ReBALAN:CE

Recycling **B**iomass to **A**gricultural **LAN**d: **C**apitalising on **E**utrophication

UNIVERSITY OF STIRLING

Eco-logic: Sustainable Resource Management

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ReBALAN:CE Workshop

University of Stirling

August 29, 2013

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BIOENERGY AND SUSTAINABLE TECHNOLOGY LABORATORY

SOIL AND WATER SCIENCE UNIVERSITY OF FLORIDA

Dr. Ann C. Wilkie
Bioenergy & Sustainable Technology

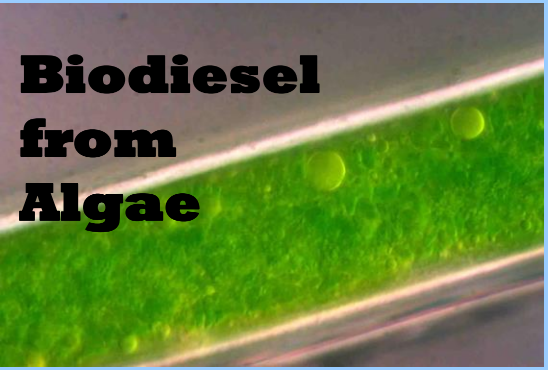
Biogas

Biomass

Bioenergy

Research:

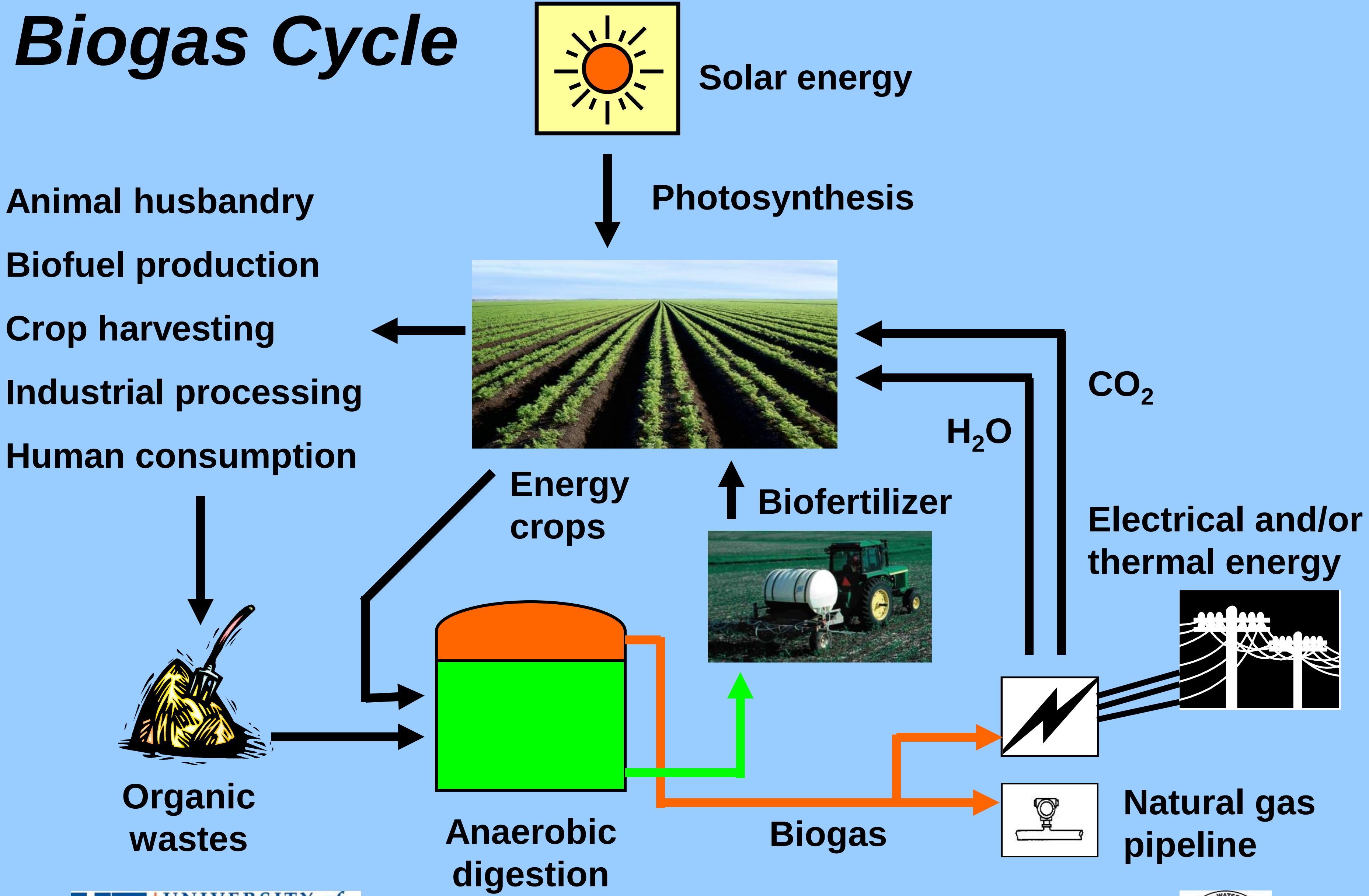
Anaerobic digestion technology for renewable energy production from biomass and organic residues, including food waste, livestock waste, bioethanol and biodiesel by-products, and energy crops.



Biodiesel from Algae

Bioprospecting for high-lipid producing algal strains and development of culturing techniques for lipid enhancement.

Biogas Cycle



Solar energy

Photosynthesis

Animal husbandry

Biofuel production

Crop harvesting

Industrial processing

Human consumption

Energy crops

Biofertilizer

CO_2

H_2O

Electrical and/or thermal energy

Organic wastes

Anaerobic digestion

Biogas

Natural gas pipeline

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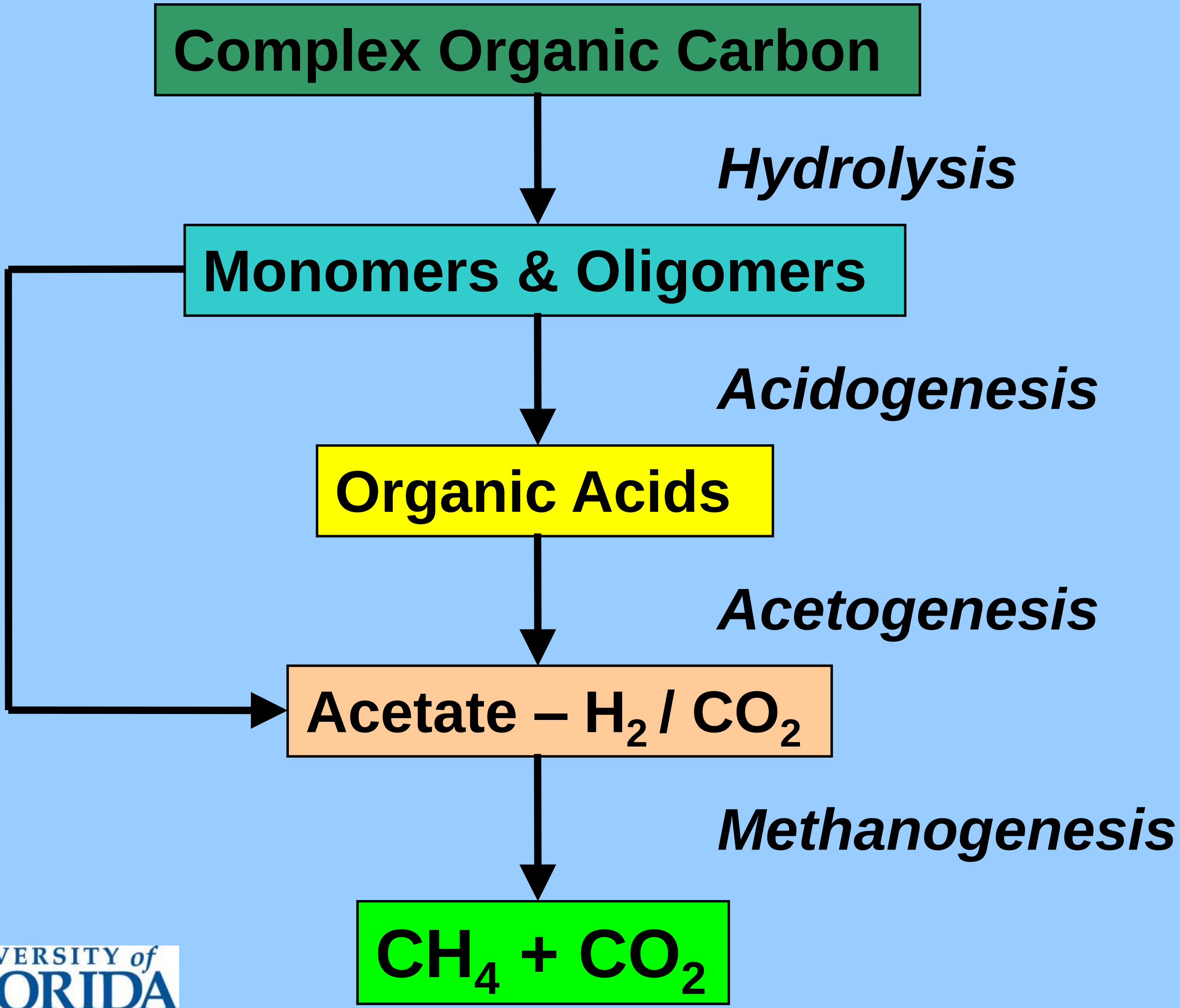
Anaerobic Digestion



Complex Organic Carbon

Hydrolysis

Monomers & Oligomers

Acidogenesis

Organic Acids

Acetogenesis

Acetate – H_2 / CO_2

Methanogenesis

$CH_4 + CO_2$

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Anaerobic digesters

Fossil Fuel is Fossil Thinking
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Biogas.ifas.ufl.edu

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Biogas as fuel

Biogas Vehicles

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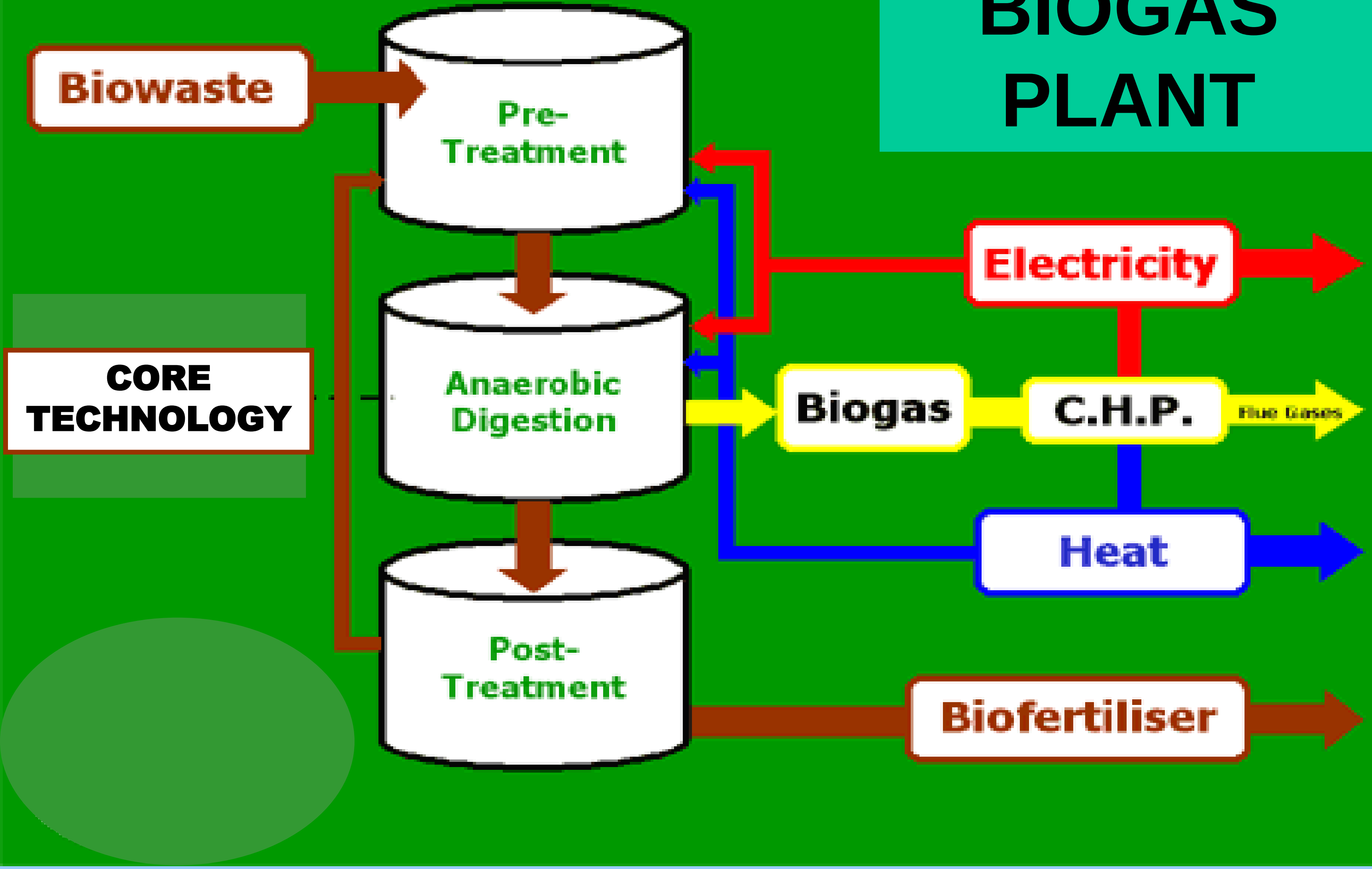
BIOGAS PLANT



