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ESNI Conference 2024

Growing the Future of Nutrient Recycling

A cautious approach to reconciling the Green Deal and the prevailing economic system

Ludwig Hermann

18th September 2024

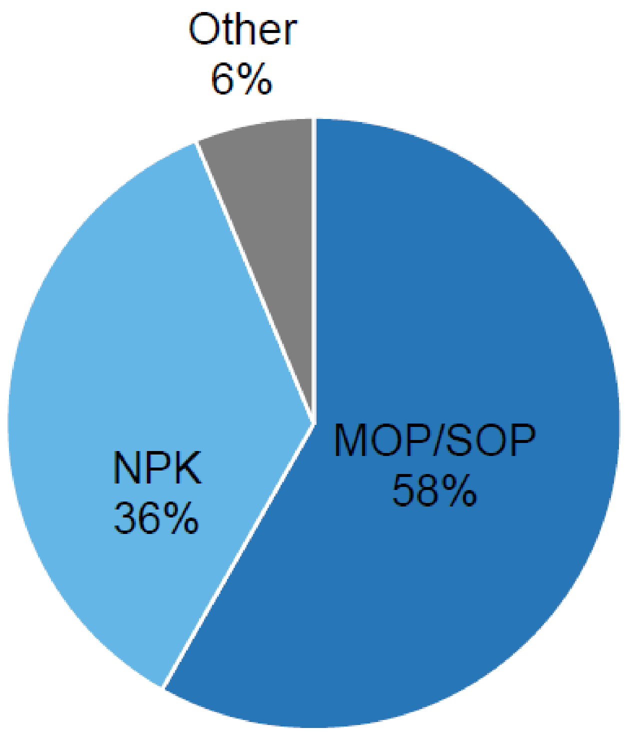
ESNI
EUROPEAN SUSTAINABLE NUTRIENT INITIATIVE

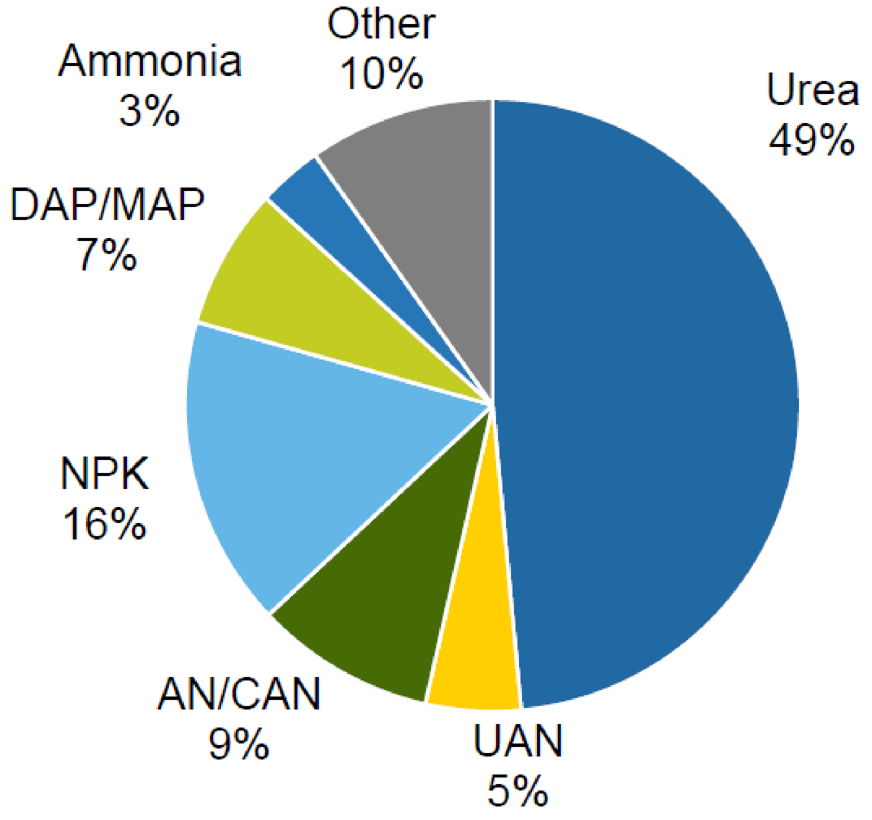
Baseline

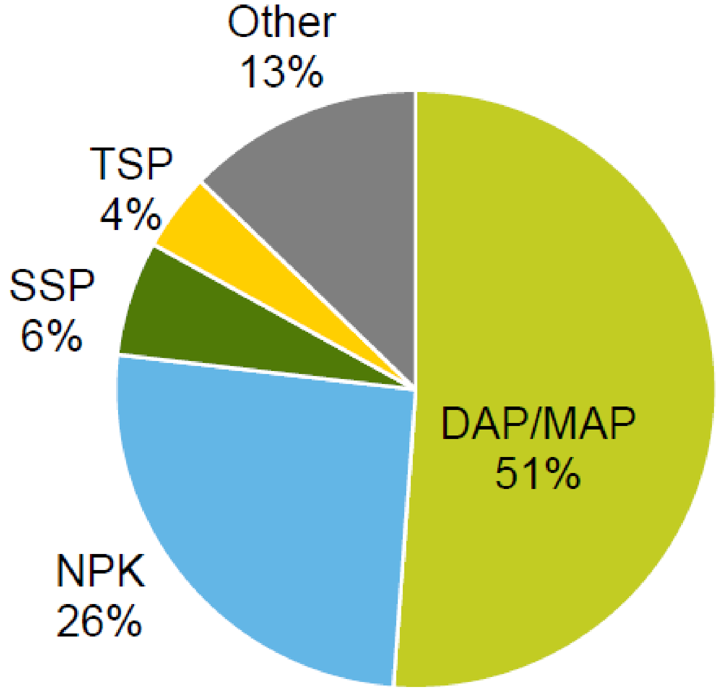
Nutrient recycling in fertilisers

Key Global and EU Fertilising Products Use (Source IFA 2022, 2020 Data)

Potash K_2O	Nitrogen N	Phosphate P2O5







	Potash K_2O	Nitrogen N	Phosphate P2O5
	40 million tonnes	**112 million tonnes***	**49 million tonnes**
EU:	2.8 million tonnes	11 million tonnes	2.5 million tonnes
	7% / 7%+	10% / 9%+	5% / 4%+

+ Share of sales / of production in the EU
* Without industrial N use

N & P recovery potential – EU "technical potential" in fertilisers

- 7 - 9 Mt N/y in livestock manure (RISE 2016)
  - plus, similar order of magnitude N lost to the atmosphere from agriculture (of which around one quarter as climate or pollutant gases: N_2O, NO_x, ammonia) and the remainder as inert N_2 (EEA)
- c. 3 Mt N/y is lost to water from agriculture (EEA)
- 2 - 3 Mt N/y in sewage sludge (RISE 2016)
- 0.4 Mt N/y NO_x emissions from industry (derived from CREA 2023)

- 1.80 Mt P/y in livestock manure (Van Dijk et al., 2016)
- 0.30 Mt P/y in sewage sludge (VanDijk et al., 2016)
- 0.13 Mt P/y in biowaste (VanDijk et al., 2016)
- 0.13 Mt P/y in meat & bone meal (VanDijk et al.,2016)
  - Total recycling potential up to 0.6 Mt/y P
  - Total recycling potential up to 1.7 Mt/y N

From all secondary nutrient resources In inorganic and organic fertilising products

Source: European Commission, Joint Research Centre (JRC), May 2023
https://dx.doi.org/10.2760/692320

Compared to

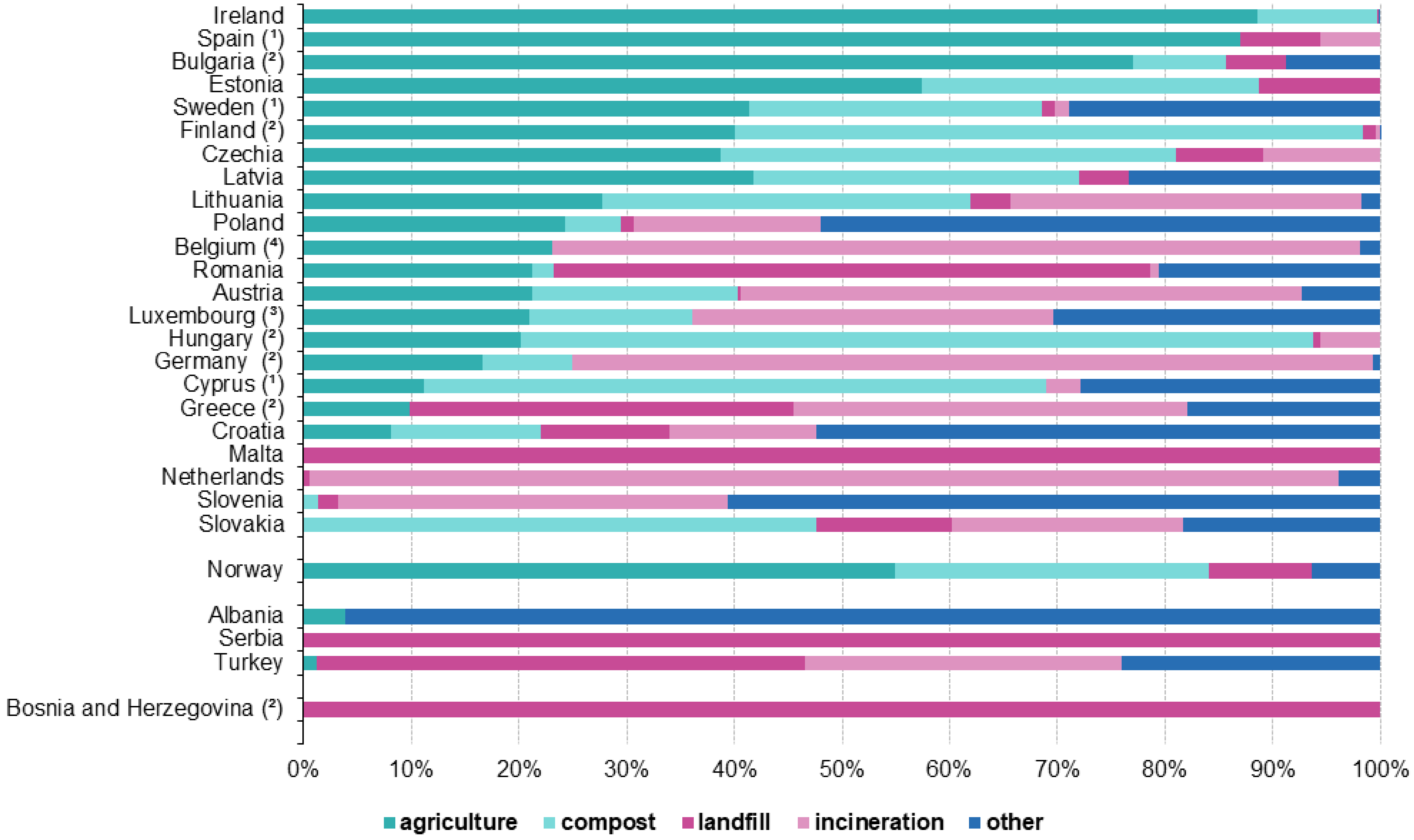
- c. 11 Mt N/y in mineral fertilisers +
- c. 3 Mt N/y in imported animal feed

