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FEES

# Boundary Conditions for CO2 Value Chains: From Emissions to a Resource

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ENERGY MEETS INDUSTRY

Lappeenranta

Greenreality

# Two business models

## Carbon Capture and...

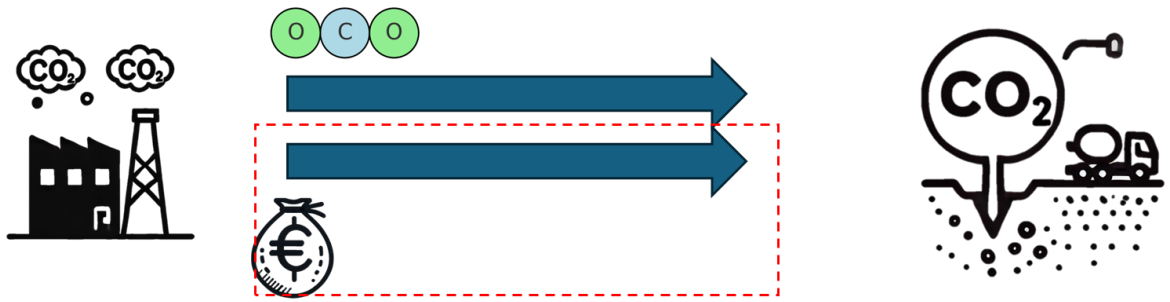
### STORAGE

"Point source pays for *the disposal of emissions*"

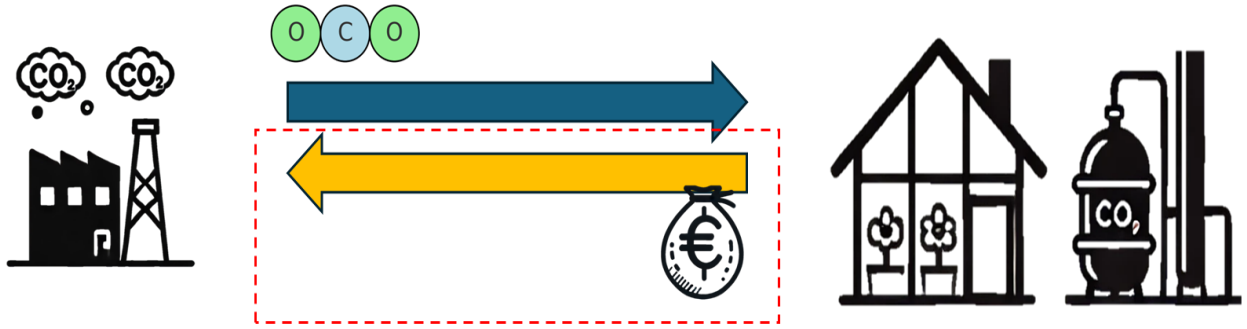

### USAGE

"End user pays for *vital ingredient*"

### CCS Model




### CCU Model



# CCS in brief

- EU Emissions Trading System (EU ETS) requires polluters to pay for Greenhouse gas emissions
- **If ~~penalty~~ *EU allowance* costs 85 € / CO2 tonne and capturing costs 120 € / t, why should we do this?** (from the economical point of view)
  - Investment support (90 M€ in Finland, decisions during the fall) https://tem.fi/teollisuuden-bioperaisen-hiilidioksidin-talteenottoavustus
  - Are customers willing to pay more for greener products?
- Northern Lights (for example) provides storaging as a service https://norlights.com/what-we-do/
- Separate voluntary carbon removal market for **carbon removal credits**
  - Requires permanent storaging for **biogenic CO2**