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Dairy Express

GatorGas

UF-IFAS Anaerobic Digester

(80-90% CH_4)

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Florida's Recycling Goal

- ***75% recycling of MSW by 2020***
- **30% of MSW is currently recycled**
- **Food waste = 7% of MSW in Florida**
- **Food waste diversion supports the recycling goal**

Food Waste in Florida

- 1.75 million tons generated annually
- Only 3% is recycled
- Most is currently landfilled

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Food Waste

- **Food waste is generated throughout the community**
  - **Farms**
  - **Food processors**
  - **Grocery stores**
  - **Restaurants**
  - **Schools**
  - **Hotels**
  - **Prisons**
  - **Households**

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Composition of Food Waste

- High moisture content
- Contains valuable plant nutrients
- Potential feedstock for biofuels

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Benefits of Anaerobic Digestion of Food Waste

- Diverts waste from landfills
- Reduces landfill GHG emissions
- Reduces pollutants and total volume of leachate
- Produces renewable energy ~ biogas
- Recovers valuable nutrients
- Reduces transportation costs and emissions when food waste is digested locally

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East Bay Municipal Utility District
Oakland, California

EBMUD's wastewater treatment plant, Oakland

Anaerobic Digesters

Food Waste Delivery
East Bay Municipal Utility District

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Dining Hall Leftovers

Diverting Food Waste from Landfills

Portable Food Waste Anaerobic Digester

Discussing food waste digestion with elementary school students in Newberry, Florida

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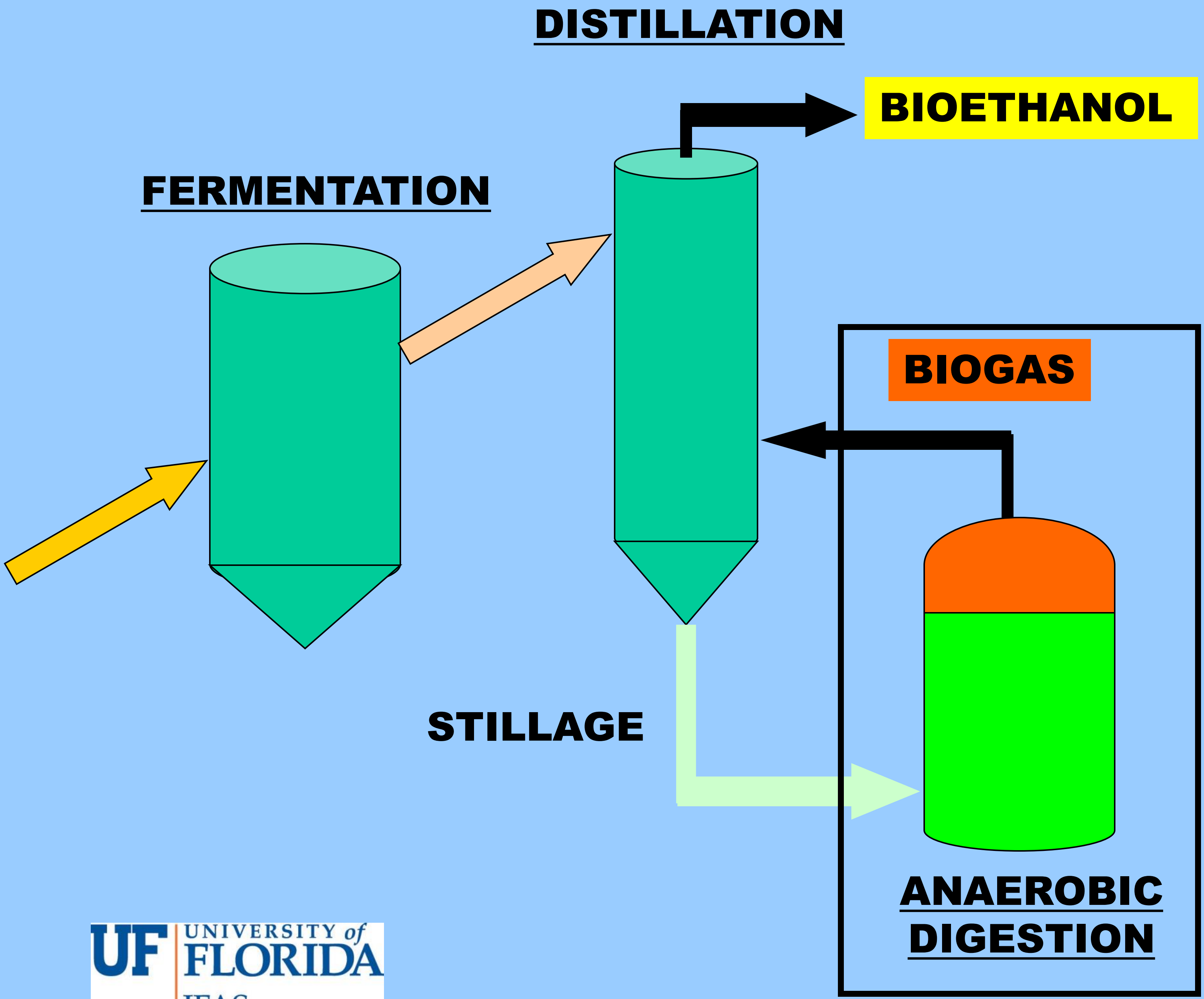
Culled Fruit & Vegetables



DISTILLATION

BIOETHANOL

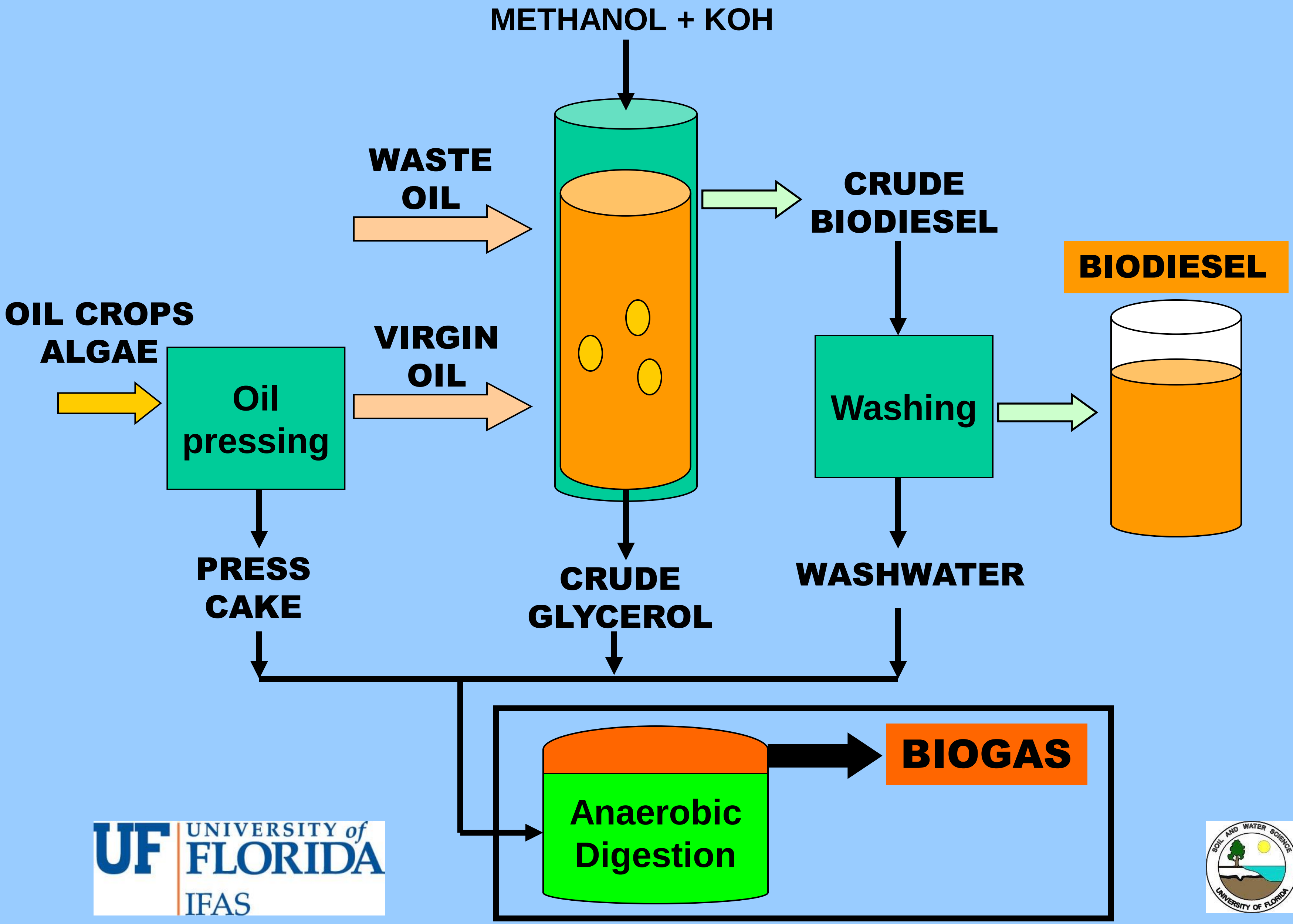
FERMENTATION

BIOGAS

STILLAGE

ANAEROBIC DIGESTION

TRANSESTERIFICATION



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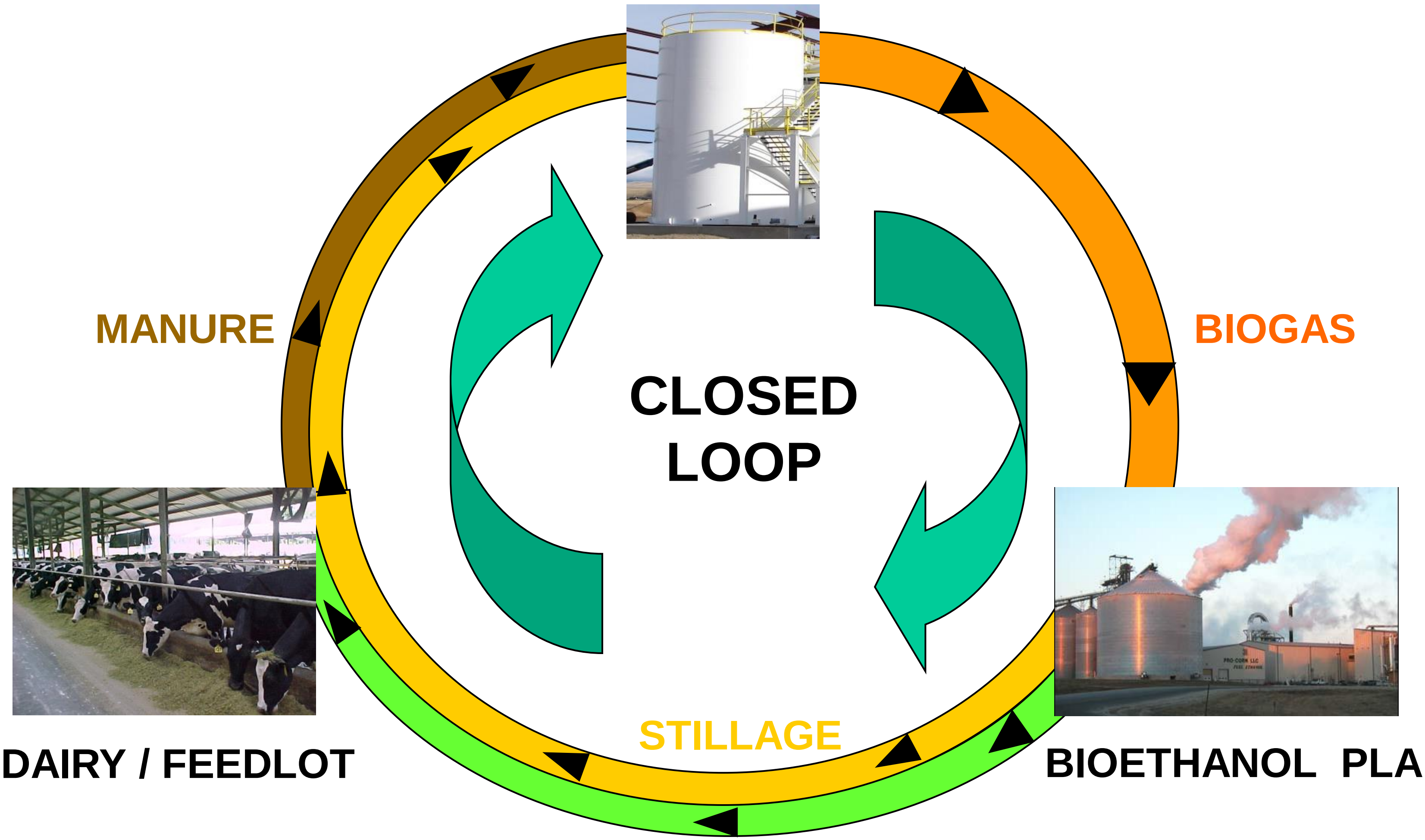