Compared to

- c. 1.1 Mt P/y in mineral fertilisers and
- c. 0.3 Mt P/y in imported animal feed

Sewage sludge derived nutrient potential in Europe

Disposal of sewage sludge from urban wastewater treatment by method of disposal, 2020
(% of total)



Note: Denmark, France, Italy, Portugal, Iceland, Switzerland, United Kingdom: no data or no recent data available
(¹) Data for 2018 instead of 2020
(²) Data for 2019 instead of 2020
(³) Data estimated
(⁴) Data for incineration and other disposal are provisional
Source: Eurostat (online data code: env_ww_spd)

eurostat

Total European production of sludge:

- >8.7 Million tonnes DS/y.

Sludge destinations:

- Agriculture: 4.1 Mt DS/y
- Incineration: 2.4 Mt DS/y
- Recultivation/land reclamation: 0.7 Mt DS/y
- Landfill: 0.5 Mt DS/y
- Other destinations: 1 Mt DS/y

Source: 2021 EurEau Survey 'Europe's Water in Figures'.

Potential for recovery of mineral nutrients from municipal wastewater in the EU:

- 67 000-80 000 t/y phosphorus
- 75 000-90 000 t/y nitrogen

Source: European Commission, Joint Research Centre (JRC), May 2023 https://dx.doi.org/10.2760/692320

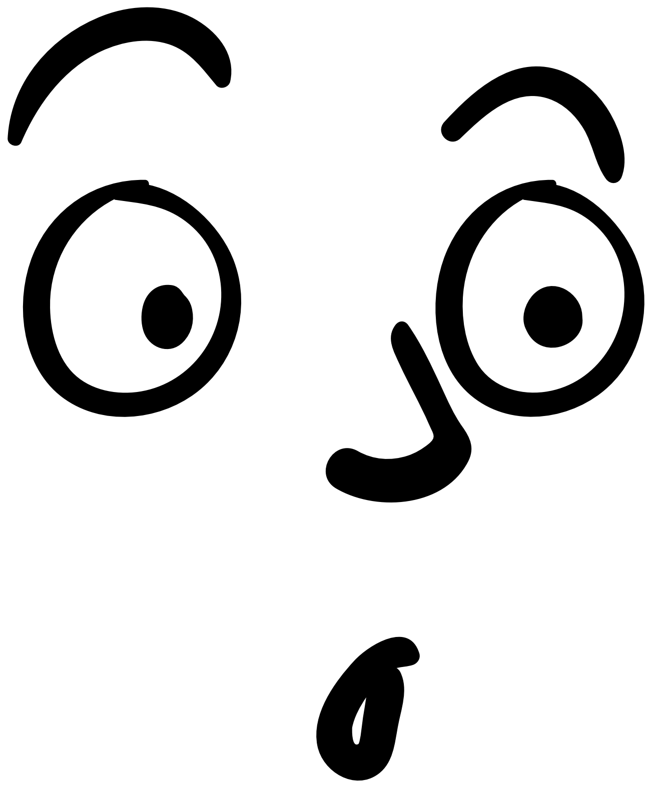
Summary of the inventory of P-recycling plants (Kabbe, 2023)

- 47 struvite plants in Europe are "operational"
  - Annual capacity 18,000 tpy of struvite*) / 5,000 t P_2O_5
- Dublin and Warsaw online by 2023/2024 adding about
  - Additional capacity 8,000 tpy of struvite / 2,200 t P2O5
- Potential gap between capacity and output could be 50% of capacity
- Beyond Europe,
  - Annual capacity about 25,000 tpy of struvite / 7,000 t P_2O_5
  - Annual global total struvite capacity = 15,000 t P_2O_5.
- Planned P recovery from ash in the EU
  - 185,000 tpy / 37,000 t P_2O_5 in existing and projected plants
- In EU countries with incineration as preferred sludge treatment route,
  - 600,000 tpy of ash with about 120,000 t P_2O_5 can be expected.

*) Struvite includes other phosphates precipitated from sludge and process water

Inventory of phosphorus "recovery and /or recycling" facilities operating or under construction at or downstream of wastewater treatment installations
(© C. Kabbe v. 2023/10)

General barriers observed



- Standard, sludge derived P products (struvite) may bring operational benefits but, without a special framework, face problems to be profitably placed on the market.
- Standard N products (ammonium sulphate solution) may be necessary for efficient biogas conversion and wastewater treatment but typically cost more than they can earn.
- Ashes from sludge incineration are not a suitable fertilising product due to an insufficient bioavailability of phosphorus = low mineral replacement value.

Business Opportunities

Nutrient recycling in fertilisers

Added value for struvite in organic farming

ESPP https://www.phosphorusplatform.eu/scope-in-print/news/2306-recovered-struvite-authorised-in-eu-certified-organic-farming

The EU Organic Farming Regulations have been modified to authorise "Recovered struvite and precipitated phosphate salts", as defined in the EU Fertilising Products Regulation (FPR). The modifying Regulation (2023/121 modifying 2021/1165), published 17th January 2023, specifies that, to be authorised for use in Certified Organic Farming, the recovered phosphates "*must meet the requirements laid down in*" the FPR and that "*animal manure as source material cannot have factory farming origin*".

