



CLIMEWORKS

Capturing CO₂ from Air

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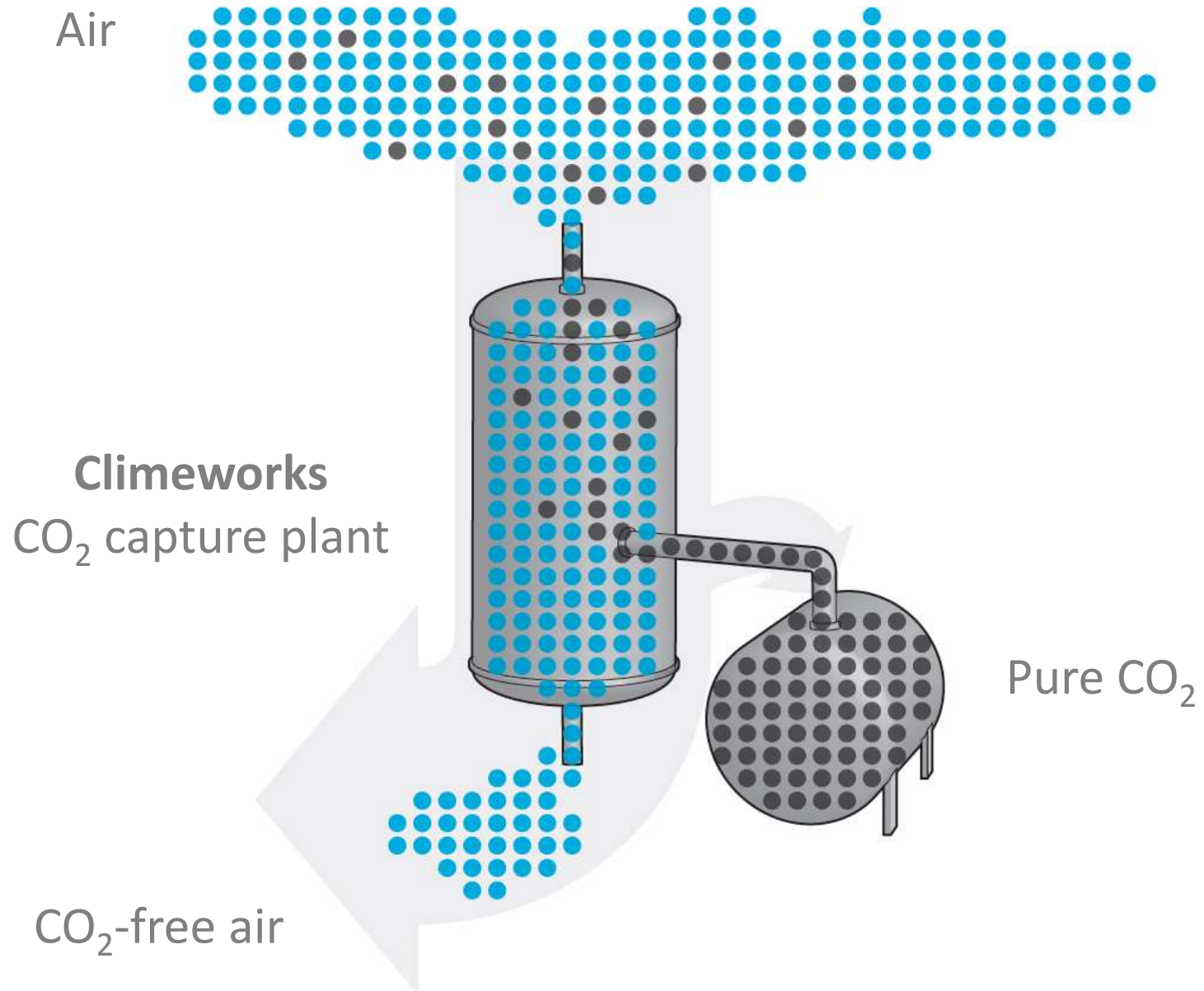


DAC Workshop @UKCCSRS, 20 February 2015



EARTH
CHALLENGE





Air

Climeworks
CO₂ capture plant

Pure CO₂

CO₂-free air

Markets



CO₂ Enrichment in Greenhouses



- Increases crop yield by 20-30% through CO₂ injection in greenhouse
- Market for Climeworks' first 1000t CO₂/y plant



Beverage Carbonation



- Short-term: Substitute fossil fuel CO₂ generation in 2nd/3rd world countries
- Long-term: application worldwide