ANAEROBIC DIGESTER

MANURE

BIOGAS

CLOSED LOOP

DAIRY / FEEDLOT

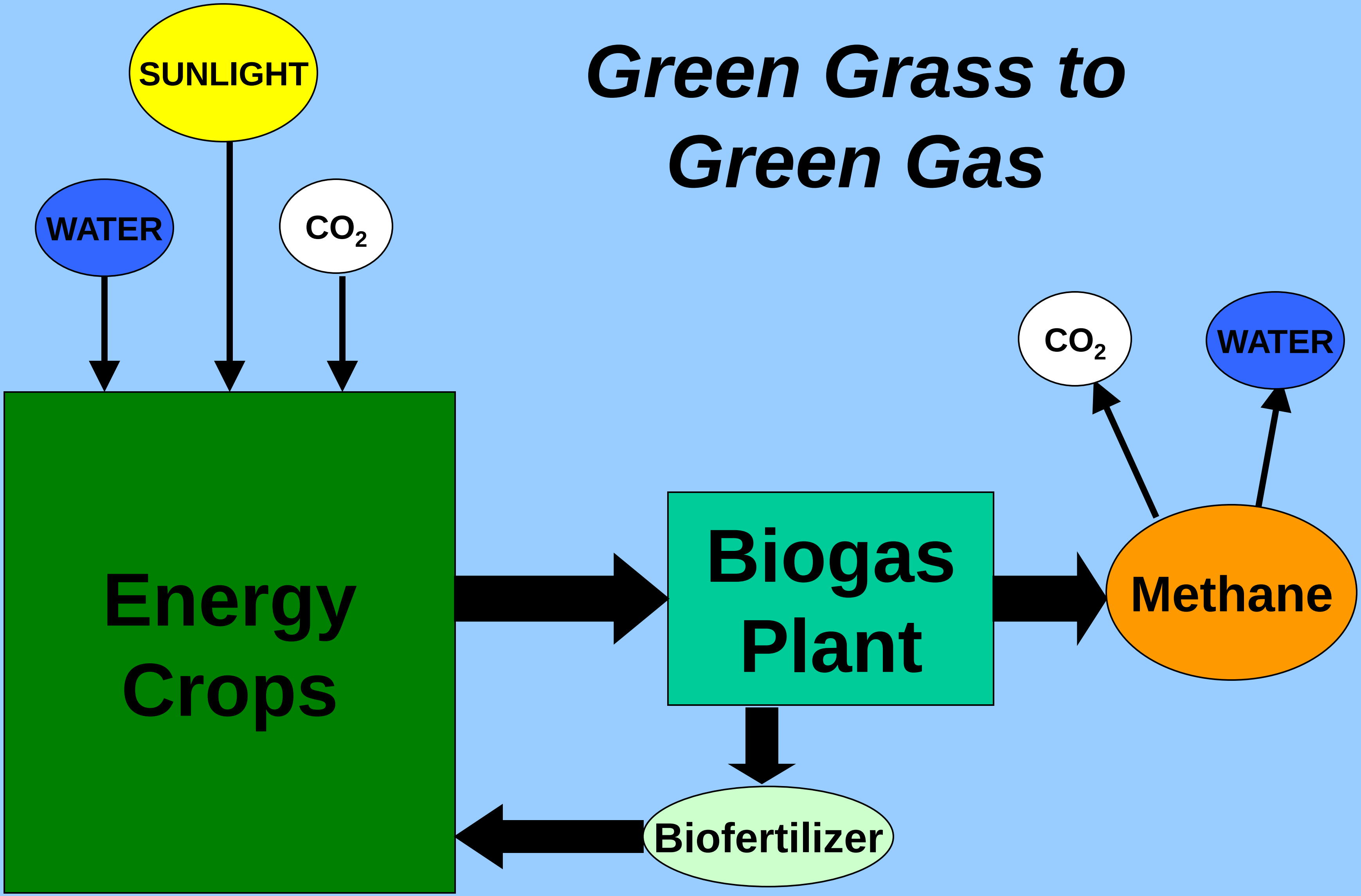
STILLAGE

BIOETHANOL PLANT

FEED

Co-location Synergies

Green Grass to Green Gas



SUNLIGHT

WATER

CO_2

Energy Crops

Biogas Plant

Methane

CO_2

WATER

Biofertilizer

Characterization of Sweet Sorghum Biomass for Biofuel and Food Production

Reginald Toussaint and Ann C. Wilkie
Soil and Water Science Department
University of Florida-IFAS

Abstract

Integration of renewable energy production into agricultural production systems offers potential advantages for simultaneously addressing the need for food and energy security. Sweet Sorghum [*Sorghum bicolor* (L.) Moench] has emerged as a promising candidate feedstock for fuel and food production because its biomass can be fractionated into food/feed components (grain) and energy components (juice, stalk, leaves). Anaerobic digestion of Sweet Sorghum (SS) simultaneously produces renewable energy in the form of methane, and biofertilizer, and therefore links energy and food production. The methane generated can be converted into electricity or used directly for cooking and heating water. Sweet Sorghum has been recognized for its low water and nitrogen requirement and its high biomass and sugar yields, but its characterization for both methane and feed production is not well described. A methane index test and proximate analysis were performed for different sorghum plant components. Total dry biomass of SS reached an average yield of 27.2 Mg/ha. If all SS components were diverted to biodigestion, the methane yield could reach 8.9 million L/ha. In a more integrated scenario, 6.3 million L/ha of methane can be obtained from the stem (juice and extracted stalk) coupled to the production of 4.0 Mg/ha of grain for animal or human consumption, and 4.1 Mg/ha of leaves that can be left in the field for increasing nutrients and soil organic matter. The high crude protein (11.2 ± 1.6%) and relatively low crude fiber (8 ± 0.2%) of the SS heads make the heads a valuable feed source. Utilization of SS grains for animal feed or human consumption avoids the conflict between energy and food production. When SS heads are used for animal feed, the animal manures can also be used for methane production.

Introduction

- Sweet sorghum has emerged as an attractive crop for its ability to produce food, fuel, and feed (Figure 1).
- Potential advantages of SS over other bioenergy crops include: high biomass yield, production of directly fermentable sugars, low water and nitrogen requirement (Erickson *et al.*, 2011).
- Integrated food and energy systems have obtained appealing interest for simultaneously addressing the need for food and energy security (FAO, 2010).
- Anaerobic digestion of organic compounds simultaneously produces renewable energy in the form of methane, and biofertilizer, therefore links energy and food production.
- Despite these attractive benefits, the characterization of SS biomass for both methane and feed production is not well described.

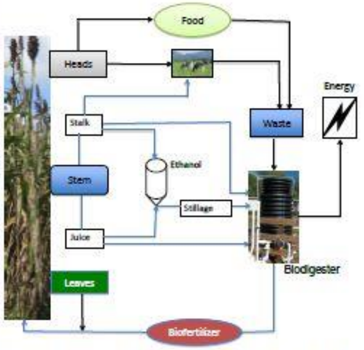


Figure 1: Integration of SS for fuel and feed production. Extracted stem and juice go to ethanol and/or biogas production, heads are used as animal or human food, leaves are left in the field.

Figure 2: Sweet Sorghum fields at different stages of maturity; flowering (*left*), ready for harvest (*right*).

Figure 3: Juice extraction from Sweet Sorghum stems.

Objectives

The purpose of this study was to assess the suitability of SS as a multipurpose crop for biofuels and food production. Specifically, this study aims at:

- Evaluating the methane index of SS plant components.
- Exploring the suitability of the SS heads for human and animal food.

Methodology

- Sweet Sorghum (M81E) components were obtained from an experimental field trial carried out in 2010 at the Energy Research and Education Park of the University of Florida, Gainesville, Florida. The total biomass of individual plants were recorded and was partitioned into its different components (Figure 2, 3, and 7).
- Proximate analyses of different biomass components were conducted in accordance to standard forage quality tests described by Van Soest *et al.* (1991). These tests included the evaluation of crude fiber and crude protein (CP), *in vitro* organic matter digestibility (IVOMD), and determination of organic matter.
- The Brix content (%) of SS juice was measured using a portable refractometer.
- A methane index test (MIT) was performed in accordance to the method described by Wilkie *et al.* (2004) to determine the methane production potential of different plant components. Samples were incubated at 35°C in batch reactor (250 mL serum bottle) using a mixed-culture as inoculum. Methane production was recorded overtime and converted to STP.
- Average yield of SS were used to determine the methane yield/ha of the total feedstock under two scenarios.

Results

- The total dry biomass yield of SS averaged 27.2 ± 5.4 Mg/ ha and was in the range reported by Erickson *et al.* (2011) (Figure 4).
- The nutrient composition of SS plant components and their suitability for feed or food production is presented in Figure 5, Figure 6 and Table 1. Heads had 11.2 ±1.64% crude protein and lower fiber content than other SS component.
- The MIT of SS biomass is depicted in Figure 8 and Figure 9. Heads, leaves and extracted stalk yielded 355 ± 1.79, 318.8 ± 1.56, and 335 ± 1.07 mL CH_4/g VS, respectively.
- The SS juice had 16% brix (Figure 12). Its cumulative gas production is presented in Figure 13.
- If all SS components were diverted to biodigestion, the methane yield could reach 8.9 million L/ha (Figure 10).
- In a more integrated scenario, 6.3 million L/ha of methane can be obtained from the stem (juice and extracted stalk) coupled to the production of 4.0 Mg/ha of grain for animal or human consumption, and 4.1 Mg/ha of leaves that can be left in the field for increasing nutrients and soil organic matter (Figure 11).

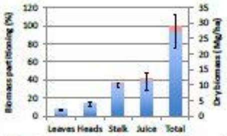


Figure 4: Sweet Sorghum biomass partitioning.

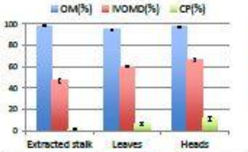


Figure 5: Crude protein and digestibility of SS biomass.

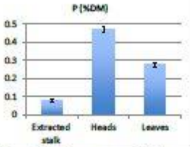


Figure 6: Phosphorus content of SS biomass.

Table 1: Proximate analysis of different SS components

Plant Components	VS (%TS)	ADF (%TS)	NDF (%TS)	CF (%TS)	CP(%TS)
Extracted stalk	98.37 ±0.15	42.23 ±1.21	63.13 ±1.51	33.60 ±1.10	1.18 ± 0.65
Heads	97.07±0.15	16.40±0.44	20.57±0.06	8.00 ±0.2	11.21± 1.64
Leaves	94.37±0.25	35.27±1.37	60.13 ±2.30	32.07±1.3	6.54 ± 1.30
Chipped stalk	96.53±0.25	32.53±2.03	46.63±2.07	26.37±1.50	2.66±0.54
Whole plant	96.33±0.40	35.8±3.63	48.5±4.56	27.47±2.33	5.24±0.66

NDF: Neutral detergent fiber, ADF: Acid detergent fiber, VS: Volatile solids

Figure 7: Different components of harvested Sweet Sorghum plants (*from left to right*): leaves, stems, juice, extracted stalk, heads.

