Greenhouse CO_2 dosing for enhanced crop growth

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Thesis…

CO_2 – compliments other “green” greenhouse technologies

The perfect greenhouse growing environment

- Water and nutrients
- Soil or growth substrate
- Good air circulation
- Good light, but not at night
- Warm, but not too hot
- Humid, but not too moist
- Plenty of CO_2 in the air, but not too much

Greenhouse CO_2 sources

- Combustion of cylinder propane or LPG
- Combustion of piped natural gas or LNG
- Natural gas fired CHP exhaust gas
- Direct CO_2 injection
  - Pipeline supply (NL special case)
  - Bulk liquid storage & vaporisation (standard for commercial growers)
  - Cylinder supply (small scale growers and hobby gardeners)

Combustion vs CO_2 injection - heat

- Combustion of LPG or natural gas yields humidity, CO_2 and heat
  - Win-win for the greenhouse?
- Simple, low cost solution but inflexible – no independent control of heat and CO_2 input
- Ideal for cold climates, eg Canada
- CHP for very large facilities, eg NL

BOC Australia differentiated CO_2 grades:

1. Beverage grade: CO_2 is an ingredient and is physically ingested
2. Food grade: CO_2 is in contact with the food that will be eaten, eg MAP
3. Environmental grade: CO_2 is introduced into the greenhouse growing environment where it will come in contact with the food in a diluted form and the food generally undergoes further processing / packaging before being consumed
4. Industrial grade

Typical case study: “Murphy Fresh”, Australia

- Tomato crop
- 2.6 ha under glass
- 1500ppm CO_2 control point
- 1.2 to 1.8 Te CO_2 per day per ha
- BOC supplies “Environmental Grade” bulk liquid CO_2
- 30 Tonne tank, filled circa 2x per week

Beyond plant crops

- CO_2 is used for algae growth
- Algae is harvested for nutrition and healthcare products
- The liquor residue (after algae harvesting) can be used as a hydroponic greenhouse nutrient & water source

Growth drivers for CO_2 usage vs combustion

- CO_2 offers better process control and increased flexibility
- Desert greenhouses in the middle east and Australia are a growth phenomenon and require CO_2, but not so much heat
- Geothermal energy in Europe is providing the required heat without CO_2 as a combustion by product
- CCU in the Netherlands (from pipeline supply of refinery SynGas and bioethanol by-product CO_2) is making CHP systems redundant

“Vertical farming” in the middle east

- Hydroponic growing can reduce water consumption by up to 95%
- Local growing reduces aviation transport environmental impact
- One grower: 70+ Ha under glass across 9 farms
- CO_2 from direct combustion would generate too much heat
- Up to 1kg CO_2 per 1kg tomato crop reported
- Example supplier: food-grade bulk liquid CO_2 from Gulf Cryo
  - Traceable product batches
  - CO_2 is a by-product of ammonia or ethylene glycol production

Seawater farming in the desert

- Sea-water desalinated with PV solar powered RO membrane desalination plant
- Evaporative cooling of pumped seawater reduces / eliminates chiller power requirements
- CO_2 from a direct combustion source would generate too much heat and be counter-productive

