Title Slide

FUNDING OPPORTUNITY ANNOUNCEMENT DE-FOA-0001235

U.S. Department of Energy, Office of Fossil Energy, NETL
Cooperative Agreement DE-FE0026490 , 10/01/15 – 09/30/17

“Microalgae Commodities from Coal Plant Flue Gas CO_2”
Awarded to: MicroBio Engineering, Inc. San Luis Obispo, CA

Principal Investigator: John Benemann, Ph.D., CEO
JBenemann@MicroBioEngineering.com

MicroBio Engineering, Inc. Background Slide

- **Incorporated in California in 2007, 5 FTE employees (10/15)**
- **Located in San Luis Obispo, CA (offices, shop, warehouse, lab).**
- **John Benemann, CEO; Tryg Lundquist, CTO, Ian Woertz, COO**
- Algae biomass production; Wastewater bioengineering; Design, fabrication and construction algae systems; Techno- economic Analyses (TEAs); Life Cycle Assessments (LCAS); Consulting.
- **Collaboration with Cal Poly on DOE EERE funded projects**:
  - **11/2014 –6/2016 ABY - Algae Biomass Yield (Cost share to CP)**
  - **6/2013 –1/2016 ASAP - Water & Nutrient Recycling Project (")**
  - **6/2015 -2/2016 STTR - Bioflocculating Algae (subcontract to CP)**
  - **10/2015 -9/2017 PNNL- "AlgaeAirFix" (subcontract to CP)**
- **Proposals recently submitted by MBE to DOE (Cal Poly sub)**
  - **DOE STTR Cultivation of filamentous algae on flue gas**
  - **DOE STTR Fermentation products from glycerol**
  - **DOE EERE Selection of high productivity algae**

Project Overview – Funding, Performance Period and Participants

– **Funding**
  - **DOE NETL: $863,327**
  - **OUC Cost Share: $282,640**

– **Project Performance**
  - **10/1/2015 to 9/30/2017**

– **Project Participants**
  - **MicroBio Engineering, Inc. (MBE)**
  - **Orlando Utilities Commission (OUC) /Stanton Energy Center (SEC)**
  - **University of Florida (UF)**
  - **Arizona State University (ASU)**
  - **Scripps Institution of Oceanography (SIO)**
  - **Life Cycle Associates LLC (LCA)**
  - **SFA Pacific / Dale Simbeck, consultant**

PROJECT PARTICIPANTS, ROLES

- **MicroBio Engineering Inc. , (MBE) Prime Recipient**

  P.I. John Benemann, CEO (over 40 years of experience in field).

  ROLES: Scale-up designs, LCAs, TEAs, gap analyses, experimental design and results monitoring for OUC and UF. Project management.
- **Subrecipients :**

– **Orlando Utilities Commission (OUC)** : provide information to MBE on Stanton Energy Center power plants, CO2 emissions, etc. ; Operate test ponds at Stanton Energy Center with flue gas CO_2

– **Univ. of Florida (UF)**: operate test ponds, algae anaerobic digestion .

– **Arizonia State Univ.**: Train OUC and UF staff in algae cultivation.

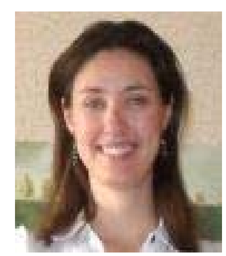
– **Scripps Institution of Oceanography (SIO), Lifecycle Associates (LCA), SFA Pacific Inc.**: LCA, TEA and engineering assistance to MBE

John Benemann MBE	**Tryg Lundquist MBE**	**Rob Teegarden OUC**	**Ann Wilkie UF**	**Tom Dempster ASU**	**Dominick Mendola SIO**	**Susan Boland LCA**	**Dale Simbeck SFA**





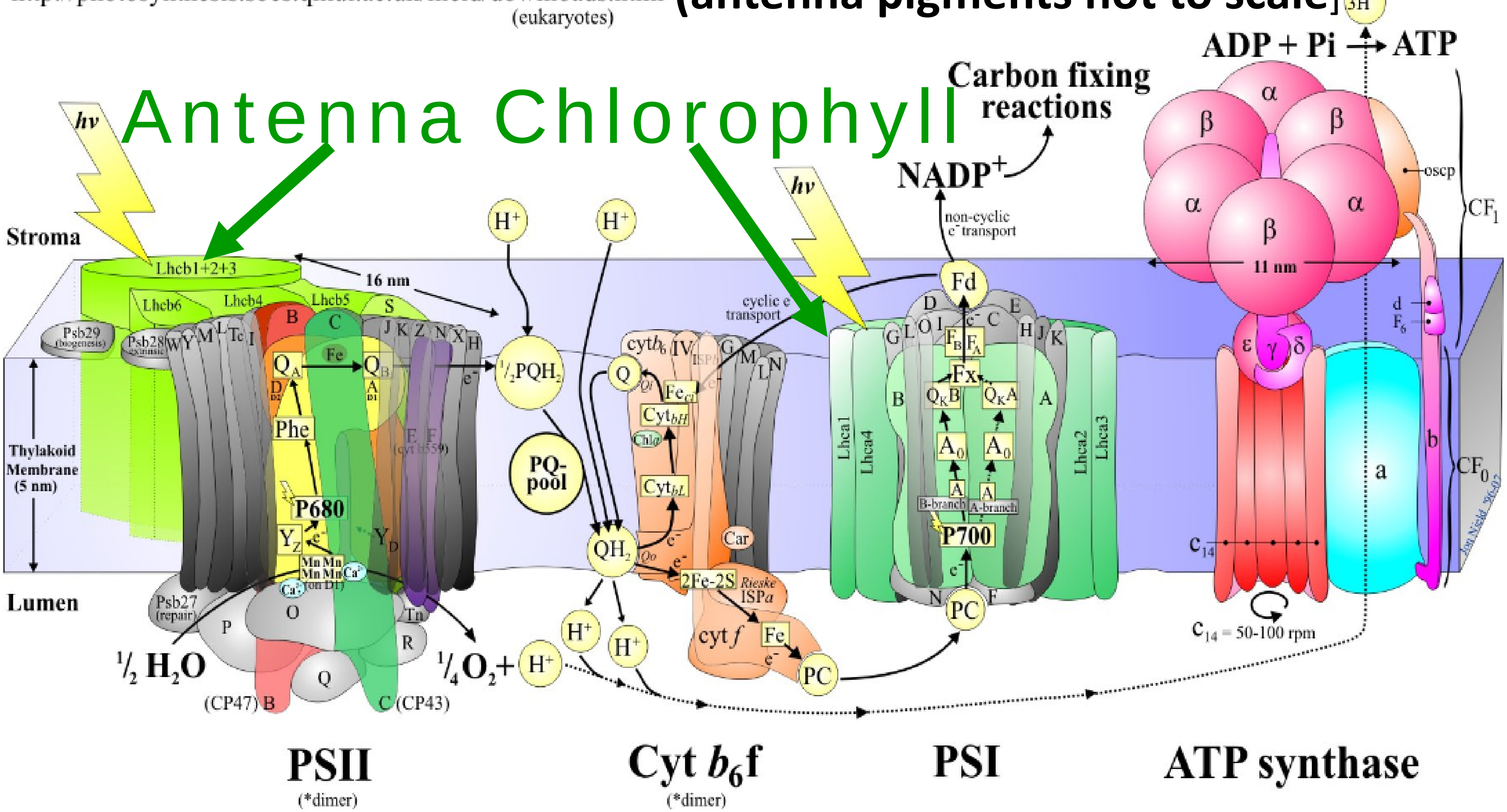





Technology Fundamentals/Background
1. Fundamental Science Driving Technology
(thermodynamics, chemistry, biology, etc.)

Schematic of Photosynthesis in green algae and plants

http://photosynthesis.sbcs.qmul.ac.uk/nield/downloads.html **(antenna pigments not to scale]**



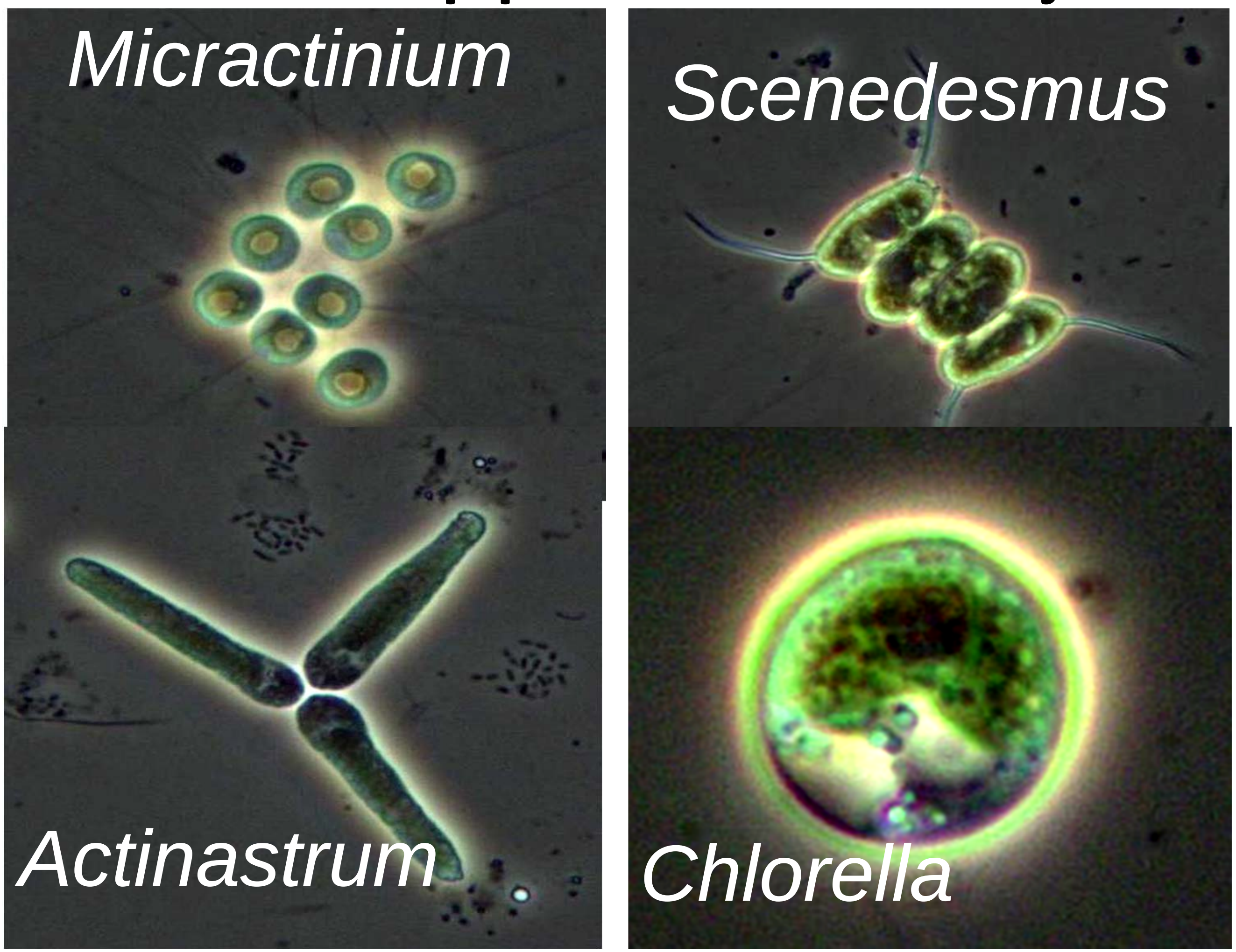
Technology Fundamentals/Background

1. Fundamental Science Driving Technology

(thermodynamics, chemistry, biology, etc.) **Contd**.