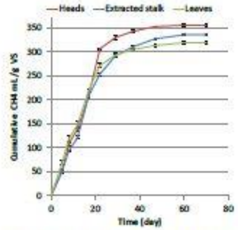


Figure 8: Cumulative methane production of SS plant components.

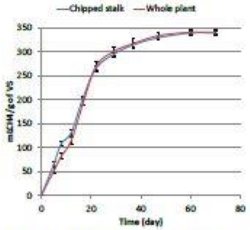


Figure 9: Cumulative methane production of SS (whole plant vs. chipped stalk).

Figure 10: Methane yield/ha (Scenario 1: all plant components are used for methane production).

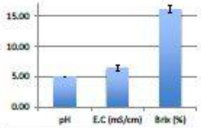


Figure 12: Sweet Sorghum juice characteristics E.C. (electrical conductivity).

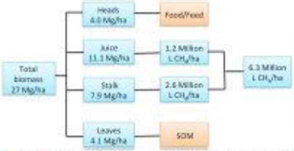


Figure 11: Methane yield/ha (Scenario 2: stalk and juice are used for methane production, leaves are left in the soil (soil organic matter, SOM), and heads are used for animal/human feed).

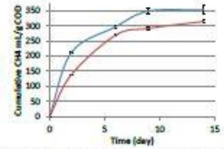


Figure 13: Cumulative methane production of SS juice at organic loading rates (OLR) of 0.5 (blue) and 1 (red) g COD/L.

Conclusion

- Sweet Sorghum is a multipurpose crop that produces food, feed and biomass for renewable energy production.
- MIT data suggest that SS plant components are a promising feedstock for methane production.
- Proximate analysis reveals that SS heads are valuable feed or food.
- Utilization of SS heads for animal or human consumption avoids the conflict between energy and food production.

Acknowledgements

- Funding provided by the Florida Department of Agriculture & Consumer Services, Farm to Fuel Bioenergy Grants, *Green Gas from Green Grass* project.
- Graduate Fellowship for Reginald Toussaint provided by USAID/Watershed Initiative for National Natural Environmental Resources-Haiti.

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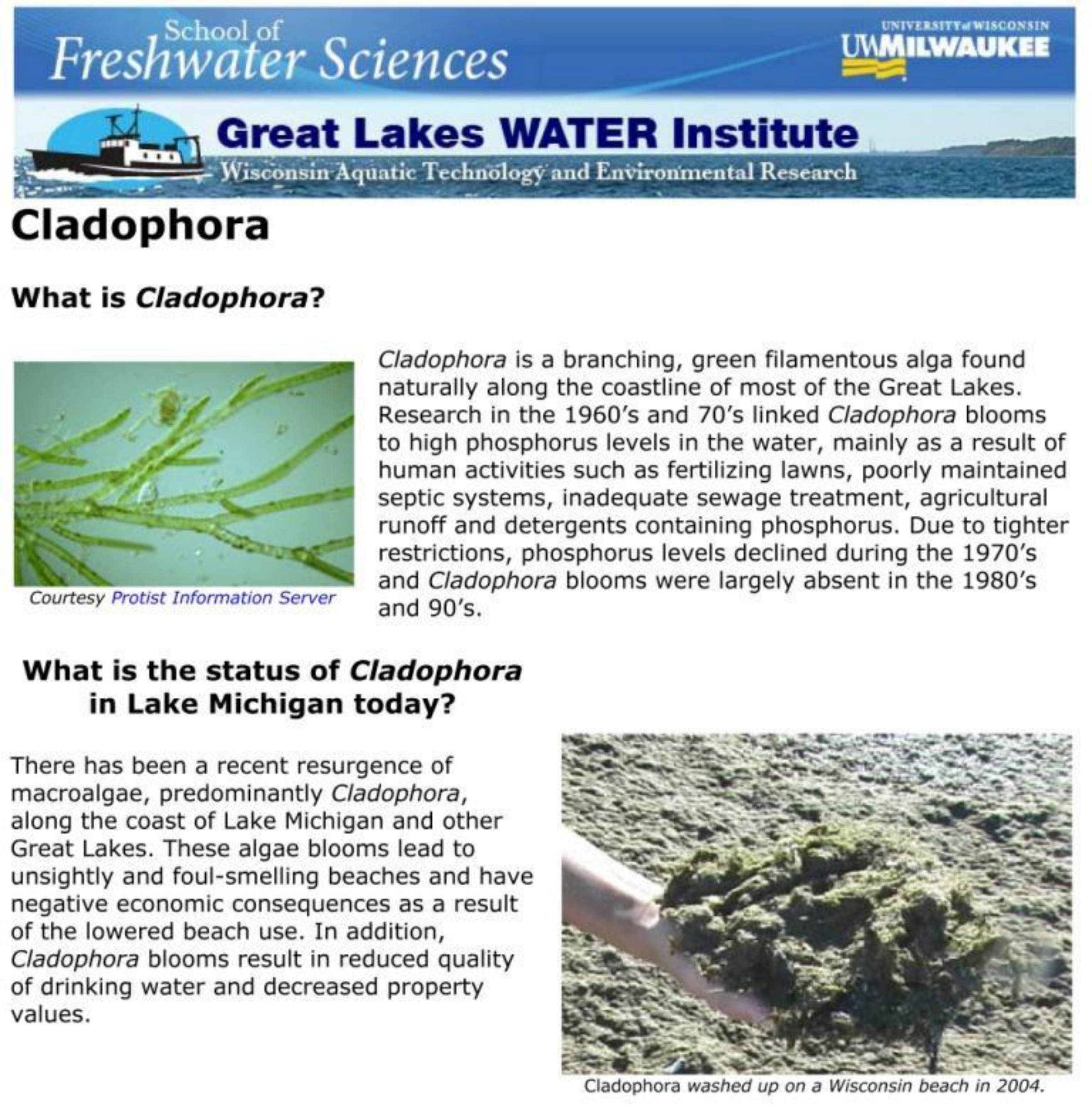
BIOGAS and ALGAE

- **Nutrient-rich effluent from biogas production can be used for mass cultivation of algae**

NUTRIENT MANAGEMENT

- Land application is the most sustainable option for manure nutrients
- Nitrogen
  - Haber-Bosch process is energy intensive
- Phosphorus
  - Finite resource



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Cladophora

What is *Cladophora*?

Courtesy Protist Information Server

Cladophora is a branching, green filamentous alga found naturally along the coastline of most of the Great Lakes. Research in the 1960's and 70's linked *Cladophora* blooms to high phosphorus levels in the water, mainly as a result of human activities such as fertilizing lawns, poorly maintained septic systems, inadequate sewage treatment, agricultural runoff and detergents containing phosphorus. Due to tighter restrictions, phosphorus levels declined during the 1970's and *Cladophora* blooms were largely absent in the 1980's and 90's.

What is the status of *Cladophora* in Lake Michigan today?

There has been a recent resurgence of macroalgae, predominantly *Cladophora*, along the coast of Lake Michigan and other Great Lakes. These algae blooms lead to unsightly and foul-smelling beaches and have negative economic consequences as a result of the lowered beach use. In addition, *Cladophora* blooms result in reduced quality of drinking water and decreased property values.

Cladophora *washed up on a Wisconsin beach in 2004.*

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- **Fugitive nutrients**
  - **Wild algae**

- **Farmed algae**
  - **Domesticated algae**

Aquatic Plants

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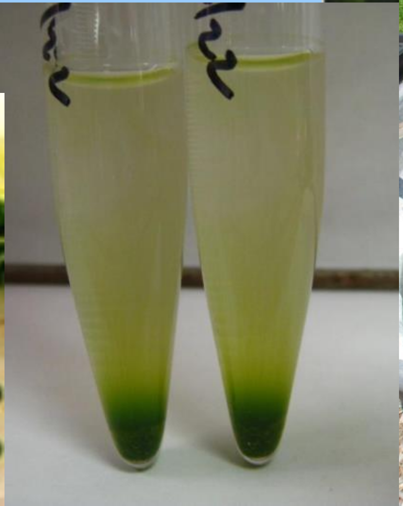
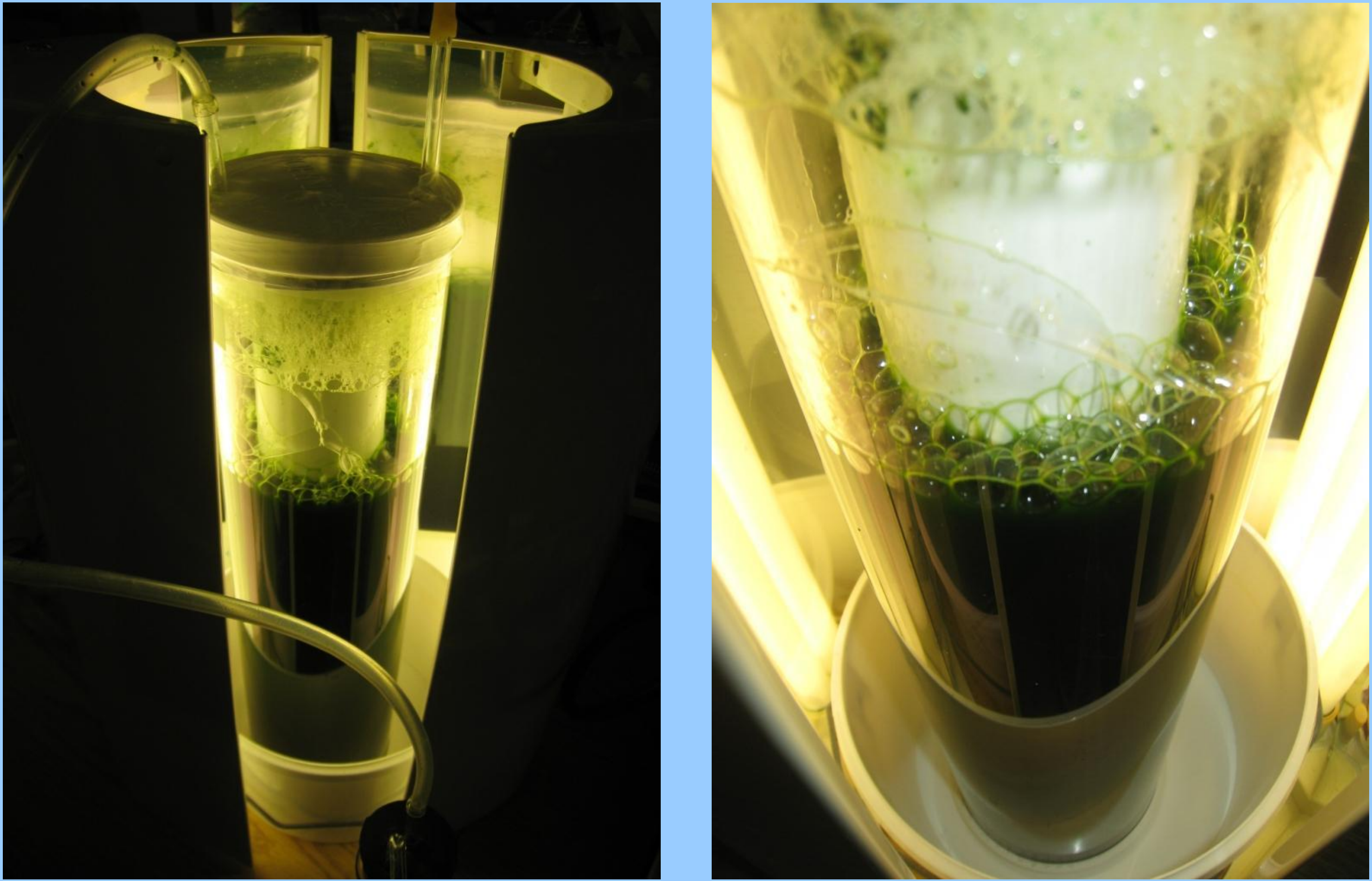
Algae

Characterizing Indigenous Algae of Interest

- Auto-flocculation
- Storage products
  (lipids, starches, pigments)
- Growth rates





