LIFE14 CCM/SE/000221

EffiSludge 4 Life

An innovative concept to improve resource- and energy efficiency in treatment of pulp and paper industry effluents

Scandinavianbiogas

Layman Report

EffiSludge for LIFE

An innovative concept to improve resource- and energy efficiency in treatment of Pulp and Paper Industry effluents
Project n. LIFE14 CCM/SE/000221

What is this and why is it important?

Industrial production of every-day goods often generate wastewater that needs to be cleaned before returning to recipients such as rivers and lakes. The problem is that this treatment requires a lot of energy and often addition of chemicals which means high carbon emissions and costs for the treatment. EffiSludge for LIFE suggests an integrated wastewater treatment as part of an industrial symbiosis approach between the pulp and paper industry, and the biogas industry. The aim of the project is to demonstrate the environmental benefits of such integrated industrial wastewater treatment by reduce electricity consumption, recirculate nutrients (nitrogen and phosphorus) and produce renewable biofuel.

The implementation

The EffiSludge for LIFE demonstration project was initiated in 2015 with Scandinavian Biogas Fuels AB as coordinating partner. The demonstration plant is located at the Norske Skog Skogn paper mill north of Trondheim in Norway. There the existing industrial wastewater treatment has been integrated with a newly build biogas plant owned by Biokraft AS, a sister company of Scandinavian Biogas AB. The wastewater treatment cleans process water from the paper mill, while biogas is generated from both the wastewater and from waste and residues primarily from the Norwegian fish industry.

EffiSludge for LIFE has been implemented by Scandinavian Biogas Fuels and Biokraft in cooperation with Norske Skog Skogn and with the support of a Reference Group including experts from both the pulp and paper industry- and the biogas field.

> **EffiSludge for LIFE demonstrates an alternative and more sustainable way to process industrial wastewaters. Its implementation leads to substantial reduction of carbon emission from industrial wastewater treatments, thus contributing to climate change mitigation.**
>
> Francesco Ometto, Project Manager for EffiSludge for LIFE

EffiSludge for LIFE project's implementation site Skogn, Norway

Biological wastewater treatment is often applied to clean water from organic pollutants. The organics can be degraded by a growing population of microbes suspended in the water. To secure an effective treatment, air is blown into the wastewater. This aeration consumes at least 60% of the total energy for the wastewater treatment. Nutrients in the form of nitrogen and phosphorus is needed and often provided as commercial chemicals. During the process, part of the microbes become a waste sludge that is difficult to find uses for mainly because it is hard to dewater. The more air that is blown into the water the less sludge is produced. The electricity needed for the aeration and the chemical demands are the two main factors associated with carbon emissions from the wastewater treatmeant.

Project timeline

2015 – Project started on September 1st after LIFE Programme call on Climate Change Mitigation.

2016 – The Norske Skog Skogn mill is identified as Project Implementation Site.

2017 – State of art evaluation of the existing wastewater treatment at the mill completetd.

2018 – Construction work completed. Start of processing biosludge and fish waste for biogas production.

2019 – Nutrient recovery/recirculation is in place. Industrial wastewater is process anaerobically via the UASB type reactor.

2020 – Monotoring of processed development and modelling of process performance with reduced sludge age.

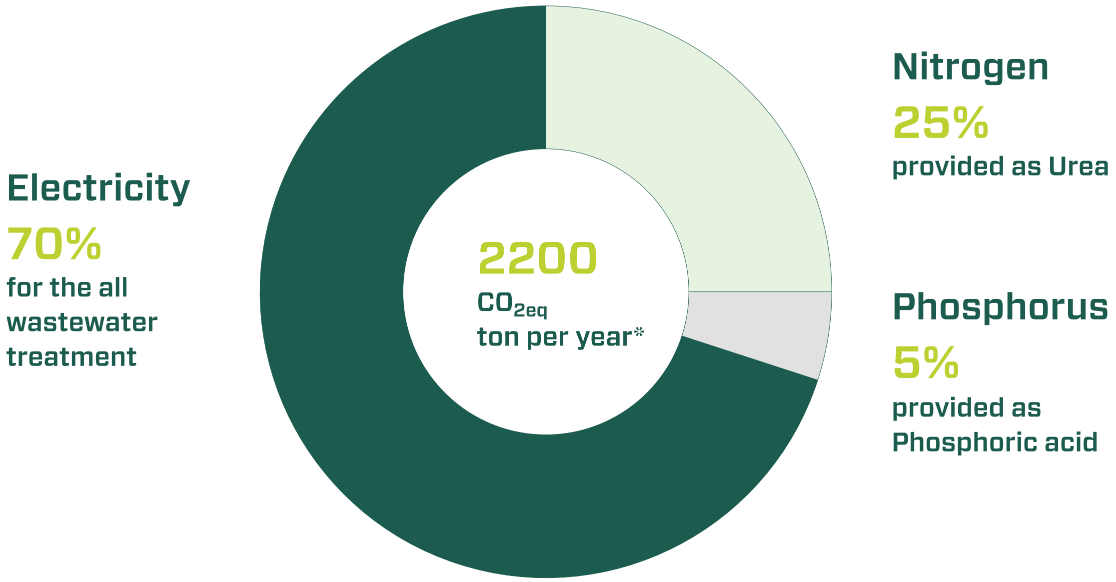
2021 – Final process evaluation and quantification of carbon emission reductions.

