



# SMART-Plant

Scale-up of low-carbon footprint  
material recovery techniques in existing  
sewage treatment plants

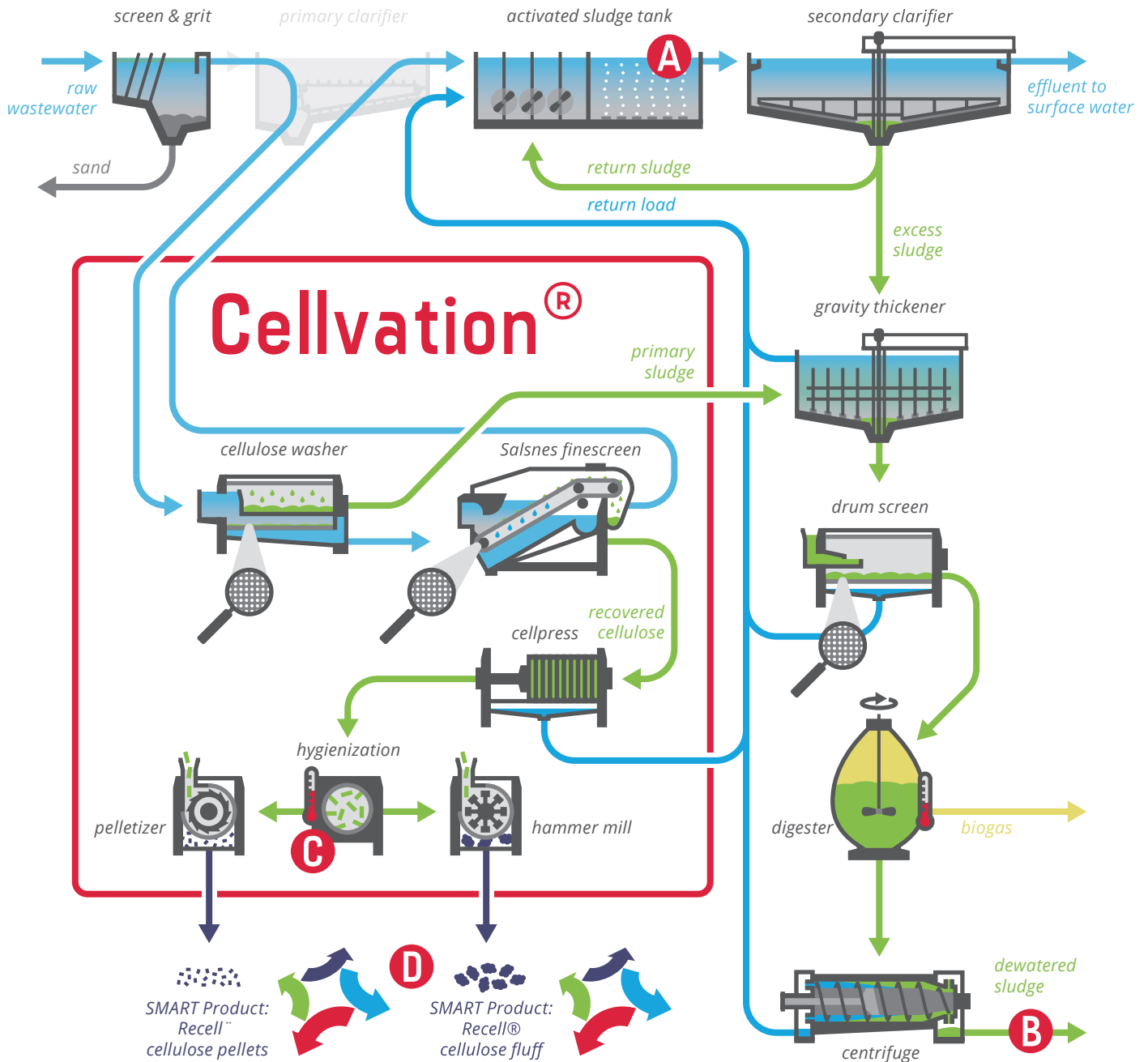


## Cellvation® *Cellulose Recovery with Dynamic Sieving as Primary Treatment*

Municipal sewage water contains a high amount of suspended solids, and up to 70% of this material consists of cellulose fibers originating from the use of toilet paper. This cellulose is a valuable resource, but is also puts an additional burden on the wastewater treatment process. CirTec has developed a dedicated process called Cellvation® to separate the cellulose from the incoming sewage water and turn it into clean cellulose fibers: the product Recell®. During primary treatment, a special Salsnes fine-sieve separates cellulosic screenings from sewage water in a separate stage, which is washed and further processed to gain clean cellulose fibers. This product can be reused in construction materials or for down-stream blending with bioplastic such as PHA to form a robust bio-composite material.

Within the SMART-Plant project, a Cellvation® system with a capacity of up to 90 m<sup>3</sup>/h was installed at the sewage treatment plant Geestmerambacht (Netherlands). It demonstrates the technical feasibility of cellulose recovery and illustrates the potential of this new technology to contribute to a circular economy in the water sector.





## Unique Selling Points

- A** Reduction of energy consumption for aeration by up to 20 % and increase of treatment capacity at the plant due to reduction of organic load in the activated sludge process
- B** Reduction of sludge volume which leads to lower polymer use for dewatering and lower sludge disposal costs
- C** Reaching EPA class A rating for the cellulose product
- D** Recovery of a high quality product: clean cellulose fluff or pellets for reuse in road construction (e.g. as additive in asphalt) or as a raw material for bio-composites and other buildings materials



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## AAT

### *Biogas Recovery in Primary Treatment with Polyfoam Biofilter*

AgRobics has developed a patented anaerobic biofilter (AAT) that transforms wastewater into renewable energy. The system combines high COD and TSS removal as well as biogas production and is installed upstream of the aerobic treatment step. It decreases the organic load of the sewage by 30%, which results in a reduction of the energy consumption of the biological stage by 30% and an increase of the biogas production by 25%. An integrated polymeric based immobilization matrix acts as a surface for the attachment of a biofilm, which prevents biomass losses and allows high biomass concentrations.

Within the SMART-Plant project, a demo system with a reactor volume of 25 m<sup>3</sup> with the aim to treat 100-120 m<sup>3</sup>/d of sewage was installed at the municipal wastewater

treatment plant of Karmiel (Israel). This plant has special challenges due to organic-load peaks (e.g. fat and olive mill residuals) from a slaughterhouse and olive mill wastewater and can serve as a representative model of many treatment plants in warm regions.