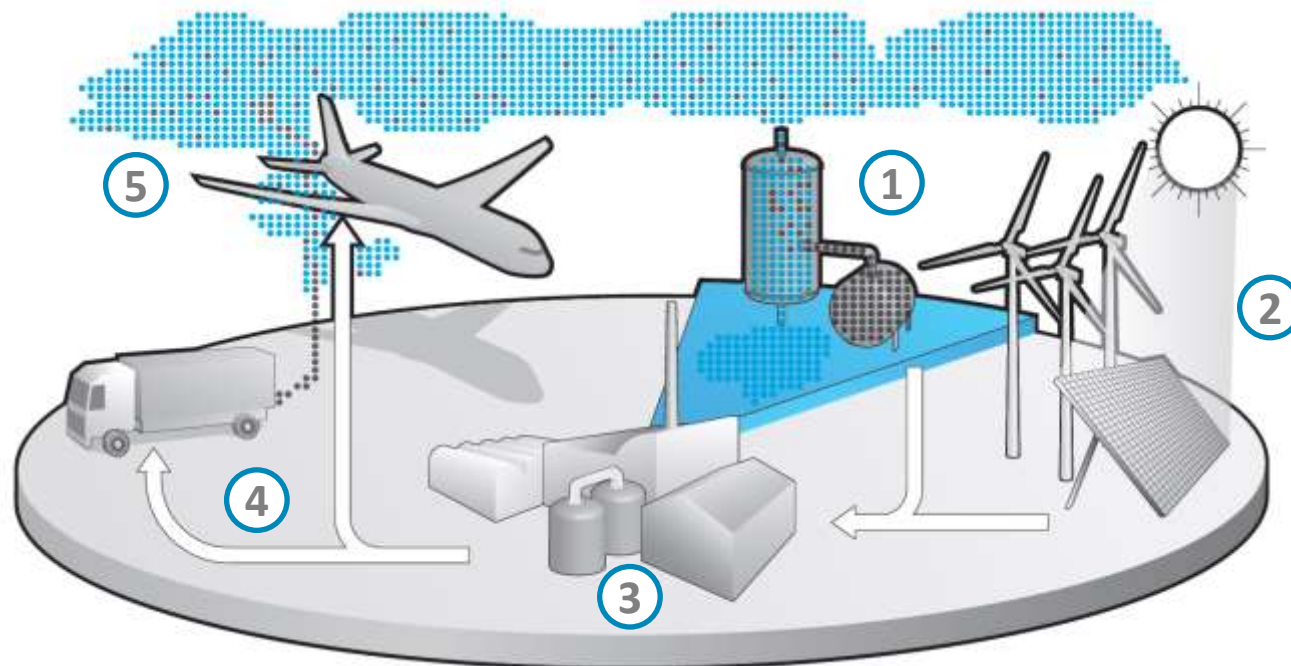
CO₂ Supply for Renewable Fuel Synthesis



- Reduce fleet CO₂ emissions through renewable fuels
- Storage of fluctuating renewable energies