...We are now looking to identify new project opportunity where to implement the EffiSludge for LIFE concept...

> **The Skogn site is a positive example of a win-win concept within industrial symbiosis where a pulp and paper mill and a biogas plant, in this case, can benefit from each other's products.**
>
> Prof Jörgen Ejlertsson, Process and R&D Director at Scandinavian Biogas.

The situation before EffilSudge for LIFE

The production of pulp and paper requires large amounts of water. This water needs to be cleaned before returned to recipients such as rivers and lakes. The treatment of the 20 000 m³ wastewater generated at Skogn each day requires addition of 1000 kg Nitrogen, 100 kg Phosphorus and 40 MWh electricity to support operation within the overall wastewater treatment. These inputs results in carbon emission of in total 2200 tonnes CO_{2eq} per year:



*Carbon emissions calculated using a carbon factor based on average European electricity mix 2021. If a higher "worst case" carbon factor is applied, the annual emissions increase to 3500 tonnes CO_{2eq}. A lower carbon factor, representative of the current Norwegian situation, reduces the value to 600 tonnes CO_{2eq}.

What is the problem?

The conventional method for treating wastewater rich in organic material is to first remove particles, fibers etc. by sedimentation, and then do an aerobic (oxygen/air mediated) biological degradation of the solved organics with carbon dioxide as the final product. This degradation often takes place in a large aeration basin (activated sludge treatment) where a diverse flora of microorganisms degrades the organic matter in the wastewater while consuming oxygen. The need of oxygen means that air must be blown into the water continuously and this aeration consumes lots of energy. In addition, the activated sludge treatment generates a sludge consisting of the microorganisms feeding on the organic material. This sludge is called biosludge and is a problematic waste that is hard to find uses for, mainly because it is hard to dewater. For the same reason it is a lousy fuel for the furnaces at the mill. To keep the volumes of biosludge to a minimum, activated sludge systems is often run at low loads and at long residence time for the biosludge (i.e. high sludge age). This combination means that the biosludge itself is partly degraded in the process which off course gives a reduction in the amounts produced but also means that the treatment takes longer time and that the amount of air that needs to be blown into the water is roughly doubled. In addition, nutrients (nitrogen and phosphorus) need to be added to the wastewater treatment to keep the biological process going and these nutrients often contribute with both fossil CO_2 trough their production and with increases in active nitrogen and phosphorus to the eco-systems.

In summery: The traditional activated sludge process comes with high operational costs and energy consumption which generates high carbon emissions together with a non-circular use of nitrogen and phosphorus.

> **The processing of wastewater always comes with high costs. Thanks to EffiSludge we can reduced chemical dosage and energy demand. This provides a cost-effective wastewater treatment, with clear benefits for the environment.**
>
> Jon Henrik Steinsli, Senior Process Engineer at Norske Skog

How can we improve it?

Instead of focusing on minimizing the formation of biosludge in the wastewater treatment the sludge can be seen as a resource where the energy trapped in the biomass can be turned into renewable biogas as part of an industrial symbiosis set-up. This would mean that the efficiency of the activated sludge system can be improved by shortening the treatment time/reducing the sludge age and by this cutting the energy consumption from the aerators by roughly half. The reduced sludge age also means that the biosludge produced contains higher amounts of energy rich biomass thus increasing its value as a substrate for biogas production.