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## SCEPPHAR

*mainstream*

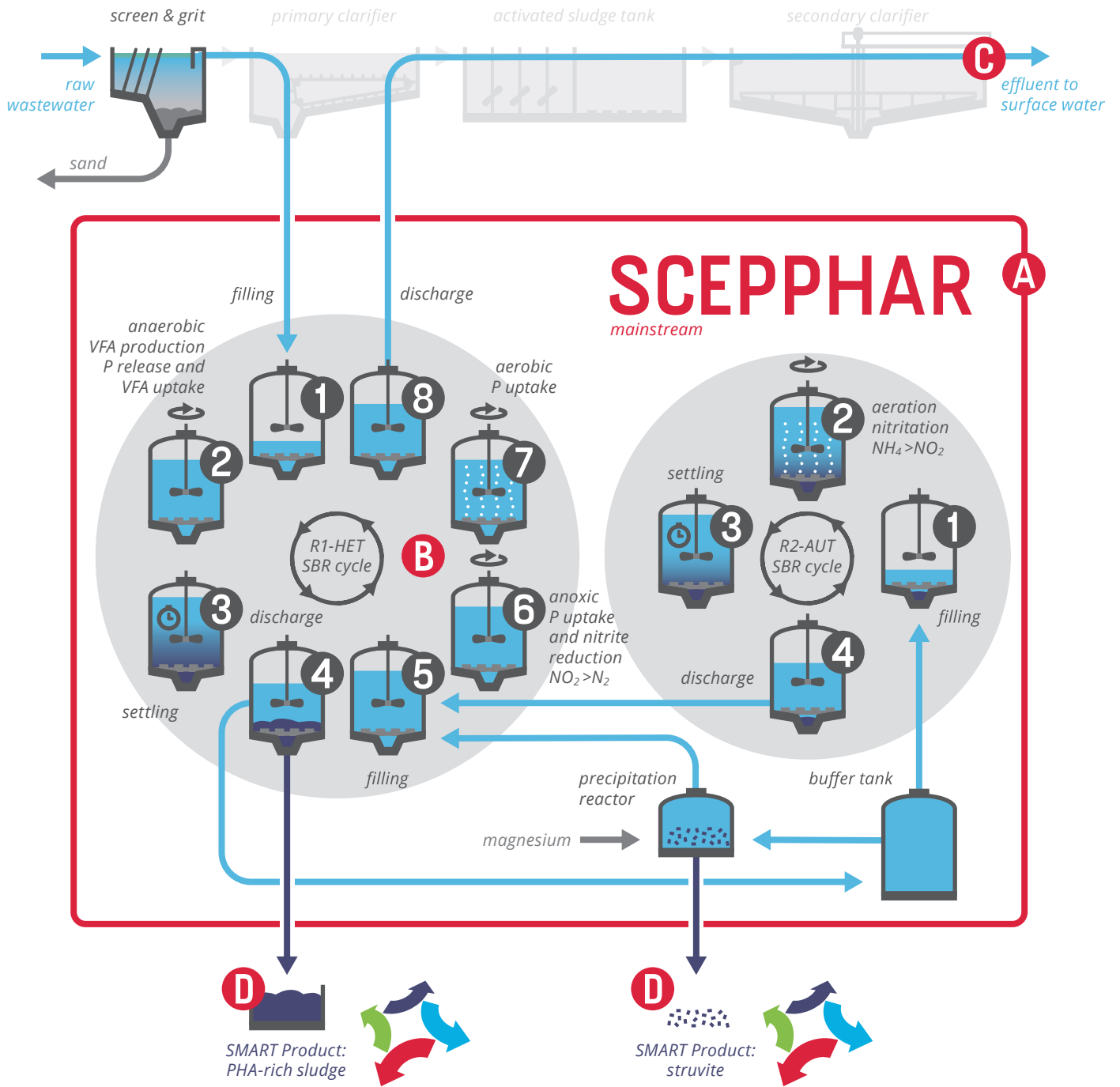
Treating wastewater while simultaneously recovering products in a mainstream process: these ambitious goals have been realised by the SCEPPHAR process developed by the Universitat Autònoma de Barcelona together with Aigües de Manresa S.A.. This two-sludge SBR system recovers up to 50 % of phosphorus and produces a sludge enriched with PHA, which can be processed to bioplastics or used to increase methane production during anaerobic digestion. While meeting comparable effluent targets, operational costs of the SCEPPHAR process are lower than traditional activated sludge systems.

Within the SMART-Plant project, the SCEPPHAR process is demonstrated in a mainstream configuration with a capacity of 10 m<sup>3</sup>/d at the Manresa wastewater treatment plant (Spain).

## Short-Cut Enhanced Phosphorus and PHA Recovery in Mainstream

The system is built to achieve effluent limits of P < 1 mg/L and N < 10 mg/L, removal up to 90 % of N via nitrite, recovery of around 50 % of the influent P and production of a waste sludge with a PHA content up to 30 %.





### Unique Selling Points

- A** Reduced energy demand and operational costs
- B** No external carbon source or metal salt needed
- C** High effluent quality (P < 1 mg/L, N < 10 mg/L)
- D** Recover 50 % of phosphorus as struvite and sludge with 30 % PHA content

	Manresa WWTP	SCEPPHAR
P Removal	FeCl <sub>3</sub> addition	Biological
N Removal	Nitrification + Denitrification	Nitritation + Denitritation
Products	None	Struvite + PHA-rich Sludge



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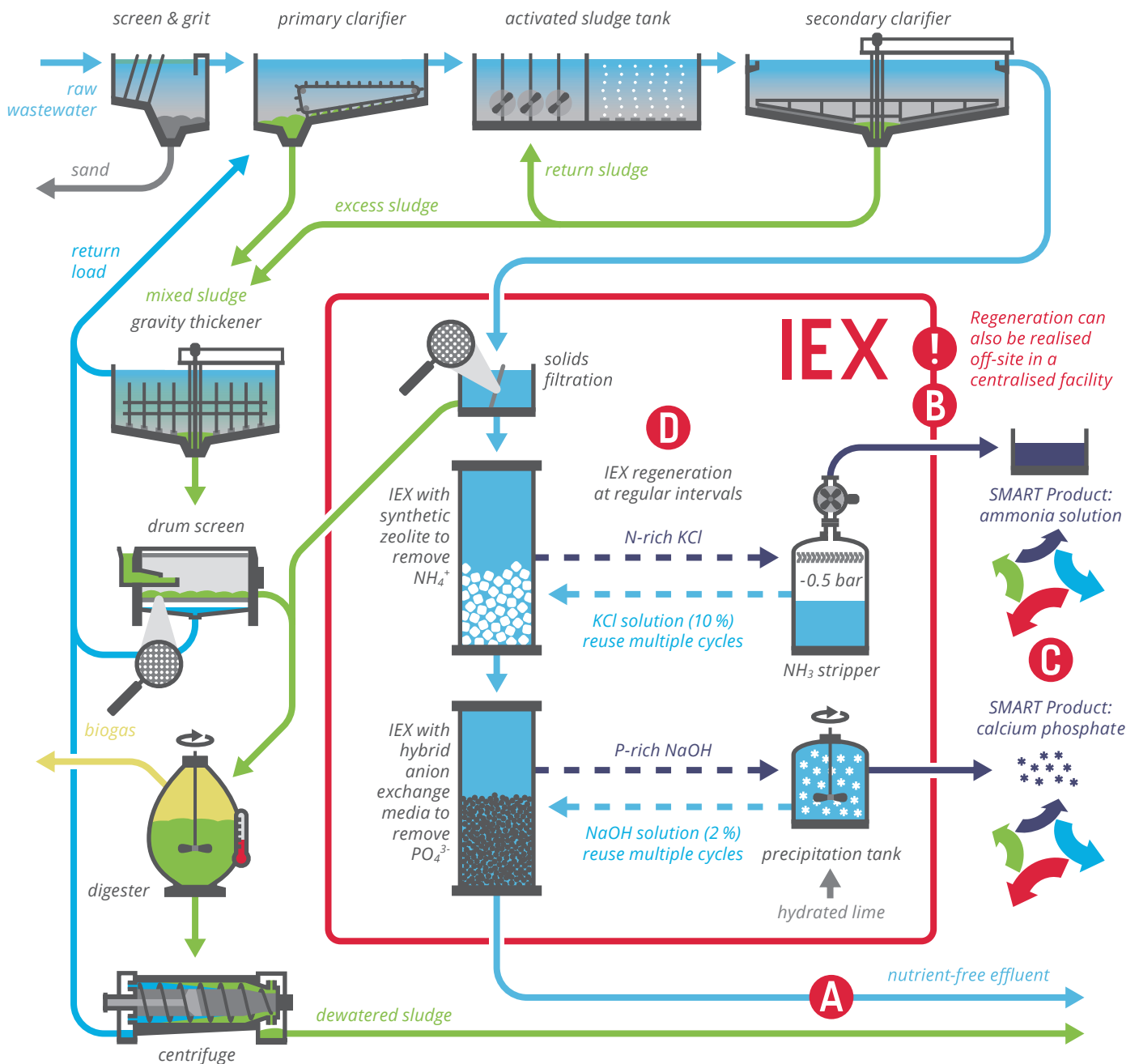
## IEX

