# Final report

## 1. Project details

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| **Project title** | Concentrated solar heat combined with biomass-ORC for combined power and heat plant |
| **File no.** | 64015-0626 |
| **Name of the funding scheme** | EUDP |
| **Project managing company / institution** | Aalborg CSP A/S |
| **CVR number** (central business register) | 21142042 |
| **Project partners** | Jan Holst Rothmann — Aalborg CSP A/S<br>Thorkil Bartholdy Neergaard — Brønderslev Forsyning<br>Jørgen Røhr Jensen — Niras<br>Per Alex Sørensen — Plan Energi<br>Simon Furbo — DTU |
| **Submission date** | 22 December 2020 |

# 2. Summary

*Describe the objectives of the project, the obtained results and how they will be utilized in the future.*

*The short description should be in two versions:*

- *English version*

The main goal of the project is to develop and establish a test plant that combines the biomass-fired organic Rankine Cycle (ORC) heat and power plant in Brønderslev with concentrated solar power (CSP) production through a shared thermal oil circuit.

Furthermore, the goal of the project is to prove that the above mentioned is possible and subsequently to make the technology competitive in order for it to be sold without grants or subsidies.

The primary market for the product will be the 250 biomass-fired ORD plants that are already established all over the world, most of which in the centrale part of Europe.

The solar plant was developed and established in 2016. For the project in Brønderslev the design of the Aalborg CSP solar collectors have been optimized and thereby resulting in a 20% price reduction on this specific part of the plant.

The thermal oil circuit, which is shared between the CSP solar field and the chip-fired boilers, and which supply the ORC turbine, have been designed, developed and established and the interconnection of the two systems has been carried out in accordance with the control strategy.

On the world market, the low prices on fossil fuels and the price of PV power have dropped significantly, which has challenged the competition.

Lately, the district heating plants have made a switch from being an electricity producer, to being an electricity consumer with electric boilers and electric heat pumps, thereby reducing the future market opportunities on the Danish.

On the foreign markets, there are still opportunities to be located. Aalborg CSP has promoted CSP / ORC plants all over the world. Especially Australia has been a point of focus and time and resources has been spent on both marketing and sales work in Australia

- *Danish version*

Projektets mål er at detailprojektere og opføre et demonstrationsanlæg, som kombinerer et biomasse kraftvarmeanlæg i Brønderslev, med en fælles termisk oliekreds til et organic rankine cycle (ORC) anlæg sammen med koncentrerede solfangere (CSP).

Projektets mål er at eftervise at ovenstående er muligt og efterfølgende gøre teknologien konkurrencedygtig så den kan sælges uden tilskud.

Det primære marked er de 250 biomassefyrede ORC-anlæg, som allerede er etableret på verdensplan, de fleste af dem i Centraleuropa.

Solanlægget er opført og detailprojekteret i 2016. Brønderslev projektet har optimeret designet på solanlægget på Aalborg CSP-solfangere, så prisen kan reduceres med ca. 20% for denne del af et anlæg.

Den fælles termiske oliekreds for CSP-solfeltet og de flis-fyrede kedler, som forsyner ORC turbinen, er detail-projekteret, opført og samkøring af de to systemer er udført iht. styringsstrategien.

På verdensmarkedet har de lave priser på fossile brændsler og prisen for PV-strøm er faldet markant, hvilket har udfordret konkurrencesituationen.

Den seneste tid har fjernvarmeværker generelt bevæget sig væk fra at være el-producent, til at være el-forbruger med el-kedler og el-varmepumper, hvorved markedsmuligheder på det danske marked fremadrettet er reduceret.

På det udenlandske marked er der stadig muligheder. ACSP har markedsført CSP/ORC anlæg over det meste af verden. Specielt Australien har været et fokuspunkt, hvor der er brugt megen tid og ressourcer på marketing og salgsarbejde i Australien.

# *3.* Project objectives

- *What was the objective of the project?*

The goal of the project is to plan, develop, establish commission and operate a thermal oil plant consisting of a 16.6MW CSP-plant and 2 chip-fired boilers which supply an ORC plant with oil temperatures of up to 320°C.

The aim of the project is to prove this possible and subsequently to make the technology marketable without the need for grants or subsidies.

- *Which energy technology has been developed and demonstrated?*

Solar power (for production of both electricity and heat) in interaction with biomass-fired boilers in a thermal oil circuit.

