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Carbon Capture and Storage Program

Techno-economic feasibility of different CCS applications in Finland

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CCSP – FINAL RESULTS SEMINAR

13TH OCTOBER 2016, HELSINKI

Introduction - Aim of the WP2 work in CCSP

- The potential of applying different CCUS concepts to different industrial applications in Finland has been evaluated
 - both from the economic performance and process integration point of view
 - based on real industrial plants and their environments in Finland
- Analysed application areas have included for example:
 - electricity and combined heat & power (CHP) production
 - pulp & paper
 - oil refining
 - hydrogen production by steam methane reforming (SMR)
 - steel industry





INFO

Combined Heat and Power (CHP) plants

Other applications

Cost & potential

Pulp & paper mills

Steel plants

Oil refineries

SHOW ME THE MONEY!

CCS applications

CCS is one of the few technological options available for energy intensive industry to reduce their carbon footprint. Each plant type needs particular processes, models and studies. In CCSP the target was to find the best CCS concepts for each industry.

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This slide includes an on-line Flash visualization which can be shown only at: <http://ccspfinalreport.fi/#/>

Presentation order of the on-line tools



Cost & potential 

5 **1** **2** **3** **4**

Summary Summary graph Bio-CCS in a CHP-system CLC power plant GTCC in a CHP-system CCS in steelmill

VTT has conducted several techno-economic concept studies for CCUS applicability within energy production and carbon intensive industry in Finland based on real industrial plants and their environments. An illustrative summary graph was developed in the following toolkit (see [Summary graph](#)) in which the potential and costs of CCUS in different applications and market conditions in Finland can be visualised. The main research questions answered are:

- What are the most profitable CCUS applications in Finland in different market situations (e.g. prices of electricity, CO2 allowances, etc.)
- What CO2 price is required to turn these CCUS cases feasible over the respective reference cases without CCUS?
- What is the estimated potential for these different applications (in Mt/a of CO2)?

Additionally, interactive case-specific toolkits have been prepared for different application areas - see tabs for examples from [biomass-CHP](#), [CLC power plant](#), [GTCC CHP](#) and [steel mill](#).

In the toolkits, the profitability of each case can be analysed according to different market situations by adjusting plants operation and the most significant input values. In addition to plant and case specific technical inputs, the economic parameters can be varied as well as CCS related costs, for example required investment and CO2 transportation costs.

This slide includes an on-line Flash visualization which can be shown only at: <http://ccspfinalreport.fi/#/>

Key findings of the summary work

- With a break-even price (BeP) below **20 €/t (CO₂) up to 0.2 Mt/a** of CO₂ could be captured (without storage costs and assuming very modest transportation costs)
 - These could be the first sources for CO₂ utilisation
- The potential for CCS is up to **10 Mt/a with a BeP below 50 €/t** including transportation and storage costs
 - This represents the beginning of large scale CCS in Finland
 - Of which 3 Mt/a is of biogenic origin
- The most cost-efficient applications are among **CHP plants fired with biomass, production of liquid biofuels and process industry**
 - However, this requires that “negative” emissions from bio-CCS are acknowledged and included in the EU emission trading system → the opportunities as well as the challenges of bio-CCS/bio-CCU are very relevant for Finland
 - Depending on the CO₂ demand, the economic potential for bio-CCU may be larger than for bio-CCS because of the typically small unit sizes and inland locations of biomass fired CHP plants and pulp mills
- CCS does not provide a simple solution to reduce CO₂ emissions in Finland as there are no suitable formations for CO₂ storage
 - CO₂ export would be required
 - Establishing ‘CO₂ hubs’ could decrease the transportation costs

