BENEFITS AND CHALLENGES OF THE ALGAL BIOFUELS INDUSTRY

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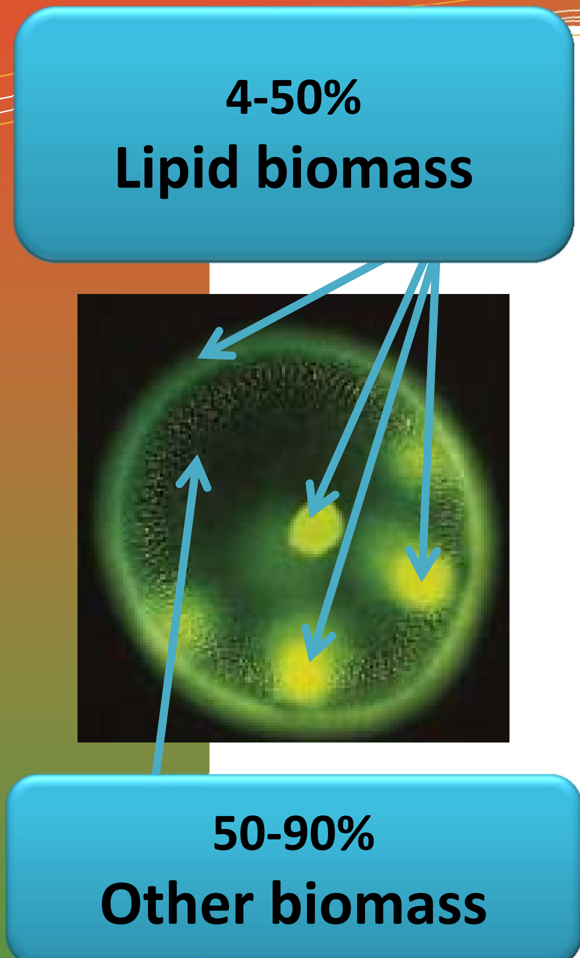
Why Biofuels from Algae



Rapid growth rate

- Efficient photosynthesis
- No heterotrophic tissues
- Double 6-12 hours

High oil content

- 4-50% non-polar lipids
- 10-45% higher energy/gdw than carbohydrate feedstocks

Biomass harvested

- 100%

Harvest interval

- 24/7, not seasonally

NAABB Team - $49M DOE project (2010 – 2013)

RAFT
Regional Algal Feedstock Testbed

Increase strain productivity	1 Algal Biology to Increase Strain Productivity ➢ New Strain Isolation and Development ➢ Genetic Engineering	Production Strains
	2 Cultivation to Sustain High Productivity at Large Scale ➢ Cultivation Tools & Methods ➢ Nutrient/Water Recycle/Wastewater Use ➢ Cultivation System Innovations ➢ Large Pond Cultivation/Biomass Production	Cultivation Processes
Reduce energy and cost of making fuels	3 Harvesting & Extraction for Scalable Efficient Processes ➢ Dewatering Technologies ➢ Wet Extraction Technologies	Harvest Extraction
	4 Fuel Conversion to Demonstrate High Energy Density Fuels Detailed Characterization ➢ Lipid Conversion to Fuels ➢ Biomass/LEA Conversion to Fuels & Chemicals	Lipid Conversion LEA Conversion Direct Conversion
	5 Agricultural Co-Products with Validated Performance ➢ Animal Feed Development & Testing ➢ Fertilizer Evaluations	LEA Agriculture applications
	6 Sustainability to Analyze Integrated NAABB Technologies ➢ Sustainability Models and Tools for Economic and Environmental Impact ➢ Model Integration, Harmonization and Analysis	