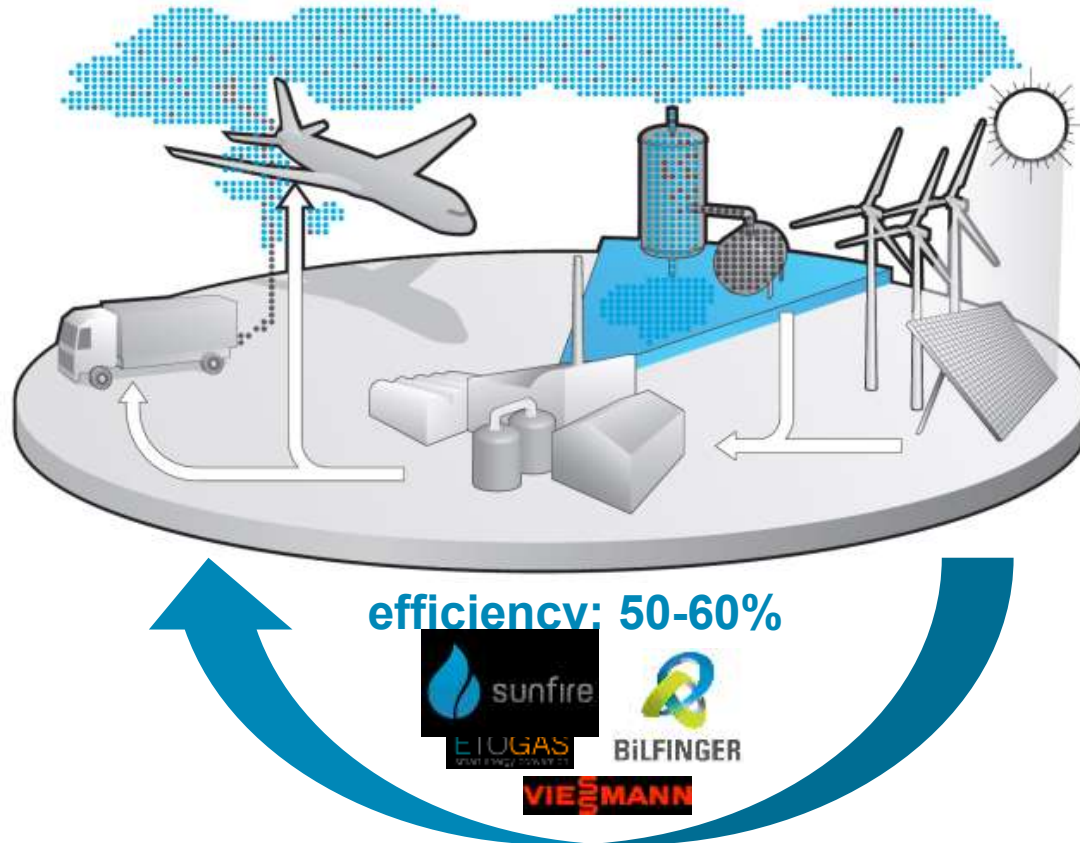


Vision: Closing the Carbon Cycle



- ① **Climeworks plant** delivers concentrated CO₂ from atmospheric air
- ② **Renewable energy source** for Climeworks and subsequent fuel synthesis plant
- ③ **Fuel synthesis plant** converts CO₂ and water to fuels → grid balancing & storage
- ④ **CO₂-neutral fuel** (gas, diesel, kerosine) is used in **existing energy infrastructure**
- ⑤ Combustion of CO₂-neutral fuels does not create net emissions since the CO₂ was captured before → **closed carbon cycle**

Efficiency of Renewable Fuel Synthesis



- efficiency from renewable electricity to heating value of fuel: **50-60%** (including energy for Climeworks plant)
- fuel synthesis available by industrial companies on industrial scale



1) Audi's Renewable Fuel «e-gas» (PtG)



(Photography source: Audi homepage)

- Since summer 2014 Audi produces renewable methane («e-gas») from biogenic CO₂, water and renewable electricity
- 1000t renewable methane (2800t CO₂) annually, sufficient for **CO₂-neutral mobility of 1500 Audi A3 g-tron cars**
- A fraction of the CO₂ needed for synthesis will be provided by Climeworks in 2015

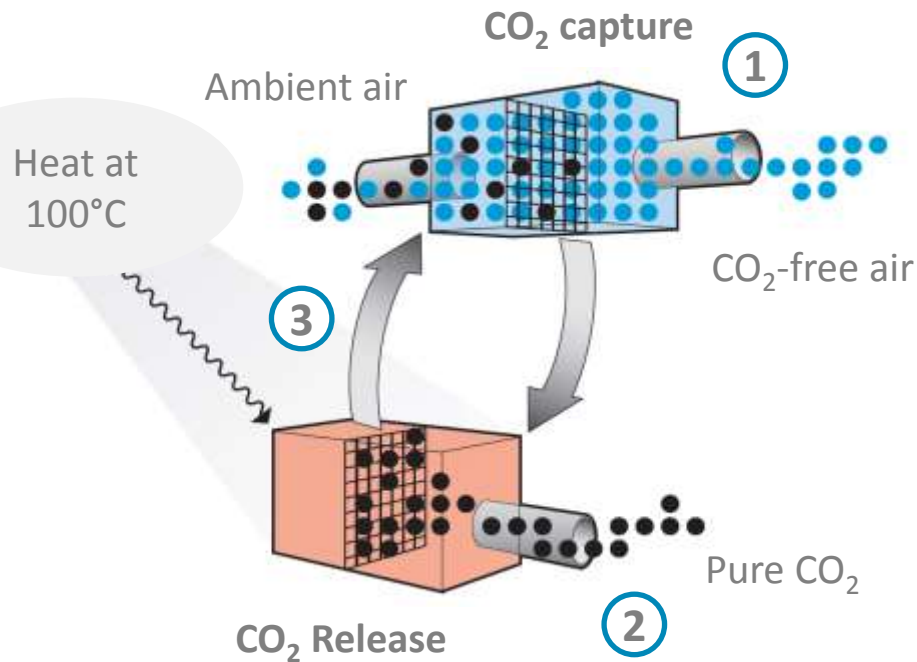


2) sunfire's synthetic fuel plant (PtL)



- Since November 2014, new project collaboration between Climeworks (CO₂ capture), sunfire (fuel synthesis) and Audi
- First batch of renewable liquid fuels in 2015 (160 L/day of Blue Crude) produced in Dresden
- 1 ton of fuel requires the capture of 3.2 ton of CO₂

