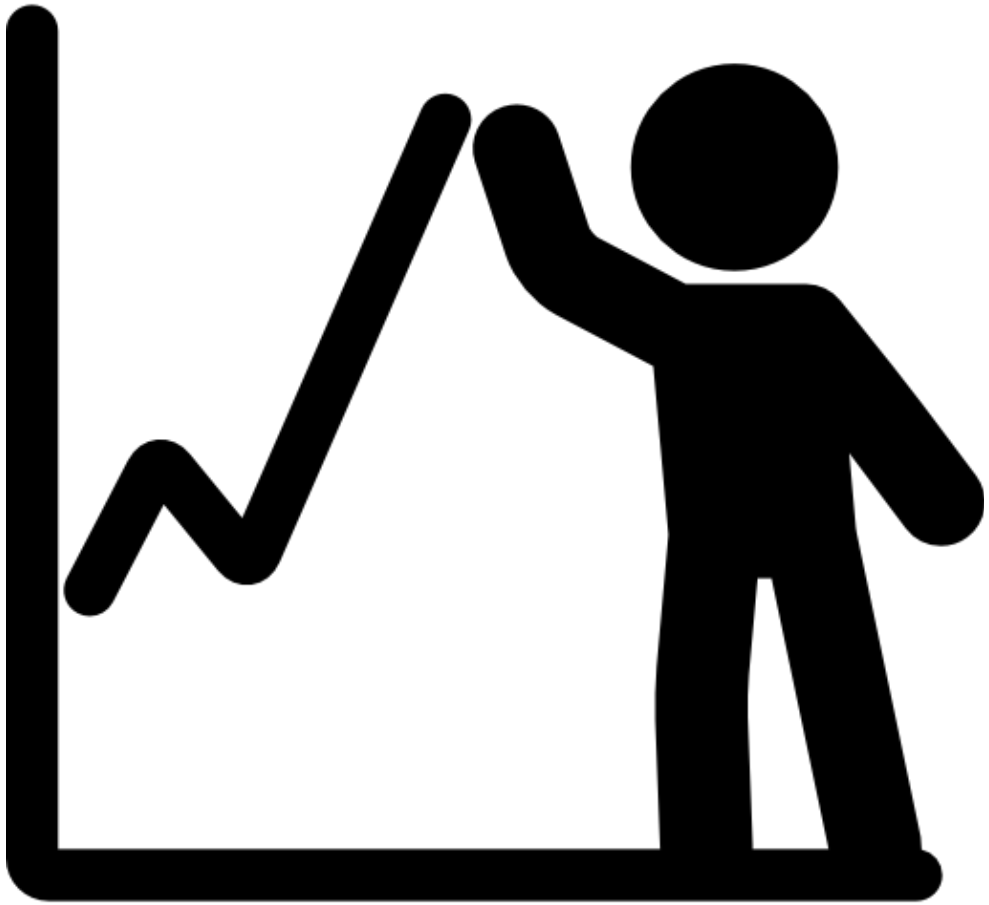


BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Production of **10kg** of s-resins **from CTT !**

Take away message : a real success !

- Upcycling to valuable s-Resins
- Succesfull partnership to produce a high quality s-Resin TRL4
- Strong eco-design to develop an innovative process :
  - LCA contribution (Quantis)
  - HSE risk analysis (INERIS)
- World's first production of s-Resins from ELT pyrolysis oil
- Promising rubber mix results



Next steps : increase the trl level until industrial scale

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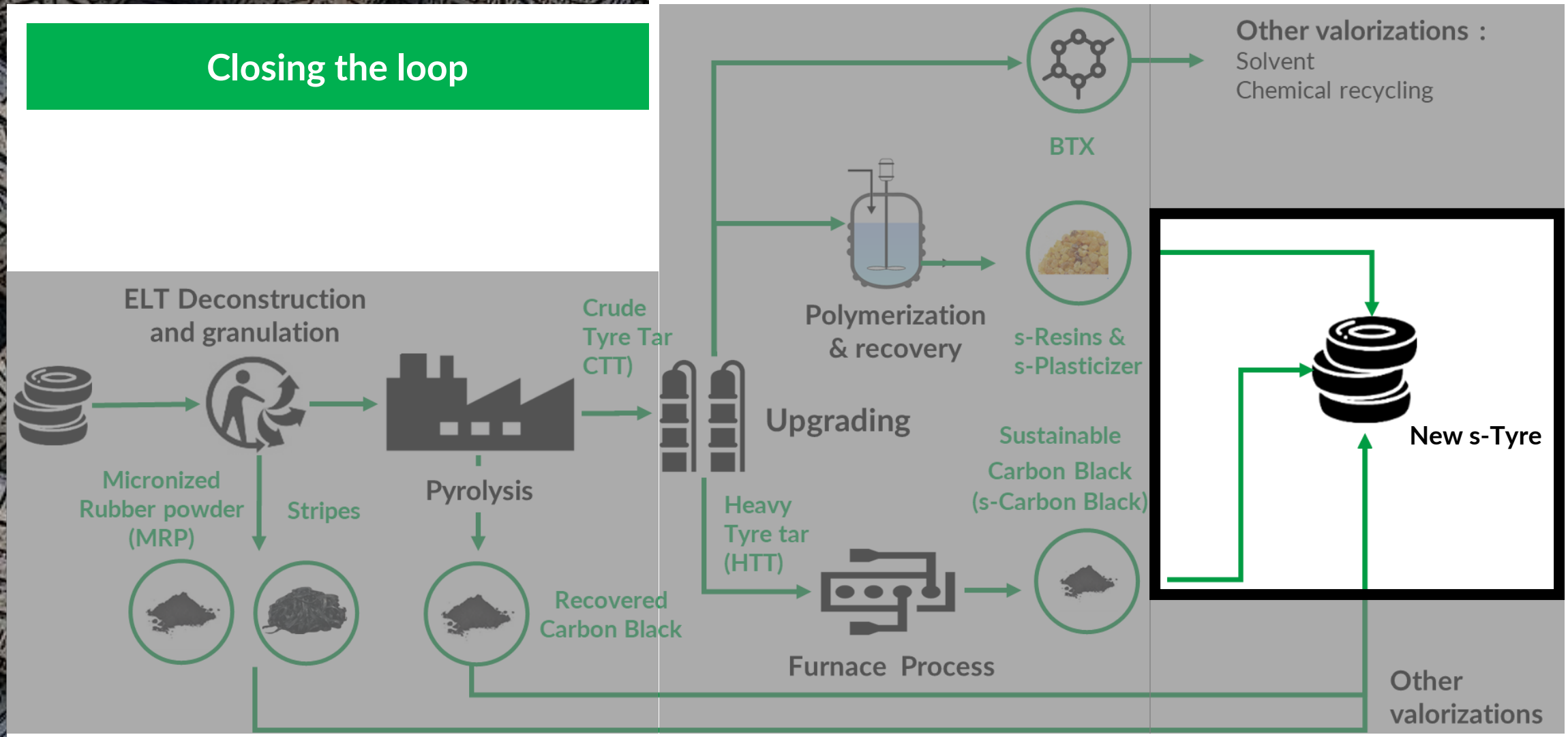
06

Closing the loop: secondary raw materials as direct replacement of fossil materials in new tyres

Magali HEURTEFEU - Michelin

BlackCycle Value chain

Closing the loop



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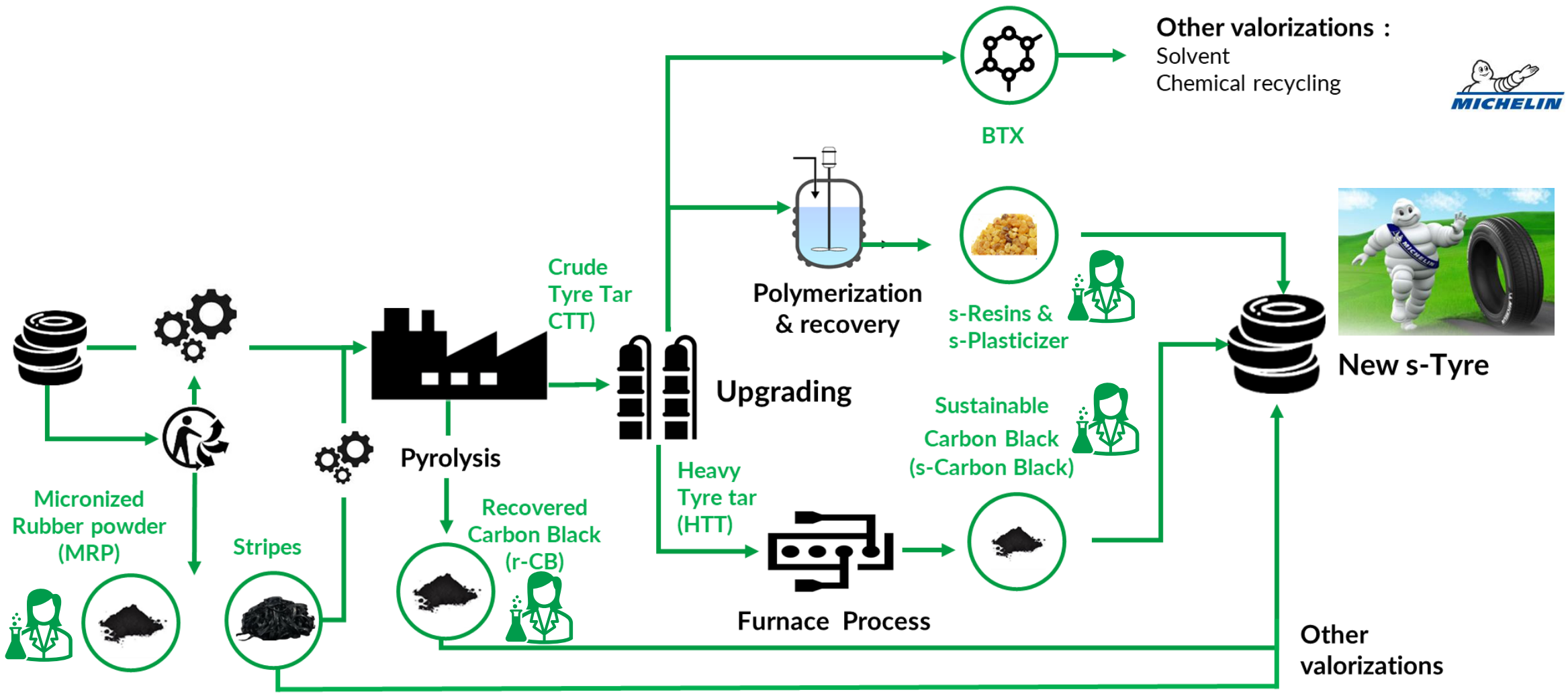
Focus on the evaluation of 4 SRMs of the value chain



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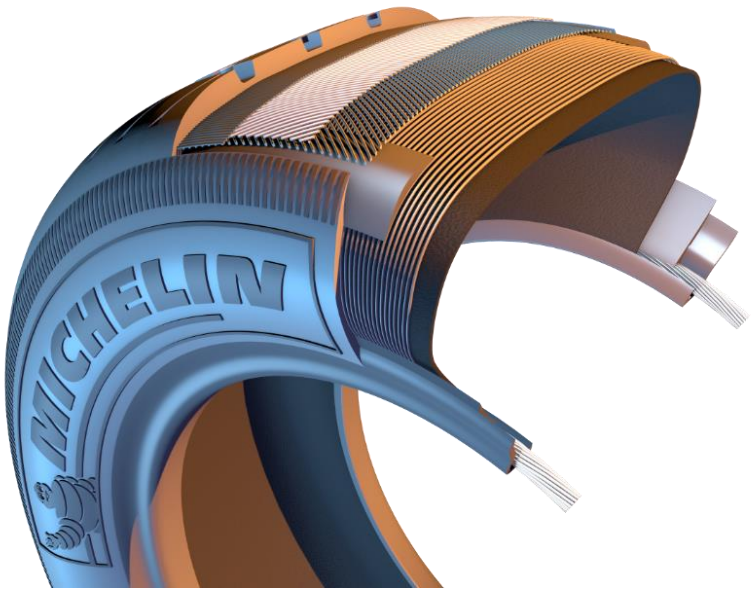
Because the tyre is a highly technical complex product the 4 BlackCycle SRMs must be carefully validated



-  **r-CB** and  **s-CB** vs regular ASTM carbon black (CB) of different tire parts :
  - in truck tread : N234 (s-CB)
  - in other rubber compositions: N550 (r-CB and s-CB) N347 (s-CB)

-  **Innerliner Micronized Rubber Powder** in virgin inner liner rubber

-  **s-resin** vs fossil resin in passenger car tires

Performance assessment of the SRM :

- in rubber compositions at laboratory scale for the 4 SRM
- in tires for s-CB and r-CB

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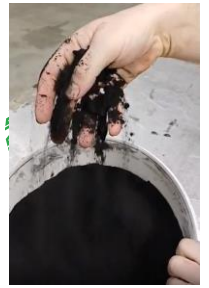
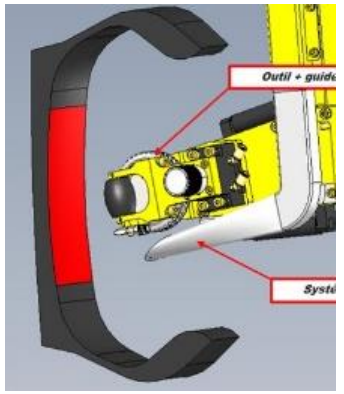
Innerliner MRP (produced by IRG machine) can be introduced in a virgin innerliner mix with no impact on its properties



Introducing a significant quantity of innerliner micronized rubber powder in a virgin innerliner surprisingly doesn't impact its key properties

- rigidity
- hysteresys
- permeability.

This shows the value of the deconstruction machine IRG (extraction of micronized Rubber powder inneliner)



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r-CB feedstock sensitivity : main impact is the ash content

r-CB tested were produced by ICB with a Auger reactor :

- raw material TRL5
- several kilograms, milled

- r-CB characteristics measured :

Feedstock	SSA by BET (m^2/g)	Ashes (%w)	Toluene extract transmission (%)	Heat loss at 125°C (%w)
Passenger cars tires	62	15	84	1,22
Truck treads	65	13	97	0,39
Passenger car treads	69	49	75	0,73

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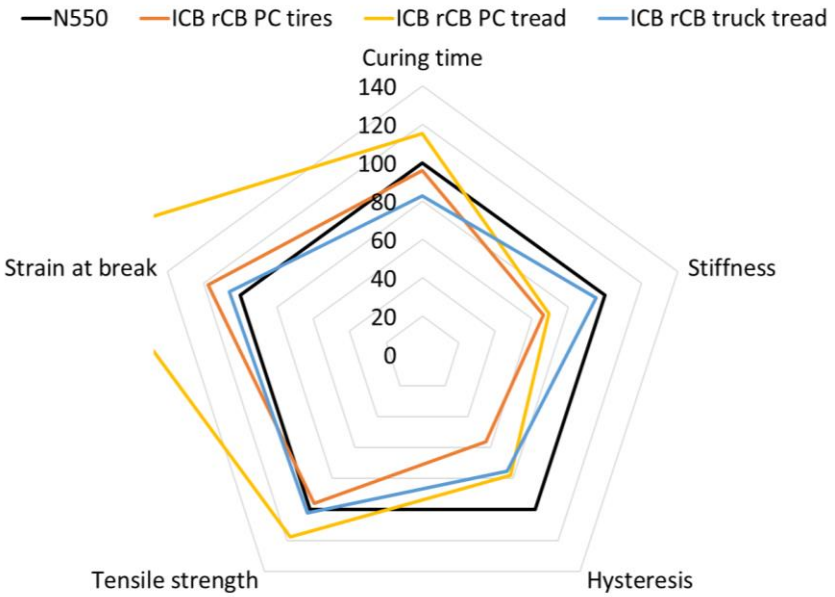
r-CB cannot totally replace N550 in rubber mixes whatever the feedstock …

- 100% rCB
- N550 ASTM reference
- Natural rubber / butadiene rubber matrix



rCB is not a ASTM carbon black, it's a **complex raw material that partially acts as a reinforcing filler**.

Therefore, it can only partially replace ASTM N550.

These results are introducing the notion of **blending rCB/ASTM N550.**

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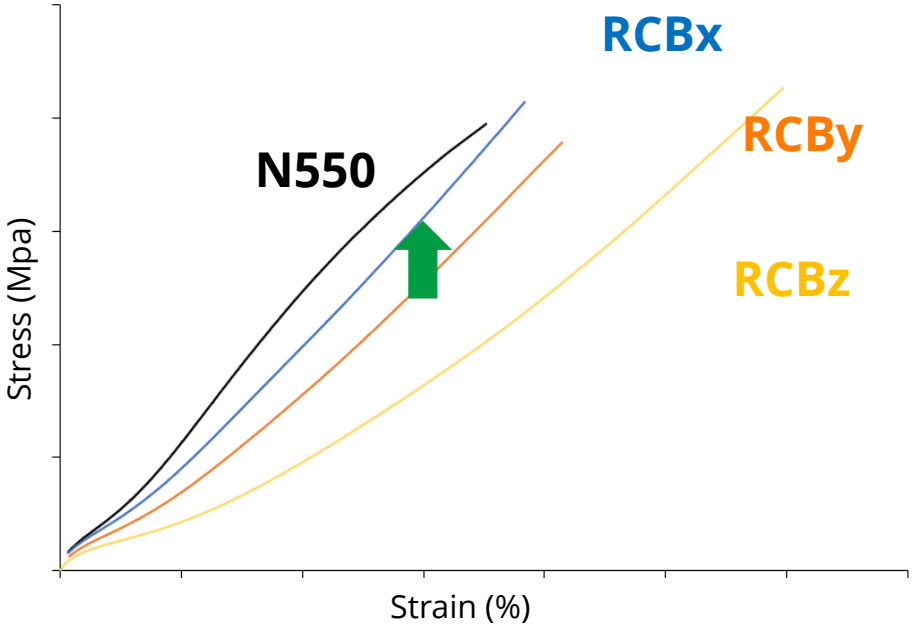
But the seleted feedstock has a positive impact on reinforcement by r-CB

- 100% rCB
- N550 ASTM reference
- Natural rubber / butadiene rubber matrix



The **seleted feedstock could improve the reinforcement of the rubber.**
This shows the value of the **ORC deconstruction machine** providing a more technical feedstock for r-CB

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s-CB : in tire evaluation

s-N234 and s-N347 Manufactured by Orion Engineered Carbons :

- from tire pyrolysis oil instead of fossil oil
- at **pilot** scale : several tons produced

- Replacing 100% of regular ASTM carbon black in up to 4 posts in a truck tire :

  N234 : tread and sidewall

  N347 : undertread and internal mix

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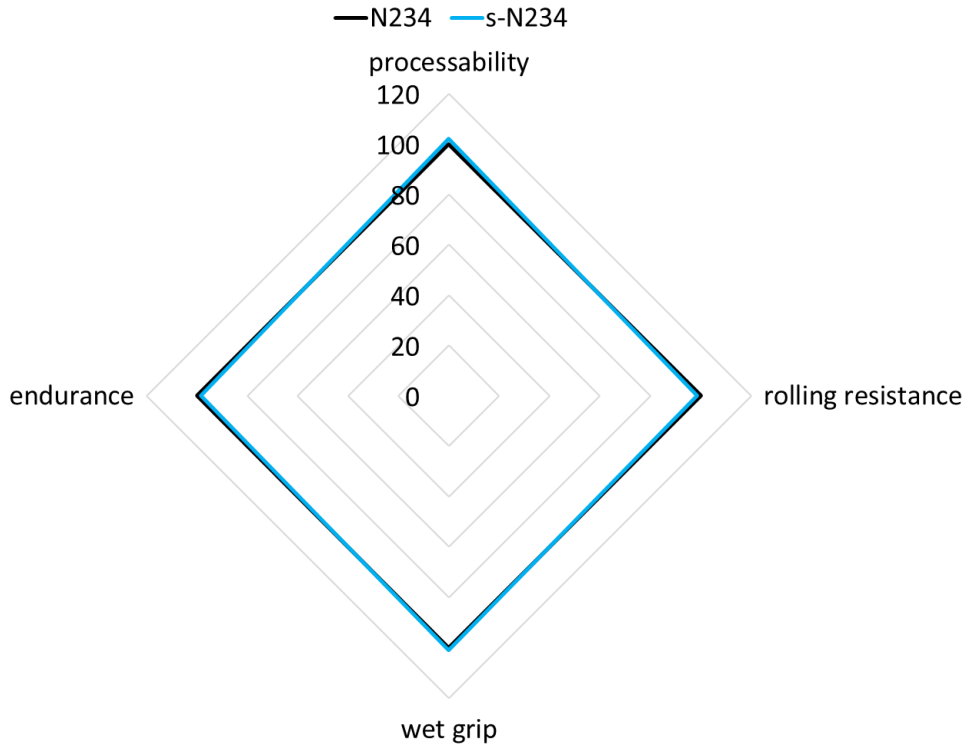
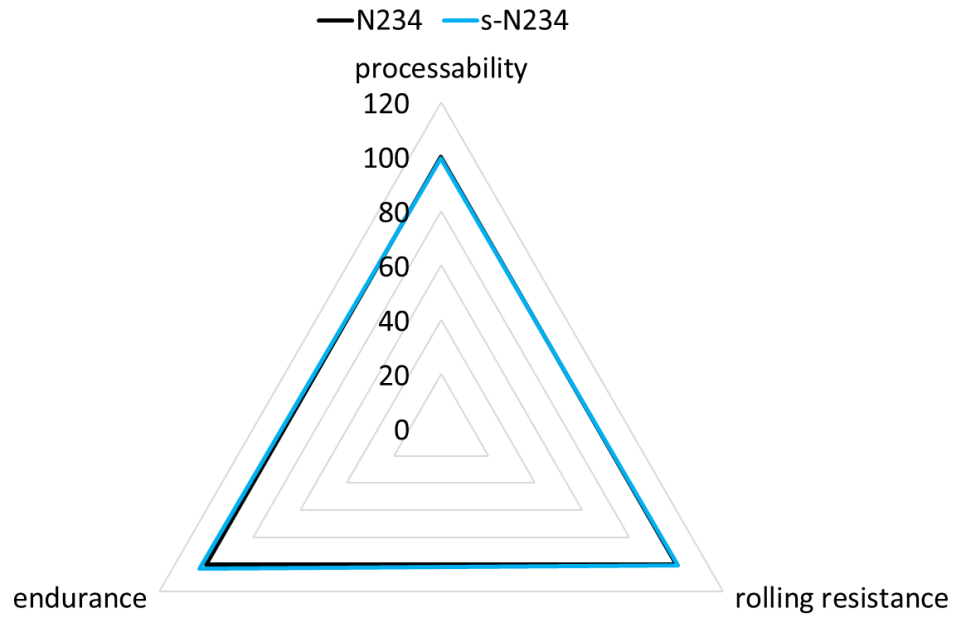
Sustainable carbon black: same in-rubber properties than with ASTM CB even for the most technical (N234) in the tread

In-rubber properties **substitutive** of tire performance of the rubber composition used in the truck tires (> 100 is better) :



Tread rubber composition



Sidewall rubber composition

Similar in-rubber properties between s-N234 and N234

Same results with N347

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s-CB: similar performance in truck tyre

N234 & N347

Tire performance	Tire with N234 and N347	Tires with s-N234 and s-N347 from Orion replacing respectively 100% of N234 and N347 in up to 4 posts
Rolling resistance	100	99
Wet adherence	100	98
Endurance	Reference	Iso reference

Tire performances are similar (inside critical difference of the measurement).

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s- resin: very promising results in rubber composition

The in-rubber results with the 1st batch resin show that that s-resin acts as a plasticizing resin:

⇒ Great result because

⇒ resins have a complex chemical structure

⇒ here obtained from a complex feedstock composition

⇒The key properties of the mixes are not exactly at the target but we are quite optimistic for the next batches of resin

Two additional batches were made to further optimize the resin characteristics which are still under evaluation in rubber mixes to better address the magic triangle performances.

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The Blackcycle Secondary Materials could be used to significantly increase the material recycled content of the tires

Secondary raw material	TRL of raw material for tire domain application	Type of test (tire domain application)	Conclusions of the tests
r-CB with selected feedstock	5	Laboratory in-rubber tests	Truck Tread Feedstock improved the r-CB quality
s-resin	2	Laboratory in-rubber tests	First promising results
Innerliner micronized rubber powder	4	Laboratory in-rubber tests	Could be introduced in a virgin innerliner keeping the same in-rubber properties level
s-CB	7	Tire tests in several posts of a truck tire	s-N234 and s-N347 equivalent to respectively N234 and N347

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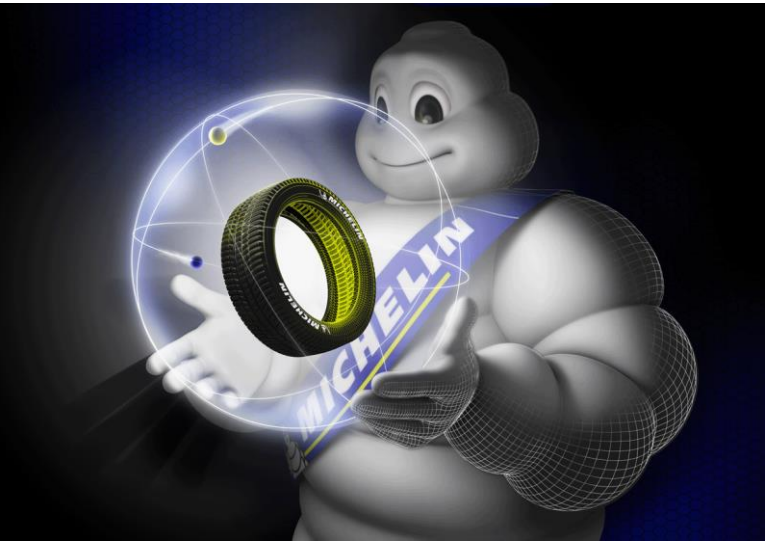
Technically*, the BLACKCYCLE SRMs can be introduced in new tyres at a high rate !