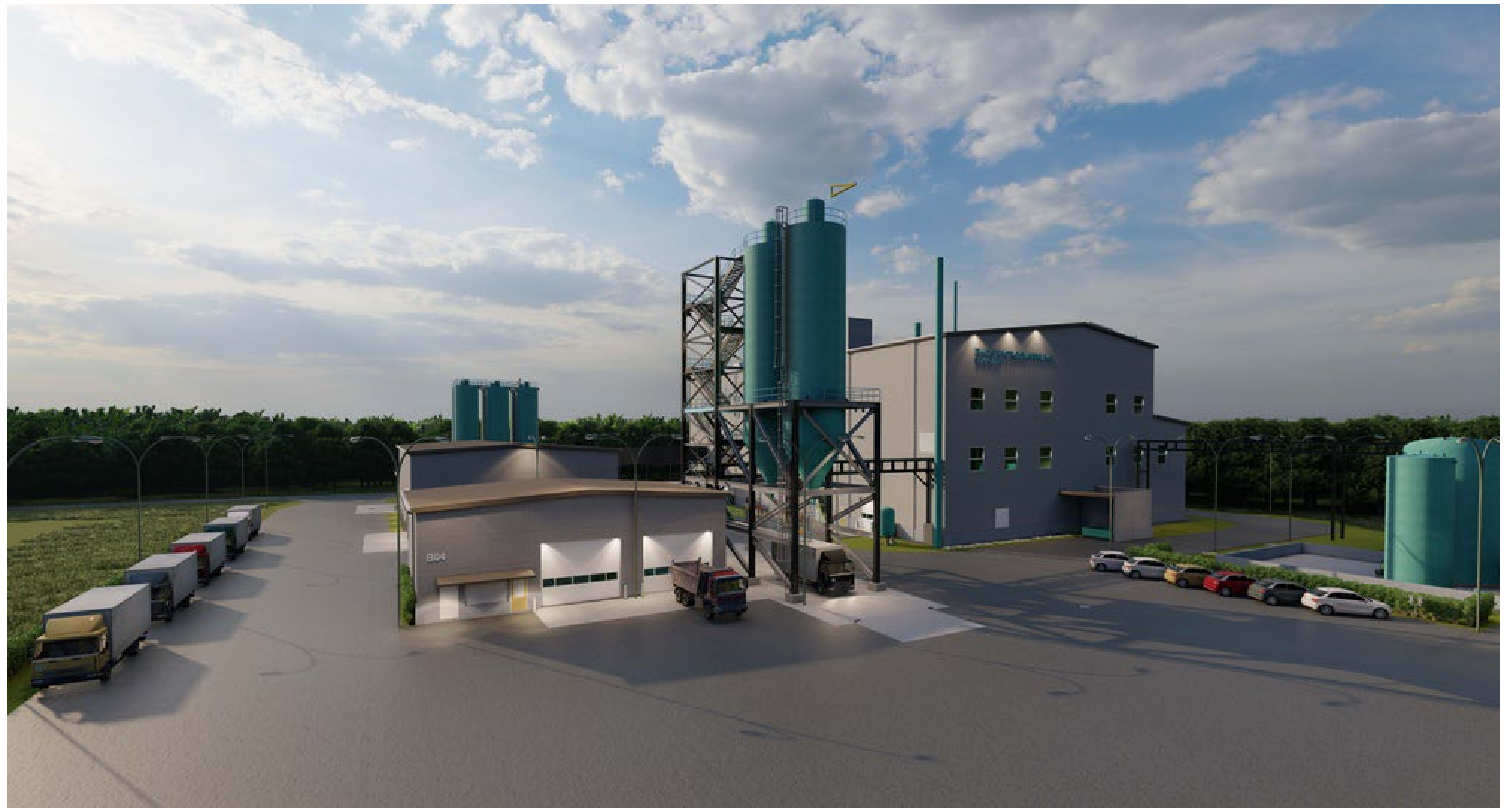
Requires CE-mark

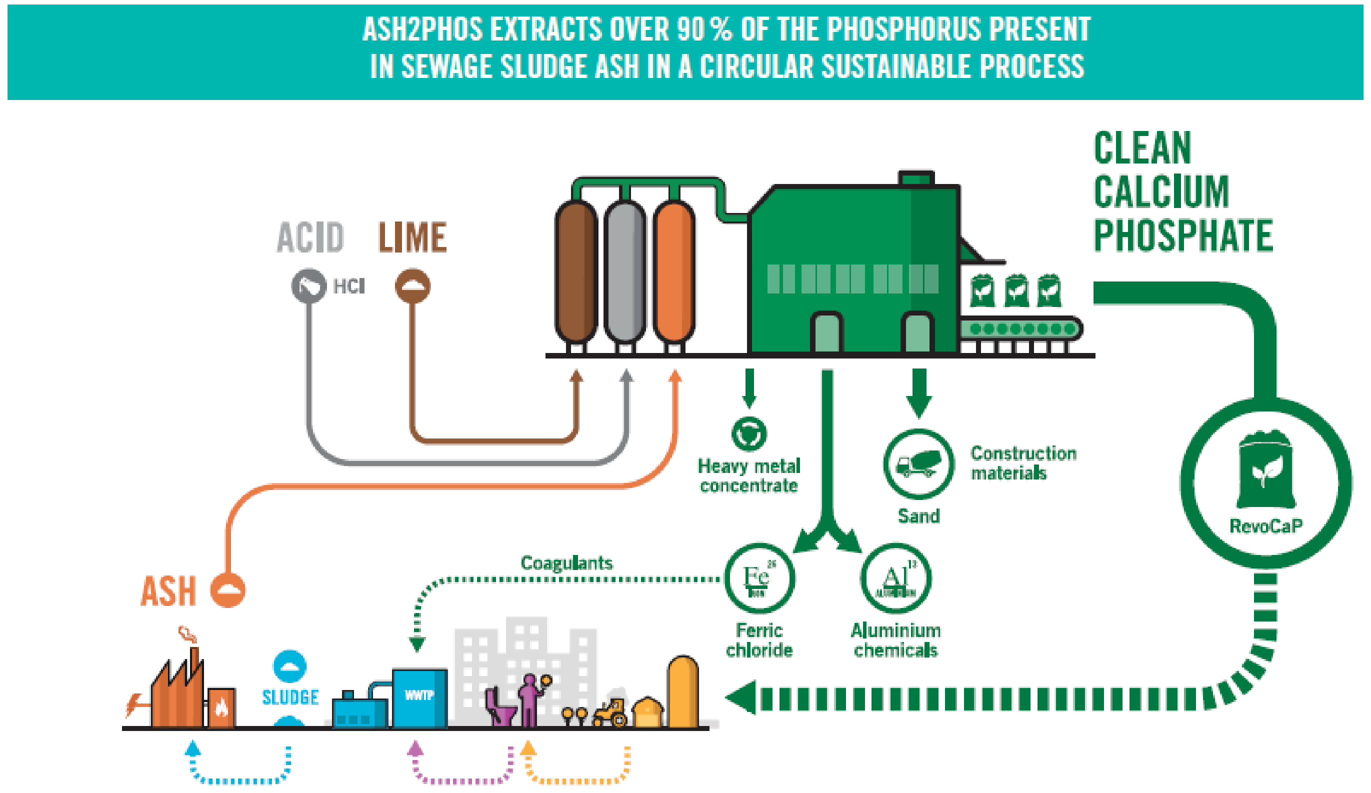
- Conformity assessment, module D1, for obtaining the CE mark for product and process is necessary

Offers

- Cooperatives are potential sales partners for fertiliser products eligible for organic farming
- Prices can be as high as = 2,000 – 3,000 €/t for white struvite microgranules in organic farming
- More than 20% of agricultural land in Austria, Estonia, Sweden

Potential added value for calcium phosphate in organic farming

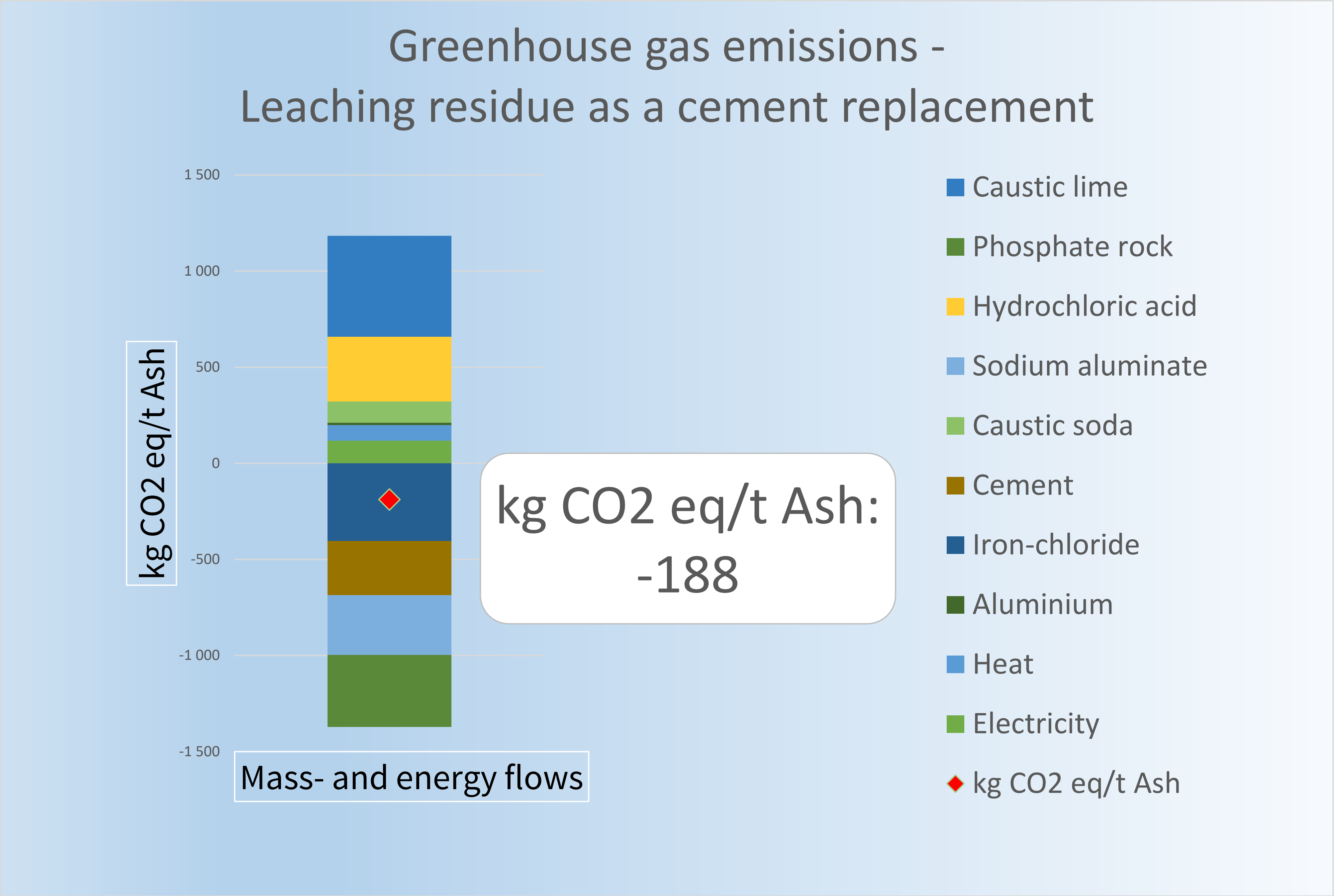




- Cooperation with one of chemical P extraction processes, for instance EasyMining
- Comprehensive extraction of N, P, Fe, Al, Si (as sand), metals
- Producing high purity, 39% P_2O_5 calcium phosphate
- Conformity assessment of products and CE marking
- In the EU and potentially in the US sales for organic farming
- Prices can be as high as = 2,000 – 3,000 €/t for calcium phosphate granules in organic farming

Ash2Phos + Sahara module – CO_2 positive P recycling from ash

The process: a first acidic step, a second alkaline step, and a final conversion step where the intermediates are processed into final products. Typical recovery rates are 90 – 95 % phosphorus, 60 – 80 % aluminium and 85 - 90 % iron (with Sahara module).



Test benches made by a cement / leaching residue blend with and without the Sahara module (source: EasyMining)

Upgrading biobased fertilisers Struvite or Ca-Phosphate

CE fertiliser certification process

- REACH registration of the substance
  - Struvite and ASL already registered under REACH
  - According to the prevailing legal opinion, which is also confirmed in question 8.13 of the FAQs on Regulation (EU) 2019/1009 on fertilisers (the "Fertiliser Regulation"), no re-registration is required for recycled products, only confirmation of "sameness“

  https://CE.europa.eu/docsroom/documents/54694
- Conformity assessment according to Module D1 of the Fertiliser Product Regulation (EU) 2019/1009 by a Notified Body = e.g., CerTrust, but also 15 other NoBos, but only a few are authorised for Module D1 (ASL + struvite).
- Declaration of conformity, authorisation for CE marking.
- In the case of struvite, the CE mark also entitles it to be approved as a fertiliser for organic farming, Ca-Phosphate is recommended for organic farming by EGTOP.
- Costs of around €10,000/year and additional one-off costs of around €5,000 are expected for certification (for <3,000 t/a production).