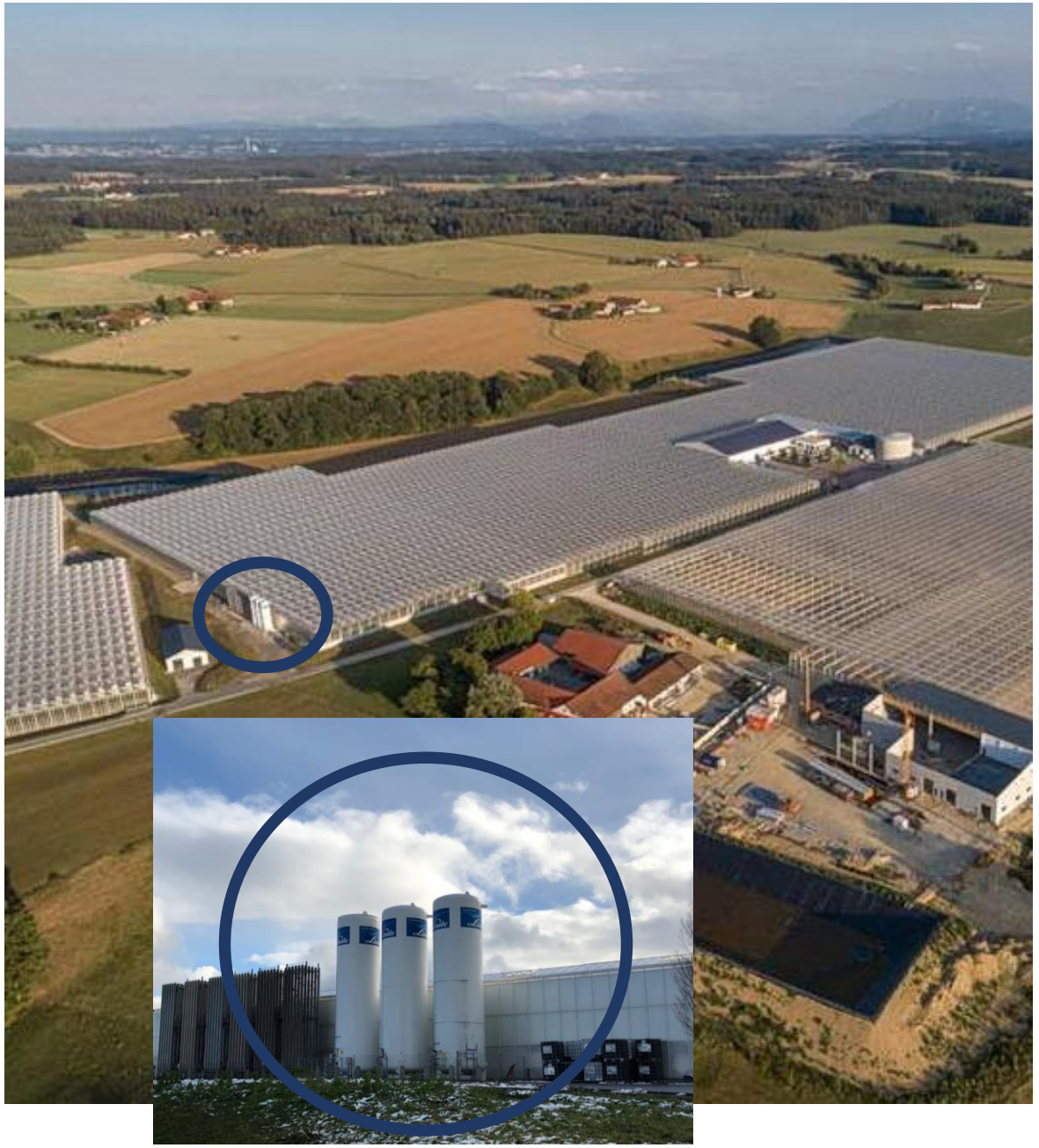
Concentrated solar power (CSP) to steam in Southern Australia

- Sundrop Farms, Adelaide
- 20 ha farm, tomato crop
- Mirrors reflect sunlight to the 126m high solar tower (Aalborg CSP)
- Energy is used for water desalination, heat and electrical power generation (via a steam turbine)
- CO_2 from direct combustion would create additional heat and be counter productive
- Air Liquide bulk liquid CO_2 supply

A Sundrop greenhouse turns seawater and sunlight into energy and water. We then use sustainably sourced carbon dioxide and nutrients to maximise the growth of our crops.

Geothermal growing in Bavaria

- Gemüsebau Steiner GmbH & Co KG
- Circa 20 ha under glass
- Tomato, capsicum & cucumber
- Heat from geothermal energy – temperature / pressure profile ideal for warmth, not sufficient for electrical power
- Linde bulk liquid CO_2 supply
- Industrial grade CO_2
- 0.4 to 0.8 kg CO_2 per kg tomato crop