The industrial symbiosis, apart from the biosludge, needs to include one or several producers of organic waste or residues that are energy rich and holds high concentrations of nitrogen, phosphorus and other nutrients (e.g. wastes from meat and fish production, food industry, manure) and can be digested together with the biosludge. The final products from this anaerobic (oxygen free) digestion process are 1) energy rich biogas, that can be used for driving cars, buses, trucks, ships or for production of electricity and heat, and 2) a nutrient rich organic residue.

The nutrients in the residue can be separated into fractions with different characteristics (dry or wet, content of specific nutrients etc.). A liquid fraction, obtained after centrifugation, can be used as a nutrient source in the activated sludge process thus replacing whole or part of the commercial nitrogen and phosphorus that otherwise are needed. The solid part of the digestate can be sold on the market as fertiliser or soil improver.

In addition, part of the organic matter that is normally oxidized in the activated sludge treatment can be turned into biogas already in a first biological, anaerobic, treatment step. This will, apart from utilising a larger part of the biogas potential from the wastewater, result in decreasing loads to the activated sludge treatment and thus reducing the need of aeration.

Nutrients such as **nitrogen** (N) and **phosphorus** (P) are needed for the growth of all living organisms, but just as for carbon dioxide is the balance of these elements disturbed by human activities. In the case of nitrogen and phosphorous is the addition of mineral fertilizers such as urea and phosphoric acid a problem as they increase the amounts of reactive forms of N and P in nature. The production of mineral fertilizers also means an increased release of fossil CO_2. To remedy these problems we need to catch and reuse as much of the nutrients as possible, not letting them out into the water and atmosphere. This can be done by reusing nitrogen and phosphorus from manure, organic waste, human excreta etc. as fertilizers after treatment.

In summery: By applying an industrial symbiosis concept, where biogas is produced both directly from the wastewater and from the biosludge formed in the activated sludge treatment, we can decrease the need of air blown into the water and thus reduce the electrical consumption. The biosludge formed is co-digested with nutrient rich waste and the residue from this process can be used to drive the biological degradation of organic matter in both the anaerobic and aerobic wastewater treatment steps thus reducing the need of commercial nutrients. **Benefits are hence threefold: production of a renewable fuel, saving of electricity and recirculation of nitrogen and phosphorus. They are all contributing to a decreased carbon footprint from industrial wastewater treatment and thus to climate change mitigation.**

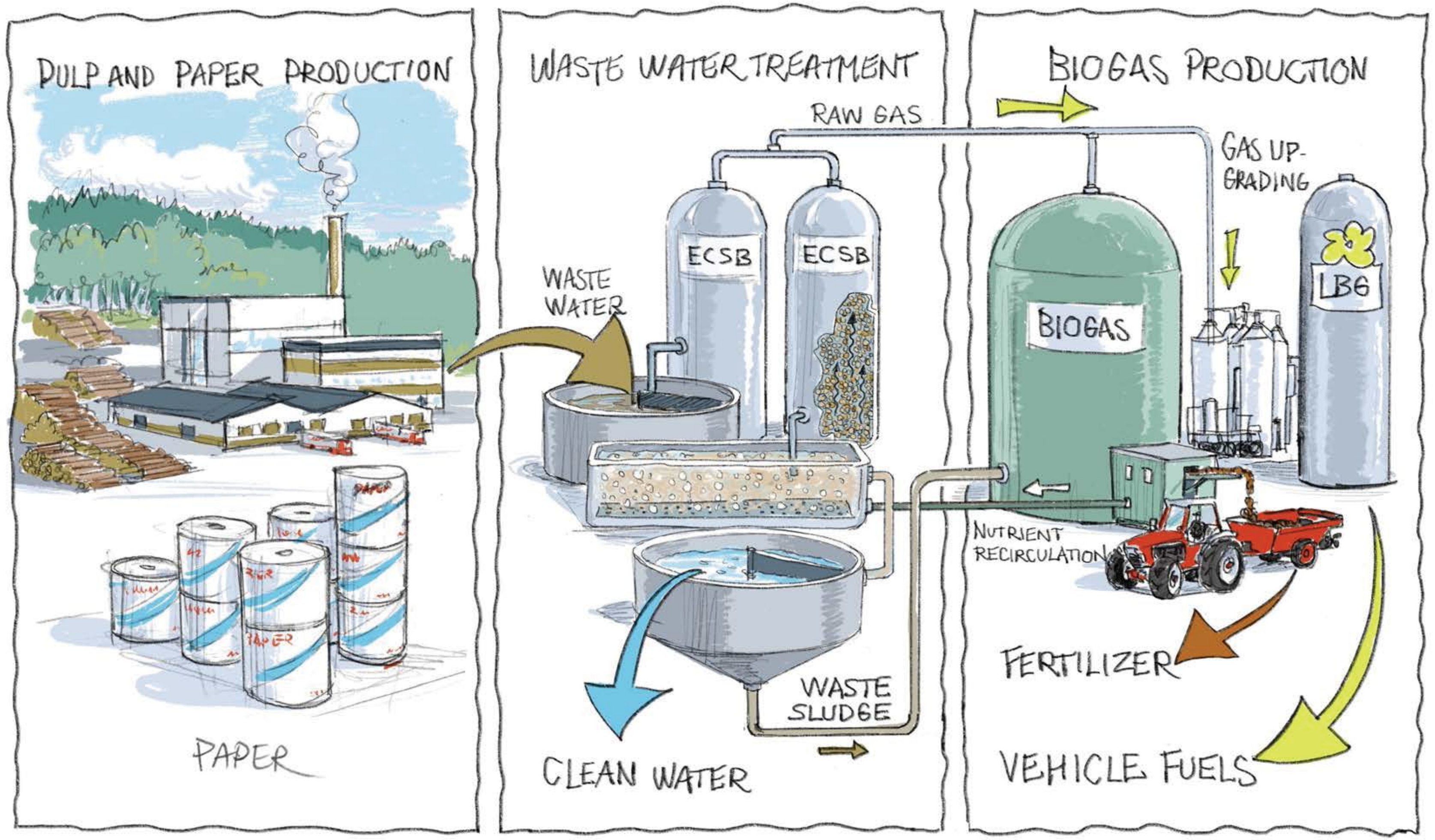
The EffiSludge concept in numbers:

100% Nitrogen saving / **80%** Phosphorous saving	**50%** Energy saving	**Biogas** to replace fossil fuels	**Zero CO_2** emissions from wastewater treatment
as commercial chemicals are replaced with nutrients from fish waste, chemical addition is replaced from fish waste first processed via anaerobic digestion for biogas production	due to anaerobic digestion of wastewater prior the aerobic step and reduced biosludge age in the activated sludge process	generated from wastewater and biosludge in co-digestion with nutrient rich biomass	thanks to the combined effect of nutrient recovery, optimized biosludge production and biogas production

EffiSludge at Skogn

> **Pulp and paper mills are often surrounded by great infrastructure. This is an advantage for the sector to rapidly develop industrial symbiosis solutions where biogas plays a key role.**
>
> Magnus Johansson Fiskeby Board

Industrial Symbiosis is a co-operation between industries where the waste or residue of one actor becomes a resource for another actor. It should be a win-win concept where the benefit of the co-operation is larger than the sum of individual benefits.



Industrial processes generate large volumes of wastewater, requiring energy intense treatments. With the EffiSludge concept, the energy demand for the treatment is reduced resulting in reduced CO_2-emissions. Easy degradable bio-sludge is generated and digested to biogas. Co-digestion of bio-sludge with local organic waste and residues supports efficient biogas production and nutrients recovery. This accounts for additional carbon saving.

500 000 ton
newsprint per year

20 000 m3
wastewater per year

125 GWh
liquid biogas

Biogas technologies at Skogn

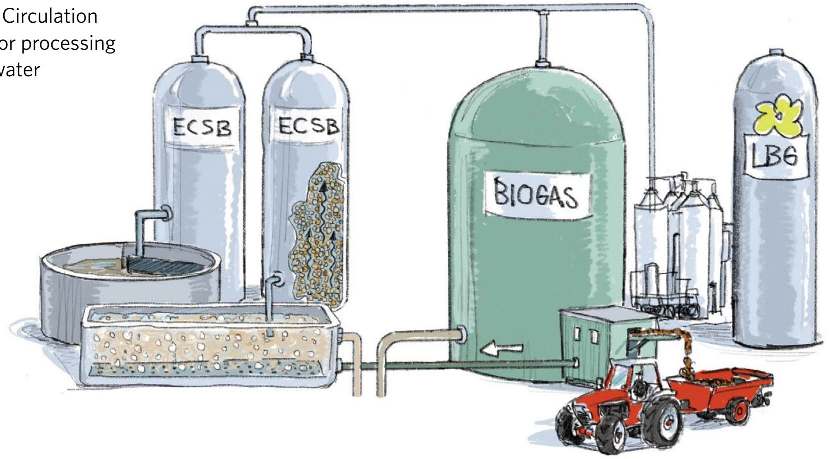
In industrial processes biogas can be produced either from solid organic wastes or from wastewater with a high content of organic matter. Two main anaerobic digestion technics are used:

1. "Solid" material (including household waste and many types of manure) is fed into a closed and mixed tank, often several times a day, at the same time as volumetric equal amounts of "digestate" is removed. The removed digestate often contains high concentrations of nutrients and can be used as fertilizer or soil-improver.

