“Efficient Capture of CO2 from Fossil Fuel Power Plants using Algae and Conversion to Value Added Products”

Phase1 Summary

Grant No. DE-SC0015719

3/27/2017

Helios-NRG, LLC

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

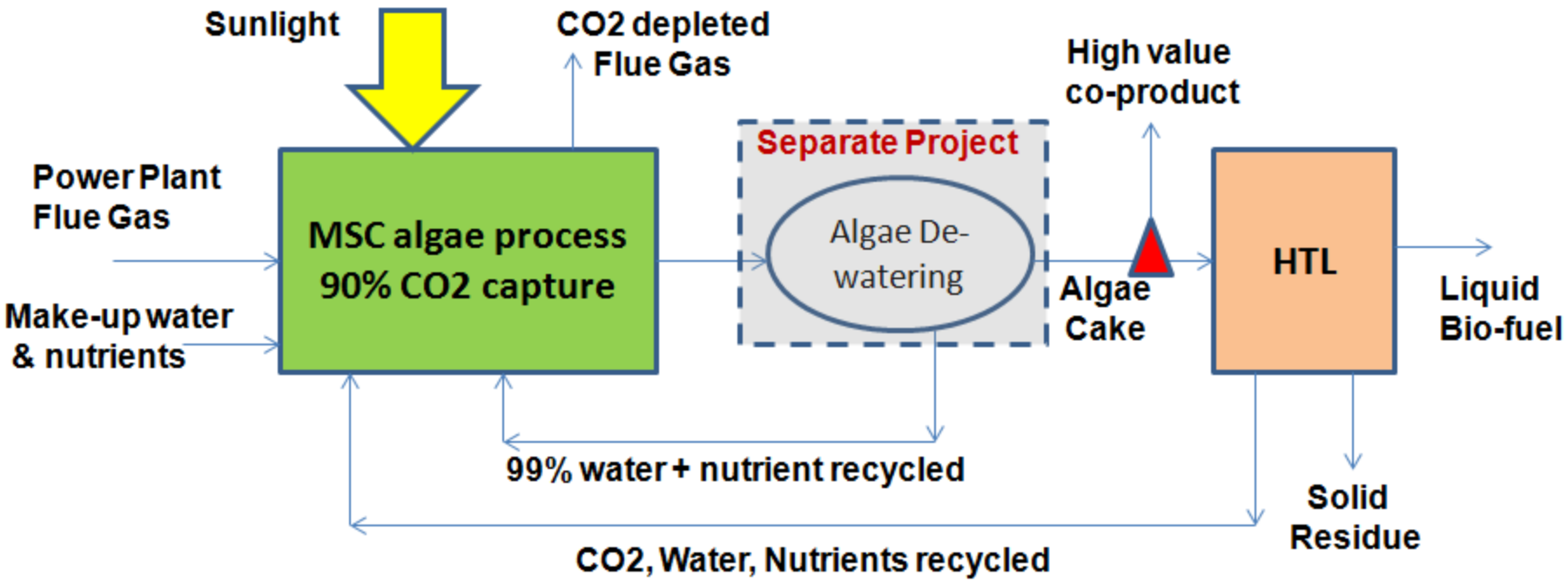
Overall Objectives

- **Develop a novel algae technology for efficient CO_2 capture from coal power plant flue gas**
- **Make bio-fuels & other products from algae to mitigate the cost of carbon capture**
- **Project Team:**
  - **Helios-NRG, LLC – Prime**
  - **Illinois Sustainable Technology Center (ISTC)**

Strategy

- Utilize algae to metabolize and capture CO2
- Use higher CO2 concentration in flue gas to improve process
- Design process to enable high CO2 capture efficiency
- Utilize fast growth rates to achieve high productivity
- De-water algae at low energy & cost
- Recycle water & nutrients to minimize consumption
- Convert algae to fuel via HTL process
- Extract high value co-products to improve economics

Concept for CO2 Capture



Challenges in Algae CO2 Capture

- **Algae is a living thing – complex & prediction difficult**
- **12% CO2 is 300x the concentration algae strains have evolved on**
- **Impact of SOX, NOX and other contaminants in flue gas**
- **Achieving 90% CO2 capture efficiency is difficult**
- **All downstream applications require dewatering**
  - Typically a capital & energy intensive step

Phase1 Objectives

- **Select algae species capable of handling major contaminants in coal derived flue gas**
  - Post FGD: 12% CO2; ~75ppm NOX; ~75ppm SO2
  - Post amine capture: 1% CO2; ~90ppm NOX; <5ppm SO2
  - Other contaminants to be addressed in Phase2
- **Demonstrate performance consistent with >70% capture**
- **Validate HTL operation on de-watered algae**
- **Perform preliminary process & economic analysis**

