Storskaliga minusutsläpp i Stockholm

Teknik Regulatoriskt Finansiering

stockholm exergi

12 november 2019

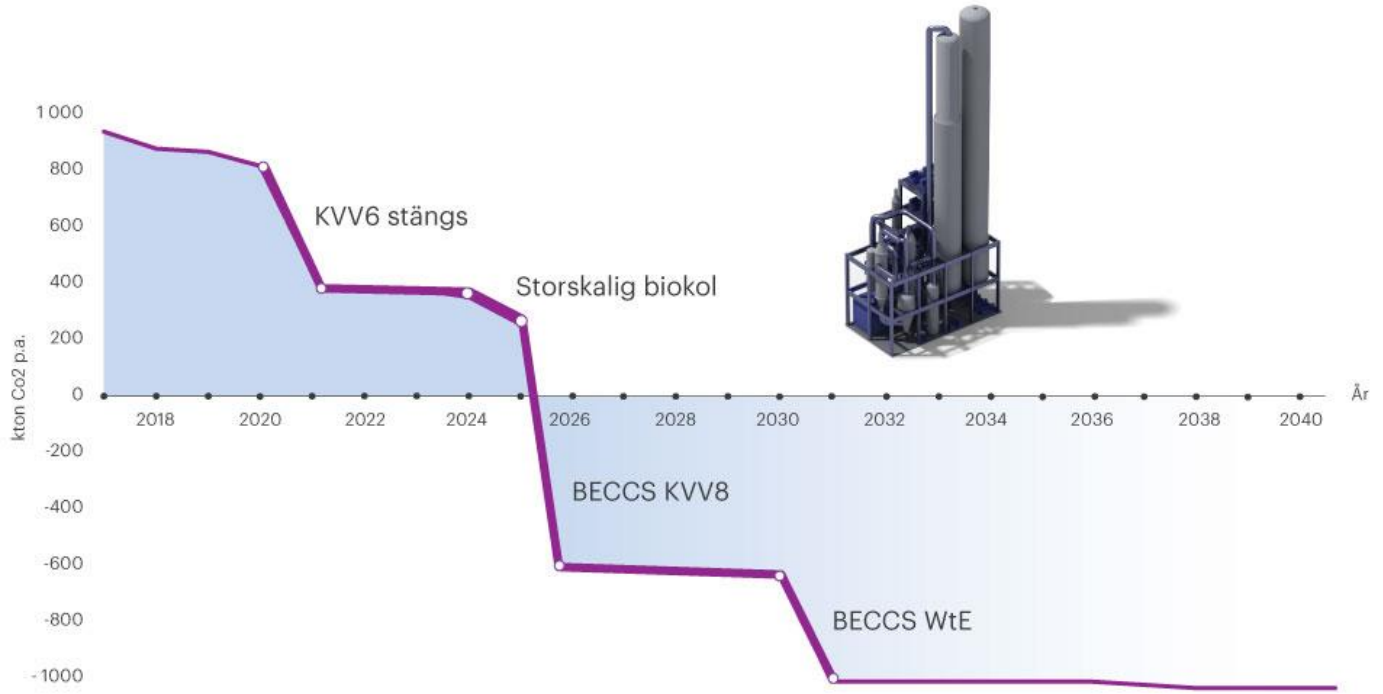
Erik Dahlén, Forskning & Utveckling

Minusutsläpp är helt avgörande i klimatarbetet

BECCS, (Bio Energy with Carbon Capture and Storage)

Från minskade utsläpp till minusutsläpp

Kombineras med biokol och smartare resursanvändning



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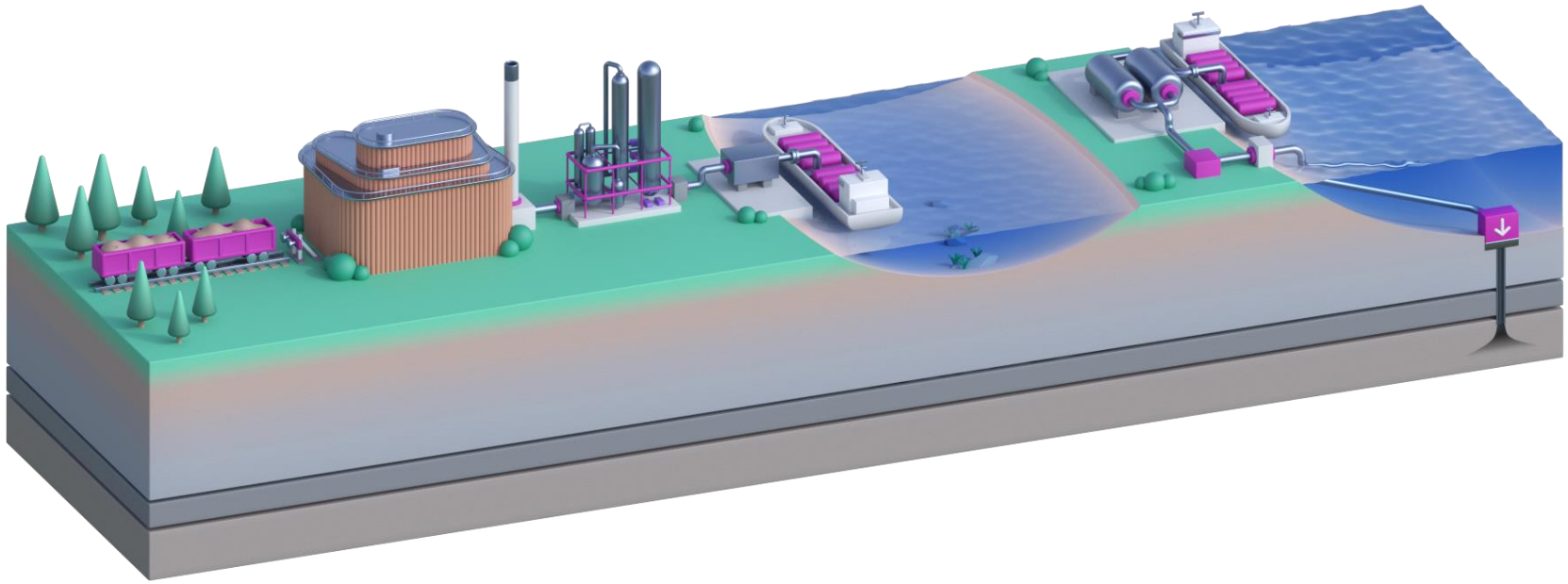
Två pågående projekt