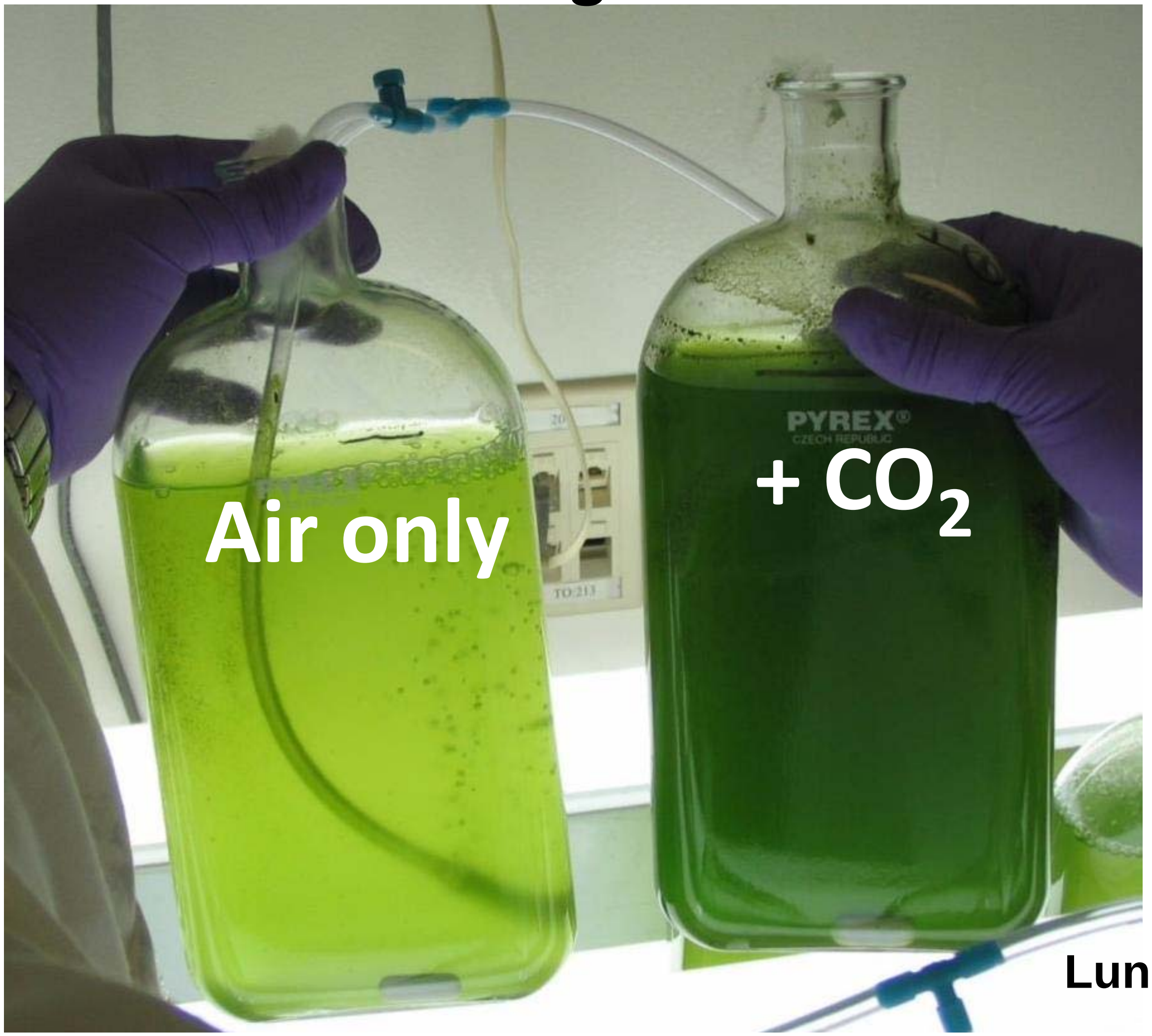
Green algae typical of fresh water algal mass cultures

Strain control and crop protection still major R&D needs



Technology Fundamentals/Background
1. Fundamental Science Driving Technology
(thermodynamics, chemistry, biology, etc.) **Contd**.

Add CO_2 to balance C:N:P ratio achieves complete nutrient assimilation during wastewater treatment



CO_2 Enhanced

600 mg/L Algae

<1 mg/L NH_4^+-N

<0.3 mg/L PO_4^{3-}-P

Air Sparged

130 mg/L Algae

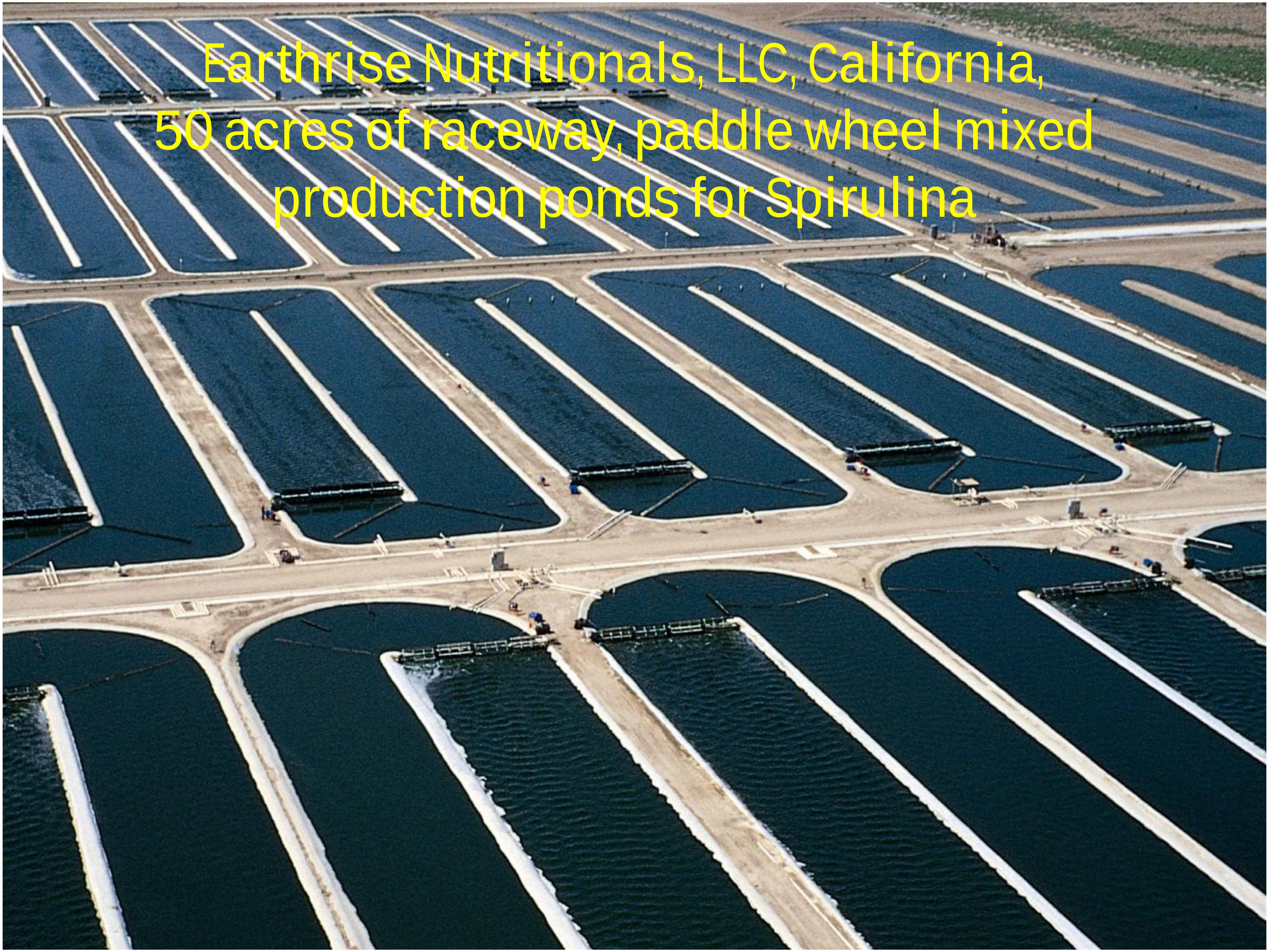
25 mg/L NH_4^+-N

3 mg/L PO_4^{3-}-P

Lundquist et al., Cal Poly

Technology Fundamentals/Background

2. How technology is to work in operation: Algae cultivation for biofuels, waste waters, CO_2


Earthrise Nutritionals, LLC, California,
50 acres of raceway, paddle wheel mixed
production ponds for Spirulina


Earthrise Nutritionals, LLC, California,
50 acres of raceway, paddle wheel mixed
production ponds for Spirulina


Rupert Craggs, NIWA
UNLINED PONDS!
Lamellar settler harvesting →
Sump for CO2 transfer →
Paddle wheel →
Christchurch, New Zealand: 4 x 1.25 ha ponds.
Largest and lowest cost algae-for-biofuels pond system (after earthquake moved to North Island!)

Paddle Wheel Mixed Raceway Ponds,

main technology for commercial algae production

- ~ 1-ft (30 cm) deep
- Mixed at 20-25 cm/s
- CO_2 sparged in water
- pH control 7.5- 8.2
- Fertilize with N, P, K and micronutrients

Seambiotics, Israel, first to use flue gas from coal-fired power plant (two 200 m^2 ponds)


Seambiotics, Israel


Hearol Plant, Yantai, China
(built under Seambiotics Ltd., license
for production of Nannochloropsis)
)
100 raceway ponds x ¼ ac (0.1ha)
(plant failed due to contamination)

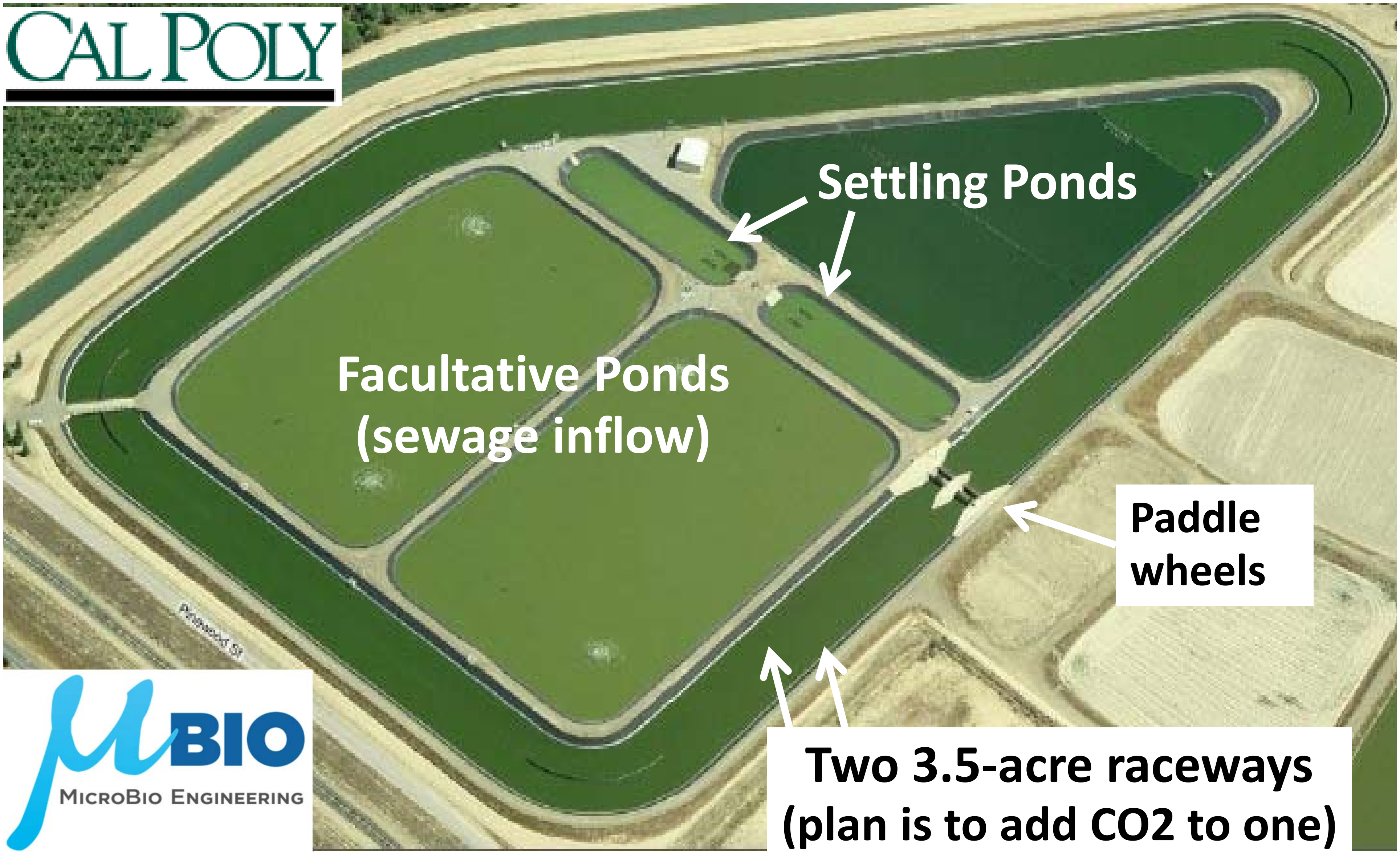
Partners

- ✓ Harris Group
- ✓ Brown and Caldwell
- ✓ AMEC/Geomatrix
- ✓ Linde (CO2 and conversion)
- ✓ Tesoro (offtake agreement)
- ✓ Phillips 66 (upgrading and part 79 registration for on road diesel fue
- ✓ DOE co-processing grant

Pilot Plant for Algae Biomass Production at a small fossil Power Plant. MBE design: six 5 acre raceway ponds, and smaller ponds

Delhi, CA: DOE BETO ABY Project - Cal Poly & MBE

Algae Wastewater Treatment Plant → Biofuels Production



At Delhi algae are coagulated, settled ,solar dried.