Assess and Optimize Sustainable practices through the value chain

Traditional raceway

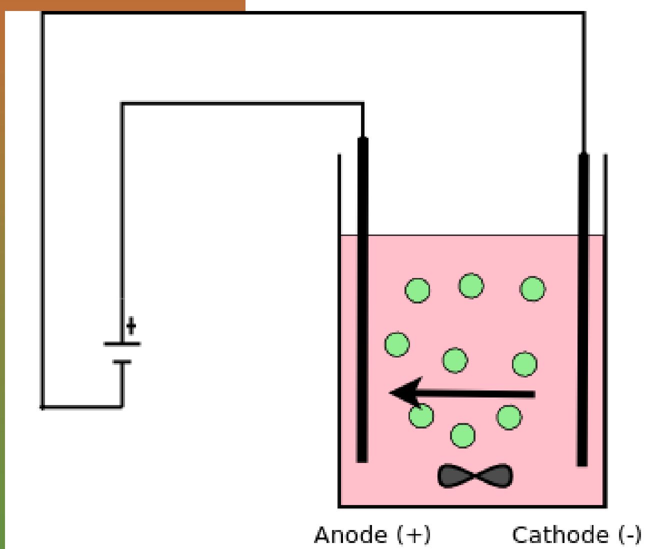
- Paddle wheel
- Runs day and night- Energy intensive
- Radiates heat to the night sky
- Not Productive in cold weather
- Not hydrodynamic design
- Algae settles to the bottom
- Accumulates bacteria, invaders and grazers
- High OPEX
- High CAPEX

Arid Reactor System

- Solar pumping system – payback period 2 years
- Efficient harvesting
- Less predators

Harvesting

- **Current bottlenecks to cost effective production of biofuels from algae – traditional is centrifuge**
- **Need to concentrate from 1 g/L to 40 or 100 g/L prior to extraction**