2. For wastewater, which doesn't hold the same high concentrations of organic matter as the solid wastes, much larger volumes need to be treated per time unit to obtain an efficient process and therefore another technic is needed. Here water is typically pumped through a bed or a biofilm of anaerobic bacteria that degrades the organic matter in the wastewater to biogas. The water is then often treated further in an aerated treatment step also this biological.

The biogas produced can in both cases be used as a replacement of natural gas and thus used for driving cars, buses, trucks, ships or used for production of electricity and heat.

ECSB - Extended Circulation Sludge Bed reactor processing industrial wastewater



Conventional biogas reactor processing fish waste, biosludge and other organic waste.

The main component of biogas is methane (CH_4). Methane is an energy-rich gas generated during oxygen free degradation of organic matter. When produced in industrial scale it can be used as a replacement of diesel and other fossil fuels both in transportation and for production of electricity and heat.

What was achieved?

Over the project period, EffiSludge for LIFE shown that:

a liquid fraction of the digestate from the biogas plant treating mainly fish industry waste can replace all urea and up to 80% of the phosphoric acids added as source of nitrogen and phosphorus, respectively, to the wastewater treatment plant.

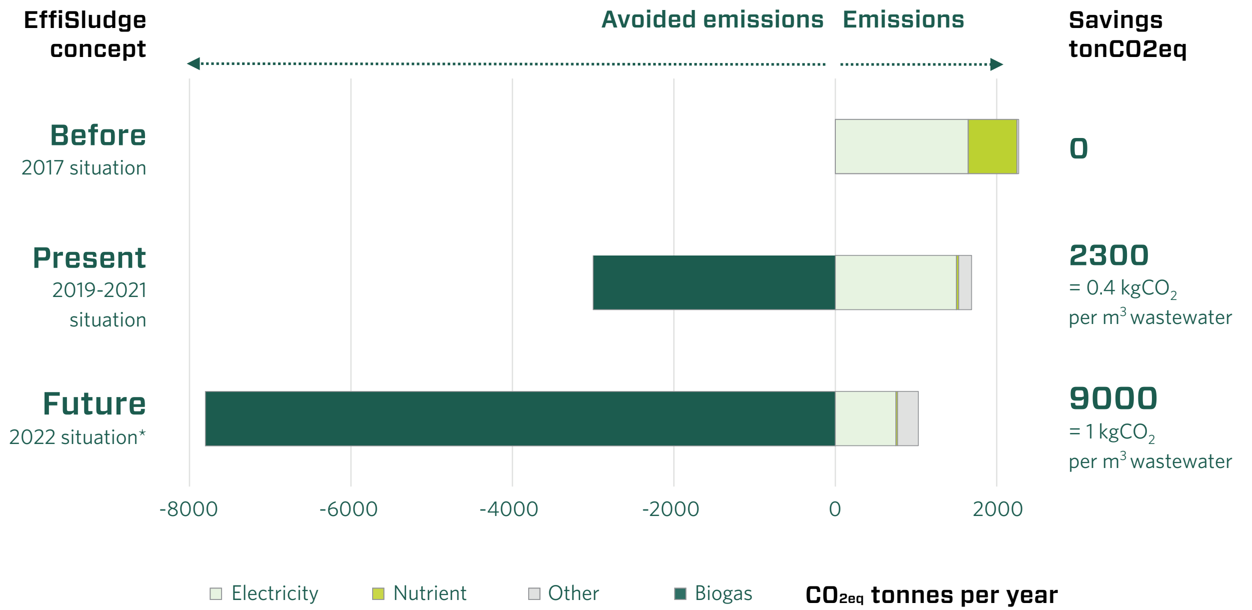
the wastewater from the paper mill is after pre-sedimentation suitable for anaerobic wastewater treatment prior the active sludge unit. About 50% of the organic matter in the wastewater can in this step be transformed to biogas. Additional biogas production is achieved by co-digestion of waste activated sludge with external biomass.*

the need for aeration in the activated sludge treatment is reduced by applying the anaerobic wastewater treatment step thus cutting the electrical consumption used for aeration.*

