Improving the Economic Viability of Biological CO_2 Utilization by Improved Algae Productivity & Integration with Wastewater Treatment

Cooperative Agreement No: DE-FE0030822

CO2 Capture Technology
Project Review Meeting
August 17, 2018

NATIONAL ENERGY TECHNOLOGY LABORATORY

Illinois Sustainable Technology Center | ILLINOIS

Helios-NRG, LLC

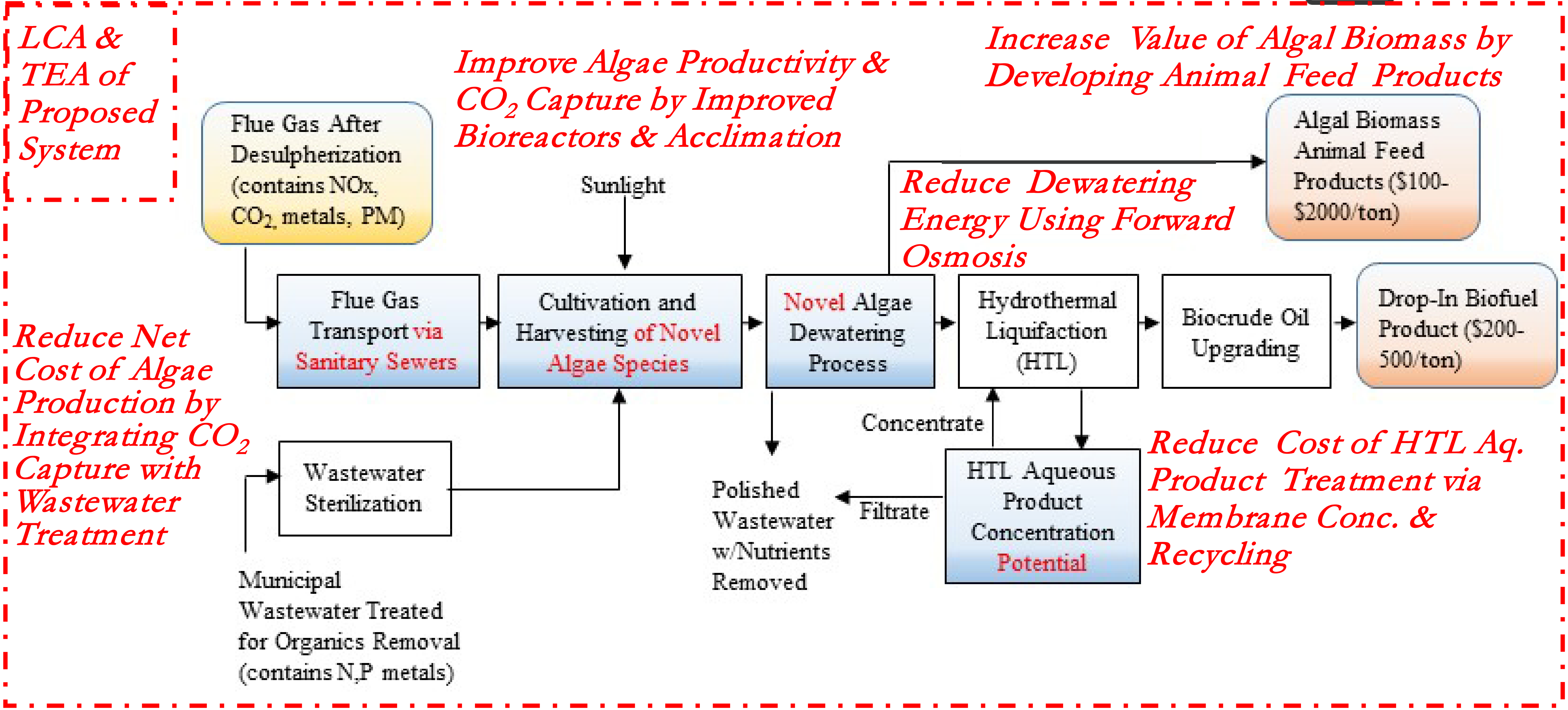
Basic Project Information

- **Title:** *Improving the Economic Viability of Biological Utilization of Coal Power Plant CO_2 by Improved Algae Productivity & Integration w/ Wastewater Treatment*
  - DOE Program Manager: Andy Aurelio
  - Lead Organization: University of Illinois - Illinois Sustainable Technology Center
  - PI: Lance Schideman, PhD, PE
  - Major Collaborating Organization: Helios-NRG
  - Project Cooperative Agreement Number: DE-FE0030822
- **DOE Funding Program DE-FOA-0001622:** ***Applications for Technologies Directed at Utilizing Carbon Dioxide from Coal Fired Power Plants***
  - Total Project Value: $ 1,249,873 Government: $999,536 Cost Share: $250,337
  - Budget Period 1 Total Value: $ 414,242 Government: $331,394 Cost Share: $ 82,848
- **3-Yr Project Duration: Oct. 1, 2017 – Sept. 30, 2020 with Annual Budget Periods**
  - Currently in Budget Period 1(BP1) - October 1, 2017 – September 30, 2018

Major Project Objectives

- *Improve Algal Productivity & CO_2 Capture by Improved Bioreactor Design & Oper.*
  - Proprietary reactor design and algal strains grown on simulated flue gas with key contaminants added
  - End of project performance goals
    - 35 g/m^2·day biomass productivity
    - 70% carbon capture efficiency
- *Reduce Net Costs and Energy Inputs for Producing Algal Products*
  - Integrate use of low-cost or negative-cost wastewater nutrient inputs
    - Large quantity of sustainable nutrients available
  - Develop low-energy forward osmosis dewatering
  - Membrane separation & recycle of aqueous byproducts from hydrothermal biofuel processes
  - Algal biomass for animal feed
    - Large-volume stable markets with potential for higher net value than biofuels
  - Sanitary sewer distribution of flue gas
- *Evaluate Life-cycle and Techno-economic Impacts of Proposed System*

Objectives in Context of Block Flow Diagram



Project Tasks

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- *Task 1- Project Management*
- *Task 2- Demonstrate Stable Algae Cultivation w/ Simulated Flue Gas*
- *Task 3- Demonstrate Stable Algae Cultivation w/ Wastewater Nutrients*

BP 1

- *Task 4- Optimize CO_2 Capture Efficiency in the Algae Cultivation Process*
- *Task 5- Evaluate Novel Algae Dewatering Processes (forward osmosis)*
- *Task 6- Characterize algal biomass for HTL and animal feed applications*
- *Task 7- Demonstrate ability to concentrate & recycle HTL aqueous phase*
- *Task 8- Evaluate the potential of sewer network flue gas distribution*
- *Tasks 9- Techno-Economic Analysis*
- *Tasks 10- Techno-Economic Analysis*