The deconstruction machines ORC et IRG have an interest to add value

*: means with no constraint of supply



- s-CB could be used at 100% in replacement of corresponding ASTM grades **even for the most technical CB.**
- Other secondary raw materials (Innerliner MRP, r-CB) could be used in limited but significant quantity with or w/o tuning of the rubber composition. s-resins are quite promising.
- These Secondary Raw Materials are complementary to each other in terms of utilization in a tyre.

- **Technically speaking, the Blackcycle Secondary Materials could be used to reach a significant rate of recycled rate content in tyres while keeping the same performances**
- Deconstruction of tires has an interest by adding value to the feedstock (MRP & r-CB)

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07

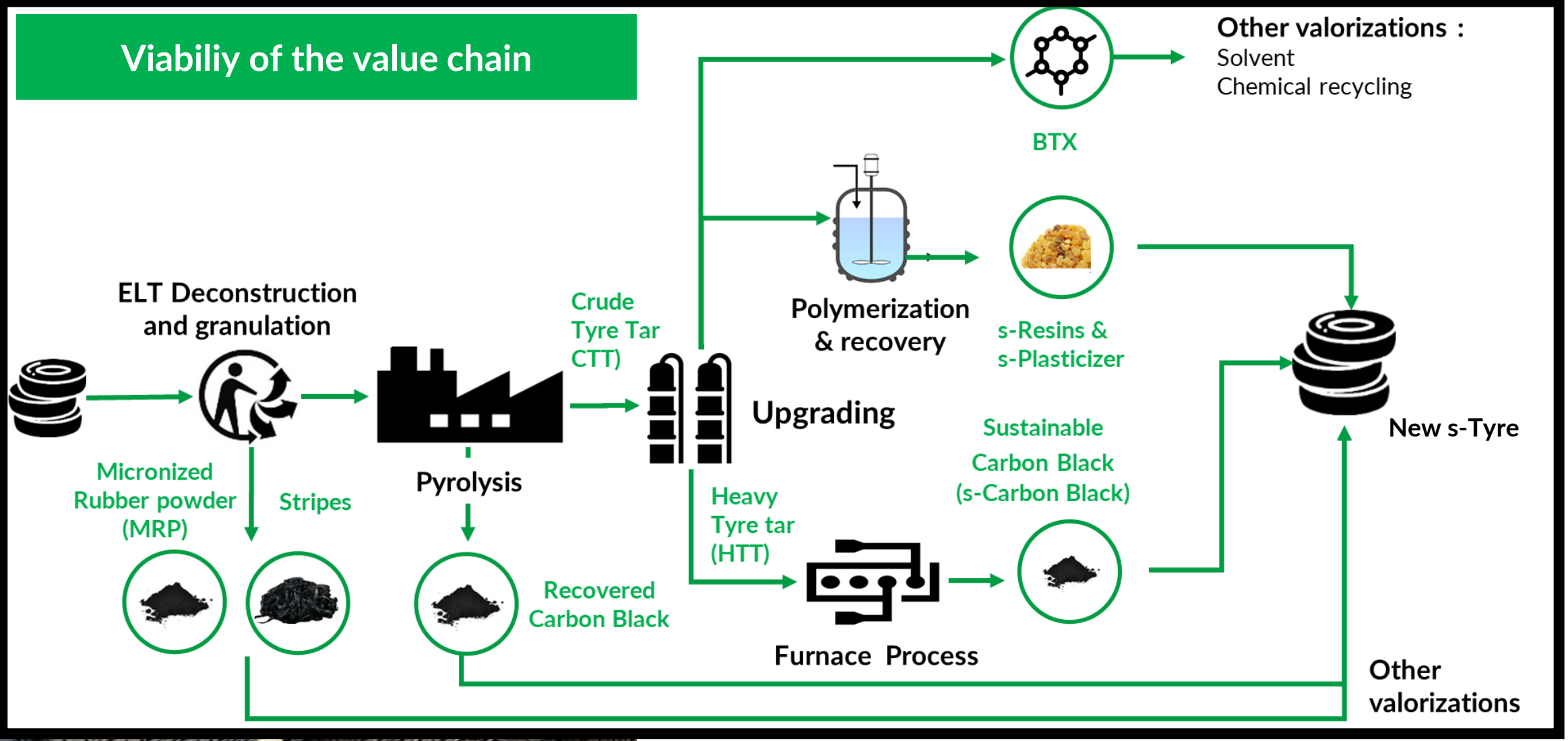
Viability of the value chain

Christina PAPADIMITRIOU, Augustin MILLION - Quantis
Margarita DORATO - Michelin

BlackCycle, enable massive and viable circular economy of tyres

BlackCycle Value chain

Viabiliy of the value chain



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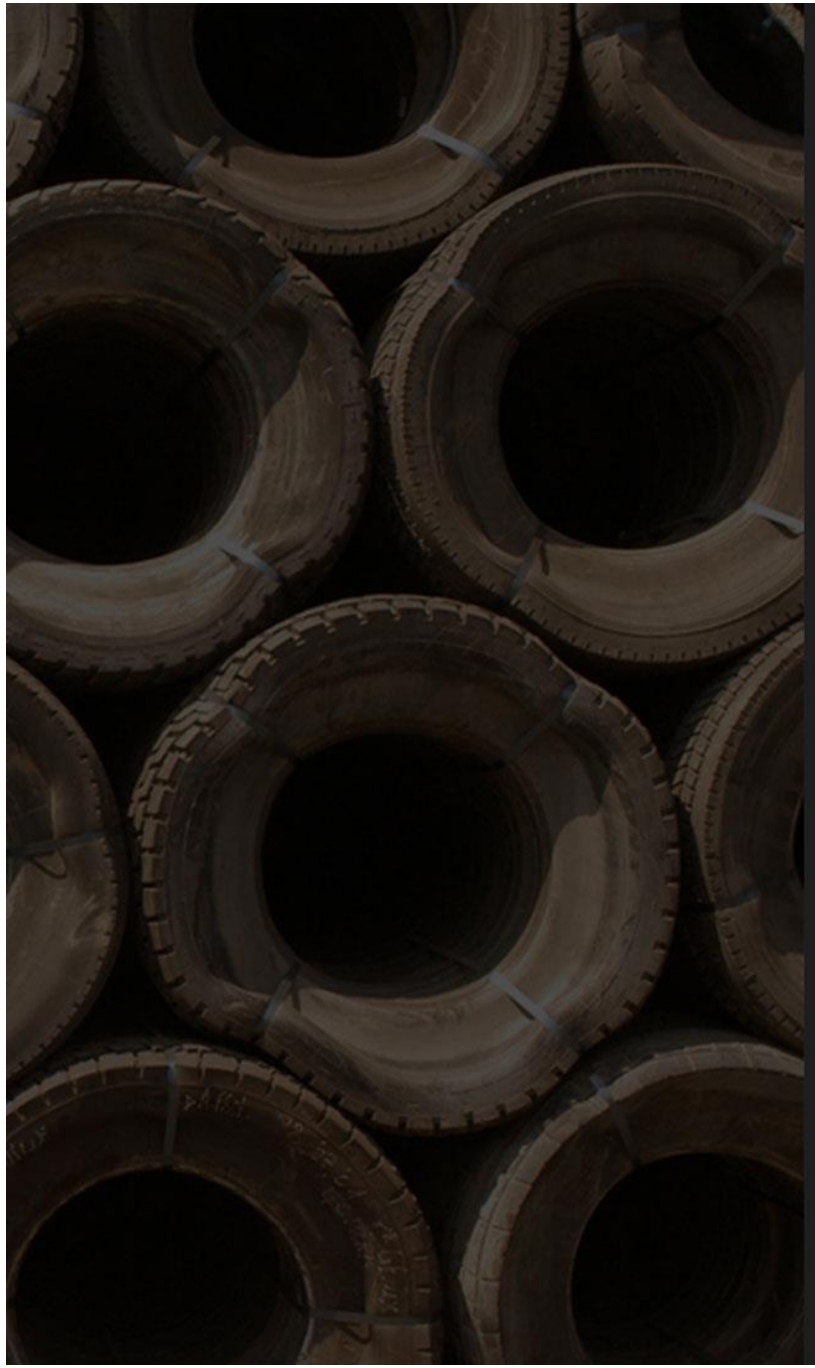


BLACK CYCLE

Move to the green revolution

Viability of the value chain

Christina PAPADIMITRIOU, Augustin MILLION - Quantis

Agenda

1. Scope of the study
2. LCA & Circularity Assessment results
3. Key outcomes

01 : Scope of the study

Objectives of the study

3 questions:

1. LCA comparison of The BlackCycle value chain producing SRM vs horizon 2030 alternative ELT recycling technologies
   - Historical: Energy recovery
   - Emerging: Chemical recycling producing alternative Naphtha for steamcracker
2. LCA comparison between SRM by Blackcycle vs Fossil alternatives
3. Circularity assessment of The BlackCycle value chain vs alternative ELT recycling technologies

The environmental performance of the BlackCycle value chain is assessed against 2 reference scenarios:

Scenario I: BlackCycle vs. *energy recovery in cement kilns*

Scenario II: BlackCycle vs. *chemical recycling*

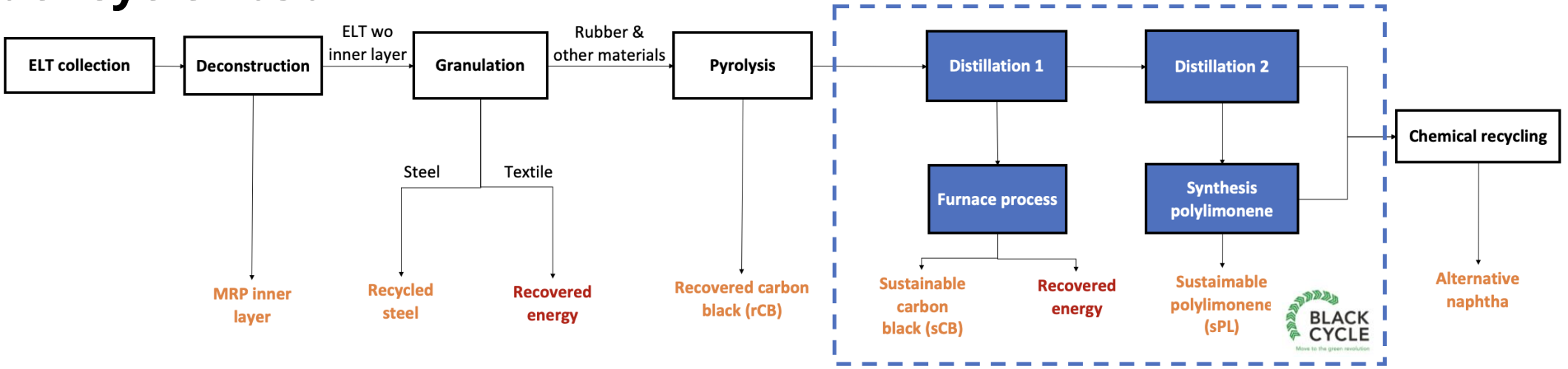
Scope of the study

Functional Units	LCA results are generated for 2 functional units: 1. 1 ton End-of-Life tyres (ELT) treated 2. 1 kg carbon black, at factory gate In addition, an LCA focusing on secondary raw materials is done: • 1 kg Micronized Rubber Powder (MRP), at factory gate
Environmental indicators	**LCA** results are produced for the *climate change* indicator, as well as for other environmental indicators of importance such are *resource use*, *particulate matter*, *water consumption* and others. The outcomes of a **circularity assessment** are presented as well, and offer a more holistic view on the sustainability performance of the BlackCycle technology.

Scenario I: BlackCycle compared to the average energy recovery route of ELTs

Legend:
Recovered material
Recovered energy

BlackCycle 2030

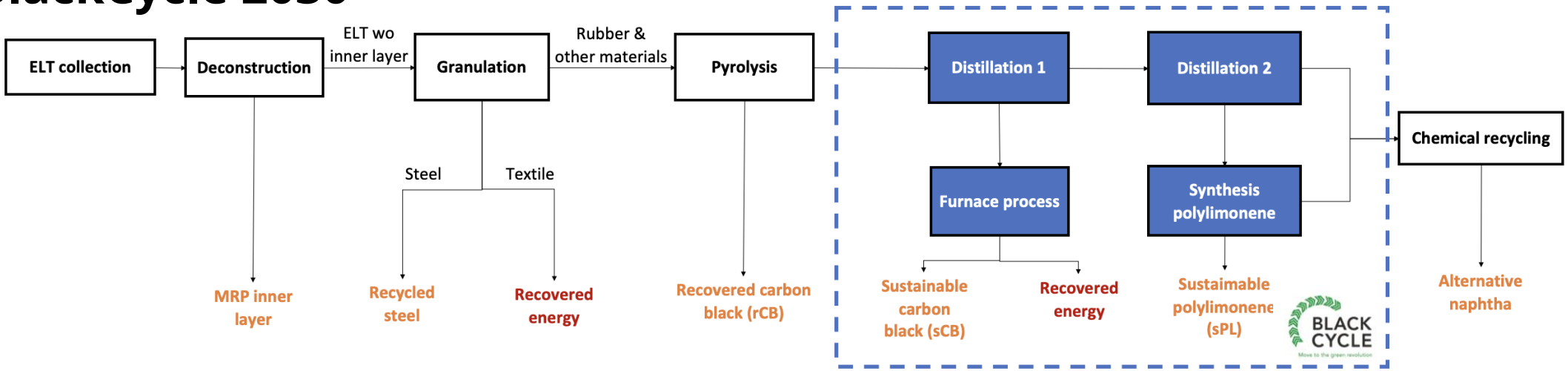


Reference 2030: 100% energy recovery in cement kilns

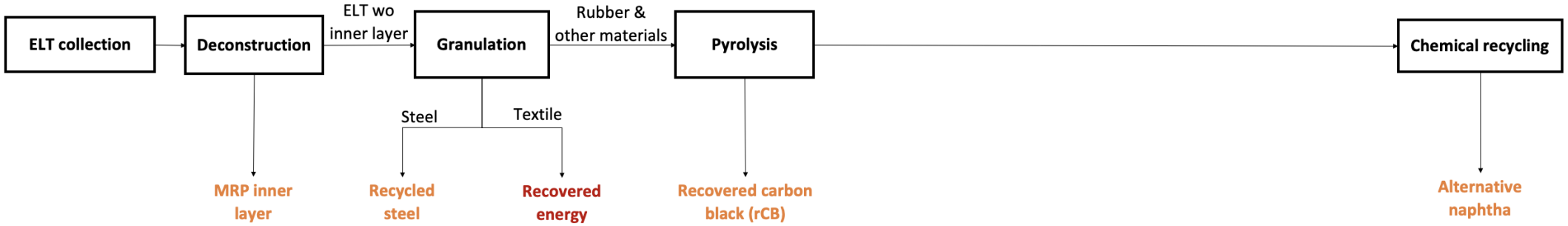
Scenario II: BlackCycle compared to chemical recycling of ELTs

Legend:
Recovered material
Recovered energy

BlackCycle 2030



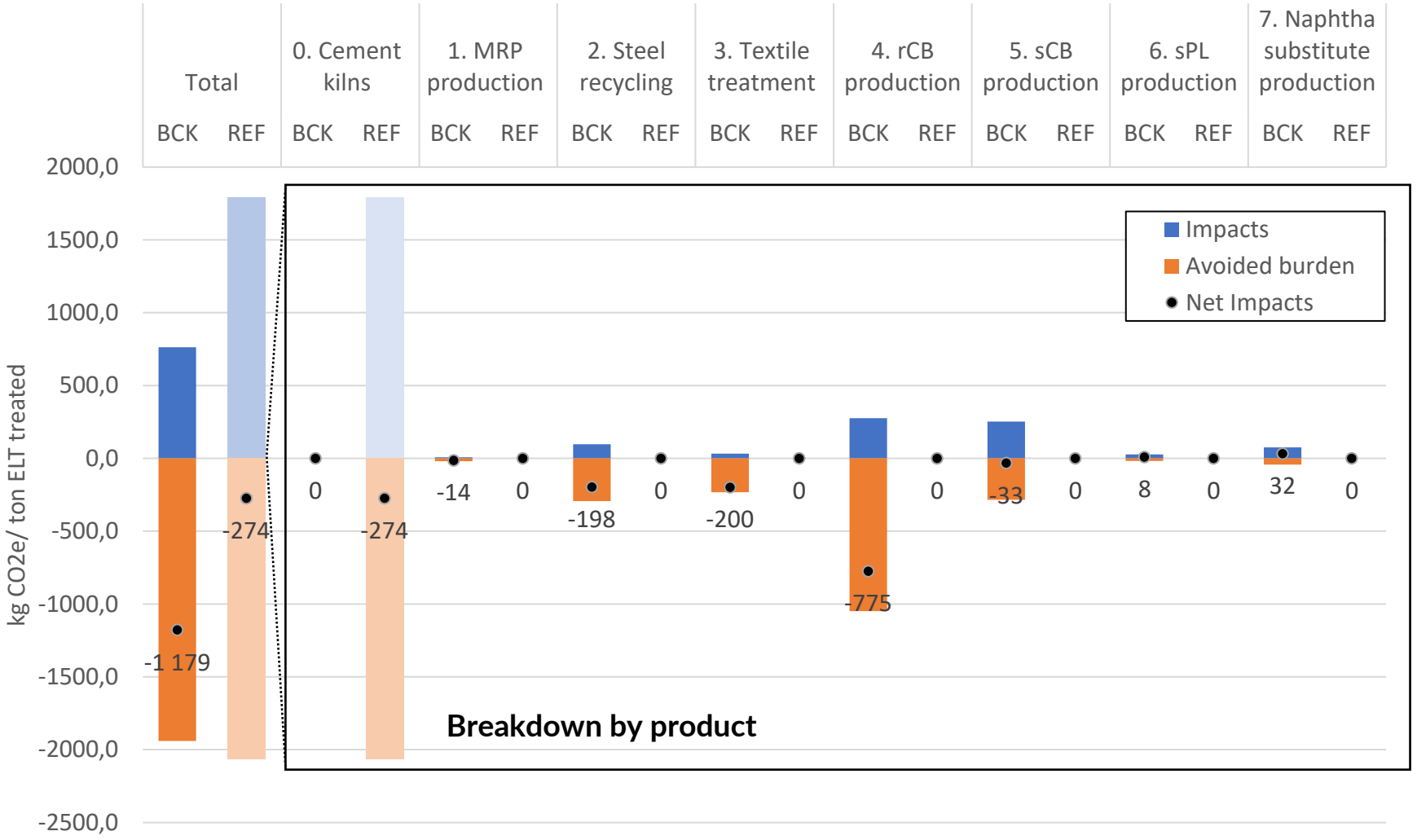
Reference 2030: 100% chemical recycling



02 : LCA & Circularity Assessment results

Blackcycle performs better than energy recovery, on climate change

climate change



Scenario I

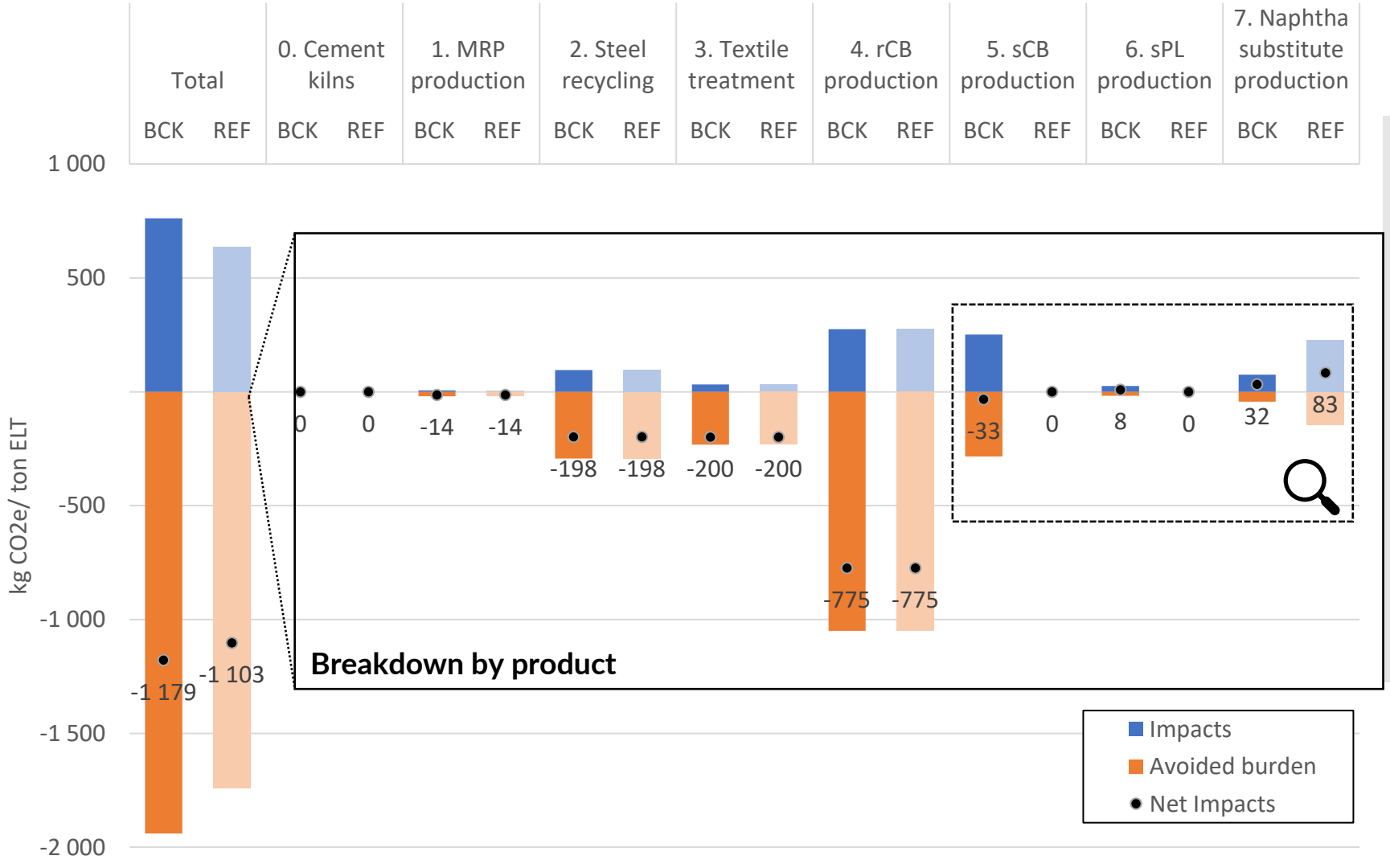
Processing 1 ton ELT in BCK value chain vs via energy recovery in cement kilns

Main outcomes:

- The BlackCycle process has a significantly **lower net impact,** up to ***-77%*** compared to energy recovery in cement kilns.
- The biggest contributor of that improvement is recovered CB.

BlackCycle performs better than chemical recycling, on climate change

climate change



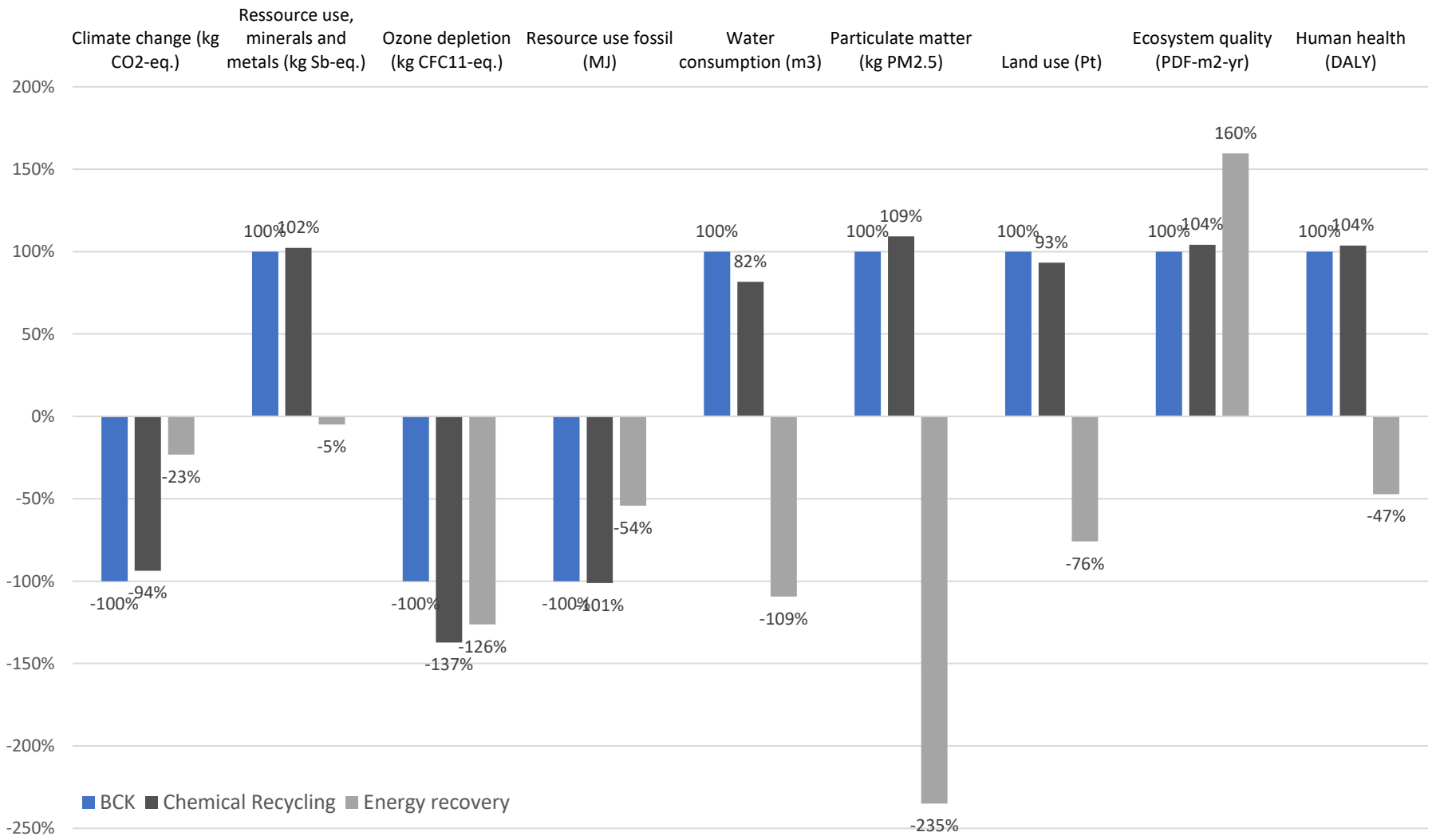
Scenario II

Processing 1 ton of ELT in BCK value chain vs chemical recycling

Main outcomes:

- BlackCycle and Chemical recycling have a similar impact
- However; BlackCycle value chain leads to 5% reduction in net
- The main contributor is sCB

Multi-indicator results: comparing the 3 ELT treatment routes



other indicators

Main outcomes:

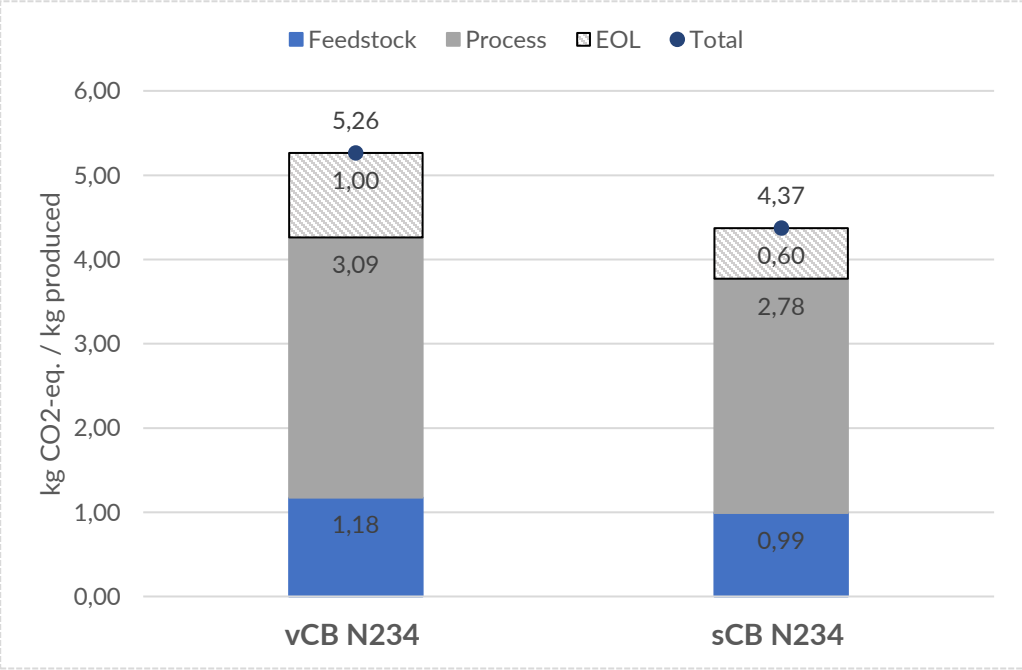
- Blackcycle and Chemical Recycling route are following the same trend on most indicators.
- Energy recovery route is performing better on Human health related indicators due to avoided fossil fuel consumption.

