Final report

1.1 Project details

Project title	Demonstration of Renescience full-scale plant - 2
Project identification (program abbrev. and file)	64015-0041
Name of the programme which has funded the project	EUDP 15-I
Project managing company/institution (name and address)	Ørsted A/S Kraftværksvej 53, 7000 Fredericia
Project partners	N/A
CVR (central business register)	27446469
Date for submission	March 16th 2020

1.2 Short description of project objective and results

English
The purpose of the project was to demonstrate the Renescience technology in a full-scale facility, as an integrated part of the waste handling system. The Renescience technology covers the principle, where the biodegradable part of household waste is utilized for biogas production, which was demonstrated during working package 6. Furthermore, the potential of separating the non-biodegradable fraction were shown. Collaboration agreements were made with 3rd parties to off take the separated fractions for recycling. By establishing a full-scale plant, the maturity and commercial potential of the technology are validated. The commercial potential needs to be verified by final testing, which are planned to be carried out in 2020, subsequent to larger improvements applied on the plant.

Danish
Projektets formål var at demonstrere de teknologiske aspekter bag Renescience i fuldskala, som en integreret del af et samlet affaldshåndteringssystem. Renescience bygger på teknologi, hvor den bionedbrydelige fraktion af husholdningsaffald udnyttes til biogas, hvilket lykkedes i forbindelse med arbejdspakke 6. Ligeledes blev det eftervist, at den restende fraktion håndteres med henblik på optimal genanvendelse ved sortering og genanvendelse af 3. part, hvor indkøbsaftaler er indgået. Ved etablering at anlæg i fuldskala demonstreres teknologiens modenhed og kommercielle potentiale. Det kommercielle potentiale mangler endnu at blive eftervist, men der er en realistisk plan for gennemførsel af dette i 2020 efter større modifikationer på anlægget.

1.3 Executive summary

The purpose of the project was, as following stated in the project proposal;

" The purpose of the project is to demonstrate the Renescience technology in full scale as an integrated part of ***total waste processing system*** *including use of the* ***biodegradable part for biogas*** *and the utilisation of the remaining parts of the* ***waste for recycling****, and to demonstrate* ***the maturity and commercial readiness*** *of the technology."*

The proposal was based on 3 working packages:
Working package 4:
Design and planning including Maturation and permitting; obtaining permits and tendering.
Working package 5:
Construction were covering execution; Civil works, machine construction, instillation on site, Mechanical completion checks.
Working package 6:
Commissioning and evaluation were covering commissioning, operation and evaluation of plant performance.
Working package 4 was completed within the deadline, working package 5 were delayed but finalised within project period and working package 6 is in the phase of final execution of objectives. The major reason causing the delay in the project pipeline was the issues caused by the large upscaling of the process, which was more than tenfold of the testing facility, and the novelty of the technology. Several technical improvements of the original design were implemented in order to achieve the desired plant capacity, thus causing delay in the commercialisation.
The potential of the Renescience technology as an integrated part of the total waste processing system was stated as the household waste was converted into recyclable fractions all with off takers on the waste recycling market. The recycling potential of the Renescience technology was additionally increased during the project, due to optimised sorting technology and the upcycling of the sludge from the anaerobic digestion plant. Additionally, the biodegradable part of the household waste was by success converted into biogas with a biogas potential comparable to the one from food waste.
Extensive knowledge and experience were conducted as a function of the establishment of the first full scale Renescience plant. It is expected, that this will be applied in the following Renescience plants in the project pipeline. The technology is expected to be utilised globally and contribute to the revolution of the waste handling system in order to establish a sustainable waste recycling system to handle the increased demand for solutions coping with the continuously increasing amount of waste.