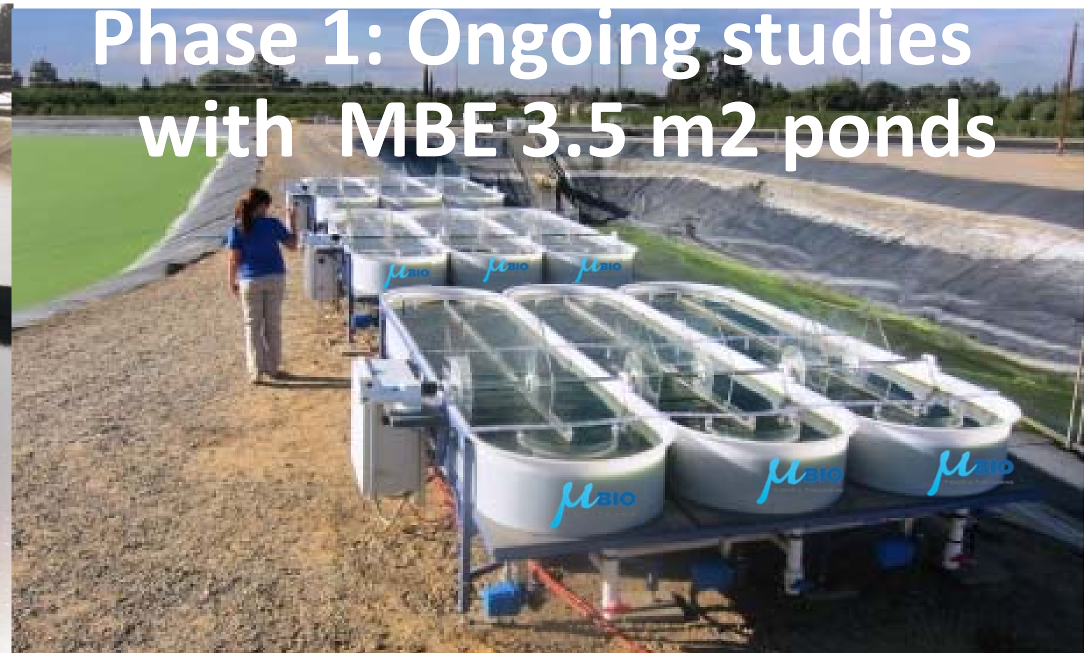
~100,000 gallons of 3% solids algae in decanted settling basin

Solar dried algae

Concrete drying pad

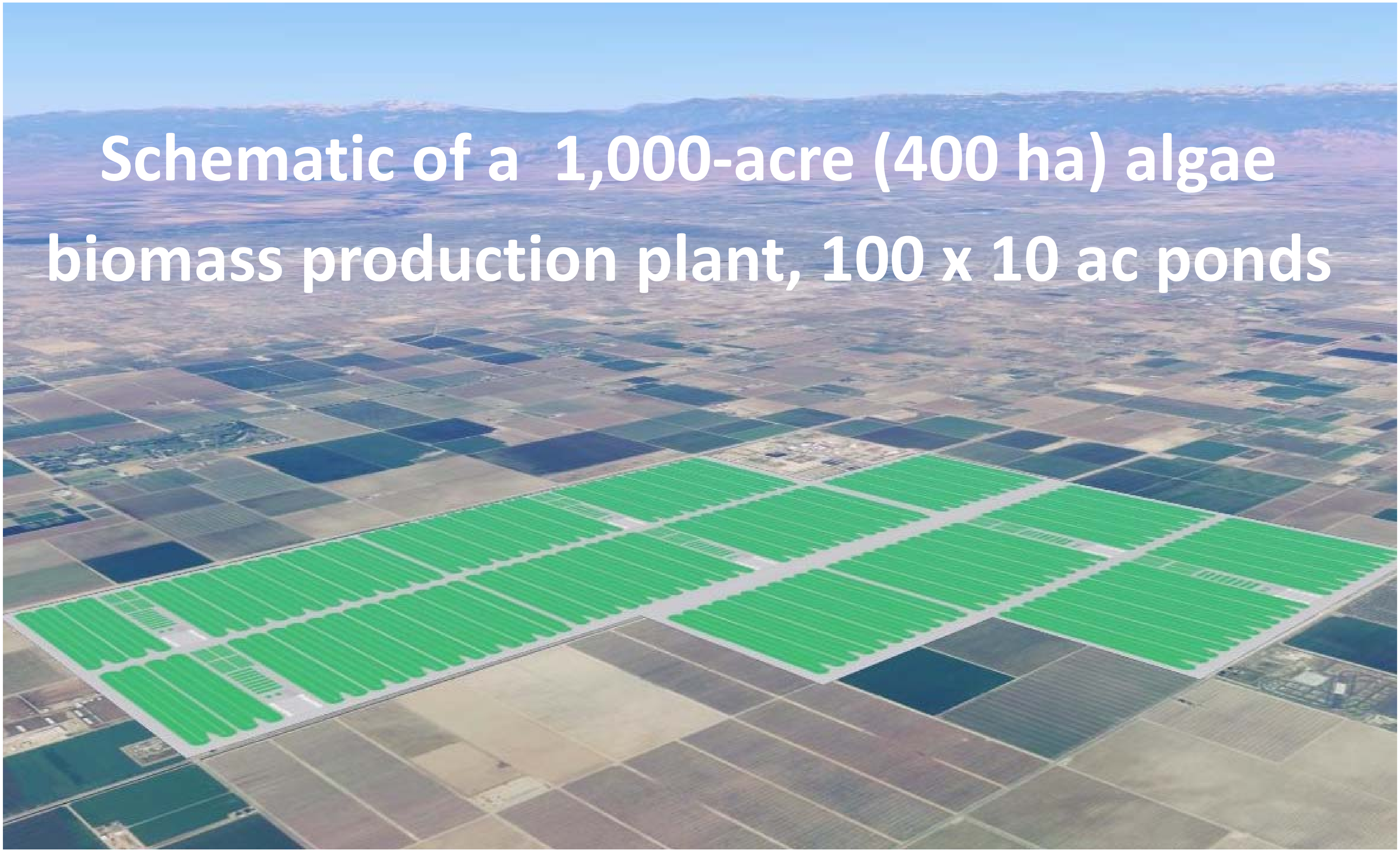
Delhi ABY Phase 1 Objective to demonstrate productivity potential (t/ac-y) and harvesting by settling, for scale-up in Phase 2 project