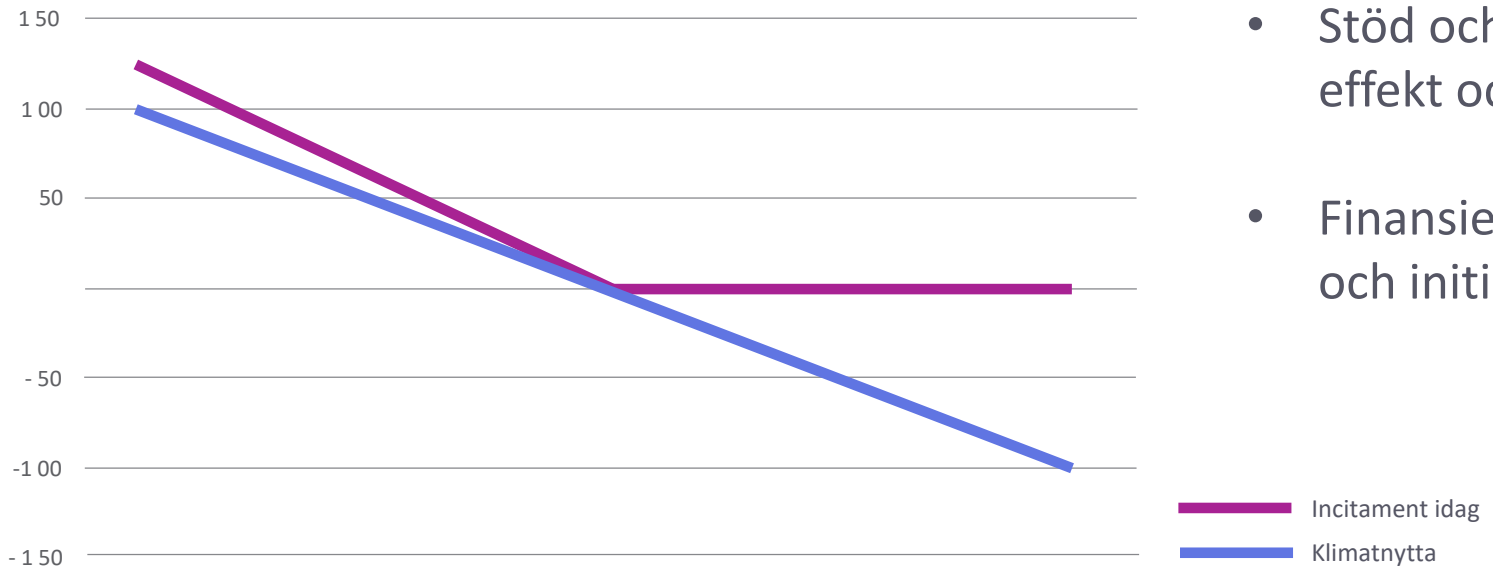
Med stöd från Energimyndigheten pågår studier för att klargöra hur en fullskalig anläggning ska byggas och drivas.

Stockholm Exergi samarbetar för att skapa en kedja från skogsavfall till lagrad koldioxid.

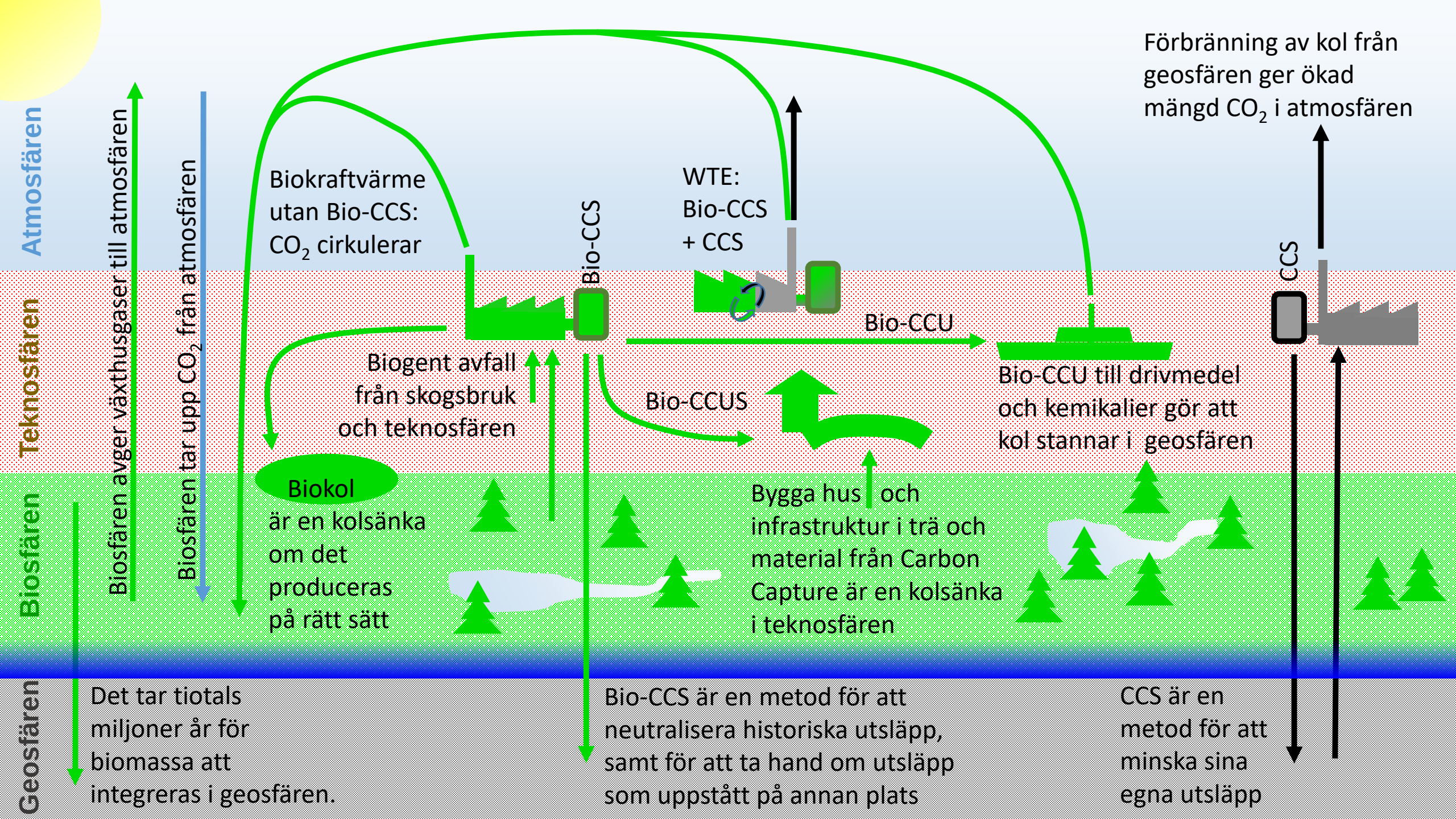


Hållbar finansiering

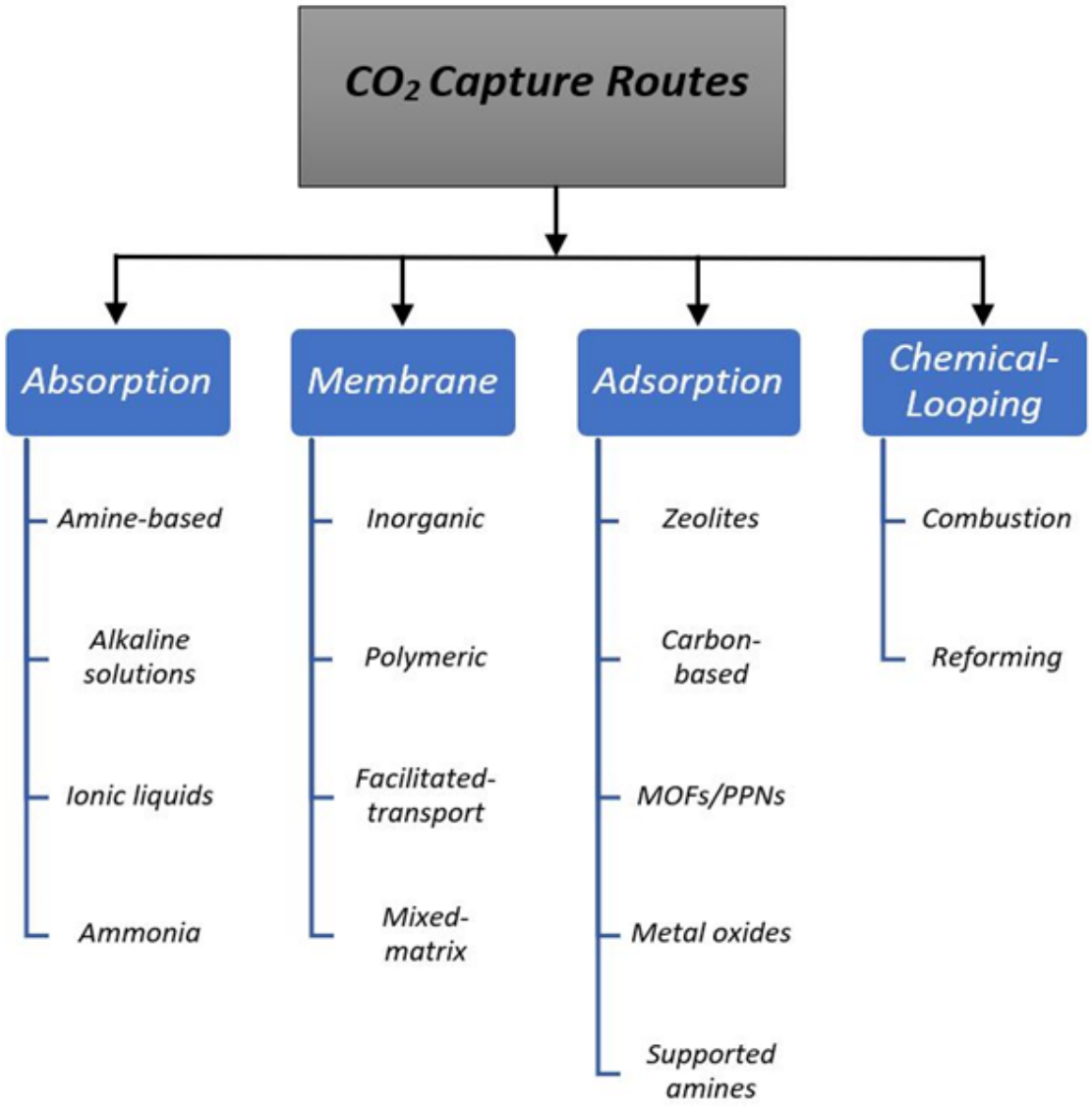
Med hållbar finansiering kan Värtaverket från mitten av 2020-talet ta bort 800 000 ton koldioxid från atmosfären varje år.