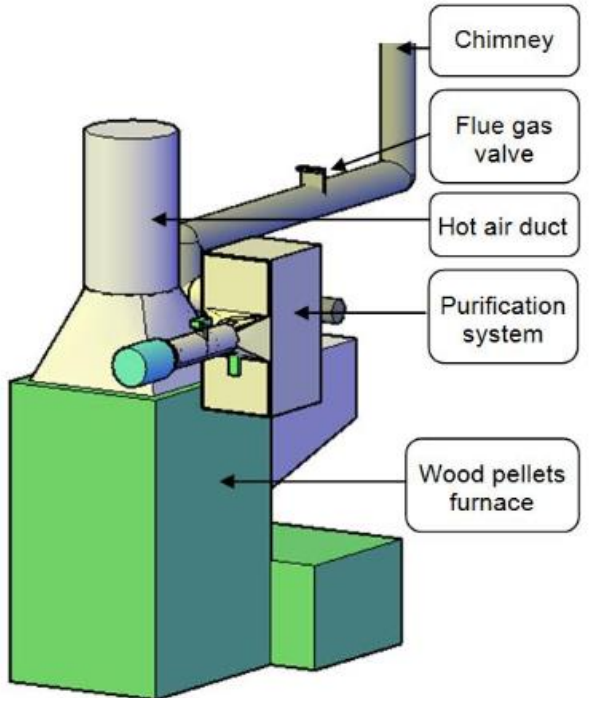


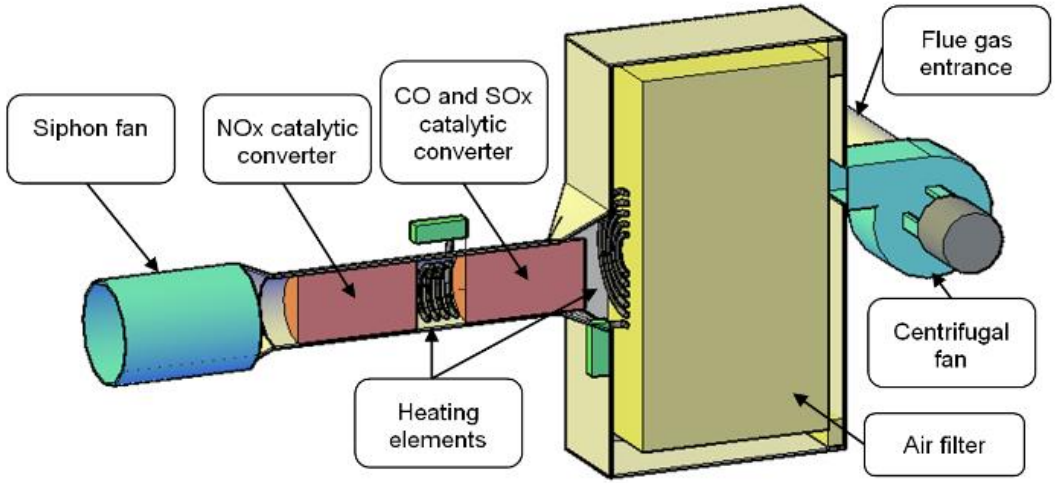
Carbon capture and re-use in NL

- OCAP pipeline delivers 400,000 TPA of CO_2 to 500 greenhouses with 2,000 ha under glass
- CO_2 from the Shell Pernis refinery (SynGas) and Abengoa bioethanol plant
- CHP is the other main CO_2 source for the NL greenhouse industry, but pressure to reduce carbon footprint
- CO_2 storage in the dis-used Q16-Maas natural gas field is proposed to smooth out the annual peak in demand (summer high, winter low) and thereby increase pipeline capacity to support growth in demand

Combustion goes green… with biomass

- Heat and CO_2, or CHP and CO_2 from wood chip
- Carbon-neutral fuel
- Requires flue gas clean up to avoid build up of CO, SO_2 & NOx
- Emerging solution in cooler northern climates with abundant forests, eg Canada





