Westerduinweg 3
1755 LE Petten
P.O. Box 15
1755 ZG Petten
The Netherlands

www.tno.nl

T +31 88 866 50 65

TNO report

TNO 2019 R10925

Final report TKI toeslag project Sludge to Power & Products (S2PP)

Date	20 June 2019
Author(s)	A.J. Grootjes, E.T. Liakakou H. Kuipers (Waterschap Zuiderzeeland) Y. van der Kooij (Wetterskip Fryslân) V. Wiermans (RWE Essent) R.W.R. Zwart (Dahlman Renewable Technology)
Copy no	
No. of copies	
Number of pages	11 (incl. appendices)
Number of appendices	
Sponsor	TKI-BBE
Project name	TKI-BBE 1708 S2PP
Project number	060.34125

Contents

1 Project information

Project number	TKI-BBE 1708
Project title	Sludge to Power & Products (S2PP)
Project duration	1-1-2018 to 31-3-2019
Coordinator	ECN part of TNO
Address and postal code	Westerduinweg 3, 1755 LE
Place	Petten
Contact person	Dhr. A.J. Grootjes
e-mail address	sander.grootjes@tno.nl

Partner 1	Waterschap Zuiderzeeland (ZZL)
Address and postal code	Lindelaan 20, 8224KT
Place	Lelystad
Contact person	Hans Kuipers
e-mail address	h.kuipers@zuiderzeeland.nl

Partner 2	Wetterskip Fryslân (WSF)
Address and postal code	Fryslânplein 3, 8914BZ
Place	Leeuwarden
Contact person	Yede van der Kooij
e-mail address	yvanderkooij@wetterskipfryslan.nl

Partner 3	Dahlman Renewable Technology
Address and postal code	Scheldeweg 10, 3144 ES
Place	Maassluis
Contact person	Robin Zwart
e-mail address	robin.zwart@synovapower.com

Partner 4	RWE Generation
Address and postal code	Amerweg 1, 4931NC
Place	Geertruidenberg
Contact person	Vera Wiermans
e-mail address	vera.wiermans@rwe.com

2 Public project summary

2.1 Introduction

The Dutch Water Authorities produce 1.3 million ton sewage sludge per year and the sludge disposal/treatment cost are between 115 – 250 M€ per year. There are opportunities under development to produce more renewable energy and raw materials from the sludges, lowering the sludge disposal/treatment cost. By doing so, the water authorities want to contribute to the renewable energy goals and agreements of the 'Meerjarenafspraken Energie-Efficientie (MJA3)', the Climate Agreement and Green Deals.

In the Netherlands, sewage sludge is being digested (approximately 50 vol.%), thermally dried and subsequently incinerated in various types of installations. Drying of sewage sludge requires approximately the same amount of energy as what it will produce when the sludge is combusted.

In lab-scale tests, treatment of sewage sludge using TORWASH®, dewatering the remaining fraction has been proven to result in 60 – 70% dry matter, significantly increasing the chain efficiency. For thermal conversion processes, potassium and chlorine are known precursors of fouling, slagging/agglomeration and corrosion as well as contribute greatly to fine particulate matter formation and emission. TORWASH® followed by dewatering results in a reduction of more than 90% of the potassium and sodium in the sludge.

Hence, the Regional Water Authority Waterschap Zuiderzeeland (ZZL) and Wetterskip Fryslân (WSF) decided to join in this project in order to facilitate the transition of waste water treatment towards reuse of energy and raw materials from waste water. Other partners in this project include utility company RWE Essent (RWE), MILENA gasifier and OLGA gas cleaning technology provider Dahlman Renewable Technology (DRT) and technology developer ECN part of TNO. With this consortium, the complete chain for sewage sludge, from production (ZZL, WSF) to upgrading (ECN part of TNO) to sewage sludge end-use (DRT, RWE) is present.

2.2 Goal

The goal of this project is to map at the lab-scale the quality and the thermal conversion properties of sewage sludge, both raw as well as pre-treated by TORWASH®. Sludge press cakes and pellets are produced and subjected to lab-scale combustion- and gasification experiments, resulting in a chain evaluation for the untreated and with TORWASH® treated sewage sludge application options.