Project Organizational Chart

PRIME CONTRACTOR
University of Illinois (UI)

Responsibilities:
- Project Management
- HTL Process improvements
- Algae biomass characterization,
- Testing for animal feed applications
- Evaluation of sewer system for flue gas transport
- Techno-economic and Life-cycle analysis for dewatering and conversion processes

INDUSTRIAL ADVISORY BOARD
Managers and Design Consultants from Power and Wastewater Industries

Responsibilities:
- Advise on current industry drivers and concerns
- Review plans for integration with existing infrastructure facilities
- Review and comment on project results

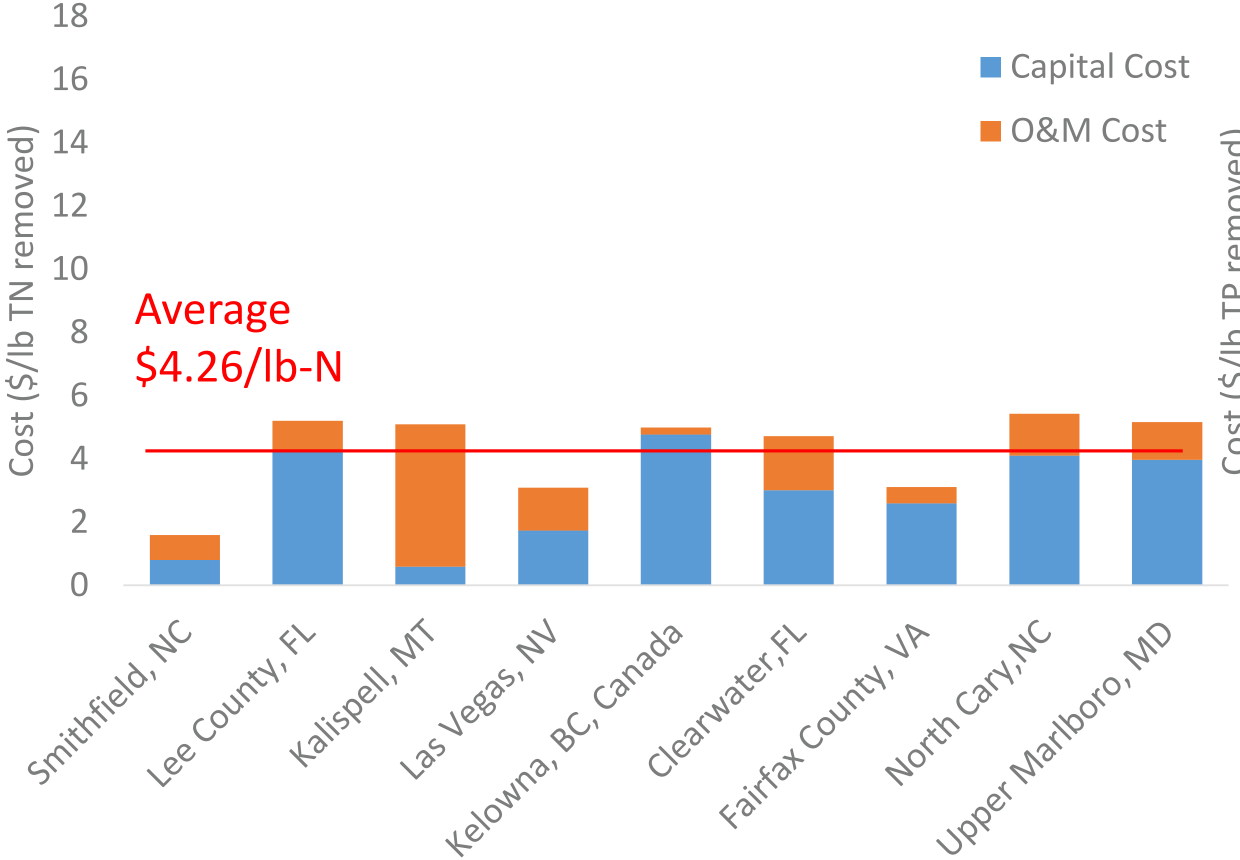
SUBAWARDEE
Helios-NRG, LLC

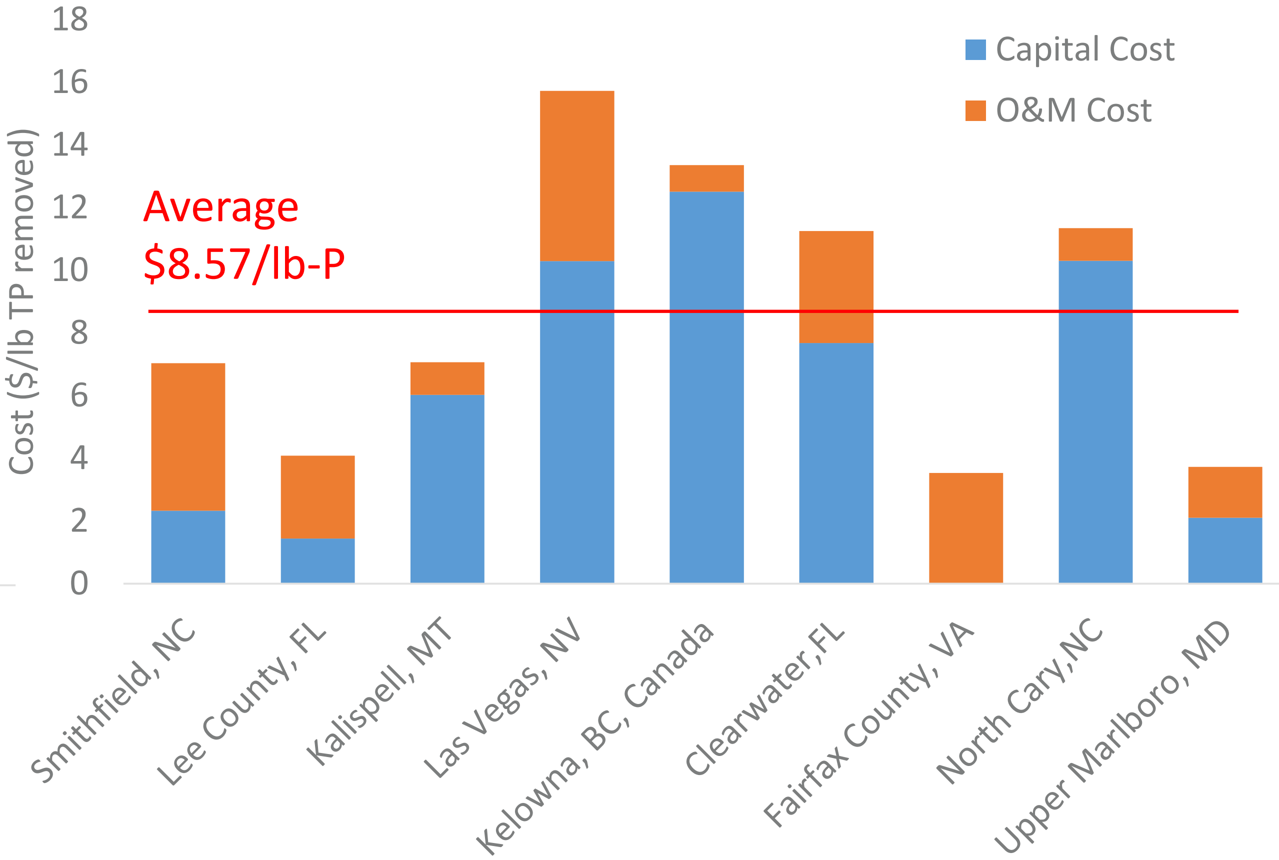
Responsibilities:
- Algae cultivation with flue gas
- Algae cultivation with wastewater
- Commercialization Strategy
- Techno-economic and Life-cycle analysis for algae cultivation and harvesting processes