https://www.ice.com/products/197/EUA-Futures/data?marketId=7895486&span=3

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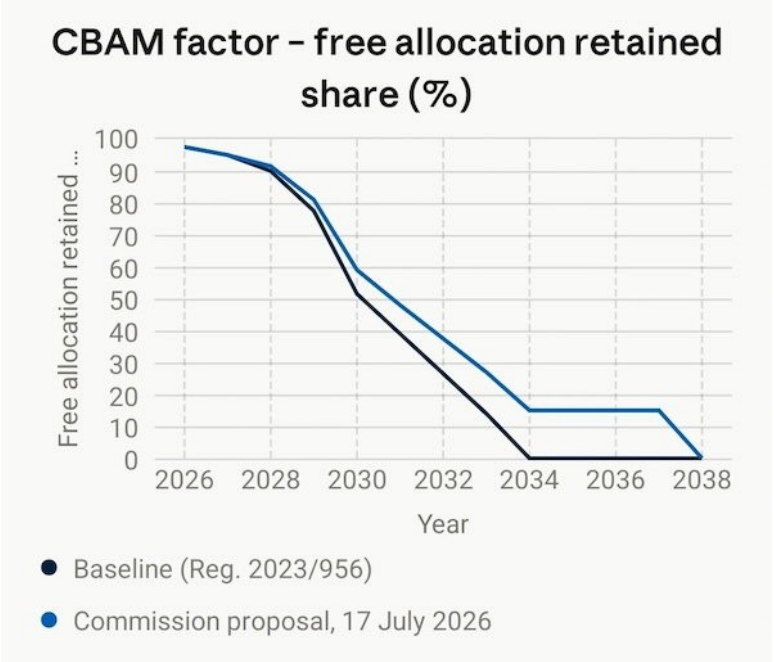
| CONTRACT | LAST | TIME(GMT) | % CHANGE | VOLUME |
|---|---|---|---|---|
| SEP26 | 83.480 | 9/3/2026 6:54 AM | -0.084 | 1 |


https://www.cemnet.com/News/story/181728/european-commission-proposes-a-more-pragmatic-ets.html

# $CO_2$ PURITY CRITERIA

Maximum allowable concentrations of 10 key impurities

ppm

| NORTHERN LIGHTS<br>CCS transport and geological storage · ppm-mol | IMPURITY | EIGA 70/17<br>Food and beverage grade · ppm v/v |
|---|---|---|
| ≤ 30 | Water ($H_2O$) | ≤ 20 |
| ≤ 10 | Oxygen ($O_2$) | ≤ 30 |
| ≤ 100 | Carbon monoxide (CO) | ≤ 10 |
| ≤ 1.5 total | Nitrogen oxides ($NO_x$)* | ≤ 2.5 each |
| ≤ 1 | Hydrogen sulfide ($H_2S$)** | ≤ 0.1 |
| ≤ 10 $SO_x$ | Sulfur oxides* | ≤ 1 $SO_2$ |
| ≤ 10 | Ammonia ($NH_3$) | ≤ 2.5 |
| ≤ 20 | Acetaldehyde ($CH_3CHO$) | ≤ 0.2 |
| ≤ 30 | Methanol ($CH_3OH$) | ≤ 10 |
| ≤ 0.5 BTEX | Aromatic hydrocarbons* | ≤ 0.02 benzene |

**If $CO_2$ stream needs to be purified anyway, should we use it as resource instead?**

* Group limits are not directly equivalent: $NO_x$ (total vs NO and $NO_2$ separately), $SO_x$ / $SO_2$, and BTEX / benzene.

** EIGA's principal sulfur criterion is total sulfur ≤ 0.1 ppm as S; species limits include $H_2S$ ≤ 0.1 ppm and $SO_2$ ≤ 1 ppm.

On an ideal-gas basis, ppm-mol and ppm v/v are numerically equivalent. The specifications serve different purposes.

Sources: Northern Lights, Liquid $CO_2$ Quality Specifications (current online version, 2025) · EIGA Doc 70/17, Appendix A (2017)

# Simplified Biogenic CO2 Value Chain

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- (1) Requires **partners** for every step
- (2) Not only **sustainable**, but also **profitable**

In many cases, capturing, purification and transportation should be less than **100 €/tonne($CO_2$)**