It is expected that sewage sludge treated by TORWASH® can be thermally converted with other fuels at higher concentrations or even as only feedstock at more optimal conversion conditions, compared to untreated sewage sludge. The organic fraction that is dissolved in the effluent during TORWASH® can be converted in bio gas in compact digesters with a relatively short residence time.

Sewage sludge treated with TORWASH® in the form of press cakes or pellets results in new applications for:
1. More efficient combustion for heat and/or power in combined heat and power installations, or

2. conversion using gasification to produce bio-based fuels and chemicals with high added value.

The TKI Toeslag project Sludge to Power & Products (S2PP) aims at mapping new processing routes of sewage sludge treated by TORWASH®. A primary advantage of this treatment technology in combination with mechanical dewatering is that the total amount of sludge can be reduced by 70%-80%. This alone implies a potential cost reduction on sludge treatment cost of approximately 100 M€ per year in the Netherlands, even without logistic costs and the impact of transport movements.

Thanks to the high level of dewatering of by TORWASH® treated sewage sludge, the press cakes have a higher net calorific value that untreated mechanically dewatered sewage sludge. At the existing incinerations facilities SNB-Moerdijk and HVC Dordrecht, nearly all produced heat is needed to dry the sewage sludge for (complete and clean) combustion. In other cases, fossil fuel is used for drying of the sewage sludge, e.g. in the natural gas fired sewage sludge dryer in Beverwijk. Thus, combustion or gasification of TORWASH® treated sewage sludge results in a net increase of renewable energy and/or other products across the complete processing chain.

2.3 Short description of activities

In the project the water authorities contributed by supplying sewage sludge and by comparing the different sludge treatment routes. ZZL used the TORWASH® pilot plant, located at the Waste Water Treatment Plant (WWTP) Almere, extensively, producing samples of by TORWASH® treated sewage sludges. ECN part of TNO has conducted several combustion and gasification experiments at lab-scale, using several treated and untreated sewage sludges. Various measurements and analyses were done with regards to the gas compositions, sludge- and ash composition, as well determination of conversion levels. Furthermore, pellets were produced and subjected to (standardized) pellet quality tests. Dahlman Renewable Technology contributed by assessing the suitability of the treated sewage sludge for indirect gasification and translate the findings to engineering solutions and the economics of this new feedstock. RWE determined quality specifications for the sewage sludge treated by TORWASH®, as well as performed mapping the feasible co-firing ratios and combustion conditions. Due to the limited amount of material produced by the TORWASH® pilot facility, no full-scale co-firing test was conducted.

2.4 Expected outcome

The results of the 15 month project contribute to a large extent to the valorization of sewage sludge by TORWASH® treated biomass streams and enables ECN part of TNO to accelerate the scale-up of the TORWASH® technology to a demonstration-scale plant.

The pre-treatment route contributes to the sustainability goals of the water authorities, as described in the ‘Bestuursakkoord Water’. Water treatment cost are expected to be significantly reduced when using TORWASH®.

For Dahlman Renewable Technology and RWE the results of characterization of TORWASH® treated sewage sludge gives useful insights into this new, locally available biomass stream. Until now, for Dahlman Renewable Technology and RWE this feedstock was not suitable for combustion or gasification, due to the problematic ash composition and the high moisture content.

3 Project execution

3.1 Results

The work conducted in this period resulted in many valuable and interesting findings, when comparing the gasification and combustion properties of several sludges, raw or pre-treated by means of TORWASH®. The TORWASH® process was shown to significantly reduce the amount and concentrations of potassium, sodium and chlorine in the sewage sludge both at the lab-scale (autoclave tests of 2015) and at the pilot-scale (framed under the EnCORE project, 2018). As has been proven at pilot-scale in the EnCORE- and this project, the TORWASH® process reduces the amount of solids and greatly improves the ability to dewater the sludge, resulting in a potential decrease of the sludge disposal cost by 80%. For the Netherlands this translates to 90 - 160 M€ per year. Extensive combustion and gasification tests and application studies (co-firing and gasification) were carried out various sewage sludges. These tests showed that undigested sewage sludge treated by TORWASH® reduce the risk of agglomeration when combusting a high ash fuel as well as reduce the required gas cleaning capacity, compared to untreated sludge. The undigested sewage sludge treated by TORWASH® is hence converted into a suitable biogenic residue for thermochemical applications, rather than energy inefficient waste disposal.