1.4 Project objectives

Description of project objectives:
Renescience is a novel waste separation technology that is utilizes a unique combination of enzymes and microorganisms to convert the biodegradable fraction of household waste into bioliquid for biogas and separates the non-biodegradable part into further fractionation. In the project proposal "core technology" covers the maximum recovery of bioliquid and supply of cleaned solid fractions for further recycling. Other activities carried out on site as anaerobic digestion of bioliquid and further fractioning of solid fraction are defined as conventional technologies and con-

sidered out of scope in this specific project, thus defined as "non-core technology". The input-output relation related to the core and non-core technologies of Renescience are collected in an overview in Figure 1

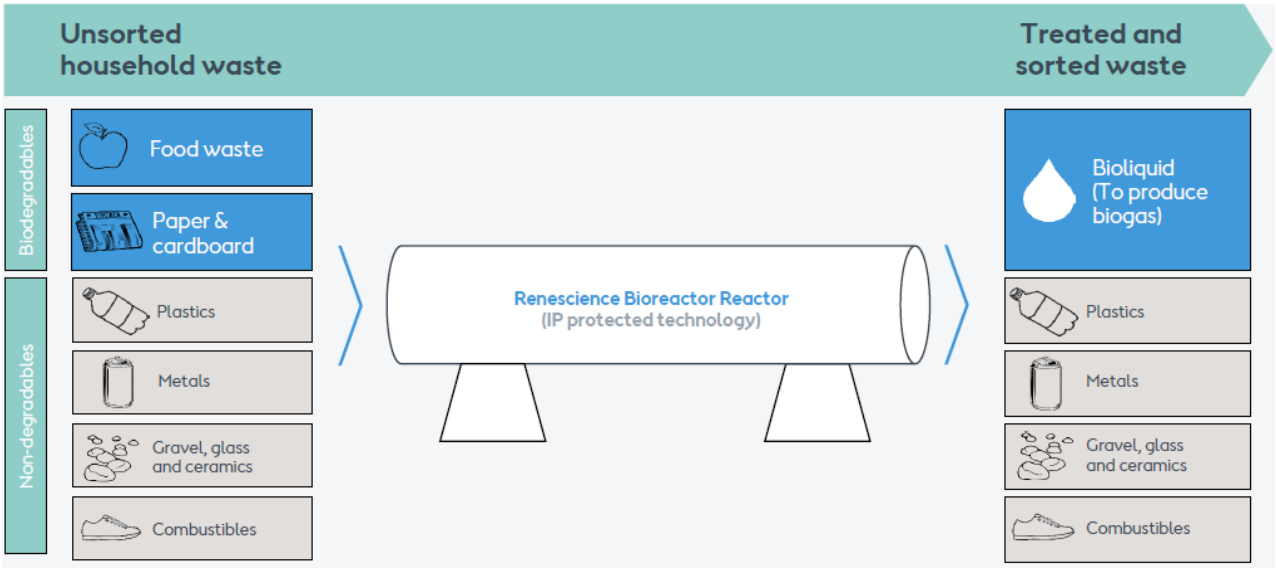

Figure 1 A figurative illustration of the biodegradable and non-degradable components of the waste and how the various fractionation from the Renescience plant are categorized.

An overview of the Renescience technology by 2020 is presented in Figure 2. The illustration covers the waste cycle from entering the plant and until fractioned into 8 different outputs. A more detailed description of the whole process is presented in Figure 2.