Parabolic annular reactor

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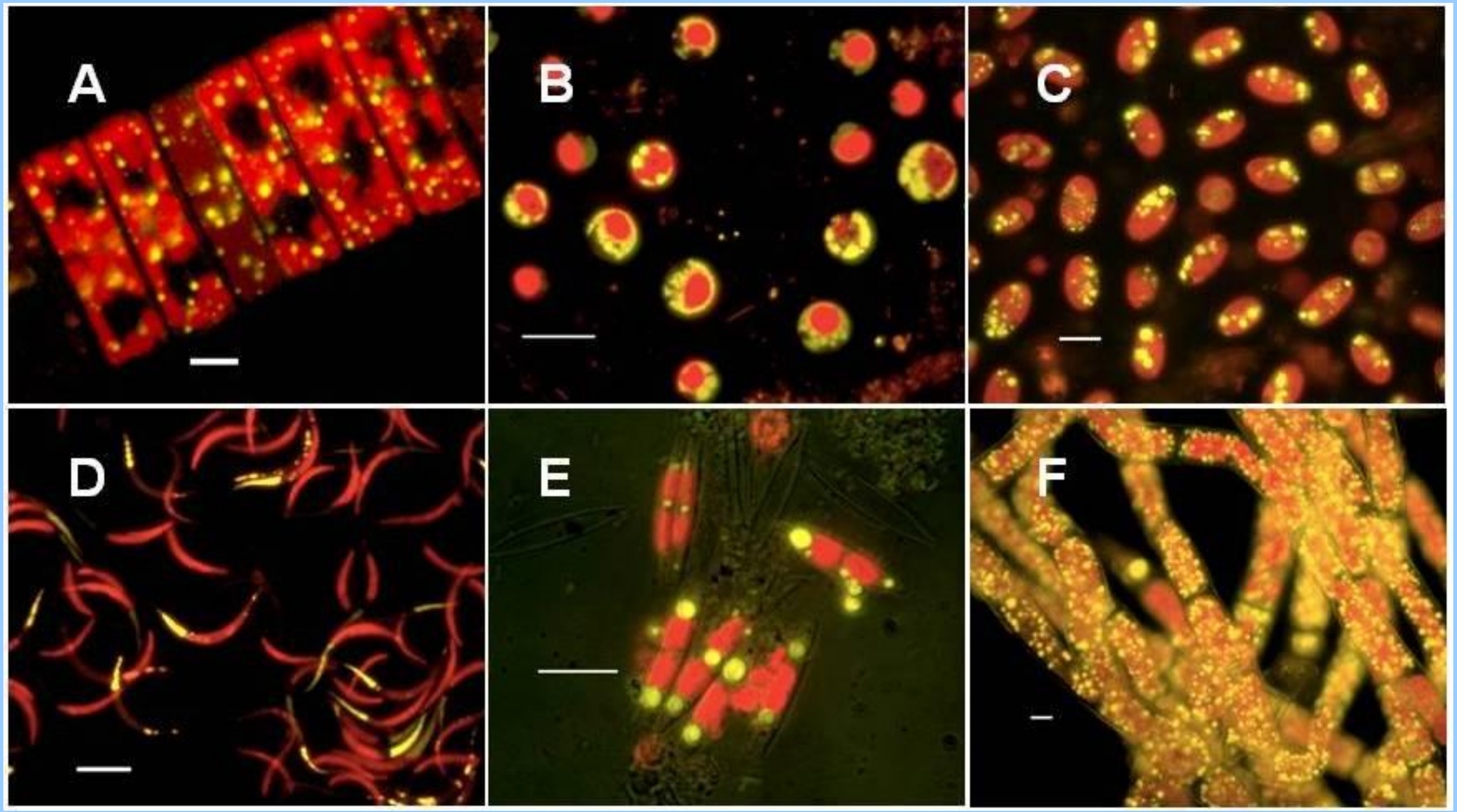

Diversity of Lipid-rich Indigenous Algae

Algae stained with Nile Red and photographed under epi-fluorescent illumination. Yellow coloration indicates stained lipid bodies and red coloration shows chlorophyll auto-fluorescence. (A) *Fragilaria* sp. from a riverine system adjacent to a major highway. (B) Unidentified chlorophyte collected from agricultural soils. (C) *Chlorella cf. ellipsoidea* from municipal solid waste landfill leachate. (D) *Ankistrodesmus* sp. from municipal solid waste landfill leachate. (E) *Navicula* sp. from a manure lagoon. (F) *Rhizoclonium* sp. from a wastewater treatment facility. (Scale bar = 10 micrometers).

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Overcoming the Challenges of Microalgae Harvesting through Cultivation of Filamentous Algae Spheroids

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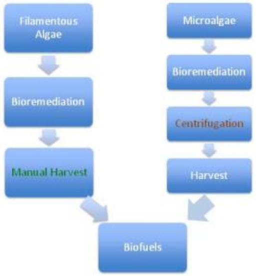
[1]College of Agriculture and Life Sciences
[2]Faculty Mentor, Soil and Water Science Department

Abstract

Application of algae in bioremediation of wastewaters and simultaneous production of renewable fuels is an innovative solution for sustainable waste management. Microalgae are effective at bioremediation. However, energy-intensive centrifugation is required to harvest the suspended biomass prior to fuel production. Filamentous algae, due to their distinct morphology, can be harvested with simple techniques such as screening, reducing the high energy costs of a centrifuge. It was hypothesized that filamentous algae biomass of several branching genera could be induced to form spheroids for ease of harvesting. Results showed that three of the four genera cultivated in a soil-extract medium using an orbital mixing pattern formed spheroids and each increased biomass

Introduction

- Filamentous algae can be manually harvested to avoid the high costs of centrifugation.
- Optimization of harvesting algae is key for bioremediation practices and for the viability of algae as a biofuel source.
- Algae have been found containing almost 50% oil by mass, indicating potential as a biofuel feedstock.



Filamentous Algae
Bioremediation
Manual Harvest
Microalgae
Bioremediation
Centrifugation
Harvest
Biofuels

Figure 1: Flow chart outlining the path of algae biofuel

Figure 2: Filamentous algae spheroids of *Rhizoclonium*

Hypothesis

If filamentous algae can be manipulated into spheres that can be easily harvested, then the economic bottleneck of centrifuging microalgae for fuels and bioremediation may be avoided.

Methodology

- Filamentous algae native to the Gainesville, FL area were phycoprospected (Wilkie *et al*. 2011).
- Collected algae were rinsed and homogenized and placed in a 4% Soil Extract Medium (Andersen 2005).
- Algae suspensions were placed on an orbital mixer at 170 rpm and illuminated by T5 fluorescent lamps at 300µE/m^2/s on a 12:12 (light:dark) photoperiod.
- Biovolume (by displacement) and pH were measured according to standard methods (APHA 2005).

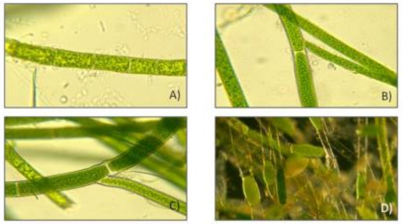


Figure 3: Genera of Algae
A) *Rhizoclonium*
B)*Cladophora*
C) Polyculture (*Rhizoclonium/Cladophora)*
D) *Pithophora*

All at 500x

Results

- Phycoprospected algae responded well to the homogenization pre-treatment and the 4% soil extract solution is an appropriate experimental medium.
- pH levels rose initially as a result of photosynthesis, plateauing as nutrients became limiting.
- The orbital mixing technique formed 9 out of 12 possible spheroids

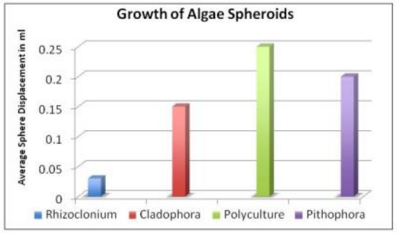


Figure 4: Final biovolume of filamentous algae by genus as determined by displacement.

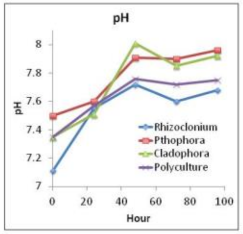


Figure 5: A graph of average pH over the course of a week

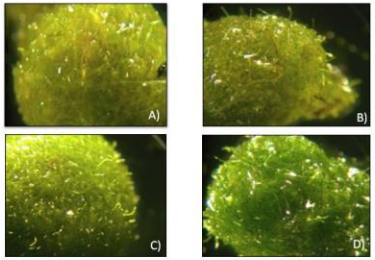


Figure 6: Qualitative photographs of successfully formed spheroids.
A)*Rhizoclonium*
B)*Cladophora*
C) Polyculture (*Rhizoclonium/Cladophora*)
D)*Pithophora*

All at 15x

Conclusions

- Results indicated that the ability to form spheroids is not limited to branching algae.
- The orbital mixer is an appropriate mixing method for the formation of the algae spheroids.
- Pending bio-remediation data, this method could be effective in harvesting filamentous algae used in bio-remediation.

Future Research

- Future experiments should concentrate on the effectiveness of filamentous algae bioremediation.
- Research should also be conducted to determine if oils in the harvested algae could be further processed to create biofuels.
- Harvest cost analysis should be conducted to measure the cost of running a large scale orbital mixer versus a centrifuge and determine the energetic practicality of forming the filamentous algae spheroids.

Acknowledgements

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Scott Edmundson was this project's graduate student mentor.

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Bioremediation with Algae

- Algae are capable of utilizing ammonia-nitrogen for cell biosynthesis.
- Photosynthetic algae produce molecular oxygen as a by-product of photosynthesis, reducing the COD.
- Algae can tolerate extreme environments, which many plants can not.

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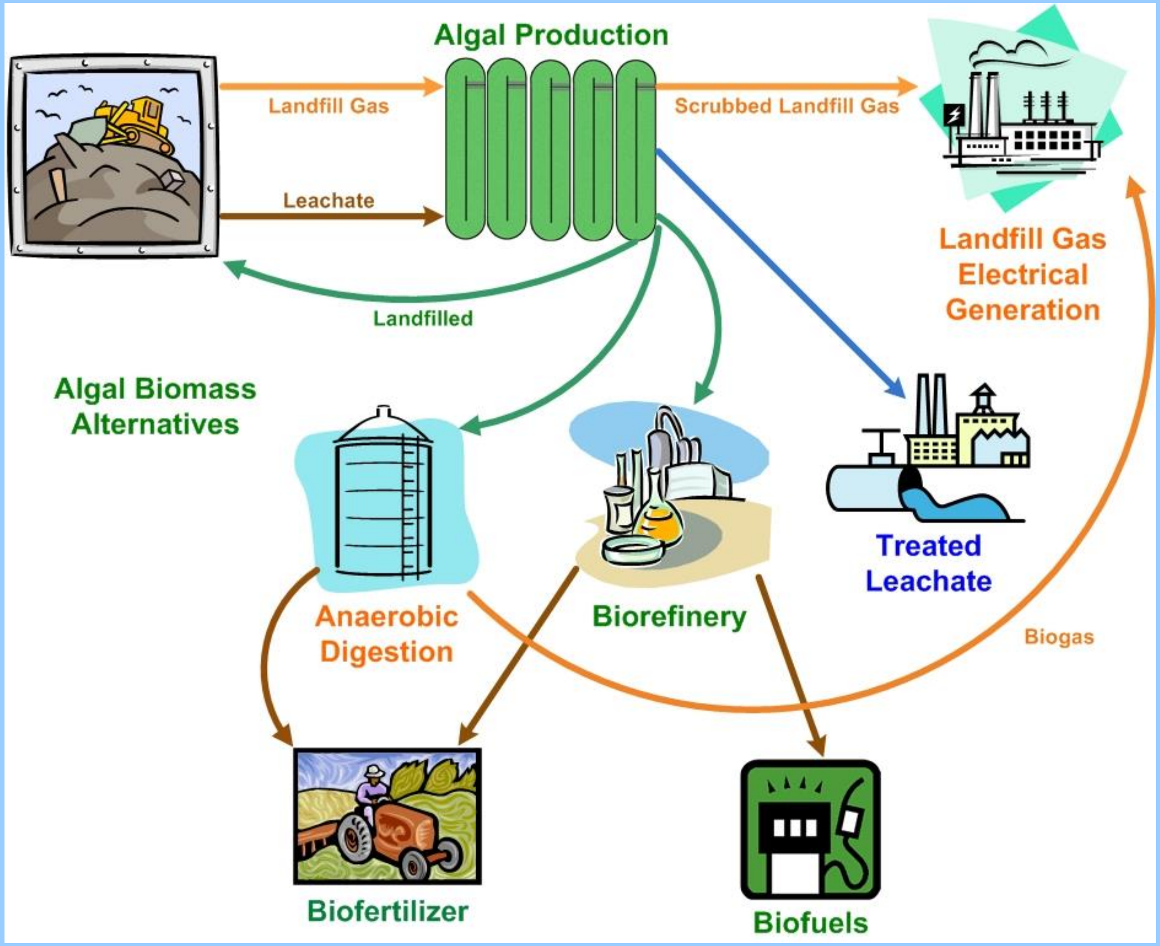
Landfill Leachate