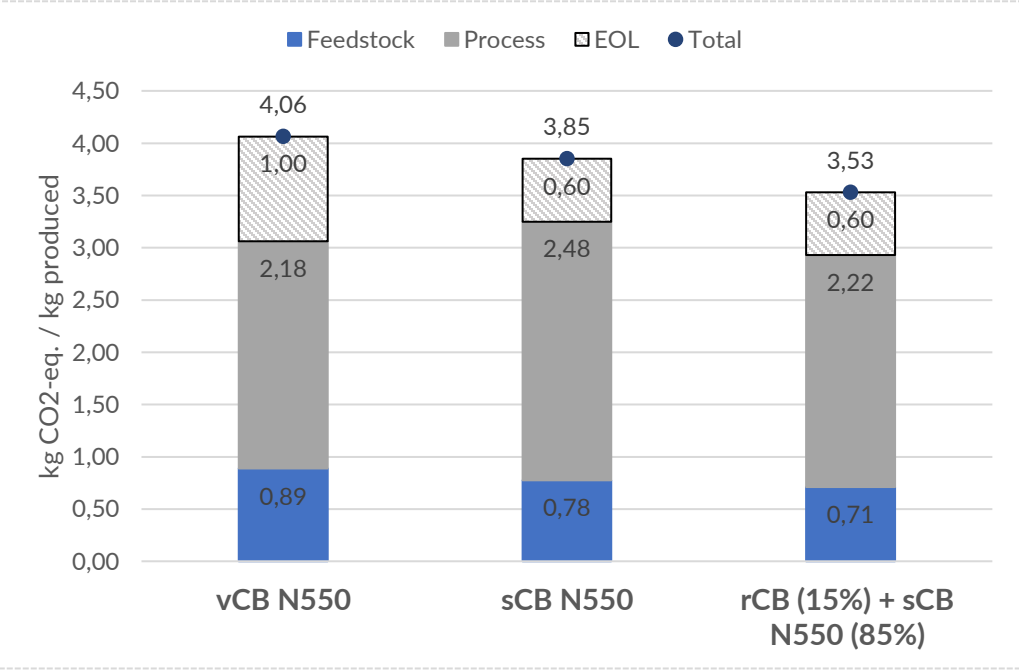
Sustainable CB from BlackCycle

climate change

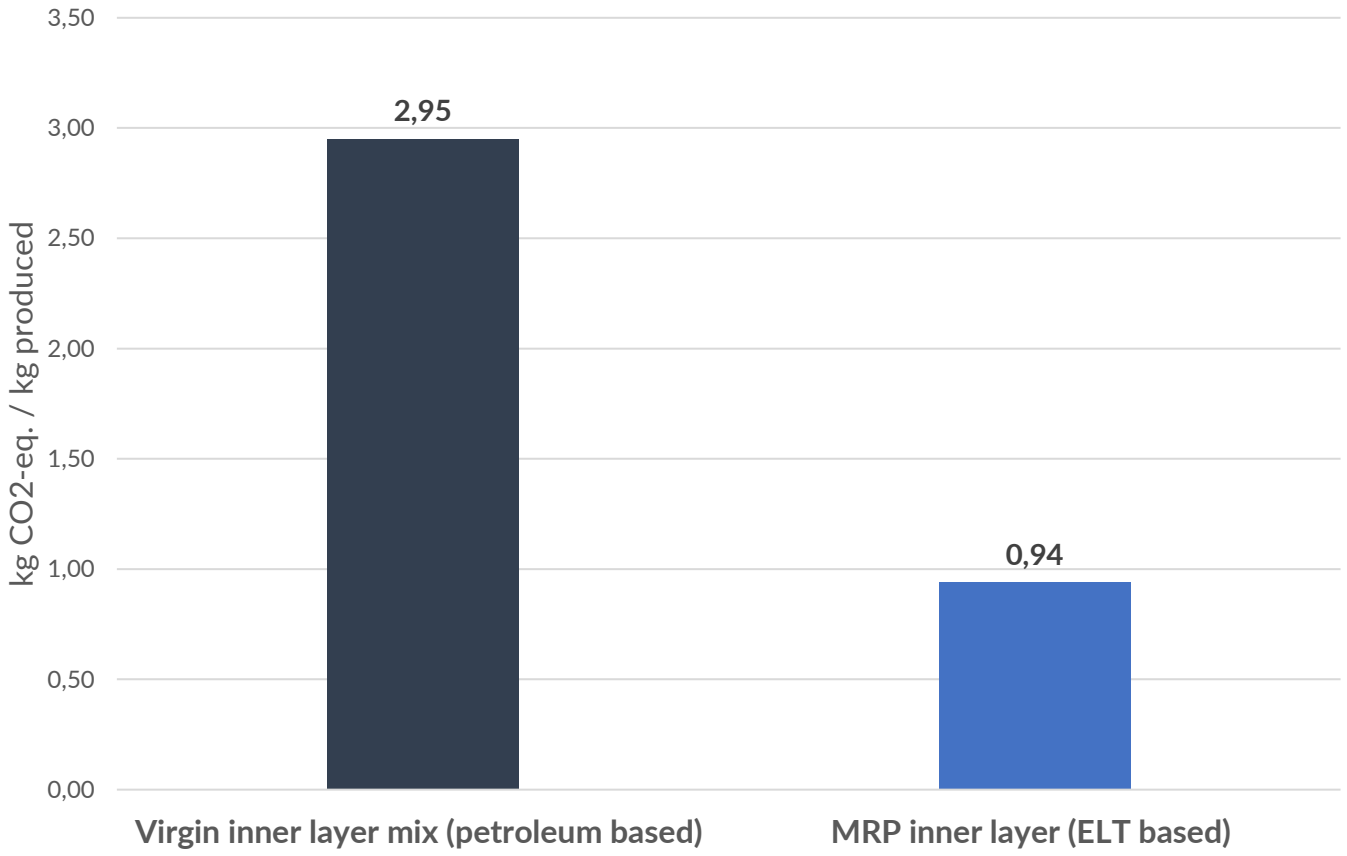
The assessed functional unit is: **1 kg of carbon black, cradle to grave**

The sustainable carbon black ***produced*** from the BlackCycle value chain has **lower climate change impacts**, for both N234 & N550 grades, when considering EOL.





Micronized Rubber Powder (MRP) from inner layer is retrieved as secondary raw material



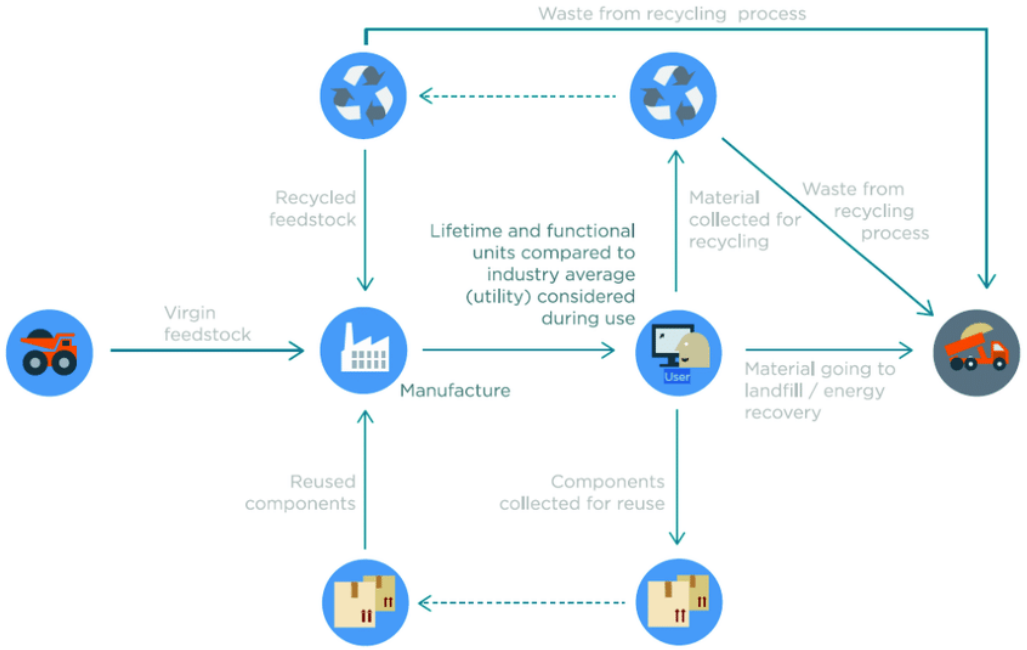
CO_2
climate change

Deconstruction of inner layer

- MRP is retrieved from ELT, at the ”Deconstruction” step.
- Virgin layer mix is **3 times** more impactful, in terms of GWP, than MRP recovered from inner layer.
- **Disclaimer**: the difference in EoL is not accounted for.

Circularity assessment result

The **Material Circularity Indicator** (MCI) by the Ellen MacArthur Foundation is used to assess the circularity performance of the BlackCycle value chain in comparison with the reference scenarios. This indicator allows to identify any circular value generated by a product (the higher the MCI, the higher the circular value).



Scenarios: treatment of 1 ton of ELTs, via	BlackCycle	Energy recovery in cement kilns	Chemical recycling
MCI Score	36%	17%	39%
kg of SRMs recovered	**541**	**170**	**611** ⚠

⚠ No fuel exemption in steamcracker considered

The Blackcycle and Chemical recycling scenarios are comparable in terms of circularity, emphasizing the efficiency of these processes in producing SRMs

03 : Key messages

The BlackCycle value chain allows to lower CO2 emissions compared to conventional ELT treatments

End of Life Tyres

The BlackCycle value chain allows to **lower CO2 emissions** compared to conventional ELT treatments.

- The advantage is clear against energy recovery in cement kilns, with a potential **GHG emissions reduction of -77%.**
- The trade-off against chemical recycling is marginal, with **-5% lower CO2 emissions** achieved.

Secondary raw materials

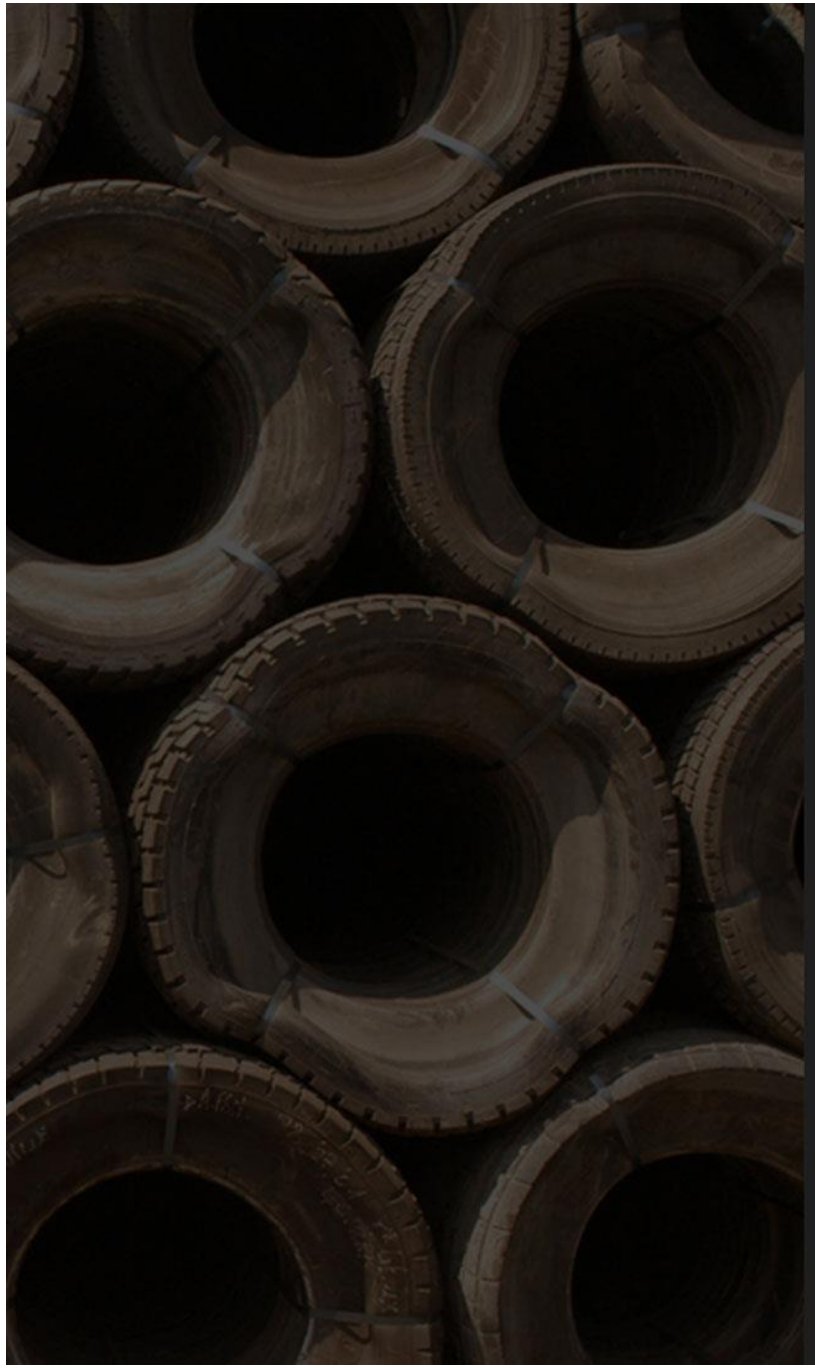
The BlackCycle carbon blacks (sustainable and recovered) have **lower CO2 emissions** compared to virgin carbon black, at full life cycle.

- Valorizing pyrolytic oil into carbon black is linked with the use of a less CO2 intensive feedstock and lower fossil CO2 emissions generated at their End-of-Life.

Recovering the MRP layer leads to **3 times less CO2** emissions in the production of a virgin layer.

Other indicators

- The Blackcycle and chemical recycling routes are following the same trend on most environmental indicators, including circularity.
- For some indicators related with human health, the energy recovery route is performing better, due to a higher energy recovery advantage.



BLACK CYCLE

Move to the green revolution

Viability of the value chain

Margarita DORATO - Michelin

CHALLENGES TO SUCCEED

Technological

The tyre is highly technological

Various performances at the same time

Supply chain creation

Large volumes, quality stability, worldwide coverage

Economical viability

of the overall value chain Vs. an optimized value chain , Customer's willingness

Environmental viability

>0 impact on LCA incl. waste avoïdance&Recycled Mat. use

Energy balance

No <0 environmental effects

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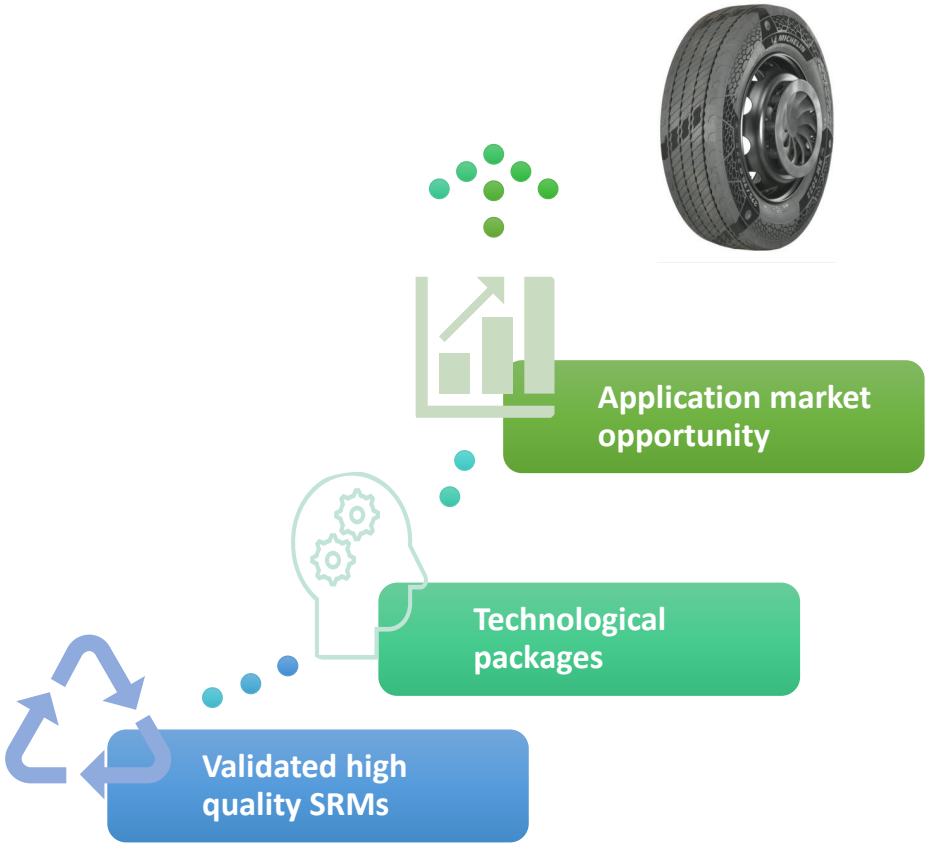
The end goal of a value chain is to create a competitive advantage by increasing sustainability while keeping reasonable impact cost



What is the impact on a cost of the product for a tyre with a higher SRMs rate?

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Multiparameter problem …

Geographic implantation

Energy price

Investment rentability

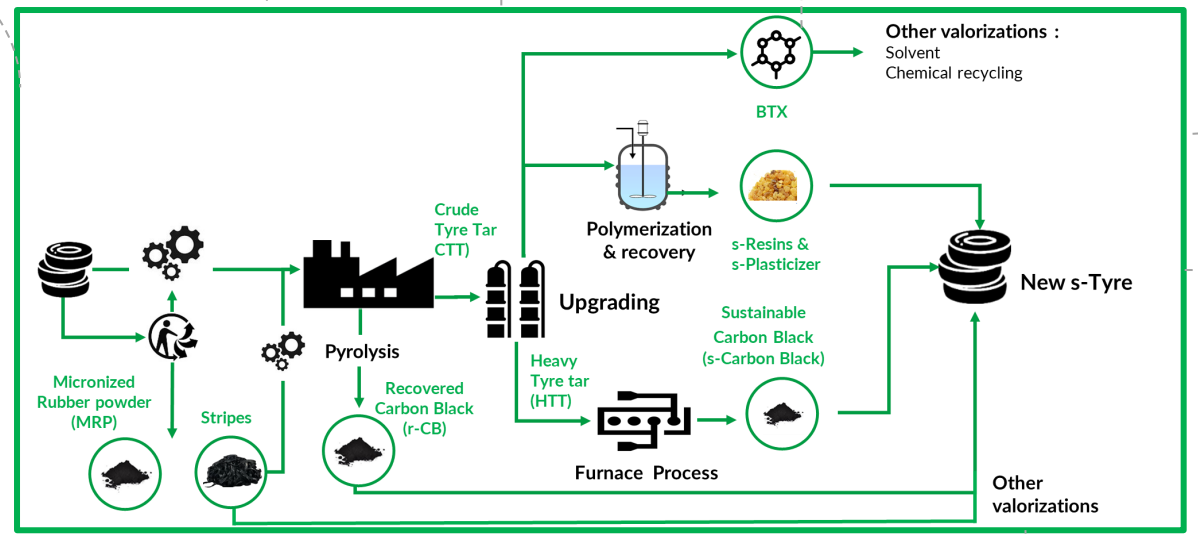
Competitor

Regulation

Product market prices

ELTS

ELT market prices



PCT/TT ?

