De Smet Engineers & Contractors and BENEO cooperate on a massive energy-saving investment plan in chicory root processing facilities

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De Smet Engineers & Contractors (DSEC) is a private limited liability company established in Belgium in 1989. It has built up an international reputation as an industrial contractor specialising in the agro-industrial sector. With many years of experience, DSEC offers a compelling business proposition that combines excellence in delivery, safety, cost control and reliability, with a focus on energy saving and sustainability initiatives. Today, the company serves five different industries worldwide, all of which belong to the natural resource processing chain. These are sugar and ethanol, vegetable oils and derivatives, bio-based products, alternative proteins and the agro-nutrient industry. In addition to its processes, DSEC's transversal activity "Decarbonisation, energy efficiency and renewable energies" is very much involved in reducing the carbon footprint of its clients' facilities.

BENEO is one of the world's leading manufacturers of functional ingredients. Part of the Südzucker Group, its organisation was formed in 2007 by the companies Orafti, Palatinit and Remy and is currently represented in more than 80 countries worldwide, with more than 1,000 employees in seven sales offices and five production sites in Belgium, Germany, Italy and Chile, ensuring that their excellent food ingredients and services can always be counted on.

De Smet Engineers & Contractors have proposed massive energy savings projects in BENEO’s factories in Belgium and in Chile. In order to achieve significant energy savings, we have to integrate the energy fluxes amongst all process units, which unavoidably increases the complexity of the production line a bit. The success of such a project requires a paradigm shift or inner awareness of the production teams from a world where energy is available at any moment and is the slave of the process to a world where energy is limited and may affect production. This cannot happen without embarking all the players – from top management to the operators - on this roadmap to a sustainable future.

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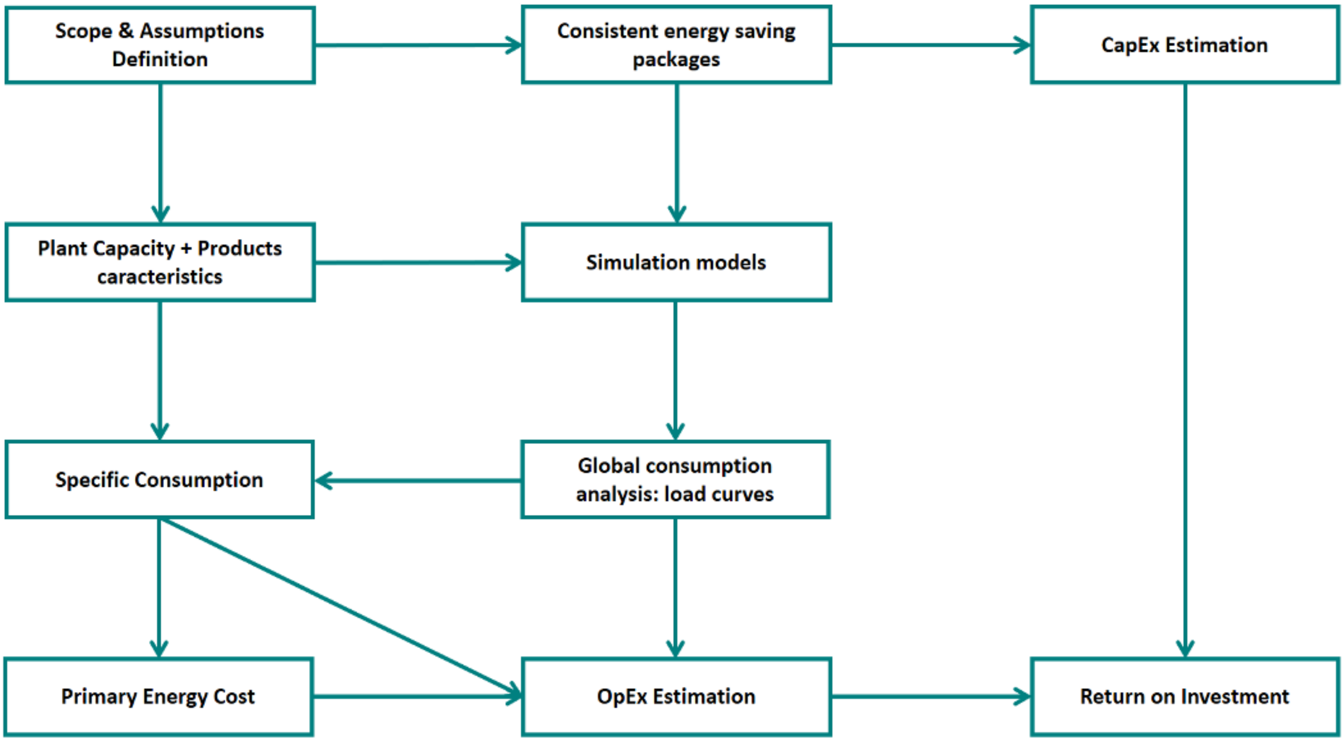
In 2018, as part of a capacity expansion at the San Pedro inulin factory of BENEO Chile, DSEC conducted an energy efficiency audit. The willingness of BENEO's management to quickly implement the energy transition of its factories has led to a 5-year investment plan. The aim of this investment plan is to shut down the fossil fuel boiler by 2023 and reduce the site's thermal energy consumption by 50%. Instead of fossil fuels, the factory would use local wood waste to produce energy from biomass. This approach is fully in line with Chilean legislation and international treaties such as the Paris Agreements.

