

ARCUS GREENCYCLING TECHNOLOGIES

CONVERSION OF MIXED PLASTIC WASTE INTO
PETROCHEMICAL FEEDSTOCK –
INSIGHTS IN ARCUS PYROLYSIS PROCESS

MIXED PLASTIC WASTE –
SUSTAINABLE VALORIZATION SOLUTION FOR MATERIAL AND ENERGY RECOVERY

Monday, 18th November 2024, IEA Bioenergy – Task 36



History of an „innovative“ technology

2000 b.c.
Charcoal
production

1973
Oil Crisis

1980s
Alternative Waste
to Energy

2000s
Biomass Research

Today
Chemical
Recycling of
Plastics



From ancient greek:
Pyro (fire) lysis (separating)



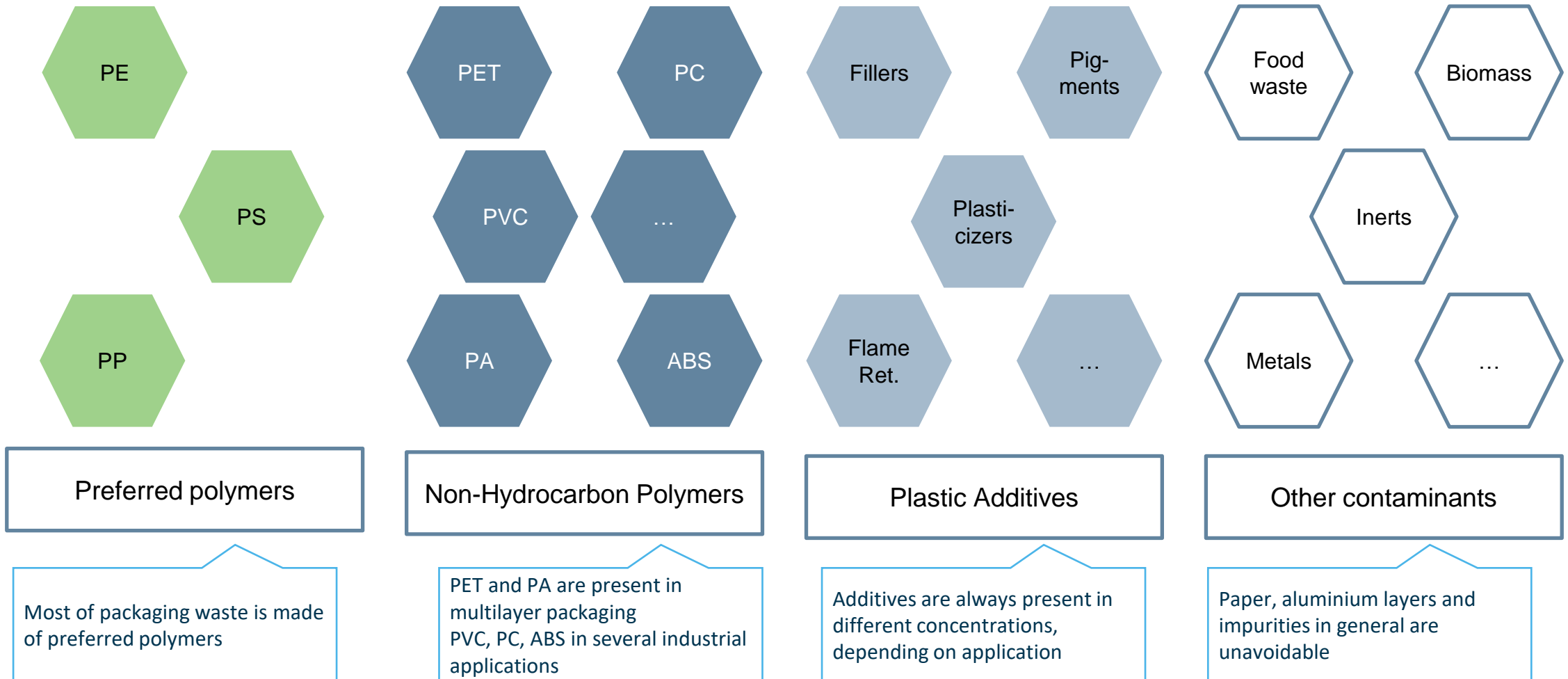
Müllpyrolyseanlage (MPA) Burgau



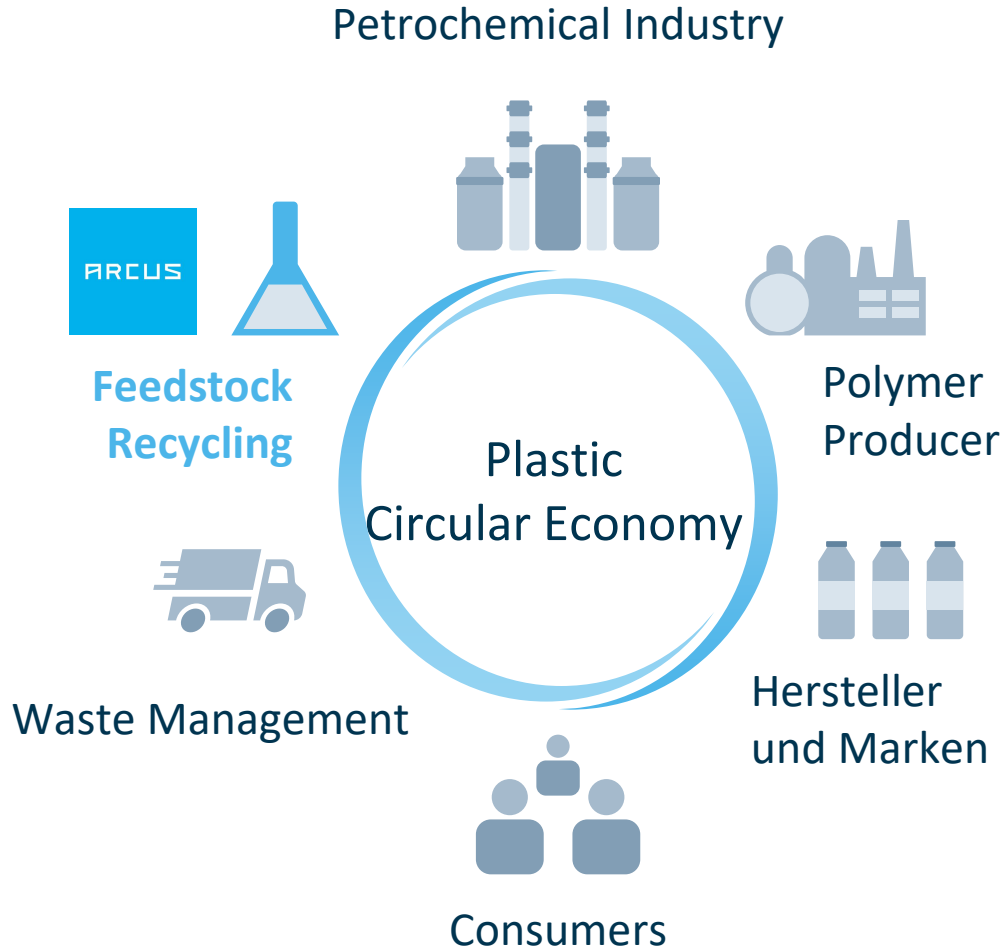
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CRE
Chemical
Recycling Europe

Not all plastics are made equal



ARCUS enables the circular plastics economy with an interdisciplinary team and strong partnerships



Funded 2016

Current status

- Stable process in semipilot scale
- Process Demonstration Unit (PDU) at industrial scale (4000t/a) in operation since Dec. 2022
- Cooperation along the plastics value chain in steady development

Executive Management

Markus Klatte

Team

Mark Eberhard

Staff

Daniel Odenthal

Paulina Dyczewska

Dr. Marco Tomasi Morgano

Julian Odenthal

Partner



Germany's first commercial plastic-to-plastic pyrolysis plant for mixed plastic waste