DOE BETO ABY Project - Cal Poly & MBE



Technology Fundamentals/Background

2. How technology is to work in operation - labeled schematic with preferred operating requirements

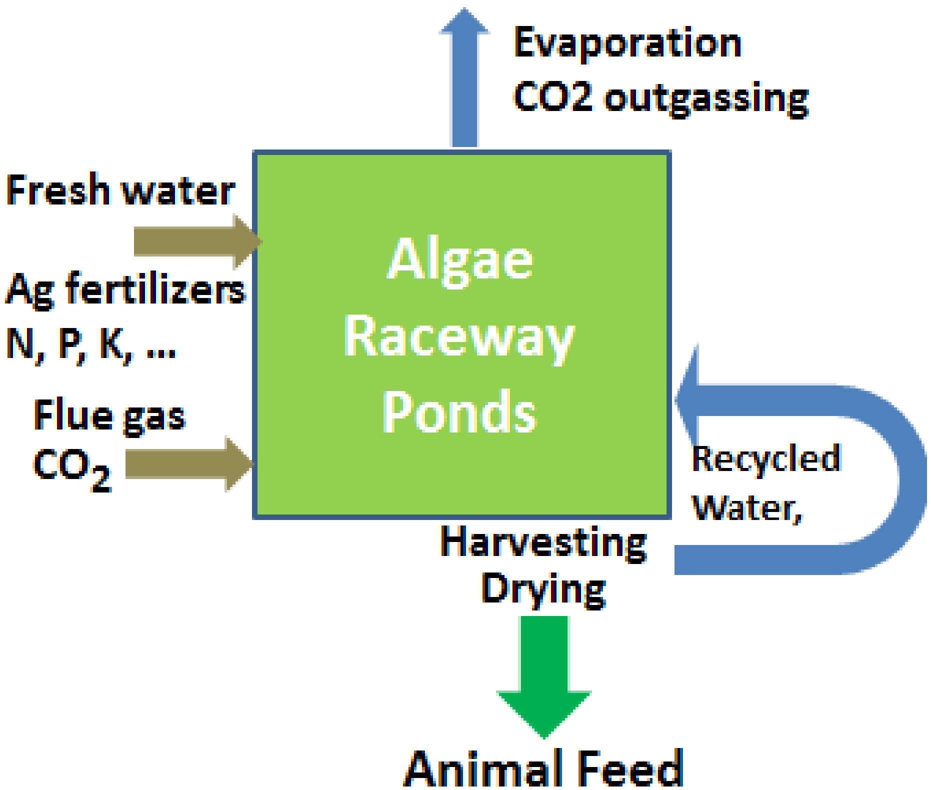


Technology Fundamentals/Background

2. How technology is to work in operation - labeled schematic with preferred operating requirements

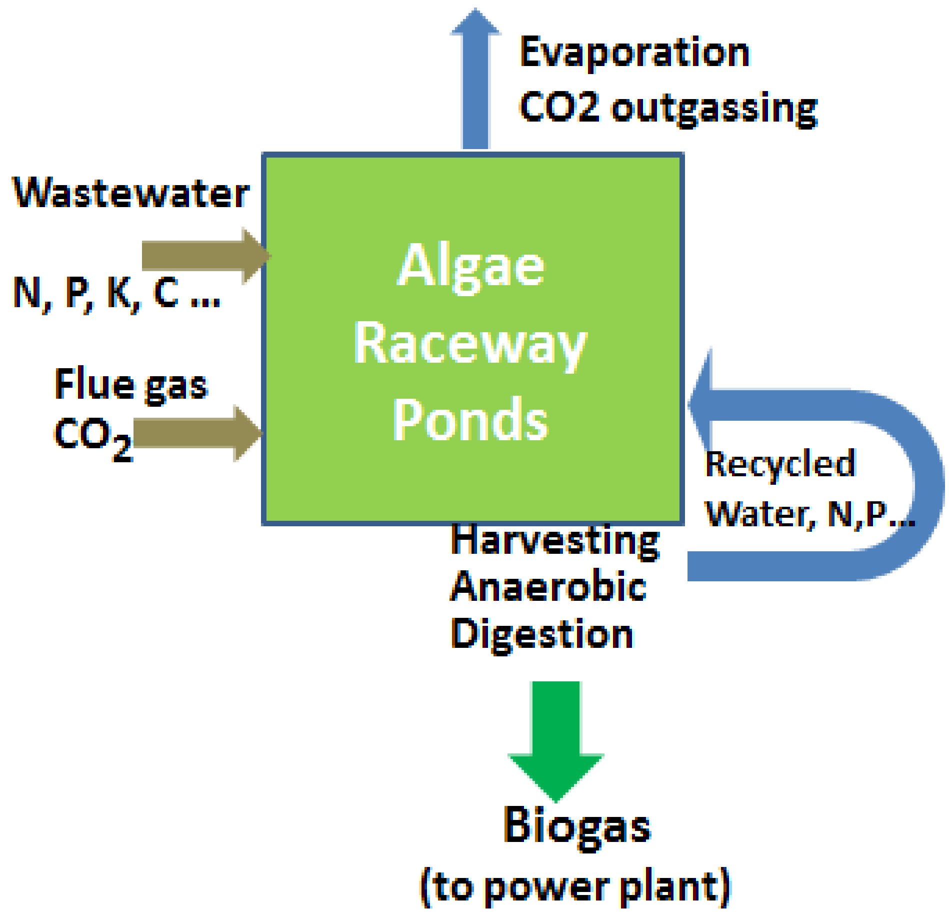
Animal Feed Case

with fresh water and agricultural fertilizers



Biogas Production Case

with wastewaters for water and nutrient make-up



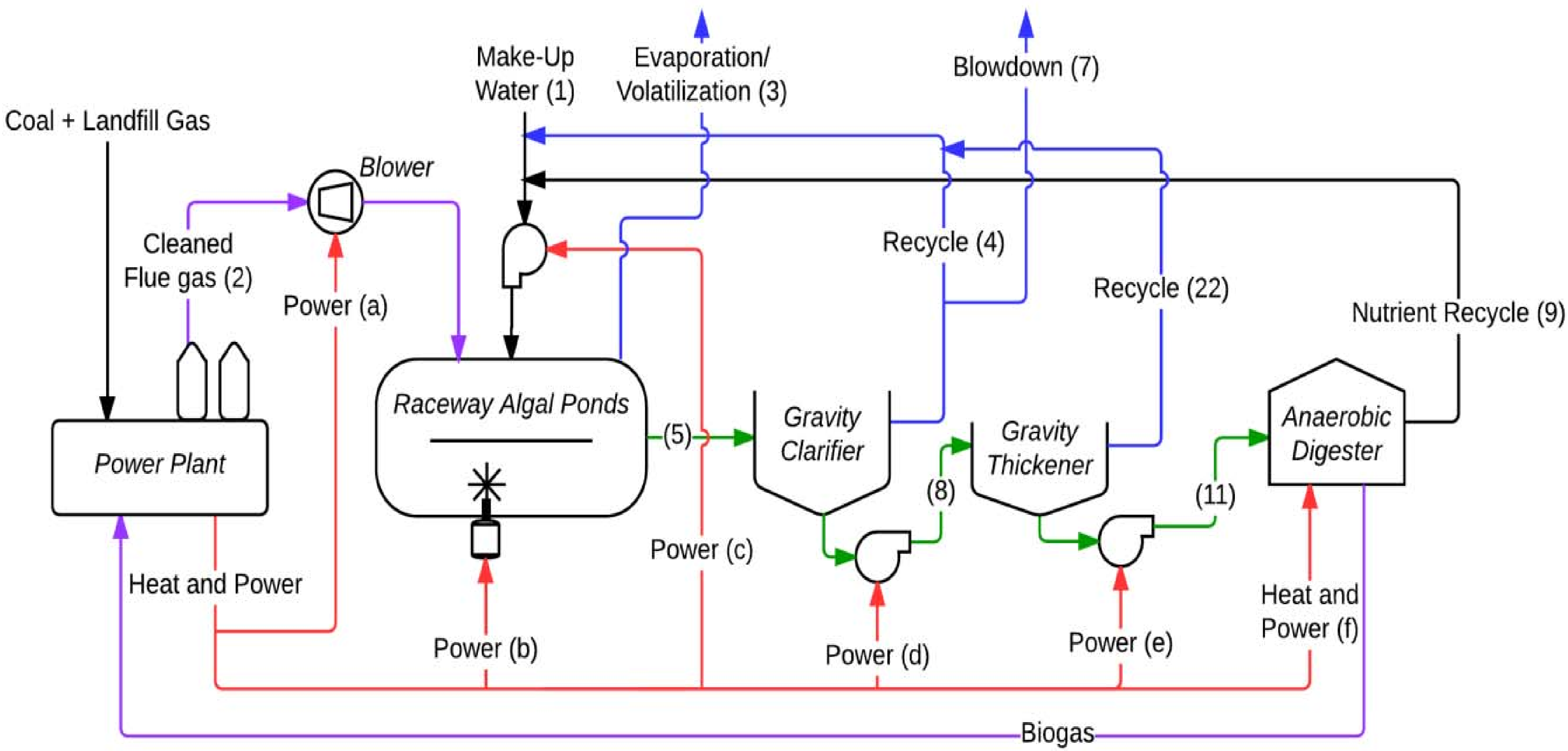
MicroBio Engineering

Technology Fundamentals/Background

2. How technology is to work in operation - labeled schematic with preferred operating requirements cont.

Biogas Production Case

(with wastewater supply for water and nutrient make-up)



Technology Fundamentals/Background

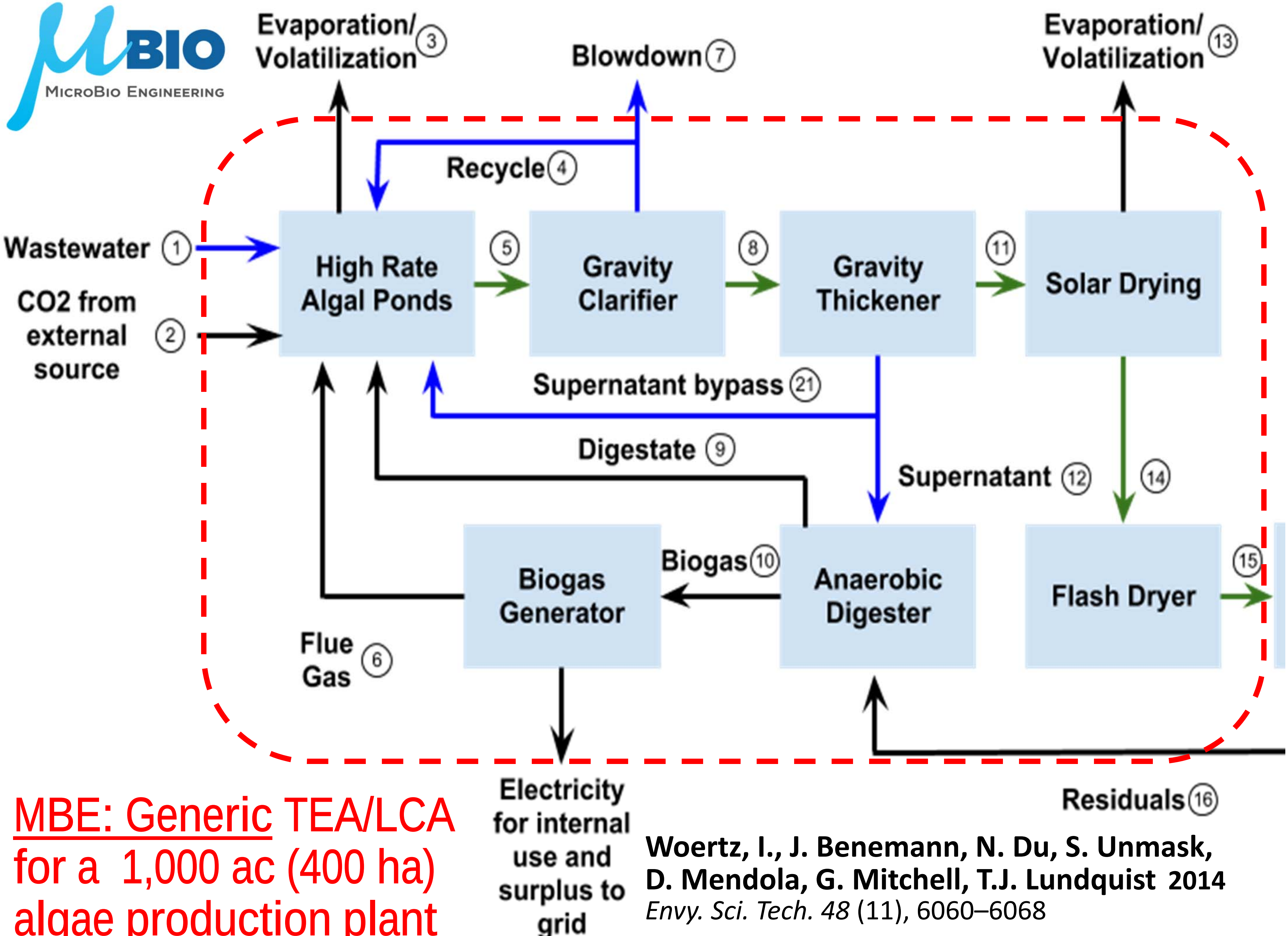
2. How technology is to work in operation: labeled schematic with preferred operating requirements Cont.

Engineering Calculations for Algae Production System

description		units
average net productivity of algal biomass	20.0	$g/m^2/day$
nitrogen content in algae biomass	5	% wt
carbon content in algae biomass	52	% wt
extractable oil in algae biomass	30	% TAG
density of algae TAG	0.92	kg/L
TAG conversion to biodiesel	1.04	kg/kg
low heating value of biodiesel	37.5	MJ/kg
low heating value of methane	50.0	MJ/kg
make-up water pumping head	40	M
recycle water pumping head	6.3	M
pump efficiency	88	%
pump motor efficiency	83	%
average hydraulic retention time of ponds	4	days
linear water velocity in pond channels	0.25/ 0.20	m/s
mixing energy required	191	kWh/day-raceway

Engineering Calculations for Algae Production System (Contd.)

harvesting efficiency in algae clarifiers	95	%
efficiency of algae gravity thickeners	95	%
hours per day of flue gas sparging	10	h/day
average energy requirement for flue gas distribution	1.87	kWh/m^3
concentration of CO_2 in flue gas	12.5	vol%
overall use efficiency of CO_2	75	%
nitrogen losses	10	%
solar drying bed area required	50	Ha
anaerobic digester HRT	30	days
methane yield from anaerobic digestion of algae biomass residues after oil extraction	0.32	L CH_4/g VS
electrical generator efficiency	33	%
heat exchanger capture of total energy	41	%
flash dryer electrical/heat energy required	40	kWh/Mg
	1187	MJ/Mg



MBE: Generic TEA/LCA for a 1,000 ac (400 ha) algae production plant

Woertz, I., J. Benemann, N. Du, S. Unmask, D. Mendola, G. Mitchell, T.J. Lundquist 2014
Envy. Sci. Tech. 48 (11), 6060–6068