In order to achieve significant energy savings, we have to integrate the energy fluxes amongst all of the factory's units, which increases the complexity of the production line. The success of such a project requires a paradigm shift of the production teams. While today energy is available at any time and consumption is dictated by production requirements, tomorrow it will be consumed in a more rational and optimised way. This cannot be done without involving all players on this journey towards a greener future.

A clear methodology has been established between the BENEO and DSEC teams.



1. DEFINITION OF THE SCOPE AND THE STUDY HYPOTHESES PROPOSING ENERGY SAVINGS BUNDLED IN COHERENT PACKAGES

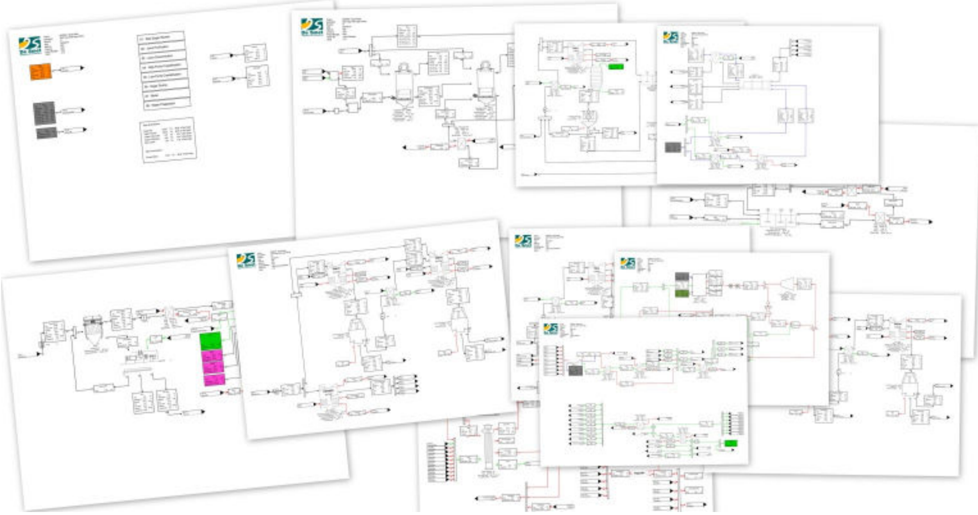
The first step is to define the scope of the project, including the study hypotheses, the design conditions and the different production scenarios: **nominal capacity of the factory, duration of the campaign and inter-campaign, quality of the chicory, quality and quantity of the finished products, unalterable imperatives and constraints of the process, cost of primary energy, cost of electricity, etc.** During the audit carried out as a preamble to this energy optimisation project, DSEC **modelled the current situation of the factory** using its tool, which enables the mass and thermal balance of the entire process to be consolidated in a single integrated calculation.

This model, unlike other simulation tools on the market, has been developed according to robust principles:

- **Fully integrated**: all process equipment is modelled, from cogeneration to the drying of the finished product, allowing the whole process to be optimised.
- **Comprehensible and easy to follow**: it takes the form of a clear process diagram showing all the physical information on the fluxes.
- **Based on physical equations and parameters** for each unit operation in the process and not on empirical ratios. This also makes it possible to optimise the design of the equipment.