ESPP information concerning application of REACH (European Chemical Regulation) to recovered struvite

v July 2023

This document presents ESPP's understanding of the legal situation only. It is not legal advice and should not be taken as such. Companies intending to place recovered struvite on the market, for sale or for free distribution, do so entirely under their own legal responsibility and should carry out their own appropriate legal verification and consult competent legal experts or advisors. ESPP is not a regulatory consultant and is not competent to offer legal or regulatory advice or support.

Information :

Struvite = magnesium ammonium phosphate EINECS 232-075-2 - CAS 7785-21-9

REACH Registration of struvite: see the ECHA (European Chemicals Agency) website (search for “struvite”): https://echa.europa.eu/

CerTrust leads the coordination group and has successfully certified the conformity of Ostara Crystal Green Struvit.

Members of the coordination group

Body type	Name	Country
NB 2806	CerTrust Kft.	Hungary
NB 2973	Eurofins Certification	France
NB 2947	Inspectorate Estonia AS	Estonia
NB 2949	Instytut Nadzoru Technicznego Sp. z o.o.	Poland
NB 2972	Jednostka Certyfikujaca Wyroby Siec Badawcza Lukasiewicz Instytut Nowych Syntez Chemicznych	Poland
NB 2929	Kiwa VERIN B.V.	Netherlands
NB 0163	LABORATORIO OFICIAL JOSE MARIA DE MADARIAGA	Spain
NB 1326	LIMITED LIABILITY COMPANY LATVIAN CERTIFICATION CENTRE (LATSERT)	Latvia
NB 1434	POLSKIE CENTRUM BADAN I CERTYFIKACJI S.A.	Poland
NB 2832	Stichting Global Network Group TIC trading as EMCI Register and EFCI Register	Netherlands
NB 1749	TNO Defense, Security and Safety	Netherlands
NB 0906	TUV AUSTRIA HELLAS LTD	Greece
NB 2979	Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH	Austria

Table from NANDO 28/03/23

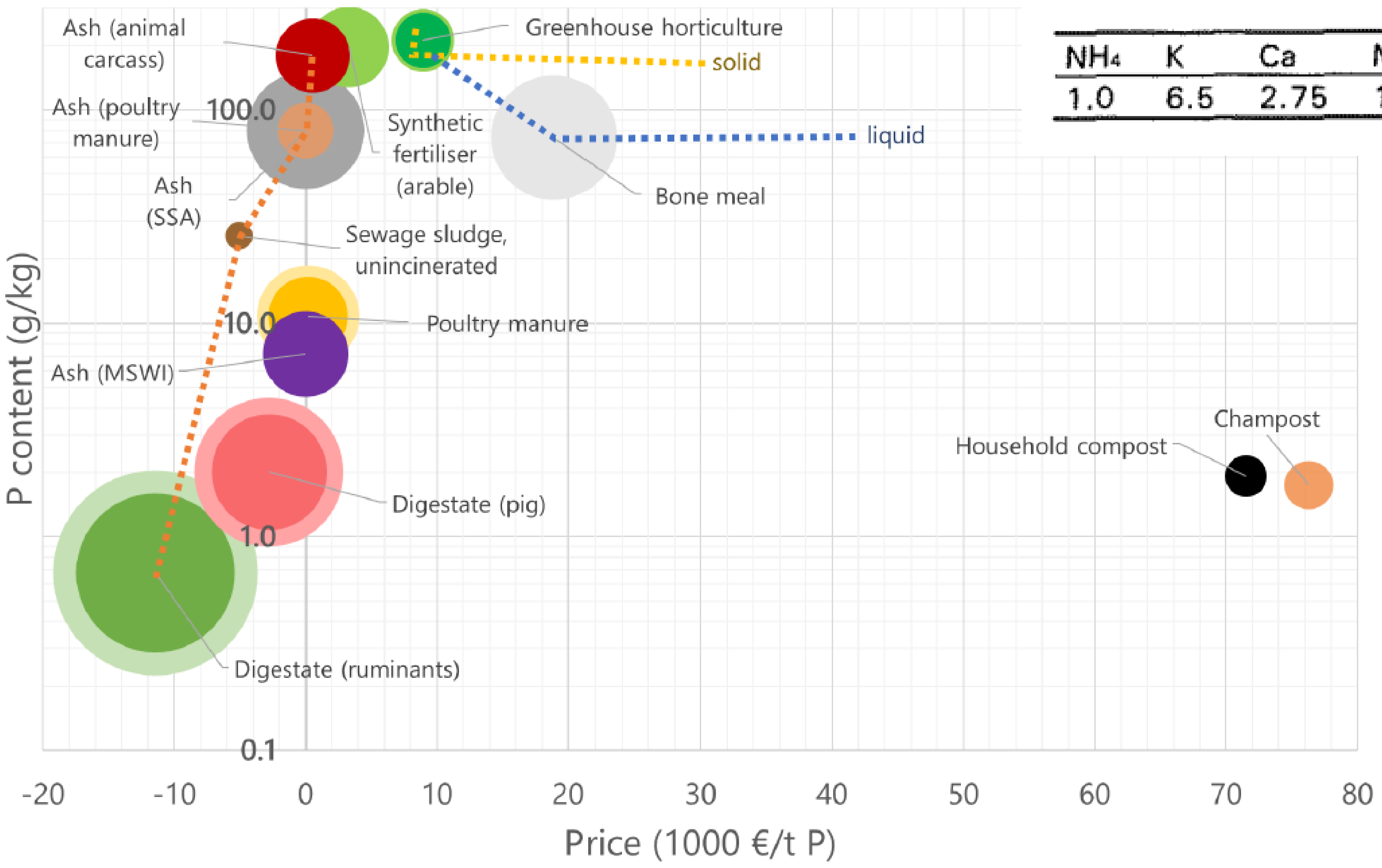
Chair: Gábor Tasnádi
Interim vice chair (elections on September 13th): Sara García Figuera
Technical secretariat: Sara García Figuera
Administrative secretariat: Katerina Asimaki

To be notified bodies (invited to meetings): CAAE (Spain), Ecocert (France), JKI (Germany)

Added value for ammonia stripping in greenhouse cultures

- Reacting with high grade, high purity, in the future possibly biobased phosphoric acid
- Producing high purity ammonium phosphate
- Conformity assessment of products and CE marking
- Sales in liquid form to greenhouses
- Price potential for 100% soluble ammonium phosphate = >1,000 €/t

Circular P & N for Hydroponic Greenhouse Horticulture (Van Tuyll et al., 2024)



P-rich side-streams in the Netherlands. Vertical axis (logarithmic): P concentration. Horizontal axis: price. The size of the circles corresponds to the annual amount of P (2500 t for greenhouse horticulture). The Pareto front is in orange. Negative prices reflect disposal costs.

Standaardvoedingsoplossing met EC = 1.6

NH_4	K	Ca	Mg	NO_3	SO_4	H_2PO_4	Fe	Mn	Zn	B	Cu	Mo
1.0	6.5	2.75	1.0	10.75	1.5	1.25	15	10	4	20	0.75	0.5

The recipe above is a typical greenhouse blend, i.e. the liquid substrate that is sent to the crops. Most N is nitrate.

Dutch greenhouses use about

- 2 500 t P per year and
- 10 000 t N per year.

Nutrient volumes of other products, e.g., fully soluble ammonium phosphates, may be calculated using these recipes. EC is in dS/m, NH_{4+} up to and including H_2PO_4- in mmol/l, other nutrients are in micromol/l.

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Circular ammonium phosphate in Hydroponic Greenhouse Horticulture

(Van Tuyll et al., 2024)

The table below shows names and chemical formulae of compounds commonly used in synthetic phosphorus fertilisers in greenhouse horticulture, adapted from Sonneveld et al. (2009). Products with high solubility are sold both in solid and liquid form, with the exception of phosphoric acid, which is only sold as an aqueous solution.

Name	Chemical formula	% P	Solubility
(Ortho)phosphoric acid	H_3PO_4	32	High
Mono potassium phosphate	KH_2PO_4	22	High
Mono ammonium phosphate	$NH_4H_2PO_4$	26	High
Polyphosphate	$HO(HPO_3)_nH$	Trademarks; exact chemical composition not published.	High
Super phosphate	$Ca(H_2PO_4)_2$	20	Low
Dicalcium phosphate	$CaHPO_4$	20	Low

Monoammonium phosphate (either solid or as a solution) is a commonly-used fertiliser in greenhouse horticulture. Wageningen research is currently pursuing a research project in this sector.

Monoammonium phosphate has the highest possible nutrient concentration N:P2O5 = 12:52, yet in solid form. Crystallisation (by evaporation) may be an option for lower transport and handling costs. Also, similar substrate solutions are used in greenhouses across Europe.