More info around our poster in this seminar

Note! Poster includes *old-school* interactive elements

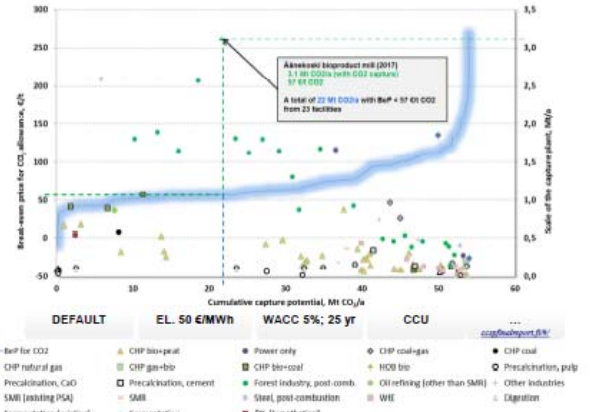


The potential for CCUS in selected industrial sectors – summary of concept evaluations in Finland

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The region of choice for bio-CCS value chains

- Finland is a land of forests. Extensive biomass use combined with CCS leads to a huge potential of 'negative emissions'.
- The rather large heavy industry offers good CO₂ capture potential:
 - CO₂ from steam methane reforming, pre-calcination, gasification, biogas production, ethanol fermentation
- CO₂ utilisation example options:
 - Precipitated calcium carbonate (PCC) fixing CO₂, used as paper filler
 - power-to-fuels and power-to-chemicals
 - pH control in pulping with CO₂
- Know-how on key technologies:
 - CHPC system integration
 - Biomass firing boilers, optimised for CCS
 - Thermo-chemical processes
 - Analytical methods for environmental impacts



Summary of break-even prices for CO₂ emission allowance and CO₂ capture potential for selected industrial sectors in Finland assuming post-combustion capture as the technology of choice. Ånnekoski bioproduct mill is used as an example datapoint.

Default parameters: electricity 25 €/MWh, CO₂ storage cost 8 €/t, WACC 8%, timeframe 20 years. An online tool is freely available for more scenarios: <http://ccspfinlandreport.fi/>

Legend

- Industrial sector
- Manufacture of organic basic chemicals
 - Energy production in paper and board manufacture
 - Energy production in pulp production
 - Energy production in petroleum products refining
 - Electricity production
 - Heat and CHP production
 - Cement manufacture
 - Lime and plaster manufacture
 - Paper and board manufacture
 - Pulp production
 - Waxes and paraffin manufacture
 - Production and processing of metals
 - Waste management in pulp production
 - Non-hazardous waste treatment

Annual CO₂ emissions 2013

- 100-500 kt
- 500-1000 kt
- 1-1.5 Mt
- 1.5-2 Mt
- 2-3 Mt
- 3-4 Mt
- >4 Mt

75 0 75 150 225 300 km



Facilities emitting > 0.1 Mt CO₂/a based on 2013 emission database (E-PRTR, VTT). For the summary work, some facilities were added to the data.

Key findings

- With a break-even price (BeP) below 20 €/t (CO₂) up to 0.2 Mt/a of CO₂ could be captured (without storage costs and assuming very modest transportation costs)
 - these could be the first sources for CO₂ utilisation
- The potential for CCS is up to 10 Mt/a with a BeP below 50 €/t including transportation and storage costs
 - represents the beginning of large scale CCS in Finland
 - of which 3 Mt/a is of biogenic origin
- The most cost-efficient applications are among CHP plants fired with biomass, production of liquid biofuels and process industry
- Establishing 'CO₂ hubs' could decrease the transportation costs

Acknowledgments

This research was carried out in the Carbon Capture and Storage Program (CCSP), coordinated by Clc Innovation Oy with funding from Tekes, Fortum Oyj, Helen Oyj and Amec Foster Wheeler Oy. Learn more: ccsp.fi
 The bio-CCS research continues in Nordic Energy Research's flagship project Negative CO₂ (2015-2019), coordinated by Chalmers University of Technology.