Mass balances from Process Schematic Generic TEA/LCA

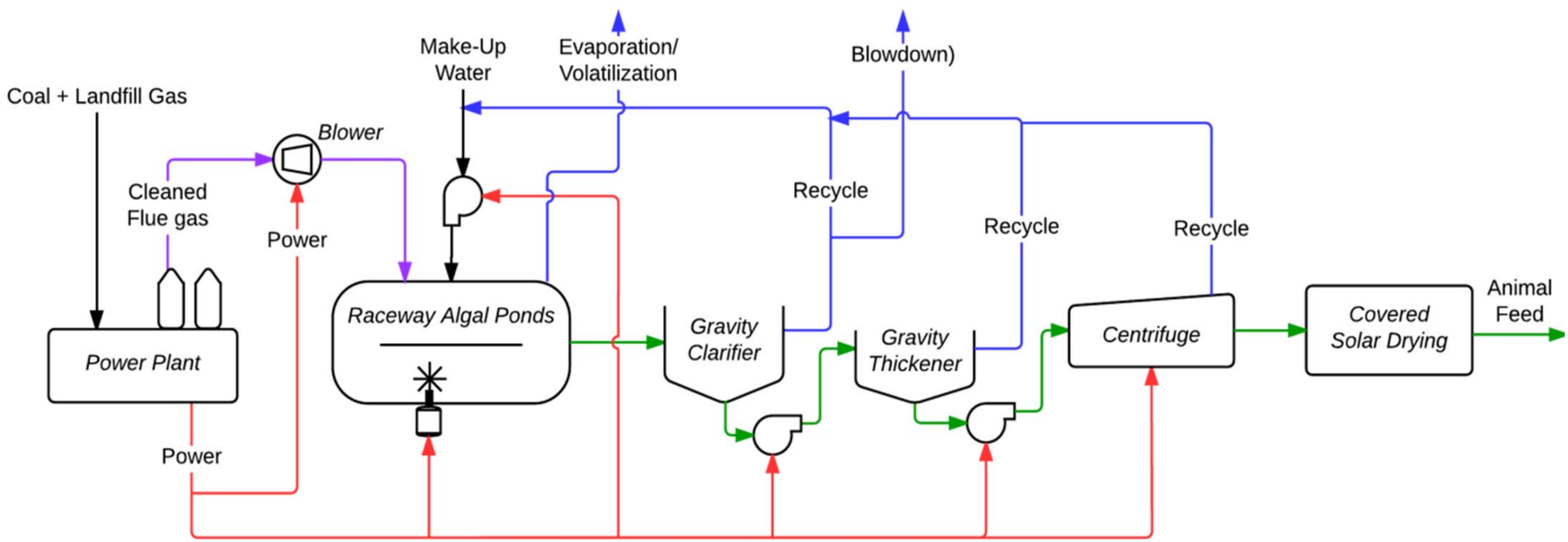
	Description	Flow Q (m^3/day)	Biomass (kg/d)	C (kg/d)	N (kg/d)	CO_2 (kg/d)	CH_4 (kg/d)
1	Wastewater	71,900	-	2,790	1,800	-	-
2	CO2 from external source	-	-	30,400	-	113,000	-
3	Evaporation/ Volatilization	38,900	-	12,400	1,520	43,700	-
4	Harvest Water Recycle	269,000	4,720	2,460	7,810	-	-
5	Algae Raceway Pond Effluent	305,000	105,000	54,500	13,700	-	-
6	Flue Gas	-	-	16,700	-	61,800	-
7	Blowdown	29,900	524	273	868	-	-
8	Gravity Clarifier Subnatant*	6,640	99,600	51,800	4,980	-	-
9	Digestate	1,390	26,300	13,700	4,750	-	-
10	Biogas	33,500	-	16,800	-	21,500	14,700
11	Gravity Thickener Subnatant	3,160	94,700	49,200	4,730	-	-

Technology Fundamentals/Background

2. How technology is to work in operation, labeled schematic with preferred operating requirements Cont.

Animal Feeds Production Case

(with fresh water and agricultural fertilizers)



Technology Fundamentals/Background

3. Technical and/or economic advantages the capture technology has for new and existing PC power plants

- Rapid growth rates, high CO_2 fixation capacity (t/ha-y) by microalgae cultures (~10X crop plants)
- Potentially low cost with fully developed technology
- Solar powered process, favorable LCA.
- Direct power plant flue gas CO_2 reuse:
  - to anaerobic digestion→ biogas to replace coal
  - to animal feeds → replace conventional feeds

Technology Fundamentals/Background

3. Technical and/or economic advantages the capture technology has for new and existing PC power plants

Prior techno-economic studies of microalgae production with large raceway ponds, projected that with reasonably favorable assumptions it would be possible to produce algal biofuels:

Benemann, J.R.; P. Pursoff; W.J. Oswald, **1978. Engineering Design and Cost Analysis of a Large-Scale Microalgae Biomass System**, Final Report US DOE. NTIS #H CP/T1605-01 UC-61.

Benemann, J.R.; R.P. Goebel; J.C. Weissman; D.C. Augenstein. **1982. Microalgae as a source of liquid fuels**. Final Report U.S.DOE BER

Benemann, J.R.; W.J., Oswald **1996**, **Systems and economic analysis of microalgae ponds for conversion of CO2 to biomass.** Report to U.S. DOE-NETL (National Technology Energy Laboratory)

Lundquist, T.J.; I.C. Woertz; N.W.T. Quinn; J.R. Benemann **(2010). A Realistic Technological and Economic Assessment of Algae Biofuels,** Report to Energy Biosciences Institute, U. Calif. Berkeley, California

Technology Fundamentals/Background

4. Challenge: Limits to Beneficial Use of CO_2 Emissions from Coal-fired Power Plants and other large sources.

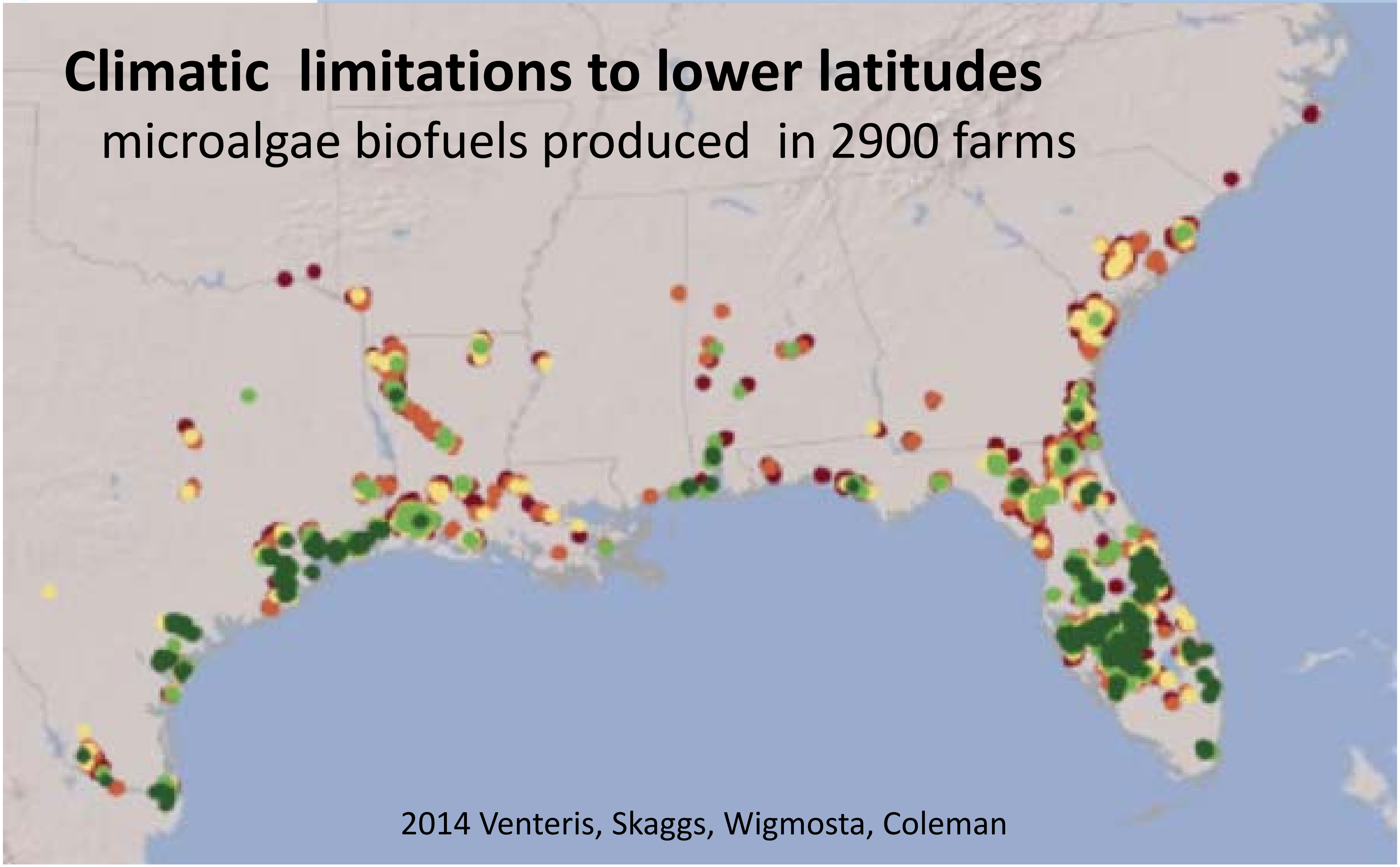
- **Large resource requirements close to power plant**:
  - **Land - flat, high clay content, on grid**
  - **Water – fresh, brackish, seawater, wastewaters .**
  - **Nutrients – N, P, K, and ~20 minor and trace elements**
- **Undeveloped technology - costs are currently very high**
- **Limited by climate to lower latitudes (see next slide)**
- **Limitations to flue gas CO_2 utilization (see next slides)**

Technology Fundamentals/Background

4. <u>Challenge</u>: Limits to Beneficial Use of CO2 Emissions from Coal-fired Power Plants and other large sources.

Climatic limitations to lower latitudes

microalgae biofuels produced in 2900 farms



2014 Venteris, Skaggs, Wigmosta, Coleman

Technology Fundamentals/Background

4. <u>Challenge</u>: Limits to Beneficial Use of CO2 Emissions from Coal-fired Power Plants and other large sources.

<u>1. Basis: ~</u>5,000,000 t/y CO_2 emissions from two units at Stanton power plant,~800 MWe, 1.86 MMt coal per year.

<u>2. C in Algae</u>: 46.5% C in ash free dry weight (afdw) algae, also ~8% N, ~0.3% P, ~1% K, trace elements (nutrient recycle needed)

<u>3. CO_2 losses:</u> 1/3rd **lost** in transfer of flue gas into the ponds and outgassing from pond to atmosphere (favorable projection)

<u>4. CO_2 required/t algae</u>: 1 t of algal biomass (afdw) requires supply of (0.465 x 44/12)/0.67 = ~2.5 t CO_2 (with 33% losses)

<u>5. Productivity</u>: project 54 mt afdw /ha-y (15 g/m^2-d annual avg.)

<u>6. CO_2 per Hectare</u>: (54*2.5=) 139 **t-ha/y** CO_2 required by algae

<u>7. CO_2 Use Factors</u>: No CO_2 fixed at night (x ~0.5), less in winter (x~ 0.5), more peak summer hours (x 0.67) = 1/6th of plant output

<u>8. CO_2 Delivered to Ponds</u>: (5 MMT/y)/6 = **0.84 MMt/y ~6,000 ha**

Technology Fundamentals/Background

4. Challenge: Limits to Beneficial Use of CO2 Emissions from Coal-fired Power Plants and other large sources.

9. Plant Outages: project10%, reduce biomass to ~50 t afdw /ha-y

10. Algal Biomass Production: 50 t/ha-y x 6,000 ha =300,000 t/y = ~500,000 t CO_2 captured in biomass (10% of total emissions)

11. Biogas Production: assume yield 320 L CH_4/kg VS algal biomass digested; 3,600,000 GJ/y gross energy yield.

12. Coal Equivalence: 2,900,000 GJ/y net yield @29 GJ/t coal =~100,000 t/y coal potential offset, ~5.4% of coal use.

13. CO2 Use Reduction: At 3tons CO_2 emissions/t coal (OUC data), reduce CO_2 emissions by 300,000 t/y by coal replacement.

14. Biogas Economics: Algae biomass cost @ $570/t afdw, ~$1,300/t coal replaced by algal CH_4 at ~$630/t of CO_2 mitigated.