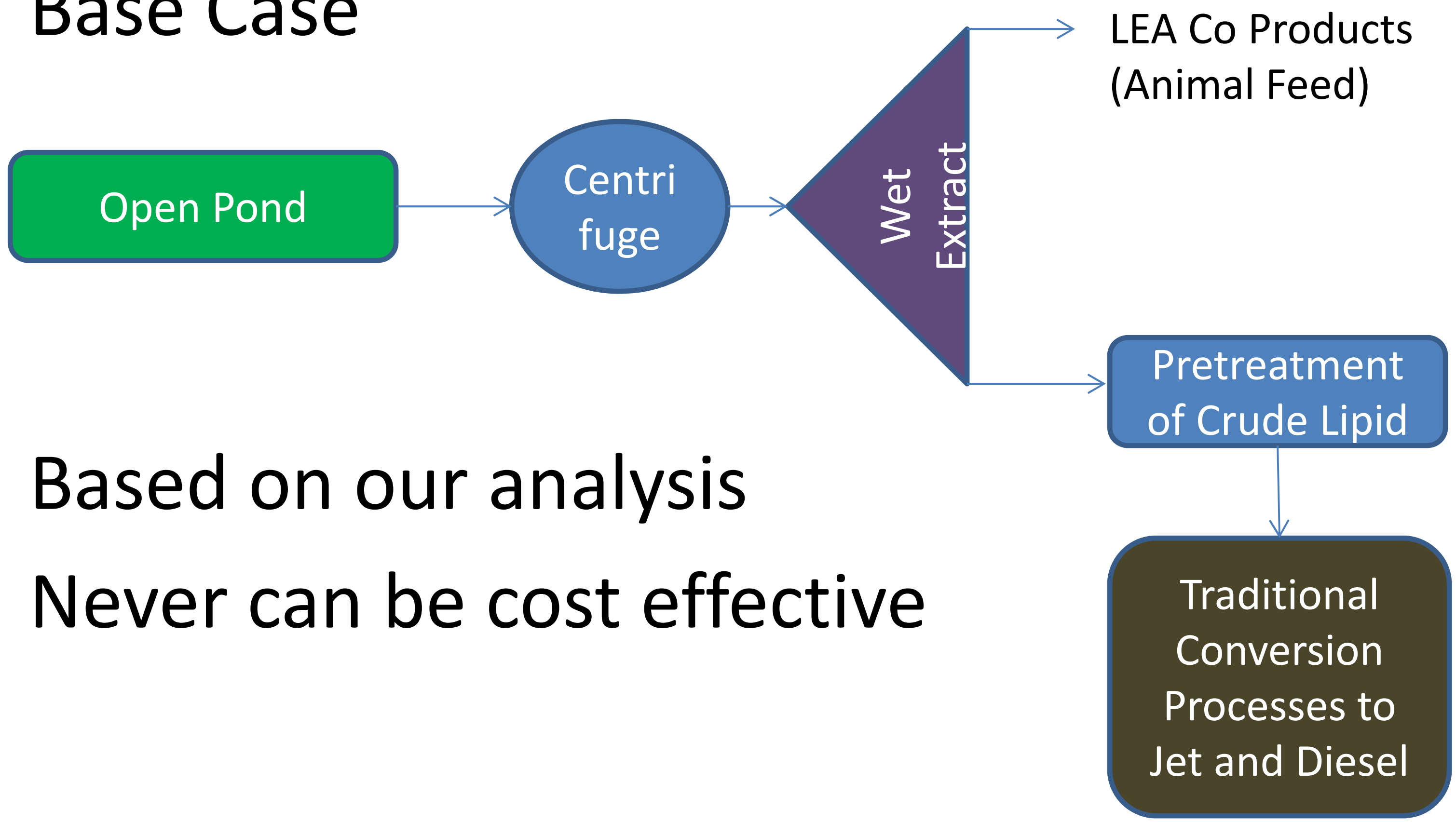
Electrocoagulation

Filtration

Acoustic Focusing

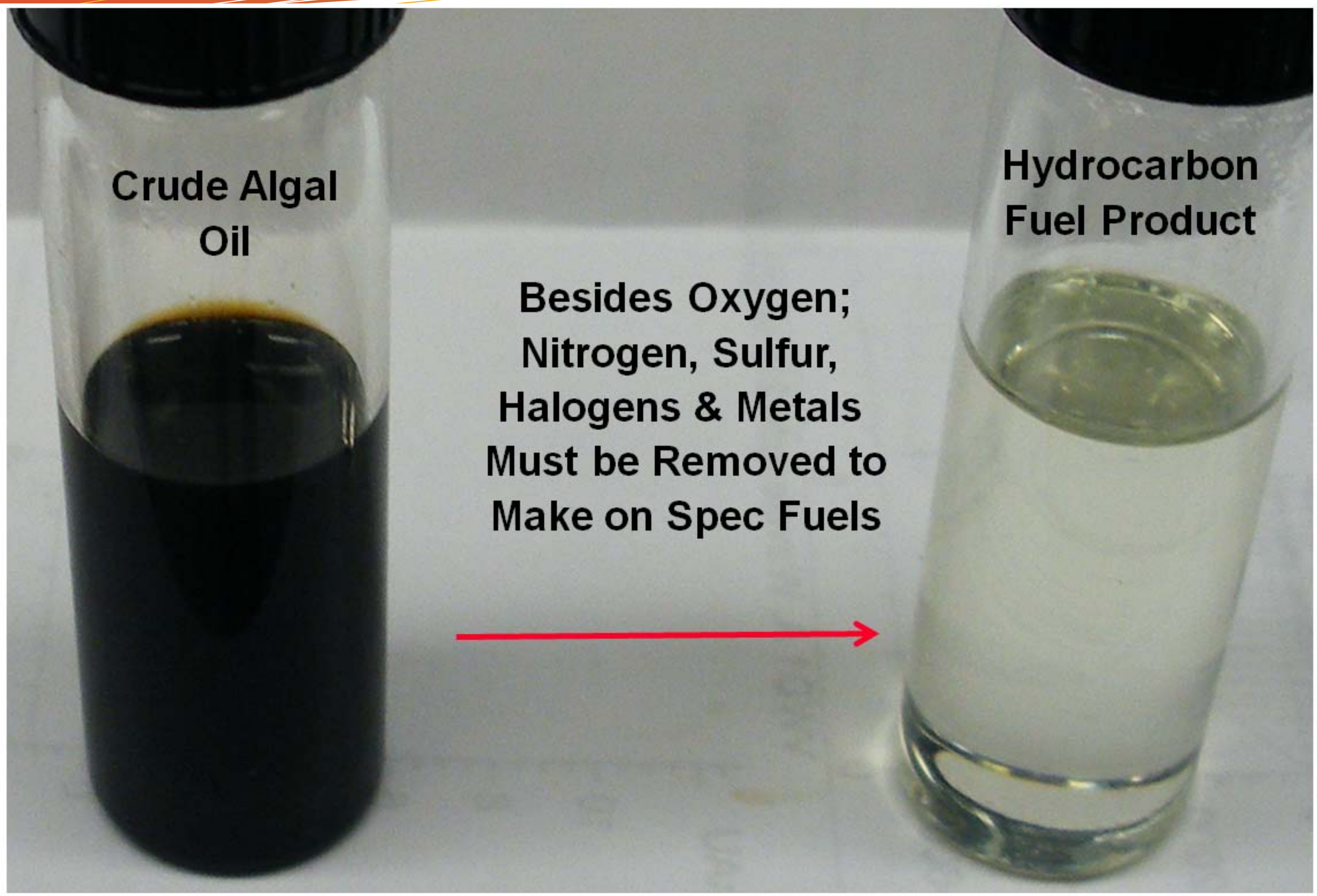
Cost Effective?