### *Ion Exchange for Ammonia and Phosphorus Removal and Recovery from Wastewater*

Cranfield University has developed a tertiary nutrient removal and recovery technology based on ion exchange (IEX) processes. After secondary treatment, ammonia and phosphate are selectively removed from the wastewater with specific IEX media. The capacity of the IEX media is regularly restored by regeneration solutions, where the nutrients accumulate. With an ammonia stripper or a combined precipitation and filtration process, the nutrients are removed as products from the regenerants. Multiple use of the regenerants and high recovery rates are key aspects of the technology to ensure economic feasibility and sustainability. The recovered products are ammonia solution and calcium phosphate salts, which can be directly re-used in the chemical and fertilizer industries.

Within the SMART-Plant project, the IEX technology is demonstrated at Cranfield's wastewater treatment plant (UK) at a flow of 10 m<sup>3</sup>/day. The challenge of this pilot-plant is to demonstrate its long-term operation with optimized regeneration, high nutrient removal and minimized losses of the IEX media.





### Unique Selling Points

- A** Achieves tight nutrient discharge limits by removing  $\text{NH}_4^+$  and  $\text{PO}_4^{3-}$  to very low concentrations ( $< 5 \text{ mg N/L}$  and  $< 0.5 \text{ mg P/L}$ )
- B** High recovery rates: up to 97 % of ammonia and 95 % of phosphorus
- C** High quality products which can be used in the chemical and fertilizer industry
- D** Multiple use and recovery of regenerants leading to an economic feasibility of the IEX technology in the wastewater industry





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## SCENA

*Short-Cut Enhanced Nutrients Abatement*

### *Energy-efficient Nutrient Removal from Sludge Liquor without External Carbon Source*

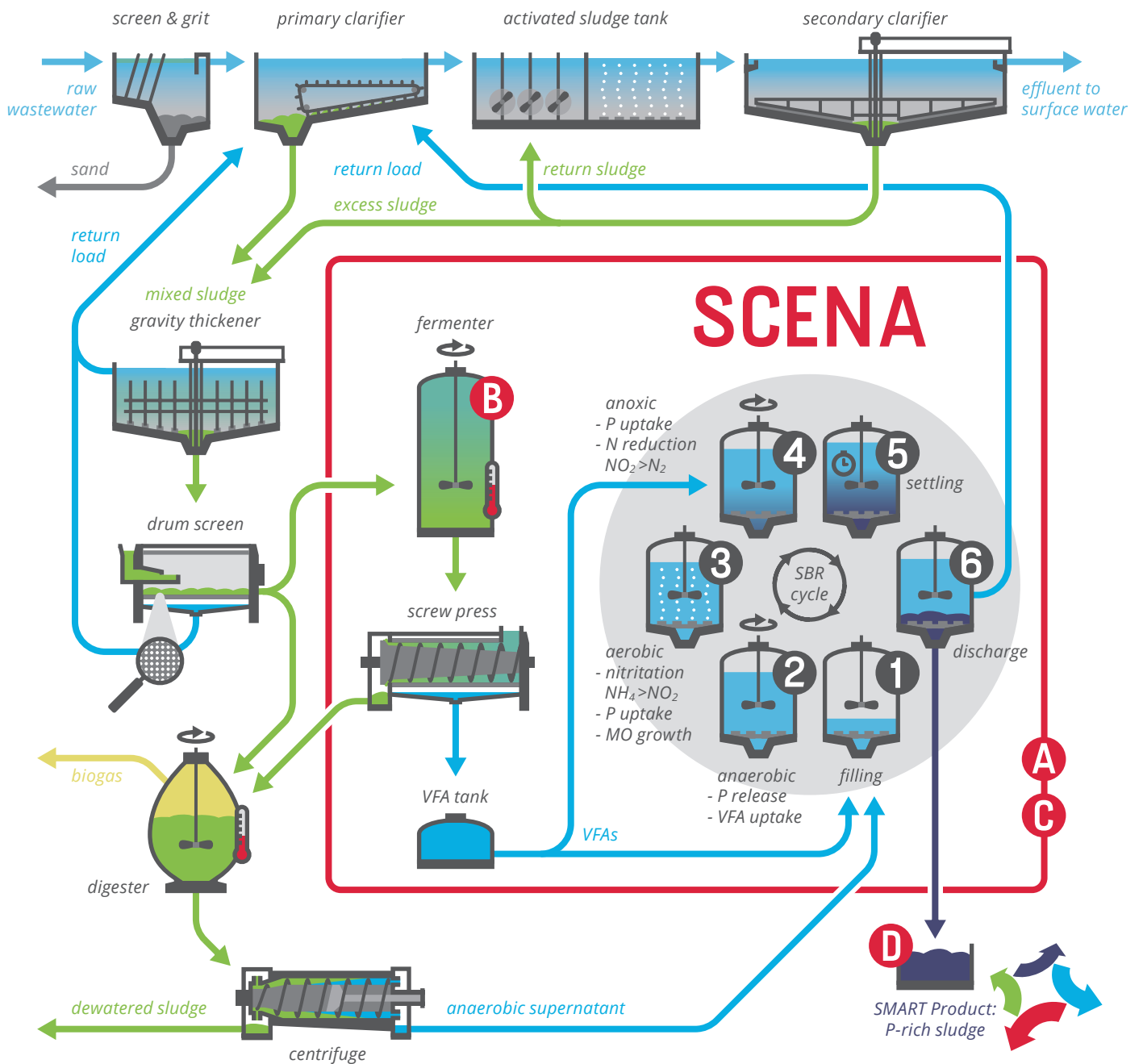
Sludge dewatering effluent after anaerobic digestion represents a highly concentrated stream of nitrogen and phosphorus, which may contribute up to 25% of the total load of the mainline WWTP. The SCENA process developed by the University of Verona aims to eliminate nitrogen and phosphorus from sidestream liquors by means of a short-cut biological process via nitrite and volatile fatty acids (VFAs) produced from acidogenic fermentation of sewage sludge. The process avoids the use of an external carbon source, which decreases the operational costs and the excess sludge production.