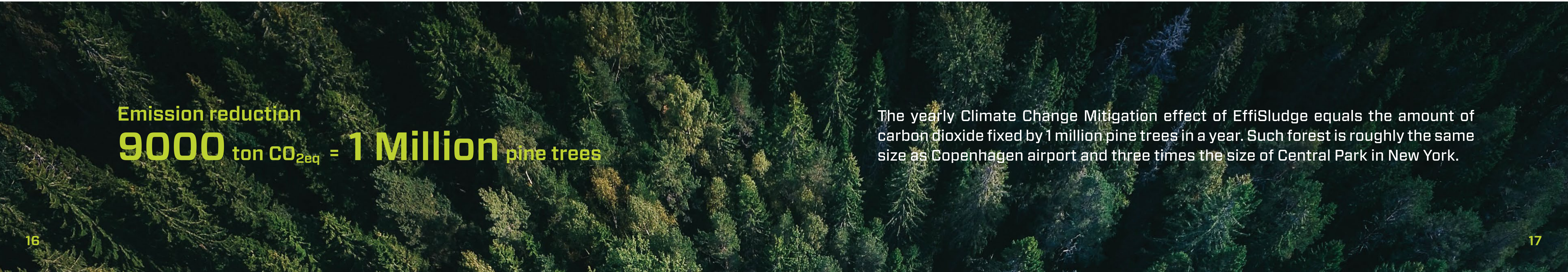
the combined effect of nutrient recovery, biogas production and energy savings, allowed for significant carbon emissions reductions.

*under the present project reference period (2019-2021) no sludge age reduction have been achieved due to technical limitation (cf. table below).

Annual carbon emissions from wastewater treatment



* Future EffiSludge scenario assumes that all wastewater and biosludge are processed anaerobically.



Emission reduction

9000 ton CO_{2eq} = **1 Million** pine trees

The yearly Climate Change Mitigation effect of EffiSludge equals the amount of carbon dioxide fixed by 1 million pine trees in a year. Such forest is roughly the same size as Copenhagen airport and three times the size of Central Park in New York.

Life cycle assessment

A life cycle assessment (LCA), comparing the climate change potential of the wastewater treatment plant "Before EffiSludge" (reference case) with two scenarios with different levels of the Effisludge concept implemented was perfomed (Present and Future EffiSlude in the table below). The LCA functional unit is "1 kg of COD treated". This means that we calculate how much CO_2 that is produced from operating the wastewater treatment plant per unit of organic matter removed from the wastewater. To estimate the benefits of producing biogas an assumption is made that it is used to substitute diesel in transport and thus avoid fossil-based climate gas emissions.

Key parameters for evaluation of the reduction of fossil CO_2-release by implementing EffiSludge

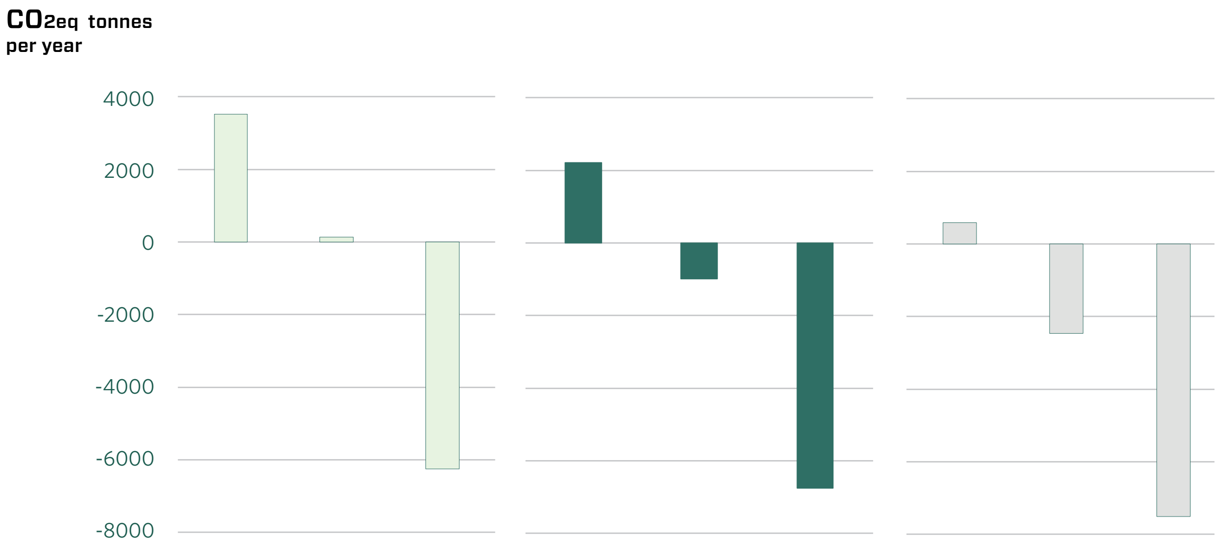
Parameter	Unit	Before EffiSludge[1]	Present EffiSludge[2]	Future EffiSludge[3]
Sludge age	days	13	12	6-8
Energy demand	MWh/day	30	23	15
Nitrogen addition (urea)	kg N/day	1000	100	0
Phosphoric acid addition	kg P/day	100	10	30
Biomethane from biosludge	Nm^3/day	0	180	1700
Biomethane from direct WWT	Nm^3/day	0	3400	7100

