# Novel Algae Technology to Utilize $CO_2$ for Value Added Products




**DE-FE0031710**

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# Project Overview

- **Project Partners:**
    - **University at Buffalo**
    - **Linde, Inc**
    - **Northwestern University**
    - **Membrane Technology & Research**
    - **National Carbon Capture Center**
- **DOE Federal Project Manager: Naomi O'Neil**
- **Project Funding:**
    - **Total: $1,734,486 Government: $1,387,588 Cost Share: $346,898**
- **Project Period: 5/1/19 – 7/31/23**

# Overall Project Objectives

- Design, build and operate a first-of-a-kind integrated MSC system
- Achieve high performance in outdoors operation
- Conduct NCCC field test on real flue gas
- Develop algae technology for high value products
- Improve dewatering technology
- Perform LCA and TEA
- Achieve projected net $CO_2$ capture cost at commercial scale of <$30/ton

# Commercial Schematic of Technology

Coal Power Plant

Post FGD flue gas

Sunlight

~1% CO2

Algae MSC Process for CO2 capture

Dewatering

Algae Slurry

HTL + Upgrading

Bio-fuels

Residue

Waste water nutrients

Water + Nutrient Recycle

Make-up water & nutrients

Algae for nutraceuticals

Dewatering

Commercial Extraction

Nutraceuticals

Water

Algae for Animal feed

Dewatering

Feed Blending

Feed Products

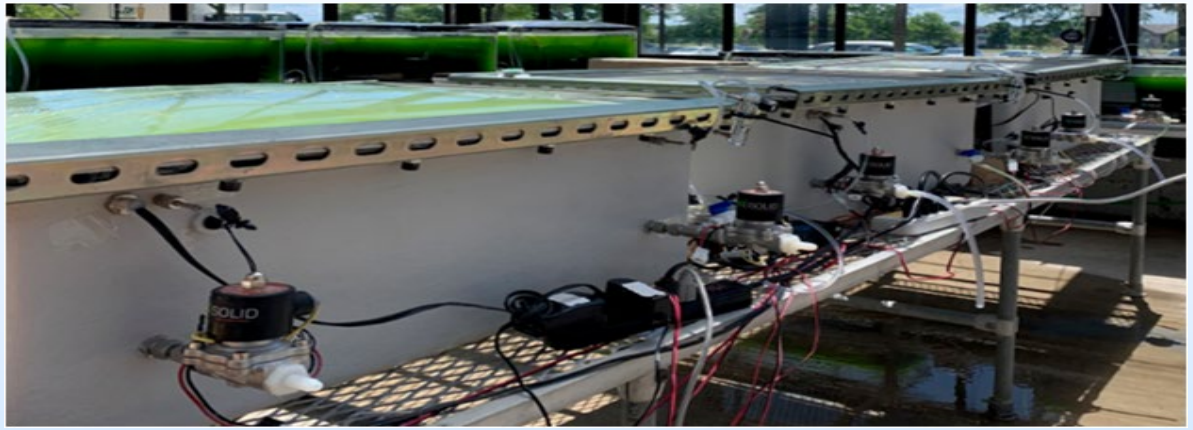
Water

# Technical Approach/Project Scope

- Capture Technology
  - Novel algae technology converts $CO_2$ to biomass
  - Capture technology has evolved significantly over the years
  - Stable operation on simulated flue gas with contaminants validated
  - Final test on coal utility flue gas
- DeAqua
  - Stage 1 dewatering
  - Stage 2 dewatering
- High-value Products to Offset Cost of Capture
- LCA and TEA