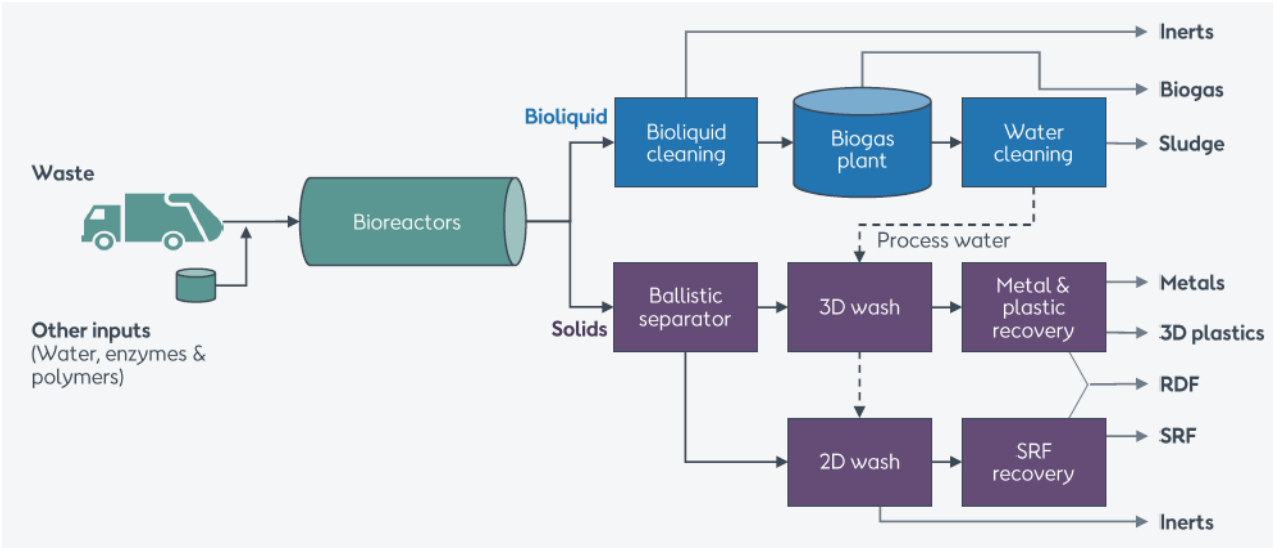

Figure 2 Renescience process; Enzymatic and microbial degradation of biodegradable material as organics and paper. Cleaning, sorting and recycling of metals and plastics.

Renescience is an important step in the revolution of waste treatment, which substantiates the increased focus on the environment and utilization of resources from waste as outlined in the EU regulation. Use of enzymes and microorganisms for waste treatment is novel and a vast amount of resources for research and development have been required in order to establish broad knowledge regarding handling a material as disparate as waste.

To optimize the utilization of Danish subsidies, the ideal location in relation to EUDP funding would have been a Danish location. Prior to initiation of the Renescience full scale demonstration plant project, a Danish location was extensively explored with several municipalities; mainly municipalities in the Triangle Area (Fredericia, Kolding, Vejle and Middelfart) were evaluated. Unfortunately, the municipalities were not able to develop a long-term strategy for the project, due to no consensus on the collaboration terms and the uncertainties about the future waste regulation in Denmark and the European Union. A collaboration with the municipality of Copenhagen were also initiated, but the time schedule for an investment decision were exceeding the actual project timeframe. The carry out of the project at a location outside Denmark were necessary, due to the importance of commercializing the technology by upscaling. The need for new solutions were important, in order to meet both the existing and coming ambitious waste regulation with emphasis on utilization of waste, both regarding recycling and production of biogas.
As an alternative to a Danish location, a project with FCC Environment in UK were chosen due to several reasons, including the below-mentioned:

- The United Kingdom's market seemed attractive for the Renescience technology on short term, since the waste system did not cover incineration and very high landfill costs are present due to high environmental taxes on waste for landfill.
- FCC Environment is a strong player on the waste market in the United Kingdom.
- FCC Environment is part of FCC Group, whose main focus is urban infrastructure, where they see great growth possibilities. Advanced waste solutions are one of their business areas and they handle 7 million tons of waste per year.
- Ørsted do already have well established activities in UK and is therefore accustomed doing business in this country.
- The partnership with a large international company within the waste area can be considered a blue stamp for the Renescience technology and thus a more valid show case than with a Danish municipality.

The demonstration of Renescience were based on the extensive market investigation decided to be placed in United Kingdom on a 100 % Danish owned facility.

The technological risk stated in the application were mainly concerning upscaling of the project. The process was tested at the demonstration plant at ARC with app. 10.000 operating hours with 3000 tons of waste processed. Testing at ARC documented the potential of the biological conversion. By successful upscaling, the project would contribute to the goals established by the European Union; 50 % recycling of household waste and aerobic digestion of biodegradable part of the waste. The upscaling was determined to be by more than a tenfold compared to the pilot scale – any obstacles occurring as a function of the large upscaling were in project definition identified as a large risk. More specific, the financial aspects from the risk were stated in the project description as;

1) Costs associated with alteration of the plant due to unfortunate design
2) Capacity and availability of the plant
3) Final price of the plant

The execution of the project was covered by 6 working packages (WP), whereas WP 1-3 were covered in EUPD project "REnescience – full scale Demonstration plant", journal number 64013-0162. WP 4-6 included in "Demonstration of Renescience full-scale plant - 2" is as following; Design and planning (WP4), the construction phase (WP5) and evaluation (WP6). Timeline for the different phases and sub categories are presented in Table 1.

WP4:
Design and planning were including Maturation and permitting; obtaining permits and tendering. The working phase were scheduled to be initiated June 2015 and finalized September 2015.