## Sources

- Biogas Plants
- Flue Gases
- Food Industry
- Air

## Capturing

- Pre-Combustion
- Post-Combustion
- DAC

## Purification

- (Dehydration)
- Amine
- PSA
- C + Membrane
- Liquefaction

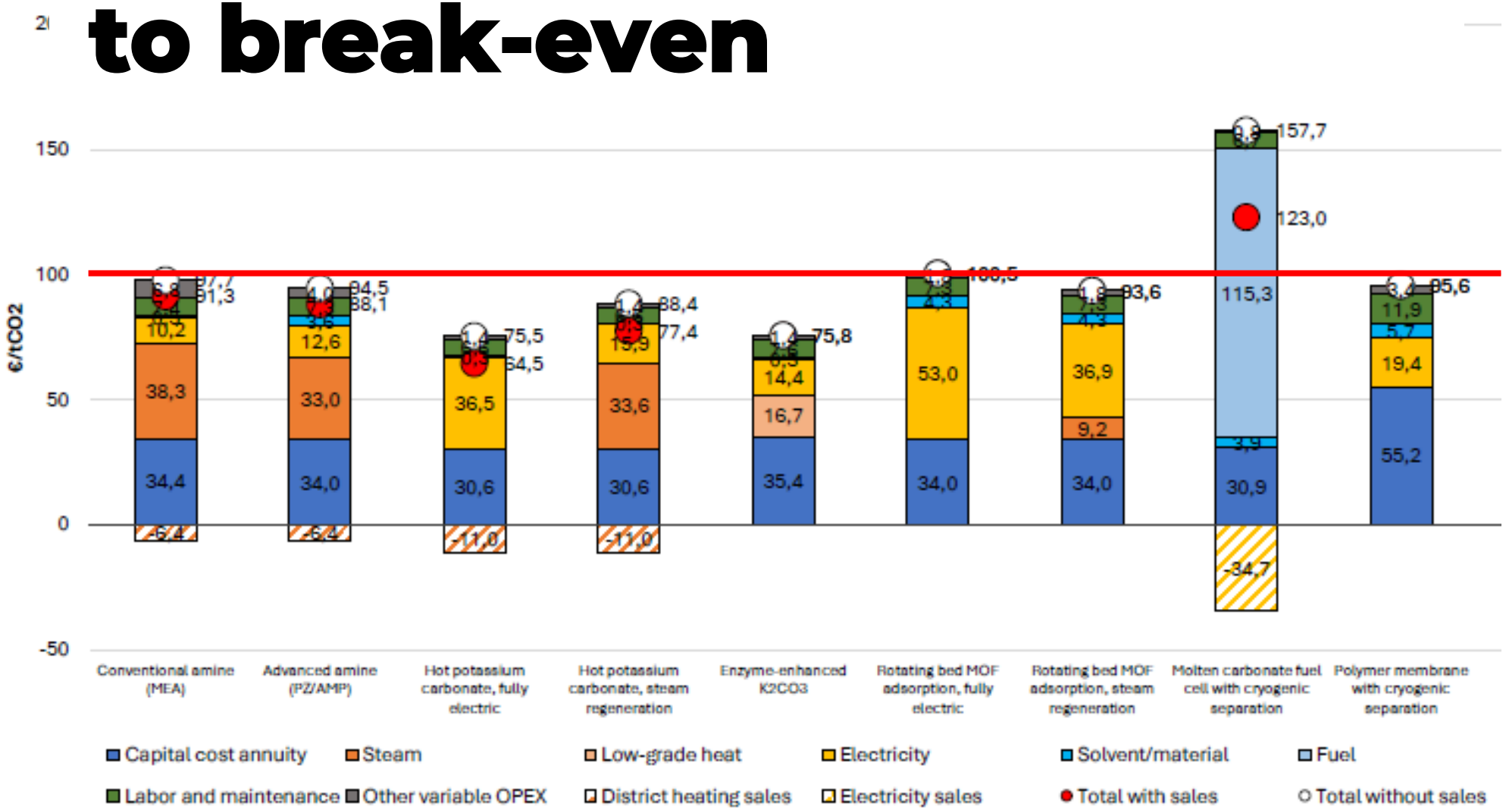
## Logistics

- Trucks
- Trains
- Ships
- Pipes

## Applications

- Food grade
- Synthetic fuels
- Green houses
- Algae
- Mineralization

# Capturing costs are close to break-even




Linjala, O. (2025). Evaluating carbon capture technology options through technology screening. Carbon Capture Journal, 107, 10-11.