# 4. Project implementation

- *How did the project evolve?*

The project started out as an interaction between the various parties and suppliers, in order to develop the right design for solving the task of connecting the oil systems to the ORC turbine for electricity and district heating production through heat exchangers - a task that had never been tried before.

The settlement of accounts for electricity production from the solar plant / biomass was not approved until January 2020. Hence, only after 1/1 2020 was it possible to obtain a settlement tariff from the Danish Energy Agency for the electricity production based on thermal solar energy. This delayed the project, and it was therefore not completed until the end of 2020.

We have succeeded in optimizing the cost of the parabolic solar troughs by 20% and thereby increasing competitiveness.

The control strategy, where the solar field achieved acceptable oil temperatures for the ORC circuit and where the interconnection of the oil systems worked as intended, was tested and commissioned during the spring of 2020. This type of plant is a flexible green solution that can produce both electricity and heat, thereby reducing the use of fossil fuels.

- *Describe the risks associated with conducting the project.*

With this testing plant it has been proven that parabolic solar troughs in Denmark are able of obtaining oil temperatures high enough to operate an ORD plant.

The settlement tariff was, however, not as expected and it has proven difficult to obtain a final clarification on the price from the Danish Energy Agency, as this type of green interaction technology was never seen before.

The project has revealed how to design an oil-based system that is flexible while still handling the task of electricity and heat production in an environment where fluctuating oil streams from the solar field might affect the interaction of the oil systems

- *Did the project implementation develop as foreseen and according to milestones agreed upon?*

From Milestone 1 to 3 the implementation went according to plan. Milestone 4 was delayed in regard to the validation of the interconnection of the biomass and ORC systems. The delay was caused partly by the lack of public approval and settlement concerning the interconnection og the solar field as well as due to the fact that the supplier of the biomass plant filed for bankruptcy in 2019. Because of these challenges we were granted a project extension until 31/12 2020 and have now completed Milestone 4.

**The commercial milestones**

- *Did the project experience problems not expected?*

The overall economic profitability of the CSP-BIO-ORC combination is of course dependable on the obtainable state imposed grants as the plant is producing electricity based on a renewable energy source (biomass). The grants are in Denmark issued in accordance with the Renewable Energy Act. During spring 2017, the Folketing changed the regulation to net being in favor of the plant in Brønderslev. This was due to the fact that the applied legal clause had to be disregarded, as the support clause had never been duly notified within the EU, and therefore was considered illegal.

It has not been possible to schedule a test run (Solar collector system / electricity / heat through the ORC plant), as a settlement tariff from the Danish Energy Agency on the electricity produced from the thermal solar energy was postponed until January 2020.

The project was affected by organizational and financial difficulties within EuroTherm (supplier of the ORC and the biomass plant) – resulting in the EuroTherm bankruptcy in June 2019. Prior to the bankruptcy, the biomass plant had failed to present a stable operation, (both when including the ORC plant and when excluding it), and hence a few flaws and errors which needed to be improved in order to obtain a stable operation suited for a test run.

When the commitment for electricity production grants for Brønderslev was withdrawn, it resulted in a lower settlement price (production grant) for electricity from both biomass and from the thermal solar collectors. Furthermore, the project is negatively affected by low prices on PV electricity, continued low prices on fossil fuels, as well as a tendency of district heating plants generally move away from being electricity producers, towards becoming electricity consumer using electric boilers and heat pumps. From 2021, the electrical heating tax will be reduced by approx. 98%, which further increases the incentive of the district heating plats of becoming electricity consumers rather than electricity producers. With the competition from the above mention in mind, the market opportunities in Denmark are therefore no longer favorable.

On the foreign market, opportunities remain. ACSP has promoted the CSP /ORC facilities all over the world. Especially Australia has been a point of focus and time and resources has been spent on both marketing and sales work in Australia. We are still to see a breakthrough in the Australian market, which primarily is due to reduced focus on green transition from the Australian Government.

# 5. Project results

- *Was the original objective of the project obtained? If not, explain which obstacles that caused it and which changes that were made to project plan to mitigate the obstacles.*

The main goal of the project of developing and establishing a test plant that combines the biomass-fired power and heat plant (with a shared thermal oil circuit) to an organic Rankine Cycle (ORC) plant and to commission and connect the plant to the concentrated solar power plant has been met.

The price of the parabolic troughs has successfully been reduced by 20%, which unfortunately has proven insufficient in order to compete on the current market for throughs, which is currently to be found in China.