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CCS in a large-scale CHP system - Bio/coal-CCS in multifuel CHP plant

Timo Arponen / Helen Ltd

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Combined heat, power and cooling system in Helsinki

One of the most developed combined heat, power and cooling (CHPC) systems in the world exists in Helsinki and is operated by Helen Ltd

- 4 CHP Power plants producing heat and power
 - 2 Natural gas (CCGT)
 - 2 Coal + Pellets (0-10 %) (PC)
- Heat-only boilers
 - Natural gas, Oil, Coal
- Heat pumps: District Heat and Cooling using purified sewage water, district cooling water and electricity
- Absorption chillers using district heat
- Free cooling (sea water)

Questions of the research

Scenario: Multifuel CHP plant replaces one coal+pellet –fired plant

Main Questions

- How to integrate a CO₂-capture plant into a multifuel CHP plant?
- How does the multifuel plant with CO₂-capture fit into the energy system and what are the impacts to the whole system?
- Is it profitable to invest in CCS technology?

Multifuel CHP plant and CO₂-capture plant 1/2

- Multifuel power plant
 - CHP: District Heat and Electricity
 - CFB-boiler (Circulating Fluidised Bed)
 - 0-80 % biomass (forest residues), 20-100 % coal
- CCS
 - Possibility to utilize the process waste heat for district heating, which would make it possible to compensate for the energy losses
 - Post combustion capture, Plug-In (as power plant already exists)
 - 50 % flue gases treated in the capture plant
 - 90 % CO₂-removal efficiency

Multifuel CHP plant and CO₂-capture plant 2/2

| BIO 80 % COAL 20 % | Base [MW] | With CCS [MW] | Diff. |
|---------------------------|--------------|------------------|--------|
| Fuel | 746 | 746 | 0 % |
| Electricity | 242 | 195 | -20 % |
| District Heat | 414 | 529 | +28 % |
| Efficiency ^(*) | 88 % | 97 % | +9 %-p |
| COAL 100 % | Base [MW] | With CCS [MW] | Diff. |
| Fuel | 717 | 718 | 0 % |
| Electricity | 243 | 205 | -16 % |
| District Heat | 414 | 466 | +12 % |
| Efficiency ^(*) | 92 % | 93 % | +1 %-p |

(*) total efficiency including electricity and district heat

CCS includes flue gas condenser. Most of the heat is recovered from the condenser.
Investment in the flue gas condenser solely would be possible and profitable also without an investment in CO₂-capture.

Approach

Prices and other variable costs

- Fuels, CO₂ emission allowances, taxes, transport and storage costs of CO₂, other variable costs
 - The scenario published by Ministry of Employment and the Economy (2015) was used as a basis for the prices of coal, natural gas, oil and electricity. The values for year 2030 were used (given in the source as 2014 money)

<http://tem.fi/documents/1410877/2148188/Skenaariokehikko+%28luonnos+14.6.2016%29.pdf/51c1e381-6892-41b4-a37c-d3aa7e5f52f5>

➔ Optimization of the production:

- Feasibility of four different cases for new multifuel plant were compared (co-firing vs. coal, with and without CO₂-capture)
- The most feasible merit orders were calculated (The plants are taken into operation starting from the plant for which the operation costs are the lowest)

