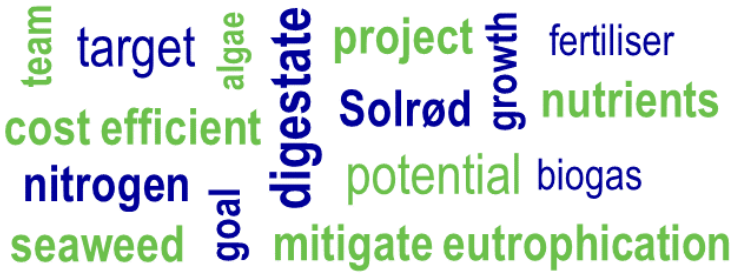
COASTAL BIOGAS

**C**luster **O**n **A**naerobic digestion, environmental **S**ervices and nu**T**rients remov**AL**

# COASTAL Biogas – a cost-efficient way to mitigate eutrophication

**May, 2021**




## A success story

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Partners

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## COASTAL Biogas

The COASTAL Biogas project revolves around anaerobic co-digestion of cast seaweed and utilisation of the digestate as an organic fertiliser. In this way nitrogen and phosphorus are physically removed from the sea, the emissions of carbon dioxide, methane and highly toxic hydrogen sulfide from decaying seaweed are eliminated and the digestate from the anaerobic co-digestion of the seaweed is used as an organic fertiliser on farmland, and thus off-sets the use of synthetic fertilisers.

> *"The COASTAL Biogas project objective is to provide solutions based on anaerobic digestion of cast seaweed to coastal regions to tackle eutrophication, contribute to the transition to a circular bioeconomy and improve prosperity."*

COASTAL Biogas is an Interreg South Baltic Programme project with project partners from Denmark, Germany, Lithuania, Poland and Sweden. More information about the project is available on the project website: https://coastal-biogas.eu

## Eutrophication in the Baltic Sea

Eutrophication has both ecological and social consequences and is one of the major environmental problems in the Baltic Sea. 97% of the Baltic Sea is affected by eutrophication. Toxic algae blooming, reduced water clarity and oxygen depletion are some of the negative consequences of the excessive input of nutrients to the marine environment. A good summary of the effects of eutrophication can be found on the HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) website: http://www.helcom.fi.

### *The European Water Framework Directive*

On the 23rd of October 2000, the EU Water Framework Directive (WFD) [1] was adopted. The WFD requires Member States to establish programmes of measures to achieve good water status by 2027 at the latest. The EU Nitrates Directive [2], concerning the protection of waters against pollution caused by nitrates from agricultural sources, forms an integral part of the WFD and is one of the key instruments in the protection of waters against agricultural pressures.

### *Køge Bay – status*

The water catchment area of the Køge Bay in Denmark is characterised by intensive agriculture giving rise to leaching and run-off of nutrients. It is no surprise that the Køge Bay suffers heavily from eutrophication and HELCOM labels the status as bad (see Fig.1). The WFD action plan 2015-2021 for Køge Bay in Denmark has a nitrogen load baseline of 1,303.3 tonnes and a target of 1,230.2 tonnes in 2021. This implies that the nitrogen load from the Køge Bay water catchment area needs to be reduced by 73.1 tonnes in 2021. Some of the instruments to achieve the target involves wetlands, afforestation, wastewater treatment and low land projects but still 51.6 tonnes have to be removed by other measures.