Within the SMART-Plant project, the SCENA process is demonstrated at full-scale within the wastewater treatment plant of Carbonera (Italy). The system treats

40-50 m<sup>3</sup>/d of anaerobic reject water under reliable and stable conditions and removes more than 75% of nitrogen and phosphorus. The produced excess sludge with a P content of up to 5% can be a valuable product for use as agricultural fertilizer.







## Unique Selling Points

- A** Low-energy nutrient removal from sludge liquor
- B** Biological N and P elimination without chemicals or external carbon source
- C** Stable and robust operation compared to other biological processes
- D** P-rich sludge can be valorized as organic fertilizer

	Nitrification Denitrification	Deammoni- fication	SCENA
External C Source	Yes	No	Bio-based VFAs from sewage sludge
Type of inoculum	conventional activated sludge	Deammoni- fication inoculum	conventional activated sludge
Cost and Energy	High	Medium	Low



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## SCENA-THP *Energy-efficient Nitrogen Removal from Sludge Liquor after Thermal Hydrolysis*

Sludge liquor from dewatering of digested sludge is heavily loaded with nitrogen and phosphorus, especially when the sludge is pre-treated by thermal pressure hydrolysis (THP) before digestion. Hence, wastewater treatment plants (WWTPs) using THP exhibit a high fraction of N and P return load, putting an additional load on the mainline and limiting the overall treatment capacity of the plant. Moreover, sludge liquor after THP contains a low fraction of biodegradable organic carbon, so that conventional biological processes for nutrient removal in sludge liquor have to be operated with costly addition of an external carbon source.

The SCENA process can remove nitrogen and phosphorus from sludge liquors with low energy demand and using an internal carbon

source such as supernatant from primary sludge thickening or VFA from fermentation of sludge. In the SMART-Plant project, this process is demonstrated at pilot scale (2 m<sup>3</sup>/d) at the Psytalia WWTP in Athens (Greece), which operates a THP for the treatment of 50% of the excess sludge.







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## SCEPPHAR

*sidestream*

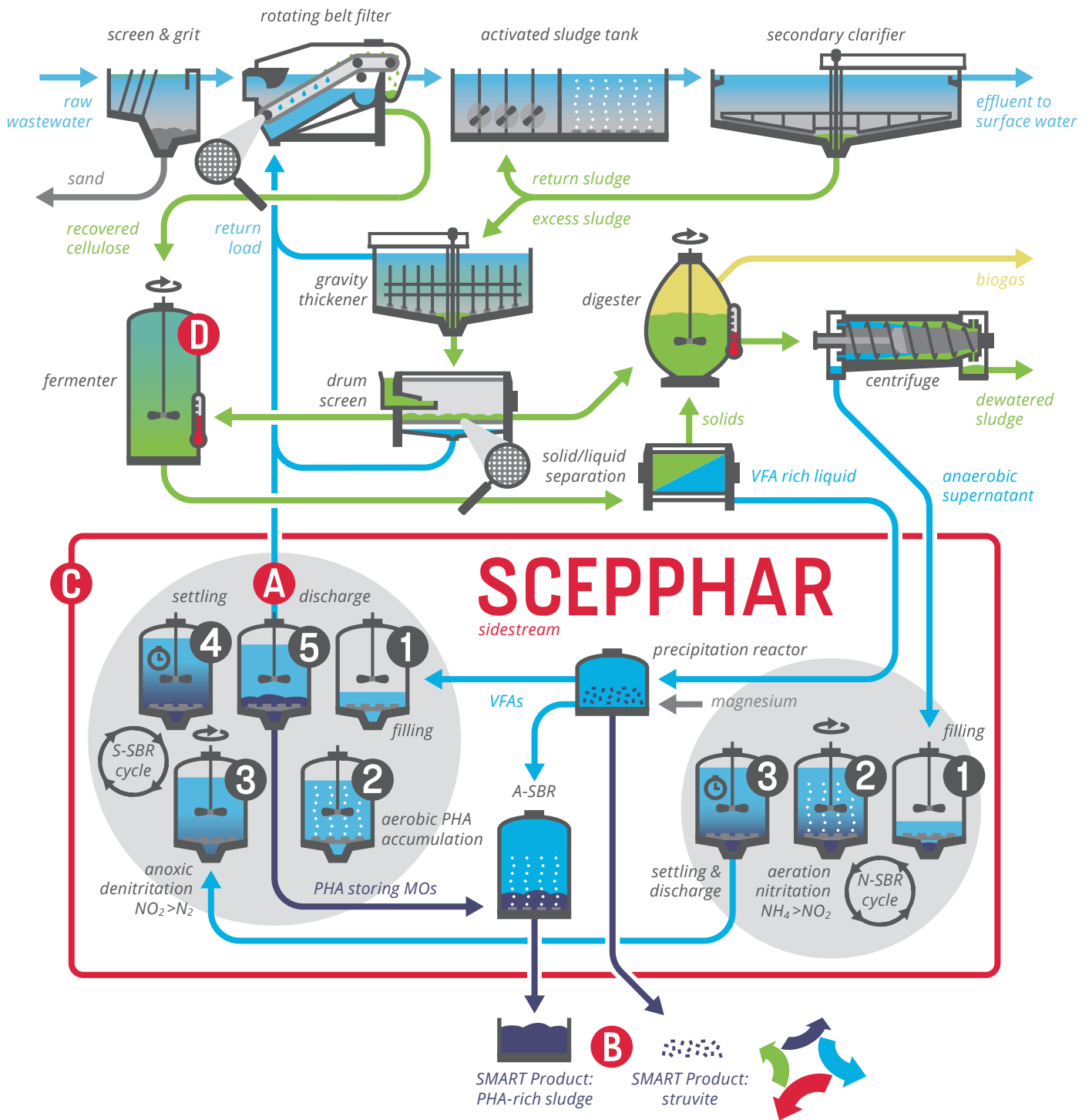
*Removal and recovery of nutrients and  
biopolymer production in sidestream*

The sidestream SCEPPHAR (short-cut enhanced phosphorus and PHA recovery) process was developed by the University of Verona to treat sludge liquor, which is highly loaded with nutrients nitrogen (N) and phosphorus (P). The process achieves up to 85% N removal, enables the recovery of phosphorus as struvite and produces a sludge enriched with biopolymer (PHA). In addition, it decreases the energy costs for sidestream treatment by up to 20%.

The system is tested in pilot scale at the wastewater treatment plant of Carbonera (Italy), treating 4-5 m<sup>3</sup> of sludge liquor per day. The carbon source for optimised biopolymer production is produced on-site by fermentation of cellulosic sludge, which is recovered from raw wastewater

using a rotating dynamic filter. The recovered struvite can be used as P-based fertilizer while the PHA content in the biomass achieves up to 50% on dry weight basis.