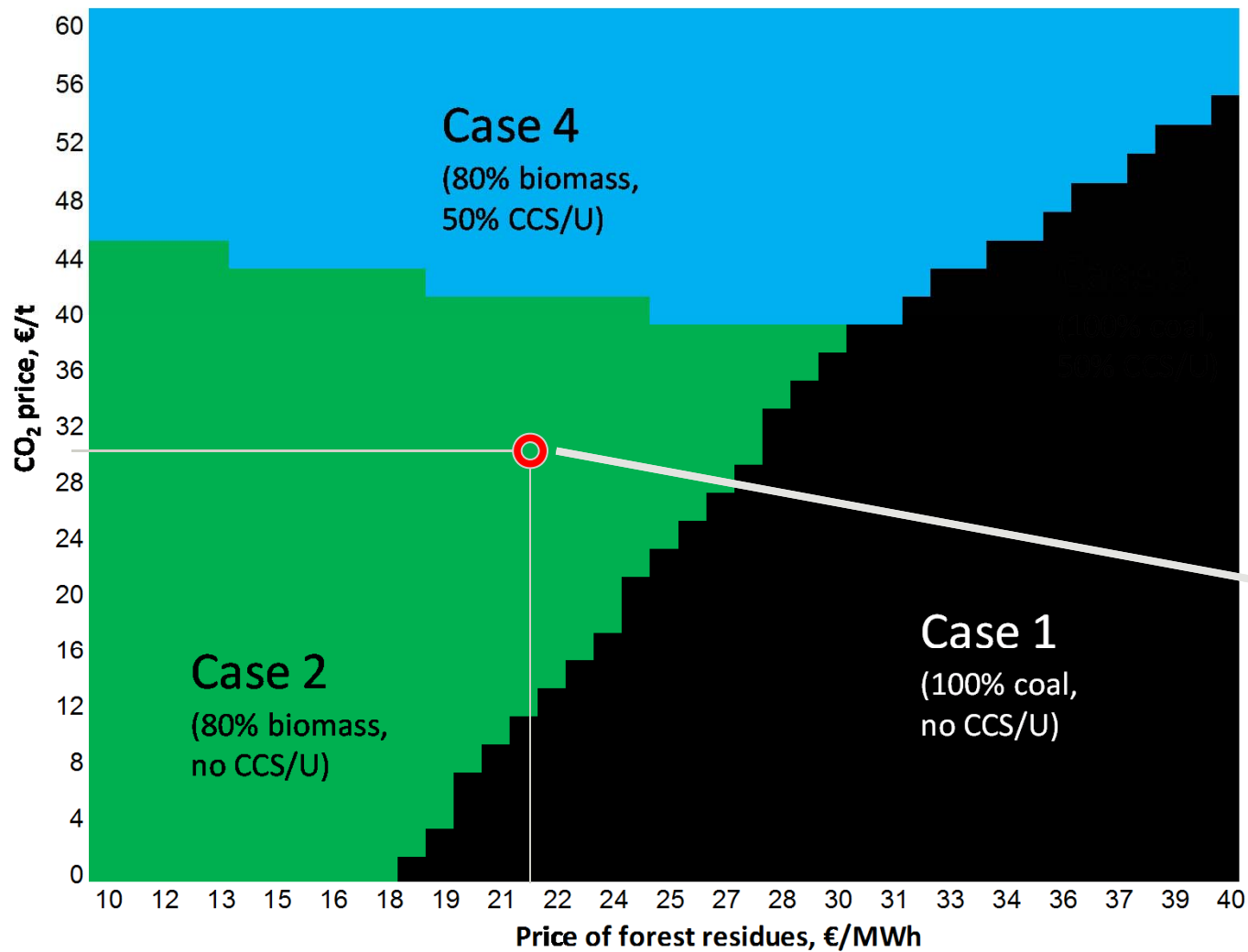
➔ Fuels, emissions, costs, incomes (electricity)