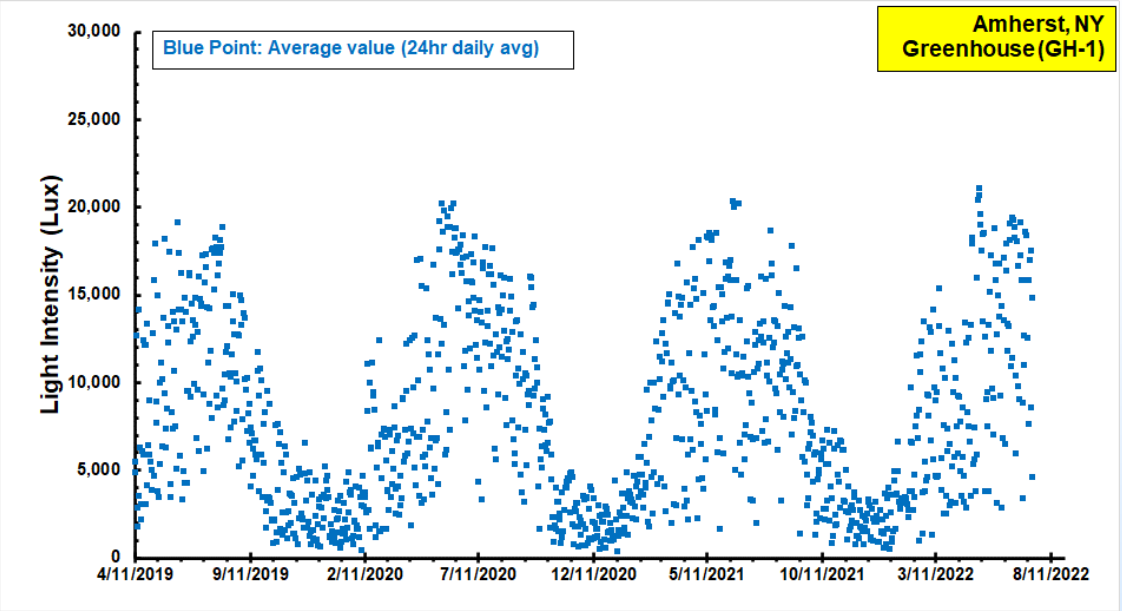
# Technology Background - MSC

- Multi-stage process
- Top lit closed system
- Stable operation
- **Predictable, controllable operation**
- High productivity & capture efficiency
- Efficient upstream/downstream integration
- Can be tailored to application
  - **e.g. Natural gas power plants**



**Integrated MSC test unit in greenhouse**

# MSC Evolution

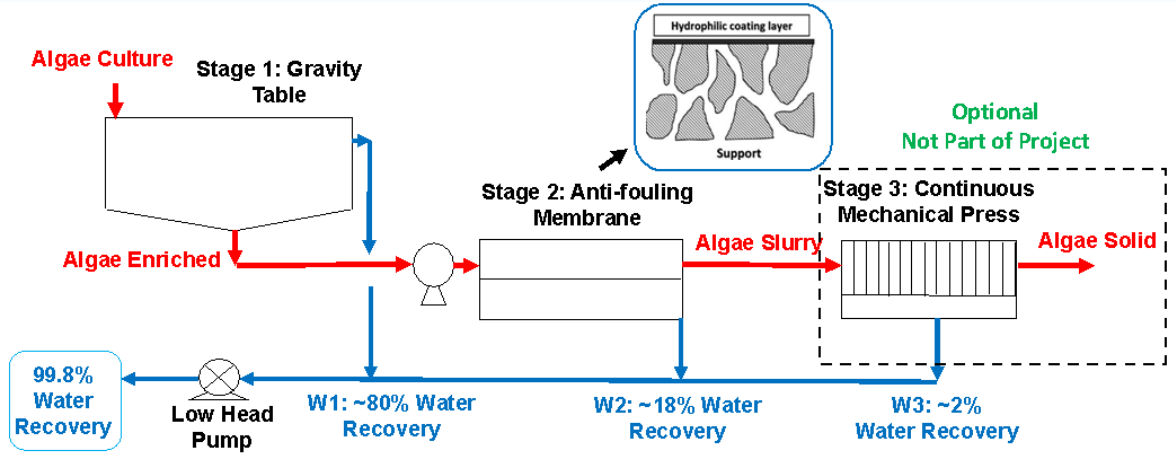



## Evolution in MSC Development

| | | | | Overall Performance | |
|---|---|---|---|---|---|
| MSC Type | Location | Feed Gas | | Normalized Algae Prod | Total CO2 Cap Eff (%) |
| | | CO2 | Contaminants | | |
| E | Lab | 12% | N/A | 56% | 54% |
| R | Lab | 12% | N/A | 80% | 80% |
| H | GH | 12% | SOX/NOX + 5HM | 85% | 73% |
| C | GH | 12% | SOX/NOX + 5HM | 123% | 74% |