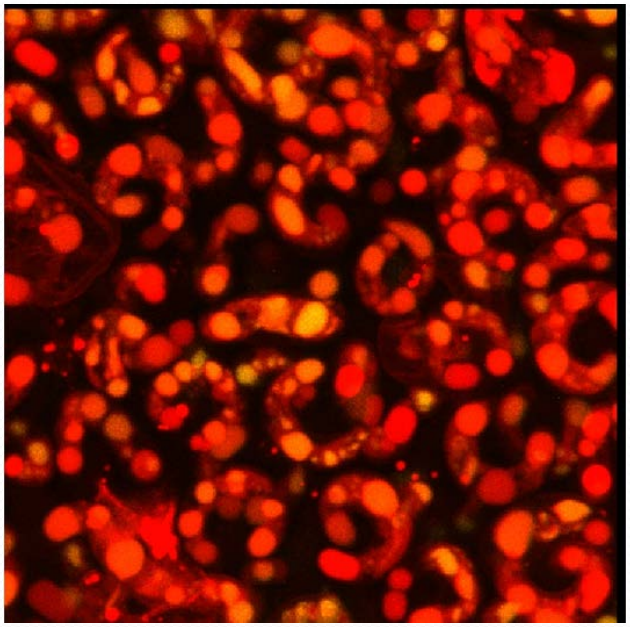
Species Selection

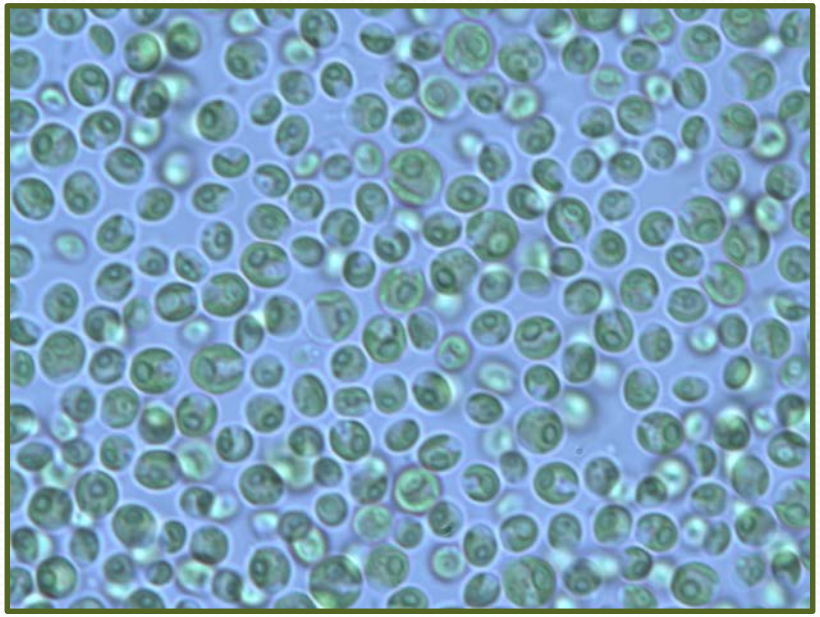
- **Primary criteria**
  - High CO2 tolerance
  - High growth rates
  - High usable energy content
  - Well characterized
- **We have evaluated several strains**
  - Only naturally occurring species – no GMO's
- **Two most promising species selected for this project**
- **PBR Facilities:**
  - ~25 PBR ranging in size from 0.5 – 100 lit used
  - Operated in natural sunlight and artificial light

Impact of Major Contaminants

- **Increasing CO2 concentration changes growth environment**
- **Acid gases will lower pH**
- **First test with increasing CO2 levels to 12%**
- **SO2, NOX tests follow CO2**

Preferred Algae Strains Selected





Algae Selection

- Two species selected
- Higher CO2 can drive higher growth rate
- Stable growth demonstrated at both1% & 12% CO2
- High rate of weight gain achieved in high CO2 concentration
- Stable algae growth demonstrated at 1% CO2 + 75ppm NOx
- Stable growth achieved in 12% CO2 + 75ppm SOx + 75ppm NOx