### Unique Selling Points

- A** High effluent quality due to effective N removal from sludge liquor
- B** Recovery of valuable products (PHA, struvite)
- C** Reduction of energy and operational costs
- D** Carbon source (VFA) for PHA production is gained in the process

	conventional treatment	SCEPPHAR
P Removal	Chemical	Chemical
N Removal	Nitrification + Denitrification with external C Source	Nitritation + Denitrification
Products	None	Struvite + PHA-rich Sludge





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## Bio-Composites

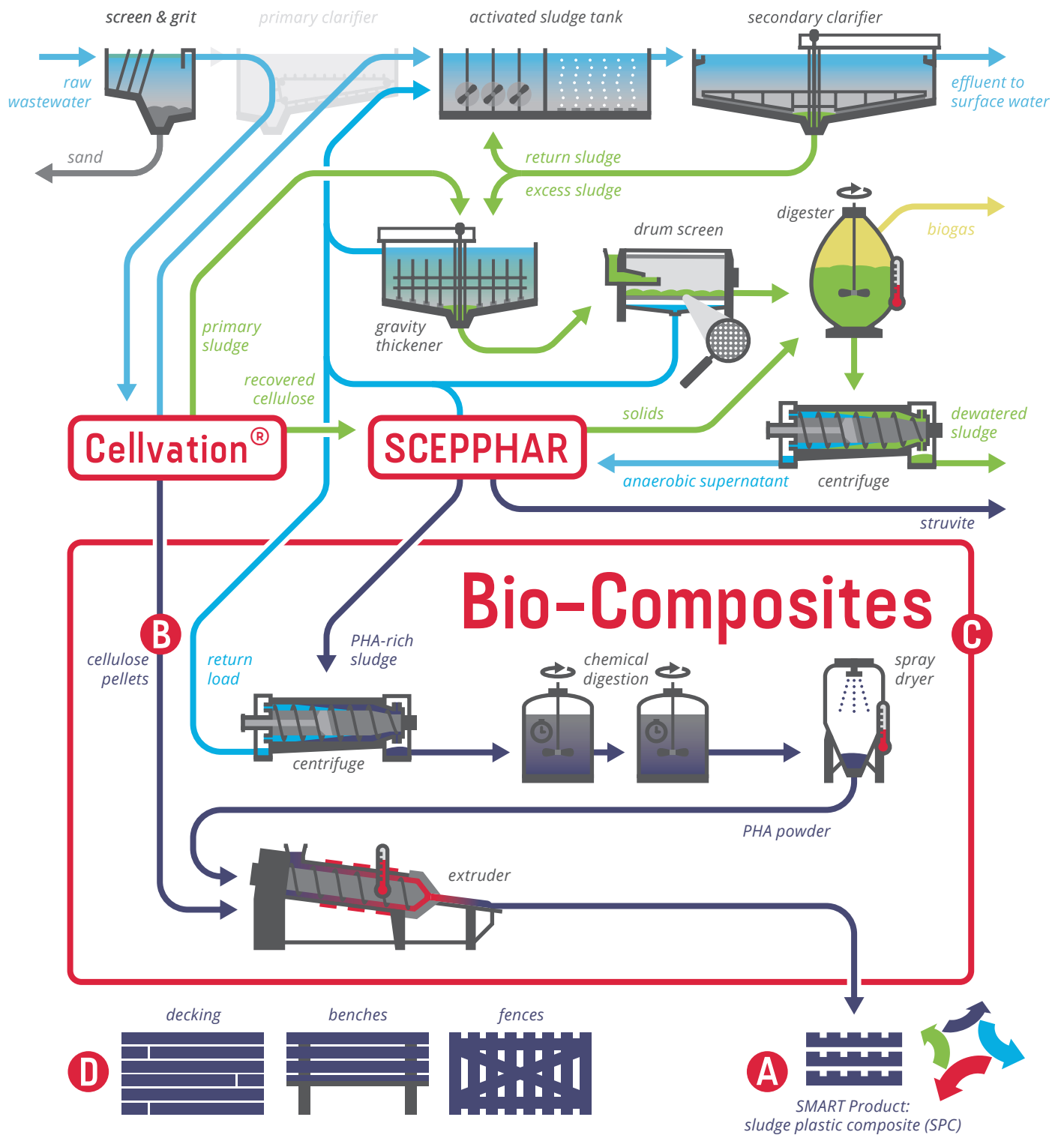
### *Composite Materials from Recovered Cellulose and PHA*

Composite materials based on a combination of biological materials and polymers are widely used in outdoor applications such as benches, fences and decking, amongst others. These bio-composite materials have excellent properties for long-lasting outdoor use and provide good mechanical strength and stability. Usually, they are produced by extrusion of a mixture of wood flour and polymer granulates. Recovered products from municipal wastewater such as cellulose or bioplastic (PHA) can also be used in the production of bio-composites, but these new materials require an adaptation of the existing production process.

Within the SMART-Plant project, different combinations of materials, additives and production conditions have been investigated

at lab-scale by Brunel University London to generate high quality bio-composite products using recycled material from the wastewater sector. The bio-composite producer SBPL (Ecodek®) has optimised the production of bio-composites based on recovered cellulose at industrial scale.





### Unique Selling Points

- A** Durable product made from recycled material
- B** Cellulose pellets can replace primary wood flour
- C** Better water resistance than conventional bio-composites
- D** Suitable for outdoor use in multiple environments



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## Biodrying and Dynamic Composting