- **Industrial Advisory Board Members**
  - Springfield City Water, Power & Light
    - 578 MW coal-fired steam turbine generators
  - Urbana-Champaign Sanitary District
    - 40 MGD Wastewater Treatment Plant Capacity
  - Fehr-Graham Engineering
    - Wastewater Design Consultant

What is the Value of Wastewater Nutrient Removal?

Source: US-EPA Tech. Reference Document: 832-R-08-006, 2008





- **Baseline Algae Elemental Mass Composition - 36%C, 7%H, 50%O, 6%N, 1%P**
- **Est. Wastewater Treatment Value of Algal Nutrient Uptake** *(0.06*$4.26+0.01*$8.57)*2000 = $680/ton*

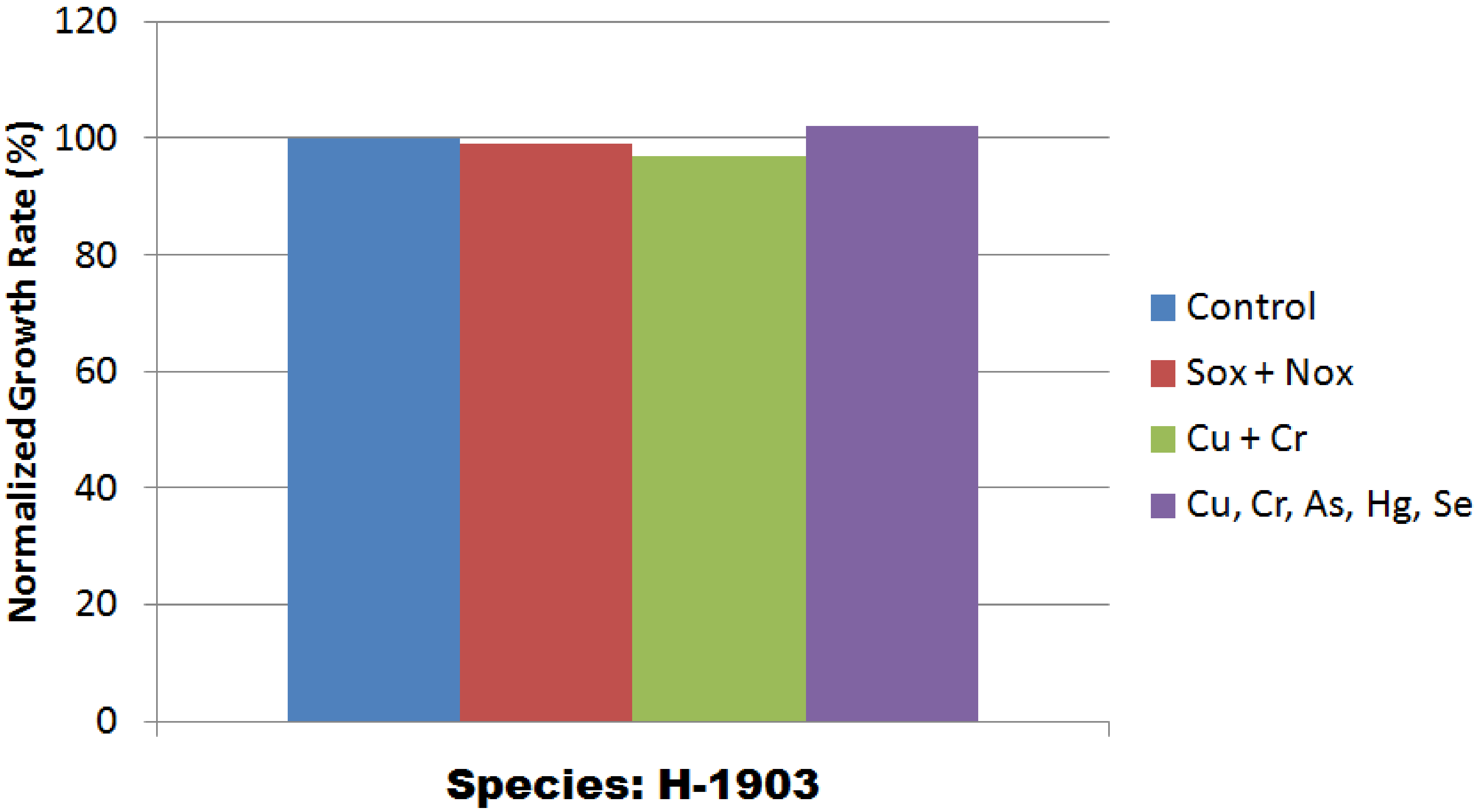
Economic Rationale: Integrating wastewater treatment can make algal biofuels cost-effective

(Ref: C.T. Kuo PhD Thesis, Univ. of Illinois, 2017)