Chicory processing factories such as BENEO in Chile are complex. Furthermore, integrating energy between the different workshops in the factory increases the number of calculation loops in the model. By way of example, the BENEO Chile factory model represents:

- 34 evaporators
- 54 heat exchangers
- 1661 fluxes that contain all the process data (flow rate, dry matter, temperature, pressure, enthalpy, viscosity, density, etc.)



2. PROPOSING ENERGY SAVINGS BUNDLED IN COHERENT PACKAGES

The second step is to develop coherent energy saving packages in the factory. By coherent, we mean that they are compatible with the operational constraints of production but also that they are consistent from a cost benefit perspective. To do this, we worked on the energy levels in the factory.

Before implementing the decarbonisation plan, the BENEO Chile factory operated with 6 energy levels:

1) **75 bar high pressure steam:** this is the highest energy level that corresponds to the stamp on the biomass boiler and is used to generate steam which will then produce a maximum of electricity through the steam turbine.

2) **40 bar medium pressure steam**: this level of energy corresponds to the stamp on the fossil fuel boiler which will be shut down as a result of the decarbonisation plan. It is used to generate steam which is necessary for the process and, in particular, to dry the finished product. By reducing steam consumption to 40 bar - 250°C to make more use of lower quality energy, we will be able to produce more electricity by expansion through the steam turbine.

3) **10 bar medium pressure steam**: like 40 bar steam, this level of energy is used to generate steam that is needed for the process, especially in high temperature sterilisation units. As with the 40 bar steam, by reducing the steam consumption to 10 bar - 180°C to make more use of lower quality energy, we will be able to produce more electrici-

Levels of energy BEFORE implementing the decarbonisation roadmap

485°C	High Pressure Steam 75 bar	Biomass Boiler Steam Turbine
250°C	Medium Pressure Steam 40 bar	
180°C	Low Pressure Steam 10 bar	
130°C	Exhaust Steam from Turbine 1,6 bar	
130°C 65°C	Process Steam	Multiple-effect evaporator line
27°C 22°C	Cooling Water	Cooling towers
6°C 0°C	Chilled Water	Air-cooled chillers

Thermal degradation of energy

Thermal degradation of energy

4) **1.6 bar exhaust steam and process steam (130°C - 65°C):** this energy level corresponds to the output pressure of the steam turbine and represents 90% of the thermal consumption of production. This low pressure steam allows for concentration of the inulin juice in multi-effect evaporation. The excess 65°C steam from this juice concentration is condensed by water from the cooling towers.

5) **Cooling tower water (25°C-20°C):** in many factories, this level of energy allows excess heat from the process to be removed by consuming electricity. To achieve energy efficiency, it is crucial to take action to recover more of the heat available at 65°C.

6) **Chilled water (0°C-6°C):** The process at BENEO Chile requires cooling certain products to around 10°C but also drying air to a dew point of 3°C. For these purposes, chilled water is produced by air-cooled chillers equipped with a screw compressor. Therefore, this level of energy consumes very valuable energy as it is generated by electricity. In addition, by using air as a heat source, the performance coefficient varies significantly with the seasons, thus affecting the power consumption.

After implementing the decarbonisation plan, the BENEO Chile factory will operate with 10 energy levels:

1) **75 bar high pressure steam:** our decarbonisation plan includes investments in the biomass boiler by significantly increasing the efficiency of co-generation. The main investment has made it possible to recover the energy contained in the boiler flue gas to preheat the combustion air.

2) **40 bar medium pressure steam:** we have reduced the consumption of 40 bar steam by further staging the heating coils and drastically increasing the exchange surface in order to achieve pinch points closer to the lowest quality steam. The finest steam then performs only the final stage of heating.

3) **10 bar medium pressure steam:** just like 40 bar steam, we have mainly shifted consumption to a new 4 bar energy level.

4) **4 bar low pressure steam:** This energy level was created to meet a specific thermal process requirement for high temperature product sterilisation. Previously, 10 bar - 180°C steam was required because the exchange surfaces were insufficient to guarantee a low pinch. Now, as a result of investment in efficient exchangers, we have focused on the consumption of steam at 145° C, which is generated by flashing condensate from higher pressure steam.