- *Describe the obtained technological results. Did the project produce results not expected?*

We managed to create a flexible oil system, where the biomass-fired boilers and the CSP solar system supply heated oil to a large manifold. The ORC system is connected to the manifold, where the heated oil is pumped to the ORC plant to produce electricity.

The pumps within the solar field must not change flow too rapidly, and a high minimum flow ensures a stable operation - even in the event of large fluctuations in the solar radiation.

The interplay between the delivered flow to the large manifold and the flow that is transferred to the ORC plant must be reasonable. It is recommended that flow meters should be used in all pipe strings that supply flow to the manifold as well as in pipe string supplying flow to the ORC system.

- *Describe the obtained commercial results. Did the project produce results not expected?*

The solar plant was developed and established in 2016. For the project in Brønderslev the design of the Aalborg CSP solar collectors has been optimized and thereby resulting in a 20% price reduction on this specific part of the plant.

When considering the flexibility of the system in Brønderslev, where you can easily switch between power and heat production on one side and pure heat production on the other side, one would think that the system would be considered attractive. However, as the tariff structure within the electricity grid does not support this flexibility, the market opportunities in Denmark are limited.

When considering the overall world market, the declining prices on fossil fuels as well as the price development on PV have challenged the competitive situation.

On certain foreign markets, there are still opportunities to be addressed. Especially Australia has been a point of focus and time and resources has been spent on both marketing and sales work in Australia

- *Target group and added value for users: Who should the solutions/technologies be sold to (target group)? Describe for each solutions/technology if several.*

The solution appeals to especially the green transition regarding CO2 reduction within the industrial as well as the power and heat sector; specifically, electricity and heat production for various processes.

- *Where and how have the project results been disseminated? Specify which conferences, journals, etc. where the project has been disseminated.*

The web cams have been in function throughout the period. Two short drone filmed videos showing the establishment of the CSP Plant and the Biomass Plant have been made and promoted on both the website and on Facebook
A lot of still pictures and drone photos have been shot.

Plant visits – We have received 20+ professional groups – several (5+) from Australia, 3 from Japan, 15+ (high) school classes and other visits at the plant per year.

Through the ERFA-group for biomass at Dansk Fjernvarme, we have promoted the new technology.
An energy conference regarding renewable energy in Nordjylland in cooperation with the Flex-Energy cluster has been planned and launched in June 2017(100+ attendees).

Social media. Brønderslev Forsyning has put up a Facebook page where neighbors, other citizens, and everybody else interested continuously are informed about the project status and progress.

A short presentation movie has been made (2017) promoting the new energy plant.

In 2018, when the biomass plant was built, a new film was made that included the brand new energy plant.

The plant has been mentioned in Danish national medias (Television, Radio, Newspapers).

The Plant was rewarded “Fjernvarmeprisen” in 2019 from the Danish Ass. of District heating

The BIO-CSP-ORC project has been promoted in a magazine about “better living” which was distributed to all households within the local municipality (April 2017)

The project has been featured in magazines such as “Maskinmesteren” and in papers as “Ingeniøren”.

Brønderslev Varme has put an advanced IT-based presentation of the new technology into production. The presentation can be seen e.g. at tablets, and due to the use of the” augmented reality”-technology the user will be presented to an artificial dynamic “look” into the stomach of the key components: The ORC, the fluid bed, the boiler etc.

Brønderslev Varme have an informative site on Wikipedia in Danish

Brønderslev Varme today operates – together with local Primary Schools, Regional High School, The University of Aalborg - a custom made permanent “learning lab-class room” at the new site, where students can learn about sustainable energy in general and specifically can do exercises and study projects based on real-data from the production site (CSP, Boilers, Cooling System, Heat Pumps, ORC, Photo voltaic cells etc.).

Regularly coordinating meetings were held between the involved partners concerning the progress of the project.