NEW TYRES

%SRM rate

Oil based raw material evolution prices

CAPEX and OPEX

Ramp-up

Alternatve technologies

By produc valorization

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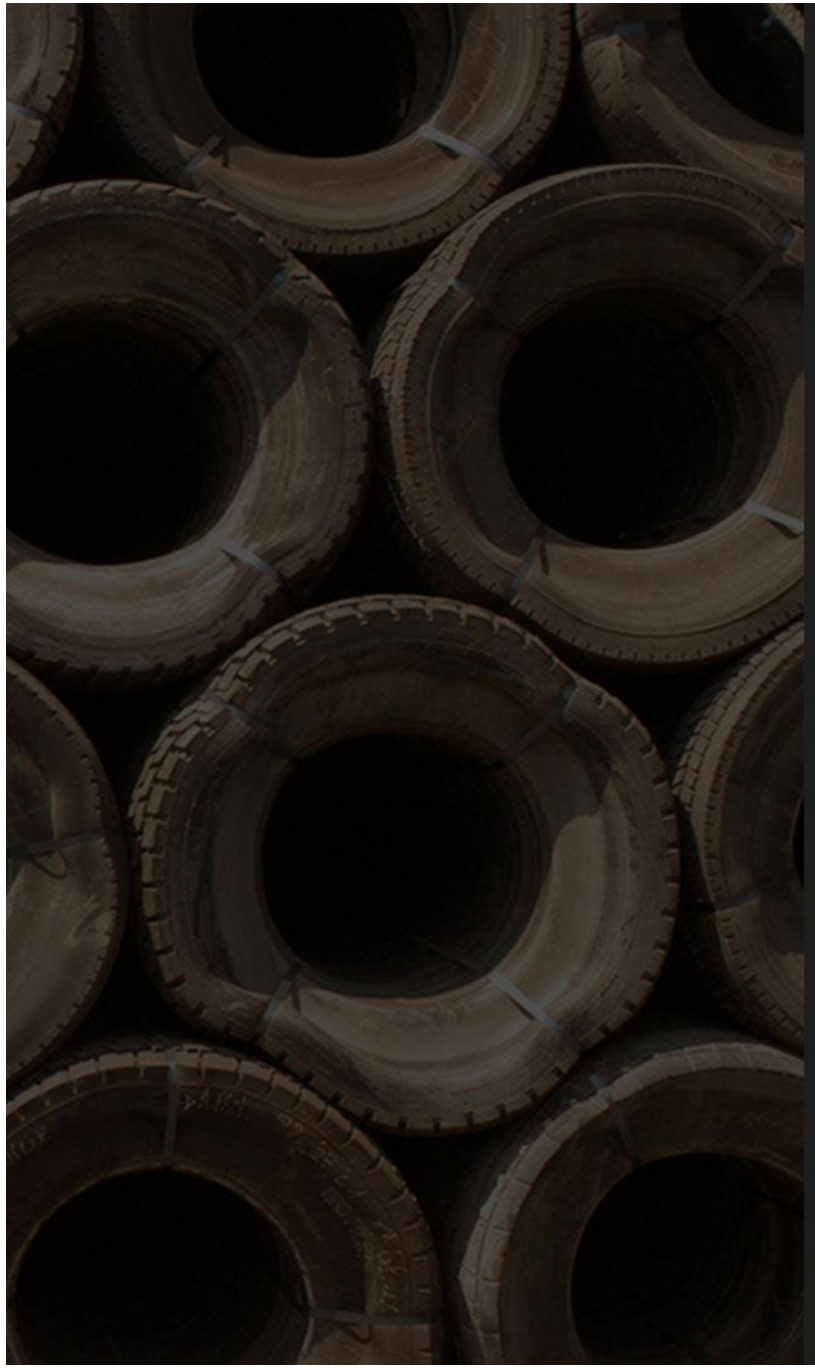
The acceptability of the higher cost could be improved by activation of different levers to minimize the over cost

- **Levers coming from Blackcycle :** business model optimization, valorization of all by products, valorization of SRM in other application, improvement of SRM quality (rCB) …
- **Levers coming from strategy of SRM ramp-up** : nature and rate ramp-up of SRM in tyres to activate the market demand…
- **Levers coming from European support** : regulatory and incentives policies to help investment and robust the economic viability

08 Introduction

Jean Michel DOUARRE - Michelin

Academic knowledge enhancement



BLACK CYCLE

Move to the green revolution

Academic knowledge enhancement

Juan Daniel MARTINEZ - CSIC-ICB,
Eleni PACHATOURIDOU - CERTH-CPERI

09

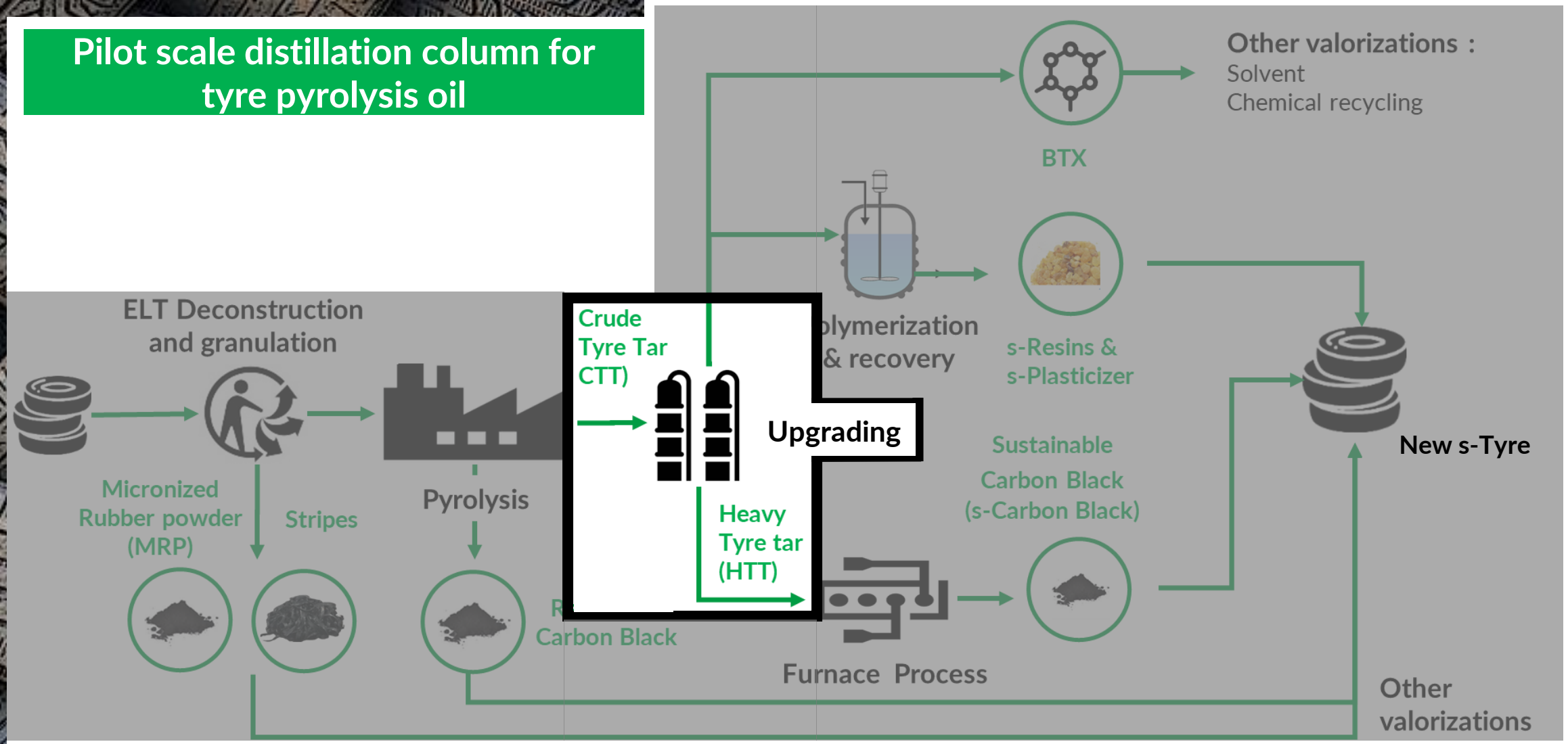
Design and operation of a packed pilot scale distillation column for tyre pyrolysis oil: towards the recovery of value-added raw materials

Juan Daniel MARTINEZ - CSIC-ICB

Academic knowledge enhancement

BlackCycle Value chain

Pilot scale distillation column for tyre pyrolysis oil



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Background: What does TPO have?

Tremendously complex hydrocarbon

- Light and aromatic compounds
- Flash point < 35ºC
- Legislative complexity
- Contamination problems
- Traces of solids, water…
- Etc…

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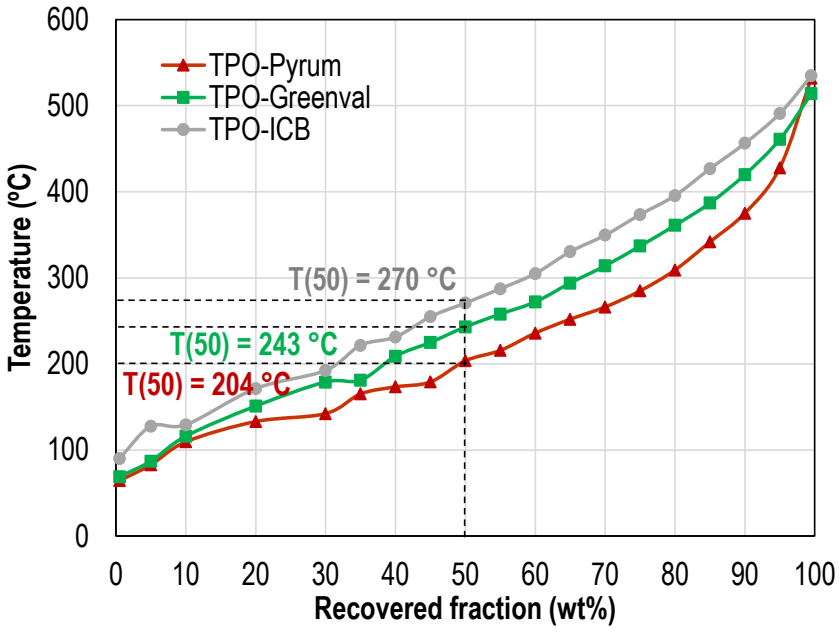
Background: What does TPO have?



SimDist curve (ASTM D2887)

Equipment/Method	Parameter	TPO		
		Greenval	ICB-CSIC	Pyrum
Thermo Flash 1112, UNE-EN 15307	Carbon (wt%)	88.0	89.2	88.2
	Hydrogen (wt%)	9.8	9.1	9.2
	Nitrogen (wt%)	0.9	0.6	0.9
	Sulfur (wt%)	0.7	1.1	0.8
From elemental analysis	H/C	1.33	1.22	1.24
Parr 6400, UNE-EN 15400	HHV (MJ/kg)	42.04	39.2	41.6
Picnometry	Density @ 25ºC (g/ml)	0.92	0.90	0.93
Crison Titromatic, ASTM E203	Water content (ppm)	153	148	165
Grabner Instruments, ASTM D6460	Flash point (ºC)	< 25	< 25	< 25
Mettler Toledo T50	pH (---)	6.4	6.2	7.6
Mettler Toledo T50	TAN (mgKOH/g)	5.3	5.1	---
Simulated distillation (ASTM D2887)	IBP (ºC)	69.0	90.0	64.4
	T_{50} (ºC)	243.1	271.0	203.4
	FBP (ºC)	513.9	534.0	532.1
Gas chromatography	Benzene (wt%)	2.1	2.4	4.0
	Toluene (wt%)	6.2	6.2	11.4
	Ethyl-Benzene (wt%)	1.0	1.3	2.6
	(p+m)-Xylene (wt%)	5.0	4.1	7.9
	o-Xylene + Styrene (wt%)	1.8	2.5	2.4
	Total BTEX (wt%)	16.2	16.5	28.2
	Limonene (wt%)	2.7	5.1	0.1

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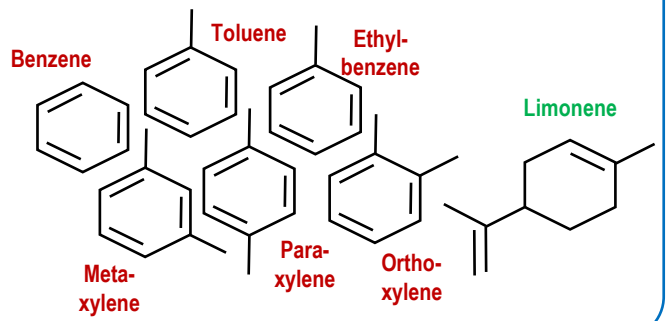
Why distillation?

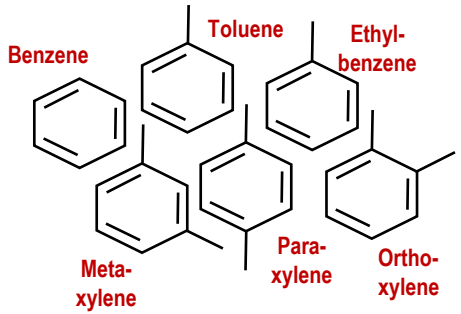
1st Distillation

Light Tyre Tar (LTT)

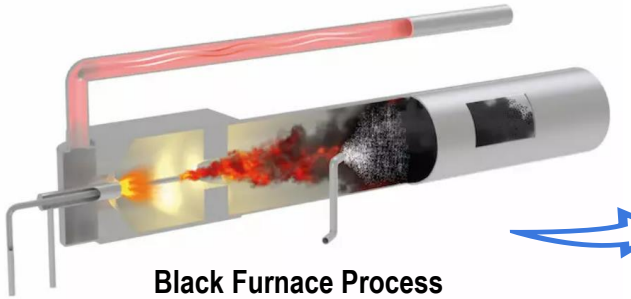


2nd Distillation

Solvent Tyre Tar (STT)



Heavy Tyre Tar (HTT) – FP > 65°C



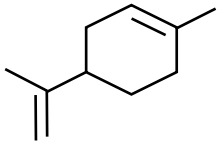
Black Furnace Process

Sustainable carbon black (sCB)

For manufacturing new tyres

Resin Tyre Tar (RTT)

Limonene

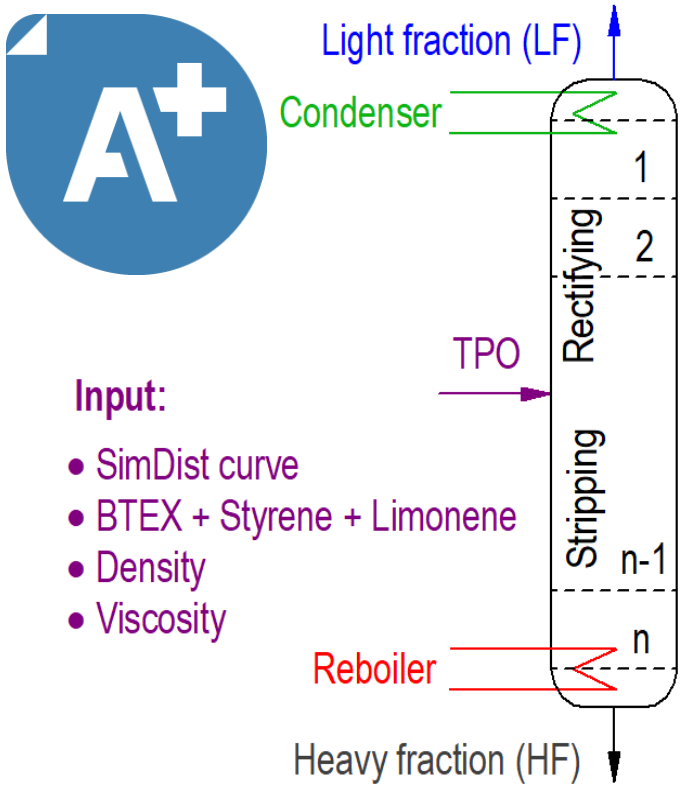


An ultra-light fraction with very high limonene (↑ 20 wt%)

→ Plasticizer ←

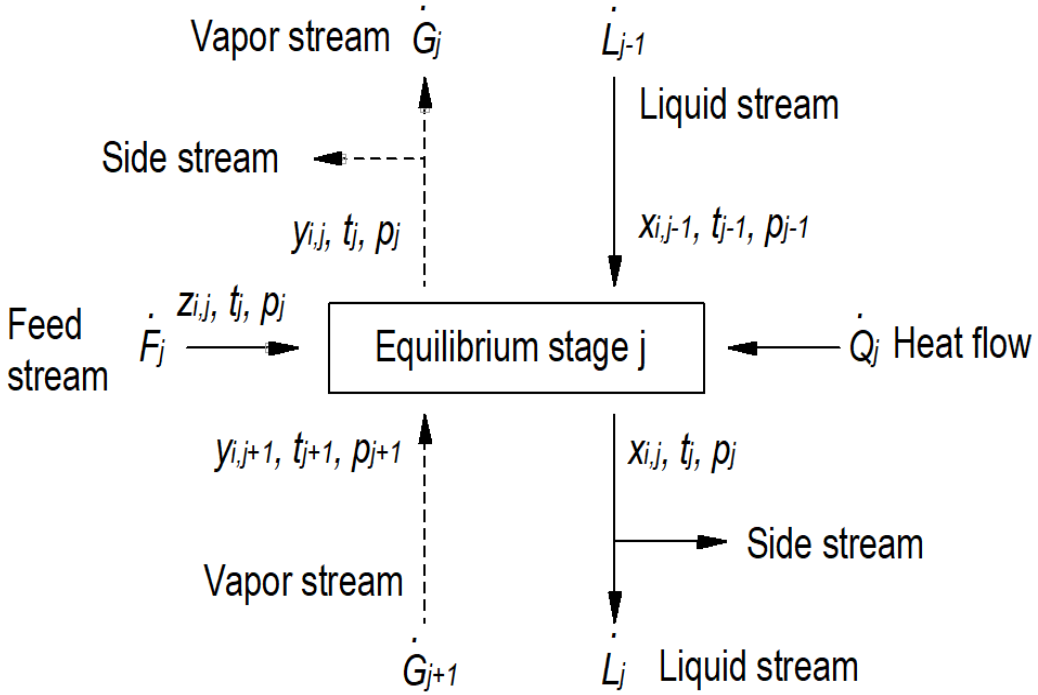
BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

How to design a distillation column?



Input:

- SimDist curve
- BTEX + Styrene + Limonene
- Density
- Viscosity



Main results

1. Column diameter and internal packing data
2. Number of equilibrium stages
3. Expected yield and LTT concentration
4. Reboiler and condenser duties

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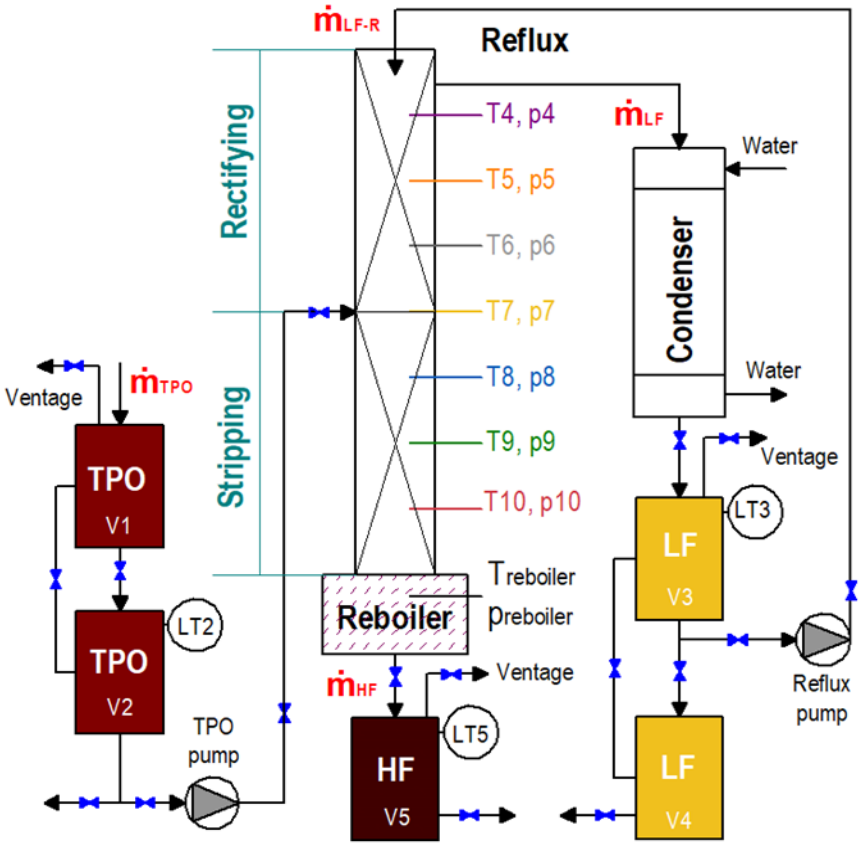
Results



Main results

1. Column diameter and internal packing data
2. Number of equilibrium stages
3. Expected yield and LTT concentration
4. Reboiler and condenser duties

→ 110 mm
Pall rings 1”
→ 8 eq. stages
3.5 m height
→ 30 wt% at 270 ºC
14.8 wt% limonene
→ 6 kW reboiler
4 kW condenser

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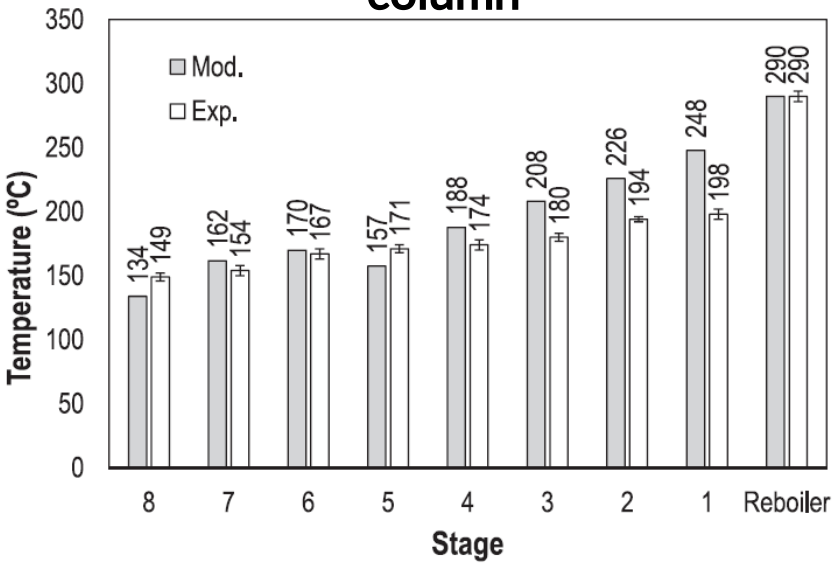
Validation → First distillation → LTT

Comparable results between the predicted and experimental values

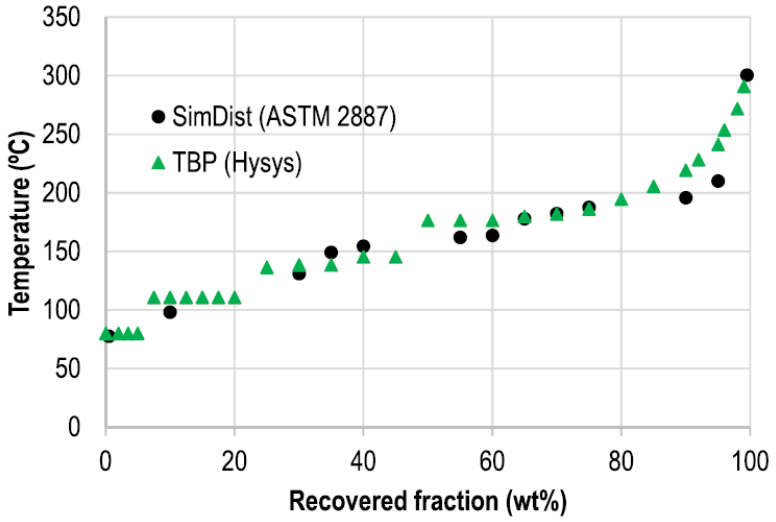
TPO: ICB-CSIC
Conditions: 18 kg/h, 290 °C and 1.9 of reflux → 8 h

The yield of LTT was 30 ± 2 wt%

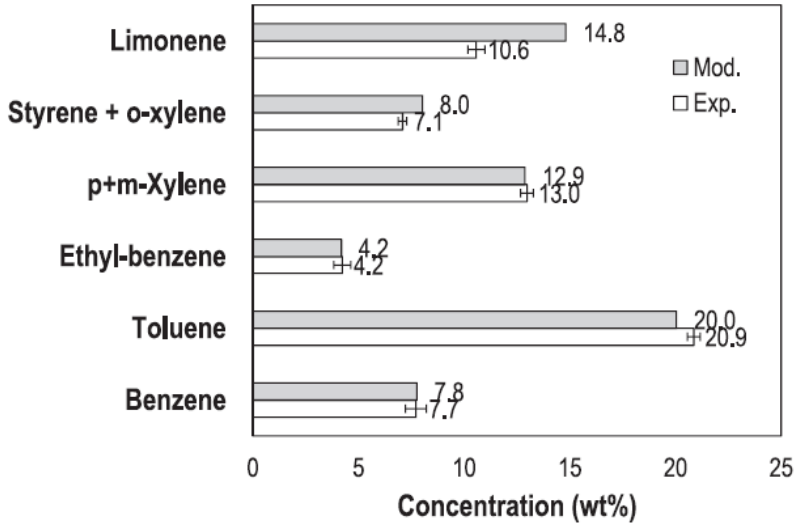
The temperature profiles along the column



Distillation curve of the LTT



BTEX + styrene + limonene concentrations in the LTT



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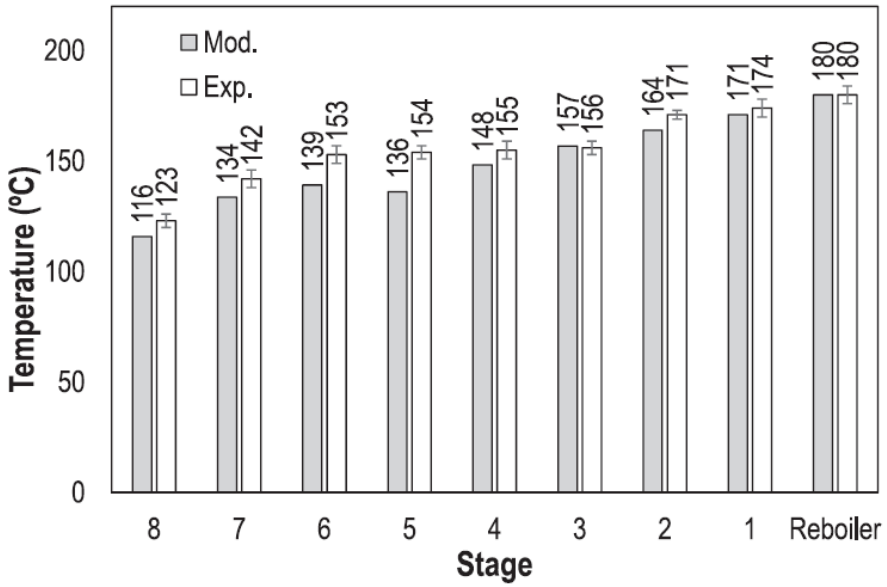
Validation → Second distillation → RTT

Comparable results between the predicted and experimental values

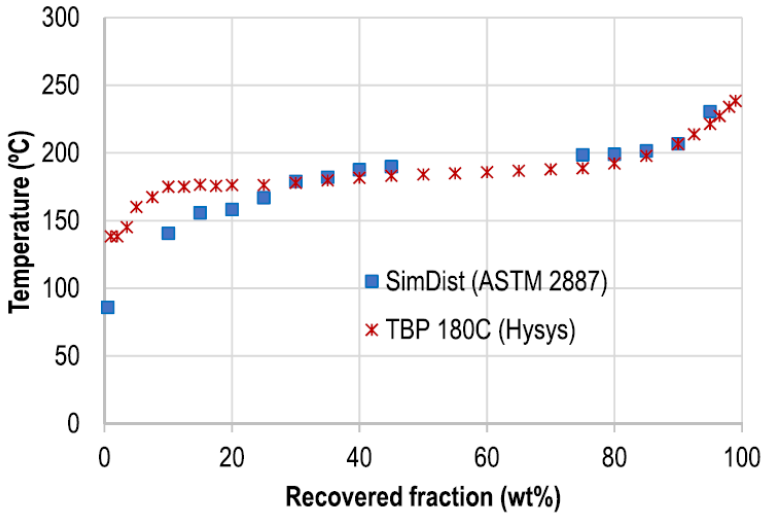
TPO: ICB-CSIC
Conditions: 10 kg/h, 180 ºC and 1.1 of reflux → 8 h

The yield of RTT was 25 ± 2 wt%

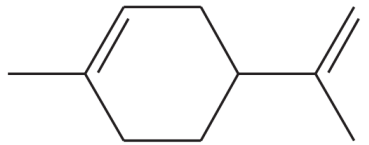
The temperature profiles along the column



Distillation curve of the LTT



BTEX + styrene + limonene concentrations in the LTT



limonene

Exp: 22.1 wt%
Theo: 20.2 wt%

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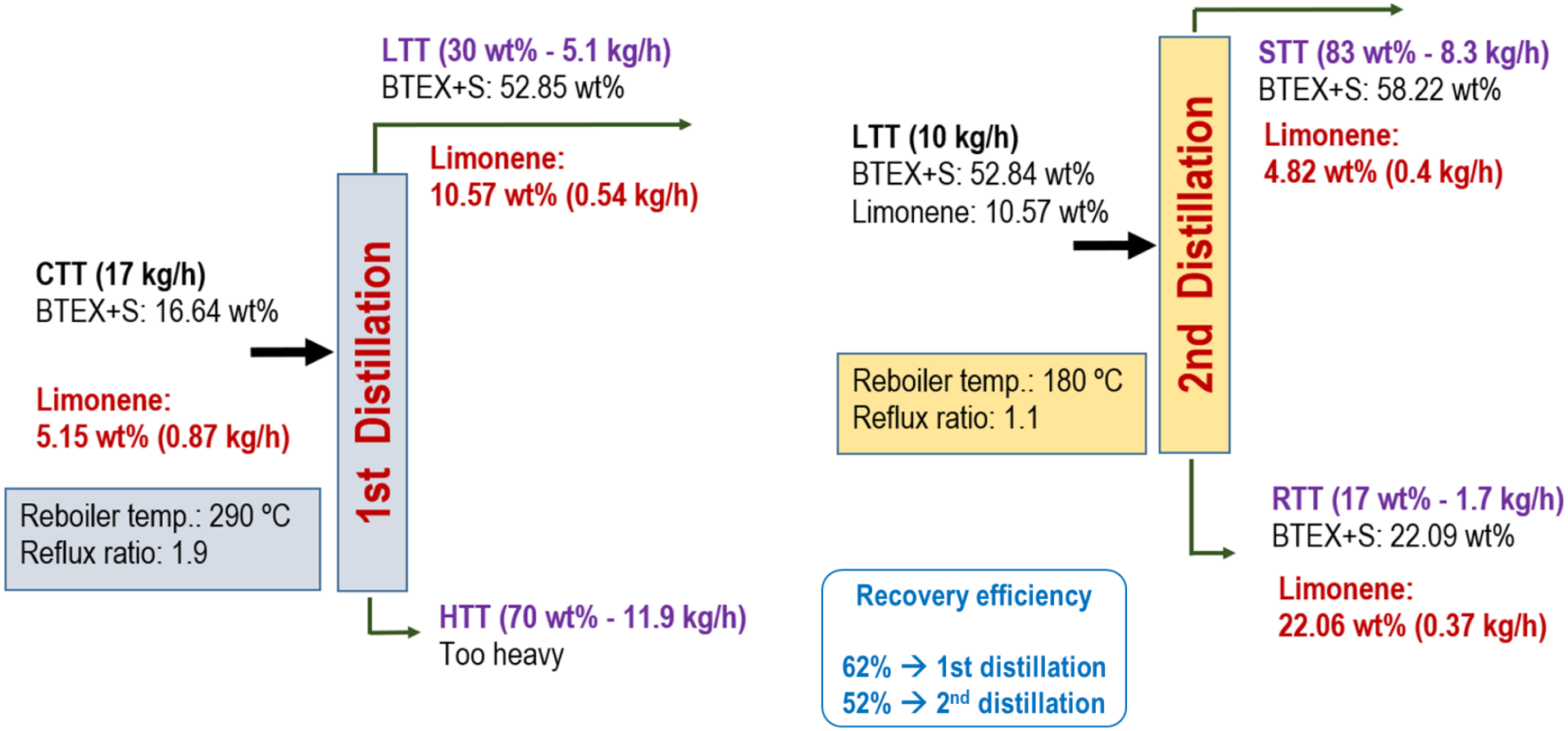
Limonene value chain

CONCLUSION:
Noteworthy results but there is still important room for optimization



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Final remarks

- The door has been opened to integrate **distillation** into the **circular economy of tyres.**
- The **distillation** works carried out by **ICB-CSIC** as part of the **BlackCycle** project **are the first ones** to demonstrate the technical feasibility of fractionating TPO into value-added products on an industrially relevant scale (>TRL5) .**This would not be possible without the help of partners**
- These studies have allowed **ICB-CSIC** to become a world reference not only in the **pyrolysis of ELTs**, but also in the **characterization of TPO and the extraction of value-added products by distillation**, and thus in the **circular economy of tyres**.