Cost Categories	2015 Current State of Technology w/ Algae Productivity of 8.5 g/m²/day	2022 DOE Projected Design Case w/ Algae Productivity of 25 g/m²/day
Algal Biomass Production Costs ($/ton)		(Project Economic Impacts)
Ponds & Inoculum	$ 1,359	$ 289 (Raceway pond mods + $44)
CO_2 Supply	$ 99	$ 97 (Carbon capture credit - $60)
Dewatering Operations	$ 82	$ 52
Nutrient Supply	$ 25	$ 24 (WW credit -$680)
Other Costs	$ 76	$ 32
TOTAL Algae Biomass Prod	**$ 1,641 /dry ton (DT)**	**$ 494 /DT (-$202/DT)**
Algal Biofuel Production Costs ($/gge)		
Algae Biomass Supply	$ 15.15	$ 3.18 (Sum of above -$1.28)
Hydrothermal Liquefaction Conv.	$ 1.18	$ 0.49
Bio-oil Upgradation/Finishing	$ 0.44	$ 0.31
Aqueous product post-treatment	$ 1.54	$ 0.57 (Conc/recycle aq prod. $0.28)
Balance of Plant	$ 0.29	$ 0.17
TOTAL Biofuel Production Costs	**$ 18.60 / gal gasoline equiv (gge)**	**$ 4.72/gge (-$0.03/gge)**

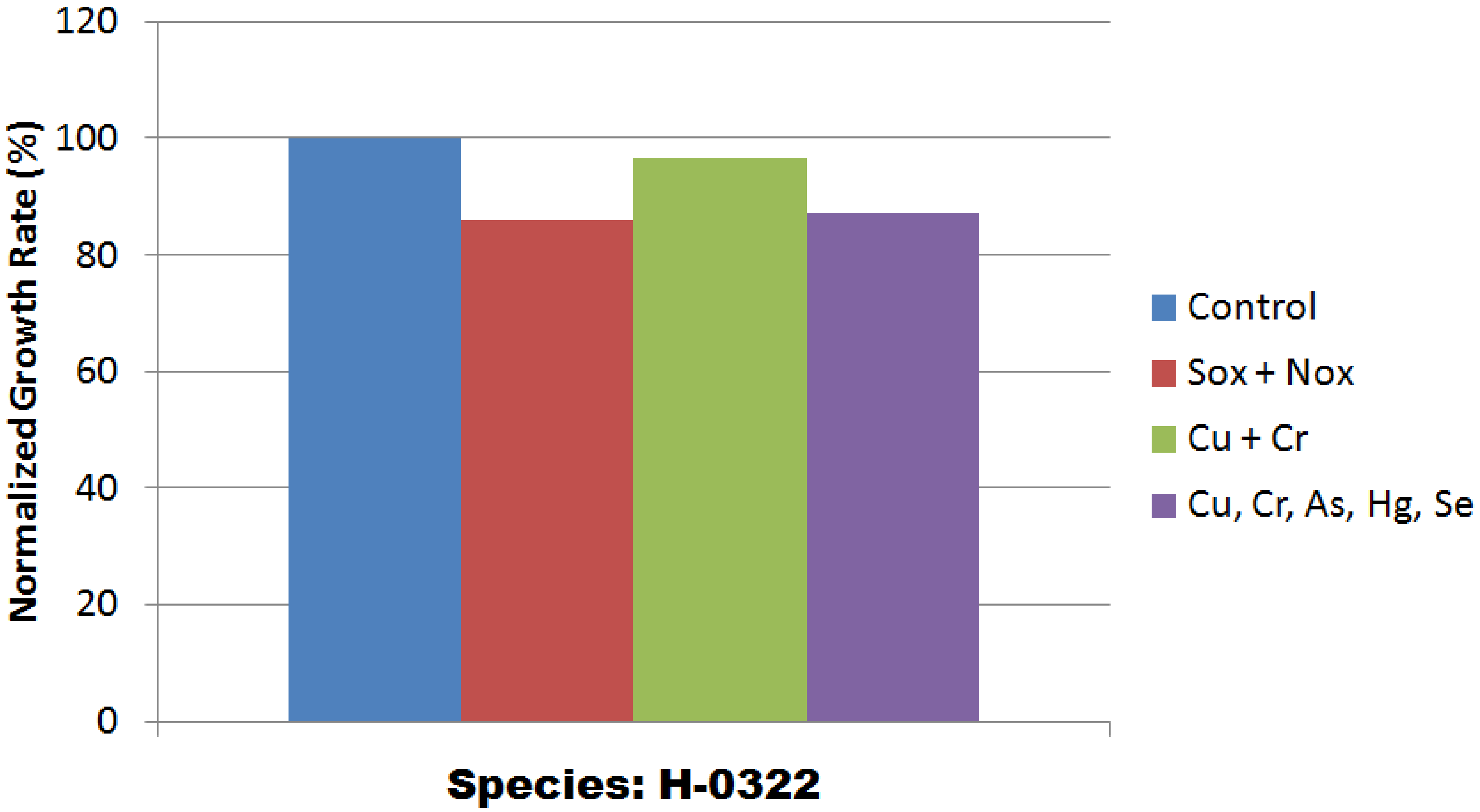
Impact of flue gas contaminants on algae growth

Simulated post-FGD flue gas (all with 12% CO_2)



Impact of flue gas contaminants on algae growth

Simulated post-FGD flue gas (all with 12% CO2)



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Algae Heavy Metal Content after Combined Heavy Metal Tests

Compared with Animal Feed Maximum Tolerable Level (MTL) (National Research Council, 2005)

Minerals	H-1903 2 HM (ppm)	H-1903 5 HM (ppm)	Poultry Feed MTL (ppm)	Swine Feed MTL (ppm)	Cattle Feed MTL (ppm)	Fish Feed MTL (ppm)
As		2.18	30	30	30	5
Cd	स़झ़	स़झ़	10	10	10	10
Cr	2.93	1.16	100	100	100	3,000* as CrO
Co	स़ञ़	स़ञ़	25	100	25	
Cu	64.8	46.6	250	250	40	100
Pb	स़ड़	स़ड़	10	10	100	10
Ni	स़ड़	स़ड़	250	250	100	50
Se		7.7	3	4	5	2
Zn	10.3	11.3	500	1000	500	250

- **Algal biomass over accumulated Cu, Se which could limit certain animal feed applications without management or mitigation**