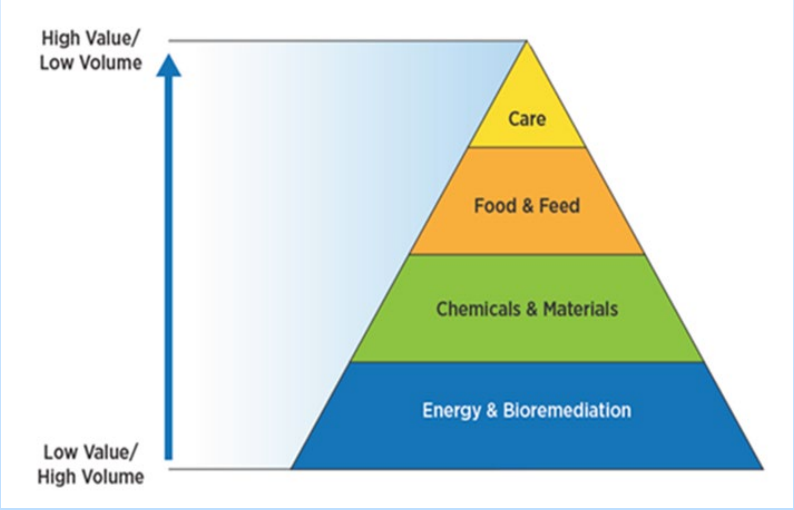
- Needs to operate in natural sunlight
  - Initially validated in non-integrated lab tests - fixed light
  - Integrated system tested in green house -sunlight
  - Integrated operation validated in outdoors tests - sunlight
- Ability of algae to grow in flue gas with high $CO_2$, acid gases and heavy metals validated
- MSC reactor and system design has evolved significantly leading to better performance

# DeAqua (Dewatering) and Products




- Products represent $CO_2$ utilization
- Several products possible with a range of market sizes/prices
  - Biofuels
  - Animal feed
  - Nutraceuticals

- Dewatering is a key, enabling technology
- Must be low energy
- As water is removed, rheology changes
- Extent of dewatering dictated by needs of downstream product



# Project Progress - MSC

- Integrated 3-stage MSC built - 2nd Gen unit
- Advanced controls enable unattended operation
- Stable GH operation 100+ days
- Various process options mapped
- Outdoors test achieved project targets
- Field test underway at NCCC

Integrated MSC in outdoors operation

| MSC Type | Location | Sim. Flue Gas Contaminant | Nutr-WW Replacement | Normalized Algae Prod | Avg CO2 Capture |
|---|---|---|---|---|---|
| H | GH-1 Indoor | SOX/NOX + 5HM | 50% | 92% | 59% |
| C | Outdoor | N/A | N/A | 139% | 81% |
| C | Outdoor | SOX/NOX + 5HM | 80% | 141% | 76% |
| G | Outdoor | N/A | N/A | 142% | 77% |
| **FE-0031710 Target** | | **NCCC SSTU Flue Gas** | **N/A** | 100% | **80%** |

# Project Progress – NCCC Field Test

- Field test underway at NCCC
- Inoculum system setup at indoor laboratory
- Bench-scale site to demonstrate performance on actual utility flue gas
- Flue gas from mixture of natural gas and coal-fired operations, post FGD
- Acid gas levels much below Helios in-house tests

Integrated MSC System at NCCC

# Project Progress – Stage 1 DeAqua

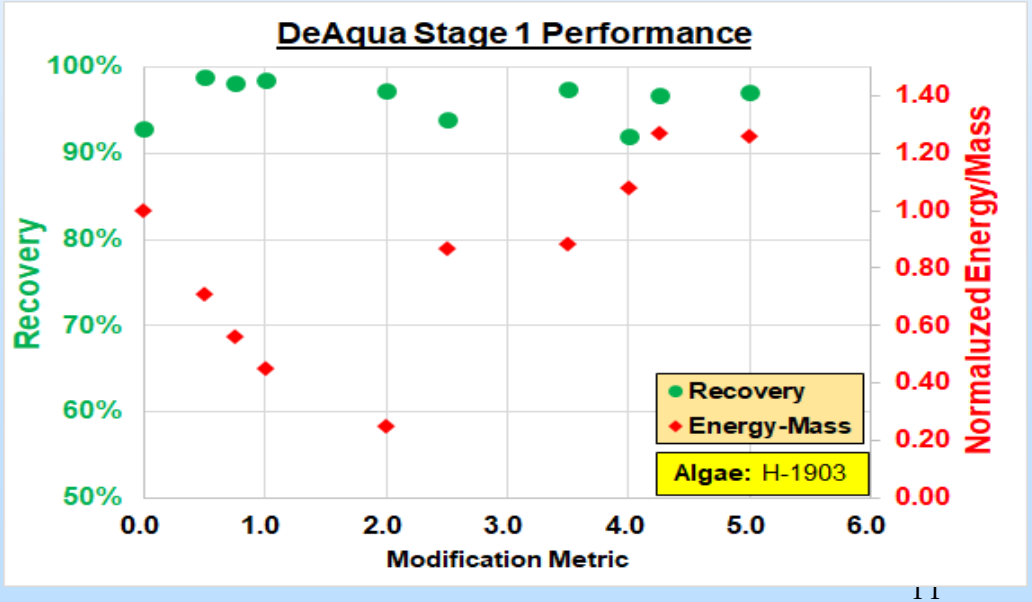
| | DeAqua Stage 1 Performance Specification | | |
|---|---|---|---|
| Project | Conc Ratio | Performance Index | Recovery |
| Prior work | 3-6 | 0.12-0.37 | 70% |
| Initial Project Target | 3-6 | 1.5 | 80% |
| Current work | 20-25 | 5.0-12.5 | 80-95% |