# Applications

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https://www.labopen.fi/lab-rdi-journal/paastovahennyksia-ja-lisaarvoa-tuotteille-hiilidioksidin-hyotykaytolla/

- **The field is expanding fast!**
- Relevant purity standards
  - EIGA70/17 (Food grade)
  - ISBT (Brewery)
  - European Pharmacopoeia
- **Consider the following**
  - *Purity grade*
  - *TRL level*
  - *Uptake and other ingredients*
  - *Environmental aspects*
  - *Locality*

| CO2-Applications (TRL 9) | | Example companies |
|---|---|---|
| Food industry | Drinks (carbonic acid) | Hartwall |
| | Decaffeination | Kahvikaveri |
| | Protein | Solar Foods |
| | Dry ice blasting | Woikoski |
| Building materials | Concrete curing | Carbonaide |
| | Filling substrates | Carbon8 |
| Chemicals | Refrigerants | Woikoski |
| | Salicylic acid | |
| | Urea | Yara |
| Plastics | Polycarbonate | Asahi Kasei |
| | Polypropylene carbonate (PPC) | Norner |
| | Polycarbonate polyol | Covestro* |
| Fuels | Methanol | George Olah (CRI) |
| | Methane | Q Power |
| Other | Green houses | Many |
| | Supercritical solvent | Nanoform |
| | Water pH-adjustment | Linde |

# Quality Standards

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- **Low-CO2 standards missing**
  - Technical committee on CCUS (**CEN/TC 474**): prEN 18397 – Properties of CO2 streams in carbon steel pipes (**in progress**)
- Things to consider
  - We cannot afford '**over-purifying**'
  - Current standards are designed for traditional sources
    - **Does it miss some impurities?**

| Food | Synthetic Fuels | Polycarbonates | Greenhouses | Concrete curing |
|---|---|---|---|---|
| No foreign taste or odour etc. | Catalytic poisons | Sulphur compounds<br>NOx<br>H2O | Ethylene<br>SO2 | O2 |

Kajolinna et al. " Assessment of carbon dioxide quality from industrial point sources for carbon utilization" (2025)

# Viable CCU depends on matching the right source with the right use

Scale, location, $CO_2$ quality and economics must align across the value chain.

## $CO_2$ SOURCE

- Available volume
- $CO_2$ concentration
- Impurity profile
- Location & continuity

MATCH

**Best-fit value chain**

volume • location • quality • cost

## END-USE DEMAND

- Required volume
- Purity specification
- Price tolerance
- Location & demand profile

INDUSTRIAL SYMBIOSIS

**Use the whole site — not only the $CO_2$**

Integrate valuable side streams, waste heat and cold, and renewable energy to strengthen the business case.

**TEA + LCA articles on concrete curing and single-cell protein are in preparation**

Report in Päijät-Häme: https://lahtibusinessregion.fi/uutisia/co2sta-bisnesta-lahdessa-rakennetaan-vahahiilista-tulevaisuutta-paikallisella-hiilidioksidiekosysteemilla