Module D1 – sampling requirements

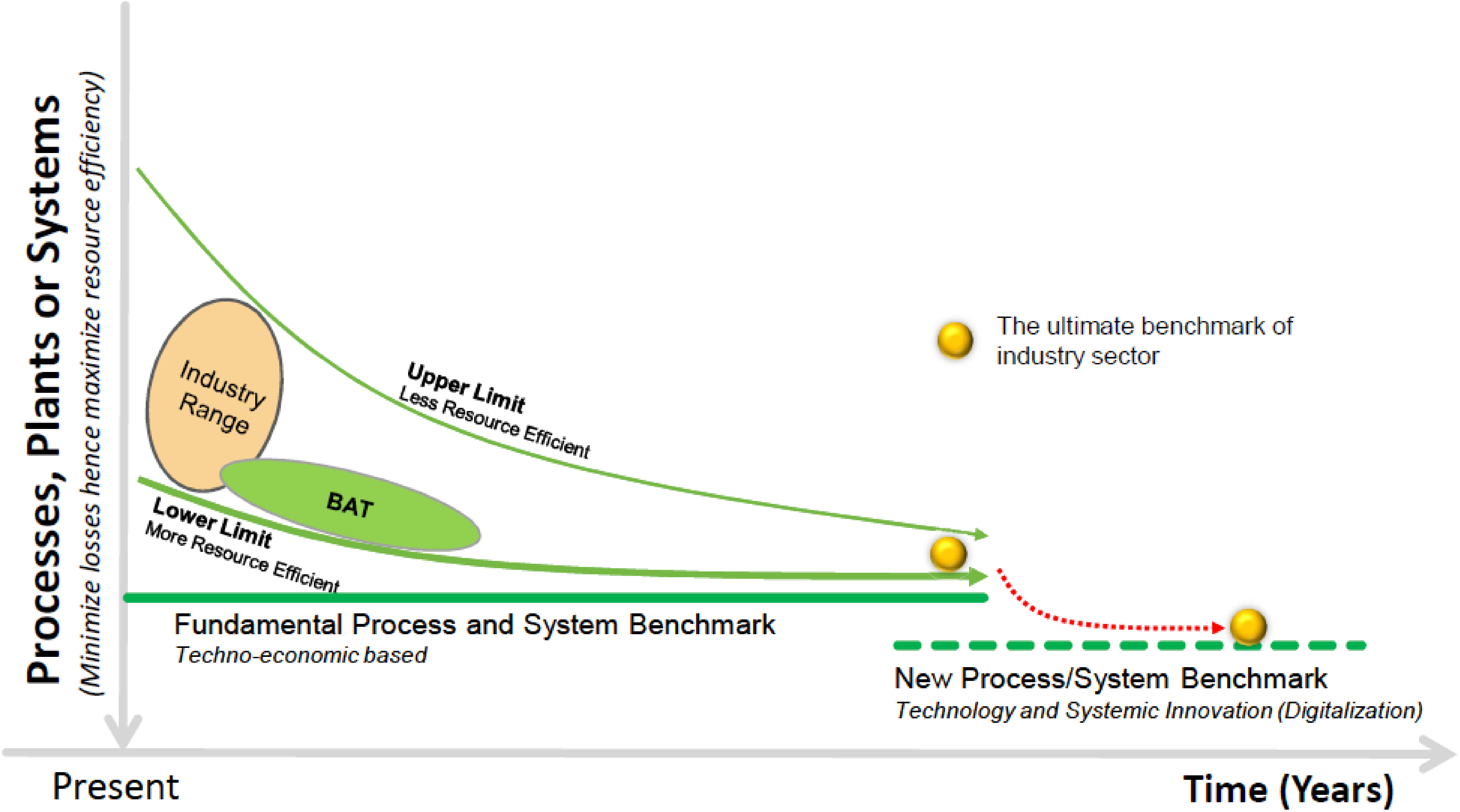
- For materials belonging to CMCs 12, 13, 14 and 15, the output material samples shall be taken with at least the default frequency defined in the Regulation, or sooner than scheduled in the case of any significant change that may affect the quality of the EU fertilising product:
- Manufacturers may reduce the default frequency of testing for contaminants as indicated above by considering the distribution of historical samples. After a minimum monitoring period of one year and a minimum number of 10 samples showing compliance with the requirements in Annex I and II, the manufacturer may reduce the default sampling frequency for that parameter by a factor 2 in case the greatest contaminant level recorded from the last 10 samples is smaller than half of the limit value for that parameter laid down in Annexes I and II.
- *Note: it might not be relevant for the supplier. In case of this is not relevant refer as: It is done by the manufacturer*

Annual output (tonnes)	Samples/year
≤ 3 000	4
3 001 – 10 000	8
10 001 – 20 000	12
20 001 – 40 000	16
40 001 – 60 000	20
60 001 – 80 000	24
80 001 – 100 000	28
100 001 – 120 000	32
120 001 – 140 000	36
140 001 – 160 000	40
160 001 – 180 000	44
> 180 000	48

The complete questionnaire for the audit proceedings is available on demand.

Techno-economics and physics-based limits

Minimising losses and maximising efficiency towards the ultimate industry benchmark



Useful sources for information

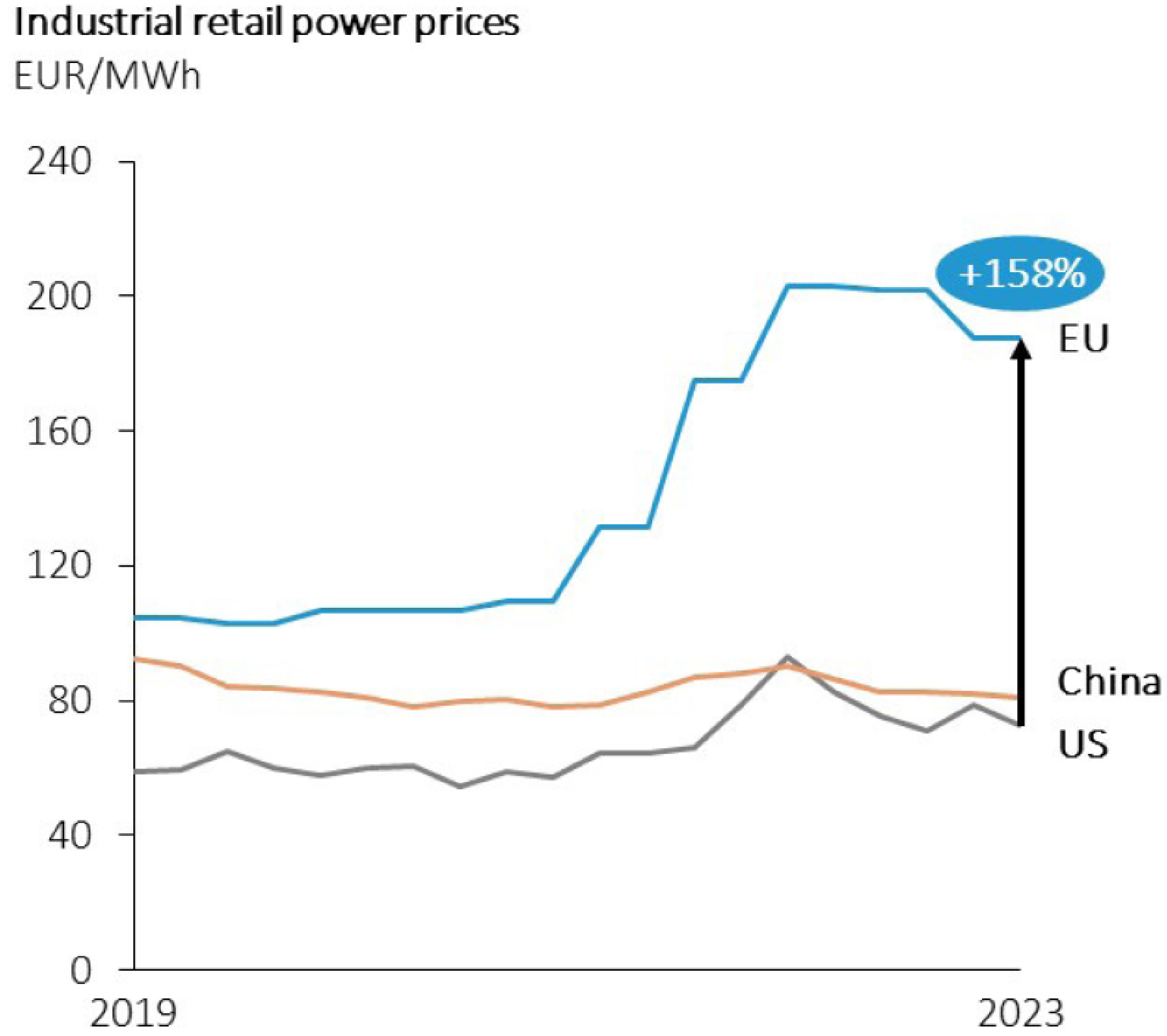
Questions	Source of information
Regarding the Fertilising Products Regulation (EU) 2019/1009	FAQs related to Regulation (EU) 2019/1009 on fertilising products (the 'Fertilising Products Regulation')
Regarding labelling of fertilising products	Guidance document labelling of EU fertilising products
Regarding the conformity assessment (CE mark)	NANDO Database: https://CE.europa.eu/growth/tools-databases/nando/index.cfm?fuseaction=na.main
Regarding market and prices	https://www.agrarheute.com/markt/duengemittel/duengerpreise-stickstoffduenger-billiger-bauern-koennen-sparen-619561