WP5:
Construction were covering execution; Civil works, machine construction, instillation on site, Mechanical completion checks. The project package was scheduled to be running from October 2015 and until December 2016.

WP6:
Commissioning and evaluation were covering commissioning, operation and evaluation of plant performance.

Table 1 – Original WP's in project "Demonstration of Renescience full-scale plant 2" and project timelines. Column 1 are showing legends for the working packages and the different sub-categories. Column 2 indicates the project timeline.

Working packages	**Timeline**
WP4 – Design and planning (Maturation and permitting)	June 2015 - September 2015
Obtaining permits	June 2015 - September 2015
Tendering	June 2015 - September 2015
WP5 – Execution (the construction phase)	October 2015 – December 2016
Civil works	October 2015 – January 2016
Machine construction	October 2015 – September 2016
Installation on site	February 2016 – November 2016
Mechanical completion checks	October 2016 – December 2016
WP6 - Commissioning and evaluation (evaluation)	January 2017 – December 2018
Commissioning	January 2017 – June 2017
Operation - ramp up profile	February 2017 – December 2018
Evaluation of plant performance and implemented solutions	July 2017 – December 2018

Development of project

Project evolvement, milestones:

1) The first milestone was obtained July 2015, where final investment decision (FID) were achieved.
2) Second milestone were initiated in February 2016, covering installation of the plant. The installation process was done January 2017. A drone photo of the Renescience plant subsequent to installation can be seen in Figure 3.
3) Final mechanical completion of the plant was initiated and completed in February 2017, 2 months after the milestone stated in the project proposal.
4) The plant was ready for handover from contractors to Ørsted ultimo December 2017, initiating WP6, "Learning and adaption phase". Due to technical obstacles, it was impossible to move the project into working package 6 at the deadline.
5) Commercial milestone 1, Full financial support: October 2016 full financial support for the project was established.
6) Commercial milestone 2, Entitled for Return on capital (ROC) support.

Figure 3 the plant subsequent to second milestone, full installation process was done and ready for handover.

Technical issues were causing the delay in WP 5, thus extending subsidy period with a year. An ideal period for execution of WP6, "learning and adaption phase" would be two years. The aim of WP 6 was to obtain extensive knowledge regarding operation of the plant in order to achieve the expected throughput, optimising process control and implementing necessary modifications.
Due to several technical issues, a lot of modifications were implemented thus leading to further extensions in WP 6.

1.5 Project results and dissemination of results

The construction of the first plant demonstrating the Renescience technology, were mainly intended to review the potential of upscaling the existing pilot plan at ARC. Even though the achievement of milestones especially concerning WP 5 & 6 were delayed, the first full scale Renescience plant is established and processing waste. The plant is demonstrating high conversion of biodegradable material into biogas by

anaerobic digestion of the bioliquid and high recycling potential of non-biodegradable material, even though the commercialisation process has been delayed according to the initial deadline.
As the result of the establishment of the first full scale Renescience plant the Renescience process proves its potential as a novel waste handling solution on the following parameters presented in Figure 4.