# Hiiliketju – $CO_2$ Value Chain Scenario Tool

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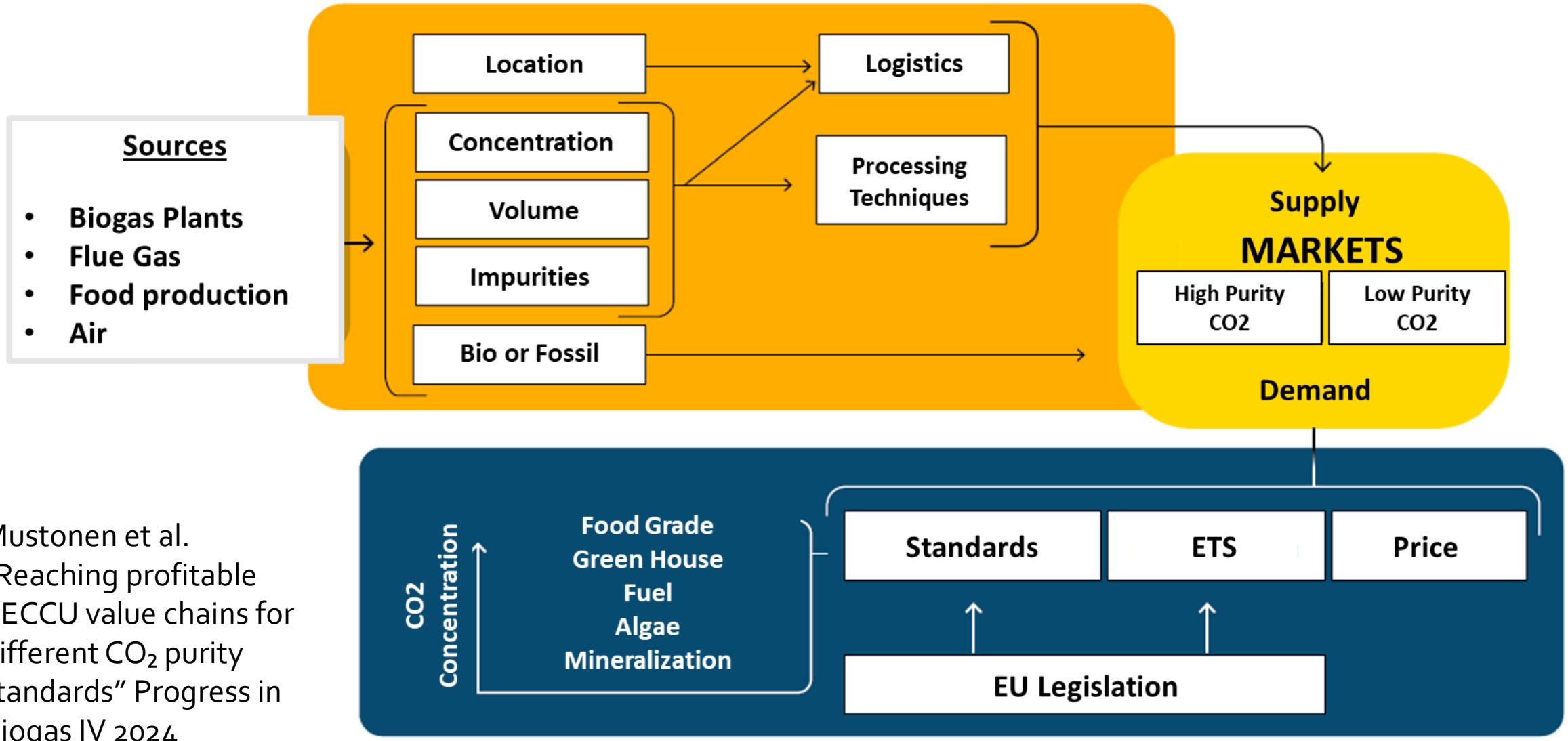
- A browser-based tool was developed to explore **when biogenic $CO_2$ can become a technically and economically viable resource**.
- The tool evaluates $CO_2$ value chains based on key boundary conditions:
  - **$CO_2$ availability and utilization rate**
  - **Temporal availability of $CO_2$ and electricity**
  - **Electricity price and $H_2$ production cost**
  - **Process assumptions and CAPEX**
  - **Product prices and revenues**
- Currently, the tool compares **$CO_2$ methanation ($CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$)** with an alternative pathway where **$H_2$ is sold directly and $CO_2$ is released**.
- **Outputs:** production volumes, energy demand, costs, revenues and **break-even / profitability thresholds**.

**hiiliketju.vercel.app**

# KEY FACTORS PERFORMING PROFITABLE CCU-BASED VALUE CHAINS




Mustonen et al. "Reaching profitable BECCU value chains for different $CO_2$ purity standards" Progress in Biogas IV 2024

Interreg

Central Baltic Programme

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BUSINESS FINLAND

# Thank you!

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