3.2 Highlights

During the past 15 months of the project, various undigested and digested sewage sludges were compared and treated by TORWASH®. The sludges treated by TORWASH® contained significantly lower concentrations of chlorine, sodium and potassium that are contaminants in thermochemical processes like combustion and gasification. These contaminants can cause severe corrosion, fouling, agglomeration and particulate and gaseous emissions, thus are undesired elements in the feedstock. Gasification of treated sludge yielded a product gas that contains more hydrocarbons and has a higher calorific value, compared to untreated sewage sludge gasification. This is beneficial for syngas applications like synthesis and chemicals valorisation. Compared to untreated sludge, the contaminant levels are lower, reducing the required gas cleaning capacity, although the levels of contaminants are still high, in comparison to clean biomass like wood. Sludge pellets made of the treated material showed excellent durability and the moisture uptake was limited.

Figure 1 First batch of TORWASH® sewage sludge pellets

Extrapolation of data to Almere full-scale waste water treatment plant capacity.
The capacity of the waste-water treatment plant of Almere (part of the Zuiderzeeland Regional Water Authority) is 300.000 inhabitant equivalents (i.e.). This capacity translates to roughly 4600 ton dry matter per year. Pre-treating the sludge by TORWASH® would result in approximately 2200 ton dry undigested sludge treated by TORWASH® per year. At a sludge moisture content of 30% and 8000 hours of operation, this translates into a thermal input of the gasifier or combustor of approximately 1.2 MW_{th}, on a Lower Heating Value (LHV) as received bases. 1.2 MW_{th} is too small for local processing and hence centralized processing at a larger scale would be needed. The MILENA technology is available at a capacity of 6 MW_{th} and 30 MW_{th}, thus suitable for centralised processing of sewage sludge from several waste water treatment plants, e.g. from the Zuiderzeeland Regional Water Authority, Wetterskip Fryslân and/or other water authorities.

When combusting 2200 ton of undigested sludge treated by TORWASH® per year for e.g. 90 degrees Celsius heat generation and a thermal efficiency of 85%, the heat output would be ±1.0 MW. In case of gasifying the sludge, the product gas output would be ±0.9 MW. This product gas contains approximately 5 kg/h of hydrogen, which would be enough for fuelling approximately one fuel cell vehicle per hour. Benzene, toluene and xylene (BTX) are valuable chemicals and as rule of thumb, for the Almere case, based on an optimized system configuration, including C_2-aromatization, lab-scale BTX recovery data for biomass, and a May 2019 EU benzene price of 680 €/ton, a yearly BTX revenue of approximately €50.000 could potentially be generated. This revenue is not enough to justify the CAPEX and OPEX of such a small system. An economical feasible gasification - BTX co-production system would need to be approximately ten times larger than the Almere case.

The following recommendations can be made:
- Additional runs treating sewage sludges from various waste water treatment plants using the pilot TORWASH® plant in order to optimize the process.
- Long-term behaviour of combustion and gasification of undigested sludge treated by TORWASH® is not yet known, therefore a duration test is recommended.

- Perform business case calculations of a TORWASH® plant and sludge application either using gasification or when co-firing.
- Valorisation of BTX can improve the economic feasibility of the gasification business case, however, BTX removal from sewage sludge derived product gas has never been investigated, thus gasification experiments with BTX co-production at lab-scale are recommended, using sewage sludge, treated by TORWASH® as feedstock.

3.3 Project challenges

In the project, the delivery of sludges treated by the TORWASH® process depended on the production by pilot-scale TORWASH® unit, located at the WWTP in Almere. This pilot-plant was developed, constructed and commissioned during the S2PP project duration, framed under the EnCORE project. As a first of a kind installation, production was delayed and only undigested sludge treated by TORWASH® could be delivered on time. For the digested sludge treated by TORWASH® we had to fall back to ECN part of TNO autoclave results of 2015.