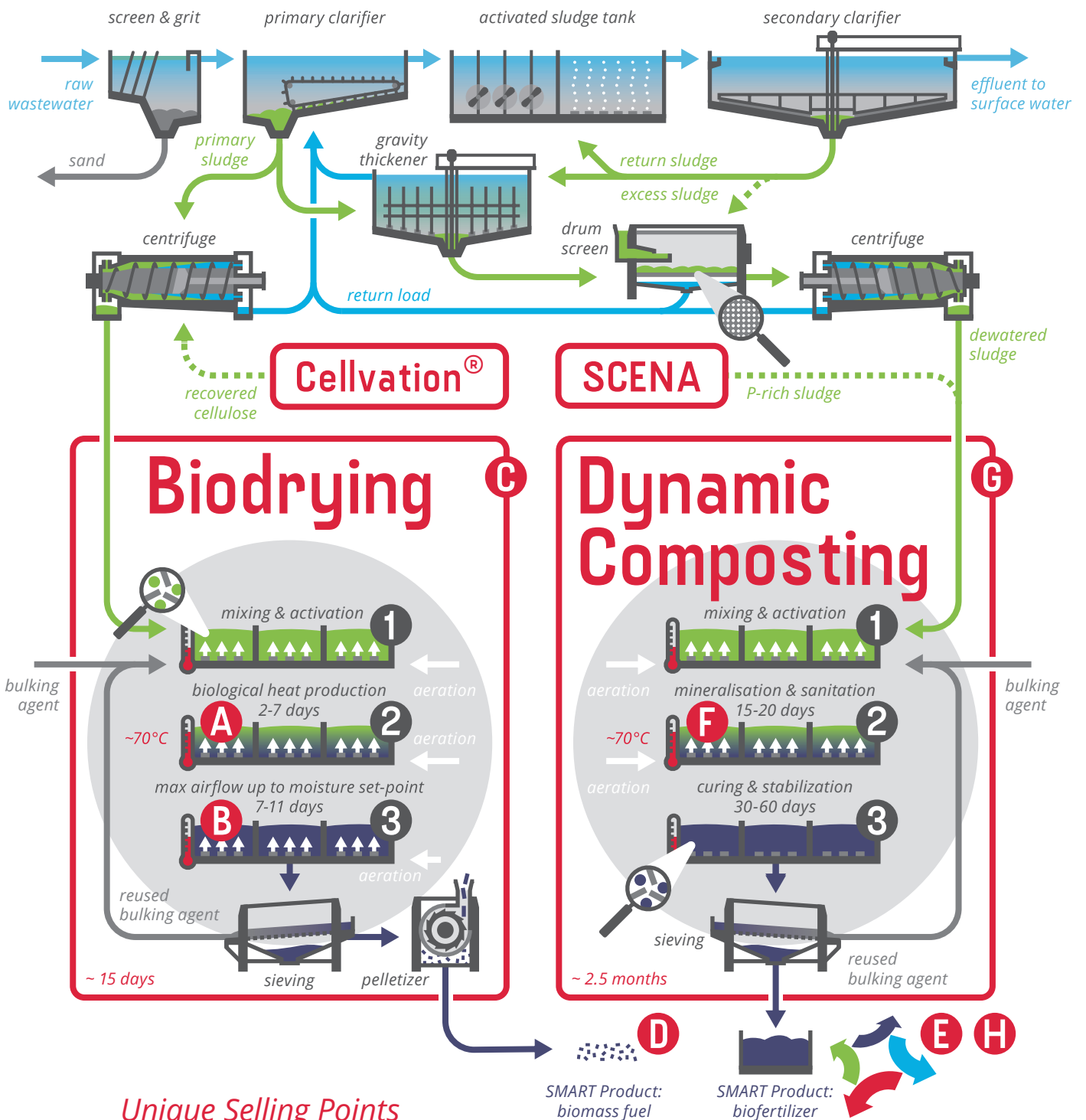
*Producing biomass fuel or  
biofertilizer from sewage sludge  
with low-energy  
biotechnology*

High prices for sludge disposal and goals of the circular economy demand for innovative processes to convert sludge into value-added materials or energy. For this purpose, BETA Tech. Center (TECNIO) from the University of Vic - Central University of Catalonia has developed advanced biodrying and composting processes to recover both energy and nutrients contained in sludge. These processes aim at producing biomass fuels with valuable calorific value and high quality biofertilizers, closing in turn material and energy cycles.

Within the SMART-Plant project, a modular pilot plant for biodrying and composting was operated at the wastewater treatment plant

of Manresa (ES). Using an energy-efficient aeration system, the biodrying plant converts cellulosic sludge into a biofuel with moisture content below 40 % and a lower calorific value between 9 and 12 MJ/kg of product. Dynamic composting of P-rich biological sludge yields a stabilised biofertilizer with high content of both phosphorus and nitrogen (> 5 % TS).





### Unique Selling Points

- A** Up to 65 % sludge moisture removal by mainly biological heat
- B** Advanced aeration control for a shorter bioprocess and optimization of land surface requirement
- C** Reduction of GHG emissions and energy consumption for moisture removal
- D** Increasing of LCV to as high as 12 MJ/kg
- E** Production of a biofertilizer with high stability + N and P content up to 5 % DM
- F** Advanced aeration control for an optimal organic carbon mineralization by maximizing the biological activity
- G** Reduction of GHG emissions and energy consumption for aeration
- H** Opportunity for tailor made fertilizers



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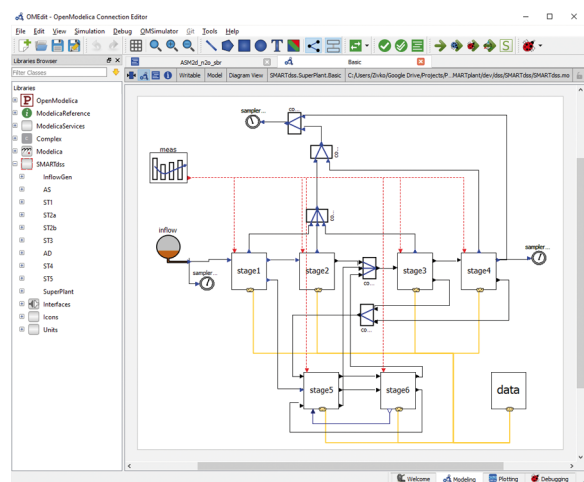


## SMART-DSS

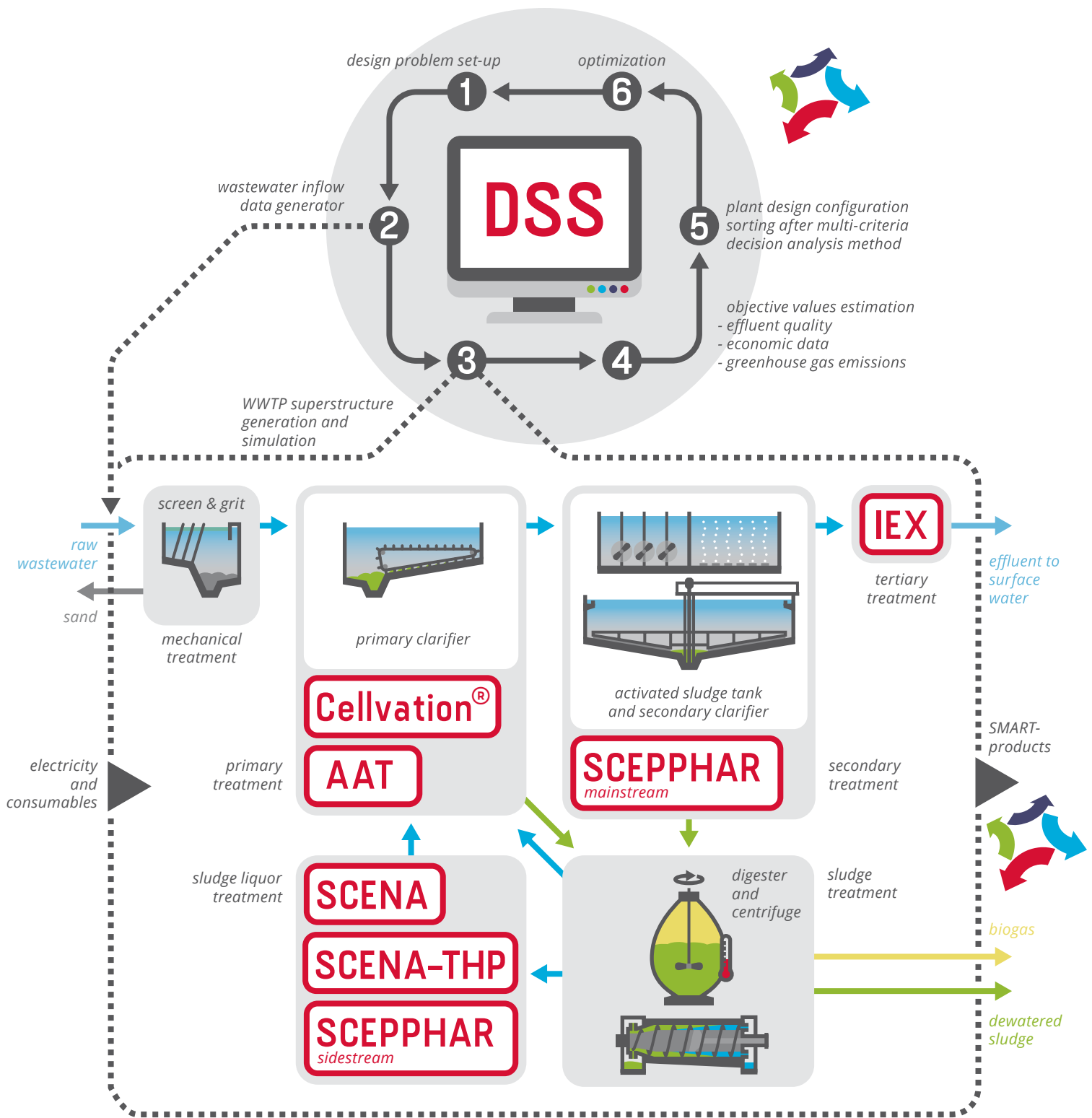
Technology selection and benchmarking for plant retrofitting have become more challenging than ever because of the large number of possible plant-designs for a given wastewater treatment problem. This challenge is faced in the SMART-Plant project by a decision support system (DSS) to find the optimal configuration of a WWTP considering SMART-Plant resource recovery processes. To get the DSS started input data like WWTP location, population equivalents, legal limits and wastewater characteristics, needs to be defined by the user. Missing input information can be also scraped from web-databases by a Python script. The tool operates with a multiple parameter analysis, such as net present value, effluent quality index, frequency of effluent violation and greenhouse gas emissions, are