$$\text{Conc Ratio} = \frac{\text{Product Algae Conc}}{\text{Feed Algae Conc}}$$

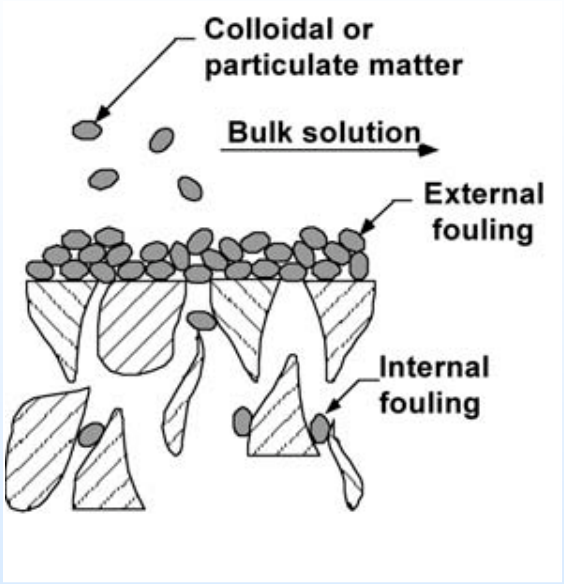
$$\text{Perf Index} = \frac{\text{Conc Ratio}}{\text{Time}}$$

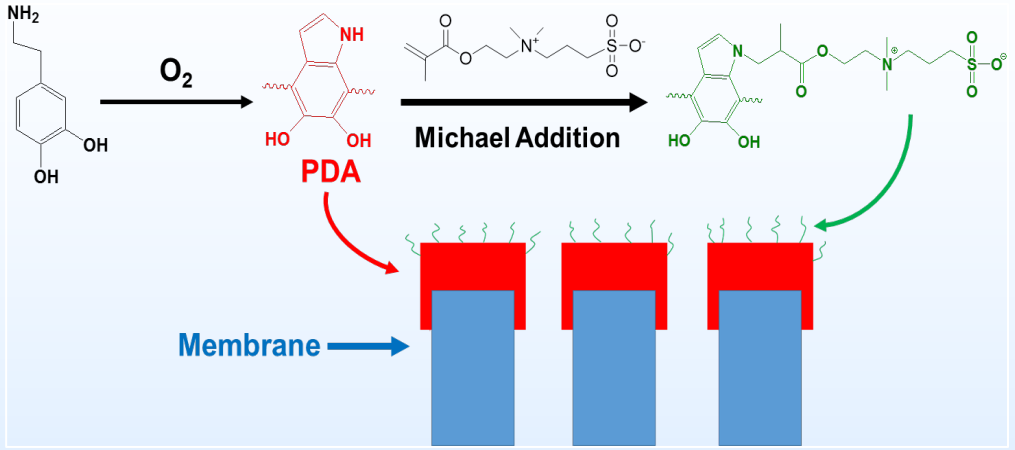
Significant progress in Stage 1 through culture modification:

- Now removes >90% water vs ~70% in prior projects
- Goal of 4X improvement in Perf Index greatly exceeded
- Validated water re-use from dewatering step