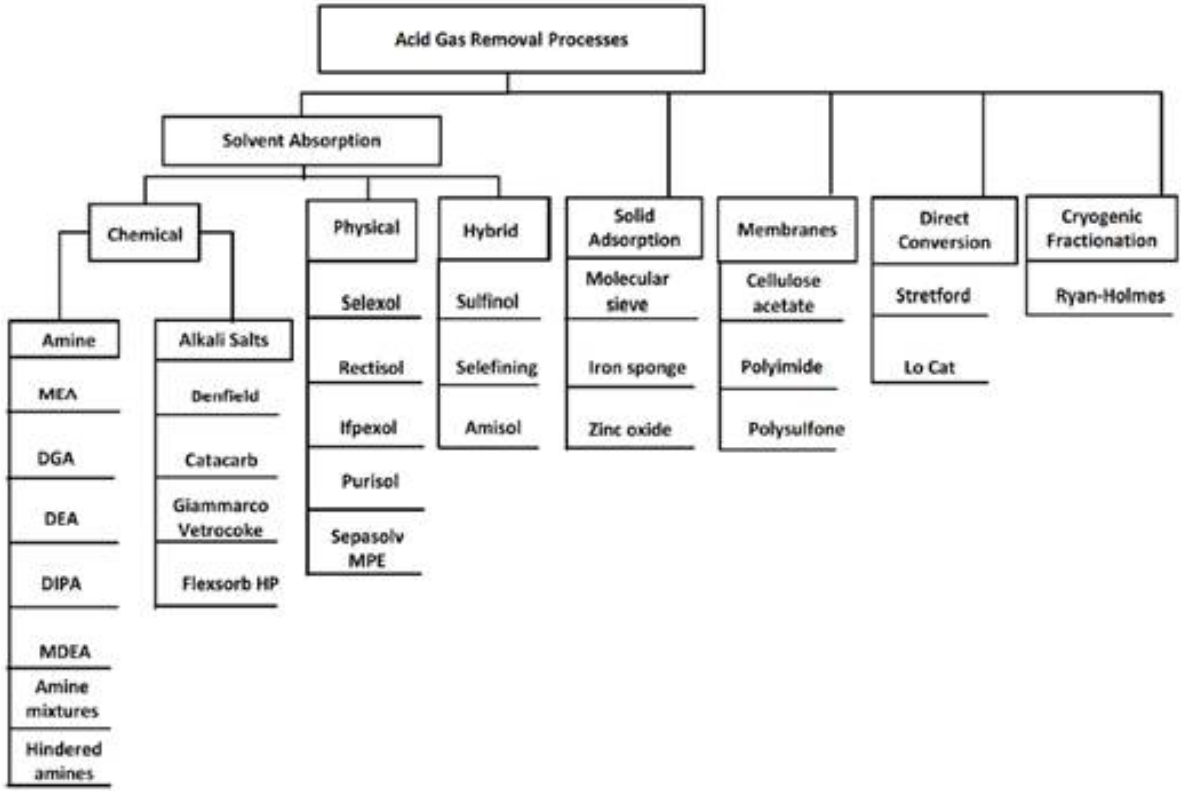


- Stöd och incitament ska/borde utgå från effekt och potential.
- Finansiering behövs för både investering och initial drift.

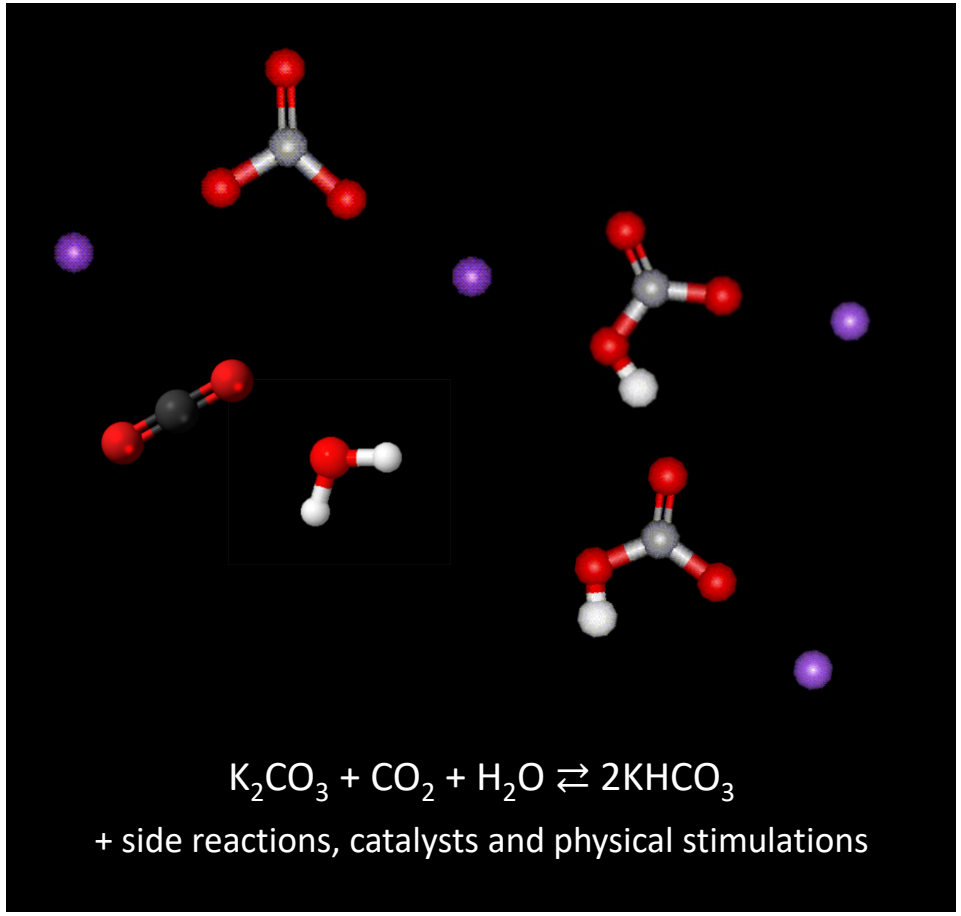

Atmosfären
Teknosfären
Biosfären
Geosfären
Biosfären avger växthusgaser till atmosfären
Biosfären tar upp CO_2 från atmosfären
Biokraftvärme utan Bio-CCS: CO_2 cirkulerar
Bio-CCS
WTE: Bio-CCS + CCS
Förbränning av kol från geosfären ger ökad mängd CO_2 i atmosfären
CCS
Bio-CCU
Biogent avfall från skogsbruk och teknosfären
Bio-CCUS
Bio-CCU till drivmedel och kemikalier gör att kol stannar i geosfären
Biokol är en kolsänka om det produceras på rätt sätt
Bygga hus och infrastruktur i trä och material från Carbon Capture är en kolsänka i teknosfären
Det tar tiotals miljoner år för biomassa att integreras i geosfären.
Bio-CCS är en metod för att neutralisera historiska utsläpp, samt för att ta hand om utsläpp som uppstått på annan plats
CCS är en metod för att minska sina egna utsläpp

