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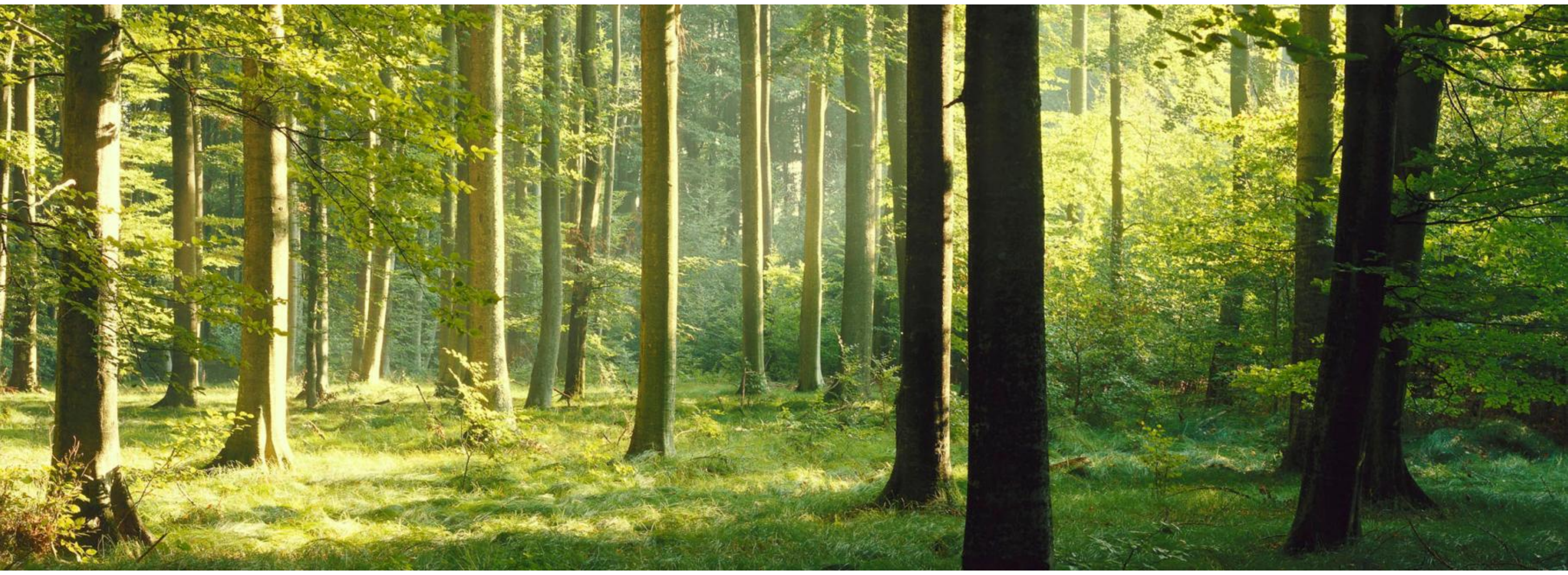
# Helsinki Energy

# Conceptual Study on Post Combustion CCS Technology for ”Vuosaari C” Multifuel Power Plant



HELSINGIN ENERGIA

ÅF-Consult Ltd
Bertel Jungin aukio 9, FI-02600, Finland
Phone +358 (0)40 348 5511. Fax +358 (0)9 3487 0810. www.afconsult.com.
VAT no. FI1800189-6. Registered office Helsinki.
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## EXECUTIVE SUMMARY

The Vuosaari multi-fuel plant (Vuosaari C, "VuC") of Helsingin Energia is part of the company's 2020+ program which aims to reduce its energy production related carbon dioxide emissions by 20% below 1990 level and raise the share of renewable energy to 20% by the year 2020. The Vuosaari C power plant with 240 MW electric and 410 MW district heat output is one possible way to meet these targets. This report is a study on how a carbon capture system (CCS) should be integrated into the possibly upcoming Vuosaari multi-fuel plant and the carbon dioxide emissions could be reduced even more in the future.