[1]The Before EffiSludge case is calculated from actual values for the year 2017. [2]The Present EffiSludge case is based on data from the full-scale implementation at Skogn for November 2019. 65% of the wastewater was during this period treated in the anaerobic wastewater unit while 100 m^3/day of the biosludge was digested together with nutrient rich residues from the Norwegian fish industry. The biomethane potential of the biosludge was set to 81 Nm^3/tonne VS for this sludge, that value is based on actual BMP measurements. [3]The Future EffiSludge Case assumes that all wastewater is treated in the anaerobic unit giving a 50% reduction of the organic material in the wastewater before going to aeration. The amount of biosludge digested has been assumed to increase due to the shorter sludge age (a factor of 0,28 kg SS/kg of COD_{red} was used for estimating the amounts). The biomethane potential for this biosludge was assumed to be 250 Nm^3/tonne VS.

What impact can the concept have?

The European pulp and paper industry, represented by the Confederation of European Paper Industries, includes a little less than 900 mills together producing about 90 million tonnes of paper and board which generates over one billion tonnes of wastewater per year. If the "Future EffiSludge" scenario is applied on all these pulp and paper mills, this would mean an annual reduction in CO_2 emission of between 0.5 and one million tonnes of CO_{2eq} per year.

EffiSludge achievement under different carbon factor condition



High
Strong influence of fossil based fuels on energy- and nutrient production

EU mix 2021
European average with a high share of green energy in the electricity mix

Low
Green electricity (Norwegian case with mainly hydropower)

Our contribution to sustainable development

The EffiSludge project can be related to eight of the 17 Sustainable Development Goals. The project is directly linked to the following targets within goals 6, 7, 8, 9 12, 13, 14 and 17:

Future EffiSludge

The future of EffiSludge at Skogn, and later after implementation at other sites, means long term operation of the anaerobic wastewater treatment unit, treating all the wastewater as a pre-step to the activated sludge treatment. The sludge age in the activated sludge treatment should also be shortened from 13-15 days to 6-8 days to improve the quality of the biosludge as a substrate for anaerobic digestion to biogas. This will also reduce the need of aeration further. All the biosludge produced should be used for biogas production. Finally, we should work to have the EffiSludge concept classified as best available technic (BAT).

> **Biogas solutions connect parts of systems creating multifunctional solutions and are inherently symbiotic.**
>
> Prof Mats Eklund, Biogas Research Center, Linköping University

Spreading the word

Over time we in the EffiSludge for LIFE project have been very active on dissemination of results, networking and interaction with stakeholders and the general public. The project website, our Twitter account and the newsletter "EffiNews" have been the main ways to spread the word about the project and its progress. We have also made a short information video (that can be seen on the website), leaflets, oral and poster presentations on conferences and workshops and taken part in fairs and local event of interest. Articles have been published both as popular science and in academic journals. The EffiSludge for LIFE has also, together with partners, hosted a workshop series. More information can be found on the project homepage: www.scandinavianbiogas.com/effisludge/

Communication and Dissemination strategy

General public

the project website offers an overview of the project development over time. Our regular newsletter "EffiNews" and twits reached thousands in Europe and beyond.

Target group

stakeholders from the pulp and paper industry and the biogas sector have been the key target groups. Our workshops have created opportunities for open discussions.

