Carbon Dioxide Management for Enhanced Plant Growth:
Learning from Terrestrial Plants to Full Solutions for Algae Biofuels

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1. Introduction to Linde’s CO2 activities: liquid CO2 supply, gaseous CO2 supply
2. Existing gaseous CO2 supply to terrestrial plants and algae to biofuel plants
3. Linde optimization tool to minimize CO2 cost for commercial algae cultivation systems
4. Increasing the CO2 dissolution efficiency by Linde dissolution equipment
5. Conclusion
The Linde Group is a world leading industrial gas & technology company

Founded:
1879 by Carl v. Linde

Merged:
with AGA in 2000
with BOC in 2006

Revenue in 2013:
$ 23.1 billion

Two Divisions:
Gases & Engineering

Global Headquarter:
Munich, Germany

Employees:
63,487

Linde Gas US Headquarter:
Murray Hill, NJ

Present in more than 100 countries worldwide
Linde US merchant (liquid CO2) network
Market leader in the US

- Linde CO2 Plants: 22
- CO2 Streams: 7
- Linde FRAC CO2 Plants: 7
- Linde Beverage Rail CO2 Depots: 7
- Linde Commercial Rail CO2 Depots: 7

(A) – Ammonia
(E) – Ethanol
(R) – Refining
(W) – Well
(O) – Other

Linde US merchant CO2 network - 2014
Linde operates the world's largest gaseous CO2 pipeline system for terrestrial plants in NL.

- **CO2 purity**: 99.95%
- **Main pipeline**: 10 miles
- **Distribution network**: \( \Sigma \) 80 miles length
- **Area supplied**: \( \sim \) 4,000 acres
- **CO2 supply capacity**:
  - Ave.: 2,500 ton/day
  - Peak: 4,000 ton/day
- **Backbone**: 50 miles
- **Air**: 400 ppm CO2
- **Greenhouse**: 500...800 ppm CO2
- **30 psi**
- **100 psi**
- **130 psi**
- **300 psi**
- **Greenhouses**: \( \sim \) 500+

OCAP = Organic CO2 for Assimilation by Plants
Switching from terrestrial to marine based plants: CO₂ is largest utility cost factor with even higher volumes

- Example: Sapphire produces Green Crude using a proprietary open pond, harvest and algae to oil conversion process
- Green crude can be directly processed in existing refineries for upgrading to drop-in fuels
- CO₂ is largest utility cost factor
- Affordable CO₂ cost including supply less than 40$/t CO₂
- Optimum management and cost-efficient supply of CO₂ is a key success factor
- One commercial algae facility will need up to 8,000 tons per day of CO₂
- CO₂ from anthropogenic (no fossil) sources only
Typical Linde scope of gaseous CO2 supply scheme for algae cultivation plants

Typical CO2 source
- Power Plant
- Gasification Plant
- SMR Plant
- NG Plant
- EtOH, Cement, or Steel Plant

Typical CO2 supply system
- Enhanc. Amine wash
- RECTISOL wash
- MEA wash
- Glycol/Amine SELEXOL
- CO2 separation
- Compression

Typical CO2 utilization system
- Pipeline, transport & Storage
- Air capture
- Algae

BOO = Build Own & Operate, SMR=Steam Methane Reforming
Linde BOO/EPC  Linde EPC  Linde/partner R&D
Linde services for algae cultivation: Scope of proprietary Linde costing & optimization tool

- Covers different configurations: Carbon Capture, Flue Gas, Short/Long Distance Transport, ...
- Overall design optimization for lowest-cost CO2 supply at the point-of-use
- Returns cost breakdown for CAPEX and OPEX

Example: CO2 cost at algae plant battery limit assuming coal fired power plant 2G amine scrubber
Important factors for CO2 dissolution within algae plant: Linde equipment helps to increase CO2 uptake efficiency

- Linde has **vast experience** in O2 dissolution in seawater
- Linde developed models to **optimize CO2 dissolution** in different pH and salinities
- Linde offers **commercial CO2 dissolution equipment and pH control**
Conclusion

• Linde owns and operates successfully a costing tool to determine and optimize the most cost effective CO2 supply option to an algae-to-fuel plant for a multitude of CO2 sources

• The costing tool was successfully validated with Linde’s gaseous CO2 supply system in the Netherlands and laboratory data

• Linde offers special equipment to improve the CO2 dissolution efficiency

• Planning for siting of algae plant location and CO2 sourcing has to be done in close cooperation between CO2 source owner/operator, industrial gas company and algae to fuel plant investor

Interested? Please contact me at the conference or

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