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For more information and details

energy&fuels

pubs.acs.org/EF

Article

On Fractioning the Tire Pyrolysis Oil in a Pilot-Scale Distillation Plant under Industrially Relevant Conditions

Juan Daniel Martínez,* Alberto Veses, María Soledad Callén, José Manuel López, Tomás García, and Ramón Murillo

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Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Design and operation of a packed pilot scale distillation column for tire pyrolysis oil: Towards the recovery of value-added raw materials

Juan Daniel Martínez *, Alberto Sanchís, Alberto Veses, María Soledad Callén, José Manuel López, Tomás García, Ramón Murillo

Instituto de Carboquímica (ICB-CSIC), Miguel Luesma Castán 4, 50018 Zaragoza, Spain

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THANK YOU

Q&A

BLACK CYCLE

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Together To Make The Circular Economy A Reality

10

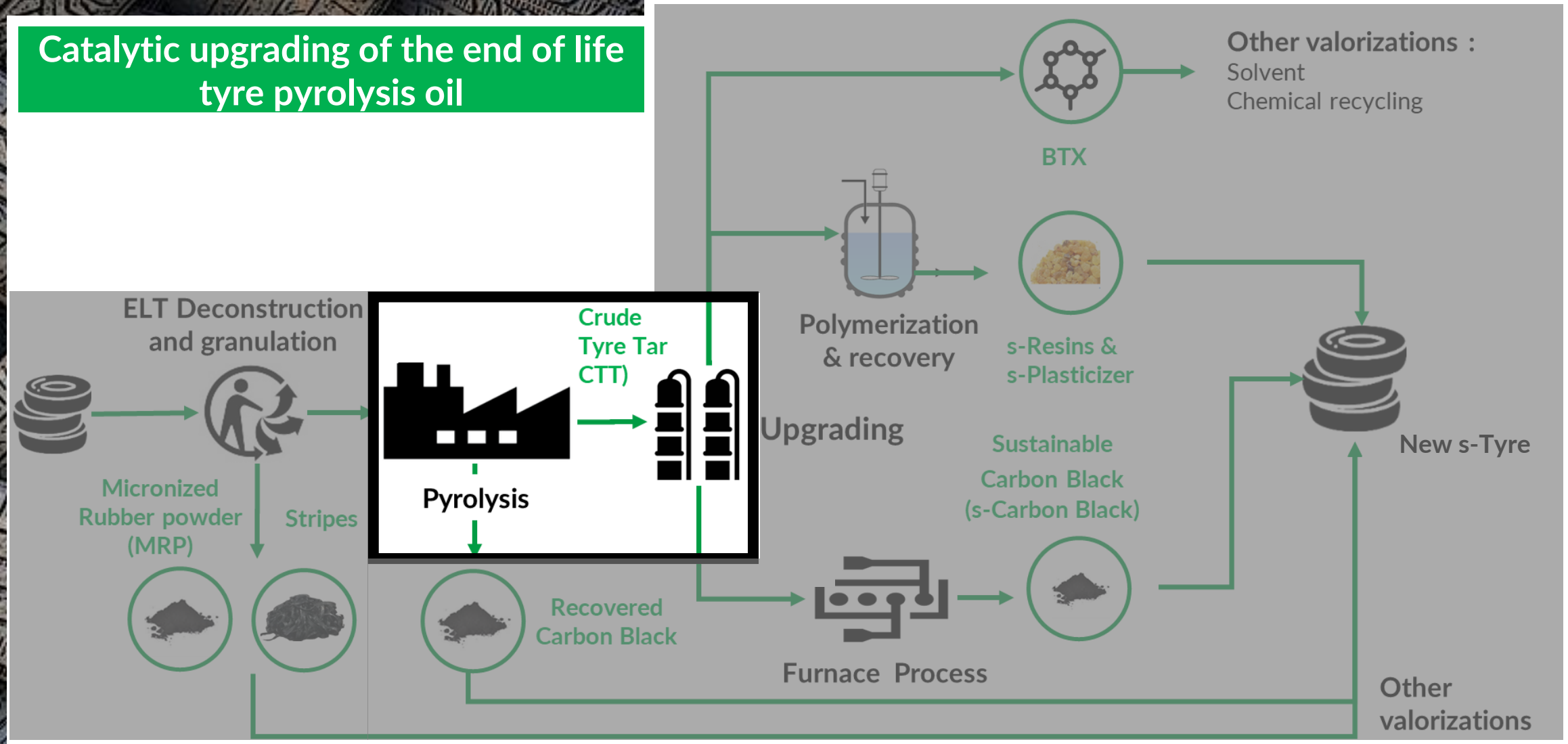
Catalytic upgrading of the end of life tyre pyrolysis oil to increase the aromatic content

Eleni PACHATOURIDOU - CERTH-CPERI

Academic knowledge enhancement

BlackCycle Value chain

Catalytic upgrading of the end of life tyre pyrolysis oil



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Catalytic Upgrading of ELT Pyrolysis Oil to Increase the Aromatic Content

End-of-Life Tyres (ELTs)

Collection, feedstock selection & deconstruction

Pyrolysis

Pyrolysis Gas

Solid (*recovered-**C**arbon **B**lack, rCB*)

Pyrolysis Vapours — *Pyrolysis Oil*

Catalytic Vapor Upgrading

Light Fraction (LTT)

Distillation

Heavy Fraction (HTT)

Aromatization

Eco-Efficient New Tyre

sustainable-**C**arbon **B**lack (s-CB)

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Production of Aromatic Pyrolysis Oil from ELTs direct via…

Catalytic Upgrading of ELTs Pyrolysis Vapours (CUPV)

End-of-Life Tyres (ELTs)

Collection, feedstock selection & deconstruction

Pyrolysis

Pyrolysis Vapours

Catalytic Vapor Upgrading

Pyrolysis Oil

Distillation

Light Fraction (LTT)

Heavy Fraction (HTT)

Eco-Efficient New Tyre

sustainable-**C**arbon **B**lack (s-CB)

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Feedstock, Catalysts & Experimental setup

Granules of multi-brand truck tyres

Properties	ELT
Particle size, μm	1000-3000
Ash, wt.%	7
Carbon, wt.%	80.7
Hydrogen, wt.%	7.6
Sulfur, wt.%	1.5-3.5
Nitrogen, wt.%	0.5
GHV, MK/kg	38.3

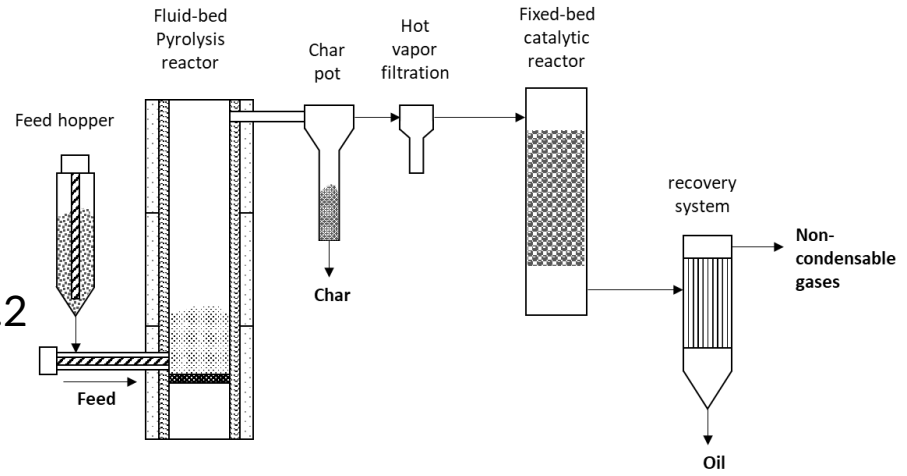
ESTATO Umweltservice GmbH

Catalysts

- ✓ Selected based on a bench scale pre-screening study [1,2]
  - Commercial Y zeolite based on SiO_2 (USY/SiO_2)
  - Commercial ZrO_2

Experimental setup

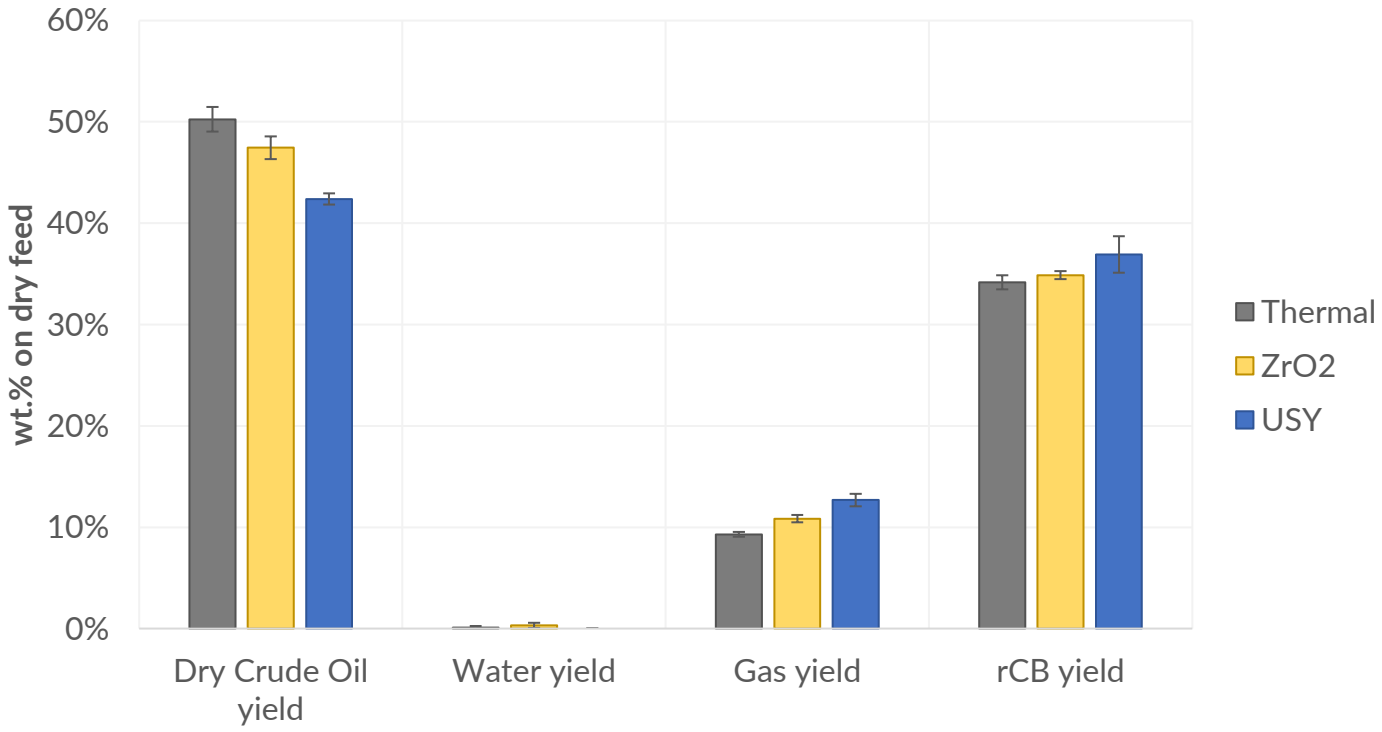
- ✓ **Fluid-bed Pyrolysis reactor with silica sand**
  - Feed rate: 600 g/hr ELT
  - T: 500 °C
- ✓ **Fixed-bed Catalytic reactor**
  - T: 600 °C
  - Catalyst/Total Feed ratio (C/F)=0.2
  - Bed material: catalyst
- ✓ **Run time: 1.5 hrs**



[1] S. Stefanidis et al. Pyro2022, Catalytic pyrolysis of end-of-life tyres: Effect of catalyst type on the production of highly aromatic oils, 15-20 May 2022, Ghent Belgium

[2] S. Stefanidis, Pyrolysis of end-of-life tyres coupled with catalytic vapor upgrading to produce secondary raw materials for a circular tyre industry, Applied Catalysis B: Environmental, to be submitted

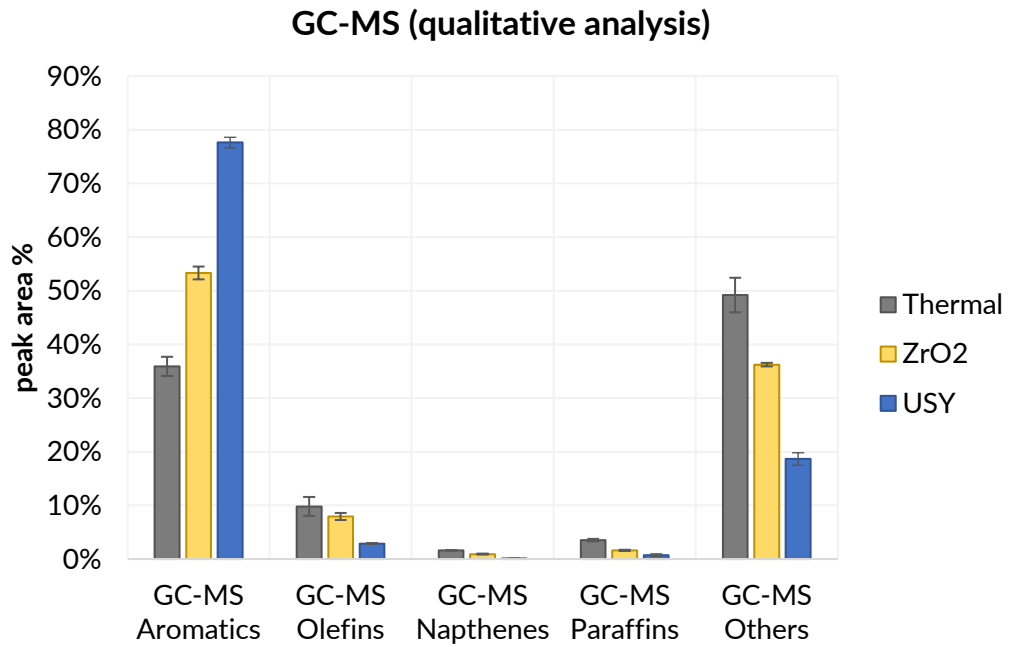
Catalytic Upgrading of Pyrolysis Vapors in a fixed bed reactor results in lower pyrolysis oil yields & higher gas yields

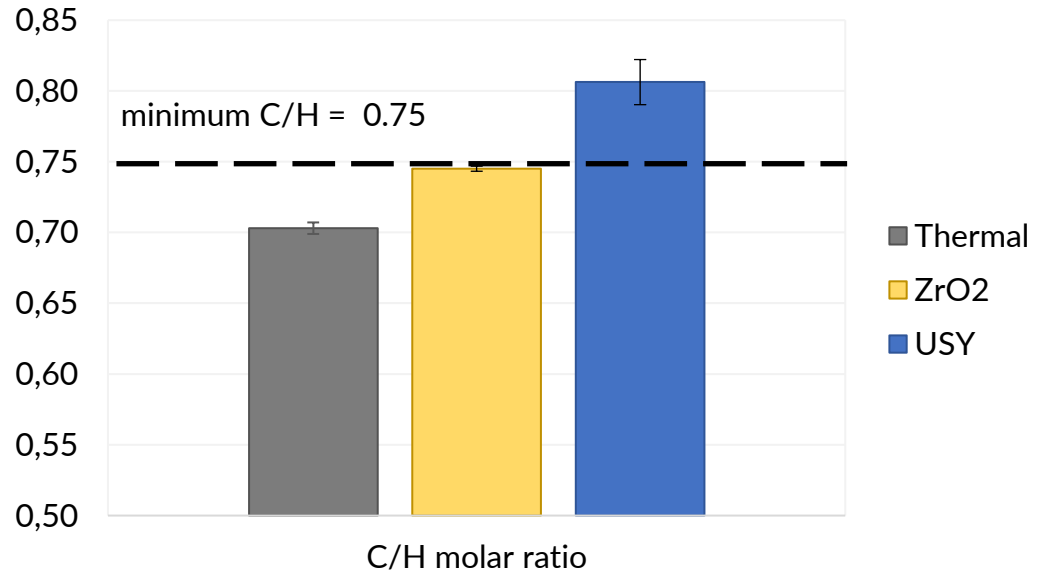


- USY catalyst is more active than ZrO_2 in cracking the vapors:
  - Produces less oil, more gases and more coke

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

USY increases significantly the Aromatics in the total pyrolysis oil producing a very aromatic oil (C/H=0.8 prior to distillation)





- There is a clear catalytic effect of the USY for higher aromatics compared to thermal pyrolysis
- C/H ratio of crude pyrolysis oil (CTT) is the most important spec for sCB production
- USY catalyst produced crude pyrolysis oil with C/H ratio 0.81-0.82

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

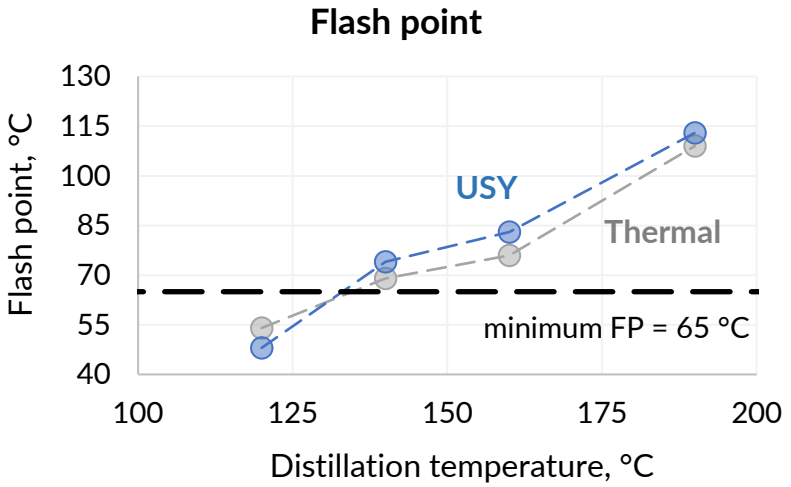
Distillation of pyrolysis oil: 71 wt.% of the USY pyrolysis oil can be used for sCB production

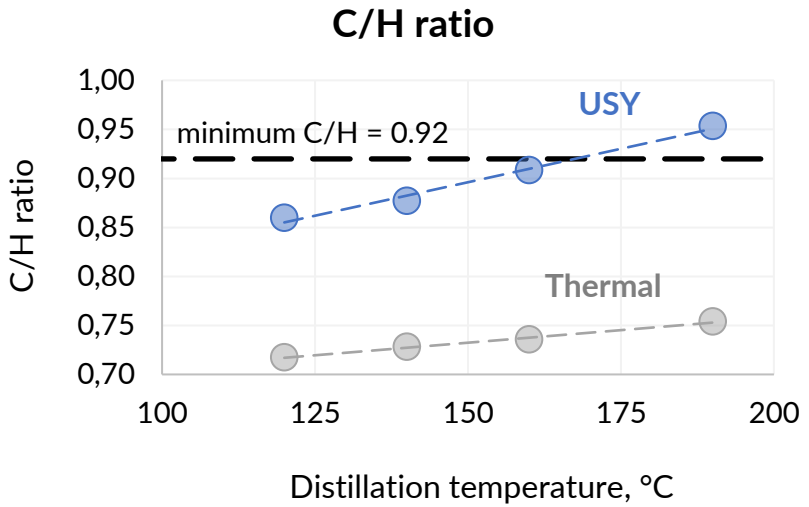
Thermal pyrolysis oil mixture

- *Starting C/H = 0.72*
- *Starting Flash Point = 25 °C*

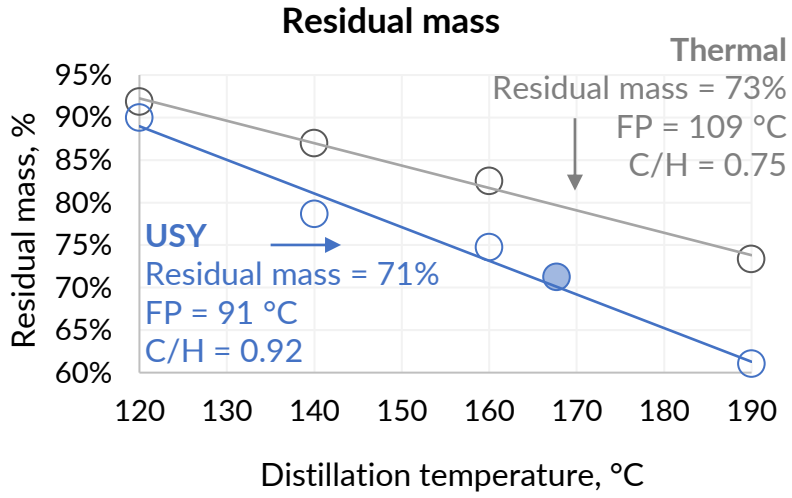
USY pyrolysis oil mixture

- *Starting C/H = 0.83*
- *Starting Flash Point < 25 °C*





- Pyrolysis oil mixtures from thermal and catalytic (USY) pyrolysis were prepared and distilled at 120-190 °C to meet specifications for sCB production.
- Considering the mass loss after distillation, the yield of pyrolysis oil suitable for sCB production is:
  - From thermal pyrolysis: minimum C/H ratio of 0.92 not reached at up to 190 °C distillation temperature that was tested
  - From catalytic (USY) pyrolysis: 30 wt.% with C/H = 0.92



Increase of Aromatic Content of Heavy Fraction Pyrolysis Oil indirect via…

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Alternative catalytic process based on a specially tailored version of the Fluid Catalytic Cracking (FCC) process

End-of-Life Tyres (ELTs)

Collection, feedstock selection & deconstruction

Pyrolysis

Pyrolysis Vapours

Pyrolysis Oil

Distillation

Light Fraction (LTT)

Heavy Fraction (HTT)

Aromatization

Eco-Efficient New Tyre

sustainable-**C**arbon **B**lack (s-CB)

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Feedstock, Catalysts & Experimental setup

Heavy Tyre Tar (*)

Properties	HTT
Sulphur, wt.%	0.99
Nitrogen, wt.%	0.53
Carbon, wt.%	88.07
Hydrogen, wt.%	9.59
C/H molar ratio	0.77
Oxygen, wt.%*	0.83
*O% = 100% - S% - N% - C% - H%	