Experts

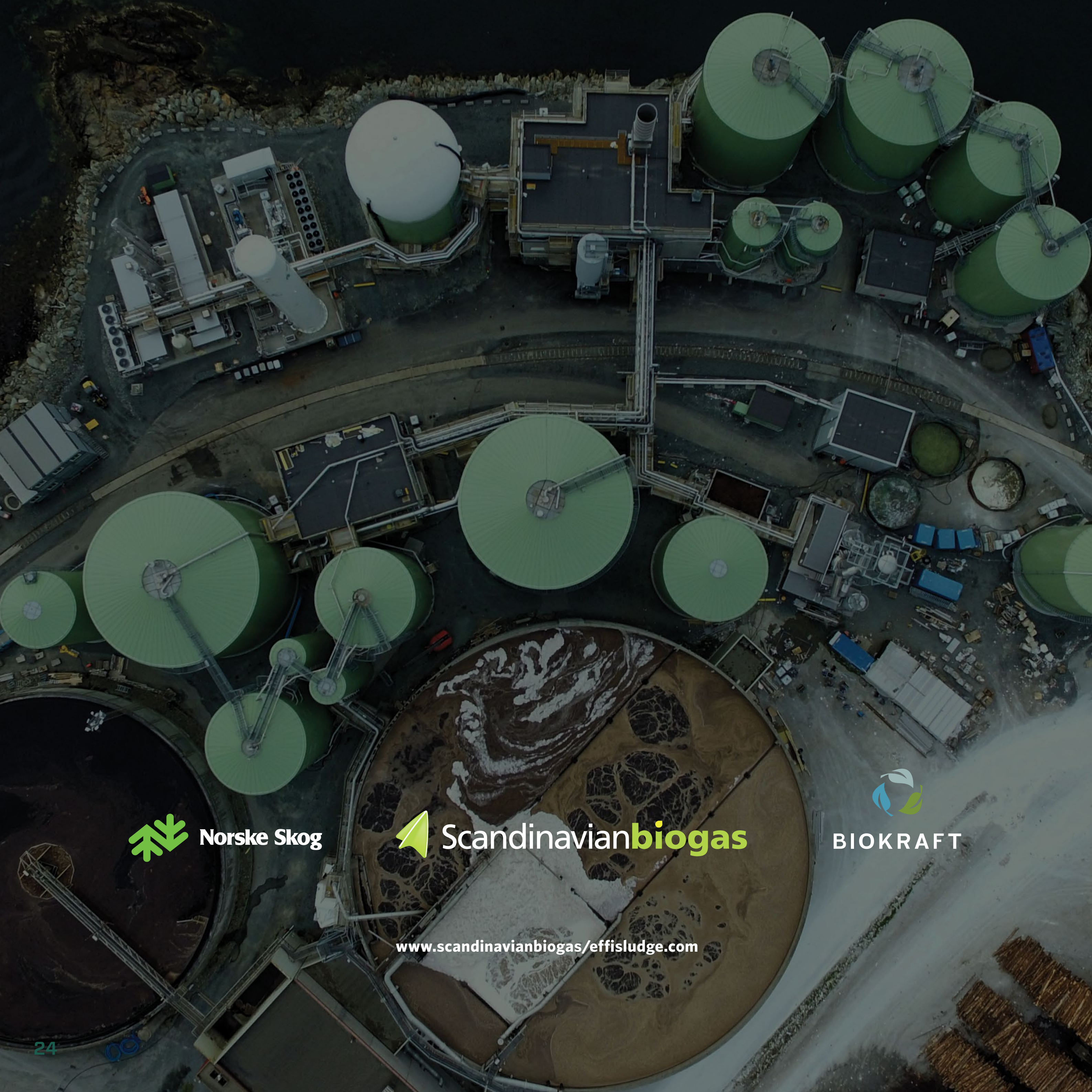
presentations on conferences, seminars, online events as well as scientific publication have disseminated the project to both the academia and the industry and also connected us with other projects in the field.

Policy Maker

the development of the project promoted a possible inclusion of the EffiSludge concept as a Best Available Technology (BAT).

> **Integrated systems where biogas is generated both from high-rate reactors (IC/USAB units treating wastewater after primary sedimentation) and conventional CSTR reactors (biosludge and possible external biomass) offer the unique opportunity for nutrient recirculation and energy saving compared to conventional wastewater treatments within pulp and paper industries.**

Take-home-message from EffiSludge workshop



Norske Skog

Scandinavianbiogas

BIOKRAFT

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