Carbon Capture Technologies



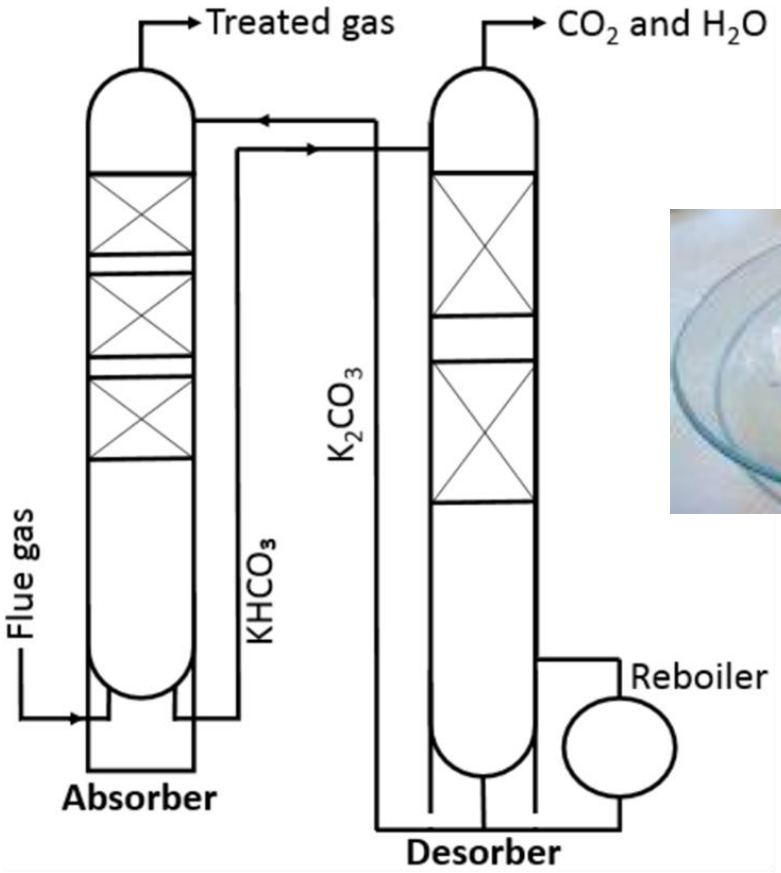


Tekniken är mycket väl beprövad



$K_2CO_3 + CO_2 + H_2O \rightleftarrows 2KHCO_3$

+ side reactions, catalysts and physical stimulations



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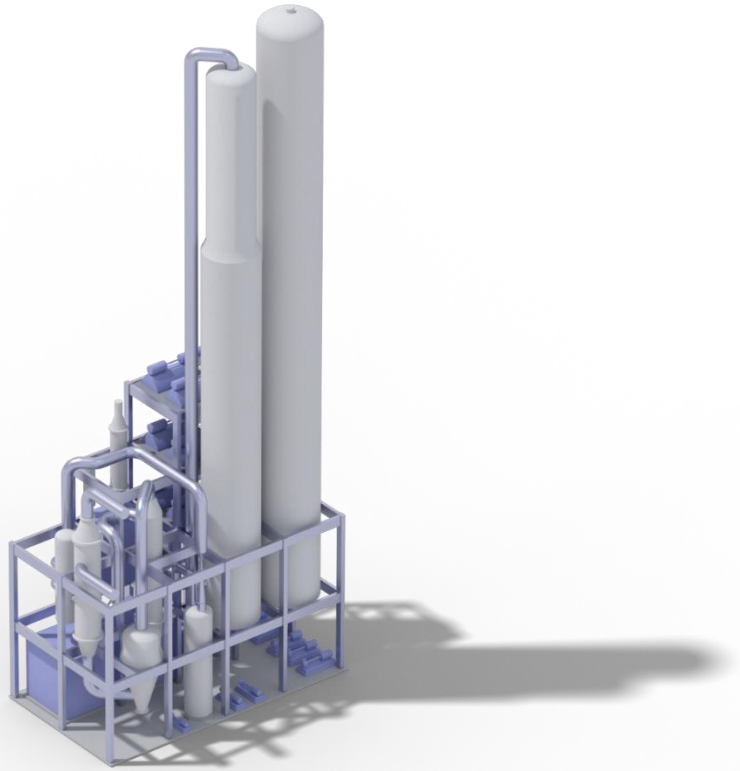
I huvudsak fem kriterier har avgjort teknikval

1. Investering
2. Systemeffektivitet
3. Technology Readiness Level
4. Miljö/Arbetsmiljö
5. Footprint



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Systemeffektivitet

- Existerande anläggning
- Biogent utsläpp
- Stort och koncentrerat utsläpp
- Närhet till hamn
- Hög CO_2-koncentration
- Rena rökgaser
- Högt rökgasflöde
- Tillgång till elektricitet/ånga
- Tillgång till fjärrvärmenät
- Närhet till marknad

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BECCS med HPC på KVV8, Publiserad vetenskaplig artikel

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Research paper

Introducing BECCS through HPC to the research agenda: The case of combined heat and power in Stockholm

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ABSTRACT

In the years since COP21 in Paris, awareness of the need for carbon sinks has grown rapidly. However, policy instruments supporting a path to this target are still lacking.

Bioenergy carbon capture and storage (BECCS) may provide a way to rapidly reduce global warming. In the Nordics, much of the basic infrastructure for successful BECCS implementation is already in place. So why is not more happening?

This study provides insights to barriers and policy implications in relation to successful BECCS implementation. Though implementation could support economic growth and welfare development, the cost is relatively high for individual utilities. In the deregulated competitive heating market in the case of Stockholm, cost transfer to customers is prohibited, effectively impeding implementation. Moreover, while present national or EU-based support schemes could cover investments, the operating cost is high, so other economic policy approaches are required.

Lastly, this paper shows that BECCS on combined heat and power plants has a potential, but requires much more research. Thus it is suggested that negative emission technologies in energy systems are brought into research agendas such as the future of combined heat and power and urban multi energy systems.

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1. Introduction

The importance of negative emission technologies (NETs) for reaching COP21 targets on limiting global warming well below 2 °C is apparent. In the IPCC Fifth Assessment Report (IPCC, 2014), 101 of 116 scenarios responding to the COP21 goals included carbon sinks (Fuss et al., 2014). NETs are therefore an important complement to other climate change mitigation efforts, such as increased use of renewable energy sources (Lomax et al., 2015). This has been further been emphasized by the SR15 report by IPCC (2018), where all scenarios reaching a 1.5 °C target with or without overshot include NETs.

One promising NET is bioenergy carbon capture and storage (BECCS). Over time, good biomass processes are normally somewhat more or less climate change neutral, as the CO_2 released during biomass processing is taken up by new biomass as it grows. By capturing and storing the CO_2 from bio-based processes, CO_2 levels are actively reduced. BECCS thus has double benefits: it addresses future CO_2 emissions by adding predictable renewable energy generation offsetting fossil fuels; additionally, BECCS addresses past emissions by reducing existing atmospheric CO_2 (Krahé et al., 2013).