Levels of energy AFTER implementing the decarbonisation roadmap

485°C	High Pressure Steam 75 bar	Biomass Boiler Steam Turbine
250°C	Medium Pressure Steam 40 bar	
180°C	Low Pressure Steam 10 bar	
145°C	Low Pressure Steam 4 bar	
130°C	Exhaust Steam from Turbine 1,6 bar	
130°C 65°C	Process Steam	Multiple-effect evaporator line
60°C 30°C	Energy recovery loop	Heat exchangers & Pumps
33°C 27°C	"Hot" Cooling water	Cooling towers
26°C 20°C	"Cold" Cooling water	
12°C 6°C	"Hot" Chilled Water	Water-cooled chillers
6°C 0°C	"Cold" Chilled water	Air-cooled chillers

Thermal degradation of energy

Thermal degradation of energy

5) **1.6 bar exhaust steam and process steam (130°C - 65°C):** There are three courses of action to reduce steam consumption at this energy level.

The first is to add one or more evaporation effects. In this project, BENEO will have invested both in a new evaporation effect and in a significant increase in the surface area of existing effects.

The second is to reduce the thermal requirements of consumers. Numerous exchangers have been added throughout the factory to improve energy recovery.

The third method is to shift steam extraction by prioritising the consumption of steam generated by evaporation at a lower pressure. For example, a major energy consumer in the factory was supplied with steam from the 3rd effect rather than exhaust steam from the steam turbine.

Furthermore, the optimisation of steam consumers should result in a minimum of excess steam to be condensed. This energy is lost in the cooling towers whose fans and pumps consume electricity, not to mention the water consumed by evaporation, drift and deconcentration, etc. When evaporation is efficient, the main effects are lower primary energy consumption and lower exhaust steam pressure. In so doing, more electricity can be produced per tonne of steam.

6) **Energy recovery loops (65°C-30°C):** although we have reduced the excess steam generated by the condenser very significantly, there is still heat available between 65 and 80°C. Rather than losing this 'free' energy in the cooling tower, we have created a new energy level in the factory: two water loops transfer the energy from one workshop to another in the factory. Some workshops had a surplus of energy while others had a deficit. The energy suppliers to these hot water loops are mainly excess steam pre-condensers that are placed upstream of the condensers on the water in the cooling towers. The consumers are varied, but include the pre-heating of osmosis water, anaerobic digestion or the drying air of the finished product.

The process units are therefore interconnected in terms of energy. This is a very important paradigm shift as it directly impacts the flexibility of production management. For each coherent energy saving bundle, we carried out risk analyses with the people running the factory on a daily basis. This exercise was particularly necessary for the implementation of these energy sharing loops between production units.

7) "**Hot" cooling tower water (33°C-27°C):** by recovering energy from the hot water loops, the thermal load on the cooling tower has been significantly reduced and, with it, the power consumption of pumps and fans. In this project, we split the cooling towers into a hotter and a colder network. The hotter network is used to condense the residual steam and maintain the desired vacuum level.

8) "**Cold" cooling tower water (26°C-20°C):** due to the reduced thermal load of the cooling tower, it is possible to get as close as possible to the site's wet bulb temperature. In the summer, this allows water to be produced at 20°C, but this temperature can drop to 15°C in winter. The colder network is designed to cool the product directly in order to consume less cooling energy from the chilled water network. Ultimately, this is a direct energy saving. A pre-cooler exchanger has been installed at many points in the process on this new energy level.