### *Decision Support System for Upgrading Existing Plants*

considered. All the possible configurations of a plant are built by automatic model replacement, simulated for a given inflow condition and sorted with a multi-criteria analysis to support decision making. During the optimization step, design parameters are refined by minimizing the NPV and constraining all other above mentioned parameters.







### Unique Selling Points

- A** Ad-hoc consulting for new or upgrading existing WWTPs
- B** Stand-alone model simulation on Windows and Linux
- C** Simulation can be performed under static and dynamic inflow conditions
- D** Enables WWTP design within discrete and continuous control process systems



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## SMART Materials

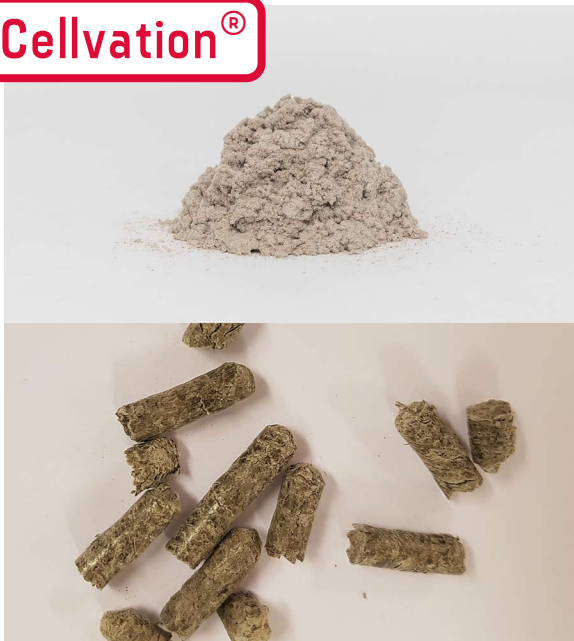
*Cellulose, Bioplastic  
and Biocomposites*

Innovative processes of SMART-Plant enable the recovery of valuable materials from municipal wastewater. Extracted raw materials can be used as intermediates for processing into commercial end products or as feedstock for different industrial applications. A primary intermediate is recovered cellulose, which can be extracted from municipal wastewater by fine-sieving (Cellvation® process) and drying into fluff fibres or compressed pellets (Recell®). Cellulose fluff can be applied in the chemical or construction industry. Cellulose pellets serve as structural material in the production of bio-composites, which are extensively used as sustainable building material for garden furniture, decks, facade covering or yard fencing. A second recovered material is bioplastic in the form of poly-

hydroxy-alkanoates (PHA), which is produced by selected bacteria growing on the organic content of wastewater. This PHA-rich sludge can either be dried and used directly as bioplastic input for low-grade applications, or PHA can be chemically extracted from the sludge, yielding a pure PHA powder with higher market value. PHA can also be used for the production of bio-composites, replacing fossil-based polymers in the value chain.



## Cellvation®



### Cellulose Fluff

- Light-weight structural material
- Hygienically safe (EPA class A)
- Odour-neutral
- Use as insulation material or asphalt binder
- Organic residue < 10 %

### Cellulose Pellets

- Dry pellets easy to handle
- Structural material for bio-composites
- Cellulose content: 60-80 %
- Reaching EPA class A rating

## SCEPPHAR



### PHA-rich Sludge

- PHA-rich organic material
- PHA content < 40 % of dry matter
- Recovery of 1 kg of PHA per pe and year
- Suitable as bio-based ingredient for bio-composites

### PHA Powder

- Dry PHA powder
- PHA content > 95 %
- Pure product with high market value
- Suitable for bio-composite production

## Bio-Composites



### Bio-Composites

- Bio-composite for outdoor use
- Suitable for benches, fences and decking
- High water resistance and stability
- Low potential for slip
- Made from recycled materials such as r-HDPE



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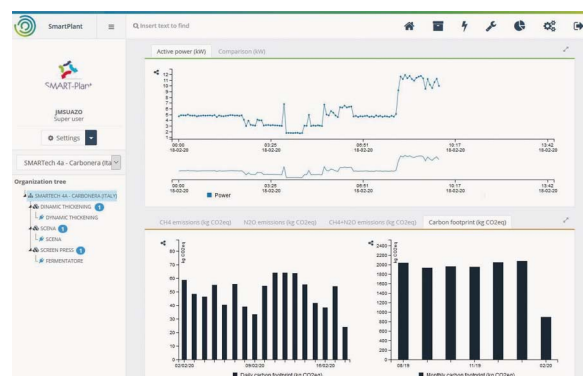
## Monitoring

SMART-Technologies for resource recovery aim to move towards low-carbon and energy-efficient wastewater treatment. Real-time monitoring of energy demand and greenhouse gas emissions during process operation is crucial to inform operators on the actual performance of SMARTechs, optimise their operation, and detect process disturbance. Based on data from energy meters and greenhouse gas sensors Wellness Smart Cities has developed a web application platform to continuously record and display energy consumption and operational carbon footprint of the processes together with sustainability indicators and other metrics conventionally monitored in wastewater treatment.

In the SMART-Plant project, Wellness Smart Cities physically installed real time energy

## Online Energy and Greenhouse Gas Monitoring and Control

consumption and greenhouse gas meters at all demonstration sites. All measured variables are directly shown in an online tool to give the plant operator optimal insight and control. On top, Brunel University developed structured approaches to analyse heterogenous data from online sensors and laboratory analyses such as data mining techniques for pattern recognition, dependencies identification, and outliers detection.