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| 26-29 September | 2017 - SolarPaces 2017 – Santiago Chile |
| 26 October | 2017 - Northern Victoria New Energy, Roundtable - Shepparton, Victoria |
| 11-12 October | 2017 - All-Energy Australia 2017 – Melbourne Australia |
| 11-12 October | 2017 - DSE Fair 2017 – Aalborg Denmark |
| 26-27 October | 2017 - Dansk Fjernvarme Landsmøde 2017 – Aalborg Denmark |

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| 27-28 October | 2017 - IEA SHC Task 55 3rd Expert Meeting - Abu Dhabi United Arab Emirates |
| 1 November | 2017 - MARTEC Erhvervsdag 2017 – Frederikshavn Denmark |
| 21-22 November | 2017 - 11th International Concentrated Solar Thermal Power Summit |

Conference poster and presentation: “A CSP plant combined with biomass CHP using ORC-technology in Brønderslev”. B. Perers, S. Furbo, G. Yuan, Z. Tian, F. Bava, P. Kvist, J.H. Rothmann, T. Neergaard, J. Jensen, P.A. Sørensen, N. From,

F. Sallaberry. The 11th ISES EuroSun 2016 Conference,
Palma de Mallorca, Spain. Conference proceedings, 2017, pp. 871-877. International Solar Energy Society.

Master Thesis project at the Technical University of Denmark:” Analyses of Brønderslev solar energy plant by use of TRNSYS”. Alejandro de la Vega, 2017.

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| 23 November | 2017 - Career Fair at Aalborg University – Aalborg Denmark |
| 25 January | 2018 - Solfaktor 2030 – Copenhagen Denmark |
| 22-23 March | 2018 - CSP Focus China 2018 – Beijing China |
| 11-12 April | 2018 - 5th International Solar District Heating Conference – Graz Austria |
| 20-23 June | 2018 - China International CSP station Conference & CSP Plaza 2018 Annual Conference |

As the interest for this one-of-a-kind plant combining both solar power, biomass and ORC has been significant, it has resulted in numerous plant visits. The visitors have in general had a high degree of technical insight/interest, has been both national and international visitors and have been potential new clients, educational institutions etc.

Conference poster and presentation: “Performance of the 27000 $m^2$ parabolic trough collector field, combined with Biomass ORC Cogeneration of Electricity, in Brønderslev Denmark”. B. Perers, S. Furbo, Z. Tian, J.H. Rothmann, J. Juul, T. Neergaard, P. Vestergaard Jensen, J. Røhr Jensen, P.A. Sørensen, N. From. The 5th International Solar District Heating Conference 2018, Graz, Austria.

Peer-review article: ”Large-scale solar district heating plant in Danish smart thermal grid: Developments and recent trends”. Z. Tian, S. Zhang, J. Deng, J. Fan, J. Huang, W. Kong, B. Perers, S. Furbo. Energy Conversion and Management 189, pp. 67-80, 2019.

Project results presented for students at the Technical University of Denmark following solar energy courses.

Technical report: Feasibility of including a high-temperature storage in the CSP-ORC system. International project ref. 968. M.Kowalska, F.Bava, N.From. 2020

Technical report: “Brønderslev Hybrid Solar Power Plant - Performance Analysis and Monitoring Report”. A. R. Jensen, S. Furbo, B. Perers. DTU Byg report: R-449. ISBN: 87-7877-550-7. 2020

# 6. Utilisation of project results

- *Describe how the obtained technological results will be utilised in the future and by whom.*

As a part of the green transition and in the search for making our energy systems more competitive, Aalborg CSP uses the technological results - especially within the Industrial and power and heat generating sector.

- *Describe how the obtained commercial results will be utilised in the future and by whom the results will be commercialised.*

Aalborg CSP will promote and develop green technologies and continuously work on creating competitive, green energy solutions.

- *Did the project so far lead to increased turnover, exports, employment and additional private investments? Do the project partners expect that the project results in increased turnover, exports, employment and additional private investments?*

The result and findings of the project has founded det basis for tenders and project offers for several new projects. As of now the new orders have not been won or the projects have not been initiated. To date, no turnover has been achieved (neither nationally nor internationally)

- *Describe the competitive situation in the market you expect to enter.*

The price on energy on the world market – meaning either heat or electricity - is related to the price of fossil fuels such as oil and gas. In recent years, these prices have been at a relatively low level (after the US initiated their shale oil extraction). We have been involved in projects in the Middle East and Australia. In both places, the projects have encountered severe barriers in terms of price/energy unit or in terms of the size of the investment measured against the risk aversion of the company in question.

- *Are there competing solutions on the market? Specify who the main competitors are and describe their solutions.*

The competition derives from multiple directions:

- Firstly, there are providers of competing brands, all of which have an advantage in having delivered more plants and thus have greater experience and an advantage in terms of a more progressed cost efficiency curve.
- Secondly, fossil energy sources are able of supplying the desired amount of energy (however, with a CO2 footprint). Meanwhile, this only has a very limited influence on decision-making.