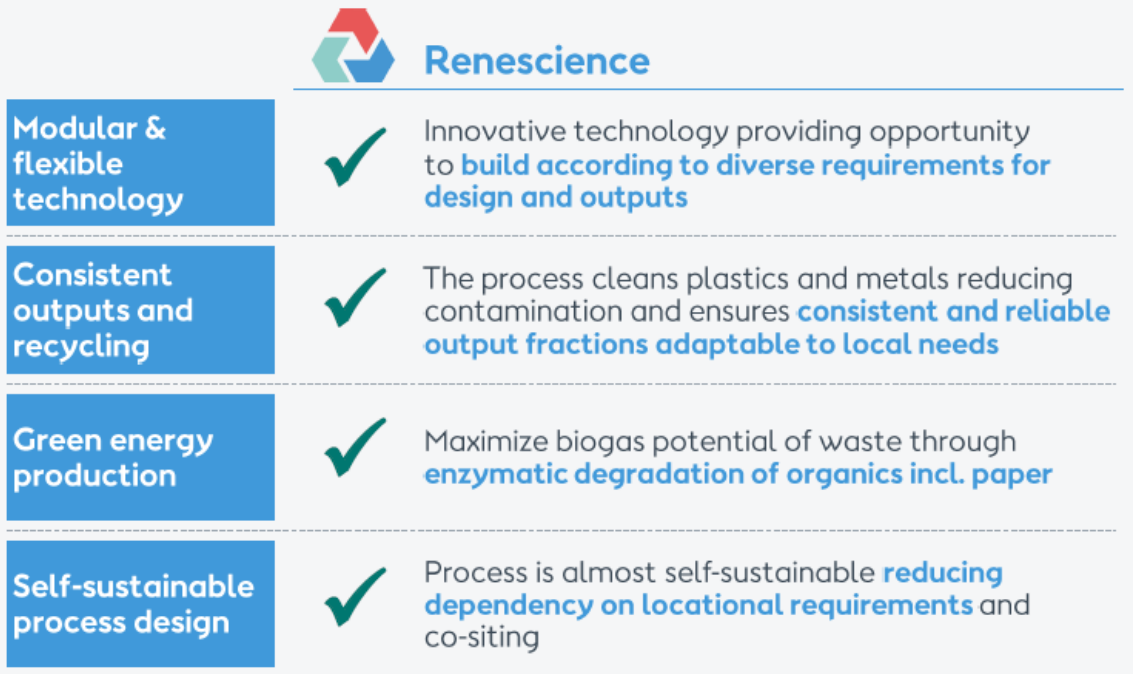

Figure 4 beneficial properties of Renescience technology

As it can be seen on the 4 parameters, the performance within the core technologies are complying with the ones expected in the project proposal. The full-scale Renescience plant has been able to enzymatically degrade biodegradable components of the waste and deliver cleaned outputs suitable for recycling.

Results delivered regarding project scope
The project scope was defined in the project proposal as;

*" The purpose of the project is to demonstrate the Renescience technology in full scale as an integrated part of **total waste processing system** including use of the **biodegradable part for biogas** and the utilisation of the remaining parts of the **waste for recycling**, and to demonstrate **the maturity and commercial readiness** of the technology."*

The following sections elaborates on results regarding the different subsections:

Commercial readiness
In order to increase current plant capacity in working package 6, several of adjustments were established along the project period in order to comply with the final target:

Ventilation system

Purpose:
Improvement of work environment

Background:
The air replacement at the plant were not at a high enough standard, since the emission from the process were higher than originally expected.
As safety and health is a key priority for Ørsted, projects of this character are prioritised above other thus leading to further delay. The status of the plant is now, that it is running according the very thorough quality, environment, health and safety requirements, proposed by Ørsted.

Solution:
The ventilation system was improved in order to ensure high quality air replacement.

The ramp-up were successfully finalised December 2019, leaving the final test prior to commercialisation to be carried out in 2020.
As stated in the project proposal, the major risks associated with the up-scaling were the large increase in capacity. The different obstacles faced during the project period were mainly caused by unfortunate design of the back end of the plant when increasing throughput, as mentioned as a financial risk in the project proposal.
Issues within both core and non-core technologies were all contributing to the final understanding of the plant design and construction and will be utilised when designing the next full-scale Renescience plant.

Turnover have not increased during the project period, since larger investments have been necessary in order to modify the plant. Full financial support has been delivered from Ørsted in order to achieve commercialisation. The plant is expected to deliver improved financial results during 2020. Employment of both local employees and employees based in Denmark have been carried out during the project period. The Renescience team now have a headcount of app. 65 persons covering a variety of professions. The concept is expected to be utilised in the near future for establishment of several plants in a global context. This will of course additionally increase the demand for labour, both inside and outside Denmark. It is expected, that all future plants should be 100 % Danish owned, and thus benefit the Danish industry.

Total waste processing system and recycling of non-biodegradable parts
Among the beforementioned modifications of the plant, a lot of improvements have been made in the sorting hall. This was in order to refine the fractions collected from the sorting process. This is an important parameter regarding the recycling potential of the plant. To reach the energy policy objectives stated by the European Union, the recycling rate needs to be maximised. The recycling rate of the initial design were satisfactory, but it is a core value in the Renescience concept to reach as high recycling potential as possible of the waste, in order to strive for the most sustainable waste recycling process on the market. A market analysis has been made during the project period comparing the recycling rate of Renescience against incineration and mechanical biological treatment (MBT), representing two other

common recycling methods. Results indicate that Renescience can reach the EU recycling goal of 55 % in 2025 and 65% in 2035. This supports the energy policy objectives for the European union, since it proofs the potential of Renescience as a more efficient method to reach the objectives.