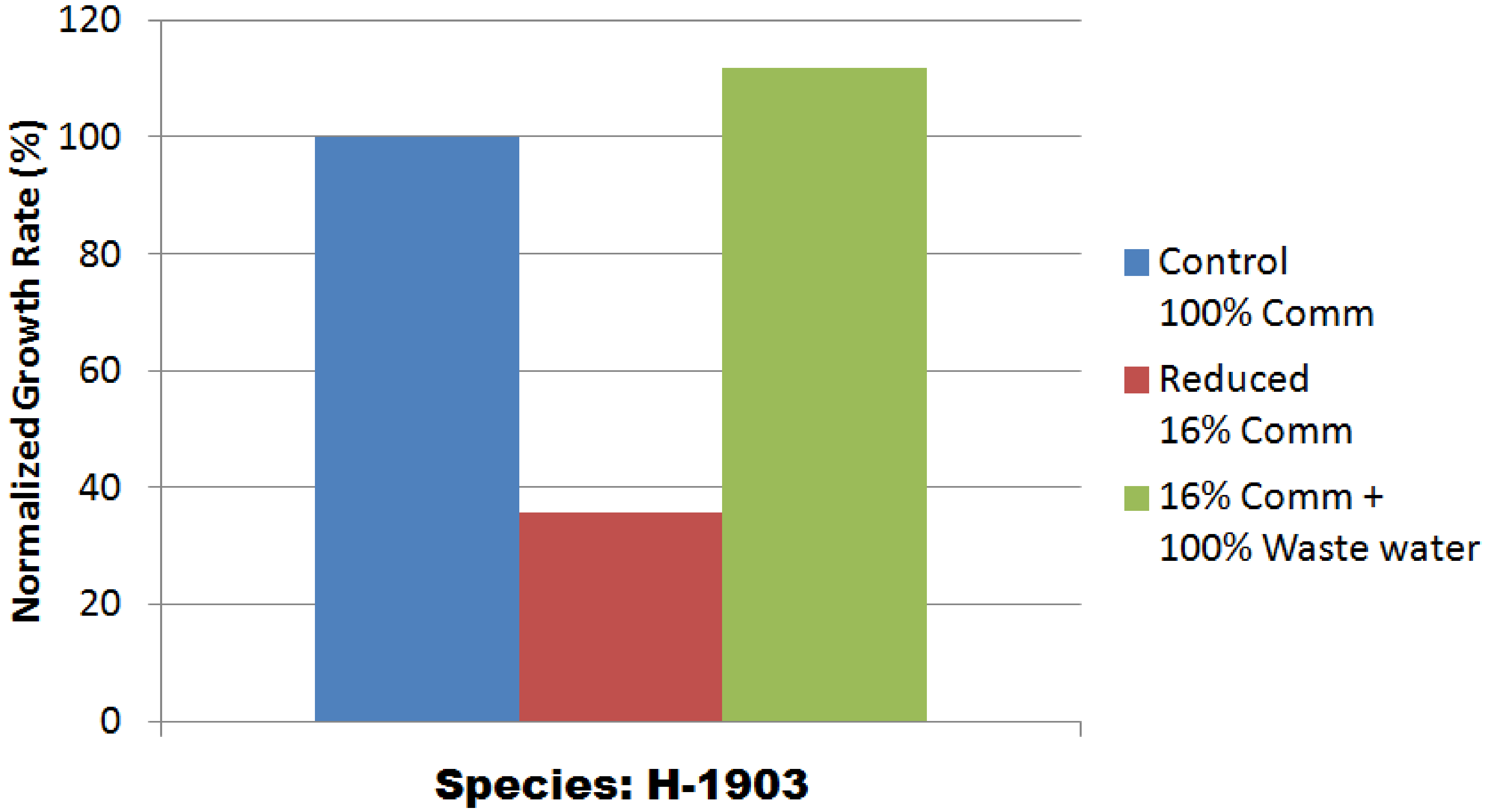
Comparison of Wastewaters Used for Algae Cultivation

Sample Type & Treatments		TSS (mg/L)	COD (mg/L)	NH3-N (mg/L)	NO3-N (mg/L)	Total N (mg/L)		Total P (mg/L)	pH
Muni-WW Centifuge Centrate	Filtered & Autoclaved	n/a	260 ±12	1021 ±8	22 ±17	1133 ±76		274 ±2	7.7
HTL Aq Product	Filtered & Autoclaved	n/a	44,177 ±326	7,206 ±66	360	10,944 ±1,237		2,108 ±7	5.6

- HTL aq product was significantly stronger than municipal wastewater dewatering centrate
  - Higher organics (~100x)
  - Higher nutrients (~10x)
  - HTL aq product has nitrogen-substituted organics and phenolics that have been shown to have inhibitory effects on microbial growth including algae

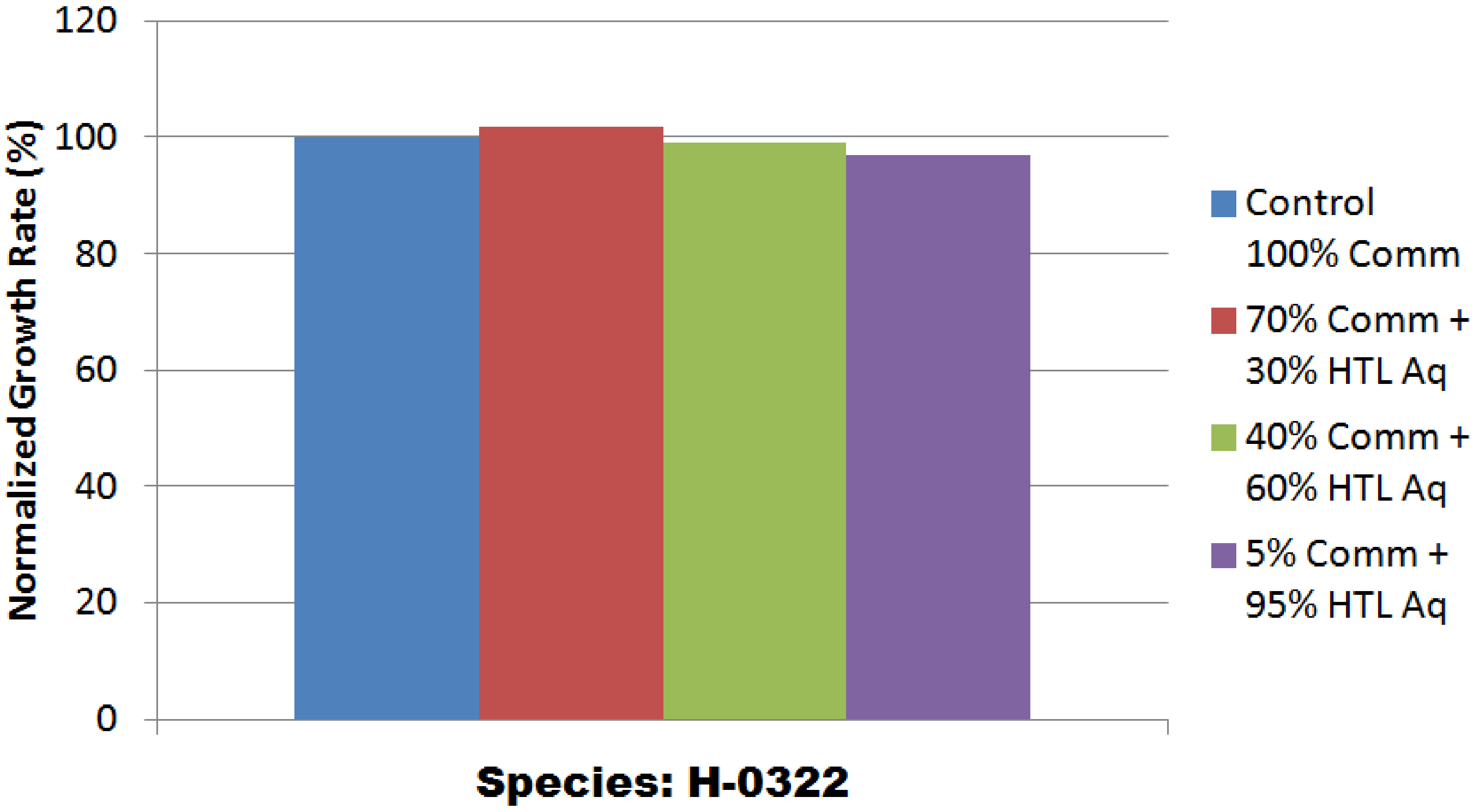
Impact of wastewater nutrient replacement on algae growth