Process Demonstration Unit (PDU): Fact sheet

Converting mixed waste plastic into new plastic raw material with food grade quality

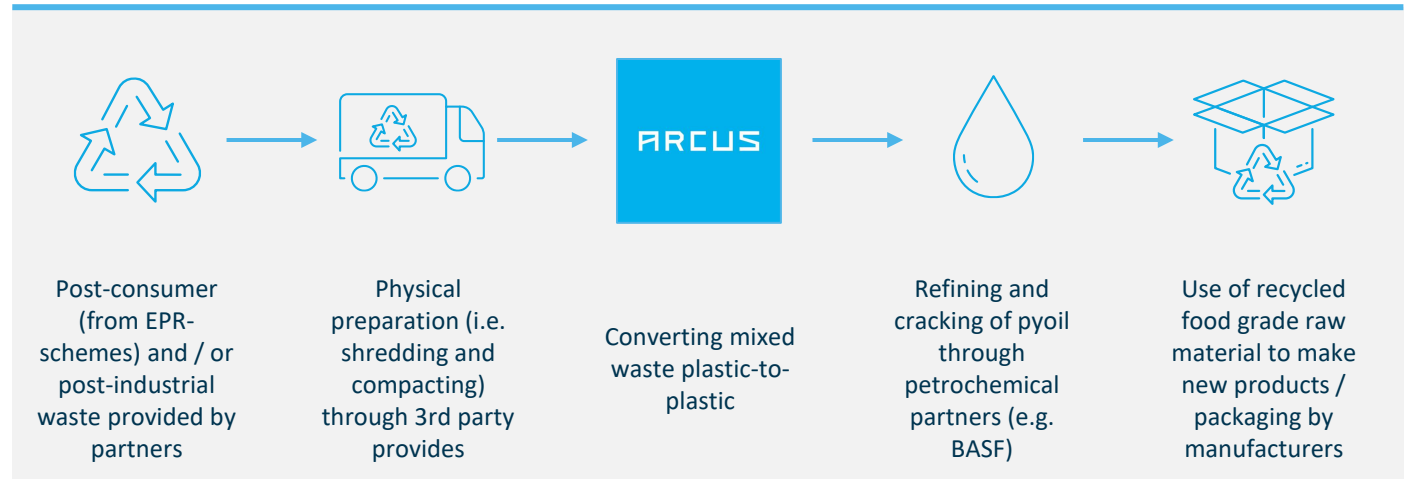
Key facts and figures

Launched	2022
Capacity	4,000 t/a of plastic waste
Output	2,500 t/a of pyrolysis oil
Power	4,000 MWh_E/a
Location	Industrial Park Höchst (Frankfurt am Main)

Operational data

Inputs	Mixed plastic waste (incl. PET, PVC, multilayers, etc.)
Supply	Full-Electric operations
Pathway	Plastic-to-plastic via e.g. BASF
Operation	Plant build, owned, operated and maintained by ARCUS