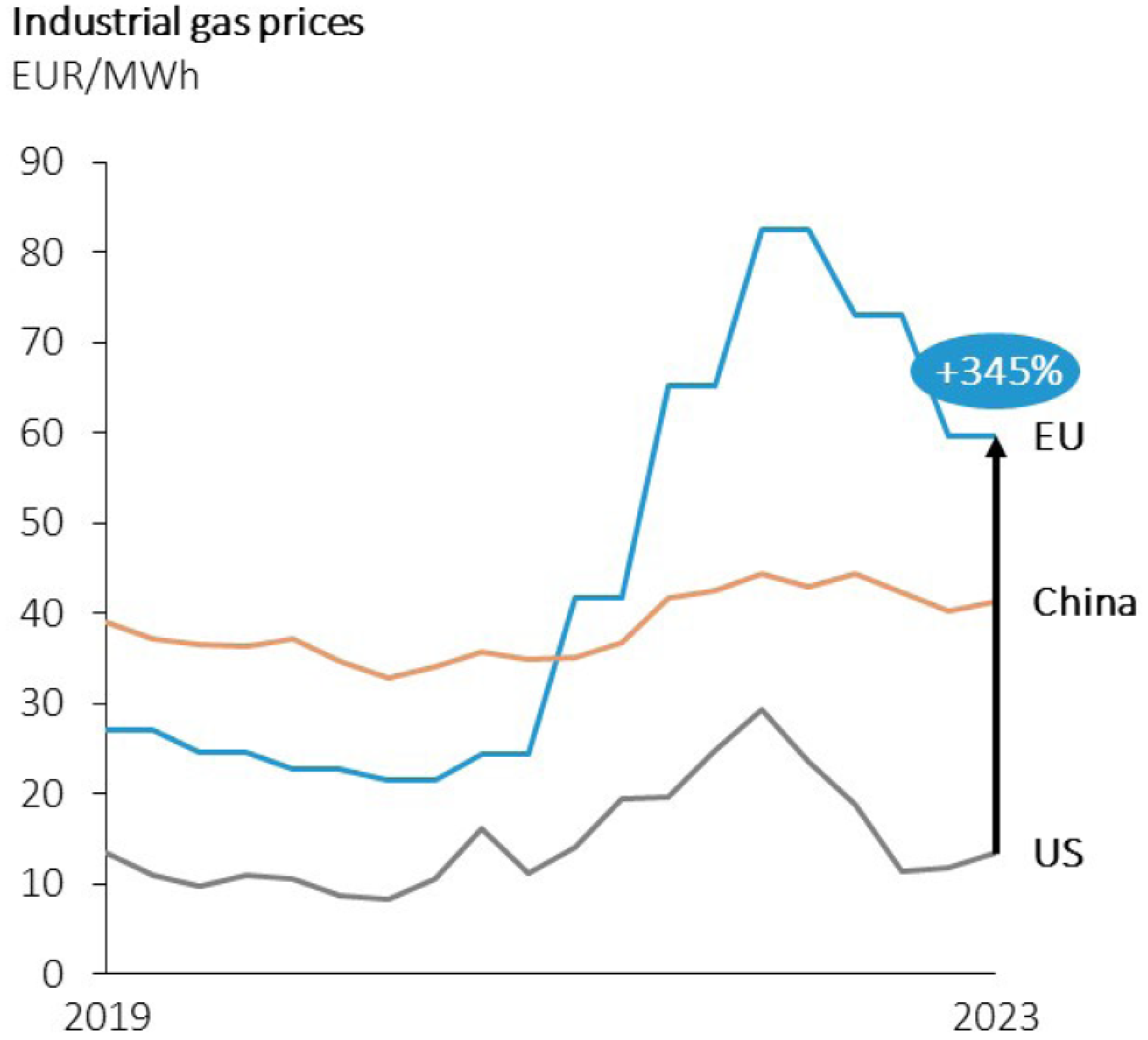
And through ESPP www.phosphorusplatform.eu

Business Opportunities

Non-fertiliser use of biogenic waste materials

Gas and retail power price gap for industry in the EU





Source: European Commission, 2024. Based on Eurostat (EU), EIA (US) and CEIC (China), 2024.

A chance for biomethane, bio-LNG, bio-CNG

Whatever downstream use you plan for biogenic waste, biogas as a first step is always a good idea, and the price gap with natural gas is narrowing.

Current cost of natural gas with CO_2 certificate	**€ 54.00 / MWh**
• Dutch TTF natural gas futures September 2024	€ 39.00 / MWh
• Emissions of 0.2 t CO_{2eq} /MWh at € 70.00/t CO_{2eq}	€ 14.00 / MWh
Current cost of biogas	**€ 65.00-95.00 / MWh**
• Biogas from biowaste generation	€ 35.00-55.00 / MWh
• Upgrading to biomethane	€ 30.00-40.00 / MWh

The remaining barrier is that there are still many free CO_2 certificates in use and many sectors not yet subject to the EU ETS. but this barrier will disappear during the years to come.

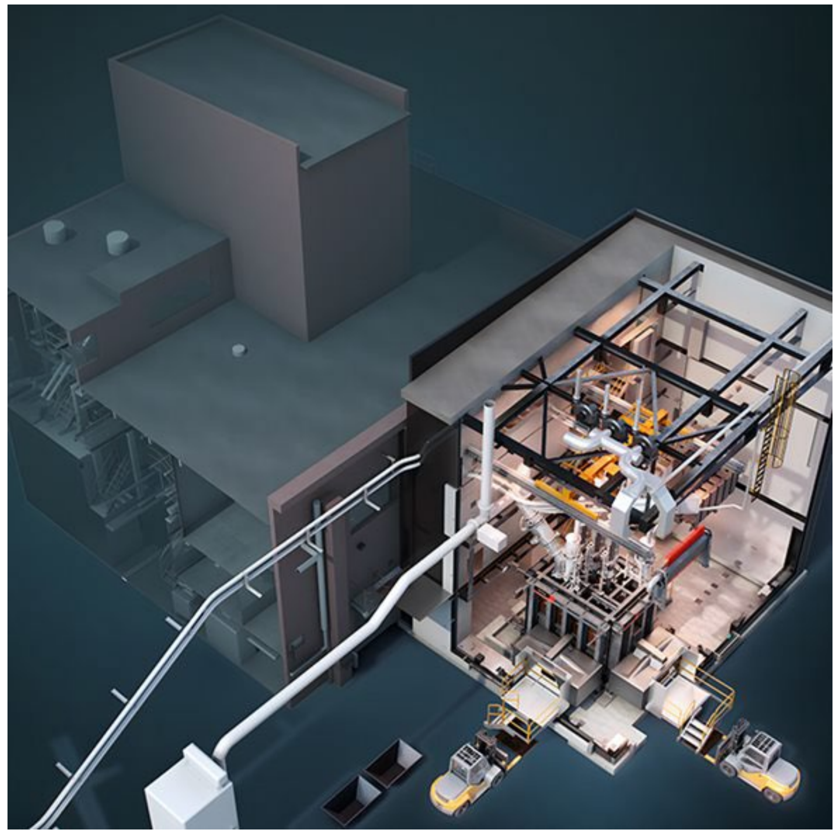
Added value for Carbon Removal and Carbon Farming (CRCF)

A HE RIA project addressing these questions will soon be submitted

A biorefinery combining the production of fertilising and CRCF products for use in sectors subject to carbon credits

- Thermal hydrolysis of sludge (with P extraction?)
- P-precipitation as struvite or calcium phosphate
- Hydrothermal carbonisation (HTC)
- Energy efficient drying
- N-recovery from condensate
- Pyrolysis of biogenic waste to biochar
- Use of hydrochar as fuel, e.g., in cement plants
- Use of biochar as a PFAS adsorbent from water, wastewater and soil
- Use of biochar as a reducing agent in green steel

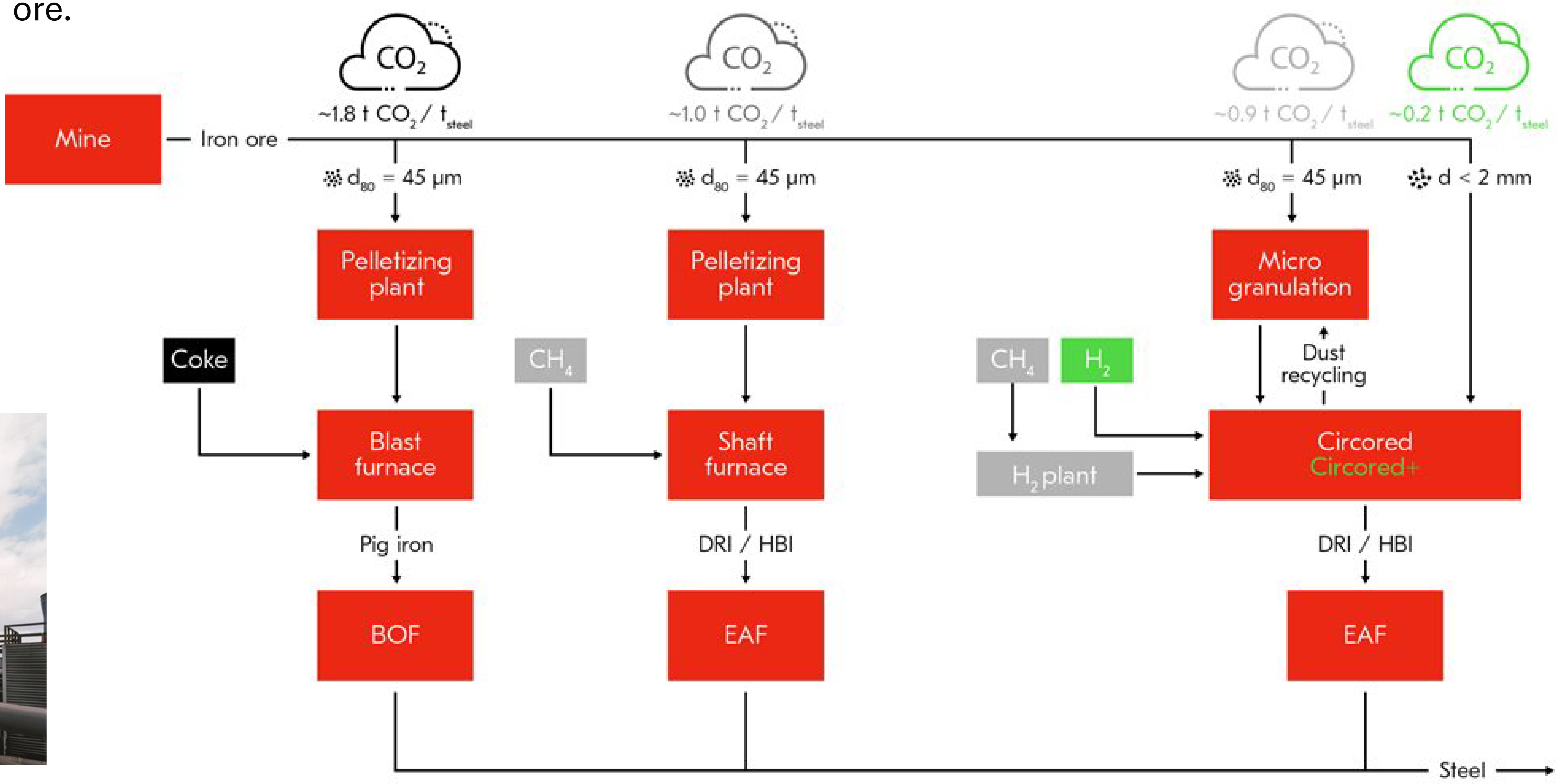
The last mile for green steel can be achieved using biochar