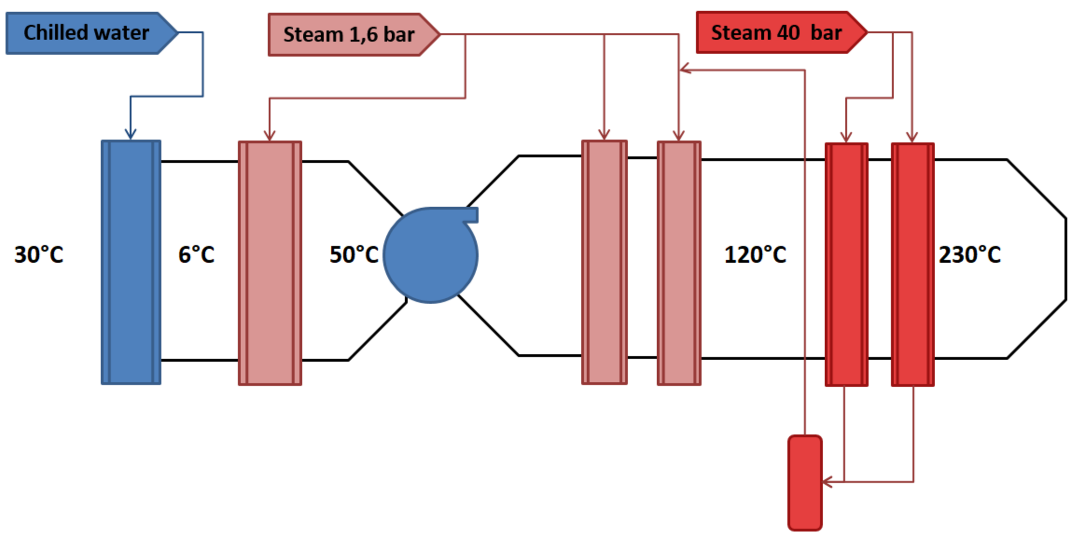
9) **Chilled water (6°C-12°C):** As with the cooling water network, the chilled water network has been split in two. Indeed, most of the cooling requirements are used to cool the product to around 10°C. It was therefore not necessary to consume water colder than 6°C as long as the temperature approaches on the exchangers were low enough. Beneo has heavily invested in more efficient heat exchangers with more surface area to achieve a pinch point of less than 2°C.

The production of this 6°C water has also been transferred to water-cooled chillers equipped with a screw compressor. The hot source is water from the cooling tower rather than ambient air. In addition to offering a 3x better performance coefficient than air-cooled chillers, these new chillers are less sensitive to the seasonal nature of outdoor temperatures.

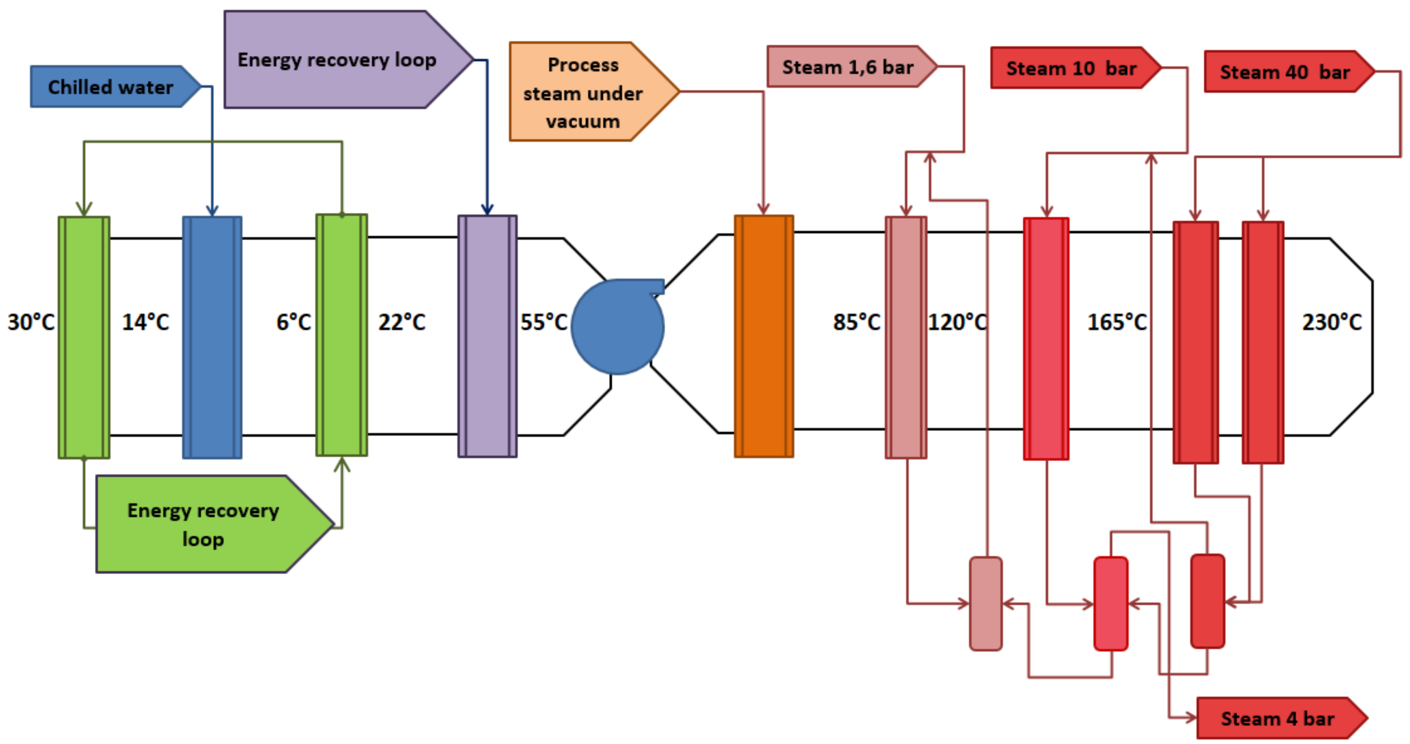
10) Chilled water (0.5°C-6°C): this coldest chilled water system provides only the essential dehumidification requirements for the drying air of the finished product. Furthermore, the addition of a local energy recovery loop has allowed us to further reduce the consumption of this high-value energy.