Lower-strength centrate wastewater from biosolids dewatering

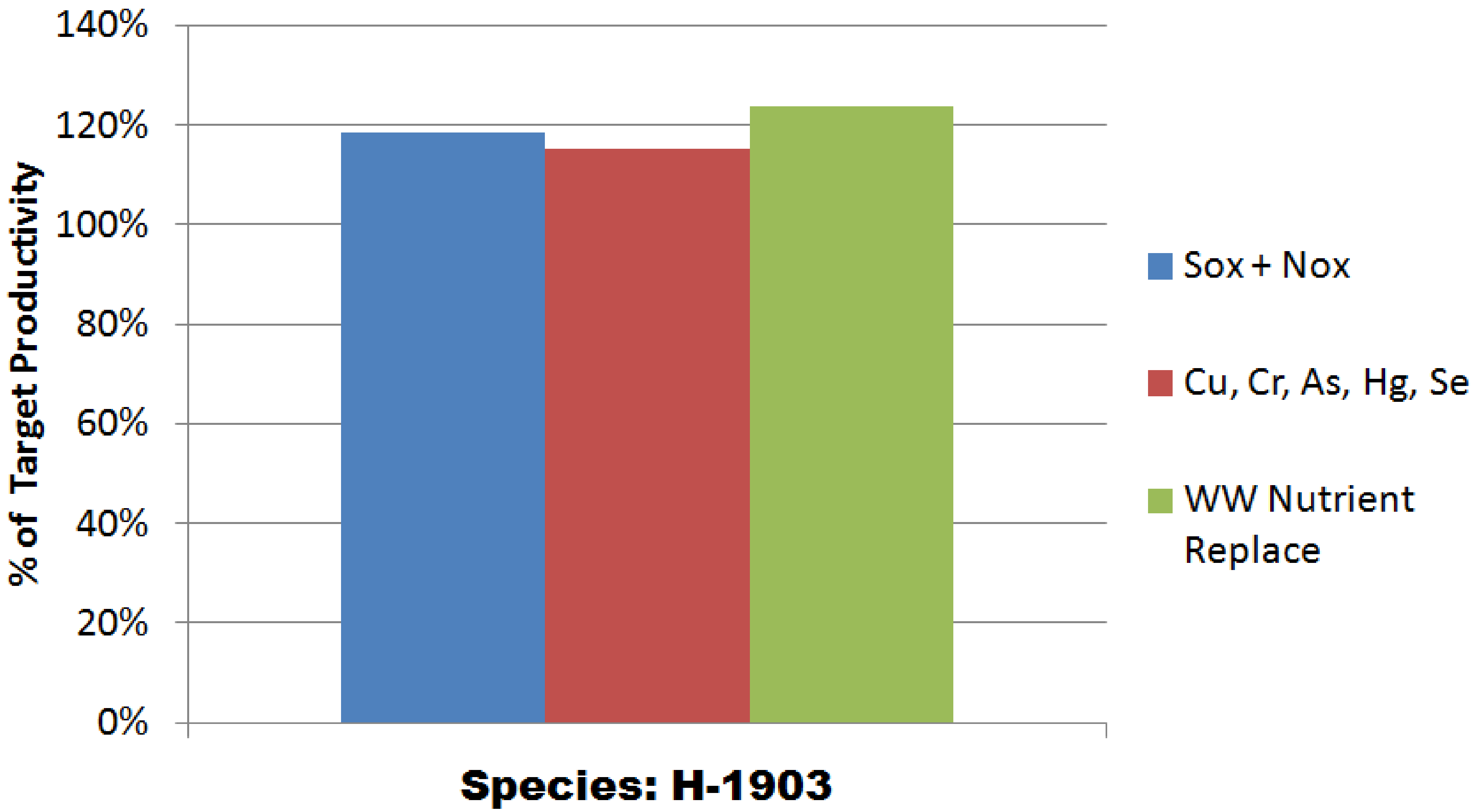


Impact of wastewater nutrient replacement on algae growth

Higher-strength HTL aq wastewater from biofuel production



Weekly Avg. Productivity With Flue Gas & Wastewater Inputs



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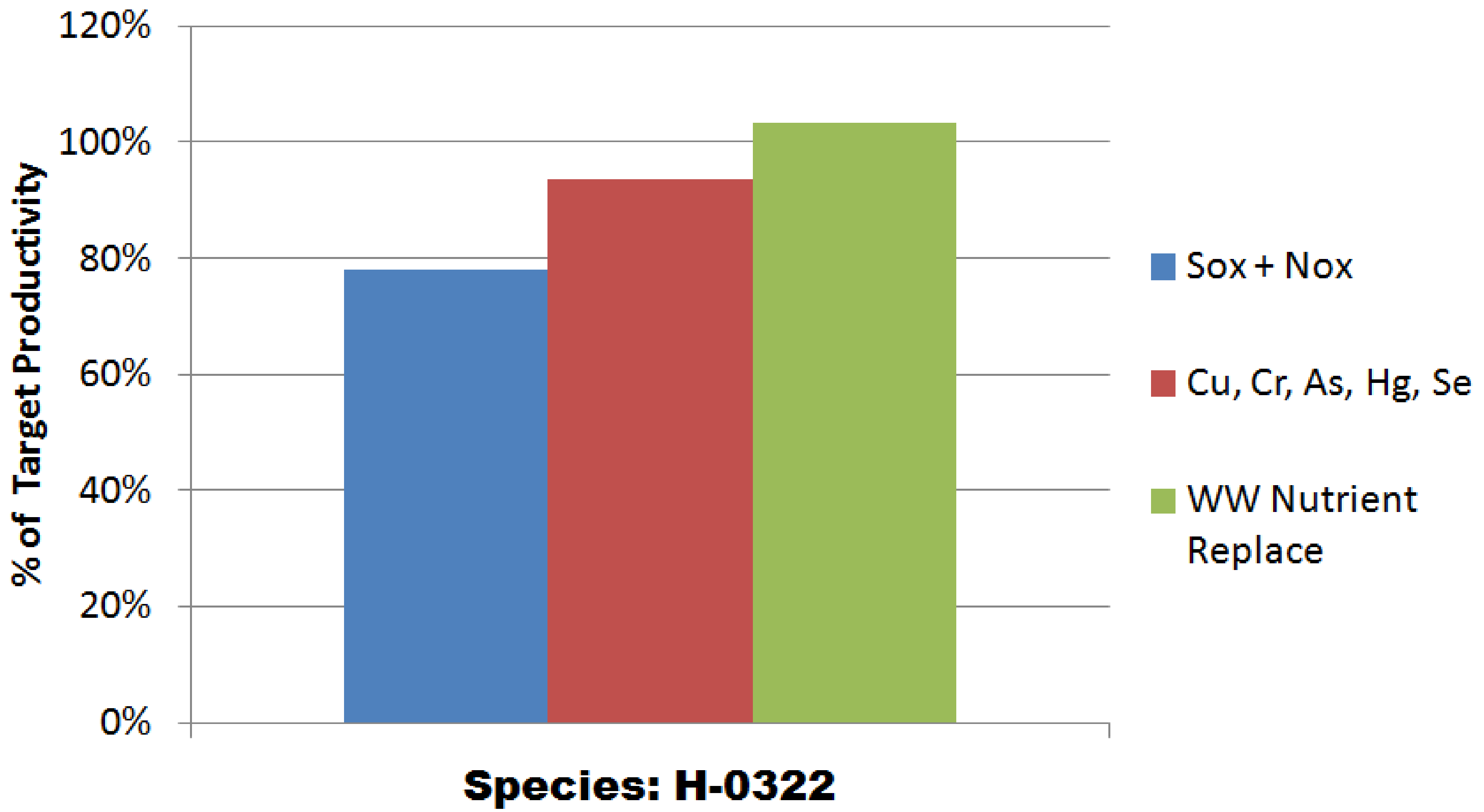

Project Milestones for Budget Period 1

Budget Period	Task #	Mile-stone #	Description	Planned Completion Date	Actual Completion Date	Verification Method
1	1	T1.1	Kickoff Meeting	Dec. 2017	Dec. 2017	Presentation file
1	1	T1.2	Updated Project Management Plan	Oct. 2017	Oct. 2017	Project Management Plan File
1	2	T2.1	Stable Algae Growth with simulated flue gas	Mar. 2018	Mar. 2018	Quarterly Progress Report
1	3	T3.1	Stable Algae Growth with wastewater nutrients	Sept. 2018		BP1 Annual Progress Report
1		G/N-1	Algal Productivity with Simulated Flue Gas > 25 $g/m^2/d$	Sept. 2018		DOE Annual Review

Project Success Criteria for Each Budget Period

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Decision Point	Date	Success Criteria
G/N-1 Go/No-Go Budget Period 1	9/30/2018	Algal Productivity > 25 $g/m^2/d$ (weekly average) with Simulated Flue gas containing 12% CO2, SOX, NOX and representative levels of heavy metals Hg, Se, As, Cu and Cr
G/N-2 Go/No-Go Budget Period 2	9/30/2019	Algal Productivity > 25 $g/m^2/d$ (weekly average) and >70% CO2 capture with Simulated Flue gas containing 12% CO2, SOX, NOX and representative levels of heavy metals Hg, Se, As, Cu and Cr
G/N-3 Go/No-Go Budget Period 3	9/30/2020	Integrated Application of Project Technologies w/ Projected Cost of Algal Biomass < $470 /dry ton