15. Animal Feeds Economics: Production costs ~$700/t afdw.

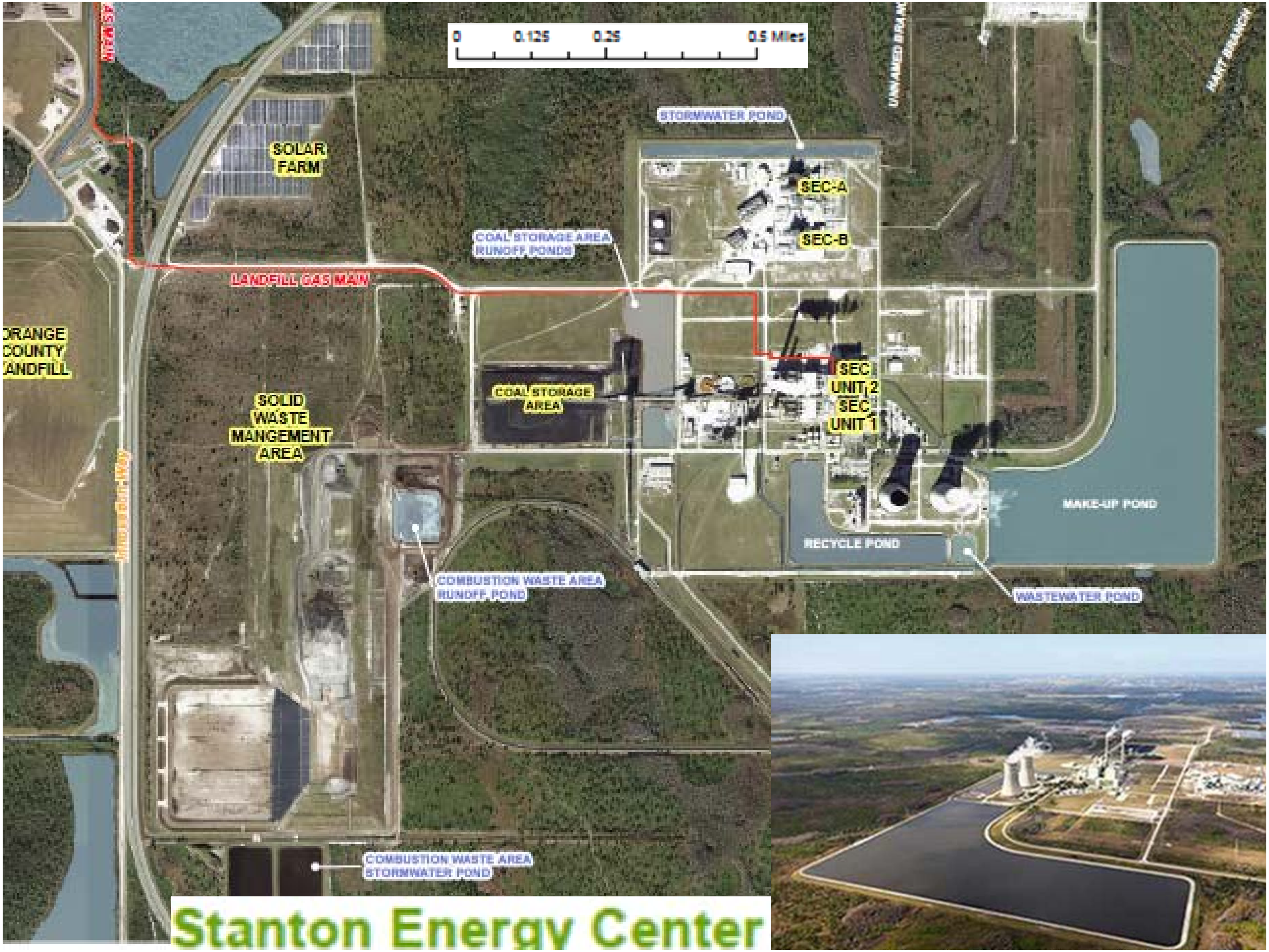
16. Conclusions. Animal feed is economically more favorable.

Project Objectives

Crosswalk to link the project objectives with the technical and economic challenges described above

- CO_2 mitigation potential with biogas or animal feeds grown on flue gas at the OUC SEC plant (Lifecycle Assessment, LCA)
- What will that CO_2 offset cost net of biofuels or commodity animal feeds revenues? (Techno-Economic Assessment, TEA)

- Primary Objective: develop detailed site specific TEAs and LCAs cases for OUC SEC for two CO_2 mitigation options
  1. Biogas production from microalgal biomass to replace coal for maximum CO_2 reductions, and
  2. Production of bulk commodity premium microalgae animal feeds, for maximum beneficial economic use of flue gas CO_2
- Secondary Objective: demonstrate feasibility of algae biomass production using OCU SEC flue gas with native algae and conversion to biogas; evaluation for suitability as feed



Stanton Energy Center

Project Methodology
Types of experiments and work to be done

- MBE- Carry out site-specific TEAs and LCAs. With OUC obtain data to inform these studies (major activity)
- OUC - at SEC cultivate algae on flue gas in small ponds
- UF: Concurrent studies to OUC-SEC, anaerobic digestion
- ASU: train OUC and UF in algae cultivation, methods
- LCAssociates: to assist in life cycle assessments (LCAs)
- SIO: to assist in both LCA and TEA studies
- SFA: to assist in engineering analysis (TEA)

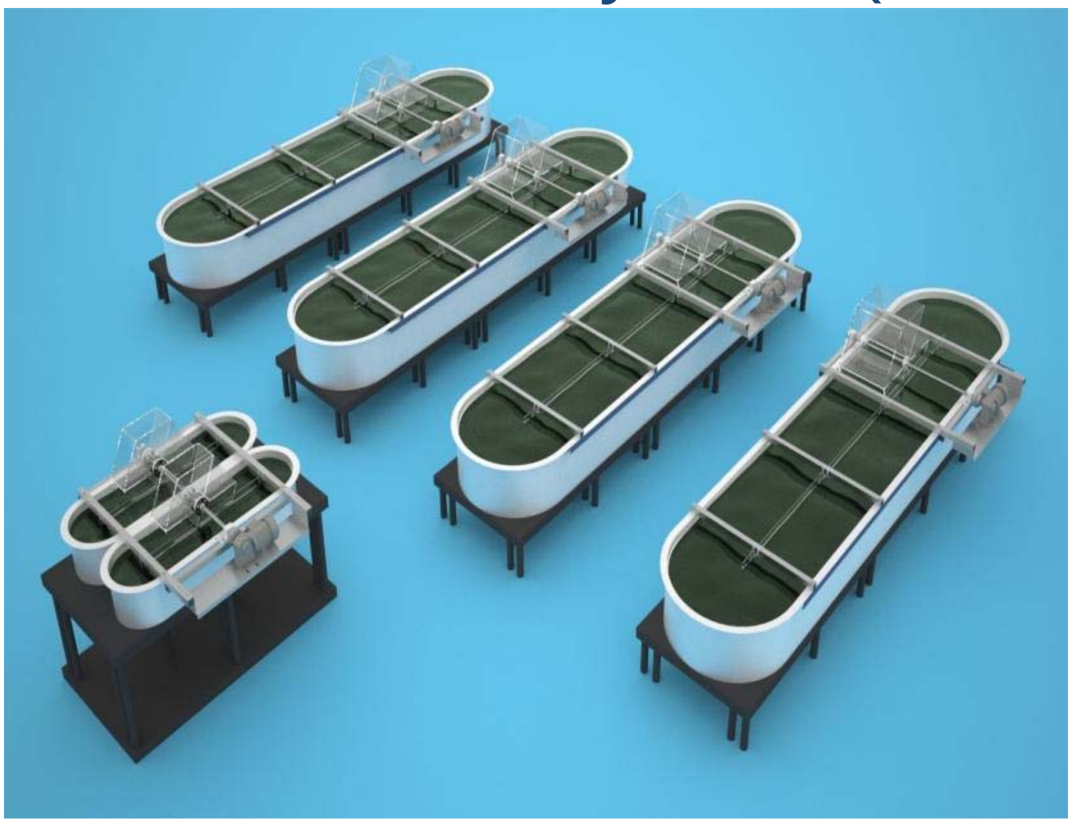
Project Methodology
Descriptions of test equipment to be used/built

- MBE designs, fabricates, ships and installs experimental to pilot-scale Algae Raceway™ cultivation systems world-wide.
- Designed to allow for progression to full scale production
- Remotely controlled, data logging capabilities

Project Methodology

Descriptions of test equipment to be used/built

Experimental Algae Raceway™ Ponds for OUC & UF, fabricated by MBE (cost share by OUC)



– OUC flue gas vs. pure CO2 algae cultures

– UF tests growth solution formulations and conducts lab digestion studies (pure CO2).

Each site will operate:

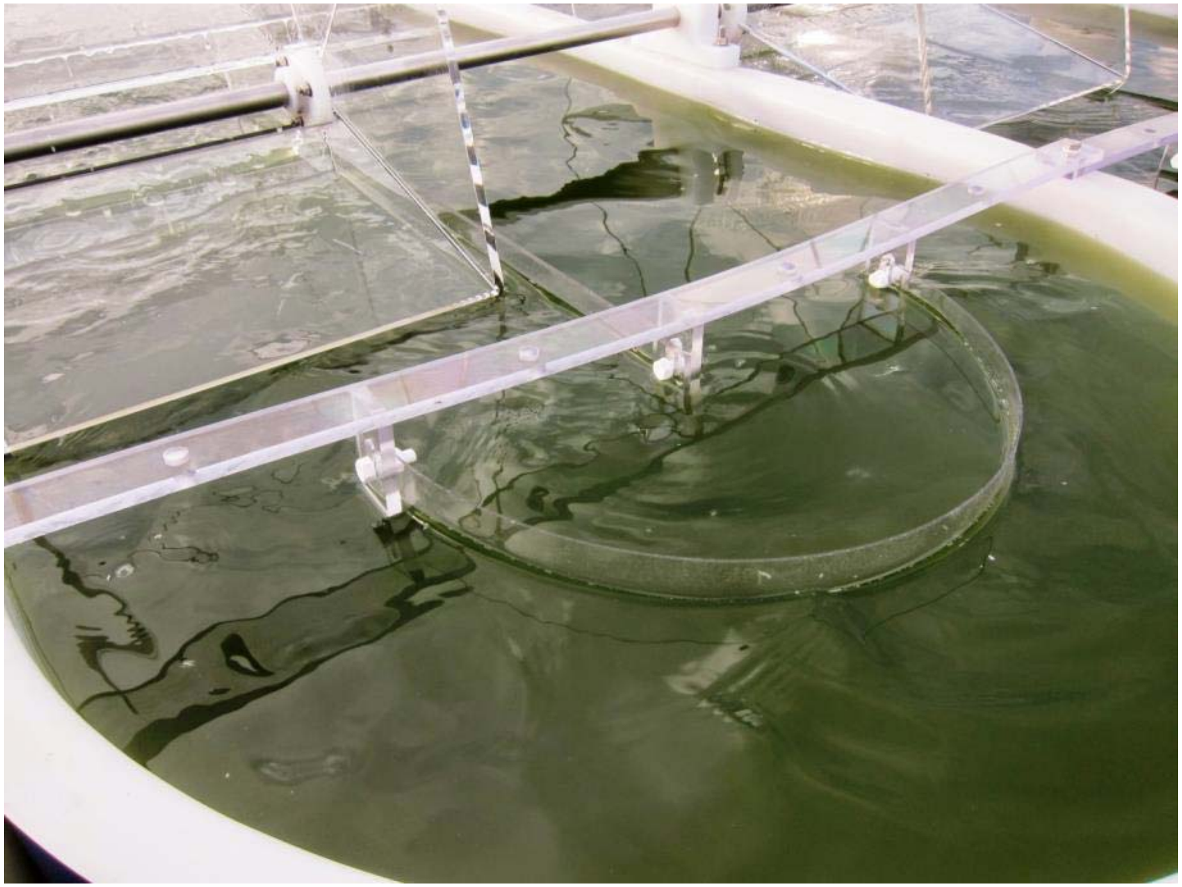
- Two 5-ft² (0.5 m²) ponds to produce inoculum algae for larger ponds
- Four 35-ft² (3.5 m²) production ponds