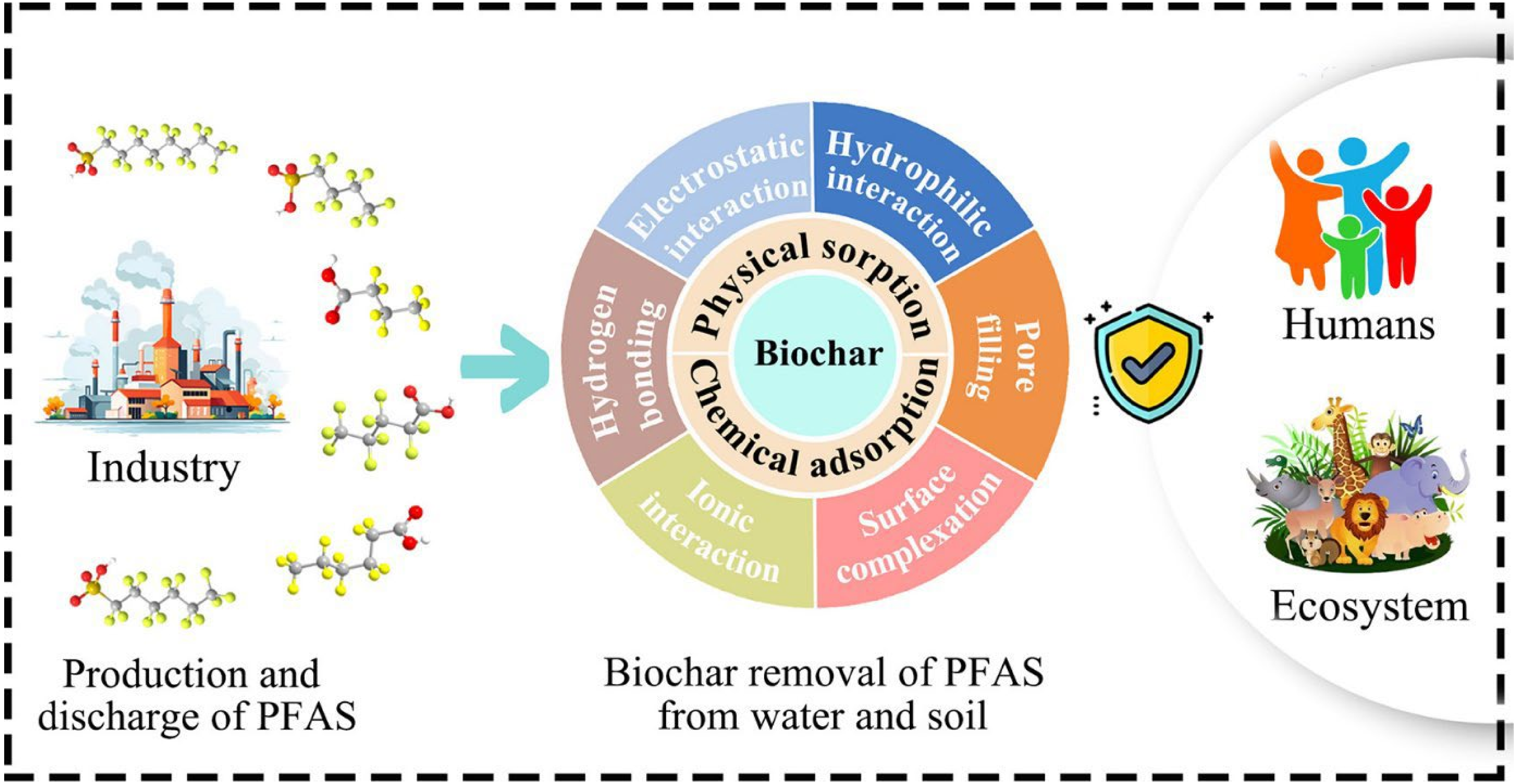
Source: Metso

Source: Metso, full scale CIRCORED plant in Trinidad

Metso's Outotec DRI Smelting Furnace combined with Metso’s CIRCORED direct reduction plant enables decarbonizing steel industry by replacing blast furnaces. Metso's Outotec DRI Smelting Furnace is based on proven proprietary equipment and enables utilizing blast furnace grade iron ore.



A promising use opportunity – PFAS adsorption in biobased chars



Biochar has proven excellent PFAS adsorption. Its performance in WWTPs will be tested.

- A comprehensive coverage of the remediation of PFAS by biochar is presented.
- Biochar's PFAS sorption mechanisms and key influencing factors are elucidated.
- Cases for remediation of PFAS contamination by biochar are discussed in detail.

Liang et al., 2024, A critical review of biochar for the remediation of PFAS-contaminated soil and water https://doi.org/10.1016/j.scitotenv.2024.174962

Proposed Fish Sludge Process Value Chain

H_2-CO mixed syngas to chemical building blocks, e.g., proteins as fish feed and aviation fuel

Fish Sludge in Norway by 2050:
1 Mt/y
33 500 t P
57 000 t N

Biogas (SNG/LNG)

Anaerobic Digestion → 5-10% DM → *De-watering* → 25-30% DM → *Drying* ⇄ 85-95% DM ⇄ *Thermal Conversion* → 100% DM → *Ash Treatment*

Steam, heat

By-products

Nitrogen

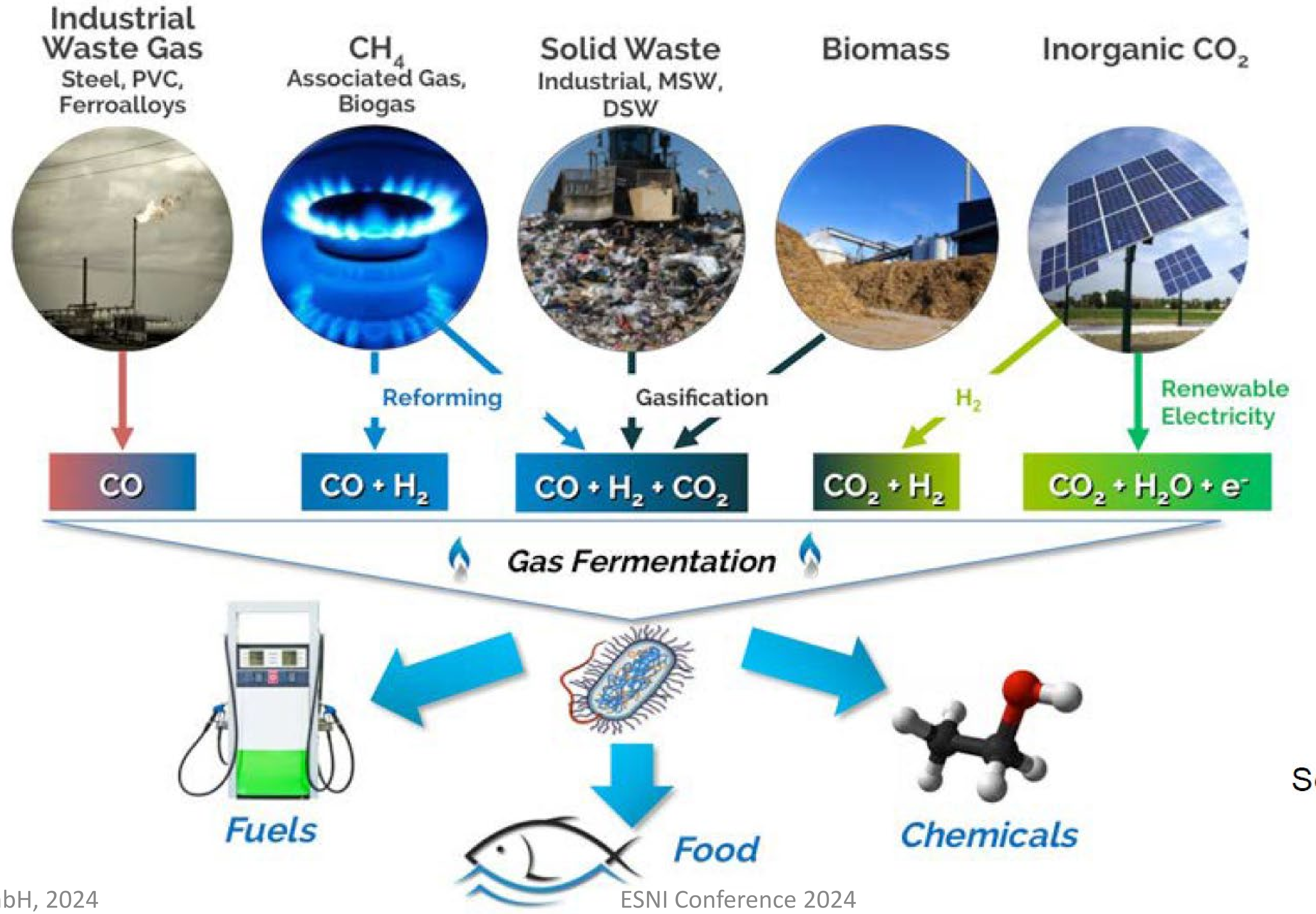
Salt recovery (?)

Efficient dryer <400 kWh/t H_2O

Phosphate

Target: Production of syngas from biomass and waste and downstream synthesis
Scale: 1 MW DUAL FLUID gasification, 250 kW Fischer-Tropsch synthesis
Operations: Campaigns for research operation
Fuel: Wood chips, sewage sludge, plastic waste, sorted waste, agricultural residues

Using gas fermenting bacteria (acetogens)



Source: Lanzatech

Flexibility of DUAL FLUID gasification

More H_2 in product gas ← **„classic“ DUAL FLUID** → **More CO in product gas**

„classic“ DUAL FLUID

Experience in commercial operation for combined heat and power production, using woody feedstock. Currently, waste fuels as basis for (bio)refinery products are evaluated for commercial roll-out.