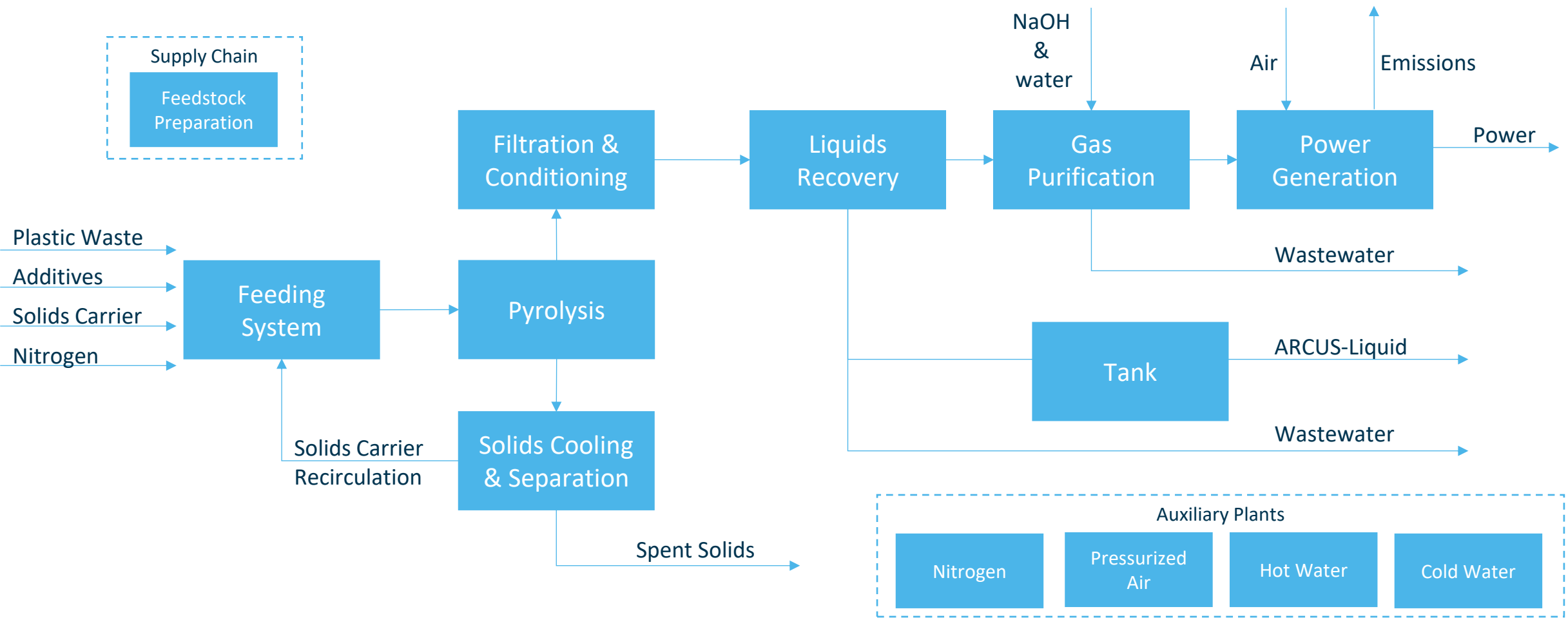
Operations in Brief



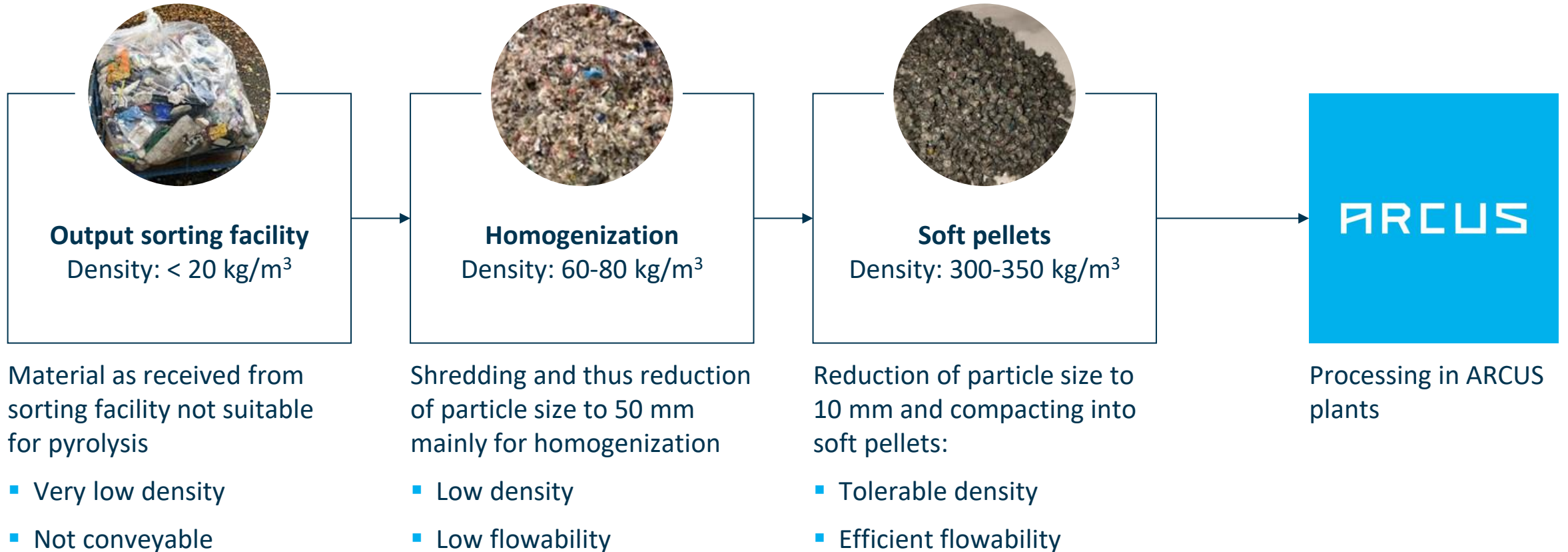
Achievements

- ✓ First of its kind fully authorized chemical recycling facility in Germany
- ✓ REACH registration for ARCUS liquid
- ✓ Reached 2000 hours of operations