Technical Risks & Potential Mitigation Strategies

Description of Risk	Probability	Impact	Risk Management- Mitigation and Response Strategies
Technical Risks:			
Algae growth is inhibited by contaminants in post-FGD flue gas (SO_x, NO_x, metals)	Medium	Medium to High	• Use adsorbents in algal culture to sequester problem contaminants • Problem contaminants can be removed from the simulated flue gas • For future applications flue gas pre-treatment may be required
Algae growth is inhibited by contaminants in nutrient-rich wastewater liquids	Low	Medium to High	• Use adsorbents to sequester problem contaminants • Wastewater filtrate can be pre-treated to remove problem contam. • Wastewater filtrate use for algae cultivation can reduced/eliminated
Algal uptake of CO_2 is not fast enough for capture goal (70-90% removal in 3 stages)	Low	Low	• Provide fine bubble diffusers if it is a physical mass transfer limitation • Add stages if it is a biological limitation
Forward osmosis dewatering flux is too low to facilitate cost-effective applications	Low	Medium	• Pre-treat algal biomass with ultrasound to open cells and reduce resistance to water diffusion through the cell walls • Use alternate dewatering methods
Concentrated HTL aqueous product is not converted to bio-oil when recycled	Low	Low	• Use alternate methods for treatment of HTL aqueous product (anaerobic digestion, or catalytic hydrothermal gasification)
Sewer conveyance of flue gas causes too much loss/dilution	Medium	Low	• Use a dedicated pipeline for transport of CO_2 from flue gas