➔ Overall operation costs of the whole system

- Investment costs (Carbon capture plant, 140 M€) ➔ CAPEX

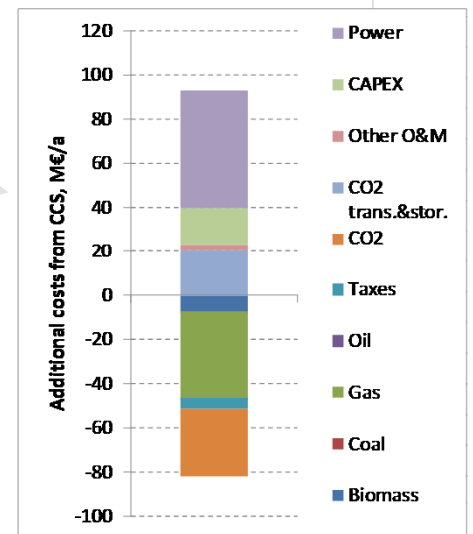
➔ Profitability of the CCS-investment

The profitability of the CCS investment



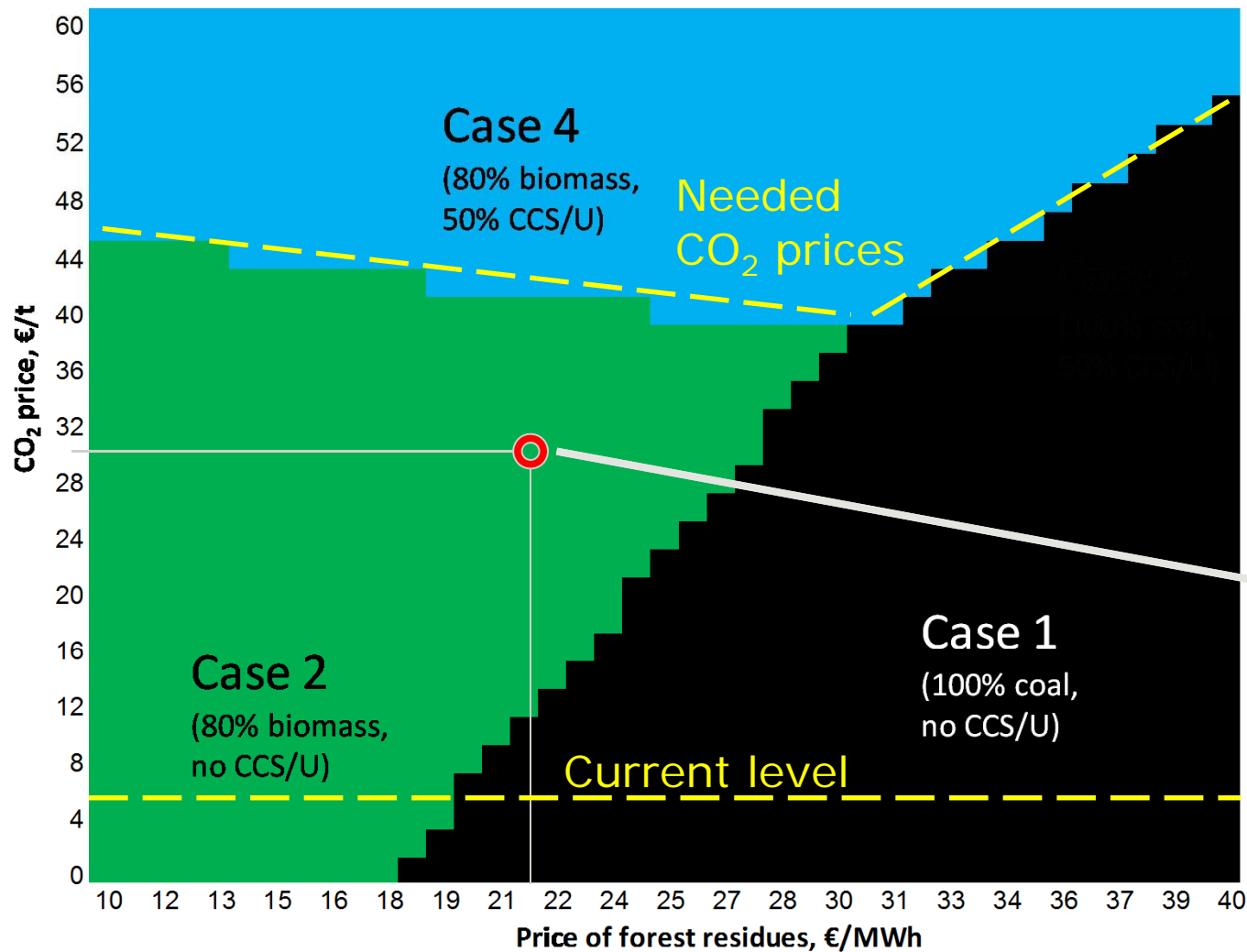
| | | |
|--|--------|---|
| System price of electricity, €/MWh | 60 | ▼ |
| Subsidy for bioelectricity, €/MWh | 0 | ▼ |
| Transport & storage sensitivity factor | 0 % | ▼ |
| Capture investment sensitivity factor | 0 % | ▼ |
| WACC | 10.0 % | ▼ |
| Economic life for investment, a | 20 | ▼ |
| Coal price, €/MWh | 12 | ▼ |
| Natural gas price, €/MWh | 38 | ▼ |
| Oil price, €/MWh | 55 | ▼ |

| | |
|-----------------|--|
| Co-firing + CCS | |
| Co-firing | |
| Coal + CCS | |
| Coal | |