# Stage 2 DeAqua – Membrane Progress



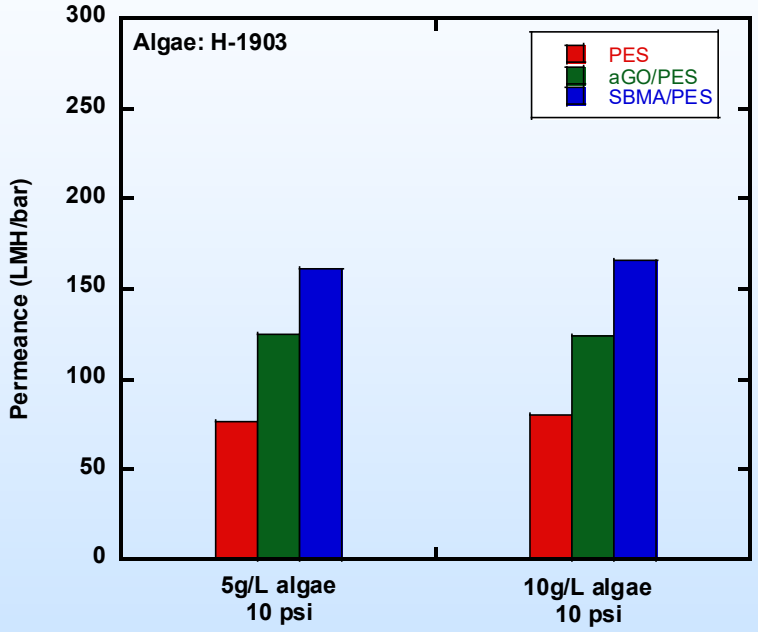




- Membrane is energy-efficient
- But fouling is a critical challenge

**Advantages:**

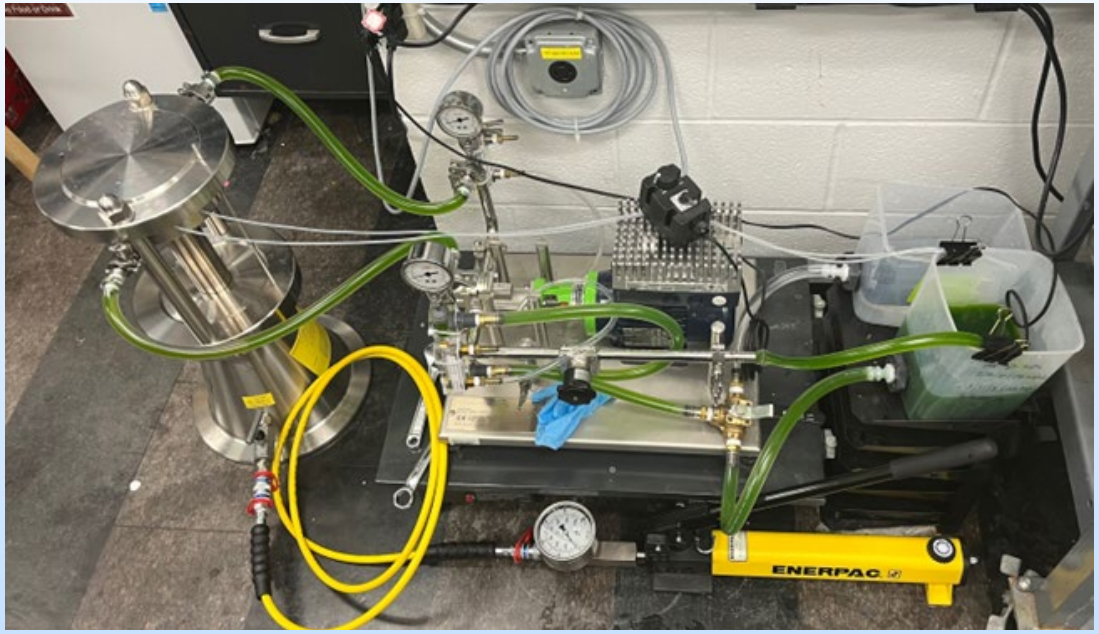
- Surface modification reduces fouling
- Simple process at 23°C, aqueous solutions
- Covalent bonds to achieve long-term stability
- Post-modification of commercial modules possible