The implementation of these energy levels is quite noticeable in the preparation of the drying air for the finished product. We moved from a system with 3 energy levels to one with 7 energy levels.

Product drying air preparation with 3 levels of energy

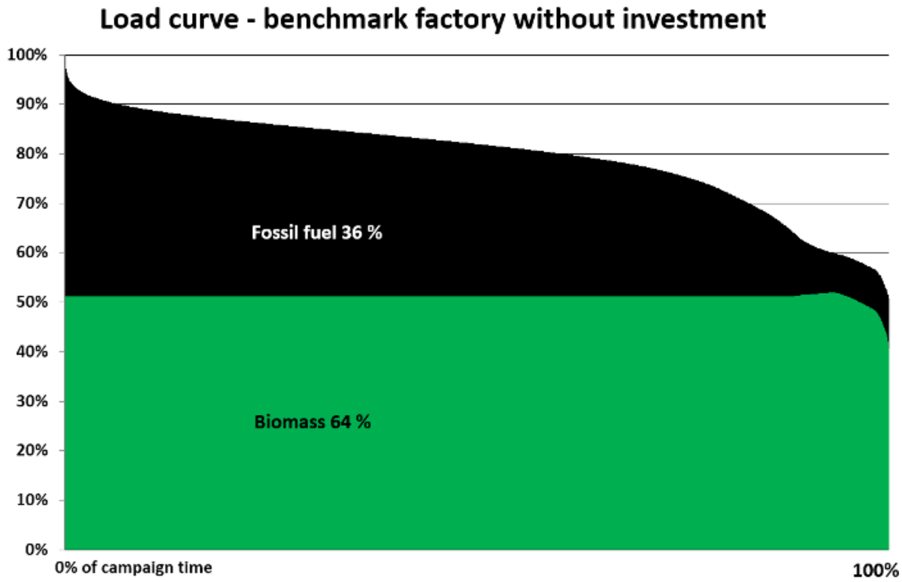


Product drying air preparation with 7 levels of energy



3. ANALYSIS OF OVERALL CONSUMPTION FOR THE ENTIRE CAMPAIGN

The complexity of chicory processing and the different end-product lines resulted in a varying energy demand for the process. In order to properly design new installations and calculate energy and financial savings accurately, it is important to consider the variability of factory operations and peak energy demands in our simulations! In the energy sector, people are used to working with a load duration curve. This curve ranks all thermal loads from largest (peak load) to smallest. The x-axis represents the capacity usage in % of time.



The load duration curve shows an overview of:

1. The peak power of the installation

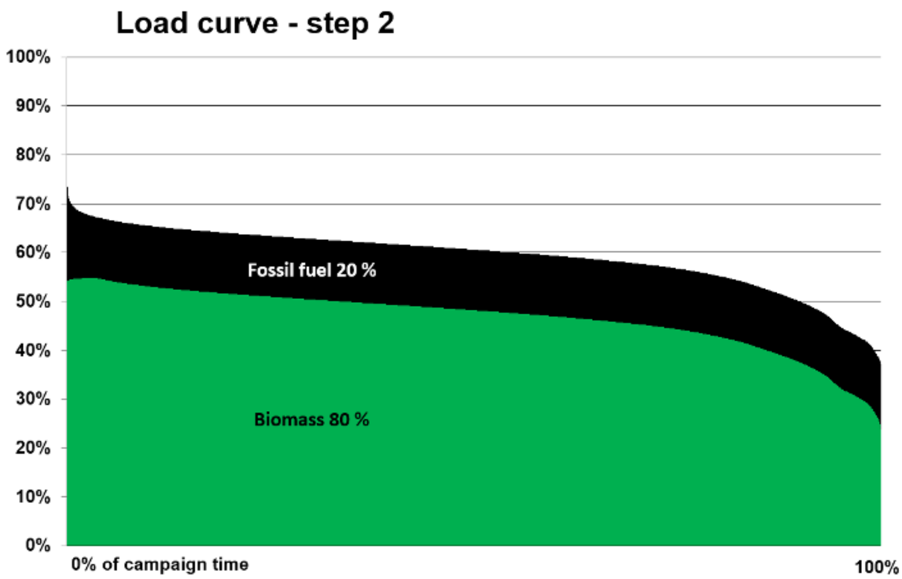
2. The total energy required during the whole period analysed (the area under the curve)

3. The potential optimisation of the use of different fuels

The use of these load curves rather than a model at a specific time has several advantages:

- We incorporate factory regularity into our savings forecasts.

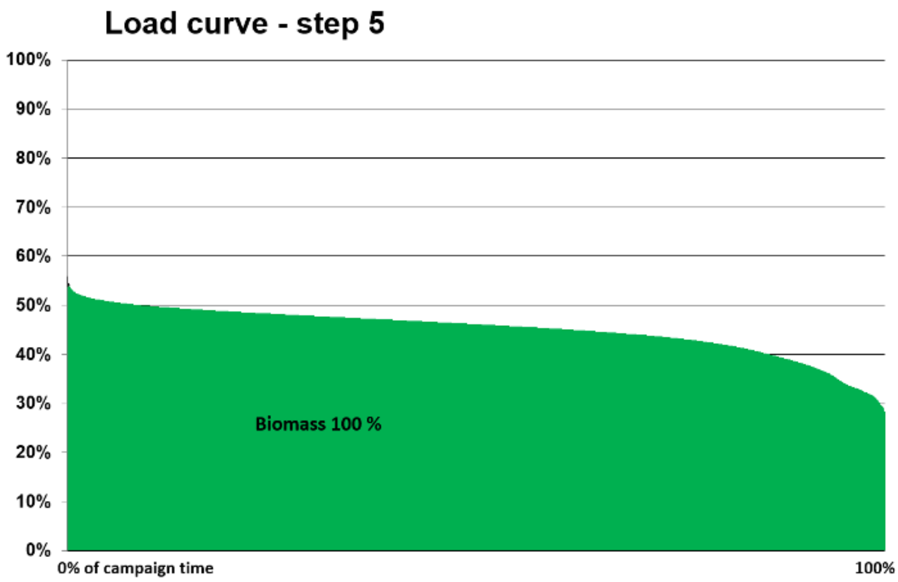
- As the different production patterns do not change much in terms of energy consumption and production days between investment stages, this load duration curve automatically incorporates all production patterns for the period.



The first figure shows the curve for the existing situation. The biomass boiler provides the base load and the fossil fuel boiler provides the backup.

The second figure shows the forecast curve after the second year of investment (starting in 2022). The fossil fuel boiler's consumption is already significantly reduced.

The third figure shows the forecast curve after the fifth year of investment (starting in 2025). The fossil fuel boiler will have been shut down.



4. ANALYSIS OF THE PROFITABILITY OF THE DIFFERENT SUB-ASSEMBLIES AND ORGANISATION OF THE DECARBONISATION PLAN

The final step in our methodology is to develop a capital budget for the project. At the same time, the operational benefits of these energy savings are valued by factoring in the projected fuel costs. Finally, the analysis of the profitability of each sub-project allows for trade-offs and investment planning.

Encouraging results after two years

As the 2022 project draws to a close, the results of the first two stages of investment are quite encouraging. While a 32% reduction in thermal consumption was expected if the project had not been implemented, the results of this project show a 35% reduction. In addition, fossil fuel consumption now only accounts for 10% of the factory's consumption. The initial targets of halving the site's specific consumption and stopping the combustion of fossil fuels are therefore achievable in the next project.