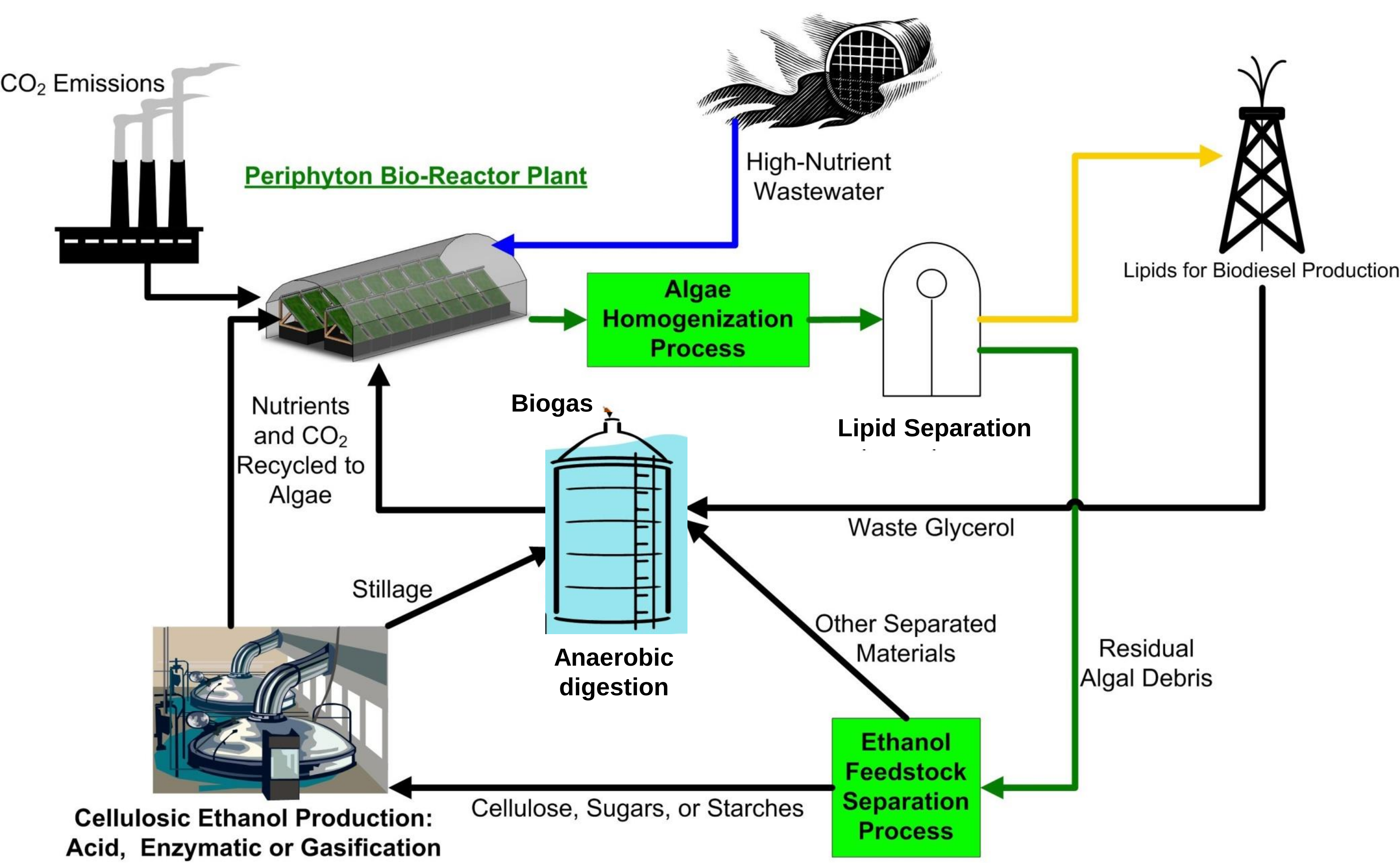
- Landfill leachates are detrimental to the surrounding environment.
- Landfill operators must manage their leachate for >30 years post closure.
- Landfills in Florida produce leachate at an average rate of ~770gal/acre/day.

Outdoor Cultivation at Landfill



Schematic of an algal bioremediation facility treating landfill leachate.

Biodiesel and Bioethanol from Algal Biomass



CO_2 Emissions

Periphyton Bio-Reactor Plant

High-Nutrient Wastewater

Lipids for Biodiesel Production

Algae Homogenization Process

Lipid Separation

Biogas

Nutrients and CO_2 Recycled to Algae

Waste Glycerol

Stillage

Anaerobic digestion

Other Separated Materials

Residual Algal Debris

Ethanol Feedstock Separation Process

Cellulose, Sugars, or Starches

Cellulosic Ethanol Production: Acid, Enzymatic or Gasification

Algae on the Farm - Challenges

- **Which algae to grow ?**
  - **Local strains are best fitted**
  - **Strains indigenous to manure types**
- **When to grow ?**
  - **Warm weather crop**
  - **Greenhouse cultivation**
- **How to harvest algae ?**
  - **Size and density**
  - **Mechanical / Chemical**
  - **Drying**
- **Is there a market for manure algae ?**

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BioEnergy Summer School Overview

- Undergraduate introduction to bioenergy and sustainability
- Hands-on research experience
- Combination of lectures, field trips, laboratory lessons, and discussions
- Group and individual projects

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CAT
PEPSI
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BIOGAS COL
DIVERTING
OD WASTE
from LANDFILLS

Using the Effluent of Anaerobically Digested Tomatoes to Fertilize Plants

Jacquelyn Neal[1], Ryan Graunke[2] and Ann C. Wilkie[3]

[1]Department of Agricultural and Biological Engineering [2]School of Natural Resources and Environment
[3]Advisor, Soil and Water Science Department

Abstract:

Anaerobically digesting tomato culls recycles a waste product and provides renewable energy, also producing effluent which can be used to fertilize plants. Using the effluent to grow tomato plants would provide a source of fertilizer for tomato growers. Tomato culls were obtained and anaerobically digested to produce effluent. The effect of effluent was compared against commercial fertilizers. Plants receiving effluent of anaerobically digested tomato culls as fertilizer had comparable growth to plants receiving chemical and organic fertilizers.

Introduction:

As the world population approaches nine billion, food producers will be faced with increasing food production without an increase in field space and with decreasing soil quality (Smil 2001). An alternative fertilizer, such as biofertilizer made from the effluent of an anaerobic digester, could potentially reduce the need for synthetic fertilizers and reduce the energy used in the production process. Biofertilizer would also create a complete system within the anaerobic digestion cycle, which would create a use for the effluent in the anaerobic digestion process (Ulusoy *et al.* 2009). Finding a use for the biofertilizer produced from anaerobic digester effluent would be beneficial to both creating a sustainable cycle for the whole anaerobic digestion process as well as creating an alternative fertilizer that does not rely on the use of fossil fuels for its production (Liedl 2006).

Method:

Tomato culls were anaerobically digested to be used as a fertilizer treatment. Five treatments were used in this experiment: a synthetic NPK fertilizer (Miracle-Gro), a traditional organic fertilizer (fish emulsion), and three rates of anaerobically digested effluent (ADE) were tested. There was a sixth group with no fertilizer applied that served as a control group for this experiment. Three sweet pepper plants per group were tested. The height of each plant was measured every third day and the number of leaves were counted.

Results

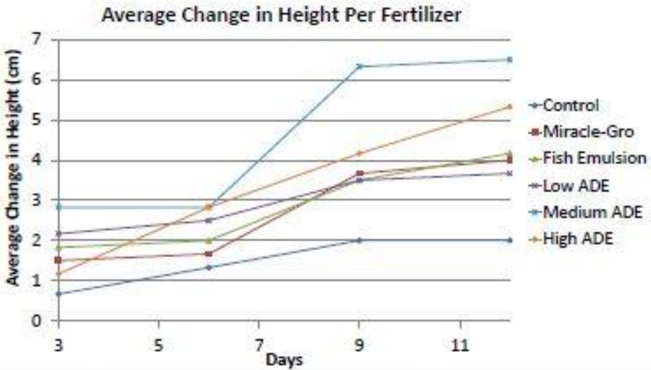

Figure 1: Average Change in Height Per Fertilizer

Figures 2-5. (Clockwise): Weighing tomatoes to be digested, adding fertilizer, adding effluent, layout of plants

Conclusion:

Medium and high ADE treatments appear to be the most effective fertilizers. The high effluent rate showed the most consistent growth over the twelve day period. The plants with Miracle-Gro and fish emulsion both yielded comparable results, with slightly less change in growth than the effluent treatments. Therefore, it was determined that anaerobically digested tomato effluent can be successfully utilized as a fertilizer.

Future Research:

- Use effluent from a digester fed tomato culls continuously for at least 6-8 weeks, with effluent being removed weekly.
- Increase the sample size with more plants.
- Compare plant growth using the total dry weight of the plant after the growth period ends
- Longer growth period will allow a more thorough assessment.
- Several applications of fertilizer treatments

Acknowledgements

This research was part of the 2011 BioEnergy and Sustainability School (BESS), a summer internship program funded by the Florida Agricultural Experiment Station, UF/IFAS.
Thank you to Haley West for supplying the pepper plants.

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Phycoremediation of Landfill Permeate: Nutrient Limitation

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[1]Soil and Water Science Department
[2]School of Natural Resources & Environment

Abstract

Every landfill produces leachate, composed of liquid that accumulates at the bottom of a landfill after it has percolated through the solid wastes. Permeate, which will be used in this experiment, is obtained by filtering landfill leachate through a reverse osmosis filter. This is the first step in the current two-stage experimental process at the Alachua County Southwest Landfill . The culture that will be utilized is a native polyculture that was collected on site. This experiment investigates the possibilities of using microalgae as a biological pathway for remediating landfill permeate as well as explores the functional consequences of nutrient limitations.

Introduction

•Groundwater is a precious resource that is decreasing rapidly around the world, which emphasizes the need to remediate water.

•There are thousands of landfills in the United States that are all producing leachate, which must be remediated.

•Algae can be cultivated to remediate wastewaters (FAO 2009).

• Alachua County SW Landfill (ACSWL) is currently using an experimental two phase reverse osmosis (RO) system to remediate leachate. The product from the first phase will be referred to as RO permeate.

• Preliminary experiments have shown that the algae are remediating permeate. These exciting results have encouraged further studies to optimize the algal remediation of permeate. It is hypothesized that the growth of algae in RO permeate is limited due to nutrient deficiencies.

Objectives

1. Demonstrate the ability of microalgae to remediate permeate.
2. Show that there is a nutrient limitation in permeate.
3. Demonstrate that the additions of growth media can dramatically increase the effectiveness of the algae to remediate permeate.

Methods

• *Algal Cultivation:* Native algae (Figure 1), collected at ACSWL, were cultivated in 125mL Erlenmeyer flasks under 24 hour illumination at 150uE/m²/s, and were mixed by aeration An inoculation density of 10% by volume was used to initiate the algal culture. Experimental treatments consisted of triplicate cultures grown in RO permeate, RO permeate + 10% Bold's Basal Medium (BBM), a standard growth medium for algae (Anderson 2005), and RO permeate + 10% BBM –phosphorous only (BBM-P Only).

• *Algal Growth:* Culture growth was monitored by optical density at 680nm using a thermo-fisher Genesys 10UV-Vis spectrophotometer.

• *Total Ammoniacal Nitrogen (TAN):* TAN was measured using an ammonia selective electrode (Orion 95-12) according to APHA (2005) standard methods 4500-NH3.

• *Culture pH:* pH was measured in accordance with APHA standard method 4500-H+.

Results

•Reverse osmosis (RO) permeate does not have all of the nutrients necessary for optimal algae growth (Figure 2).

•The addition of BBM dramatically increases the growth of the algae on permeate (Figure 3). This allows for faster remediation (Figures 4 and 5).

•Simply adding the phosphorus component of BBM did not solve all of the nutrient limitation issues. Indicating that other nutrients, aside from phosphorus, are lacking in RO permeate and are preventing optimum growth and remediation.