During the project period, additional 4 patent applications have been filed based on the Renescience technology. A European patent has been published regarding the potential of using the sludge from the anaerobic digestion at Renescience Northwich as a partly replacement for or additive to bitumen in asphalt. The unique composition of the remaining organic fraction from the Renescience process, allows it to be used in asphalt, thus replacing a fraction of the bitumen and acting as a polymer modified bitumen. Recycling rates of the Renescience technology are improved by this initiative, originating from testing of output materials from the full-scale plant. The overall interest of the project is expected to be correlated to the increased recycling rate, as the focus on new green energy alternatives have solely increased since project proposal.

Utilisation of biodegradable part for biogas production

During the ramp-up period, the potential of biogas production from the bioliquid delivered from the Renescience technology were evaluated. Even though the process were not running at maximum capacity, the biogas potential of the Renescience plant were able to produce biogas comparable or above the potential in household waste.

As it can be seen in Table 2, the source separated household waste has biogas potential of 50-70 m^3 CH_4/ton source separated household waste, where bioliquid from the Renescience process produces methane in the high end of this range.

Table 2 - biogas potential of different substrates. The potential is defined as m^3 methane (CH_4) produced per ton of substrate

Substrate	**Biogas [m^3 CH_4/ton]**
Manure	10
Source separated household waste	50-70
Organic industry waste	50-100
Straw	100

Technical maturity

The maturity of the technology was verified by the production of high-quality outputs. Biogas were produced at satisfactory amounts according to the input into the anaerobic digestor. The sludge from the biogas production were valorised as stated in the patent publication as a replacement for some of the bitumen fraction in asphalt. The fractionation in the sorting hall were optimised delivering even more specialised outputs with higher recycling potential than expected. An example showing two outputs from the sorting part in the plant are presented in Figure and Figure 6. Off takers were found for all substrate, which just verifies the maturity of the concept and the demand for substrate for products made from recyclables.

Figure 5 - Metal fraction produced at the full-scale demonstration plant, Renescience Northwich

Figure 6 – 3D and 2D plastic fraction produced at the full-scale demonstration plant, Renescience Northwich.

Dissemination of results

It is expected, that the results will be disseminated to visitors from the public during 2020, visualising the potential of the technology counter the large interest from the public.

The maturity of the project has been stated in the construction of the first full scale plant. It has been shown that the technology can deliver a high-quality waste processing solution, which can be applicable to unsorted household waste.

Figure 7 - Commercial data on the Renescience demonstration plant, REMO (Mobile testing unit of Renescience) covering objectives, timescale and requirement.

By having a physical demonstration plant established, the potential customers can see how the technology is applied and discover the potential regarding flexibility of the solution.

Along dissemination of the full-scale plant Renescience Northwich, a mobile testing unit of Renescience have been designed to prove of concept anywhere in the world. The container size model demonstrating the technology can be shipped to the location of interest and applied in the local waste handling system. The objectives, timescale and requirements to potential customer are specified in Figure 7 whereas the results from tests around the world are presented in Figure 8. It is expected, that a combination of the full-scale plant and REMO in combination can serve as a practical example of the great potential of applying Renescience in waste handling systems on a global scale.