As the first results of the investment plan in the Chilean factory were very positive, BENEO decided in 2020 to launch the same process for its factory in Oreye, Belgium. Following the example of the Chilean factory a progressive investment plan was drawn up by DSEC to drastically reduce energy consumption. The challenge in Oreye is even greater as there is no local biomass to provide the required residual energy. Therefore, it will be necessary to further electrify the factory in order to benefit from low-carbon electricity from the grid in the future. Other potential sources of energy have also been studied: solar panels, switching from fossil gas to hydrogen when it becomes available, production of biogas by anaerobic purification.

The management and teams of De Smet Engineers & Contractors are highly motivated by these improvement projects, which make sense for our common future:

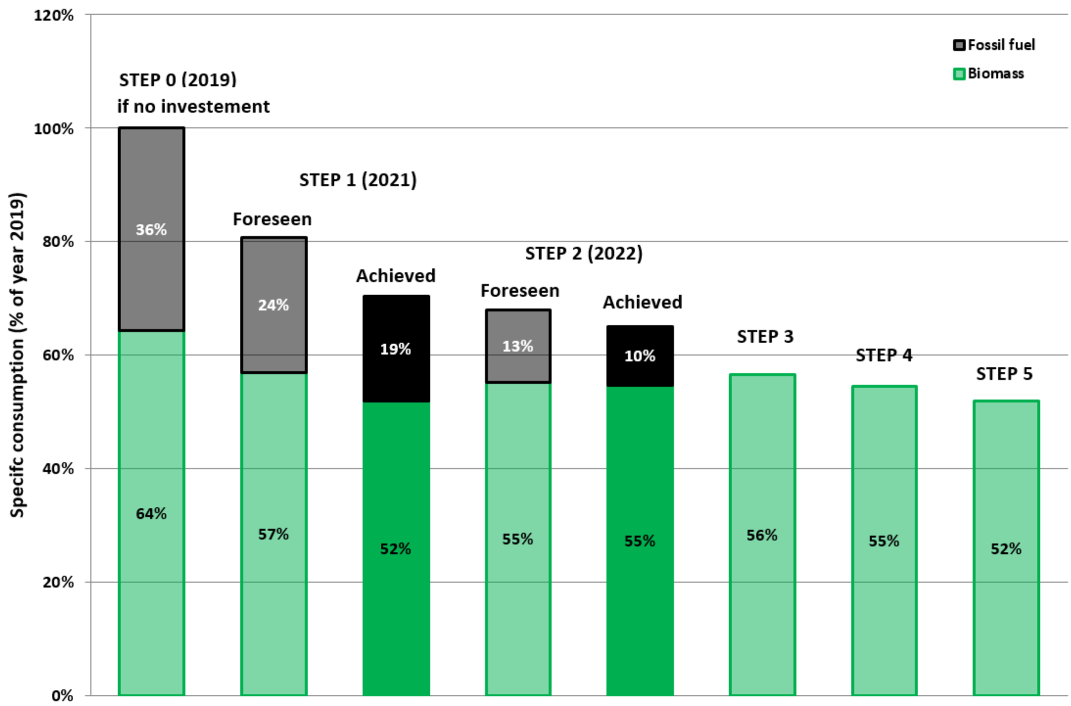
We are committed to exporting the expertise of our energy and process specialists across the world. As we all know, carbon dioxide does not stop at borders! So any possible reduction in emissions will benefit everyone, everywhere! The food industry will face huge challenges in terms of energy reduction in the near future. We are ready to support our clients in this transition to sustainability.

We are committed to providing realistic and viable solutions that will improve and optimise production lines in order to achieve industrial excellence.

Our aim is to improve the efficiency of factories by increasing their production output and reducing their energy consumption. When designing and building factories, we always carry out projects in such a way as to achieve low levels of water and energy consumption.

We believe that it is essential to involve everyone, regardless of their position in our organisations, in this major change for industries. Listening to the concerns and needs of the people who manage the factory on a daily basis helps us to achieve our ambitious goals. Collective intelligence is key!

With the knowledge and skills to transform complex, energy efficient factories, DSEC is a key player in energy saving solutions. Thanks to the trust that BENEO has placed in DSEC, BENEO is now a leader in energy transition in the food industry.



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