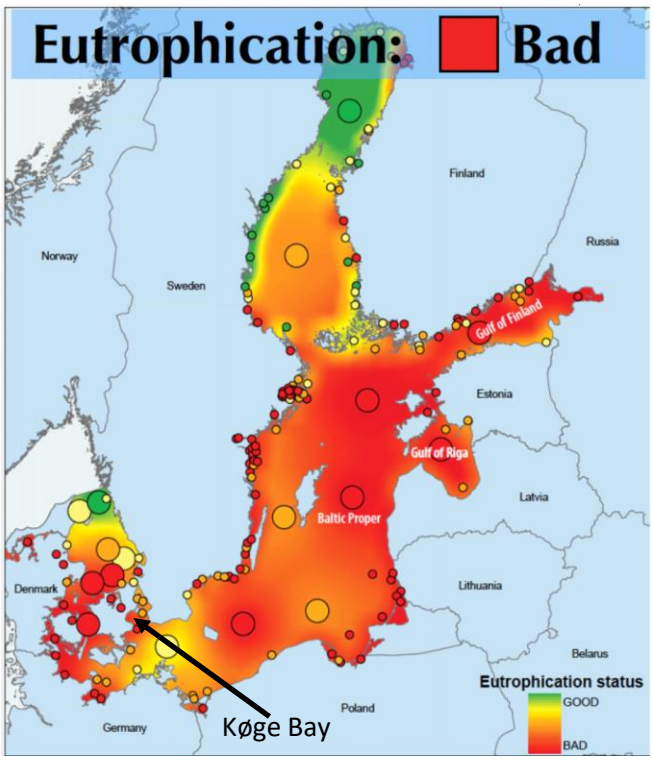


*Figure 1. Classification of eutrophication status in the Baltic Sea region by HELCOM. The arrow is pointing at the Køge Bay.*

In this context, two measures are compared in this publication:

1) direct reduction of nitrogen use on farmland
2) removal of nitrogen from the sea through the COASTAL Biogas concept

### *Direct reduction of nitrogen use on farmland*

To determine the discharge of nitrogen into the Køge Bay, it is necessary to know the area of farmland in the catchment area, the amount of applied nitrogen per area of farmland and the retention level, i.e. how much of the nitrogen is taken up by the crop on the farmland or absorbed before reaching the sea.
According to data from Roskilde University, the catchment area is 49,492 hectares, the nitrogen input through synthetic and organic fertilisers is 145.2 kg per hectare and the retention level is 80%, i.e. out of the nitrogen applied on farmland 20% will enter the Køge Bay through leaching and run-off. As a result, it is necessary to reduce the nitrogen use on farmland with 5 kg to reduce the amount of nitrogen reaching the sea by 1 kg. The retention level depends on many factors. The longer the distance to the sea, the higher is the retention level. Furthermore, the retention level depends on the soil properties. Sandy soil, for instance, is normally characterised by a very low retention level. Hence, if nutrients are put on a sandy soil close to the sea it can be expected that most of the nutrients will end up in the sea.

The reduction of nitrogen use on farmland is associated with lower crop yields and a lower content of protein in the crop. J. Eriksen et al. [3] indicates that a 10% reduction in nitrogen applied on farmland, based on Danish conditions, results in a net cost of 30 DKK (approx. 4 EUR) per hectare.

To reduce the amount of nitrogen entering the Køge Bay with 51.6 tonnes, the use of nitrogen on farmland, based on a retention level of 80%, has to be reduced by 258 tonnes. This can be achieved by a 10% reduction of the nitrogen input on 17,769 hectares of farmland resulting in an associated cost of approx. 533,070 DKK or 71,684 EUR[†]. This gives a cost of 10.33 DKK or 1.39 EUR per kg nitrogen not discharged to the sea.

### *Nitrogen reduction – the COASTAL Biogas concept*

The COASTAL Biogas concept is based on physical removal of seaweed, in which nitrogen is bound, from the sea by collecting cast seaweed and use it as a co-substrate in anaerobic digestion in combination with utilisation of the digestate as an organic fertiliser. The Solrød Biogas plant, which is the only facility in the South Baltic Sea region using cast seaweed as co-substrate on industrial scale, is located within the water catchment area of the Køge Bay. The biogas plant capacity is designed for around 226,000 tonnes of wet substrate per year. The amount of cast seaweed used as co-substrate varies from year to year. The figure for cast seaweed in Table 1. refers to the year 2019.