A Post Combustion-type amine based CCS process was selected by the client as the carbon capture technology. MEA solvent was selected as absorbent together with the client based on a survey by VTT. The advantages of the selected CCS technology are the separation of the actual CCS process from the power plant, allowing phased construction as well as the possibility to utilize the process waste heat for district heating (DH), which would make it possible to compensate for the energy losses characteristic for this technology. In addition, Post Combustion CCS is currently the most widely studied method of carbon capture technologies in power applications and can be found in numerous commercial applications, even though full-scale power plant applications are still missing also in this technology.

In particular, the impact of a CCS process on the CHP plant is a new element in the study. According to our knowledge, similar studies on CHP plants with district heating applications are scarce. Further, the number of studies on CCS applications for biomass fuelled power plants is very limited.

The aim of the study was to determine the impact of a CCS process on the power plant's characteristic figures, such as net electric power, district heat output and electric efficiency by using an integrated heat balance calculation model covering both the power plant and the CCS process. The starting point was the power plant concept from the pre-engineering phase of the VuC-plant.

In addition, the study covers also following areas: Specifying the requirements for flue gas cleaning, determining the effects of the wide range of fuel quality to the CCS plant, identifying the main interfaces required by the CCS plant and finally, defining the space requirement of the CCS plant.

The portion of the total flue gas stream to be treated in the CCS plant ("slipstream") was defined to be 50%, which is likely to be close to the optimum considering the prevailing boundary conditions. Since the power plant is designed as a multi-fuel power plant firing biomass for the most part (on the average about 70..80% of the fuel input the balance being coal), treatment of the entire flue gas stream is not feasible. On the other hand, limiting the CCS plant capacity to treat only the $CO_2$ generated by coal combustion would result in unreasonably small capacity considering the substantial fixed cost component of the CCS plant being independent of capacity. The calculations proved that the cooling steam flow required for the steam turbine low-pressure part will limit the slipstream in any case to about 90% of the total flue gas stream.

The base case to be investigated was a CCS retrofit case, ("CCS Plug-In"), meaning that the CCS plant would be built only later after the power plant itself would be in operation. The only preparatory measure during the power plant project would be limited to sufficient space reservation close to the flue gas treatment plant.

The second case that was investigated was "CCS Optimized" in which the implementation of the CCS plant would be considered so likely that preparatory measures for the integration of the CCS process would be included already at the power plant engineering stage. In addition, the "Optimized" case included also certain process improvements such as reduction of the LP steam source pressure (cross-over pipe between IP and LP steam turbine parts) closer to the actual requirements of the CCS process, as well as dimensioning of the flue gas condenser for the entire flue gas flow.

In the "Plug In" case 2,7 GJ/t $CO_2$ was used as the specific heat consumption for solvent regeneration, which was reported by Siemens PG as actual figure for the year 2011. In the "Optimized" case, the

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near/intermediate future development of the solvent was anticipated by using a lower consumption figure of 2,2 GJ/t $CO_2$, being the near future target value of the same manufacturer. 90% $CO_2$ removal efficiency has been assumed throughout, which is a widely accepted representative figure.

The heat balances (HB) were calculated both for fuel-mix operation with 80% of fuel input being biomass, as well as for 100% coal firing case. The HBs were calculated using Thermoflow's SteamPro and ThermoFlex software, which includes since recently a CCS calculation module.

The energy streams entering the CCS process consist of streams introduced by regeneration steam, flue gas, cooling water and electricity for the CCS process consumers. The heat in the flue gas is mainly sensible heat, since the latent heat originating from the moisture in the biomass is recovered already in the flue gas condenser upstream the CCS process. The compression of the $CO_2$ stream is by far the biggest power consumer of the CCS process.