Climeworks Technology



- 1** Air is driven through system w/ ventilator and CO₂ is bound chemically to filter material w/o conditioning of air stream; duration: 2-4h
- 2** System is closed, pressure inside chamber reduced and system heated to 100°C; thereby pure gaseous CO₂ is released; duration: 1-2h
- 3** System is cooled to ambient temperature, CO₂ capture is re-started; duration: 0.5h

**Commercial plants contain many parallel modules
→ Continuous delivery of concentrated CO₂**

*developed in collaboration with:

Climeworks Products



Demonstrator



- 2 tons CO₂ / year
- Online since 12/2012
- 99.3% CO₂ purity*
- 1 piece sold

CO₂ Collector



- 50 tons CO₂ / year
- Full scale module
- Online since 08/2014
- 1 piece sold

CO₂ Capture Plants



- 1000 tons CO₂ / year
- Modular, turnkey, standalone
- Available Q1/2016
- Sales contract signed

* Analysis by Airborne Labs International, Inc., April 2013

The 1st Industrial CO₂ Capture Plant: Sale



Climeworks CO₂ Capture Plant



- Status: sales contract closed → beginning of production
- Operational in 2016
- 1000 tons CO₂/year

Specifications

- **Customer:**
 - Gebrüder Meier
 - Uses CO₂ for greenhouses
- **Location:**
 - Hinwil, Switzerland
 - Plant located near customer
- **Energy supplied:**
 - Heat (~ 105 °C in) and electricity supplied by nearby waste incineration plant

The 1st Industrial CO₂ Capture Plant: Product Specifications



Climeworks CO₂ Capture Plant

Specifications



- Modular design
- Turnkey solution
- Standalone operation (fully automated)

- **Heat requirement:**
 - 1500 – 2000 kWh / t CO₂
 - ~ 105 °C in / 95 °C return
- **Electricity requirement:**
 - 200 – 300 kWh / t CO₂
- **Area requirement:**
 - 330 t CO₂ per year per 40 ft container
 - Vertical stacking of containers possible

Summary of Latest Developments



- Closed two financing rounds amounting to total USD 5.6 MM, received grants/awards with total of USD 2.6 MM
- Two years of measurement data under realistic conditions. Climeworks understands:
 - Influence of temperature/RH on plant capacity
 - Degradation of amine-functionalized adsorbents
- Completed technology scale-up to final product scale (CO₂ collector module) and gathered 6 month operational experience
- Entered market:
 - Sold one Climeworks demonstrator (delivery April 2015)
 - Sold one Climeworks CO₂ collector (delivery September 2015)
- Closed sales contract for 1000t/y plant (start CO₂ production Q1/2016)
- Partnership with carmaker AUDI in the mobility sector



Full-Scale CO₂ Collector Unit



Specifications

- 50 t CO₂/year nominal capacity
- Light-weight desorption chamber (\approx 2 t module weight)
- 15'000 – 20'000 m³/h adsorption flow
- 60 kW desorption power
- Autonomous operation, online performance measurement



Principle of Fuel Synthesis



- **1. step: water electrolysis**

electrolyzer splits water to yield hydrogen → this step is the major energy consumer



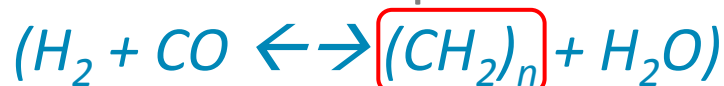
- **2. step: CO₂ reduction**

hydrogen is brought into contact with high purity CO₂ and thus splits CO₂ to yield carbon monoxide



- **3. step: fuel synthesis**

carbon monoxide and hydrogen are combined to yield any desired fuel → process well known for decades



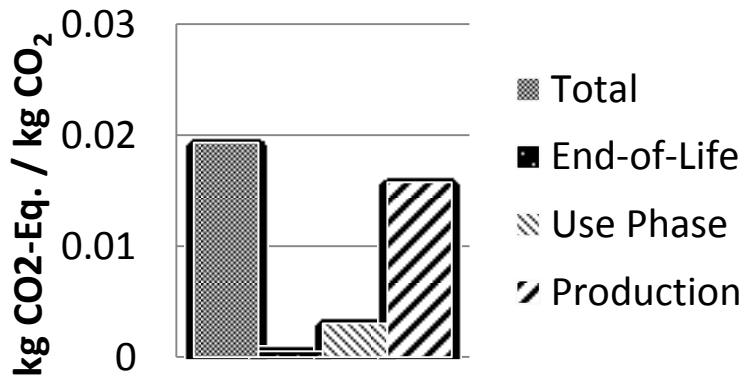
→ = any desired liquid or gaseous fuel

Life Cycle Analysis



- CO₂-equivalent emissions from production, use, and end-of-life of the Climeworks plant
 - Heat supply through waste heat (no emissions associated)
 - Electricity from renewable energy

Global Warming Potential



Production of facility in detail