BECCS is not one technology, but rather comprises many technologies, such as bio refineries and power and heat generation (Kato et al., 2017). Bioresources comprise a multitude of material sources ranging from virgin wood to the biogenic fraction of various waste streams, such as municipal solid waste (MSW) (Pour et al., 2017). Carbon-capture technologies could in turn be either part of new plant design or retrofitted to existing production units.

Given the importance of NETs, surprisingly little relevant R&D has taken place recently; for example, many projects were canceled in the European carbon capture and storage (CCS) industry from 2010 to 2015 (Billson and Purkashanian, 2017). Mander et al. (2017) discussed the fact that BECCS requires three distinct elements: (1) a biomass supply chain, (2) energy generation, and (3) transport and storage infrastructure. According to Billson and Purkashanian (2017), the many project cancellations are because the oversized infrastructure that must be in place imposes high initial costs on the first mover, acting as a barrier blocking government support. For many CCS projects (refineries excluded), CO_2 storage and transport also require capabilities external to the energy sector, resulting in a demand for cross-sector coordination (Bennet and Heidug, 2014) if projects are to succeed.

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https://www.sciencedirect.com/science/article/pii/S2352484719301829

Litteraturstudier till grund för testprogrammet

Table 3
Specification of the absorber used in the pilot plant [24]

	Parameter	Value
Packed column	Column height/m	4.25
	Column diameter/m	0.1
	Number of packed section	3
	Height of packed section/m	0.8
Operating conditions	K_2CO_3 apparent concentration/wt%	20, 30
	Inlet gas flowrate/kg·h^{-1}	30
	Inlet gas temperature/°C	31
	CO_2 concentration in inlet gas/vol%	25
	Lean solvent loading	0.08–0.14
	Inlet lean solvent temperature/°C	Refer to Table 4
	Lean solvent flowrate/kg·h^{-1}	120, 180
Packing materials	Type	Stainless Steel 304 Pall Ring
	DN/m	0.01
	Specific area/m^2·m^{-3}	483
	Voidage	0.93

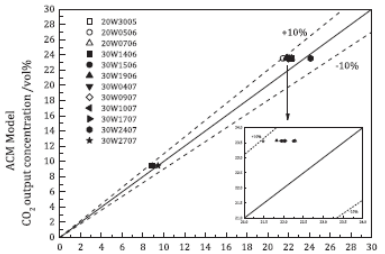


Fig. 8. Gas outlet CO_2 concentrations of ACM simulation and experiments.

previous works [24, 25]. Here loading represents the holding capacity or absorption capability of CO_2 in K_2CO_3 solvent, which is defined using the following equation:

$$\text{Loading} = \frac{\text{CO}_2\ \text{absorbed}}{\text{initial}\ [K_2CO_3]} = \frac{[HCO_3^-]}{[HCO_3^-] + 2[CO_3^{2-}]} = \frac{[HCO_3^-]}{[K^+]} \quad (7)$$

The Murphree efficiency was applied to validate the experimental data with the ACM model, in order to rectify the non-ideal performance of the pilot plant. The definition is indicated as:

$$\eta_{i,j} = \frac{G_j y_{i,j} - G_{j-1} y_{i,j-1}}{G_j y^*_{i,j} - G_{j-1} y_{i,j-1}} \quad (8)$$

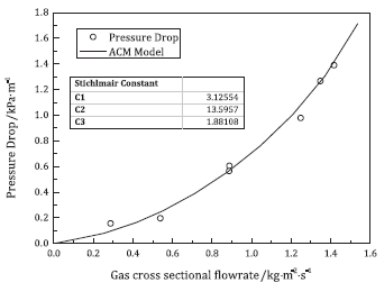
where $y^*_{i,j}$ is the equilibrium molar composition of the component i at stage j when its liquid composition is $x_{i,j}$.

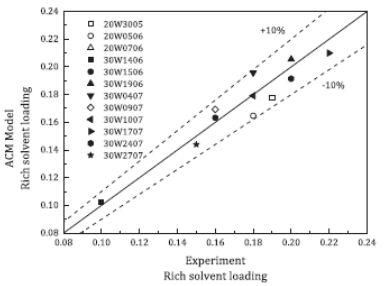
According to Mores [26], the Murphree efficiency of the CO_2-amine absorption system was dependent on gas and liquid mass transfer, chemical reactions and packing hydraulics. Here a similar estimation of the Murphree efficiency related to the characteristics of the K_2CO_3 solvent systems can be described as:

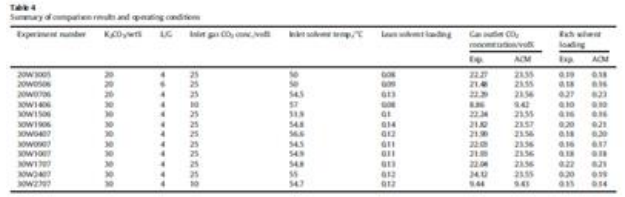
$$\eta_{i,j} = 1 - \exp\left\{-\left(\frac{h}{a'}\right)\left(\frac{G'_j}{RTk_g\rho_g}\right)\Big/\left(\left(\frac{m_i G_j}{L_j}\right)\left(\frac{L'_j}{k_l\rho_l E_j}\right)\right)\right\} \quad (9)$$

where h is the height of each packing section (m); a' is the effective area (m^2·m^{-3}), which can be calculated from the Onda correlation in Eq. (10); G_j' and L_j' are the gas and liquid cross-sectional mass flowrate (kg·m^{-2}·s^{-1}), respectively; k_g and k_l are the gas mass transfer coefficient (kmol·m^{-2}·s^{-1}·kPa^{-1}) and liquid mass transfer coefficient (m·s^{-1}), respectively; m_i is the component vapour–liquid equilibrium constant; G_j and L_j are the gas and liquid molar flowrates (kmol·s^{-1}), respectively; E_j is the enhancement factor which describes the overall absorption is enhanced by chemical reactions at the stage j, and the expression is indicated in Eq. (11).

$$\frac{a'}{a} = 1 - \exp\left[-1.45\left(\frac{\sigma_c}{\sigma}\right)^{0.75}\left(\frac{L'}{a\mu_L}\right)^{0.1}\left(\frac{L'^2 a}{\rho_L^2 g}\right)^{-0.05}\left(\frac{L'^2}{\rho_L \sigma a}\right)^{0.2}\right] \quad (10)$$







Summary of comparison results and operating conditions

Experiment number	K_2CO_3/wt%	L/G	Inlet gas CO_2 conc./vol%	Inlet solvent temp./°C	Lean solvent loading	Gas outlet CO_2 concentration/vol%		Rich solvent loading	
						Exp.	ACM	Exp.	ACM
20W3005	20	4	25	50	0.08	22.27	23.55	0.19	0.18
20W0506	20	6	25	50	0.09	21.48	23.55	0.18	0.16
20W0706	20	4	25	54.5	0.13	22.29	23.56	0.27	0.23
30W1406	30	4	10	57	0.08	8.86	9.42	0.10	0.10
30W1506	30	4	25	53.8	0.1	22.24	23.55	0.16	0.16
30W1906	30	4	25	54.8	0.14	21.82	23.57	0.20	0.21
30W0407	30	4	25	56.6	0.12	21.90	23.56	0.18	0.20
30W0907	30	4	25	54.5	0.11	22.03	23.56	0.16	0.17
30W1007	30	4	25	54.9	0.11	21.80	23.56	0.18	0.18
30W1707	30	4	25	54.8	0.13	22.04	23.56	0.22	0.21
30W2407	30	4	25	55	0.12	24.32	23.55	0.20	0.19
30W2707	30	4	10	54.7	0.12	9.44	9.43	0.15	0.14

where a is the factory packing specific area (m^2·m^{-3}); σ_c and σ are the critical surface tension of packing materials and liquid surface tension (N·m^{-1}), respectively.

$$E_j = \frac{\sqrt{k_r D_{CO_2,j}}}{k_l} \quad (11)$$

where k_r is the rate reaction constant of Reaction (3) by assuming Reaction (3) was a pseudo first order reaction (s^{-1}); $[CO_2]_i$ is the CO_2 mole fraction in the liquid phase; $D_{CO_2,j}$ is the CO_2 diffusion coefficient in the liquid phase (m^2·s^{-1}).