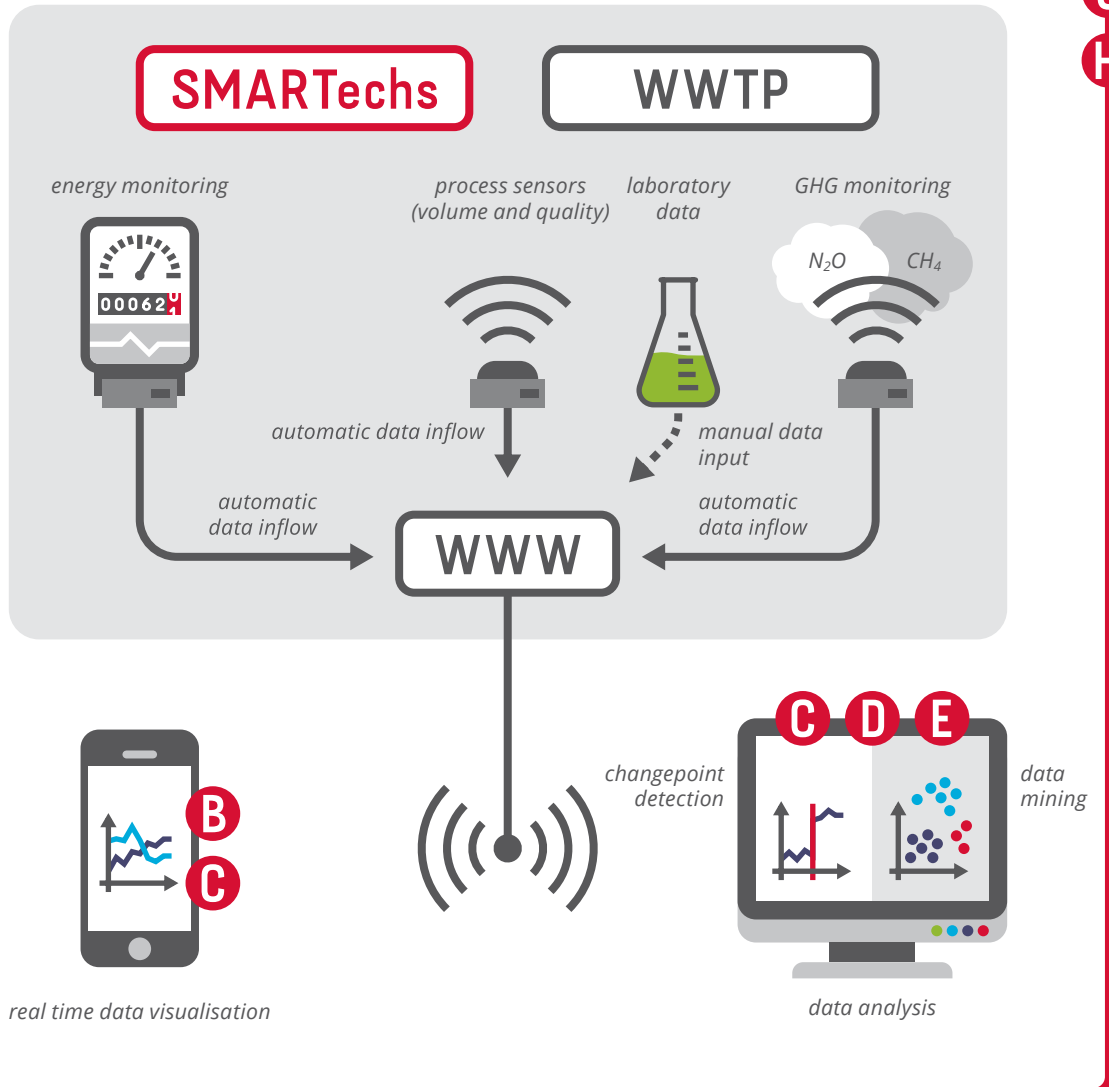




# Monitoring

Online Energy and  
Greenhouse Gas  
Monitoring and  
Control

A  
F  
G  
H



## Unique Selling Points

- A** Real-time monitoring of energy demand and greenhouse gas emissions
- B** Actionable insights 24 hours a day
- C** Detection of process irregularities
- D** Identification of operational modes to mitigate greenhouse gases
- E** Integration of monitored data to build prediction models
- F** Compatible with multiple technologies and manufacturers
- G** Easily integrated with other sensors
- H** Reduction of operational costs by process optimisation





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## SMART Nutrients

Elemental nutrients, including phosphorus and nitrogen, are essential to all living organisms and key resources to enable food production security and manufacturing in Europe. Economically strategic industries rely on nutrients to deliver products and services, including agriculture, pharmaceutical and chemical industries. Following a circular economy approach, SMART-Plant demonstrated the recovery of various nutrient products from municipal wastewater using innovative technologies.

Ion exchange processes (IEX) were tested to remove nutrients from municipal wastewater and recover them as calcium phosphate, aqueous ammonia and ammonium sulphate.

*Calcium Phosphate, Aqueous  
Ammonia and Ammonium Sulphate,  
Spent Zeolite Resin,  
Struvite and Biofertiliser*

Phosphate was also recovered in the form of struvite in the SCEPPHAR process, and this can be applied directly in agriculture for its good fertiliser properties. The new EU fertiliser regulation even allows the application of struvite in organic farming, which opens new market opportunities.

Biofertiliser is a phosphorus rich compost, which is produced from P-rich sludge using an advanced composting process. A highly stable product rich in P and N is obtained in less than 3 months, and it can be applied as a bio-based fertiliser.



[WWW.SMART-PLANT.EU](http://WWW.SMART-PLANT.EU)

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IEX



## Calcium Phosphate

- High purity product with 13 % P content
- Low impurities (Al < 0.4 mg/g, heavy metals < 0.1 mg/g)
- Used as a raw material for fertiliser, pesticide and chemical production

## Aqueous Ammonia and Ammonium Sulphate

- Aqueous ammonia (3 - 7 g N/ L) as raw material for plastic, textile and cleaning products
- Ammonium sulphate (21 % N) as raw material for fertiliser and in chemical production
- Low impurities (heavy metals < 5 µg/L)

## Spent Zeolite Resin

- IEX media rich in potassium and ammonia that can be used as a conditioner in composting
- Direct use as slow release fertiliser in agriculture, forestry, energy crops and gardening

SCEPPHAR



## Struvite

- Use as a feedstock in fertiliser industry
- Direct use in agriculture, forestry, energy crops and gardening
- Slow-release fertiliser
- High purity and safe for the environment

Dynamic Composting



## Biofertiliser

- Direct and safe use in agriculture
- Bio-based fertiliser: nutrient rich stabilised organic amendment
- Demonstrated high agronomic quality equivalent to mineral fertiliser



[www.cranfield.ac.uk/smartplant](http://www.cranfield.ac.uk/smartplant)  
[www.innovent.it](http://www.innovent.it)  
[www.betatechcenter.com](http://www.betatechcenter.com)  
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