Figure 1. Native algae culture used in RO growth experiments

Figure 2. Appearance of culture grown on RO permeate, RO permeate +10% BBM-P only, and RO permeate + 10% BBM media (from left to right).

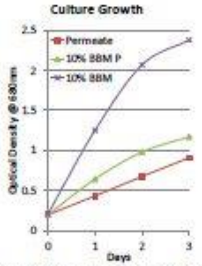

Figure 3. Algae growth as measured by optical density within RO Permeate, 10% BBM-P, and 10% BBM media.

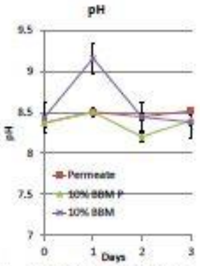

Figure 4. pH measurements within RO Permeate, 10% BBM-P, and 10% BBM media.

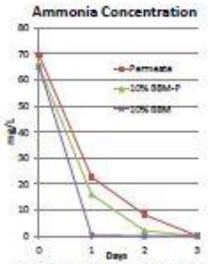

Figure 5. Ammonia concentrations within RO permeate, 10% BBM-P, and 10% BBM media.

Conclusions

•The RO permeate is nutrient deficient

•Limiting nutrients limit the growth of the algae

• Phosphorus alone does not account for the limitation

• Growth limitation of algae limits remediation capacity

• Algae need complete nutrition for effective remediation

• An addition of nutrients increases the growth rates of algae, which increases the remediation capacity of algae.

Future Work

More research needs to be done on optimizing the growth of algae on permeate and determining exactly what nutrients are missing in order to achieve optimal growth and remediation. This experiment also needs to be scaled up to a larger volume to ensure the same results. Addition of CO_2 may increase the remediation capacity of the algae further. The effect of the duration and intensity of illumination on remediation time should be investigated.

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Acknowledgements

This research was part of the 2011 BioEnergy and Sustainability School (BESS), a summer internship program funded by the Florida Agricultural Experiment Station, UF/IFAS.

Outreach

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SOIL AND WATER SCIENCE
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Biodigester under construction in Pursat, Cambodia – July 2010.

National Biodigester Programme
Cambodia (July 2010)

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Production of Biofertilizer through Biodigestion of Organic Residues to Sustain Food Security in Haiti

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BIOENERGY AND SUSTAINABLE TECHNOLOGY LABORATORY

Abstract

Agricultural productivity in Haiti suffers from soil quality depletion principally attributable to human-accelerated erosion processes and inadequate natural resource management. To sustain the food production system and maintain soil fertility, Haitian farmers must adopt sustainable practices including the use of alternative sources of soil nutrients, reduction of soil erosion, and recycling of plant nutrients. Anaerobic digestion, or biodigestion, of organic materials (*e.g.* crop residues, manures, by-products, *etc.*) produces a biofertilizer with elevated mineral nitrogen concentrations that can be used instead of synthetic fertilizers to substantially increase food production. In addition, biodigestion of organic materials produces renewable energy (biogas) that can be used to improve the living conditions of the population. The applicability of biodigestion to sustain food production in the Haitian context was explored. The yields of bean, maize and onion were compared in a field study under different fertilization regimes: anaerobic digester effluent (ADE), urea, fish emulsion (FE), and a control group receiving no fertilizer. Yields of onion, bean, and maize grown with ADE fertilization increased relative to the control by 42.4, 40.5, and 65%, respectively. Yields of onion and bean grown under ADE fertilization were equivalent to yields using either urea or FE. Maize yields from plants treated with ADE were comparable to plants receiving urea and reached a higher yield than FE and control groups. Adoption of biodigestion in the Haitian farming system may help sustain long-term improvement in food security, promote access to energy in rural areas and support the prosperity of local economies.

Introduction

- The Haitian population is expected to reach 13.5 million by 2050, food production needs to substantially increase to sustain food security.
- Agricultural productivity in Haiti suffers from soil quality depletion principally attributable to human-accelerated erosion processes and inadequate natural resources management **(Figure 1)**.
- Lack of access to basic agricultural inputs such as fertilizers, improved seeds, irrigation water, and appropriate farming practices have contributed to the unsatisfactory performance of Haitian agriculture.
- To sustain food production, farmers must adopt sustainable practices using alternative sources of soil nutrients, reduce soil erosion, and recycle plant nutrients to maintain soil fertility.

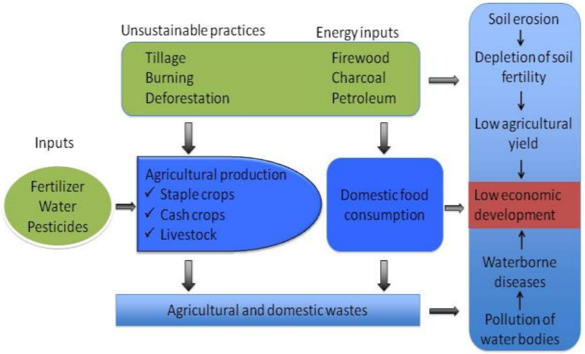

Figure 1. Current state of Haitian agricultural practices

Biodigestion of Organic Residues: A Method of Plant Nutrient Recycling

- ✓ Biodigestion is the microbial degradation of organic materials under an oxygen-starved environment by a consortium of microorganisms that produces biogas and a rich plant nutrient end-product.
- ✓ Biodigestion combines the production of renewable energy and biofertilizer, and other environmental benefits such as greenhouse gas emission mitigation, reduction of odors, pollution control and pathogen removal **(Figure 2).**
- ✓ Anaerobic digester effluent (ADE) is a biofertilizer with elevated mineral nitrogen concentrations and organic matter that can be used to increase food production **(Figure 3)**.

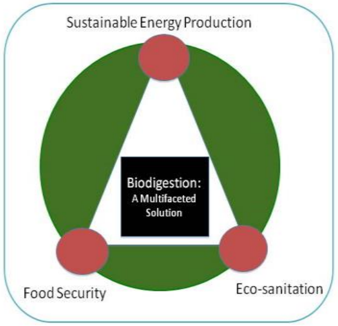

Figure 2. Biodigestion : A multifaceted solution for Haiti

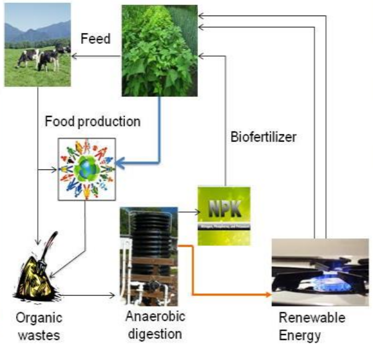

Figure 3. Integration of anaerobic digestion into a farming system

Research Objectives

Explore the applicability of biodigestion to the Haitian farming system to sustain food production and generate renewable energy.

✓Assess the effects of ADE on the growth and yield: Staple crops: bean and maize, Cash crop: onion
✓Compare the yields to: Urea (46-0-0): synthetic fertilizer, Fish emulsion (5-1-1): organic fertilizer

Key Findings

•Anaerobic digester effluent provides plant nutrients in a readily available form.

•Addition of ADE to the soil had a positive effect on the yield of onion, bean and maize (**Figures 4 and 5**).

•Anaerobic digester effluent increased the yield of onion, bean, and maize by 42.5, 40.5, and 65%, respectively **(Tables 1 and 2)**.

Figure 4. Onions grown with ADE as the sole fertilizer source yield large full bulbs.

Figure 5. Maize grown with ADE as fertilizer, *from left to right:* maize grown with urea, no fertilizer, and ADE

Table 1. Effects of ADE on Onion Production

Treatment	Total biomass (Mg/ha)	Bulb Yield (Mg/ha)	Marketable yield (Mg/ha)
ADE	20.0 ± 3.2a	15.2 ± 1.2a	11.0 ± 1.0a
Urea	19.3 ± 1.5a	13.9 ± 2.3ab	10.8 ± 3.3a
FE	22.2 ± 3.6a	17.5 ± 2.4a	11.9 ± 2.5a
Control	15.0 ± 2.5b	10.9 ± 2.8b	7.8 ± 1.0b

Table 2. Effects of ADE on Bean and Maize Production

	Bean		Maize	
Treatment	Total biomass (Mg/ha)	Grain yield (Mg/ha)	Total biomass (Mg/ha)	Grain yield (Mg/ha)
ADE	4.5 ± 0.5a	2.11 ± 0.4ab	27.9 ± 2.6a	13.9 ± 1.6a
Urea	3.7 ± 0.2a	1.89 ± 0.2b	30.1 ± 5.7a	12.9 ± 2.2a
FE	4.3 ± 0.2a	2.25 ± 0.1a	16.3 ± 3.7b	7.7 ± 1.9b
Control	2.6 ± 0.1b	1.24 ± 0.1c	10.3 ± 2.7c	4.8 ± 0.8b

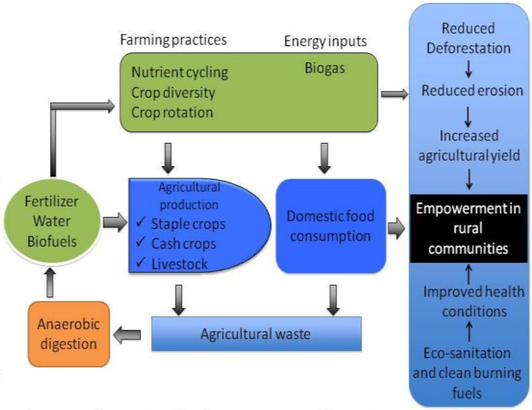

Figure 6. Alternative, *food-centric* approach to Haitian agriculture

Conclusions

- ✓ Farmers in developing countries such as Haiti can use biodigestion as a method to recycle farm wastes and generate biofertilizer **(Figure 4).**
- ✓ Adoption of biodigestion in the Haitian farming system may help sustain long-term improvement in food security, promote access to energy in rural areas and support the prosperity of local economies.

Acknowledgement: USAID FROM THE AMERICAN PEOPLE | WINNER WATERSHED INITIATIVE FOR NATIONAL NATURAL ENVIRONMENTAL RESOURCES

Algae Cultivation for the Bioremediation of Waste Streams and Production of Biomass for Fuel and Feeds

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Abstract

Algae bioremediation offers an innovative method for the simultaneous remediation of waste streams and production of renewable resources in the developing world. Oxygenic photosynthesis produces supersaturating levels of dissolved oxygen in aqueous environments. High levels of molecular oxygen provide a solar-powered oxidation treatment system, capable of reducing the oxygen demand of many types of municipal and industrial wastes. *Scenedesmus*, a common microalga genus found throughout the world, was cultivated in a municipal waste stream (landfill leachate). Photosynthetically derived dissolved oxygen levels in excess of 24mg O_2/L (279% saturation) were recorded in 2L photo-bioreactors processing municipal solid waste landfill leachate. In addition to producing molecular oxygen for the oxidation of wastes, algae cultivation sequesters fugitive nutrients such as nitrogen and phosphorus, preventing the cultural eutrophication of natural water bodies often used as critical water supplies. The by-product of algae bioremediation is algae biomass, which can be anaerobically digested to produce methane gas for heating and lighting applications in rural communities of the developing world. Algae biomass can also be used as a food and feed supplement, by thermally sterilizing the incoming waste stream, and has tremendous potential in supplementing diets poor in protein and vitamin A, two components found in high quantities in algae biomass.

Introduction

- Algae cultivation (Fig.1) has a tremendous ability to remediate anthropogenic wastewaters
- Wastewaters including sewage, animal manures, landfill leachates and industrial wastes have been treated with algae
- Photosynthetic oxygen production (Eq.1) reduces the environmental load of discharged wastes
- The cultivation of algae is not limited to arable land and freshwater making it an opportunity crop in areas limited in these resources
- Algae biomass provides antioxidants, vitamin A, iron and protein (Fig. 2)
- Algae can be cultivated for feeds and fuels (Fig. 3)
- Algae biomass is often high in protein (Fig. 4 and Table 1)

$$2CO_2 + H_2O \overset{Light}{\Longrightarrow} 2(CH_2O) + O_2$$

Equation 1. Photosynthetic oxygen production

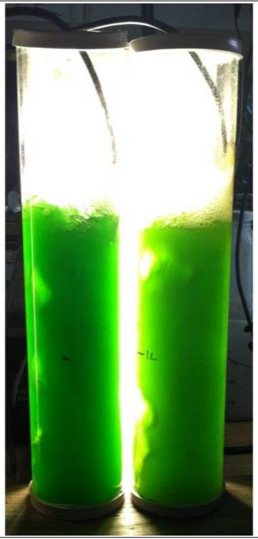


Figure 1. Photobioreactors cultivating *Scenedesmus* sp. in municipal solid waste landfill leachate.