# Project Progress - DeAqua Membrane



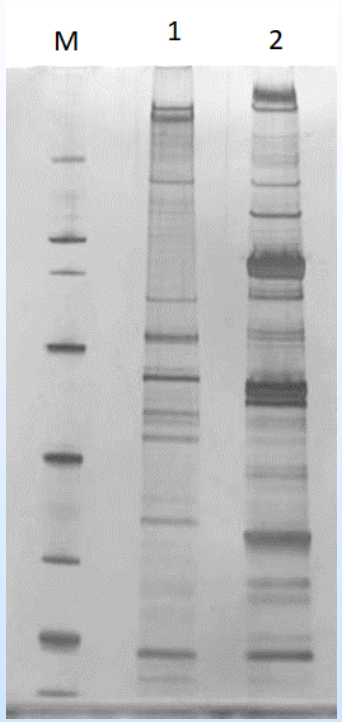

- Surface modification decreases pure water permeance
- But improves the performance in algae dewatering

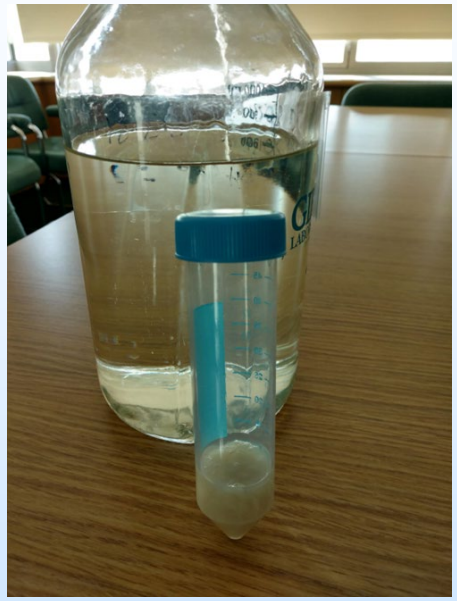
**Setup of M20 Plate and Frame Module**




- Membranes being tested in prototype module

# Nutraceutical Products From Algae (H-1601)



Increased product from pre-treatment
M = Molecular Weight Markers
1 = extract w/o pretreatment
2 = extract w/ pretreatment

Left Panel – cells separated from media
Middle Panel – product recovered from media
Right Panel – high value product from cell extract

# Nutraceutical Progress Summary

## Improvements

- Developed two phase extraction for recovery of increased number of products
- Developed pretreatment for enhanced yield
- Species grown on MSC slipstream to decrease flue gas contaminants

## H-0326

- Analyzed time course of required induction
- Three high value products verified