* *Whole tyre passenger car & whole truck tyre*

Catalysts – Commercial zeolites

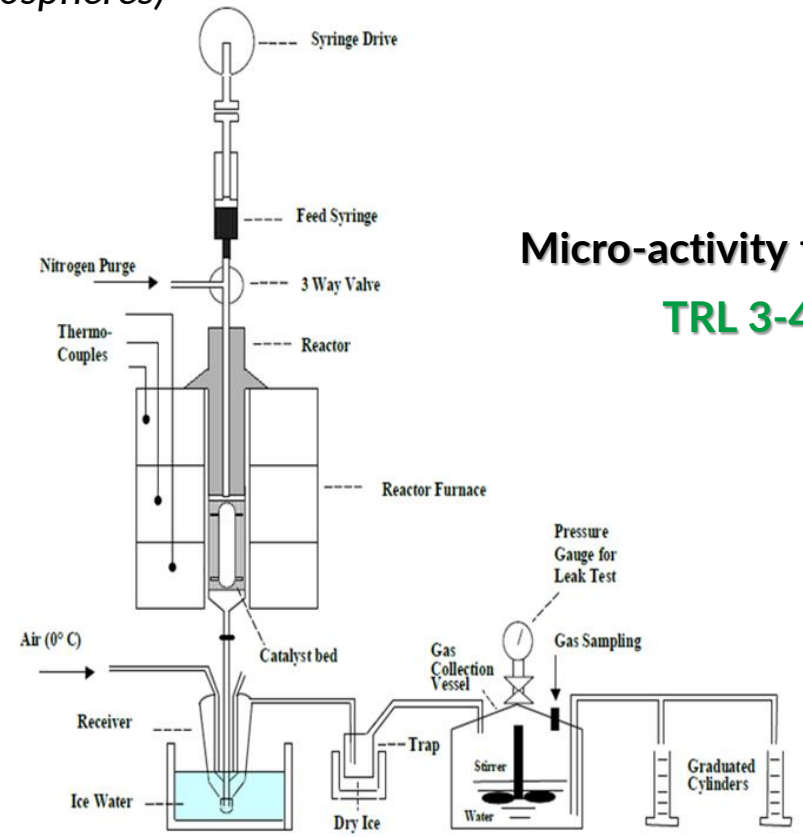
✓ Selected based on an bench scale pre-screening study [1]

- USY *(refinery FCC catalyst in microspheres)*
- HBETA
- HZSM-5
- HY

Experimental setup

✓ **Fixed-bed Catalytic reactor**

- Temperature: 538°C
- Catalyst-to-Oil ratio: 2

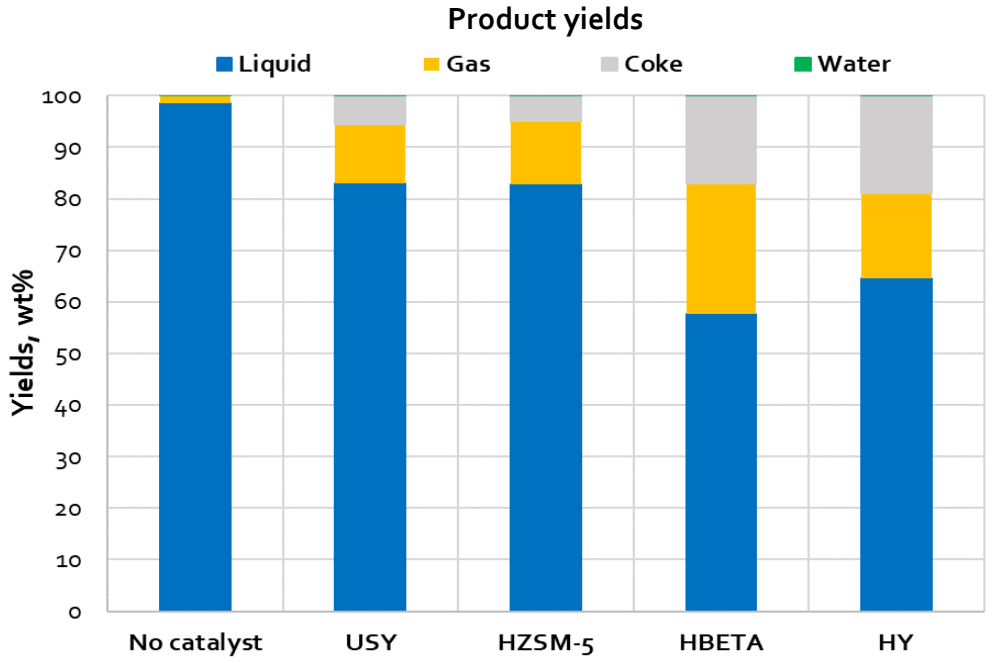


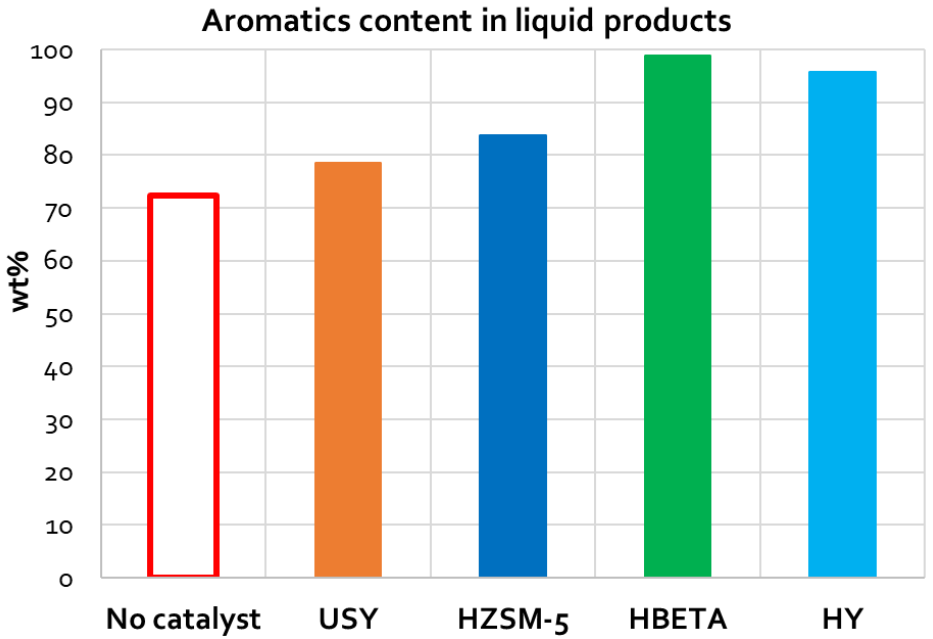
Micro-activity test unit

TRL 3-4

[1] *E. Pachatouridou et al. EuChemS August 2022, Upgrading the Heavy Pyrolytic Oil from End-of-Life Tyres to High-Quality Carbon Black Feedstock via Hydrodesulphurization and Aromatization, Lisbon, Portugal*

Catalytic Aromatization of Heavy Fraction Oil in a fixed bed reactor results in lower pyrolysis oil yields, but significant increase in Aromatics





- ✓ HBETA & HY increase the aromatics content in HTT:
  - Produce less liquid yields & high coke yields

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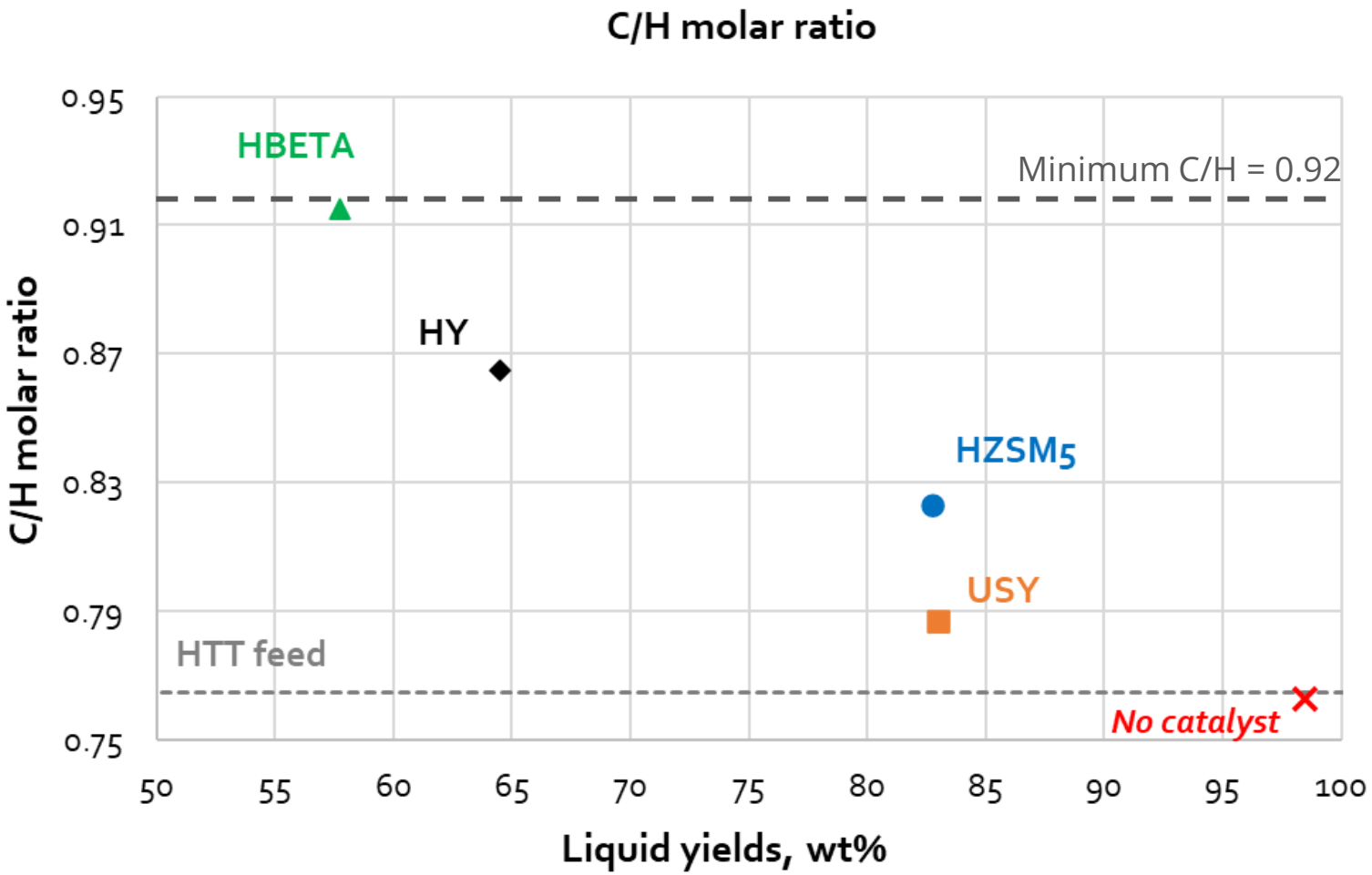
HBETA increases the aromaticity of HTT (C/H ~ 0.91) at the expense of liquid yields (58%)



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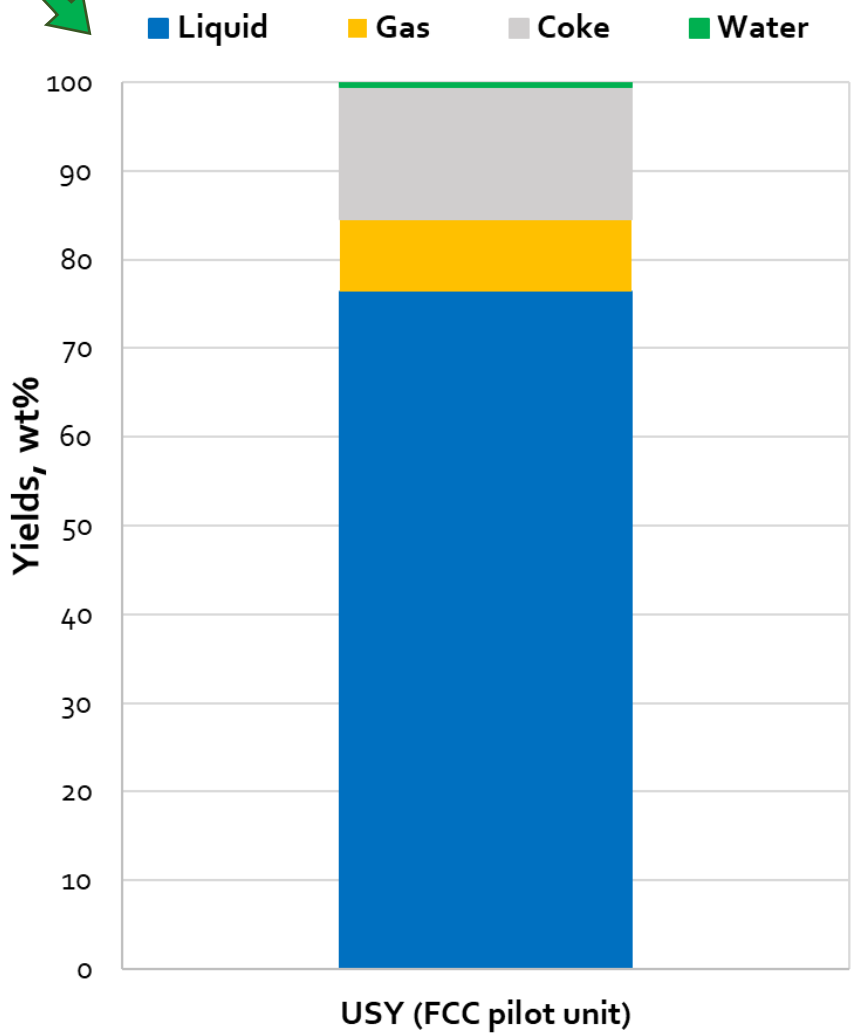
Demonstration of aromatization process of HTT on FCC pilot-scale unit

Fluid Catalytic Cracking Unit

TRL 5-6

Experimental parameters	
Catalyst	FCC USY
Temperature	538 °C
Catalyst-to-Oil ratio	16
Pressure	Atmospheric

Product yields



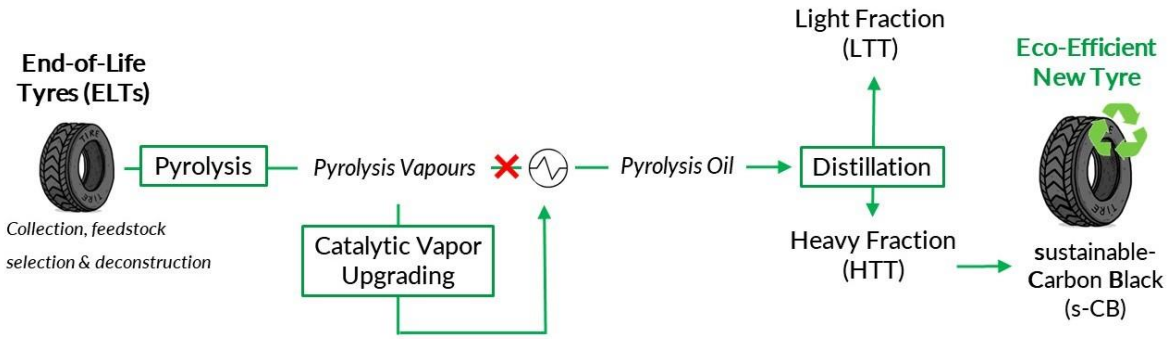
Properties of Aromatized HTT

Properties	HTT	Aromatized HTT
Sulphur, wt%	0.99	0.49
Nitrogen, wt%	0.53	0.33
Carbon, wt.%	88.07	89.58
Hydrogen, wt.%	9.59	9.18
C/H molar ratio	0.77	0.81
Oxygen, wt.%*	0.83	0.42
**O% = 100% - S% - N% - C% - H%*		

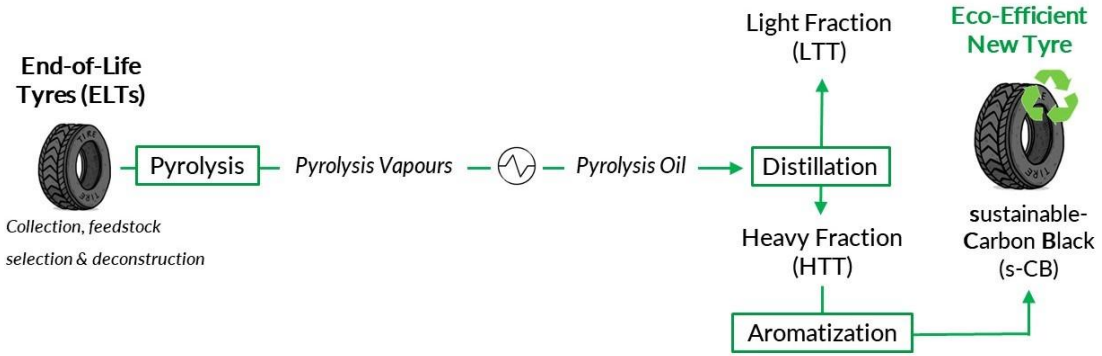
Conclusions

Catalytic Upgrading of ELT Pyrolysis Oil to Increase the Aromatic Content

Direct



Indirect



Catalytic Upgrading of ELTs Pyrolysis Vapors:

- ✓ *increases the aromaticity of the oil produced at low pyrolysis temperature with only moderate reduction in the oil yield*
- ✓ ***is a promising technology!***

Aromatization process of heavy fraction oil:

- ✓ *increases the aromaticity of the heavy fraction oil at the expense of oil yield*

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

THANK YOU

Q&A

BLACK CYCLE

Move gr evolution

Together To Make The Circular Economy A Reality

11 Introduction

Margarita DORATO - Michelin

Making the tyre circular economy a success

CHALLENGES TO SUCCEED

Technological

The tyre is highly technological

Various performances at the same time

Supply chain creation

Large volumes, quality stability, worldwide coverage

Economical viability

of the overall value chain Vs. an optimized value chain , Customer's willingness

Environmental viability

>0 impact on LCA incl. waste avoïdance&Recycled Mat. use

Energy balance

No <0 environmental effects

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BLACKCYCLE is a POWERFUL tool to create a MASSIVE tyre Circular Economy

Delivering validated high quality SRM and technological packages

To recycle at least **50%** of the European ELTs

Application market opportunity

Technological packages

Validated high quality SRMs

10 innovations along the value chain

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

BLACKCYCLE is a POWERFUL tool to create a MASSIVE tyre Circular Economy

Showing market opportunity to massive deployment

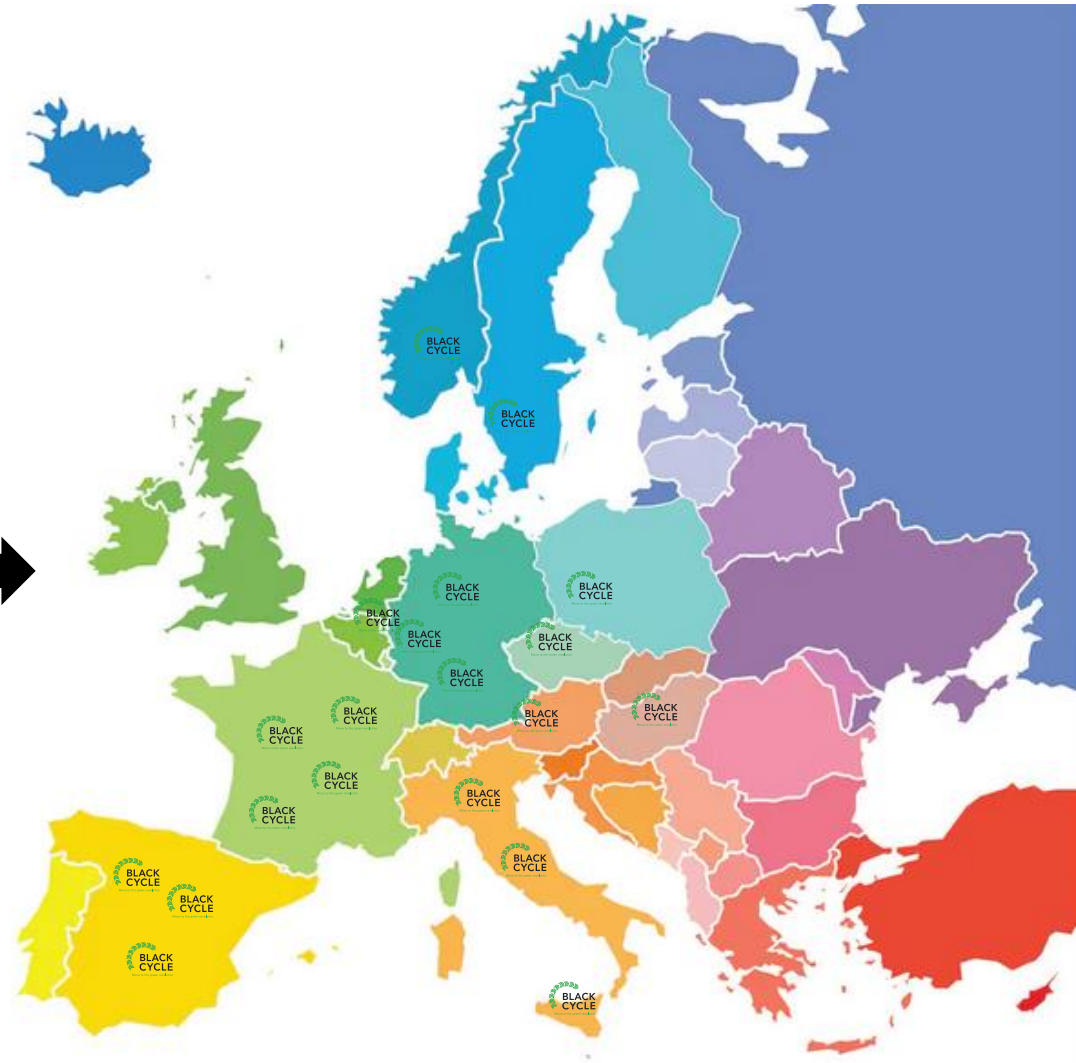
To recycle at least **1,5Mt** of the European ELTs

>**50** units

10-30 kty ELT treatment
(Value chain : deconstruction, shredding, granulation, pyrolysis, distillation)

s-Resins units

Billons € investment



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BLACKCYCLE is a POWERFUL tool to create a MASSIVE tyre Circular Economy

Non technical barriers to overcome for the deployment

To recycle at least **1,5Mt** of the European ELTs

Social acceptance: construct the sufficient conditions so that the project could be integrated harmoniously

Regulatory: The status of “waste” creates numerous administrative and financial complications, both for transport, transformation (recycling), trade and use of materials

Business model: creating values for the project partners and in Europe thanks to its replication

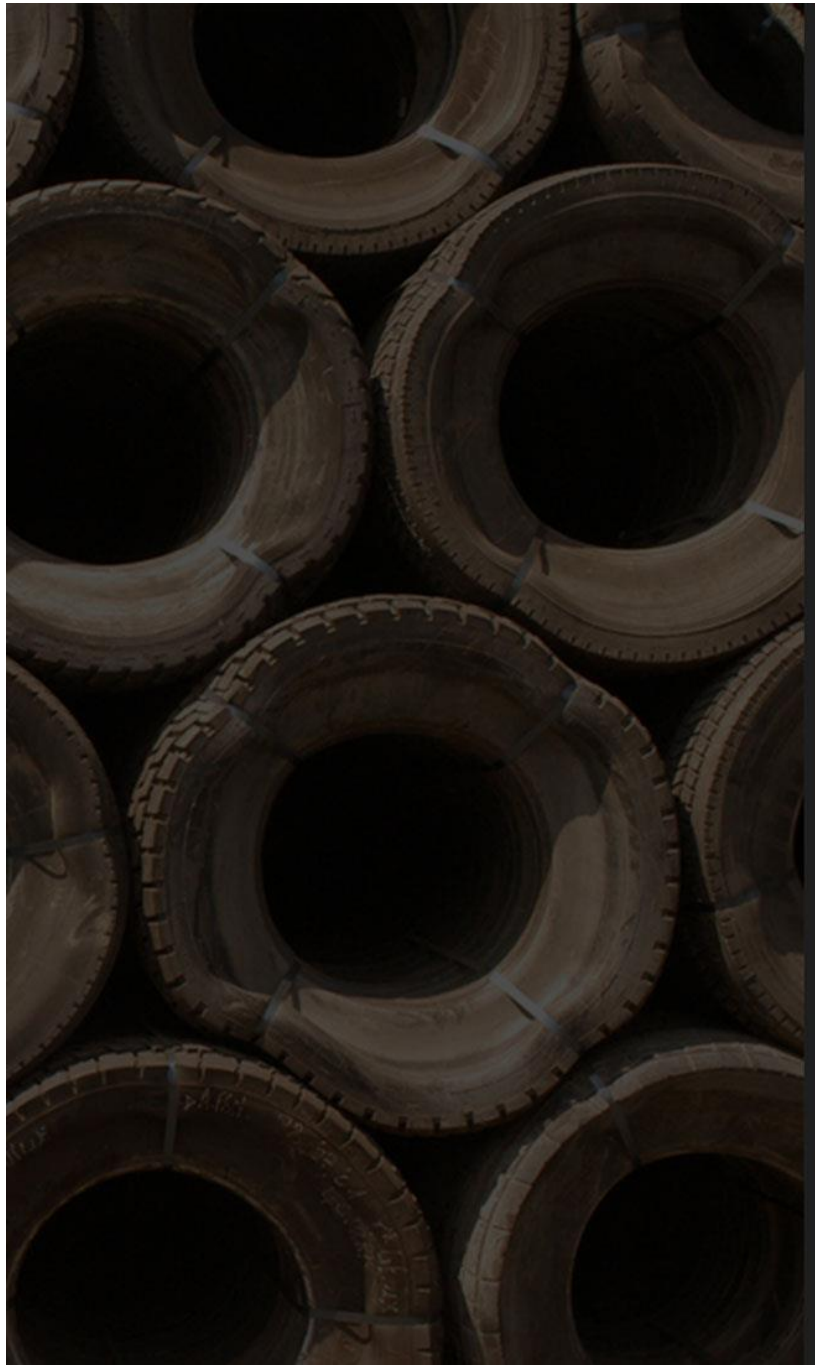
BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

12

Achieving social acceptance while ensuring health, safety, and environmental compliance

Jean-Philippe WEBER – Michelin
Cédric PERBEN – Eastman
Guy MARLAIR - Ineris

Making the tyre circular economy a success



BLACK CYCLE

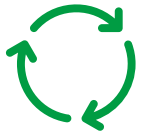
Move to the green revolution

Achieving social acceptance while ensuring health, safety, and environmental compliance

Jean-Philippe WEBER – Michelin

Social License To Operate
From broad vision to local collective acceptance and long-term trust among communities and stakeholders

- Today SLO is key to succeed in implementing any new industrial project. New projects need to be inspired to do what is right to earn trust in the eyes of others, especially, local communities and stakeholders.