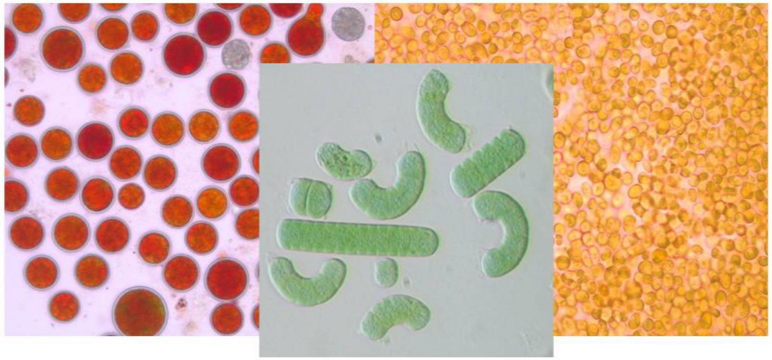
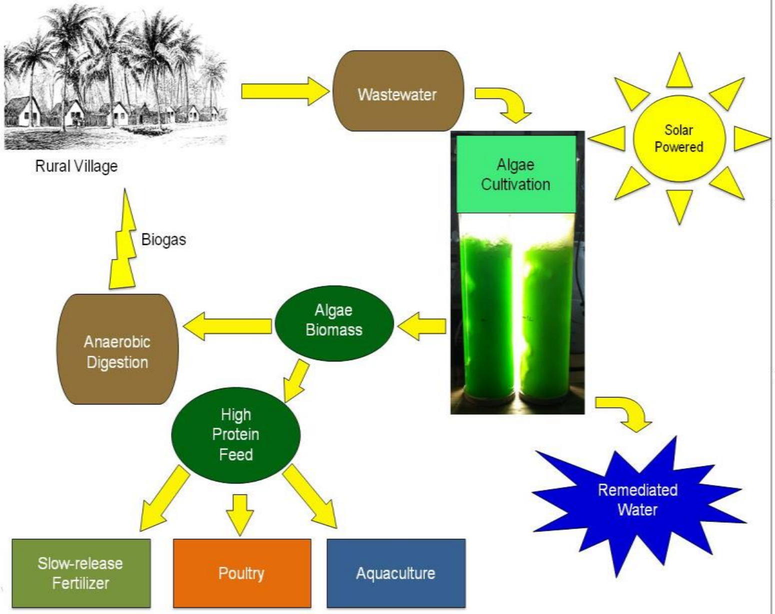


Figure 2. Algae with nutritional properties, *from Left to Right*: *Hematococcus* sp. cells filled with the red antioxidant astaxanthin, *Arthrospira* sp. cells rich in protein and iron, and *Scenedesmus* sp. cells rich in the orange pigment *beta*-carotene, a vitamin A precursor. All photos taken at 500x optical magnification and © BEST Laboratory.



Rural Village

Wastewater

Algae Cultivation

Solar Powered

Biogas

Anaerobic Digestion

Algae Biomass

High Protein Feed

Slow-release Fertilizer

Poultry

Aquaculture

Remediated Water

Figure 3. Integrating algae cultivation in wastewater remediation and resource (Feed and Fuel) production as appropriate for a rural village anywhere in the world. Oxygenic photosynthesis oxidizes wastewater and produces algal biomass, which can be used directly for anaerobic digestion and biogas production or for the generation of high protein and mineral feeds for poultry and aquacultural applications. Algal biomass can be land applied and act as a slow release fertilizer for terrestrial crops. (Inspired by Fox 1993)

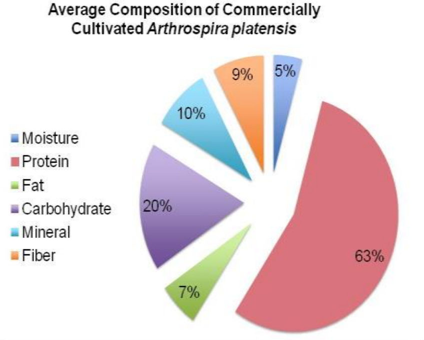


Figure 4. Average % Composition of commercially cultivated *Arthrospira platensis (Earthrise Nutritionals Inc., adapted from Belay 1997)*

Table 1. Composition of selected algae on a % dry weight basis (adapted from Becker 2007)

Alga	Protein	Carbohydrates	Lipids
Chlamydomonas rheinhardii	48	17	21
Chlorella pyrenoidosa	57	26	2
Chlorella vulgaris	51–58	12–17	14–22
Dunaliella salina	57	32	6
Porphyridium cruentum	28–39	40–57	9–14
Scenedesmus obliquus	50–56	10–17	12–14
Spirogyra sp.	6–20	33–64	11–21
Arthrospira maxima	60–71	13–16	6–7
Spirulina platensis	46–63	8–14	4–9

Conclusions

- Algae cultivation can remediate many types of anthropogenic wastewaters
- Algae have considerable potential in providing both high protein feed and renewable fuel for developing regions

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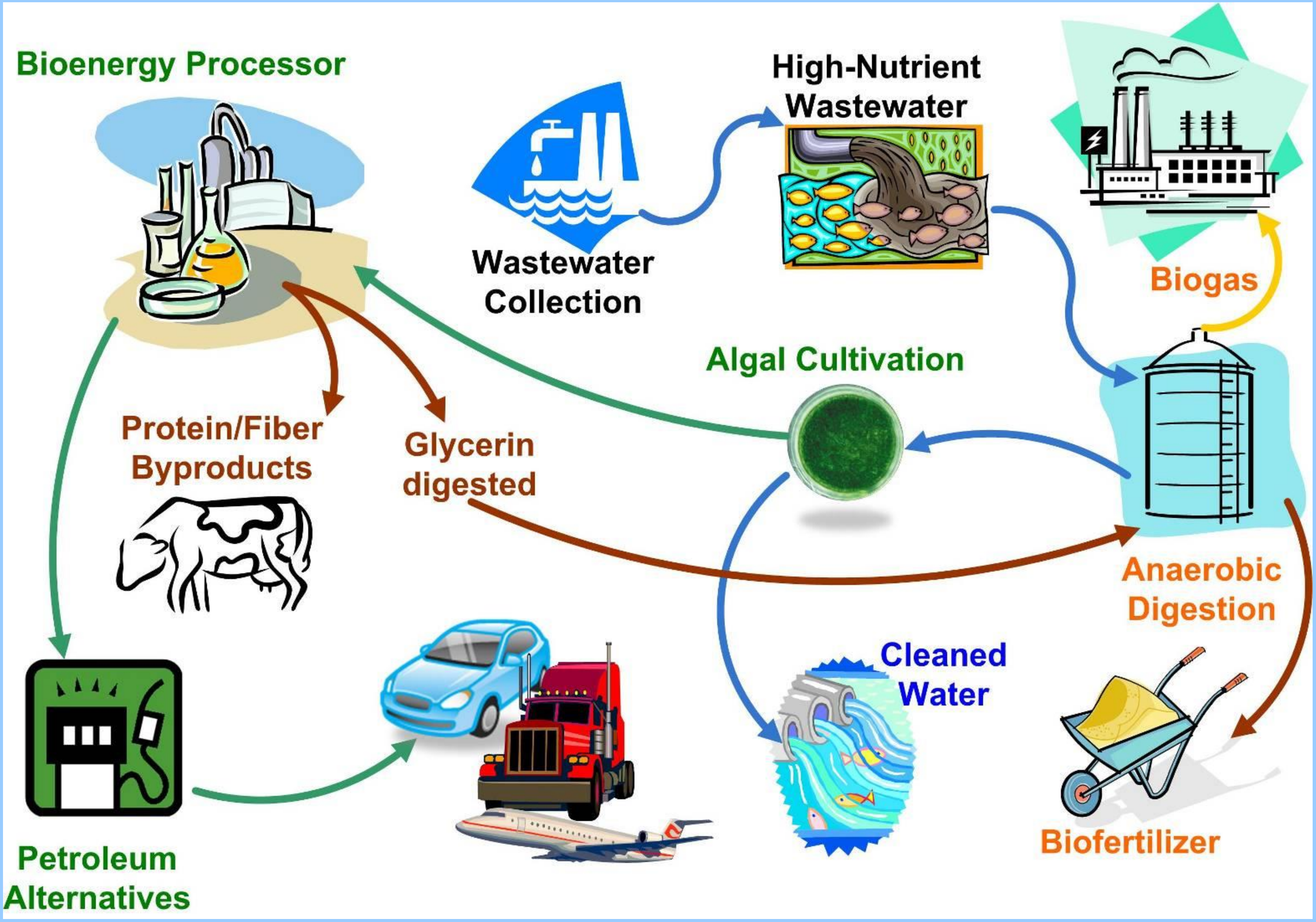
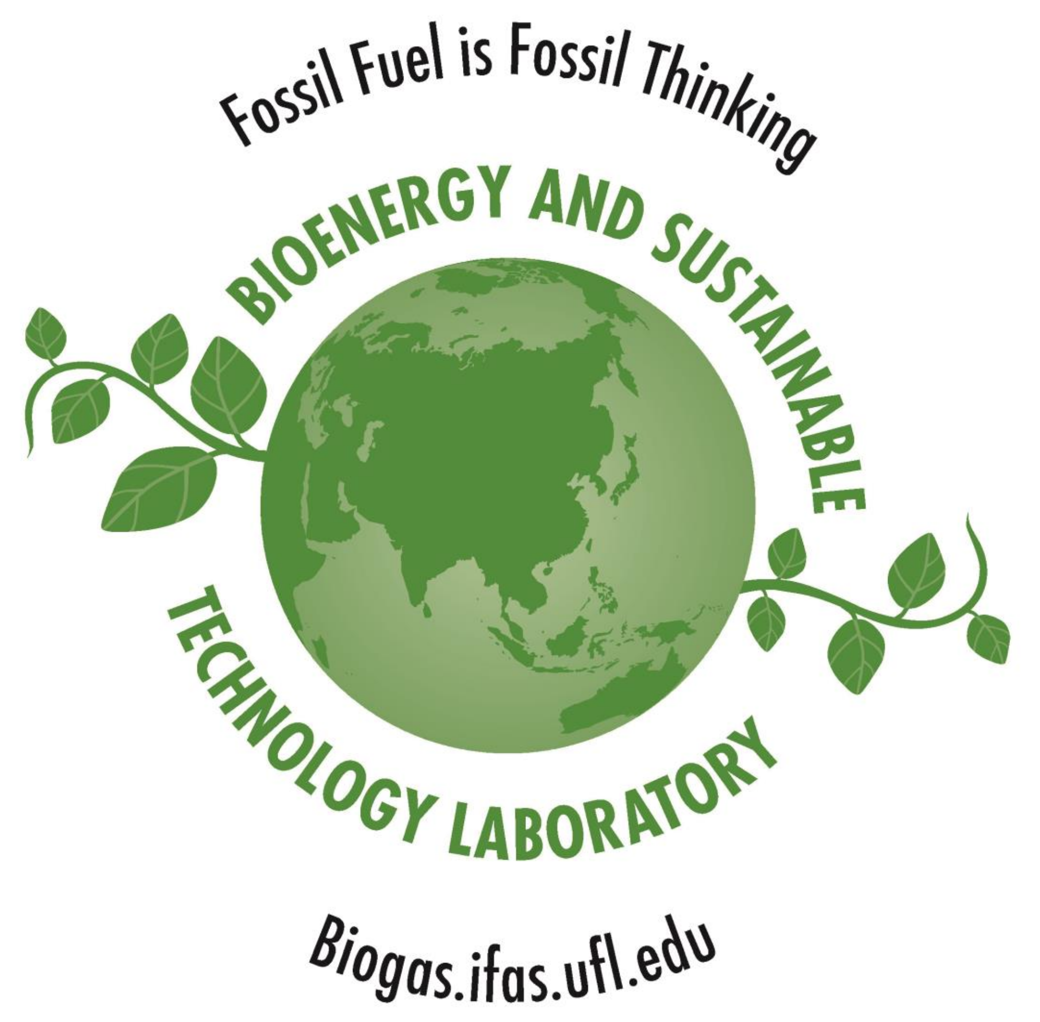
The Human Ecosystem





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SOIL AND WATER SCIENCE

Recycling **B**iomass to **A**gricultural
LANd: **C**apitalising on **E**utrophication

Eco-logic: Sustainable Resource Management

Ann C. Wilkie

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ReBALAN:CE Workshop

University of Stirling

August 29, 2013