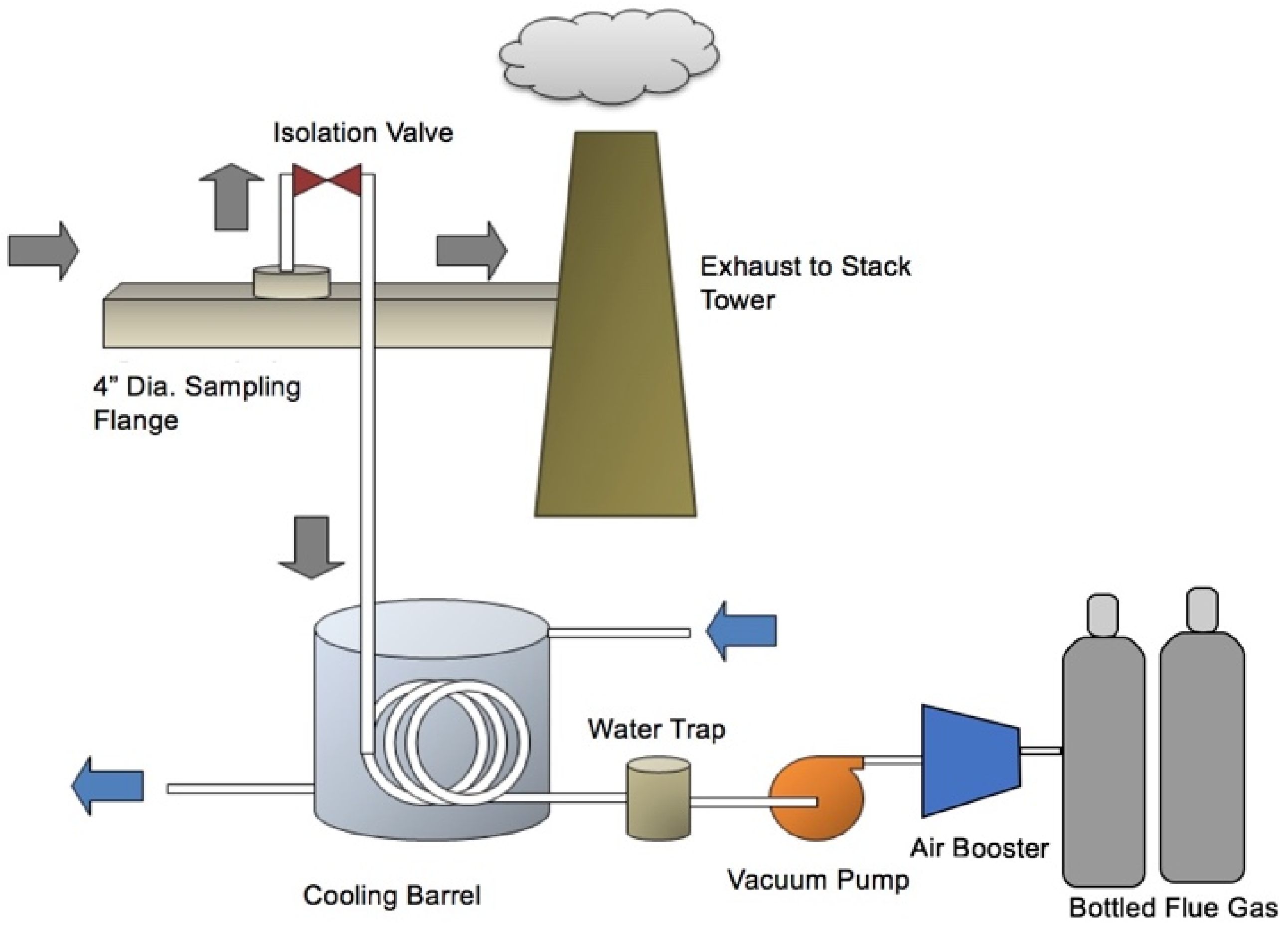
BP1

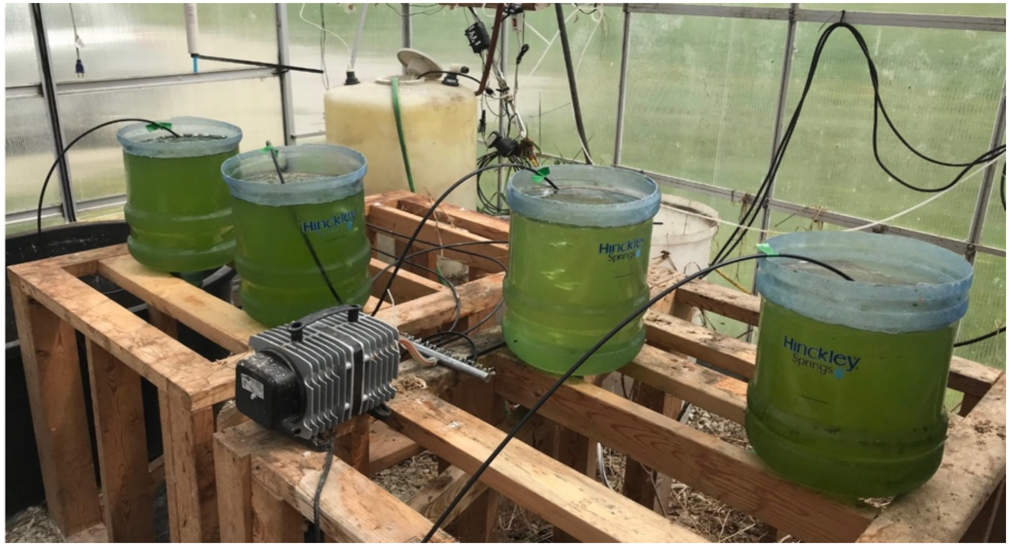
Summary of Major Project Activities

- **Task 1- Project Management (Ongoing)**
  - Monthly Progress Conference Calls with DOE Program Manager
  - Three Quarterly Progress Reports Submitted
  - Individual Meetings with Three Industrial Advisory Board Members
- **Task 2- Algae Cultivation using Simulated Flue Gas w/Contaminants (Completed)**
  - Demonstrated acclimation & robust growth of 2 algal species w/ acid gasses (CO_2, NO_x, SO_x)
  - Demonstrated acclimation & robust growth of 2 algal species w/ heavy metals (As, Se, Hg, Cr, Cu)
- **Task 3- Algae Cultivation w/ Wastewater Nutrients (Ongoing)**
  - Demonstrated acclimation & robust growth of 2 algal species with 2 wastewater sidestreams
    - Centrate from wastewater biosolids centrifuge dewatering
    - Raw hydrothermal liquefaction (HTL) aqueous product from conversion of biomass to biofuels
  - >50% nutrient replacement achieved with all combinations of wastewater nutrients & algal species
  - Full nutrient replacement achieved with several combinations of wastewaters & algal species
  - Ongoing testing to optimize productivity of algal cultures

New Flue Gas Testing Capability

Small-Scale Algae Cultivation w/ Bottled Flue Gas Samples





	LOW FLUE GAS	MEDIUM FLUE GAS
Flue Gas CO_2 concentration	6.01%	6.01%
Air pumping rate (L/min)	0.5	0.5
Flue gas Injection rate (L/min)	0.05	0.1
Influent CO_2 conc.	0.58%	1.04%
Exhaust CO_2 conc.	0.44%	0.85%
CO_2 removal efficiency	24%	18%
Carbon Capture (mg-C)	183.0	258.3
Assimilated Carbon (mg-C)**	178.6	243.7

Questions and Comments…

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