*Table 1. Input of substrates to the Solrød biogas plant in the year 2019.*

| Biomass | Amount (tonnes) | Main contribution |
|---|---|---|
| Seaweed | 1,522 | Nutrients removal from the sea, process stability |
| Manure and other | 49,478 | Gas production, nutrients and process stability |
| Pectin, carrageenan | 95,000 | Gas production |
| Eluate | 60,000 | Gas production and nutrients |
| Biopulp (organic waste) | 20,000 | Gas production and nutrients |
| **TOTAL** | **226,000** | |

The collection and co-digestion of cast seaweed contributes to several other socio-economic benefits besides the nutrient removal. The inhabitants and tourists appreciate the clean beaches and that the inconveniences caused by rotten seaweed on the beach are eliminated (smell and flies) and the improved water quality. Spontaneous methane, carbon dioxide and highly toxic hydrogen sulfide emissions from decomposing seaweed to the atmosphere are also avoided when the seaweed is used as a co-substrate. Local value chains, job opportunities, the possibility for organic farming where synthetic fertilisers are forbidden and the transition to a circular bioeconomy are other benefits.

To calculate the cost of removing 51.6 tonnes of nitrogen from the sea by collecting cast seaweed, it is necessary to know how much nitrogen cast seaweed contains. Based on a large number of laboratory tests of the nitrogen content in seaweed, Roskilde University suggests that 1 tonne of wet and sand free seaweed contains approx. 8.1 kg of nitrogen and 1.75 kg of phosphorus. This implies that 6,360 tonnes of wet and sand free seaweed needs to be removed in order to reduce the amount of nitrogen in the Køge Bay with 51.6 tonnes. However, since the seaweed contains sand, approx. 8,900 tonnes of seaweed need to be collected and transported to the Solrød biogas plant, which is located approx. 4 km from the beach where the seaweed is collected.

[†] The currency conversion, 1 DKK = 0.13 EUR, is used throughout this publication

*Table 2. Value of outputs and cost of transport and production for the COASTAL Biogas concept*

| | DKK | Comment |
|---|---|---|
| Value of collected nitrogen | -380,000 | Actual market price in Denmark, 7.36 DKK/kg |
| Value of collected phosphorus | -15,000 | Actual market price in Denmark, 12.00 DKK/kg |
| Value of produced biogas | -1,324,000 | Value of produced biogas including production subsidies, 5.77 DKK/$Nm^3$ methane |
| Collection cost | 1,647,000 | Estimated cost for collection, 185 DKK/tonne of seaweed incl. sand |
| Transport cost | 30,000 | Estimated cost for transport, 0.85 DKK per tonne and km of seaweed incl. sand |
| Production cost | 246,000 | Cost for production, fixed and variable, based on financial accounting for Solrød Biogas 2018 and 2019 |
| **TOTAL COST** | **204,000** | |

The cost for removing 51.6 tonnes of nitrogen from the Køge Bay through the Coastal Biogas concept is 204,000 DKK corresponding to approx. 27,400 EUR. This gives a cost of 3.95 DKK (approx. 0.53 EUR) per kg nitrogen not discharged to the sea.

If the cast seaweed is collected and removed from the beach for recreational and touristic reasons, the only additional costs are associated with the transport to the biogas plant and the fixed and variable cost related to the processing of the seaweed at the biogas plant. Omitting the collection cost results in a negative cost, i.e. a profit of 1,443,000 DKK (approx. 194,000 EUR). One could argue that there is a capacity utilisation cost associated with the anaerobic digestion since the biogas operator could use substrates with higher biogas yield than cast seaweed. However, data from the Solrød Biogas plant suggests that there are synergy effects when cast seaweed is co-digested, improving the biogas yield from the other substrates, and as long as the cast seaweed constitutes a minor part of the total substrate, the capacity utilisation cost is neglected in this report.