## H-1601

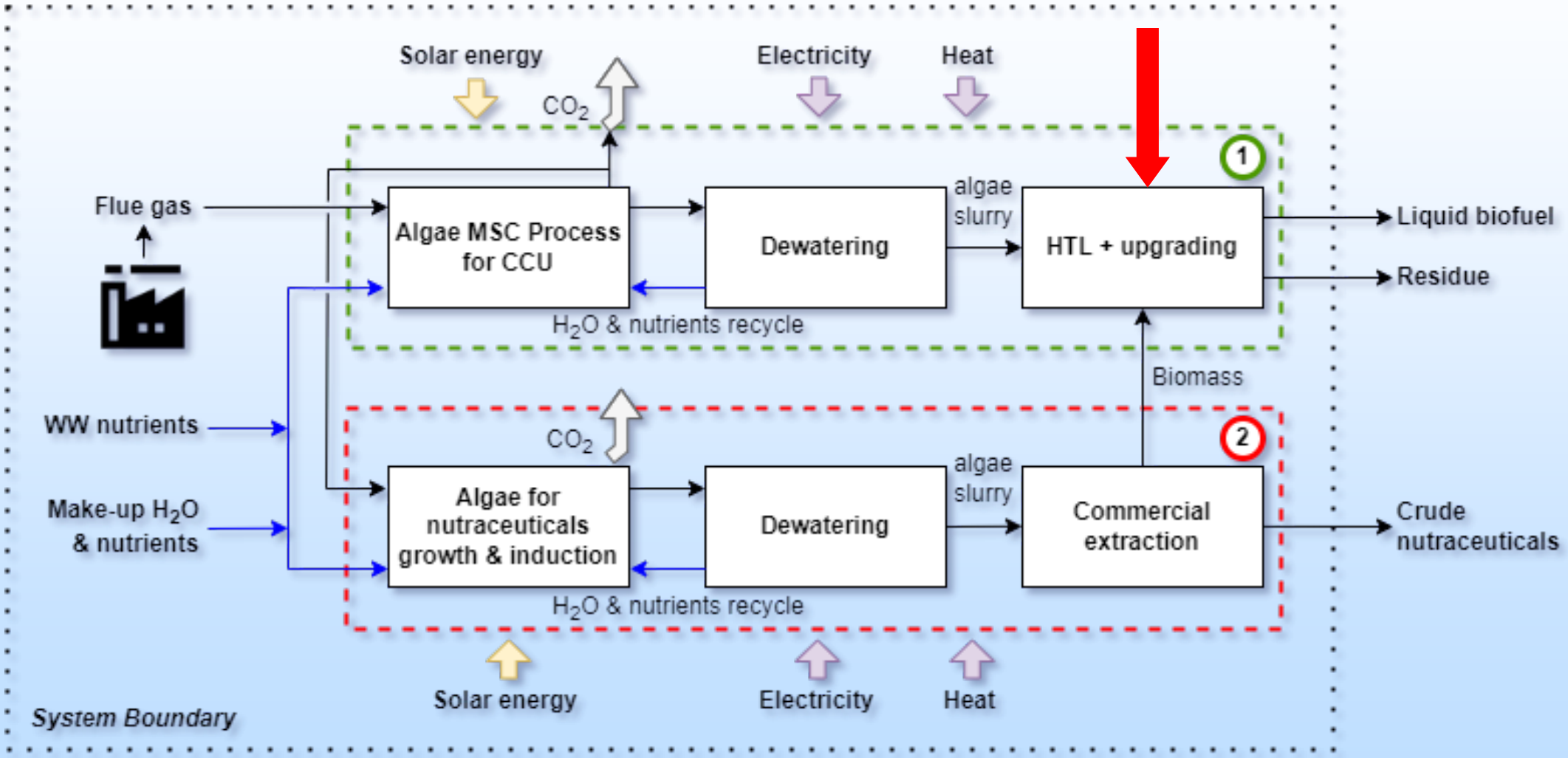
- Requires no induction
- Product A - Food & pharma applications (No cell extraction required, recovered from media)
- Product B - High value lipids (extract phase 2)
- Product C - Potential for food coloring, pharma applications (extract phase 1)

# TEA - Linde Commercial $CO_2$ Technology

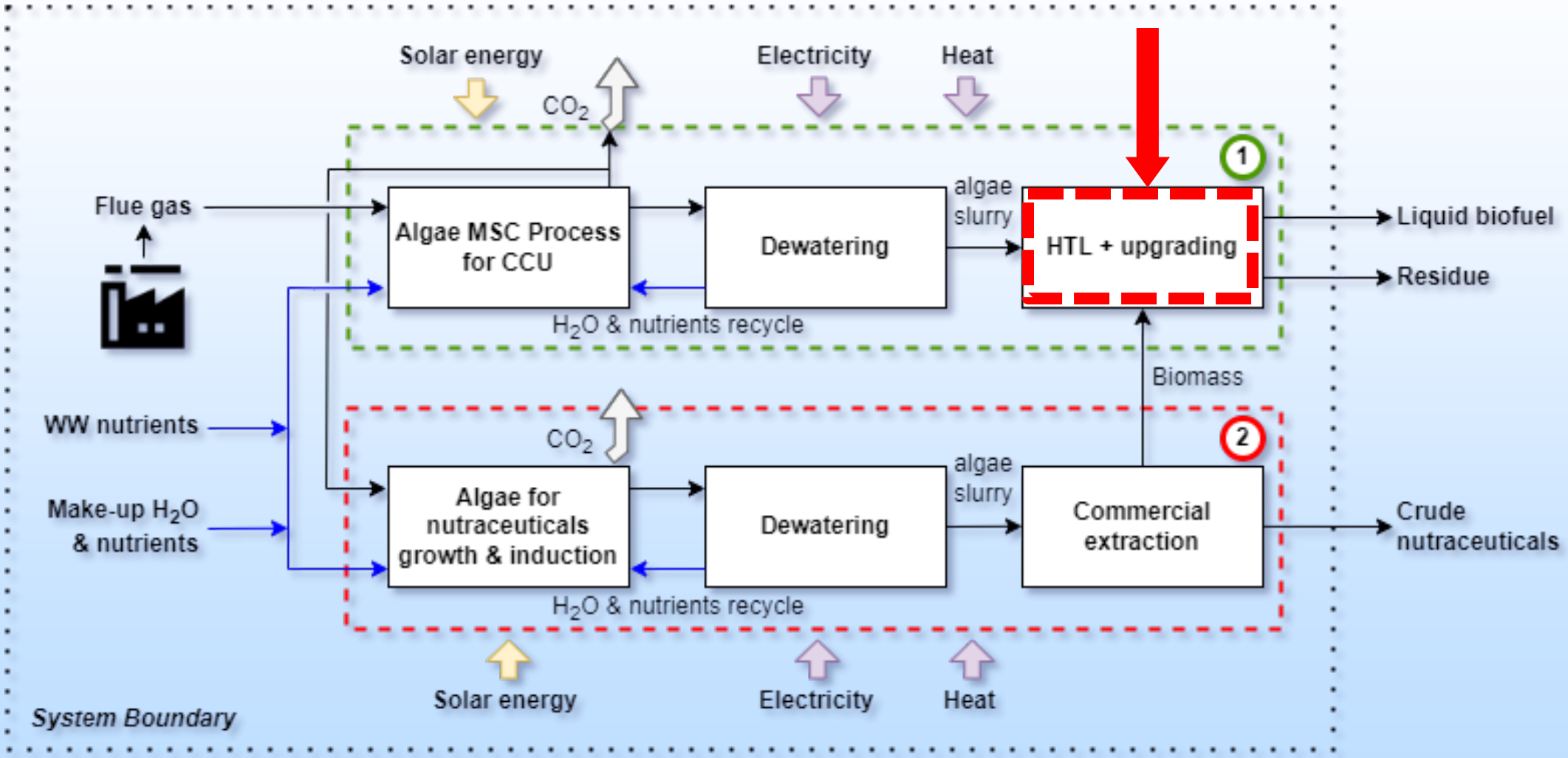
- Evaluate technologies for flue gas injection into algae based on effectiveness and cost
- Linde reviewed portfolio/other SOA systems and proposed an optimal solution
- Based on the optimal recommendation, Linde will evaluate costs of the gas injection system and assist in TEA