- ✓ ISCC+ and RedCert² certification (mass balance schemes) for ARCUS liquid
- ✓ Recognised and certified waste disposal company (EfB) by high German standards
- ✓ Plant Certification as "Letztempfängeranlage" under the German Packaging Act

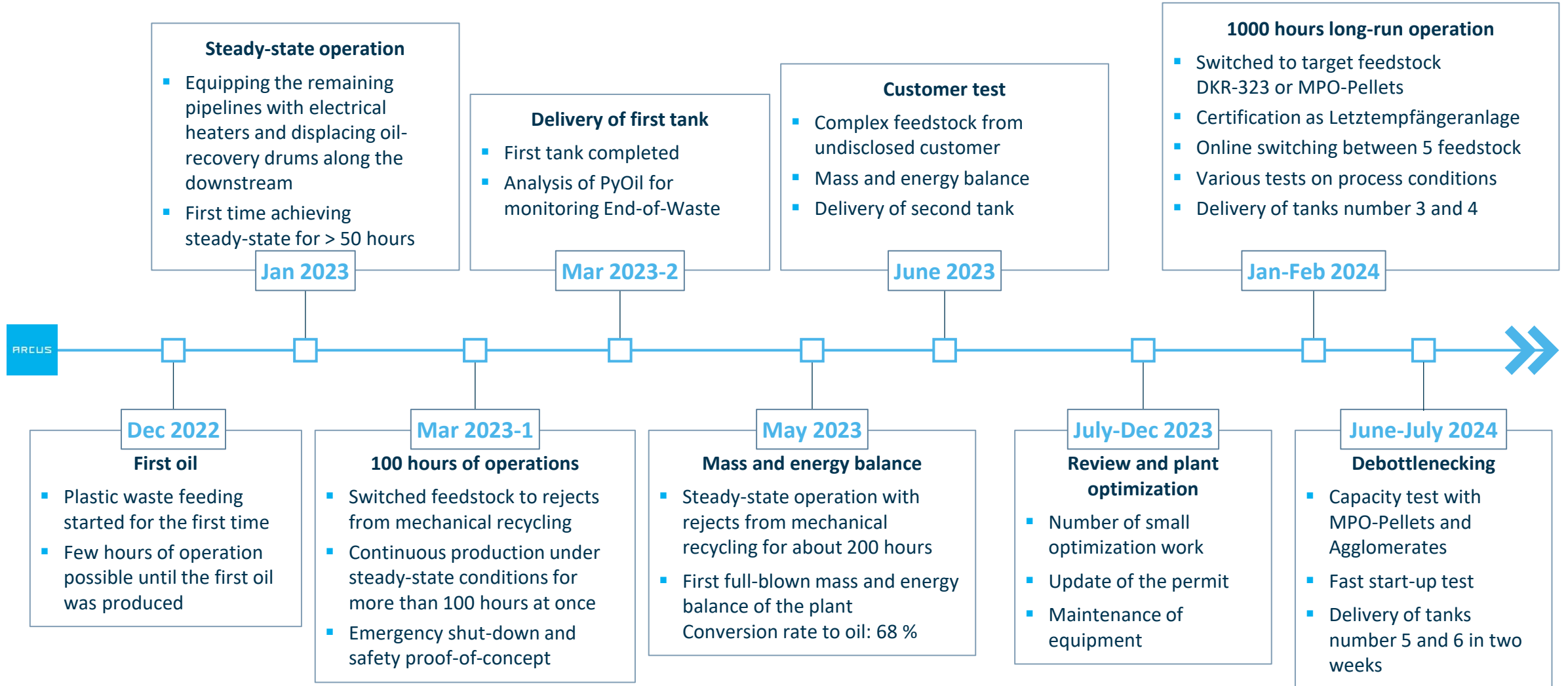
Robust process for waste-to-chemicals conversion