SER DUAL FLUID

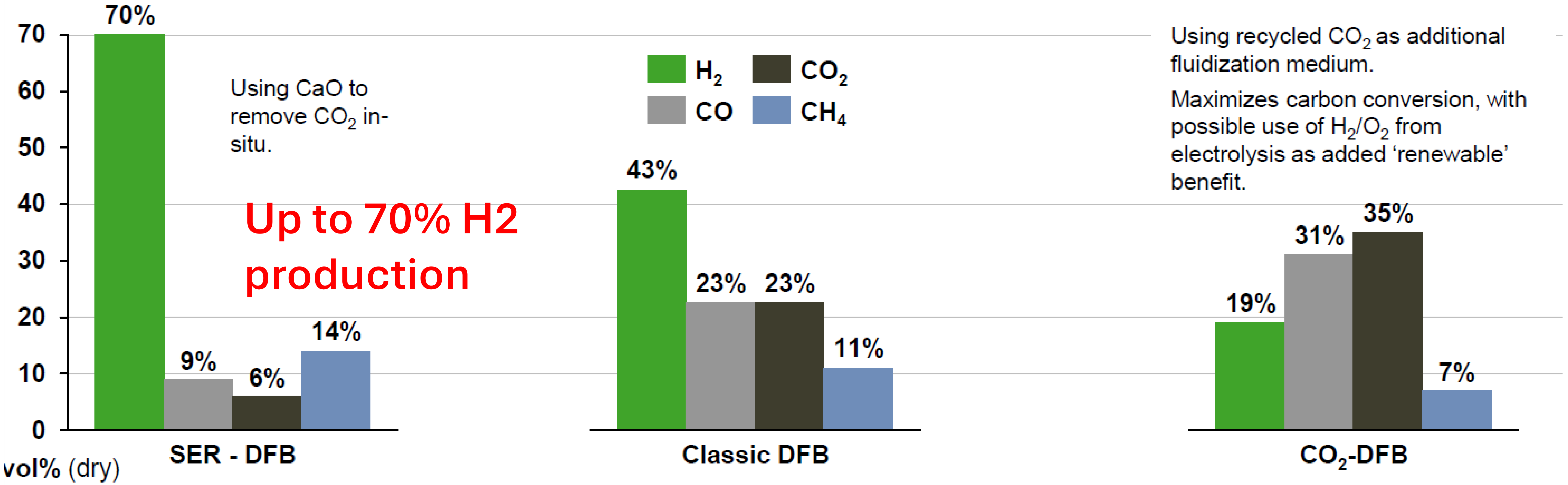
Tests show over **70 vol% H_2** with **S**orption **E**nhanced **R**eforming (SER),

Product gas contains more hydrogen and less CO and CO_2

CO_2 DUAL FLUID

Tests show an increased **CO** yield of **+30 %**

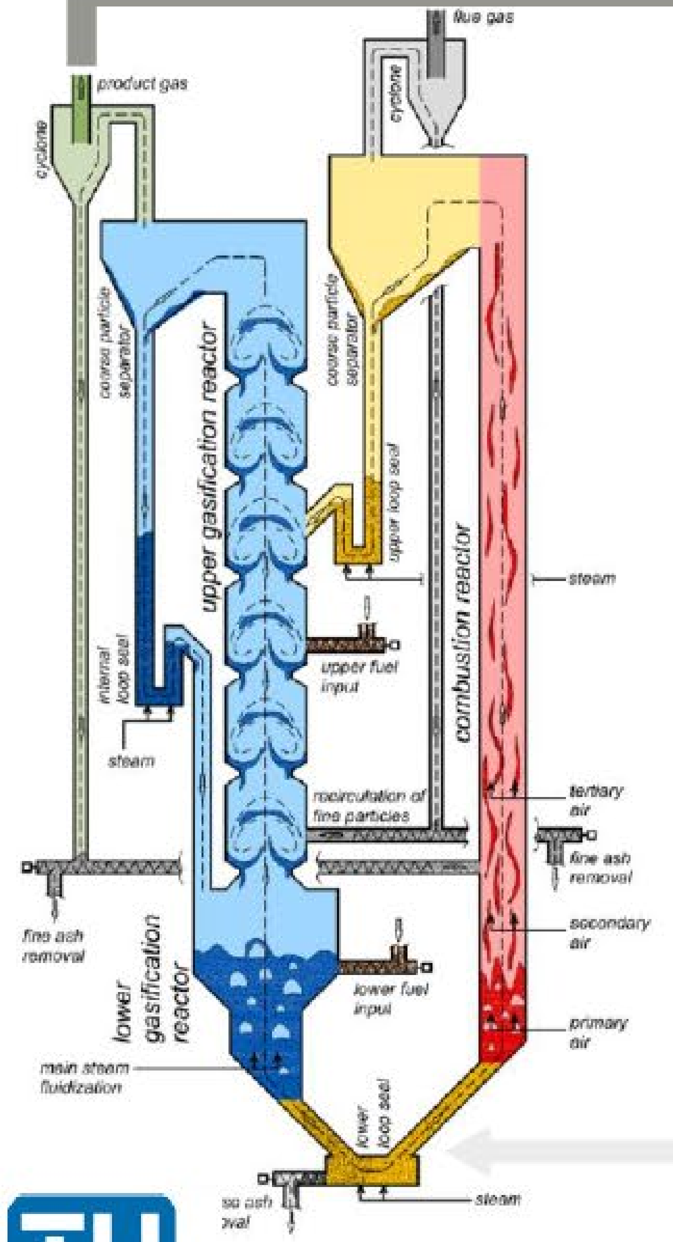
Low H_2/CO ratio, increased carbon conversion rate



Source: BEST Research

Using waste to make sustainable refinery products

CO/H_2 → Gaseous or liquid energy carriers



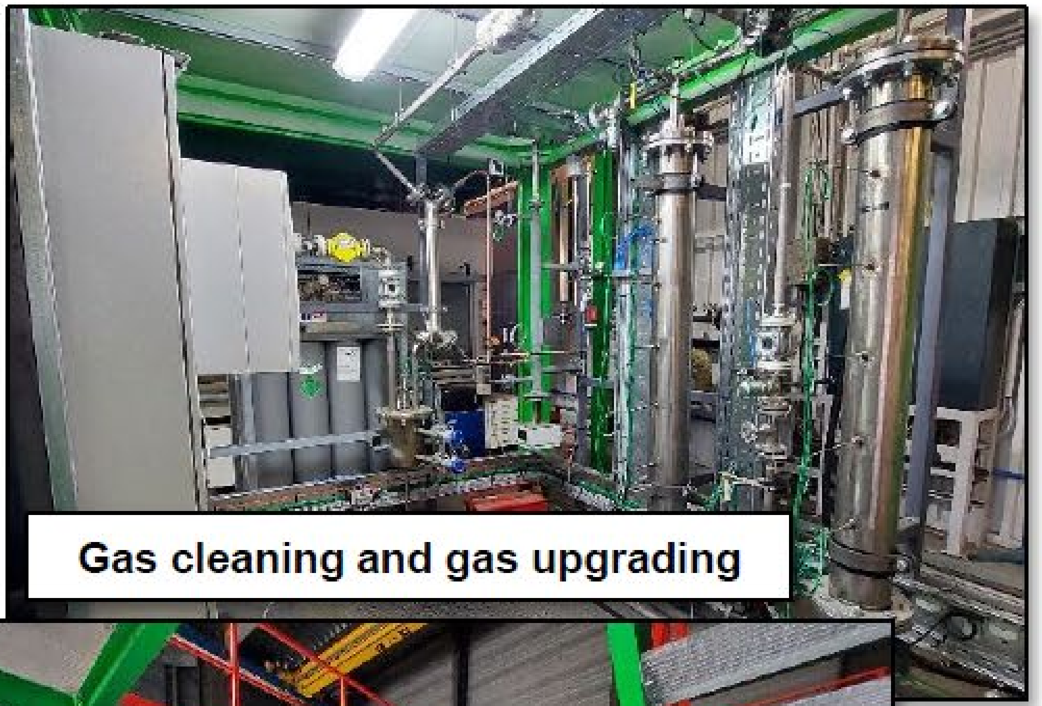
CO_2 removal

CO_2 recycling for fluidization

H_2 from electrolysis (wind / PV)

H_2/CO ratio = 2:1

SNG, diesel, aviation fuel
(via downstream synthesis)



Gas cleaning and gas upgrading

e.g. Fischer-Tropsch synthesis

Source: BEST Research

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Options at lower TRL - biorefineries with chemical treatment

- Ammonia gas reacted with clean water, supplemented with sequestered CO_2, used to produce Chlorella (non-axenic culturing with LED day and night).
  - Algal biomass harvested as a thick slurry subsequently boiled to a syrup
  - Its accreditation is not yet achieved but likely in view of the analogy with other plant-based syrups
  - The central point = clean liquid / transfer of gaseous NH_3/ harvesting a nice looking 'large' cell and transforming the latter by heat to a syrup in a way analogous to other agro-based syrups .
- PHA (Phytohaemagglutinin) for bio-plastics, bio-composites, fibre-based materials
- Carboxylic Acid Platform (CAP) and aerobic fermentation to yield volatile fatty acids / microbial proteins from agricultural biowaste (e.g. caproic acid)
- Ammonia bound by formaline to hexamine / the latter used as chemical feedstock

  Problem is that formaline handling has become complicated regarding regulation
- Bio-based surfactants from lignin or dairy residues (University of Graz)
- Microbial protein as a food additive

Conclusions

- The fertiliser market offers opportunities in niches – organic farming, greenhouse cultures - but the main market is a non-elastic, low-price market. Also, there is no demand for new fertilisers – farmers find the products they wish to buy.
- Bio-based products are frequently more expensive than fossil-based products and cannot compete.
- Opportunities can be identified by holistic approaches, including all materials and all use options.
- Not every nutrient rich material should be recovered as fertilising product, other products may offer better returns. Fertilisers can be by-products.
- The good news is that markets with demand exist, where industries need to cut CO_2 emissions and where recovered products replace fossil products with high climate footprint.
- The energy potential of biogenic waste materials must not be neglected, the price gap of bio- and syngas is narrowing.

Kalderis, 2019, Hydrochar & biochar

Metso DRI smelting pilot plant

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