- *Describe entry or sales barriers and how these are expected to be overcome.*

Aalborg CSP is recognized for having completed projects in several parts of the world and has always been capable of delivering well-functioning projects. The solutions are generally innovative but often also placed in the high end of the price range - however, the quality has never been compromised. On the world market, price is often preferred over quality. With the full-scale test plant, Aalborg CSP has the opportunity to attracting potential clients to a well-functioning plant, and while touring the plant arguing why quality should be prioritized. However, the fact that the payback period without grants or subsidies amounts to more than 10 years complicates the sales process.  Most often the industrial

clients are not interested in investing in plants holding an expected lifetime of 20-30 years. We have therefore tried to establish projects after the BOOT principle (Build-Own-Operate-Transfer). Off hand. it solves the investment issues, however, the client has to enter into a relatively long energy purchase agreement, which, in the end makes the energy more expensive.

- *How does the project results contribute to realise energy policy objectives?*

  The project in Brønderslev and the effect of being able of showing off the result (which is a high-performance energy plant which has met all the required quality criteria) is a necessary element in building trust towards potential clients.

- *If Ph.D.'s have been part of the project, it must be described how the results from the project are used in teaching and other dissemination activities.*

Master Thesis project at the Technical University of Denmark: "Analyses of Brønderslev solar energy plant by use of TRNSYS". Alejandro de la Vega, 2017.

Project results presented for students at the Technical University of Denmark following solar energy courses.

# 7. Project conclusion and perspective

- *State the conclusions made in the project.*

The shared thermal oil circuit of the CSP solar field and the chip-fired boilers that supply the ORC turbine have been planned, designed and constructed and the interconnection of the two systems has been carried out in accordance with the control strategy. It is a green energy solution that is flexible as it can produce both electricity and heat.

The solar plant was developed and established in 2016. For the project in Brønderslev the design of the Aalborg CSP solar collectors has been optimized and thereby resulting in a 20% price reduction on this specific part of the plant.

When the commitment for electricity production grants for Brønderslev was withdrawn, it resulted in a lower settlement price (production grant) for electricity from both biomass and from the thermal solar collectors.

On the world market, the low prices on fossil fuels as well as the price on PV have declined drastically, which has challenged the competitive situation and thus the breakthrough for this type of plant as a green energy solution.

- *What are the next steps for the developed technology?*

  To continue the further development of the knowledge gained throughout the Brønderslev project and have it translated into integrated green energy solutions, which can lower the energy costs for our clients.

- *Put into perspective how the project results may influence future development*

With the plant in Brønderslev, Aalborg CSP has documented that the company can integrate various components such as a solar system with parabolic troughs, a chip-fired biomass boiler and an ORC system in a well-functioning unit. If it proves impossible to promote Aalborg CSP as a supplier of parabolic troughs, an alternative solution for promotion could be to introduce the parabolic troughs as an add-on component.

# 8. Appendices

- Peer-review article: ”Large-scale solar district heating plant in Danish smart thermal grid: Developments and recent trends”. Z. Tian, S. Zhang, J. Deng, J. Fan, J. Huang, W. Kong, B. Perers, S. Furbo. Energy Conversion and Management 189, pp. 67-80, 2019. https://www.sciencedirect.com/science/article/pii/S0196890419303759

- Peer-review article: “Optimizing Efficiency of Biomass-Fired Organic Rankine Cycle with Concentrated Solar Power in Denmark”.A.Zourellis, B.Perers, J.Donneborg, J.Matoricz., Energy Procedia volume 149, September 2018, Pages 420-426
https://www.sciencedirect.com/science/article/pii/S1876610218305022

- Conference poster and presentation: “A CSP plant combined with biomass CHP using ORC-technology in Brønderslev”. B. Perers, S. Furbo, G. Yuan, Z. Tian, F. Bava, P. Kvist, J.H. Rothmann, T. Neergaard, J. Jensen, P.A. Sørensen, N. From, F. Sallaberry. The 11th ISES EuroSun 2016 Conference, Palma de Mallorca, Spain. Conference proceedings, 2017, pp. 871-877. International Solar Energy Society. http://proceedings.ises.org/paper/eurosun2016/eurosun2016-0084-Perers.pdf