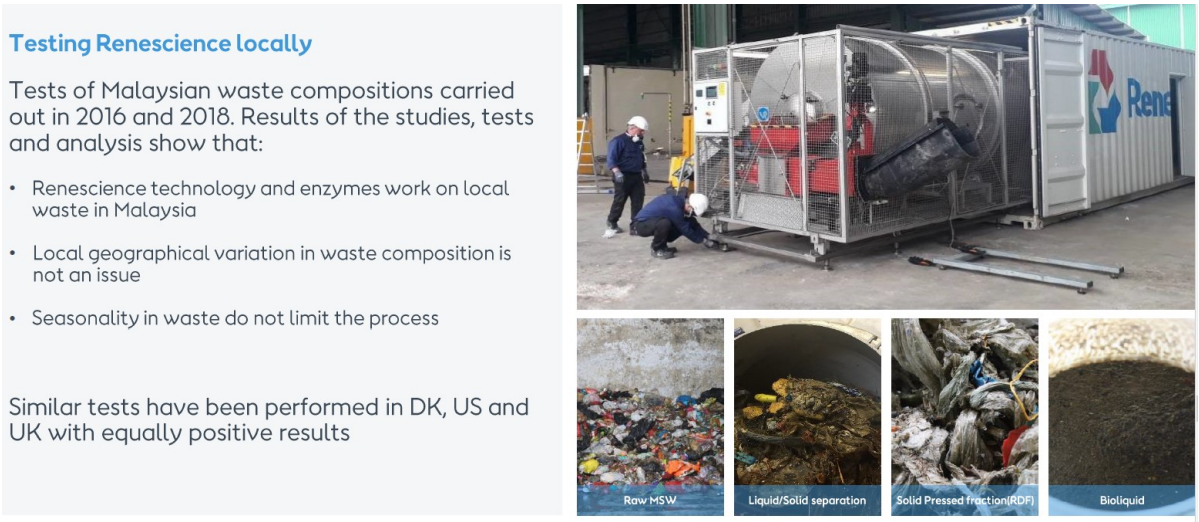

Figure 8 - Results from the test of waste processing with REMO in Malaysia 2016 and 2018

1.6 Utilization of project results

Future context for the Renescience technology

Renescience Northwich is established as a full-scale plant, demonstrating the functionality of the Renescience technology. Extended knowledge regarding the construction and commercialisation of the plant were gathered during the project and are expected to be used in further development and implementation of the Renescience technology. The intention is to use the first Renescience Northwich plant as a Prototype, transferring the learnings into a version two plant.

The mission is, to apply Renescience at the global market, with locations based on where the demand is highest for a green waste technology. An important criterion for future locations is, that Renescience should be applicable as an integrated part of the total waste handling system or at least be adapted to the current system due to the highly flexible concept. Furthermore, the intention is for Ørsted A/S to have ownership of the plants, and thus ensure Danish ownership.

Since the concept is highly flexible and the experience obtained regarding the technology is complex, it would be an opportunity to offer an individualised solution, adopted to the different stakeholder's demand. This aspect can be incorporated into an updated business model among other learnings gained from the project.

Due to the novel aspect of the technology, is it expected to continuously claim patents within the technology as the experience and knowledge are expanded. Since the technology is incommensurable to other already existing waste processing technologies on the market, its potential for protection of intellectual properties by publishing patents are important in order to ensure lead time and protect the future position on the market.

Energy policy objectives

It was stated in the project proposal, that the Renescience technology would contribute to the EU framework of reducing energy emissions of greenhouse gasses by 20 % in 2020 in sectors without quota. Even though it has not been accomplished to contribute as expected to the reduction of green house gasses, extensive knowledge and experience has been gained regarding the technology. The roll out of the following plants are expected to have a huge impact on the waste processing industry. As stated in the project proposal, it is estimated that only 25-30 % of household waste is currently used as a resource. As it can be seen in Figure 9, a slight increase in the utilised waste fraction has been applied since the project proposal was submitted, but as it also shows, the total volume of municipal solid waste has been increasing and the trend is expected to continue.

Figure 9 - Development in the municipality solid waste globally.

Life cycle analysis

During the project period, a life cycle analysis has been conducted by the external company CE delft, showing the sustainable potential of Renescience compared to other waste processing technologies. The assessment was based on the following functional unit; The treatment of 1 tonne of residual household waste (composition stated in the annex in the summary) and the subsequent treatment of (valuable) recovered materials and final waste stream. Impact assessments evaluated in the analysis were based on 40 % human health, 40 % Ecosystem and 20 % resources. The columns in Figure 5 shows the results from the life cycle analysis, where the score is indicating how positive an environmental effect the different methods have. As indicated, Renescience is scoring above 50 % higher than incineration and are also showing higher potential than the mechanical biological Treatment. As stated in the report, the main advantages of Renescience compared to mechanical biological treatment are the higher biogas production and plastic recovery. The only advantage of the mechanical biological treatment is the less input of other resources (e.g. enzymes, heat and electricity)[1].

This strengthens the hypothesis as Renescience as an effective tool to support the achievement of the energy policy objectives stated by the European Union.