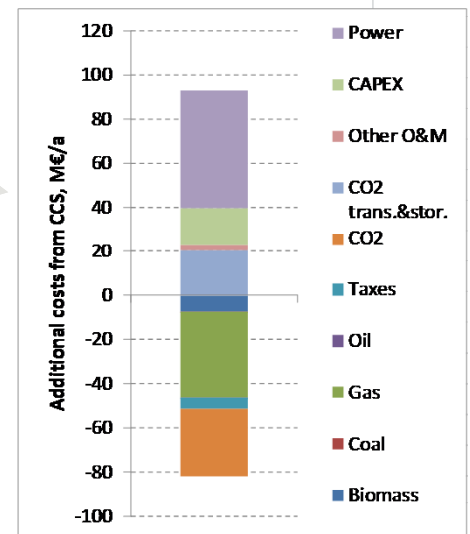
The profitability of the CCS investment

Break-even price for CCS is in the range of 40-45 €/t



| | | |
|--|--------|---|
| System price of electricity, €/MWh | 60 | ▼ |
| Subsidy for bioelectricity, €/MWh | 0 | ▼ |
| Transport & storage sensitivity factor | 0 % | ▼ |
| Capture investment sensitivity factor | 0 % | ▼ |
| WACC | 10.0 % | ▼ |
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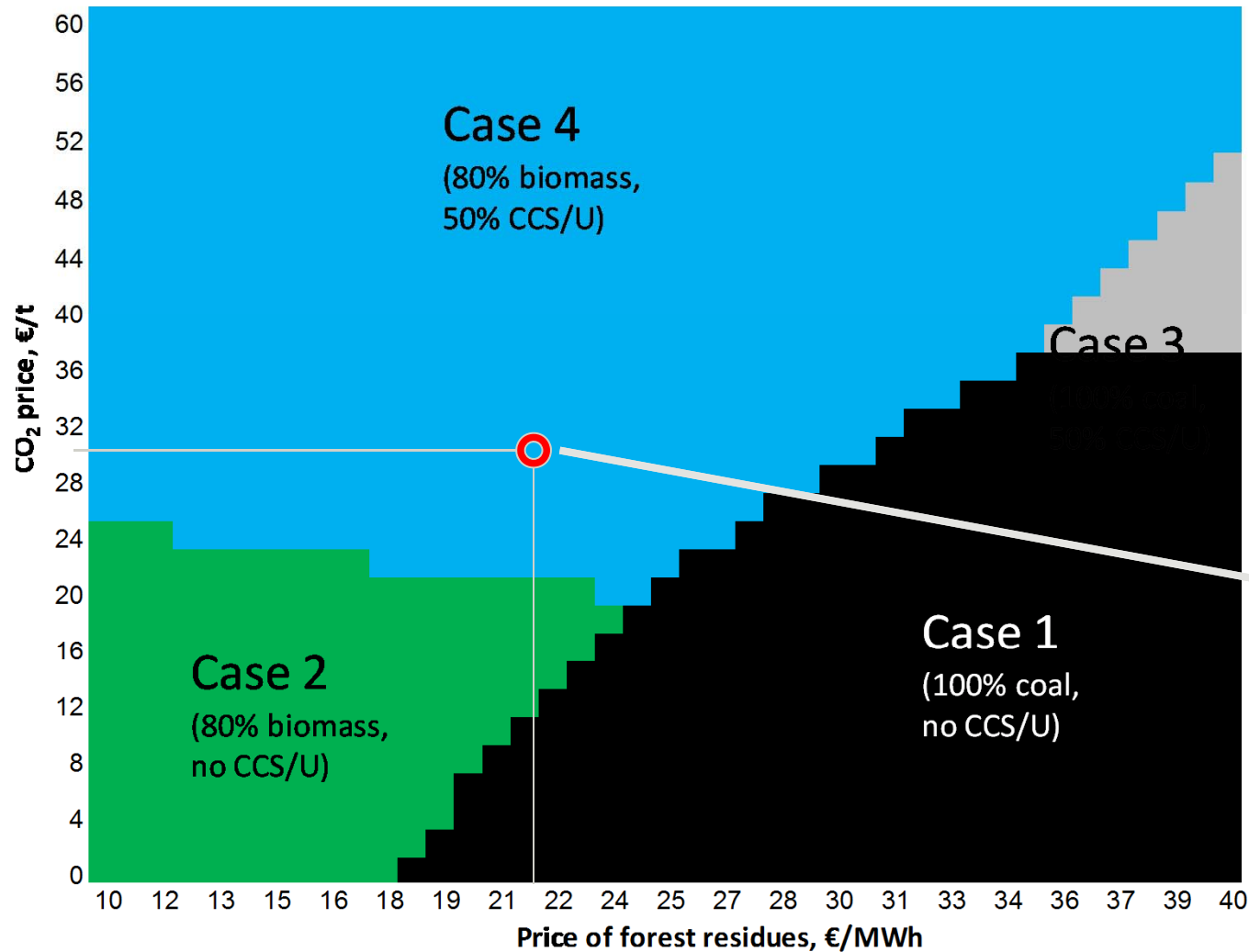
| | |
|-----------------|--|
| Co-firing + CCS | |
| Co-firing | |
| Coal + CCS | |
| Coal | |