The pressure drop was measured by flowing air and water through the pilot plant, at a constant water flowrate of 4 kg·m^{-2}·s^{-1}. The pressure drop predicted by the ACM model using the Stichlmair constants corresponding to the specific packing materials used in the absorber matched the experimental data. The validation results are shown in Fig. 7.

In order to predict the absorption results more accurately, 6 stages were used in the model, with each stage measuring 0.4 m based on the packing height of the absorber used in the pilot plant.

Figs. 8 and 9 show the validation results between the ACM model and experimental data. The results include gas outlet CO_2 concentrations and rich solvent loadings. The operating conditions and comparisons are summarised in Table 4. Both figures indicate the error between simulation and experiment is within 10%, which means the results predicted by the ACM equilibrium model using the Murphree efficiency are reliable. The assumption of an equilibrium model for the chemical reaction results in a small Murphree efficiency (about 0.01) to predict the non-ideal behaviours of the absorber. ACM cannot predict the temperature accurately because it is assumed an adiabatic process in the ACM model, whereas there was significant heat loss during the experiment. The model may be modified to account for heat loss as required later. In addition, under the certain operating circumstances, for example, the inlet CO_2 concentration is 25 vol%, the ACM model provides stable results which are nearly the same when compared to the experiment results.

4. Rate Based CO_2 Absorber Modelling

According to Ooi [18], although employing an equilibrium model in conjunction with a Murphree efficiency can achieve acceptable results for a CO_2 absorption process using carbonate solvents, the efficiency needs to be determined based on experimental data to get an empirical value, or determined using transport parameters such as mass transfer coefficients and enhancement factors. These parameters can be derived from a rate based model. The Murphree efficiency correlated with mass transfer coefficients and enhancement factors has been successfully applied to the equilibrium model as discussed in Section 3. This means that in order to obtain an accurate equilibrium-stage model for a CO_2 capture process using K_2CO_3 solvents, a rate based model is essential and prerequisite. The difference between the two models is presented schematically in Fig. 10.

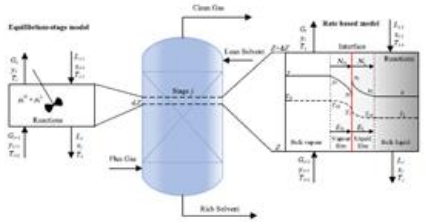


Fig. 10. Equilibrium model and rate based model for simulating a CO_2 absorber.

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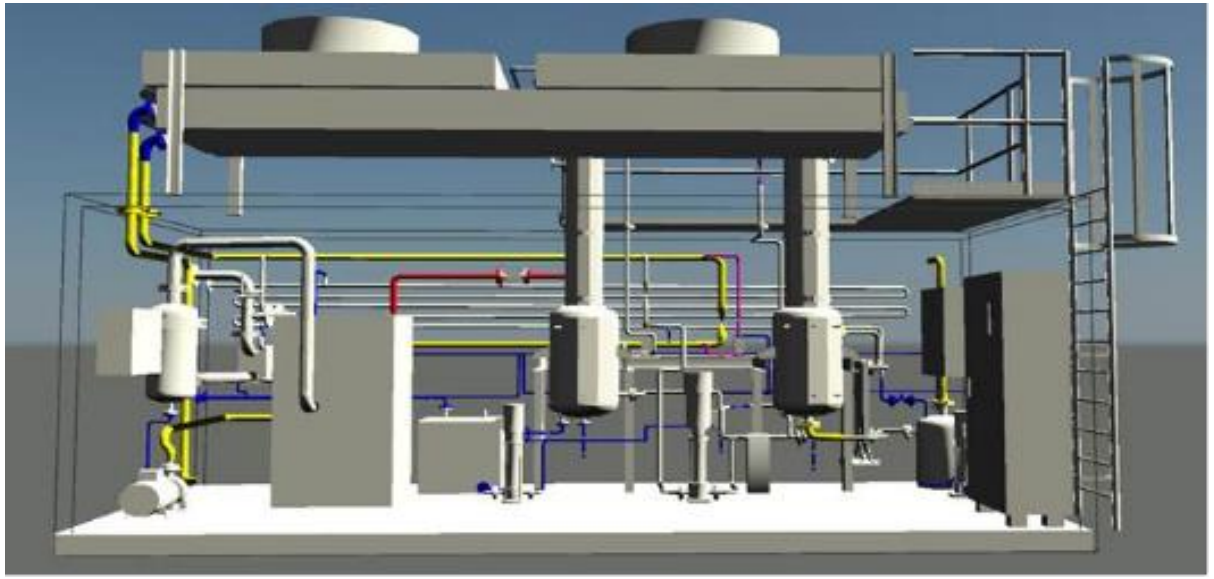
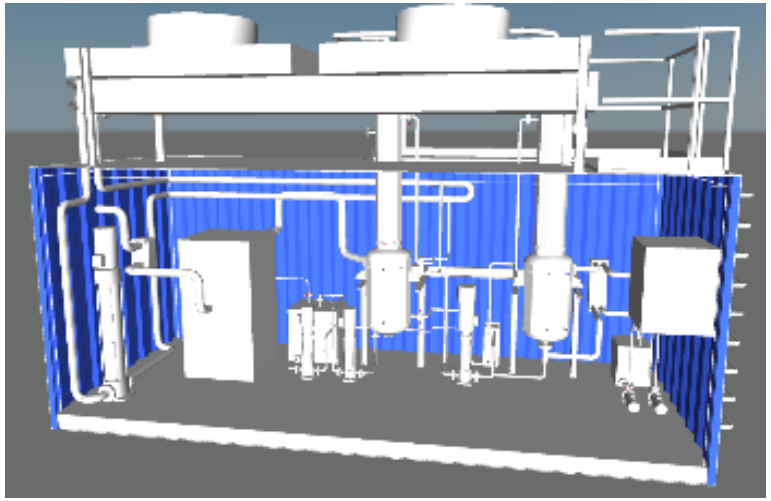
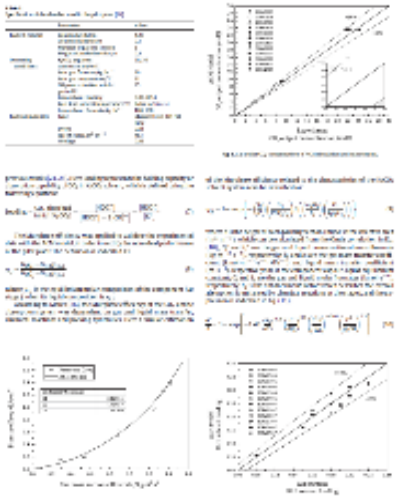
Forskningsanläggningen

Driftsättning november 2019

- Sammansättning sorptionsvätska
- Degenerering och ackumulationer i sorbent
- Optimering av fysikaliska data
- Olika rökgasers inverkan
- Reality check av massbalanser, capture rates, tryckfall etc
- Modelleringar och simuleringar
- Rökgasdesign
- Stresstester
- Långtidstest (2000 hours)







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Parallella tester i Norge och Storbritannien

- Avfallsförbränning
- Biokraftverk (ej värme)
- Organiska katalysatorer

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CO_2 Capture, transport och permanentlager