Conclusion - growth

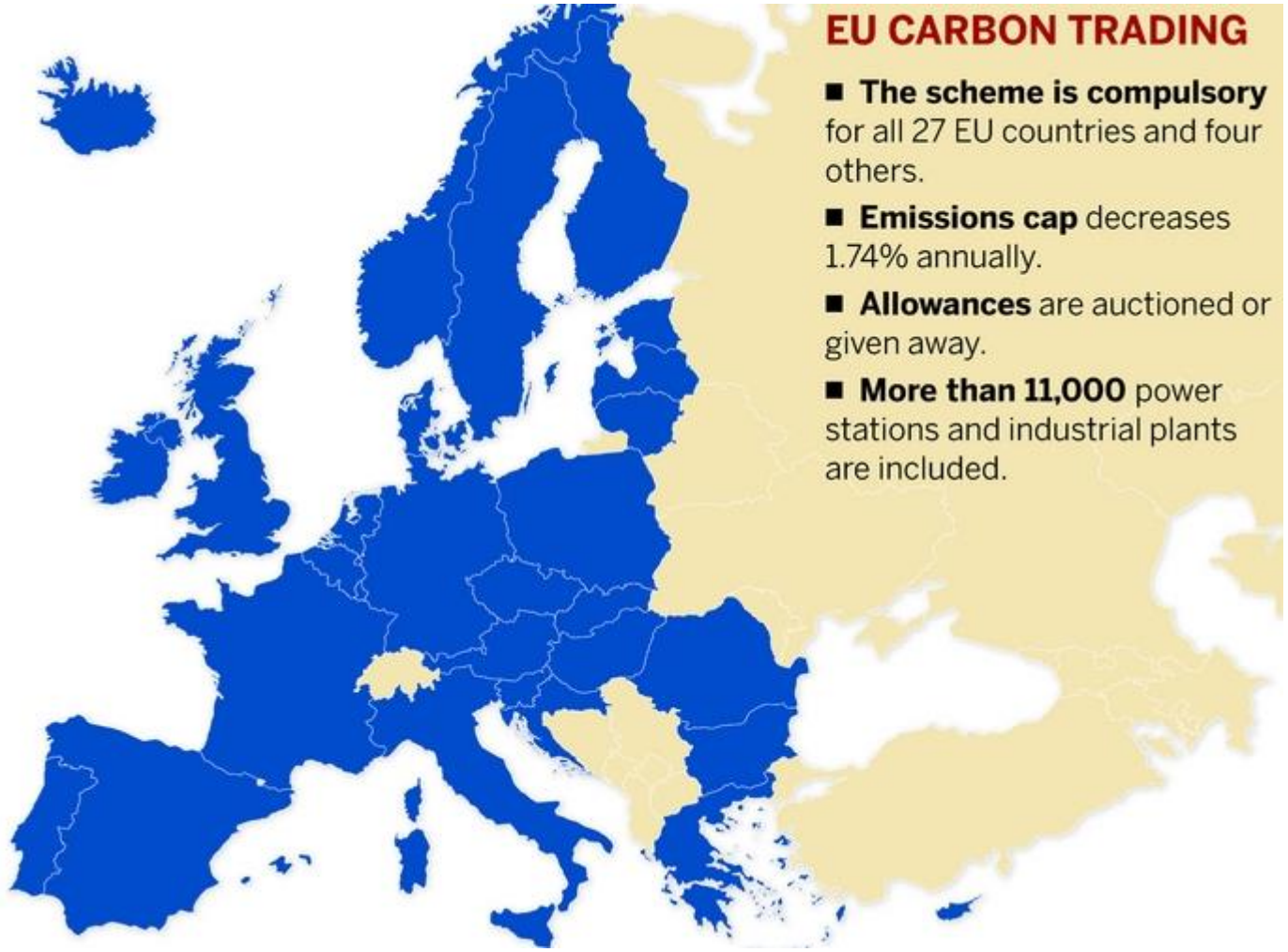
- Demand for CO_2 in greenhouses is growing in many locations…
  - Geographic expansion to hot climates
  - New crops, eg algae
- CO_2 injection de-couples CO_2 & heat input to compliment green technologies, eg geothermal
- Combustion-generated CO_2 is likely to remain popular in cooler climates with abundant energy resources, eg Canada

Conclusion – commercial impact

- Opportunities for the broad industrial gases industry…
  - Propane / LPG
  - CO_2 in various supply modes
  - Pipeline infrastructure
  - Cylinders, tanks etc
  - Gas control equipment
  - Gas sensor calibration gases

Conclusion – environmental impact

- Likely to be viewed as positive
  - CO_2 Carbon capture and re-use
- Potentially viewed as carbon neutral
  - Biomass combustion for heat & CO_2
  - Biomass fired CHP for heat with exhaust gas for CO_2 dosing
- Likely to be viewed as negative
  - LPG/Natural gas combustion for CHP or heat and CO2 production



Acknowledgements – images and case studies

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- Gulf Cryo - Mike Huggon, Sami Huneidi

- Gemüsebau Steiner – Wolfgang Steiner

„Alle sagten: Das geht nicht. Dann kam einer, der wusste das nicht und hat's gemacht.“

Thank you.
Questions?

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