The profitability of the CCS investment

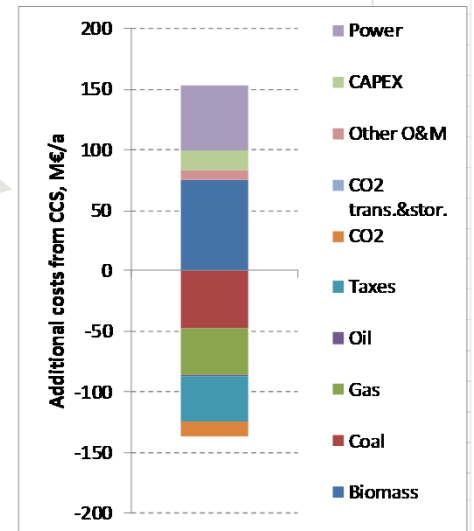
No transportation/storage costs (e.g. CO₂ utilisation)

Break-even price for CO₂-capture is over 20 €/t



| | | |
|--|--------|---|
| System price of electricity, €/MWh | 60 | ▼ |
| Subsidy for bioelectricity, €/MWh | 0 | ▼ |
| Transport & storage sensitivity factor | -100 % | ▼ |
| Capture investment sensitivity factor | 0 % | ▼ |
| WACC | 10.0 % | ▼ |
| Economic life for investment, a | 20 | ▼ |
| Coal price, €/MWh | 12 | ▼ |
| Natural gas price, €/MWh | 38 | ▼ |
| Oil price, €/MWh | 55 | ▼ |

| | |
|-----------------|--|
| Co-firing + CCS | |
| Co-firing | |
| Coal + CCS | |
| Coal | |



Key messages

- Result pictures show the most feasible cases in relation to prices of CO₂-emission allowances and biomass purchase
 - Including investments in CO₂-capture
- CCS with biomass seems to be more feasible than with coal, but still not profitable
 - CO₂ allowance price level 40-45 €/t needed for bio-CCS
 - Coal-CCS needs much higher CO₂ prices and/or high biomass prices
- *Assuming that bioenergy is carbon-neutral and capturing biogenic CO₂ is acknowledged in the EU ETS as "negative emissions"*
- *Investment in the flue gas condenser solely would be possible and profitable also without an investment in CO₂-capture.*