3.4 Application of results

Studies of end-use of sewage sludge treated by TORWASH® by means of gasification and co-firing with coal/biomass were conducted by DRT and RWE. In the case of gasification and compared to clean biomass gasification, the gas cleaning section needs to be revised for removal of the acid and base contaminants, but these changes are not insurmountable obstacles within the industrial design of the MILENA and OLGA. Gasification of sewage sludge results in a product gas that is suited for gas boilers, engines and after further optimization for synthesis purposes. For co-firing sludge with coal and biomass in the Geertruidenberg (Amer) bio-CHP, the study indicates that the emissions are not a critical factor at the studied co-firing percentages. However, the ash quality is strongly influenced by the type of sludge and of all studied cases, only the case in which 5% of undigested sludge treated by TORWASH® was co-fired yielded on-spec ashes. Phosphate levels in the ashes were too high in most cases, thus all other cases yielded off-spec ashes that would need to be disposed of as industrial waste, leading to the highest financial costs. The fate and distribution of phosphorus in the TORWASH® process is tuneable and R&D focus should lie in reducing the amount in the solids by either concentrating the phosphorus in the TORWASH® effluent or by recovering the phosphorus from the solids before combustion.

In general, for thermochemical applications undigested sludge treated by TORWASH® is preferred above digested sludge treated by TORWASH® because the digested sludge feedstock contains very high levels of phosphorus, sodium and sulphur which can cause issues like agglomeration, fouling and costly ash disposal.

3.5 Contribution to the Bio Based Economy

The pre-treatment of sewage sludges by the TORWASH® process contributes to the Bio Base Economy by contributing to renewable energy goals because the total amount of sewage sludge can be reduced by 70-80%. As has been proven in the EnCORE- and this project, the TORWASH® process reduces the amount of solids and greatly improves the ability to dewater the sludge, resulting in a potential decrease of the sludge disposal cost by 80%. For the Netherlands this translates to 90 - 160 M€ per year. The reduction of the total amount of sewage sludge to dispose of implies a significant reduction in sludge transport movements, their associated greenhouse gas emissions, a significant fossil fuel reduction for drying the

sewage sludge. The treated sewage sludge changes from a waste with practical no calorific value into a viable bio-feedstock for thermochemical processes that result in a net increase into renewable energy and/or products across the value chain.

Case studies have been performed and for gasification there are possibilities to use the product gas in various applications (boiler, gas engine, BTX co-production), although the high levels of sulphur compounds and nitrogen compounds in the gas will require a re-design of the gas-cleaning island. Fossil fuel derived BTX aromatics are very important petrochemical materials for production of polystyrene, polycarbonate, phenolic resins, polyurethane, polyester, etc. Co-production of BTX from sewage sludge derived product gas, contributes to the bio-based economy by production of ‘green BTX’ to produce ‘green polymers’.

From the co-firing studies of coal, biomass and sewage sludge it can be concluded that the undigested sludge treated by TORWASH® is a suitable co-firing fuel that can contribute to >20% of the Geertruidenberg bio-CHP renewable energy production from the studied co-firing mixes. The next step in de development of new application routes for sewage sludges treated by TORWASH® is large-scale production of the treated sludge and full-scale test burns.

4 Dissemination

With this work package of project management and dissemination besides the confidential and public reports provided to the TKI-BBE specific deliverable were defined with regards to scientific publications in a journal or at international conference. The table below shows what and where the TORWASH® technology was presented.

Table 1 Dissemination activity

Activity	Where	Date
TORWASH® sewage sludge treatment	Symposium slibontwatering, Utrecht	14-9-2017
Twitter News items	#TORWASH	
Demonstration of a continuous TORWASH® pilot plant for dewatering of sewage sludge	Innovaties binnen slibverwerking, Soest	20-6-2019
TNO Website: TORWASH technology successfully tested on pilot scale at a wastewater treatment plant in The Netherlands	https://www.tno.nl/en/focus-areas/ecn-part-of-tno/roadmaps/towards-co2-neutral-fuels-and-feedstock/biomass-to-fuels-and-feedstock/torwash-technology-successfully-tested-on-pilot-scale/	
News article: TORWASH®: innovatie voor het verwerken van zuiveringsslib	https://www.waterforum.net/torwash-innovatie-voor-het-verwerken-van-zuiveringsslib/	20-5-2019

5 Signature

Petten, 25 June 2019

ECN part of TNO

A.J. Grootjes
Author

P. Nanou
Scientist

M.H.F. Overwijk
Research Manager