| Linde technology | Highlights | $CO_2$ Flowrate Range (kg/hr) | Product Image |
|---|---|---|---|
| SOLVOCARB® mobile | -Minimum power consumption<br>-Ease of maintenance<br>-Low CAPEX and OPEX | 15-45 |  |
| SOLVOCARB® venturi | -Easily retrofitted to existing hydraulic systems<br>-Ensures consistence performance while requiring low maintenance | 10-400 |  |
| **SOLVOCARB® diffusion hoses (most cost-effective, practical option for pilot testing)** | **-Very low maintenance<br>-Fast and easy installation<br>-Ideal for temporary and long-term use** | **20-60 (per 40 m of hose)** |   |
| SOLVOCARB® reactor | -Most versatile product, working in a full range of temperatures, flowrates, and pressures<br>-Suited for inline or sidestream use | 30-2,000 |  |
| SOLVOCARB® in-line reactor | -Eliminates need for static mixer in most cases due to high solubility and reaction rates of pressurized $CO_2$ | 10-50 |  |

# LCA


Solar energy
Electricity
Heat
$CO_2$
Flue gas
Algae MSC Process for CCU
Dewatering
algae slurry
HTL + upgrading
1
Liquid biofuel
Residue
$H_2O$ & nutrients recycle
Biomass
WW nutrients
Make-up $H_2O$ & nutrients
$CO_2$
Algae for nutraceuticals growth & induction
Dewatering
algae slurry
Commercial extraction
2
Crude nutraceuticals
$H_2O$ & nutrients recycle
Solar energy
Electricity
Heat
System Boundary

# LCA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# Summary

- **Outdoors MSC tests achieved project targets 25 g/m$^2$/d and 80% capture**
- **Dewatering technology has potential to dewater to varying degrees depending on product requirements**
- **Utilization of algae for products generates revenue and significantly offset the cost of capture**

# Plans for future development

Advance MSC $CO_2$ Capture:

- Implement dynamic process control
- Develop in-ground system - the building block for commercial application
- Integrate MSC with dewatering and operate with high recycle rate
- Utilize municipal WW for purchased nutrient reduction & remediation credits

Advance Utilization:

- Biofuels: Optimize process & test product
- Animal Feed: Develop/test feed applications
- Nutraceuticals: Advance extraction & purification; define products

# Acknowledgement

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