### *Nitrogen removal in the Køge Bay*

To reach the nitrogen load target for the Køge Bay, the nitrogen load has to be reduced by an additional 51.6 tonnes in 2021. The cost to achieve this reduction by direct reduction of nitrogen on farmland corresponds to a cost of 533,070 DKK or 71,684 EUR assuming an average nitrogen retention level of 80%.

Removing 51.6 tonnes of nitrogen from the Køge Bay through the COASTAL Biogas concept, implemented in the Solrød Biogas plant, corresponds to the removal of approx. 8,900 tonnes of cast seaweed incl. sand and transport to the biogas plant for further processing. The corresponding cost is 204,000 DKK or 27,400 EUR. If the seaweed is collected anyway, due to the inconveniences of rotten seaweed on the beaches, and the cost is omitted, then the removal of nitrogen through the COASTAL Biogas concept is associated with a negative cost, i.e. a profit of 1,443,000 DKK or 194,000 EUR.

## *Conclusions*

The WFD action plan 2015-2021 for the Køge Bay in Denmark has a nitrogen load baseline of 1,303.3 tonnes and a target of 1,230.2 tonnes in 2021. This implies that the nitrogen load from the Køge Bay water catchment area should be reduced by 73.1 tonnes in 2021. Some of the instruments to achieve the target involves wetlands, afforestation, wastewater treatment and low land projects, but still 51.6 tonnes have to be removed by other measures. In this publication, two such measures have been investigated and compared:

1) direct reduction of nitrogen use on farmland
2) removal of nitrogen from the sea through the COASTAL Biogas concept

*Direct reduction of nitrogen use on farmland*
The associated cost with this measure is related to lower yields and the lower protein content in the crops minus the reduced cost for fertiliser. The cost is heavily dependent on the retention level. For the Køge Bay water catchment area the cost for reducing the nitrogen load by 51.6 tonnes is estimated to 533,070 DKK or 71,684 EUR based on a reduction of nitrogen applied on farmland by 10% on 17,769 hectares and a retention level of 80%.

*Removal of nitrogen from the sea through the COASTAL Biogas concept*
Anaerobic digestion of cast seaweed brings several other socio-economic benefits than the removal of nitrogen (and phosphorus) from the sea. The inconveniences of rotten seaweed on the beaches such as smell, flies and emissions of carbon dioxide, methane and highly toxic hydrogen sulphide from decaying seaweed are eliminated for the benefit of recreation and tourism as well as increased value of coastal residential properties. The anaerobic co-digestion of cast seaweed results in a high-quality fuel, biogas, and an organic fertiliser containing all the nutrients and it contributes to the transition to the circular bioeconomy and creation of local and resilient value chains.

The cost for the COASTAL Biogas concept depends strongly on the cost for the collection of the seaweed and its content of sand. Based on a cost of 185 DKK/tonne wet seaweed including sand, the cost of removal of cast seaweed corresponding to 51.6 tonnes of nitrogen and utilisation of the seaweed as a co-substrate in anaerobic digestion is estimated to 204,000 DKK or 27,400 EUR.

The cost for direct reduction of nitrogen use on farmland exceeds the cost of the COASTAL Biogas concept by more than a factor of two, i.e. 533,070 DKK or 71,684 EUR versus 204,000 DKK or 27,400 EUR. If the seaweed is collected and removed from the beach for other reasons (e.g. smell, recreation, tourism etc.), the additional cost to implement the COASTAL Biogas concept is negative, i.e. it is profitable, based on the conditions in the Køge Bay.

The main conclusion is that the COASTAL Biogas concept is a cost-efficient way of mitigating eutrophication, and the implementation of the COASTAL Biogas concept by Solrød Biogas plant in Denmark is a true success story.

## References

[1] DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02000L0060-20141120&from=EN (accessed September 29, 2020).
[2] COUNCIL DIRECTIVE 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01991L0676-20081211&from=EN (accessed 29 September, 2020)
[3] Eriksen, J. et al. Virkemidler til reduktion af kvælstofbelastningen af vandmiljøet. DCA, Århus Universitet, 2020

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