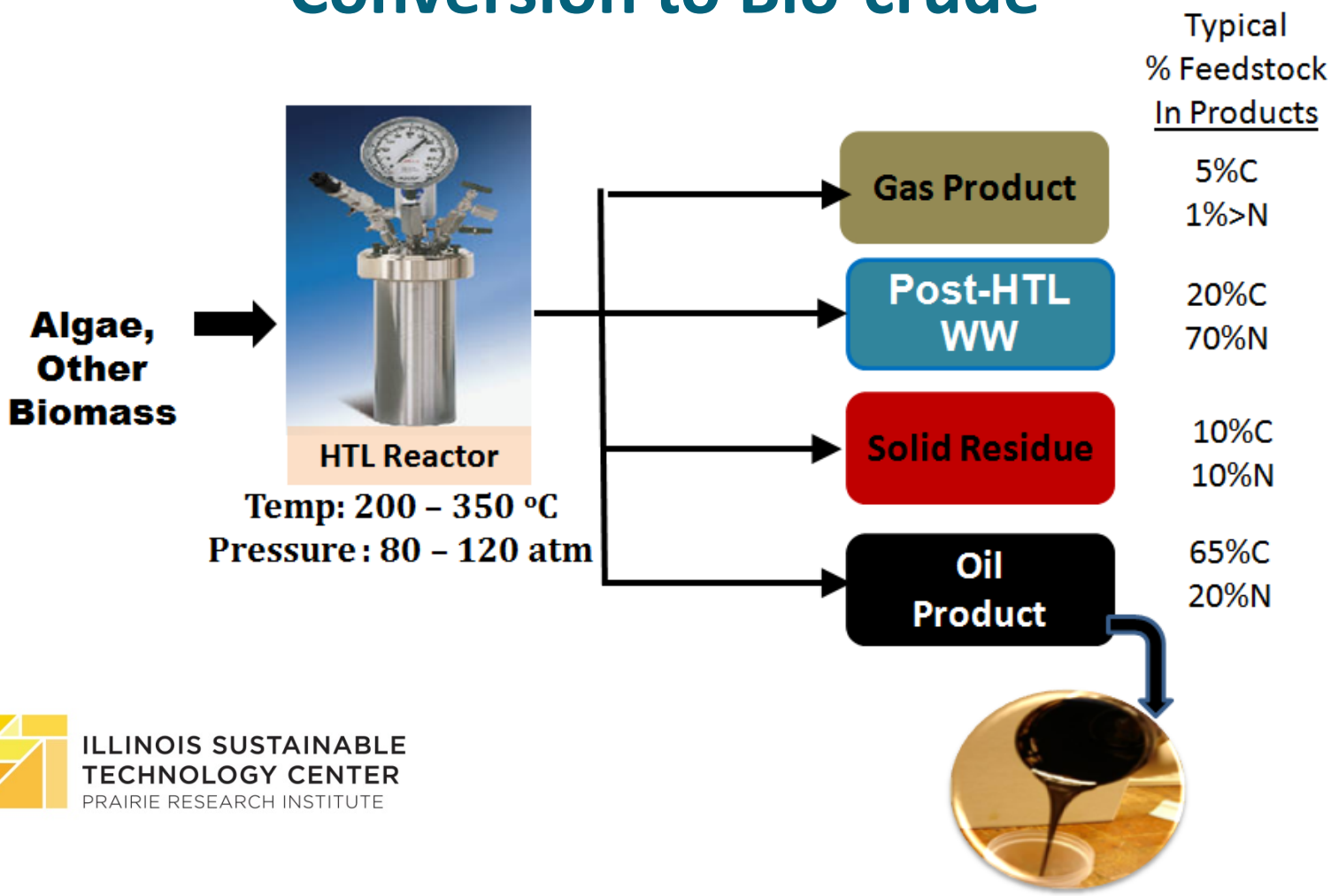
Demonstration of CO2 Capture

- **Developed new process**
- **Used model predictions to set up experiments**
- **Very high stage capture efficiencies achieved**
- **Test results exceeded Phase1 target:**
  - Stable MSC operation and CO2 capture validate primary design assumption
  - Achieved >80% CO2 capture efficiency in simulated flue gas tests for both post amine and post FGD cases

Benefits of New Process

- **Enables stable capture efficiency with time**
- **High growth rate & capture efficiency**
- **90% CO2 capture efficiency possible**
- **High productivity & low down time**
- **Suitable for integrating with upstream & downstream processes**
- **Easier to maintain culture health**

Hydrothermal Liquefaction (HTL) for Algae Conversion to Bio-crude



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Benefits of HTL

- **Can process wet biomass including slurry (~20 wt% solid)**
- **Produces liquid bio-crude (easily stored)**
- **Bio-crude easily used in existing infrastructure**
- **High biomass utilization**
- **No catalyst**
- **Most nutrients remain in solution & can be recycled**
- **Favorable Economic & Energy Balances Projected**
  - DOE-BETO MYPP 2022 projection:
    Diesel fuel production costs by HTL = $1.54/gal (+ feed cost)

HTL Tests on Algae

- **Assessed the effect of HTL operating conditions & algae type on process performance**
  - Tested many different HTL operating conditions
  - Optimized process for oil yield and oil quality (HHV)
  - Characterized HTL aqueous product for recycle

- **High oil yield demonstrated for both algae species**
- **Bio-crude with good HHV produced**
- **Biochar yield as low as 15%**
- **Ability of algae to handle recycle and potential for nutrient reduction demonstrated**

Basis for Economic Analysis

Parameter	Value
Power Plant Size (MW)	550
Flue gas flowrate TPY (Tons/yr)	1.98E+07
CO2 in Flue gas TPY	3.89E+06
Flue gas CO2 conc	12.9%
CO2 capture efficiency by MSC	90%
Hours of sunlight/day	12
Total CO2 Capture by Algae (TPY)	1.75E+06
Annual Algae Production (TPY)	9.29E+05

Phase 1 Summary

- **All Phase 1 objectives were met or exceeded**
- **Survival & growth of two algae species validated in simulated flue gas**
- **>80% CO2 capture efficiency demonstrated**
- **Good HTL conversion of algae to bio-crude demonstrated**
- **Co-product generation can substantially lower CO2 capture cost**