[1] LCA by Delft: https://www.ce.nl/en/publications/1971/summary-lca-renescience-comparison-of-wet-and-dry-post-consumer-municipal-waste-separation

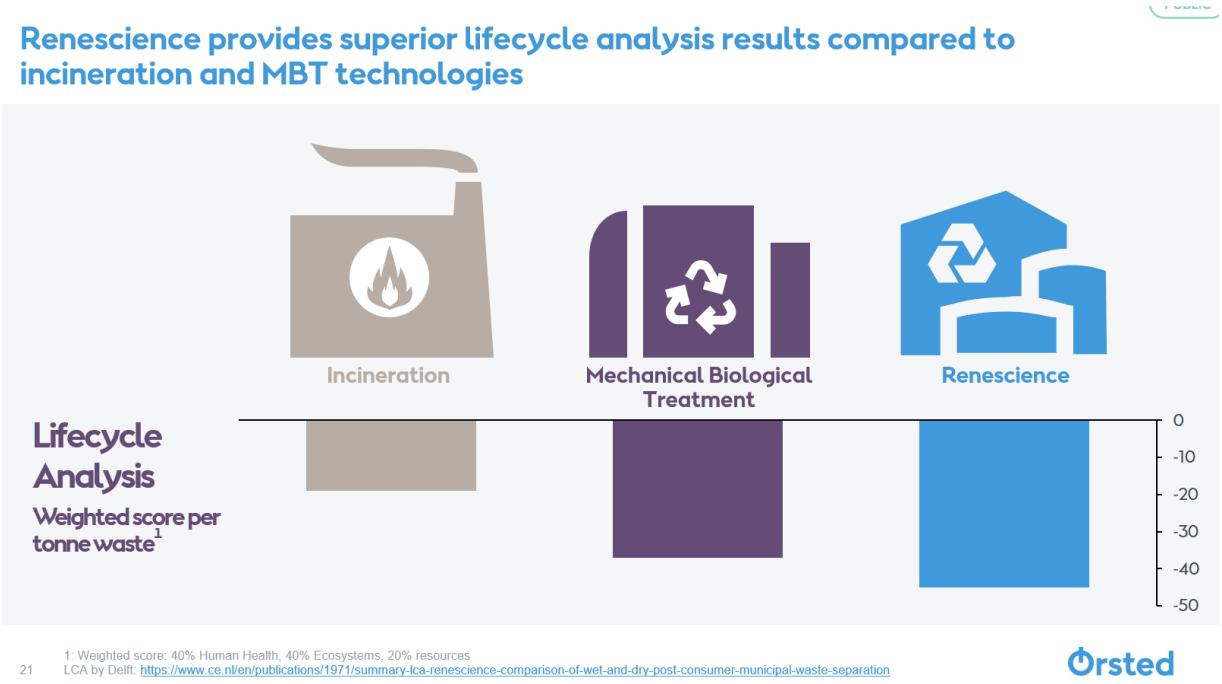

Figure 5 Results from Life Cycle Analysis carried out on Incineration, Mechanical Biological Treatment and Renescience technologies

1.7 Project conclusion and perspective

The purpose of the project was to establish the first full scale version of a Renescience plant. Previous testing at ARC substantiated the potential of a full-scale version of the production. During the project period, it was possible to fulfil the two working packages; WP 4 "design and planning" and WP 5 "The construction phase". The remaining project package "Evaluation" is expected to be finalised within a short time frame. During the project period, several obstacles were causing delays in the progression. Improvements of the plant design were implemented in order to reach the expected potential of the plant, showing good results. Taking the novelty of the technology into consideration, the outcome of the project in the form of experience and knowledge have been extensive. According to the sustainable profile of the technology, it has been substantiated by both the proved biogas potential of the bioliquid, enriched recycling rate and the positive life cycle analysis, stating Renescience as a strong alternative to the existing waste processing technologies on the market.

As the commercialisation is expected to be finalised soon, the wide knowledge and experience during the project is ready to be utilised in the next Renescience plant. The maturity of the technology has been proved in construction of Renescience Northwich. This substantiates the establishment of more Renescience plants globally, hence providing the waste recycling market with a green and novel technology with the potential of a major impact in the process of reaching the European energy objectives.

The improvement of recycling rate and the verification of the biogas potential during the establishment of the first full scale plant have shown the potential of development of the technology in order to continuously improvement of the technology in order to reach even higher recycling potential of household waste than expected prior to project execution.