100 ppm O_2

3 step

10-20 ppm O_2

Purification

18-20 bar

Heat

Condensate

10-12 kton

15-18 bar
-30 °C

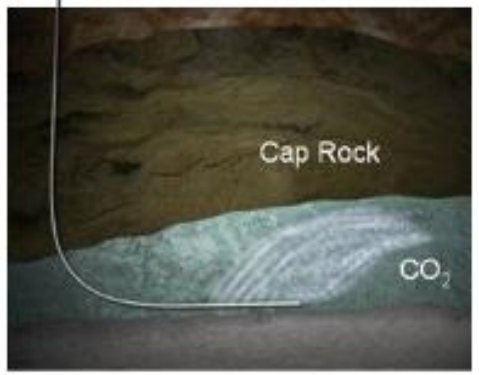
15-18 bar
-30 °C

7.500 ton

3000 m

300 bar

Significant heat



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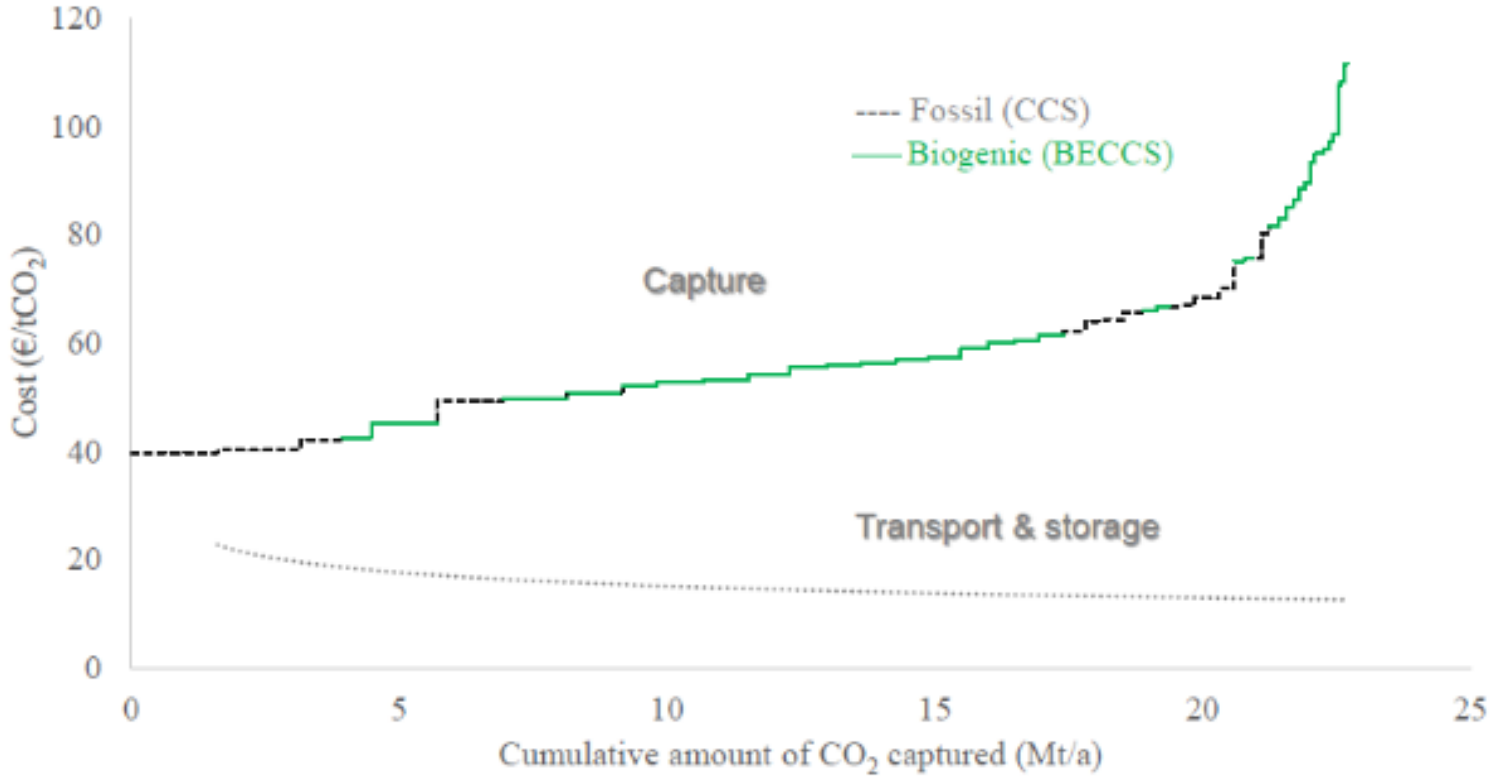
Förstudie

1. Teknoekonomiska förutsättningar
2. Integrationsstudier i befintlig anläggning
3. Capex vs Opex
4. Tillstånd och legala frågor
5. Riskanalys



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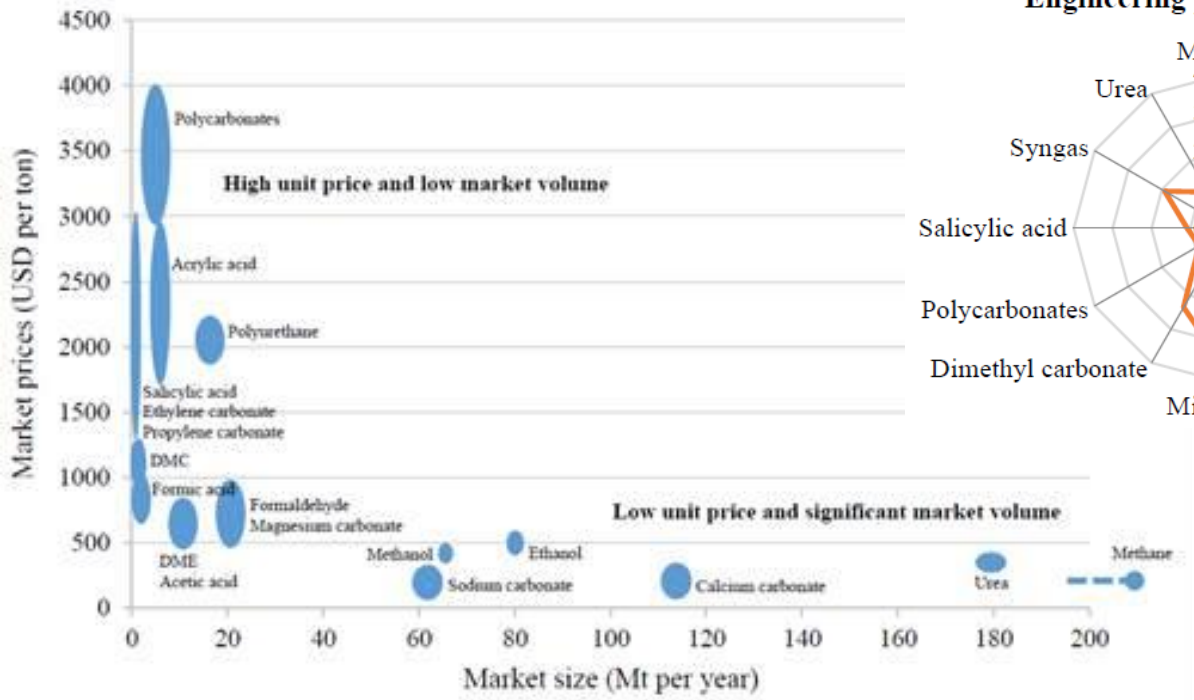
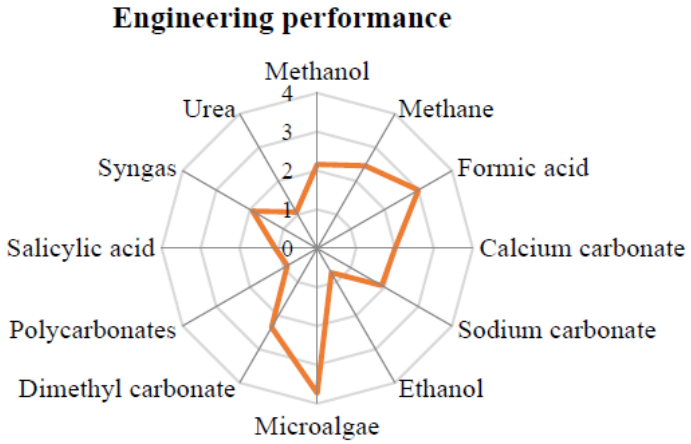
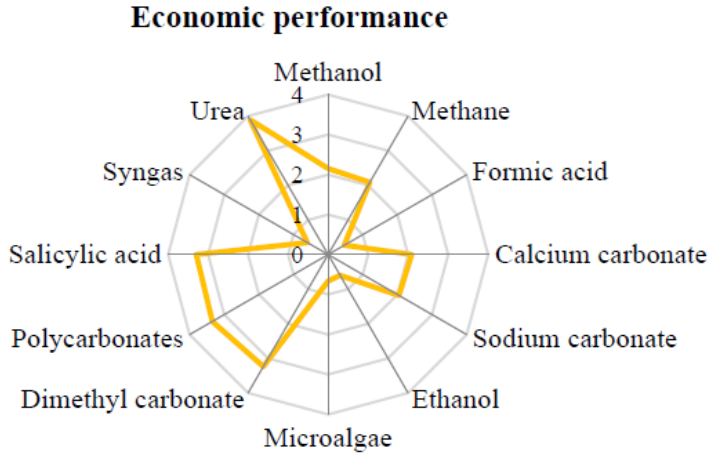
Carbon Capture Utilization (and Storage)