- It is a continuous process which remains consistent over time and is continuously re-evaluated

- National regulations (impacts studies, emissions, public consultations) or REACH compliance rules are keys inputs but it is CAPITAL to work efficiently with the LOCAL eco-system for a respectful, loyal and honest local integration. Universal rules are not sufficient.

Social License To Operate
How not considering SLO can put an industrial project at risk

Plastics to Fuel Pyrolysis Plant by Foy Group in Australia

In 2016, Foy Group announced plans for a plastics-to-fuel plant in Australia. However, **public backlash** led to a government review in early 2017, which highlighted **fire hazards and other risks**. Despite Foy Group's efforts to proceed, the project was halted in April 2018, ending a controversial chapter in the region's environmental and industrial history.

Tire waste-to-energy plant by SOBE Thermal Energy Systems in Ohio

SOBE Thermal Energy Systems proposed a tire waste-to-energy plant in Ohio to recycle used tires and generate renewable energy. However, the project encountered significant obstacles and was ultimately halted due to:

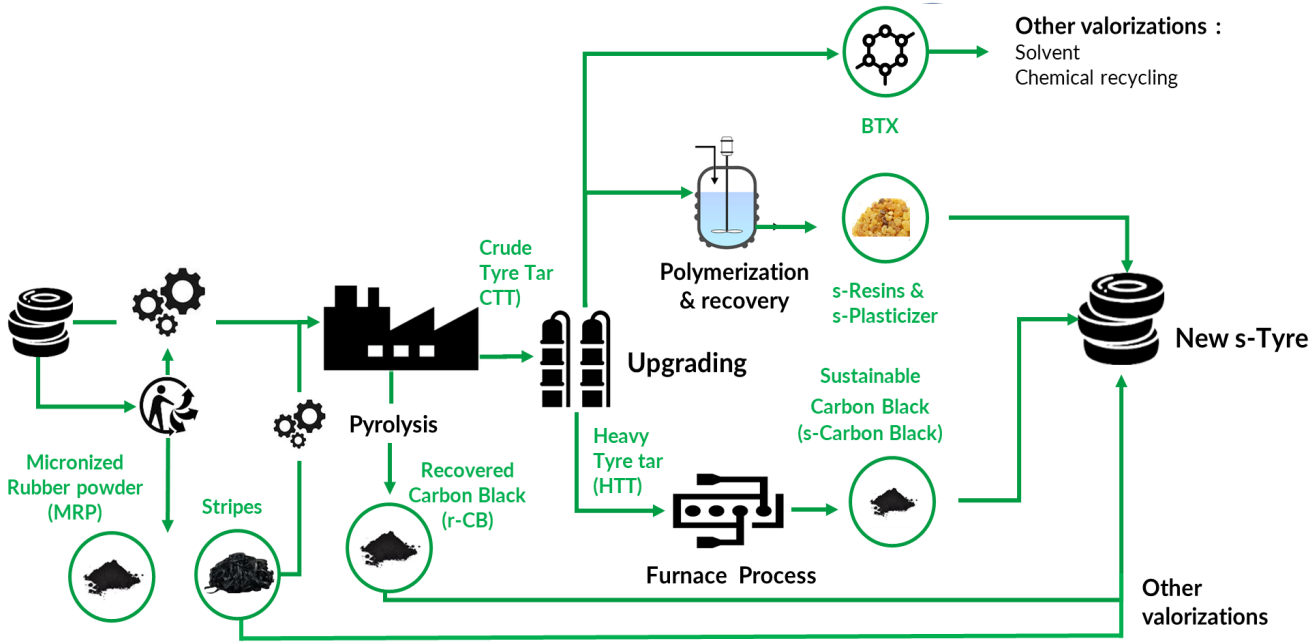
- Community concerns about potential environmental and health impacts, leading to public protests.
- Regulatory hurdles and permitting delays, complicating the project's development.

Social License To Operate
Main Areas Of Potential Concern To Consider In The Used-Tyres Recycling Process

TOP 5 CONCERNS

- Air pollution & GHG emissions
- Safety risks
- Soil artificialization
- Effluent management
- Olfactory & acoustic pollution

BLACKCYCLE aims at creating, developing and optimising a full Value Chain



BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

For BLACKCYCLE it is Key to master the above questions.

A specific attention was given to these topics which will be shortly presented by Mr Guy Marlair, from INERIS in the HSE section.

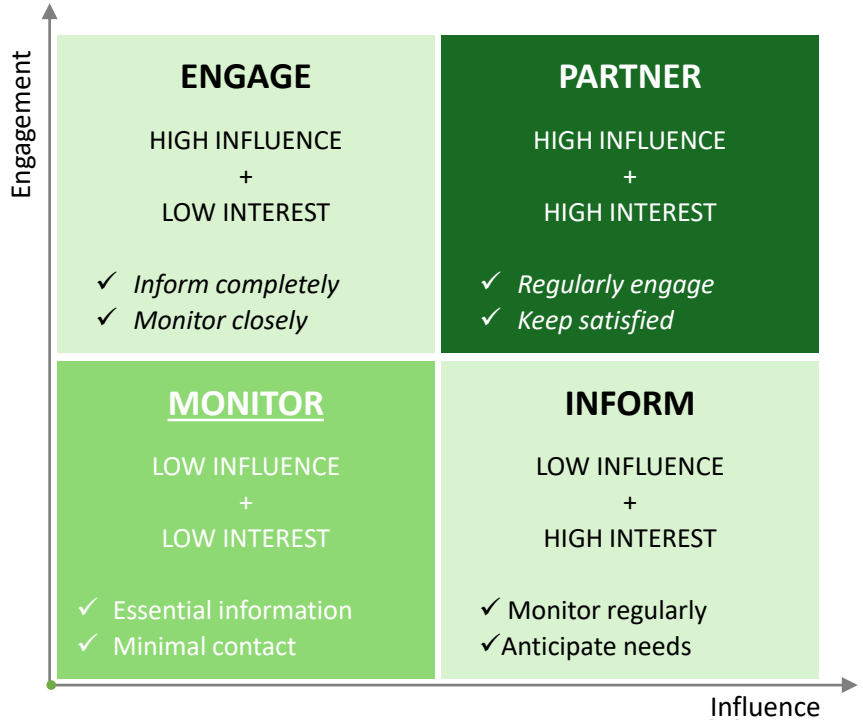
Social License To Operate
Tools at your disposal to support your Social License to Operate (SLO)

An **operational guidebook** providing brief theoretical reasoning and guiding you through a step-by-step process to help you ask yourself the key questions when working on your SLO.

It includes:

- A practical guide is available with guiding principles on SLO
- Tools for self-assessment and stakeholder mapping is proposed
- Key recommendations and case studies

A **stakeholder mapping tool** with over 500 stakeholders identified (NGO, authorities, media, academia, business) at national level for all 27 countries in the EU – to use as a basis for your own local stakeholder mapping tool



Social License To Operate
Key Actions To Be Successful In The Preparation of SLO

Identify the **relevant stakeholders**

Early engagement anticipation with stakeholders is Key. Be proactive rather than reactive.

Implement a **local social network** to manage grievances and provide stakeholders with answers

Raise awareness, train & inform all : **by providing visual vulgarization, through narrative & storytelling**

Implement **collective engagement** through organized processes at national level for better impact

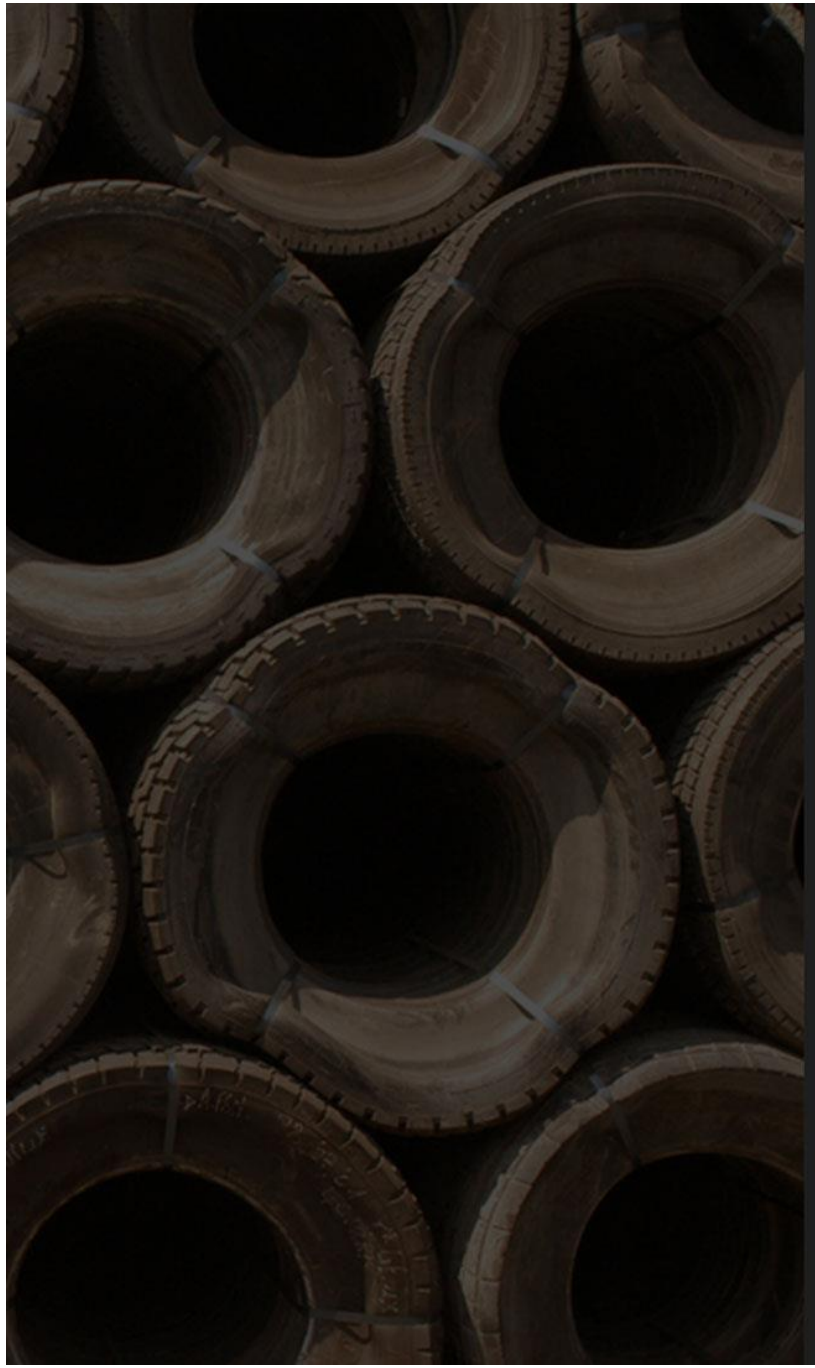
Both tools developed by BlackCycle & Ksapa will facilitate awareness and implementation of an efficient SLO approach for new projects of ELT's CIRCULAR ECONOMY

Social License To Operate Benchmark and robustification of our guide

In order to strengthen our SLO guidebook, the Blackcycle team, with the help of Ksapa, decided to further benchmark case studies and identify best practices amongst experiences other recycling projects in Europe.

Today we are honored to have a short presentation by M. Cedric Perben from Eastman, currently in charge of the development of a molecular recycling plant for PET, planned for 2026/2027 with a 200kT recycling capacity.

He will illustrate how important it is to acknowledge and anticipate one's SLO, prior to publicly announcing it – as it can sometimes lead to media and political interest. **It is in those contexts where having a robust and well-engaged SLO is key.**



BLACK CYCLE

Move to the green revolution

Achieving social acceptance while ensuring health, safety, and environmental compliance

Cédric PERBEN – Eastman

Accelerating a circular economy

Molecular recycling plant Project in Normandy

Michelin x Blackcycle
| Social License to Operate

Let share our experience!

May 28, 2024, Cédric Perben

EASTMAN

Three simultaneous global crises need solutions.

WASTE

CLIMATE

10 BILLION

Eastman's molecular recycling project in France

Key facts and figures

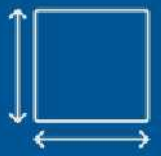
110 k+ T of PET waste processed / year in phase I
200 k+ T of PET waste processed / year in phase II

Phase I of plant start-up in **2027 / 2028**

1+ billion EUR of investment for phase I

350 direct jobs

1,500 indirect jobs in recycling, energy and infrastructure



40-hectare plot on the industrial zone of Port-Jérôme

* For more information about the project, visit our dedicated website https://concertation-eastman-normandie.fr/

EASTMAN

In phase I, this facility will process 110 k+ T of hard to recycle PET waste each year

10 Eiffel Tour

Nearly 2 National Stadium of France

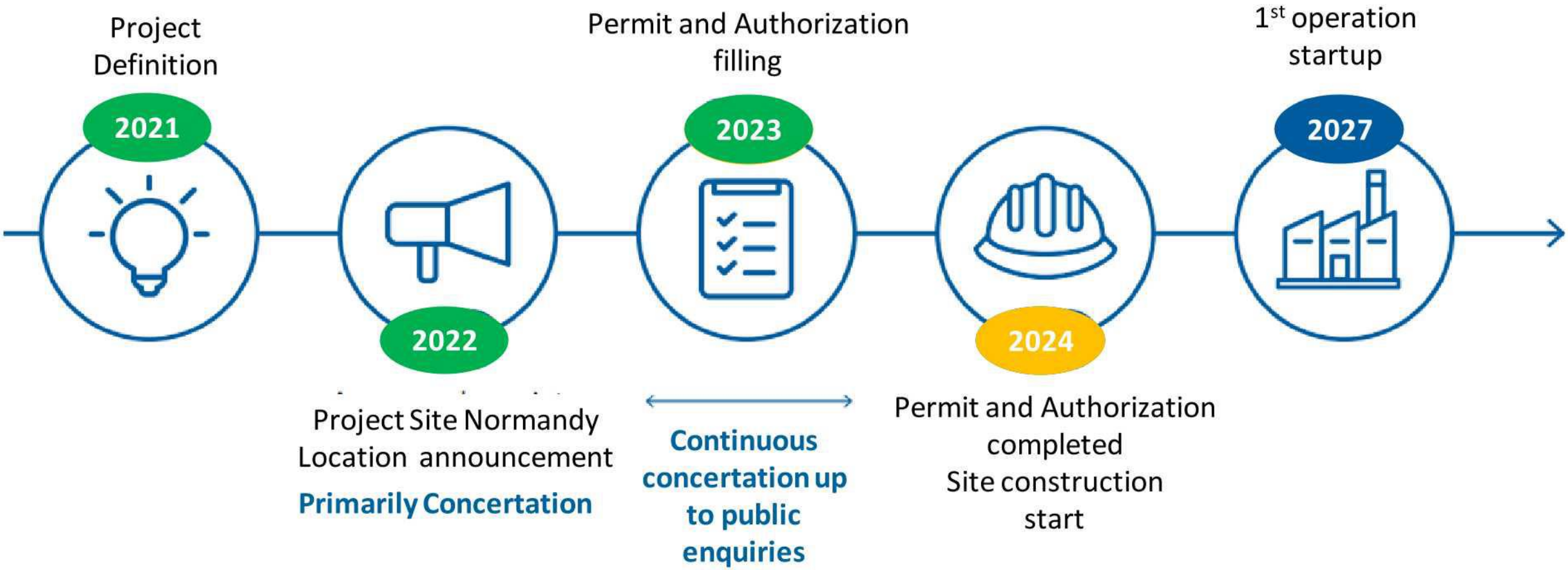
How much is 110k T?

11 Billion

790 Million

2.7 Billion

A schedule that follows its course



Questions

Cedric PERBEN | Eastman
FRANCE Project Director
Pronouns: he / him / his
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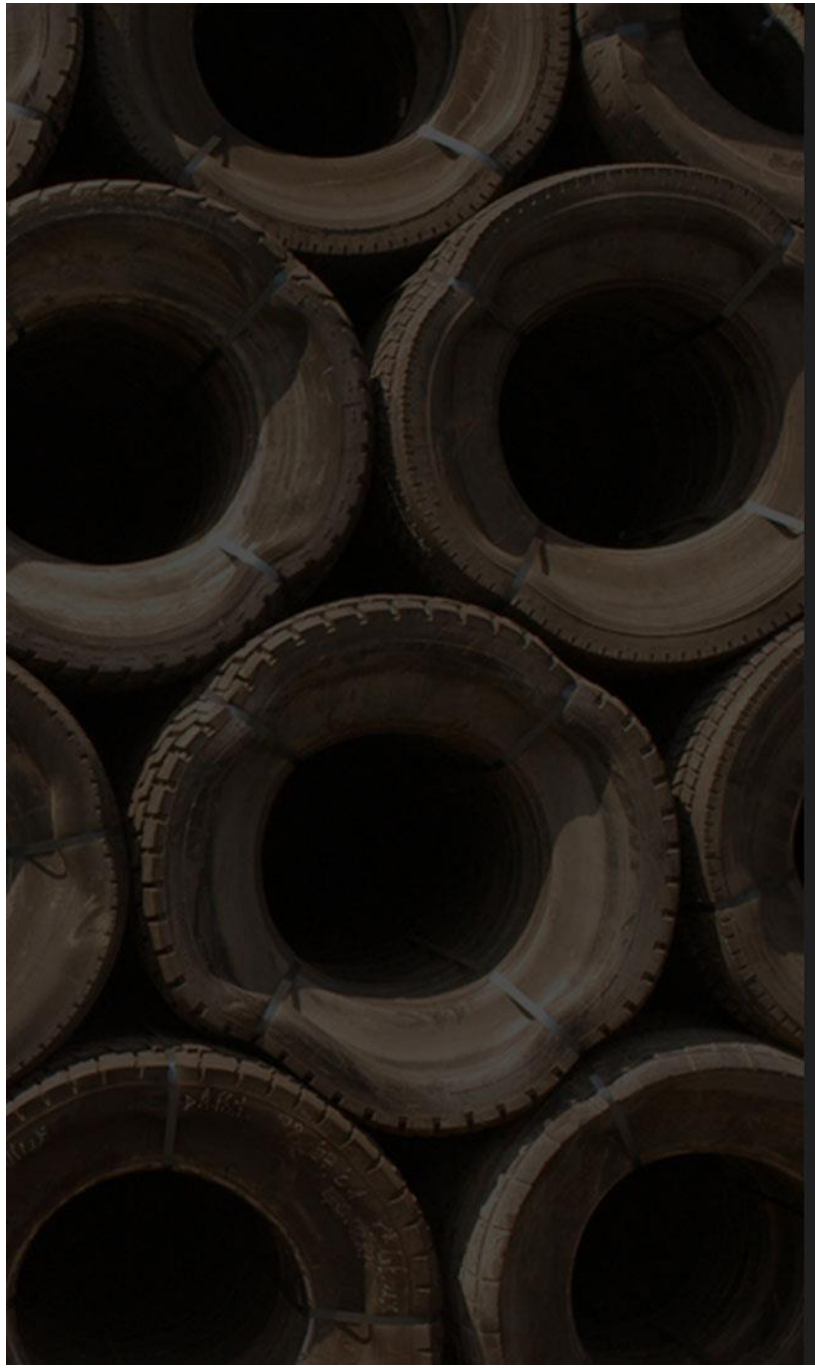
69380 LES CHERES, FRANCE
Office: +33 (0)4 72 54 23 48
Mobile: +33 (0)6 08 60 12 64
Email cperben@eastman.com



BLACK CYCLE

Move to the green revolution

Ensuring health, safety, and environmental compliance

Guy MARLAIR - Ineris

HSE considerations : a sensitive issue in the context of SLO/social acceptance

- The ever increasing of risk aversion feeling is expressed by the general public whatever industrial facilities concerned
- Complying with safety and environnement relating regulations is not enough
- Safety consideration in early stages of new technologies can be cost effective

Making a safe and environmental friendly ELT circular economy is one of the 4 prerequisites to achieve end of status of waste (according to EU WFD):

- HSE conditions : the use of the substance or object will not lead to overall adverse environmental or human health impacts

BLACK CYCLE is a project funded by the European Commission - Project Number : 820687

HSE issues from the deployment of the BlackCycle value chain : not necessarily to be feared or perceived negatively, but to be considered proactively !

- **A full task devoted to HSE considerations**, as part of the multicriteria sustainability studies ! Task also aiming at promoting inherently safer processes and managing potentially emerging risks from innovation

- **Large tire massive environment damaging and difficult to extinguish fires have occurred in the past in all parts of the planet and remain a sigificant risks**
  - 16 million abandoned used tire fire in Hagersville (Ontario), lasted 17 days in summer 1990 and provoked post exposure long term sanitary issues to Firemen
  - 7 million used tires fire in Koweit August 2021

BLACK CYCLE is a project funded by the European Commission - Project Number : 820687

Strategic workplan deployed in support to HSE management anticipating future BCK value chain SLO

- Both « top down » and « bottom up approaches » rendered possible thanks to efficient commitment of the key partners :
  - Actions at Ineris initiative (according to GA):
  - Analytical / paperwork actions
  - Routine & continuous literature review, review of pyrolysis process data, accidentology review, pollutants emission review,; safety related input data collection through technical visits to consortium partner sites…
  - Experimental on key materials/intermediates throughout the BKC value chain, several experimental campaigns from 2020 to 2024
- Collaboration work on demand, responding to specific safety-related questions identified by partners or raised during BCK research project deployment

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Typology of analytic work (not exhaustive)

- Promoting safe by design innovative deconstruction machines ORC and IRG in collaboration with Michelin and Estato (focus on ATEX risk and electrostatic potential discharge
- BCK key thermochemical processes incident records survey (continuous)
- Assessment of risks for safe storing flammable TPO crudes before distillation and assistance for implementation of prevention and protection measures on Sisener site
- Literature review of potential emissions from oil pyrolysis processes
- Process safety of s-resins/and so-called extension solvents…

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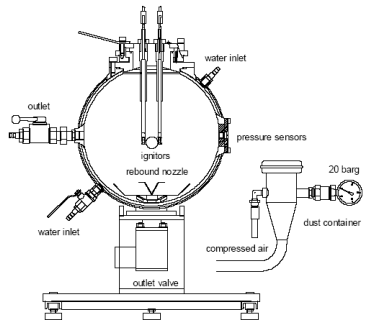
In depth experimental safety profiling of key products throughout the entire BKC value chain



Samples considered

- 1 model resin supplied by Michelin
- S-CB from Orion and relating CB oil (HTT)
- RTT from Michelin
- rCR sample from PYRUM
- 3 series of pyrolysis various distillation fractions (CTT,LTT,HTT,STT,RTT) summer 2022 and summer 2023 from three sets provided by CSIC-ICB
- R-resin sample and relating optimised upstream oil feedstock

Type of testing

- Thermal stability,
- explosion risk profiling,
- combustion behaviour in fire conditions by use of the FPA,
- physico-chemical characterization of influencing parameters.

BLACK CYCLE is a project funded by the European Commission - Project Number : 820687

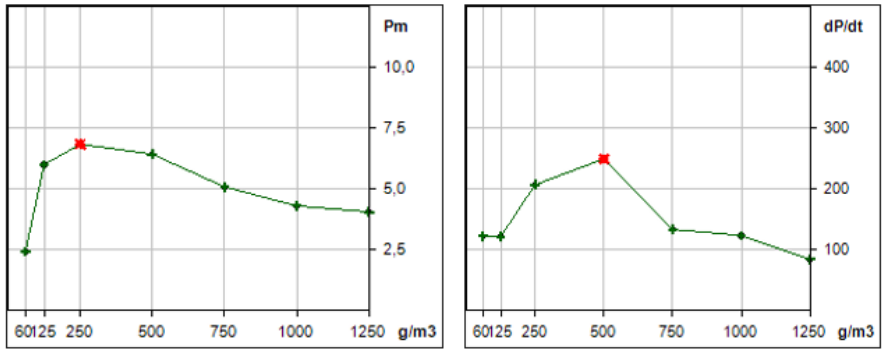
Experimental: explosion risk evaluation of carbon blacks

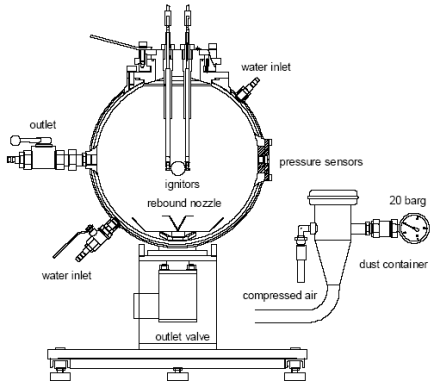
rCB dust explotion severity

Max. explosion pressure : Pmax = **6.8 bar**

Max. rate of pressure rise : (dP/dt)max = **249 bar/s**

Product specific constant : Kst = **68 m.bar/s**



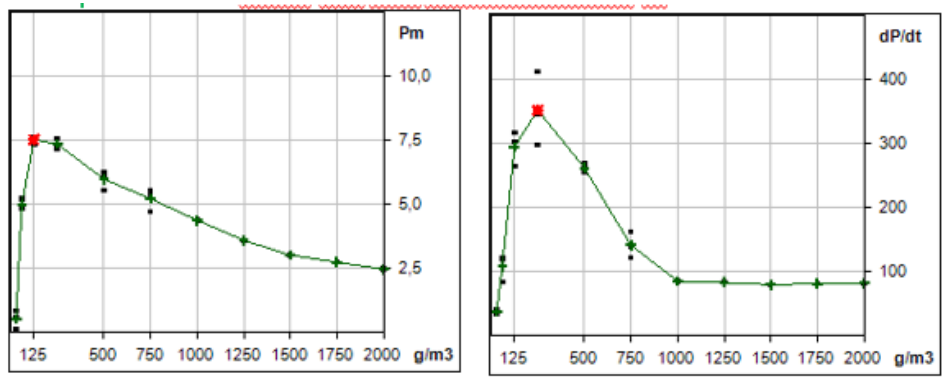


sCB dust explotion severity

Max. explosion pressure : Pmax = 7.5 **bar**

Max. rate of pressure rise : (dP/dt)max = 352 **bar/s**

Product specific constant : Kst = 95 **m·bar/s**



Dust Explosion Classification	Dust explosion index Kst (bar.m/sec)	Qualification
St-0	0	No explosion
St-1	0-200	Weak to moderate explosion
St-2	201-300	Strong explosion
St-3	>300	Very strong explosion

Conclusion: despite of rather different physico-chemical characteristics, **similar « weak to moderate » explosion risk**, with data allowing the sizing of protection system where needed

BLACK CYCLE is a project funded by the European Commission - Project Number : 820687

Experimental: assesing thermal and chemical threats from fire scenarios involving chemicals

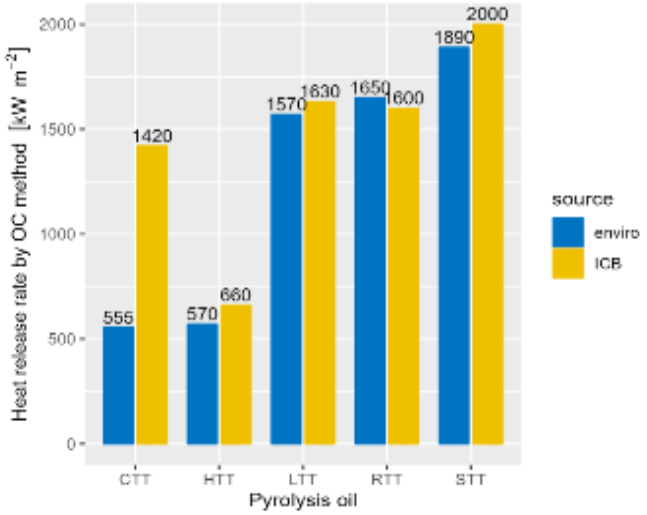
Why?