Existing waste streams only need minor preparation in order to be suitable for recycling via the ARCUS-technology

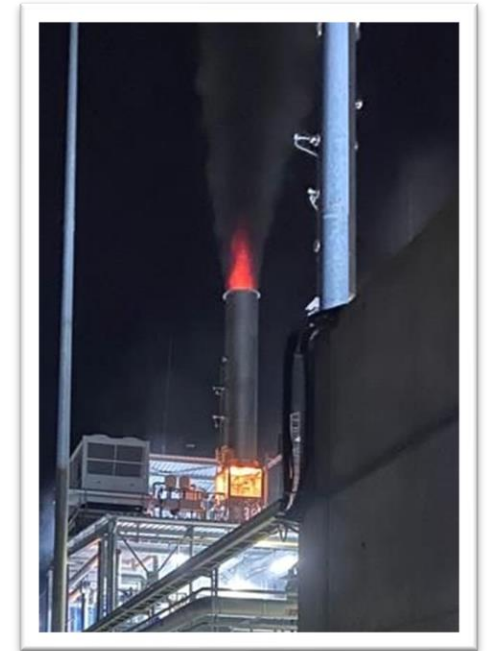


First 18 months of operation like a rollercoaster



Experimental validation at scale of Murphy's Law: „Everything that can go wrong, will go wrong“

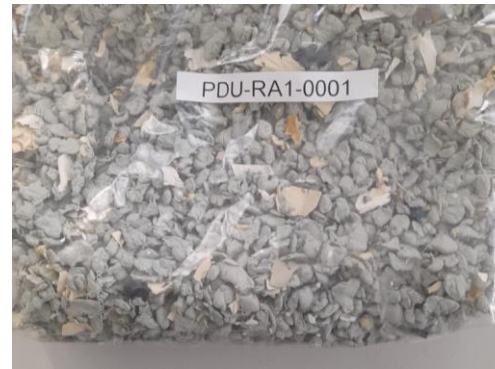
- **Start-Up Feedstock** is far away from being agreed with the supplier
- **Solid Carrier Loop** is too sharp designed. More buffer is required
- **Equipment** that should show the robustness of the system is the first malfunctioning
- **Pyrolysis reactor** is not gas-tight and the **Inertization lasts days** instead of hours
- **Pyrolysis furnace** has very high **heat losses**
- **Cold-water chiller** reacts slowly and do not follow the power demand
- Everything that is not equipped with **electrical heaters** leads to problems earlier or later



Even with all the childhood troubleshooting that a prototype plant has, we have been able to **deliver the first tank of pyrolysis oil within the first 4 months of commissioning**

Start-up Material: from Theory to Praxis

		First sample	Start-up material
Carbon	m/m %	83,1	52,0 – 56,6
Hydrogen	m/m %	12,6	8,2 – 9,6
Ash 550°C	m/m %	4,4	34,2 – 41,2
Water content	m/m %	0,1	1,4 – 3,9
Heating value	kJ/kg	40.130	24.250 – 26.060



Effects:

- **Massive Difference** in the ash content leads to overloading of the vibration sifter
- **Solid carrier loop** overstressed due to non-complete separation of fine dust
- **Conversion rate** much lower than expected
 - Oil-Yield gross: 45 %
 - Oil-Yield net: 62 %



1000 hours at once!