Chauvy et al: Selecting emerging CO2 utilization products for short to midterm deployment.







Metan: $CO_2 + 4H_2 \rightarrow CH_4 + H_2O$

Metanol: $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

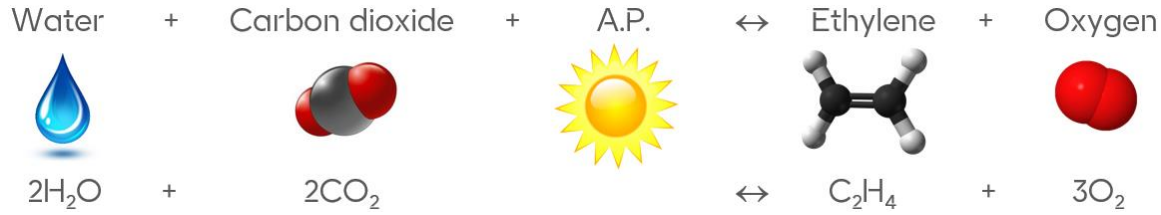
Myrsyra: $CO_2 + H_2 \rightleftarrows HCOOH$

Ureasyntes

$2NH_3 + CO_2$ (180-200 °C; 13-20 Mpa) $\rightleftarrows NH_2COONH_4$ (ammonium carbamate)

$NH_2COONH_4 \rightleftarrows H_2O + NH_2CONH_2$ (urea)

Polymera konstruktionsmaterial:



Betong: $CaO + CO_2 \rightarrow CaCO_3$

$MgO + CO_2 \rightarrow MgCO_3$

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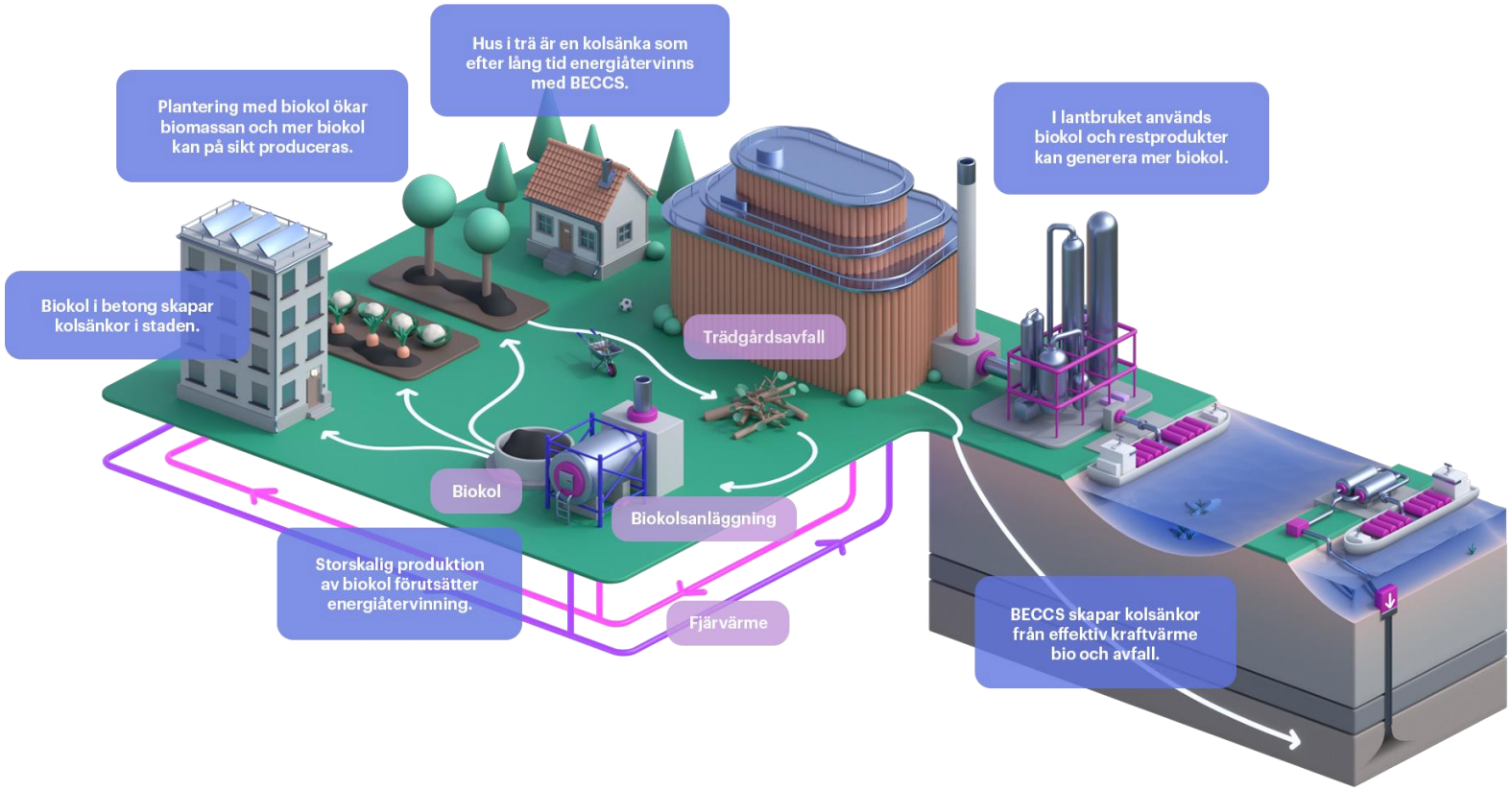
Minusutsläpp är helt avgörande för att nå klimatmålen

1. CCS och BECCS: Samma teknik med olika syften
    1. CCS: Minska sin egna utsläpp
    2. BECCS: Skapa minusutsläpp och därmed hantera utsläpp som orsakats på annan plats
2. Utmaningar med BECCS:
    1. Teknik: troligen OK
    2. Legalt: troligen OK
    3. Ekonomi: marknad och/eller styrmedel behöver utvecklas
3. Vilken teknik som är bäst beror på lokala förutsättningar och kan med fördel kombineras



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