At OUC Two ponds with flue gas and two ponds with pure CO_2

At UF only pure CO_2

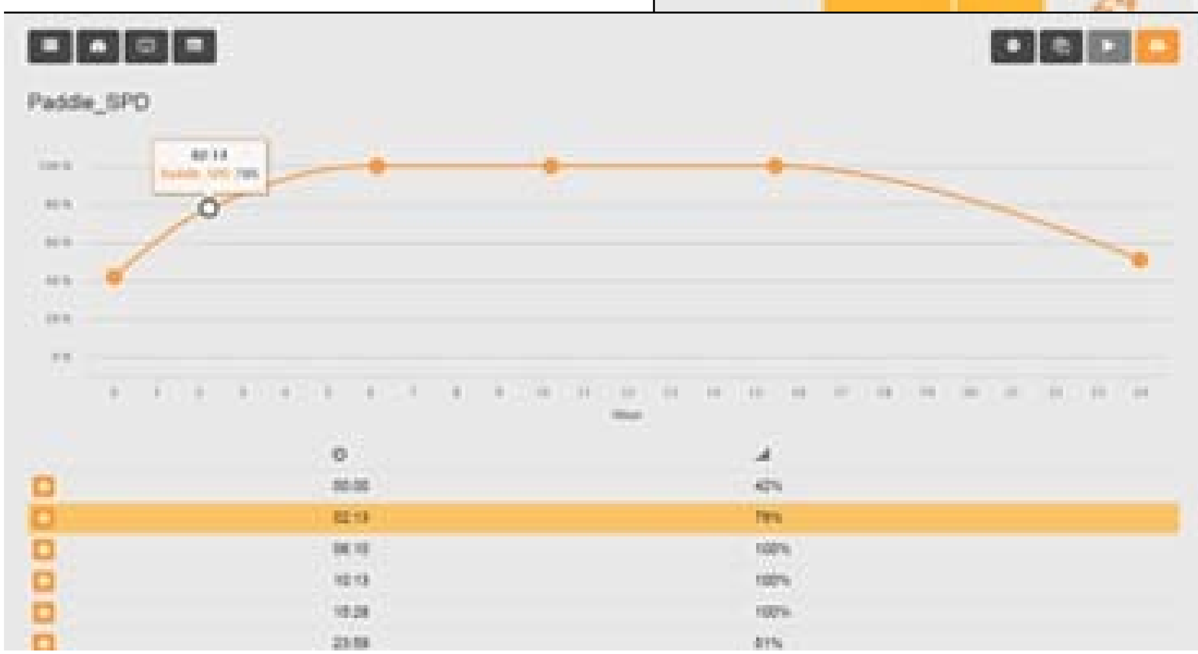
MBE Design /built Algae Raceway™ Ponds

Shading edge effects minimized by reducing freeboard and using transparent paddles, dividers.



Remote control, data logging capabilities of MBE Algae Raceway ™ ponds

Water, nutrient feed rates, CO_2 dosing, paddle speeds, etc. controlled with timers and also remotely.



Project Methodology
Schedule of project activities (Period 1)

		Start Date	End Date	Cost	
Task 1	**Project management and planning**	10/31/2015	9/30/2017	$158,506	
	Updated Project Management Plan				o
	Kickoff Meeting				o
Task 2	**Biogas-case microalgae cultivation studies**	10/31/2015	9/30/2016	$184,892	
1	Install six 0.5-m2 ponds each at SEC and UF				
2	Pond startup & shakedown at OUC				
3	Pond startup & shakedown at UF				
4	Training & consultations in algae cultivation, sampling & analysis				
5	Spring cultivation trials with flue gas				
6	Summer cultivation trials with flue gas				
7	Optimize spring strain cultivation conditions & produce biomass for di				
8	Optimize summer strain cultivation conditions & produce biomass for				
9	Biogas digestion studies				
Task 3	**Biogas-case plant integration engineering analysis**	10/31/2015	5/31/2016	$181,273	
1	Site and plant specific resource analysis for biogas-case				
2	Description of models used to predict process performance and capa				
3	Conceptual design for coupling the proposed biological CO2 use/conv				
4	Recommend operating pressures and temperatures for coal-fired flue				
5	Preliminary concepts for flue gas conditioning and delivery				
6	Analyze impact of flue gas contaminants on growth rates and biomas				
7	Analyze fate of flue gas contaminants				
8	Produce updated Performance, Cost, Emissions, Market, and Safety				
Task 4	**Biogas-case technical and economic feasibility study**	12/31/2015	7/31/2016	$43,333	
1	Detailed accounting of capital costs				
2	Detail accounting of operation and maintenance costs				
3	Detailed market assessment for all value-added products				
Task 5	**Biogas-case Life cycle analysis of CO2 mitigation**	2/29/2016	9/30/2016	$95,069	
1	OUC site resource assessment				
2	Define process & boundaries				
3	Build model & report for OUC				
Task 6	**Biogas-case technology gap analysis**	4/30/2016	8/31/2016	$26,667	
1	Brief review of biological CO2 conversion process under investigation				
2	A summary of the current level of research on key components or sm				
3	Summary table of the R&D gaps				
4	Identify potential vendors				

Project Methodology – Activities - Budget Period 1

Task 1.0 - Project Management and Planning (both periods)

Task 2.0 – Microalgae cultivation for Biogas Case

Bench- and small-scale experiments will be conducted at OUC and UF for algae cultivation and at UF for algal biomass anaerobic digestion to validate and inform engineering analyses and life cycle analyses.

Algae will be grown on CO2 from flue gas at OUC and, for comparison, on pure CO2 at OUC and UF.

Productivities, species, metals accumulation and other constituents will be monitored to determine the effect of flue gas CO2.

Biomass harvested from these systems will then be digested at UF to determine the any effects of flue gas on biogas yields.

Project Methodology – Activities - Budget Period 1 (contd.)

Task 1.0 - Project Management and Planning (both periods)

Task 2.0 – Microalgae cultivation for Biogas Case: SUBTASKS

1	Site and plant specific resource analysis for biogas-case
2	Description of models used to predict process performance and capa
3	Conceptual design for coupling the proposed biological CO2 use/conv
4	Recommend operating pressures and temperatures for coal-fired flue
5	Preliminary concepts for flue gas conditioning and delivery
6	Analyze impact of flue gas contaminants on growth rates and biomas
7	Analyze fate of flue gas contaminants
8	Produce updated Performance, Cost, Emissions, Market, and Safety

Project Methodology – Activities - Budget Period 1 (contd.)

.**Task 3.0 – Plant integration engineering analysis of flue gas and biogas** Conduct an engineering analysis of integration of the Biogas Case: the use of flue gas to grow and digest algae biomass to displace coal energy. Methods for flue gas delivery to large scale pond systems and biogas delivery to existing boilers will be analyzed. **SUBTASKS:**

1	Site and plant specific resource analysis for biogas-case
2	Description of models used to predict process performance and capa
3	Conceptual design for coupling the proposed biological CO2 use/conv
4	Recommend operating pressures and temperatures for coal-fired flue
5	Preliminary concepts for flue gas conditioning and delivery
6	Analyze impact of flue gas contaminants on growth rates and biomas
7	Analyze fate of flue gas contaminants
8	Produce updated Performance, Cost, Emissions, Market, and Safety

Project Methodology Activities Budget Period 1 (contd.)

Task 4.0 – Biogas-Case technical and economic analysis (TEA)

The recipient team will perform technical and economic investigation of the Biogas Case: the use of flue gas to grow and digest algae biomass to biogas to displace coal. **SUBTASKS:**

1	Detailed accounting of capital costs
2	Detail accounting of operation and maintenance costs
3	Detailed market assessment for all value-added products

Task 5.0 – Biogas-Case Life cycle assessment (LCA) for CO_2 reduction

The recipient team will conduct an assessment of total life cycle impacts of the Biogas Case: the use of flue gas to grow and digest algae biomass to biogas to displace coal. **SUBTASKS:**

1	Brief review of biological CO2 conversion process under investigation
2	A summary of the current level of research on key components or sm
3	Summary table of the R&D gaps
4	Identify potential vendors

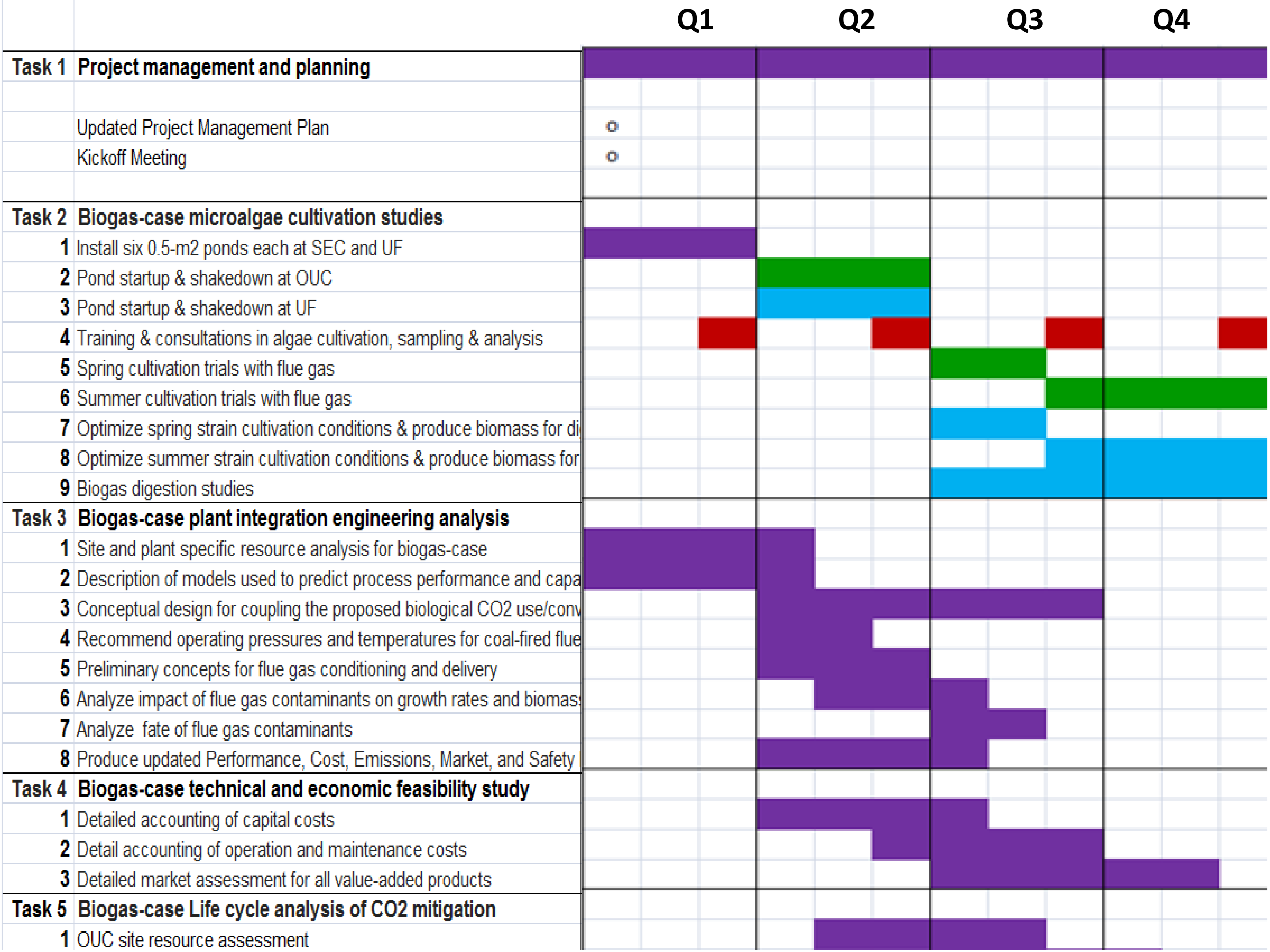
Project Methodology
Activities Budget Period 1 (contd.)

Task 6.0 – Biogas-Case technology gap analysis

The recipient team will analyze the current state of development of all of the major/critical process components, and provide a realistic view of all of the research needs required to fully develop the technology to commercialization.