A very successful operation campaign!

- **Smooth Start-Up** of the plant and steady-state reached after 10 hours
- **Evaluation of feedstock variability** within large charges (100 tons)
- **Online switching of feedstock** proving the plant is robust and reliable
- **Hot Gas Filtration** is core equipment for successful operation
- **No Fouling and/or corrosion** in downstream equipment
- **Testing of Re-Cleaning Strategies** successful. We can handle pressure build-up
- **Gained enormous amount of data** for process optimization and final scale-up
- **Long operation effects** monitored for continuous **Debottlenecking**
- **Inbound and outbound logistics** still require optimization



Overview Analysis for MPO-Pellets – Standard ARCUS waste stream

Feedstock Analysis – Composition

Elemental Analysis	ARCUS MPO-Pellets (mg/kg wt.%)	Main Oxides	ARCUS MPO-Pellets (mg/kg wt.%)	Heavy Metals	ARCUS MPO-Pellets (mg/kg wt.%)
C	- 72,2	Al	5.535 -	As	< 0,8 -
H	- 10,1	Ca	11.390 -	Pb	25 -
N	6.620 0,662	Fe	1.605 -	Cd	0,5 -
O*	96.025 9,60	K	810 -	Cr	22 -
S	894 0,089	Mg	1.050 -	Cu	100 -
F	70 0,007	Mn	42 -	Ni	6 -
Cl (tot.)	6.520 0,652	Na	925 -	Hg	0,10 -
Cl (wat. sol.)	520 0,052	P	542 -	Tl	< 0,2 -
Proximate Analysis	ARCUS MPO-Pellets (mg/kg wt.%)	S (SO ₃)	542 -	Zn	207 -
Ash @ 550°C	- 7,7	Si	10.405 -		
Ash @ 815°C	- 6,7	Ti	4.610 -		
C Fix	- 3,6				
Moisture	- 9,0				

- **Polymers** are are mainly **Polyolefins** – content of polyolefins about 85 % of total
- **Main contaminants** are in middle (Oxygen and Sulfur) to high (Nitrogen) range
- **Ash content** constant over 100 ton material and several analyses
- **Ash composition** relatively complex. Metals will act catalytically and play a relevant role in overall reaction chemistry

You were not supposed to be there!

Findings in feedstock



Feedstock preparation runaways

Findings after processing



Earthing connections



Big stones



Metal wires



Aluminium sheets

PyOil looks good. Delivered more than 100 tons and 6 tanks to customers

Parameter	Unit	PyOil from Tank 1	PyOil from Tank 2	PyOil from Tank 3-4
Carbon	m/m %	84,8	85,9	83,6
Hydrogen	m/m %	13,8	13,6	12,8
Nitrogen	mg/kg	1.650	1320	2400
Oxygen	m/m %	< 0,5	< 0,5	1,4
Sulfur	mg/kg	< 5	38,9	110
Chlorine	mg/kg	25	< 10	70
Silicium	mg/kg	< 20	36	13
Phosphorus	mg/kg	< 2,5	3	< 2,5
Water	mg/kg	1.850	210	30.400
Density	kg/m ³	791,2	794,9	810,5
Viscosity @ 40°C	mm ² /s	1,579	1,551	2,233
Flash Point	°C	-9	< -25	15
Pour Point	°C	4	9	13,8
Bromine Number	g / 100 g	77,3	72,6	45,7
Total Acidic Number	mg KOH / g	< 0,01	< 0,1	0,24
Heating Value	kJ/kg	42.860	42.523	42.014