- Safety studies need to consider worse case scenarii, zero risk never exists
- LUO around potential welcoming sites need such info
- Modeling effects of such scenarii require pertinent input data

Very useful for :

- 1st order evaluation of fire scenarii, sizing storage, reactor,welcoming site
- Emergency crisis communication preparedness

ISO 12136 Ineris customized FPA



Key achievement :

- Source term of pollutions for reference fire scenarii obtained for main key chemicals (TPO, distillation fraction, rCB, sCB)
- Including major pollutants (Cox, SOx, NOx, soot, THCs)
- Also PAHs
- Combustion kinetics, RHR, THR

BLACK CYCLE is a project funded by the European Commission - Project Number : 820687

HSE Task for Blackcycle provides positive data to SLO but reassesment of the future local implementations is always needed

- **The task devoted to HSE considerations**
  - Shows no significant safety or environnement hurdles for the deployment of the Blackcycle value chain
  - Provides a lot of useful data for future implementation

- **However,**
  - New implementation will need further HSE considerations integrating local specificities (regulations, local environnement of the local sites..)
  - Some parameter evolutions (like ELT composition..) will need to trigger update of HSE reassesment

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

13

Unlock regulatory constraints and accelerate value-chain deployment

Jean Michel DOUARRE - Michelin

Making the tyre circular economy a success

How to make this value chain massively deployed in Europe ?

The success of this innovative value chain depends on a coordinated effort involving:

- **European industries** adopting and implementing the BlackCycle solution in the market.
- **Investors** providing funding for the necessary equipment.
- The **Society** embracing and advocating for this industrial and ecological transition.
- The **European Commission** facilitating the process through incentives and regulatory support.

It’s a collective responsibility and Europe is a key enabler

BLACKCYCLE is a POWERFUL tool to create a MASSIVE tyre Circular Economy but…

Other than Social acceptance, 5 Non technical barriers for the industrial scale-up

Availability of ELT : in competition with other recovery types

Recognition of Pyrolysis as material recovery process

Industrial Investment and ramp-up:
- Investment is needed to create the capacity of ELT transformation
- The productivity during the ramp up (2 years?) won't be optimized

Waste Status : This status of “waste” creates numerous administrative and financial complications, both for transport, transformation (recycling), trade and use of materials

Lack of economical attractivity of products with more expensive SRM: the SRM will be more expensive than fossil Raw materials (supply chain less optimized, investment depreciation). .

HOW Could EUROPE help the deployment of that VIRTUOUS value Chain ?

Availability of ELTS :

- A clear policy direction to promote material recovery as the best option within the European Waste hierarchy
- A strategy to retain ELTs in the EU, rather than exporting,
- In parallel, focus energy recovery operations on waste that cannot be converted to secondary raw materials.

Recognition of pyrolysis as a material recovery process:

- Regulatory or policy instruments to clarify the definition of pyrolysis especially vs incineration under the EU Industrial Emissions Directive.
    - example: technical description of pyrolysis in a dedicated Best Available Techniques Reference Document (or BREF)).

Industrial scale-up Investment :

- Setting policies and regulations that
    - boost the flow of investments into the tyre-to-tyre recycling industry
    - support attainment of profitability during production ramp-up.

HOW Could EUROPE help the deployment of that VIRTUOUS value Chain ?

Waste Status:

- Set EU-wide **harmonized** EoW criteria that define when a material output from tyre recycling product ceases to be waste while ensuring specific quality standards and relevance for safe use in the production of new products.
- Place the end- of- waste status as upstream as possible in the value chain, to avoid downstream operators in the value chain being required to qualify their facility as a waste treatment installation.

Economical Attractivity of product with more SRM

- Set a minimum non fossil content in final product to
  - Accelerate the circular transition to shift customers towards recycled (and bio-based) materials solutions
  - Increase the market demand for the recycled materials and help the industrial scale-up of their value chain and the improvement of their economical competitivity
- Reduce financial and administrative impediments not faced by business-as-usual processes relying on extraction and use of virgin resources.

COLLECTIVE RESPONSIBILITY BUT EUROPE CAN HELP

- **To ensure Availability of ELT**
- **To recognize Pyrolysis as material recovery process**
- **To support Industrial Investment and ramp-up**
- **To Harmonize EoW Status in EU :**
- **To increase economical attractivity of products with SRM**

A POLICY BRIEF SUMMARIZING THOSE RECOMMENDATIONS WILL SOON BE SENT TO EU POLICY MAKERS

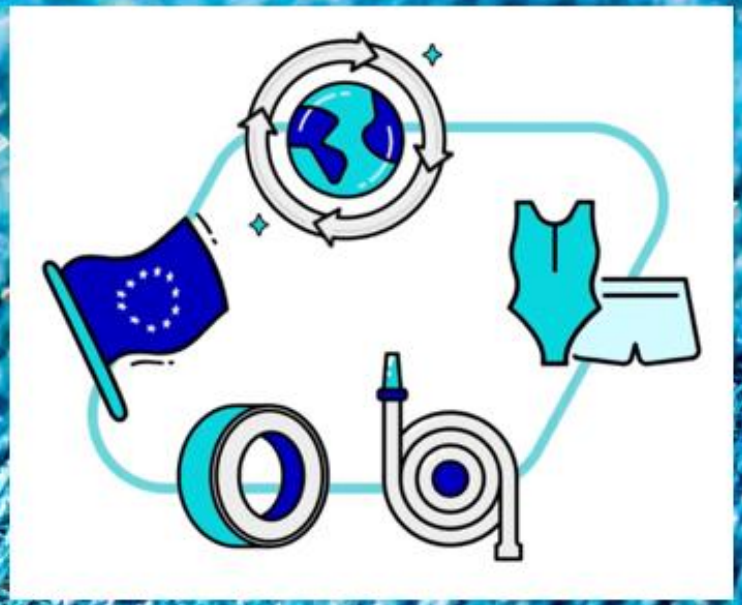
14

Circular economy complementary initiative: WhiteCycle

Thomas SIMONELLI - Michelin

Making the tyre circular economy a success


white
cycle



white cycle

Recycling PET from Complex Wastes to TRL 6-8 in a circular economy

Call: HORIZON-CL6-2021-CIRCBIO-01
Duration: 48 months
Estimated project cost: 9,541,261.25€
Requested EU contributions: 7,080,251.50€

Coordinator : MICHELIN / Sébastien NOEL sebastien.noel@michelin.com
Tech Director : MICHELIN / Thomas SIMONELLI thomas.simonelli@michelin.com

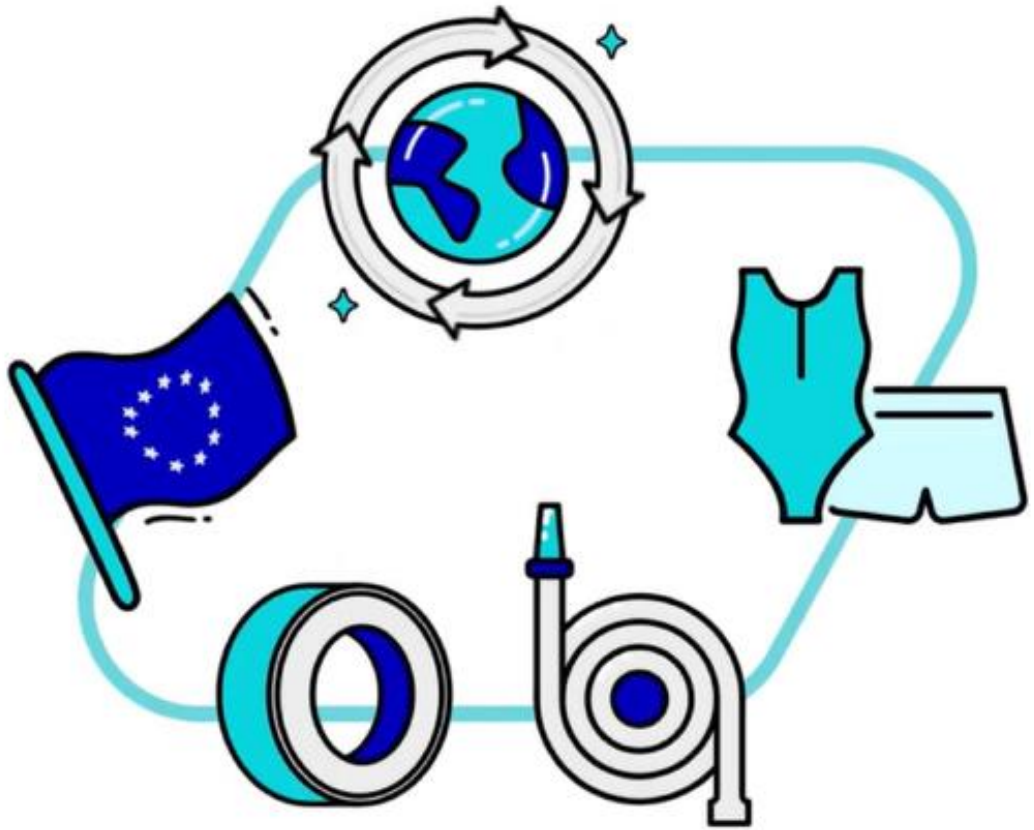
Project website : https://www.whitecycle-project.eu
Project LinkedIn : https://www.linkedin.com/company/whitecycle/

Co-funded by the European Union
Project n°101059639

white cycle

An innovative **European** project to **recycle PET** from 3 complex wastes **at the end of their life** : tires, hoses and clothes.

Developing technologies to use this r-PET in new tires, hoses and clothes in a **circular value chain**



Co-funded by the European Union

Project n°101059639

Potential r-PET / year in Europe

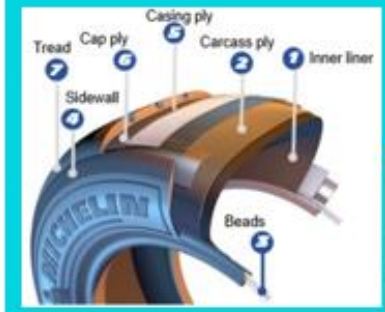
1850 kt in complex clothes

200 kt in End of Life tires

10 kt in End of Life hoses

Total : 2 Mt / year

white cycle



Co-funded by the European Union

Project n°101059639

Potential environmental impact

avoid up to

1.8 milion tons of plastic

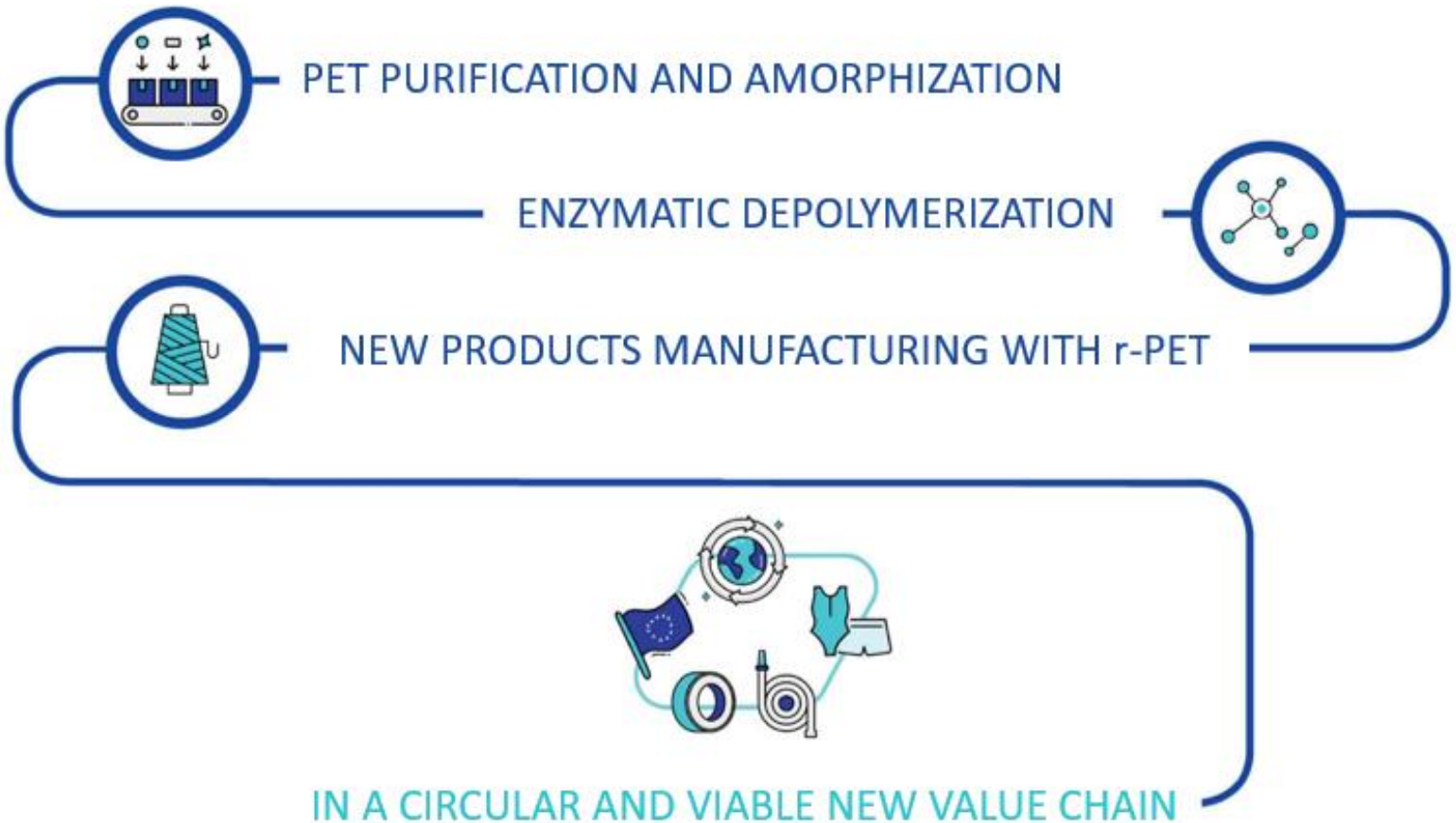
landfilling or incineration each year

avoid up to

2 milion tons

CO_2 emissions

WhiteCycle process



Co-funded by the European Union
Project n°101059639

WhiteCycle

A multiskilled Consortium with 16 European partners

MICHELIN FRANCE	axelera FRANCE	CARBIOS FRANCE	DITF GERMANY	Dynergie FRANCE	ERASME / Université Clermont Auvergne FRANCE
ESTATO Umweltservice GmbH GERMANY	ifth Institut Français du Textile et de l'Habillement FRANCE	INDITEX SPAIN	INSTITUT P' FRANCE	iPoint GERMANY	IRIS SPAIN
KORDSA TURKEY	mandals since 1775 NORWAY	SYNERGIESTLC FRANCE	Université de Poitiers FRANCE	Western Norway University of Applied Sciences NORWAY	

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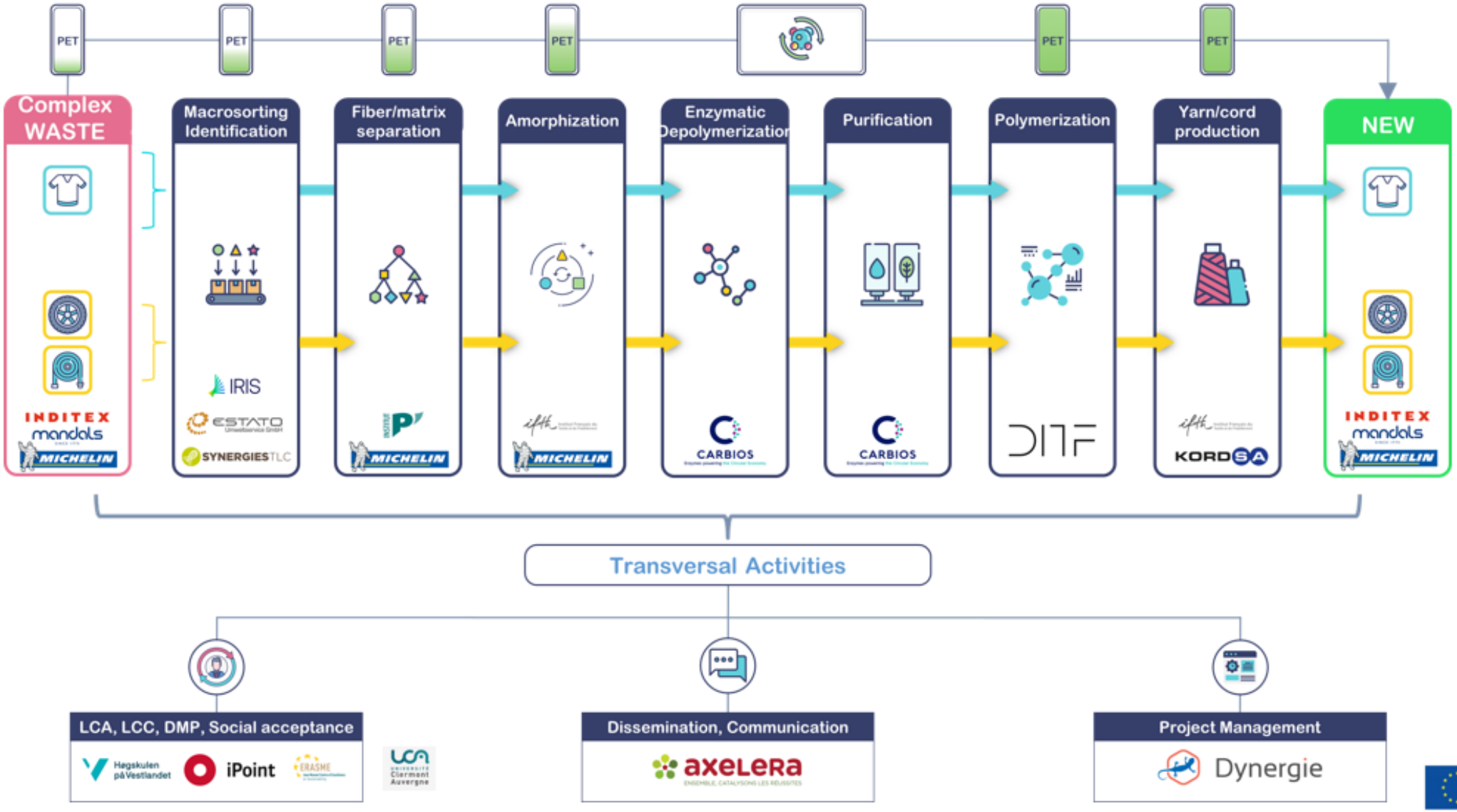
Project n°101059639

WhiteCycle value chain

white cycle



Co-funded by the European Union

Project n°101059639

WhiteCycle specific objectives

white cycle

- ***Processes developments to TRL 5 (2022 → 2024)***
  - *PET recognition in complex clothes (multilayers, coated…)*
  - *Electrostatic fibers separation (for ELT and ELH)*
  - *Fibers amorphization*

- ***Full demonstration at pilot scale (2022 → 2024)***
  - *25 tires, 25 m of hoses and 20 m² of complex fabric (with r-PET from our 3 complex feedstocks)*

- ***Processes upscale to TRL 6/8 (2024 → 2026)***
  - *PET recognition, Electrostatic separation and Fibers amorphization*

- ***Demonstration at pre industrial scale (2024 → 2026)***
  - *100 tires, 1500 m of hoses, 4 lines of technical garments (with r-PET from bottles and food packaging)*

- ***With LCA, LCC*** *and* ***social impact evaluation, FAIR data*** *implementation and sharing*

Co-funded by the European Union
Project n°101059639

white cycle

Thanks!

Follow #WhiteCycle

Co-funded by the European Union

Project n°101059639

15

Advanced Materials for Industrial leadership

Philipp RUNGE - DG Grow - European Commission

Making the tyre circular economy a success

16

Conclusion: We have moved to the green tyre revolution

Jean Michel DOUARRE - Michelin

Making the tyre circular economy a success

The European BlackCycle project is a POWERFUL Tool to move to the Tire revolution!!!

Person & skills

Europe support

Systemic approach

Results

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

BLACKCYCLE is internationally recognized and has won 2 awards

RECIRCLE AWARDS 2023

The Best Tyre Recycling RESEARCH Project

Tire Technology international AWARDS 2024

Environment Achievement of the YEAR

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

Why is BlackCycle a revolution?

→ **BlackCycle is a unique and innovative project** bringing differentiating solutions to the market

→ BlackCycle produces **high-quality raw materials** for new tyres.

BLACK CYCLE is a project funded by the European Commission - Project Number : 869625

BLACK CYCLE
Move to the green revolution

"ENABLE A MASSIVE AND VIABLE CIRCULAR ECONOMY OF TYRES"

BlackCycle has successfully transformed End of life Tyres (ELTs) into 100% valorized high quality secondary materials mainly in tyres and rubber goods

HOW? Thanks to 5 mature innovations

NEW TYRES

ELTS

1 DECONSTRUCTION MACHINES

Innovative machines to selectively **deconstruct** parts of ELTs, allowing the production of high quality micronized rubber powder or stripes and high quality rubber.
Ready to be deployed

2 PYROLYSIS & REFINING PROCESS

Pyrolysis process of the ELTs using an Auger reactor or a Moving bed reactor for the production of an optimized pyrolytic oil and improved recovered Carbon Black.
Ready to be deployed

3

Refining process of pyrolytic oil aimed to optimize Heavy Tyre Tar (HTT) and Resin Tyre Tar (RTT) to produce S Carbon Black and S plasticising resins.
Ready to be deployed

PRODUCTION OF SECONDARY RAW MATERIALS

From the 2 fractions of refined pyrolytic oil of ELTs

4 Plasticizing **resins** for new tyres using as feedstock the Resin Tyre Tar (RTT).

5 **Carbon Black** produced on a furnace process using the Heavy Tyre Tar (HTT).
This sustainable Carbon Black is a drop-in alternative of fossil Carbon Black.
Ready to be deployed

This project has received funding from the European Union's Horizon 2020 research and innovation program undergrant agreement No.869625

BLACKCYCLE HAS ANSWERED to THE CHALLENGES TO SUCCESS

Technological

The tyre is highly technological

Various performances at the same time

Supply chain creation

Large volumes, quality stability, worldwide coverage

Economical viability

of the overall value chain Vs. an optimized value chain , Customer's willingness

Environmental viability

>0 impact on LCA incl. waste avoïdance&Recycled Mat. use

Energy balance

No <0 environmental effects

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No <0 environmental effects

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BLACKCYCLE HAS ANSWERED to THE CHALLENGES TO SUCCESS

Technological

The tyre is highly technological

Various performances at the same time

Supply chain creation

Large volumes, quality stability, worldwide coverage

Economical viability

of the overall value chain Vs. an optimized value chain , Customer's willingness

Environmental viability

>0 impact on LCA incl. waste avoïdance&Recycled Mat. use

Energy balance

No <0 environmental effects

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How to make this value chain massively deployed in Europe?

The success of this innovative value chain depends on a coordinated effort involving:

- European industries adopting and implementing the BlackCycle solution in the market.
- Investors providing funding for the necessary equipment.
- The Society embracing and advocating for this industrial and ecological transition.
- The European Commission facilitating the process through incentives and regulatory support.

To actively support this collective effort, the BlackCycle consortium has sent a policy brief to European Commission policymakers making recommendations to bolster the deployment of the circular economy of tyres (critical needs of new regulations particularly around the end-of-waste status).

Cooperation&skills

Systemic approach

Results

BLACK CYCLE

Move to the green revolution

A game changer in Europe and Beyond

- ✓ A solution for segregated High Quality SRM production
- ✓ 1st project around the feasibility of the tyre circular economy ecosystem
- ✓ A project stimulating the ecosystem
- ✓ A similar project created in Asia

SPECIAL THANKS

BLACK CYCLE

Move to the green revolution

- The 13 Partners

(research centers, institutes, start-up, Industry, SMEs, Consultants, innovation cluster)

- The EUROPEAN commission with the Horizon 2020 Program