SUBTASKS:

1	Brief review of biological CO2 conversion process under investigation
2	A summary of the current level of research on key components or sm
3	Summary table of the R&D gaps
4	Identify potential vendors


Q1
Q2
Q3
Q4
Task 1 Project management and planning
Updated Project Management Plan
Kickoff Meeting
Task 2 Biogas-case microalgae cultivation studies
1 Install six 0.5-m2 ponds each at SEC and UF
2 Pond startup & shakedown at OUC
3 Pond startup & shakedown at UF
4 Training & consultations in algae cultivation, sampling & analysis
5 Spring cultivation trials with flue gas
6 Summer cultivation trials with flue gas
7 Optimize spring strain cultivation conditions & produce biomass for di
8 Optimize summer strain cultivation conditions & produce biomass for
9 Biogas digestion studies
Task 3 Biogas-case plant integration engineering analysis
1 Site and plant specific resource analysis for biogas-case
2 Description of models used to predict process performance and capa
3 Conceptual design for coupling the proposed biological CO2 use/conv
4 Recommend operating pressures and temperatures for coal-fired flue
5 Preliminary concepts for flue gas conditioning and delivery
6 Analyze impact of flue gas contaminants on growth rates and biomas
7 Analyze fate of flue gas contaminants
8 Produce updated Performance, Cost, Emissions, Market, and Safety
Task 4 Biogas-case technical and economic feasibility study
1 Detailed accounting of capital costs
2 Detail accounting of operation and maintenance costs
3 Detailed market assessment for all value-added products
Task 5 Biogas-case Life cycle analysis of CO2 mitigation
1 OUC site resource assessment

Project Methodology
Schedule of project activities - Period 2

		Start Date	End Date	Cost	Budget Period 2 Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Task 7	**Animal feed microalgae cultivation studies**	10/31/2016	9/30/2017	$153,700												
1	Fall-spring strain & source water trials															
2	Summer strain & source water trials															
3	Fall-spring animal feed strain trials															
4	Summer animal feed strain trials															
5	Operations & analytical consultations and biomass analytical services															
6	Preparation of final reports															
Task 8	**Animal feed-case plant integration engineering analysis**	10/31/2016	5/31/2017	$159,658												
1	Resource analysis for additional power plants															
2	Description of models used to predict process performance and capa															
3	Conceptual design for coupling the proposed biological CO2 use/conv															
4	Recommend operating pressures and temperatures for coal-fired flue															
5	Preliminary concepts for flue gas conditioning and delivery															
6	Analyze impact of flue gas contaminants on growth rates and biomas															
7	Analyze fate of flue gas contaminants															
8	Produce updated Performance, Cost, Emissions, Market, and Safety															
Task 9	**Animal feed-case technical and economic feasibility study**	11/31/2016	7/31/2017	$34,845												
1	Detailed accounting of capital costs															
2	Detail accounting of operation and maintenance costs															
3	Detailed market assessment for all value-added products															
Task 10	**Animal feed-case Life cycle analysis of CO2 mitigation**	2/28/2017	9/30/2017	$86,581												
1	Additional sites resource assessment															
2	Define process & boundaries															
3	Build model & report for an additional site															
Task 11	**Animal feed-case technology gap analysis**	4/30/2017	8/31/2017	$21,443												
1	Brief review of biological CO2 conversion process under investigation															
2	A summary of the current level of research on key components or sm															
3	Summary table of the R&D gaps															
4	Identify potential vendors															

Project Methodology – Activities Budget Period 2

Task 7.0 – Animal feed microalgae cultivation studies

The recipient team will establish culture media formulations to maximize the value of algae as feed (digestible protein, lipids, pigments).

Task 8.0 – Animal Feed-Case plant integration engineering analysis

The recipient team will conduct engineering analysis of integration of the Feed Case: the use of flue gas to grow algae biomass for animal feed. Establish differences, if any, between the Biogas Case and the Feeds Case in terms of methods for flue gas delivery to large scale pond systems and large scale dewatering and drying of algae biomass.

Task 9.0 – Animal Feed-Case technical and economic feasibility study.

The recipient team will perform technical and economic investigation of the Feed Case: the use of flue gas to grow algae biomass for animal feeds.

Project Methodology – Activities Budget Period 2 (contd.)

Task 10.0 – Animal Feed-Case life cycle assessment (LCA) of CO_2 reduction.
The recipient team will conduct assessment of total life cycle impacts of the Feed Case: the use of flue gas to grow algae biomass for animal feeds.

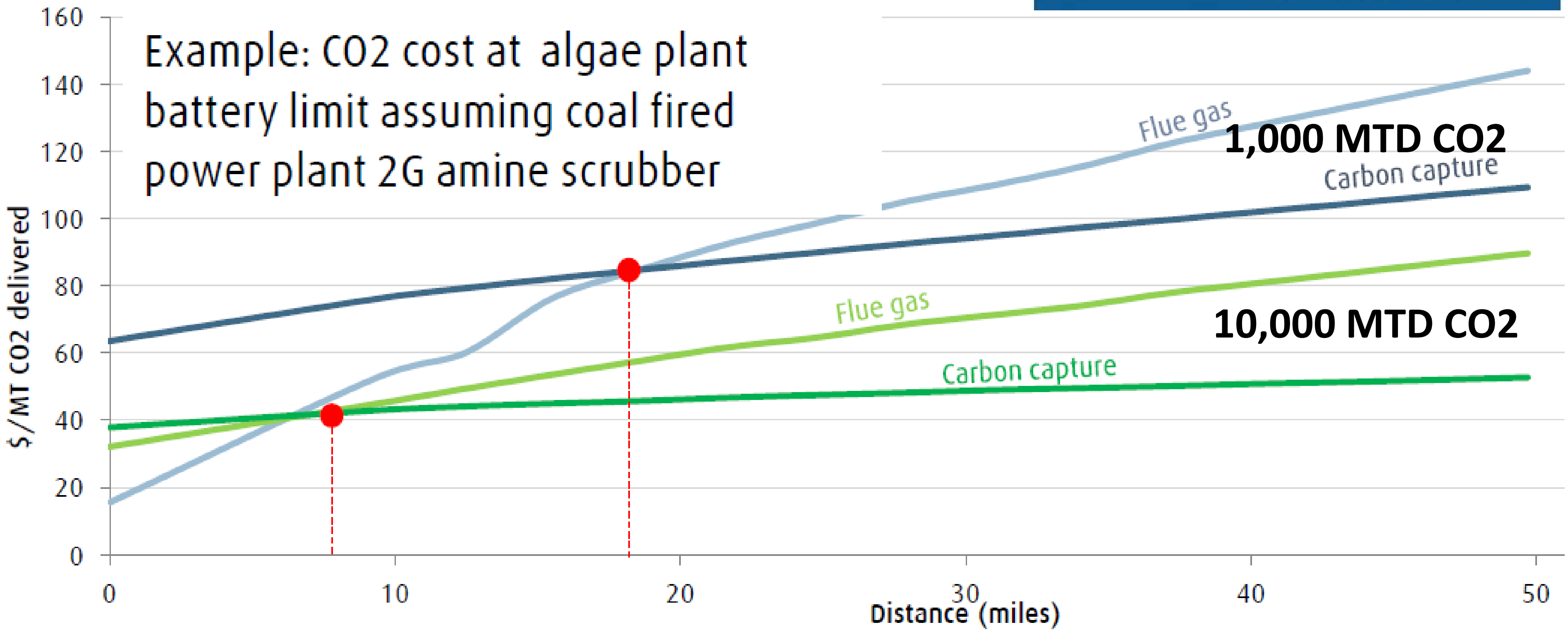
Task 11.0 – Animal Feed-Case technology gap analysis.
The recipient team will analyze the current state of development of all of the major/critical process components. Provide a realistic view of all of the research needs required to fully develop the technology to commercialization.

Plans for future testing / development / commercialization

- Commercial applications will depend on project results.
- Long-term R,D&D will be required to develop this process.
- Outreach planned by OUC and MBE to other coal-fired power plants /projects for joint development project(s).
- Proposal submitted to DOE BETO to address key issue of maximizing productivity through enrichment cultures.
- **DOE SBIR Phase 1 application by MBE to cultivate filamentous algae for low-cost harvesting.**
  Phase 2 would allow for continuation of present project.

Important Presentation Omissions: Capture /storage / transport of CO_2 vs. flue gas transport coal–fired power plant

Linde services for algae cultivation: Scope of proprietary costing & optimization tool



Property of Linde, 2014

Technology Challenges Ahead

Technology advances still required:

- **Highest possible biomass productivities**
- **Lowest possible cost harvesting**
- **Crop protection (pests, invasions, etc.)**
- **Biomass processing, conversion, utilization**
- **CO_2 supply and utilization efficiency**
- **Scale-up (to 10 acre, 4 ha) unlined ponds**
- **Algal strain selection and development**

Contract and Management Actions in November 2015

Teaming agreement with OUC Completed.

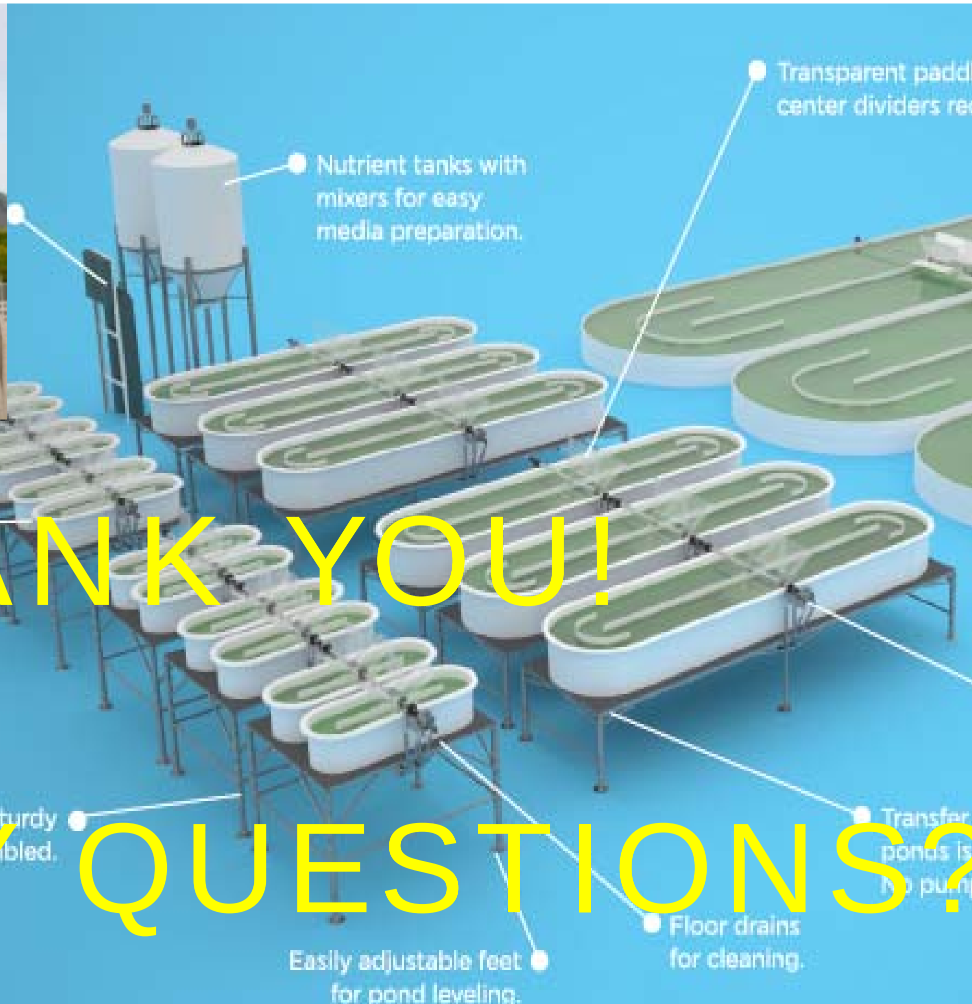
MBE Algae Raceway™ ponds to be ordered next week, delivered and installed in two months

Discussion with OUC and UF for siting ponds and flue gas CO_2 supply to experimental ponds.

Initiate OUC SEC plant specific resource analysis.

Teaming agreement with UF and ASU (initiated)

Teaming agreements with SIO, LCA, SFA



THANK YOU!

ANY QUESTIONS?


Tryg Lundquist


Neal Adler


Ian Woertz


Matt Hutton


Ruth Spierling


Braden Crowe

μBIO

MicroBio Engineering