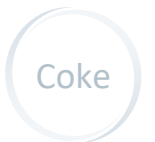


End-of-waste is not an issue for ARCUS-Liquids

		PyOil from tank 1	PyOil from tank 4
Quicksilver	µg/kg	4	4
16 EPA-PAK	mg/kg	982	553
PCDD/F (WHO-TE 2005 incl. BG)	µg/kg	0,003	0,012
dI-PCB (WHO-TE 2005 incl. BG)	µg/kg	0,001	0,007
Sum PCDD/F + dI-PCB (WHO-TE 2005 incl. BG)	µg/kg	0,004	0,019
Sum 6 PCB (incl. BG)	mg/kg	0,032	0,195



- **Analysis** are carried out regularly on tank basis for monitoring the End-of-Waste
- **Polyaromatic Hydrocarbons (PAHs)** are generated in gas-phase reactions
- **Dioxins and Furans (PCDD/Fs)** are constantly three orders of magnitude **below limitations** according to German TRGS 905 and to ChemVerbotsV (Regulations of forbidden chemicals)
- **Heavy metals concentrations** are all in the range of ppbm (µg/kg). **Si and P** are the only trace elements above 1 mg/kg



Dealing with hazardous waste along the way

Fine Dust (PyCoke) is our contaminants sink

- Particle size < 10 μm
- Heating Value > 6.000 kJ/kg
- HCs C₁₀-C₄₀ > 2.500 mg/kg
- TOC > 10 % w/w
- TiO₂ > 1 % w/w



Sludging



Pelletizing



Suction Silo Truck docking at
ARCUS-PDU Fine Dust Silo

Exciting months in front of us

- **Several tests for customers**

- Tests with different contaminated feedstock from different origins
 - High concentrations of oxygen and/or halogens
 - Legacy additives (heavy metals, etc.)

- **Doubling Production rate with continuous Debottlenecking**

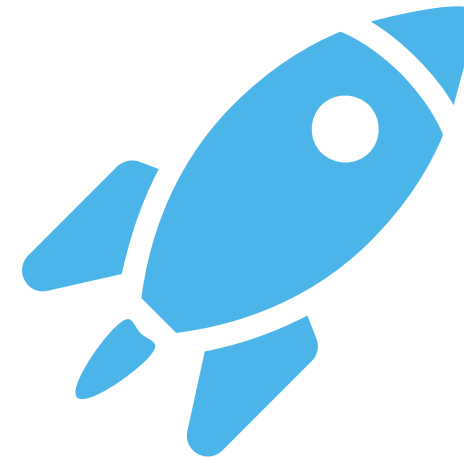
- Evaluate where we can make process improvements
 - Long run operations effects
 - continuous delivery of in-spec PyOils

- **Preparing for self-sustained operation**

- Final Plan for the arrival of the Gas Motor
 - Product gas and emission measurements
 - Optimization of gas properties

- **Getting ready for next generation plant**

- Review of all the learnings and starting designing the first commercial plant
 - Implementation of lines concepts
 - Upscaling of logistics
 - ...



Thank you for
your attention



Contact

ARCUS
Greencycling Technologies GmbH

Dr. Marco Tomasi Morgano | CTO
+49 (1 72) 41 73 65 8
Marco.TomasiMorgano@arcus-greencycling.com

Markus Klatte (MBA, Kellog) | Gründer/Founder
+49 (1 74) 13 11 11 8
Markus.Klatte@arcus-greencycling.com

Daniel Odenthal (MSc.) | Gründer/Founder
+49 (1 72) 10 50 72 9
Daniel.Odenthal@arcus-greencycling.com

Sitz der Gesellschaft: Ludwigsburg
Amtsgericht Stuttgart: HRB 755461

Hindenburg Strasse 45 – D-71638 Ludwigsburg
kontakt@arcus-greencycling.technology
www.arcus-greencycling.com