The energy streams leaving the CCS process consist of streams leaving the process as cooling water, various losses as well as the clean gas and the $CO_2$ stream. The heat recovery into district heating water covers about 90% of the total energy input in the CCS process the balance being lost mostly as sensible heat in the clean gas flow, as well as other minor losses (heat losses, drain losses etc.).

In the Plug-In case the CCS process will increase the district heat output by about 115 MW (+ 28%) compared to the base case (VuC). The CCS process will increase the plant auxiliary power consumption and decrease the plant net electrical output by about 47 MW (19%). About 60% of the decreased net electric output results from the increased auxiliary power consumption, the rest is caused by the regeneration steam consumption (LP steam). The net electrical efficiency of the plant will reduce by about 6,3%-points. The power- ratio (ratio of electricity to district heat generation) will reduce by about 0,22 units (0,59 → 0,37) due to increased district heat output. The impact of the CCS process on the plant key parameters on fuel-mix operation is summarized in the table below.

*Table: Key parameters of alternative concepts. Fuel-mix: Biomass 80 % / coal 20 % (from fuel input).*

| Performance<br>Fuel-mix operation | Unit | Base case<br>(VuC) | CCS Plug In<br>slipstream 50% | CCS Optimized<br>slipstream 50% |
|---|---|---|---|---|
| Fuel Input (LHV) | MW | 745,9 | 746,1 | 746,1 |
| Power Output, gross | MW | 267,1 | 247,6 | 250,8 |
| Power Output, net | MW | 242,0 | 194,7 | 197,3 |
| Aux. power cons., tot. | MW | 25,1 | 52,9 | 53,5 |
| District Heat (DH) Output | MW | 413,9 | 529,3[1] | 588,9 |
| Electrical Efficiency, gross | % | 35,8 | 33,2 | 33,6 |
| Electrical Efficiency, net | % | 32,4 | 26,1 | 26,4 |
| Power-Ratio | - | 0,59 | 0,37 | 0,34 |
| Overall Effieciency | % | 87,9 | 97,0 | 105,4 |

1 In the HB calculations 42 °C has been used as DH return temperature.

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In the Optimized case the CCS process increases the plant district heat output still further by about 175 MW (+ 42%) compared to the base case (VuC). The significant increase in the DH output is accomplished by the bigger flue gas condenser, designed for the entire flue gas stream. This will further decrease the power-ratio by about 0,03 units (0,37 → 0,34). The net electrical efficiency will be slightly better than in the Plug-In alternative.

At 100% coal firing operation the moisture that is introduced into furnace with the fuel is reduced significantly, hence lowering the vapor content of the flue gases. This will reduce the heat recovery from the flue gas condenser. The impact of the CCS process on the plant key parameters on 100% coal firing operation is summarized in the table below.

*Table: Key parameters of alternative concepts. Fuel-mix: Coal 100 % (from fuel input).*

| Performance 100 % coal firing | Unit | Base case (VuC) | CCS Plug In slipstream 50% | CCS Optimized slipstream 50% |
|---|---|---|---|---|
| Fuel Input (LHV) | MW | 717,3 | 718,0 | 718,0 |
| Power Output, gross | MW | 267,0 | 250,0 | 252,5 |
| Power Output, net | MW | 242,6 | 204,7 | 207,1 |
| Aux. power cons., tot. | MW | 24,4 | 45,3 | 45,4 |
| District Heat (DH) Output | MW | 413,9 | 465,5 | 467,8 |
| Electrical Efficiency, gross | % | 37,2 | 34,8 | 35,2 |
| Electrical Efficiency, net | % | 33,8 | 28,5 | 28,8 |
| Power-Ratio | - | 0,59 | 0,44 | 0,44 |
| Overall Effieciency | % | 91,5 | 93,3 | 94,0 |

Another important task of the study was to identify the practical consequences on the power plant of adding a CCS process. For the retrofit case, the report lists essential changes that have to be taken into account. Similarly, a check-list of essential issues to be addressed is included, so as to minimize any significant changes to the power plant, in case of a future CCS implementation.

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