- Base Case



- Based on our analysis
- Never can be cost effective

Conversion Lipid Extracts to Fuels

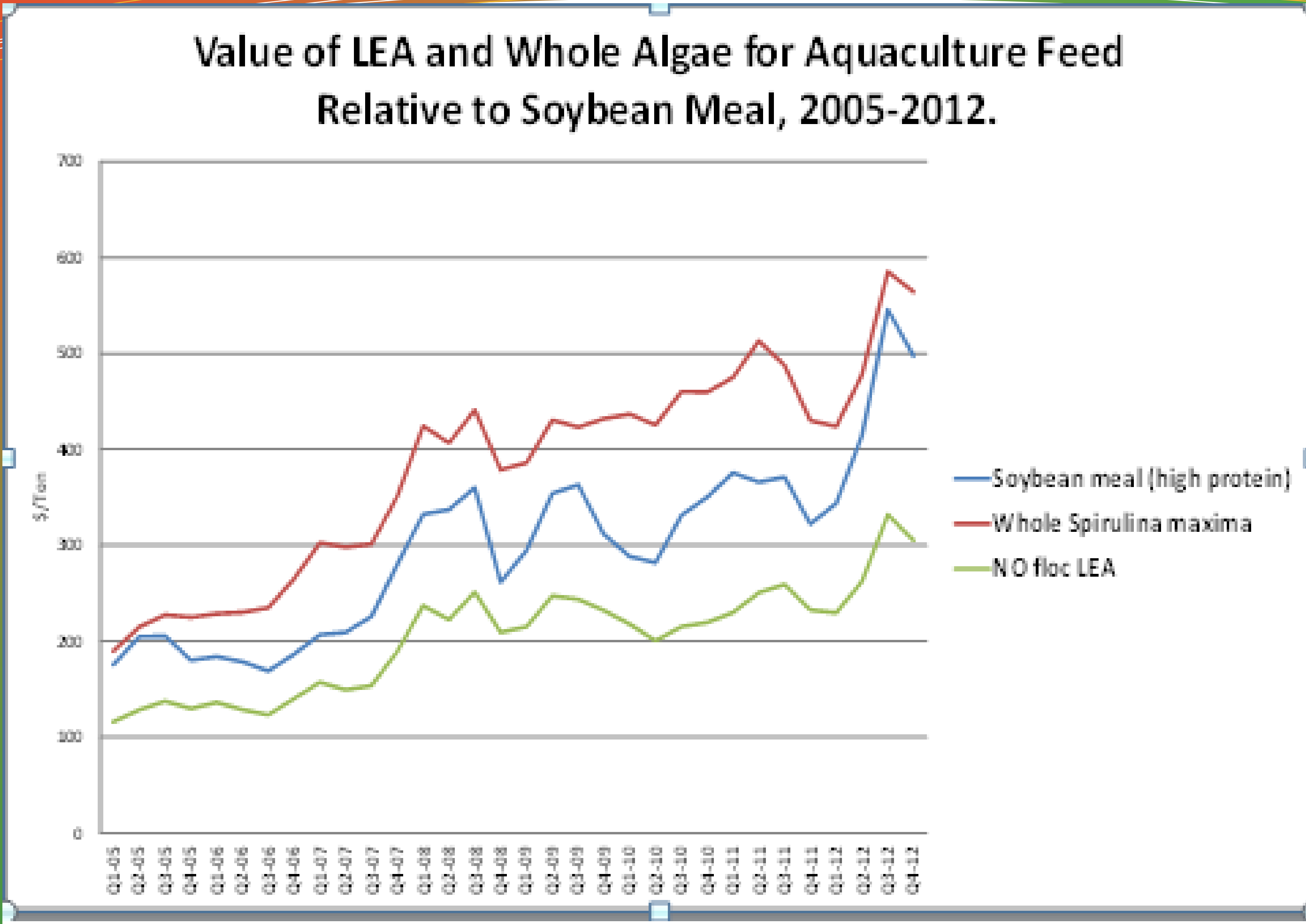


"Contaminants" for Conversion are "Nutrients" for Cultivation

Feeding Results

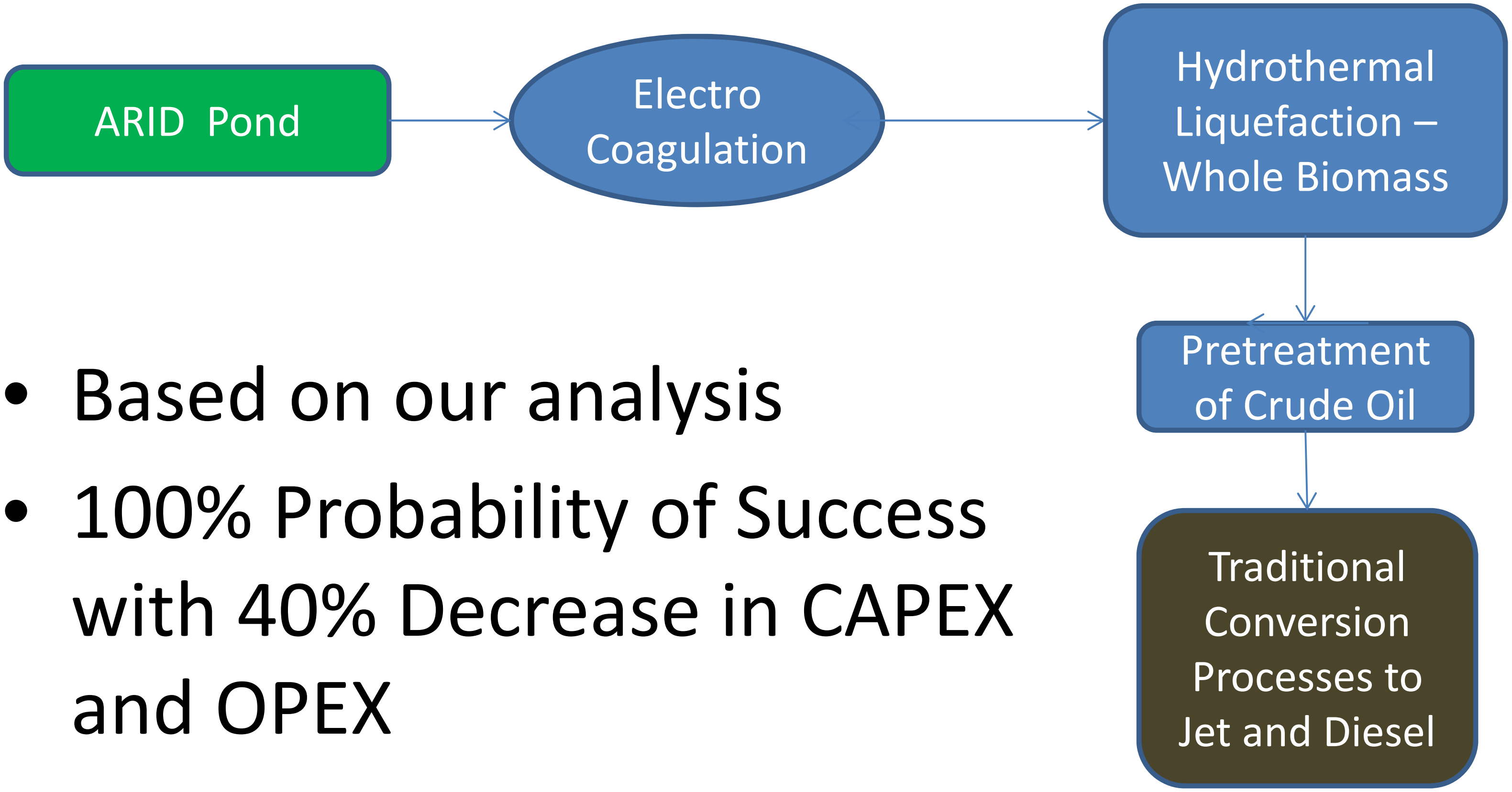
Type of Animal Tested	Performance	Digestibility	Value
Ruminants Lambs, Cattle* *Biomass provided by DARPA (GA)	Palatable Growth, histology and blood metabolites similar to soybean -lambs	Supplementation of LEA does not impair fiber digestion Similar to cottonseed and soybean meal	Value of LEA in relation to soybean meal is ~ $160 US
Nonruminants Pigs	Reduction in growth Blood not affected		
Aquaculture Red drum, Shrimp	LEA is a suitable replacement for traditional protein feeds for fish and shrimp production		Excellent but minerals of concern

Feed Value


Value of LEA and Whole Algae for Aquaculture Feed
Relative to Soybean Meal, 2005-2012.
$/Ton
700
600
500
400
300
200
100
0
Soybean meal (high protein)
Whole Spirulina maxima
NO floc LEA

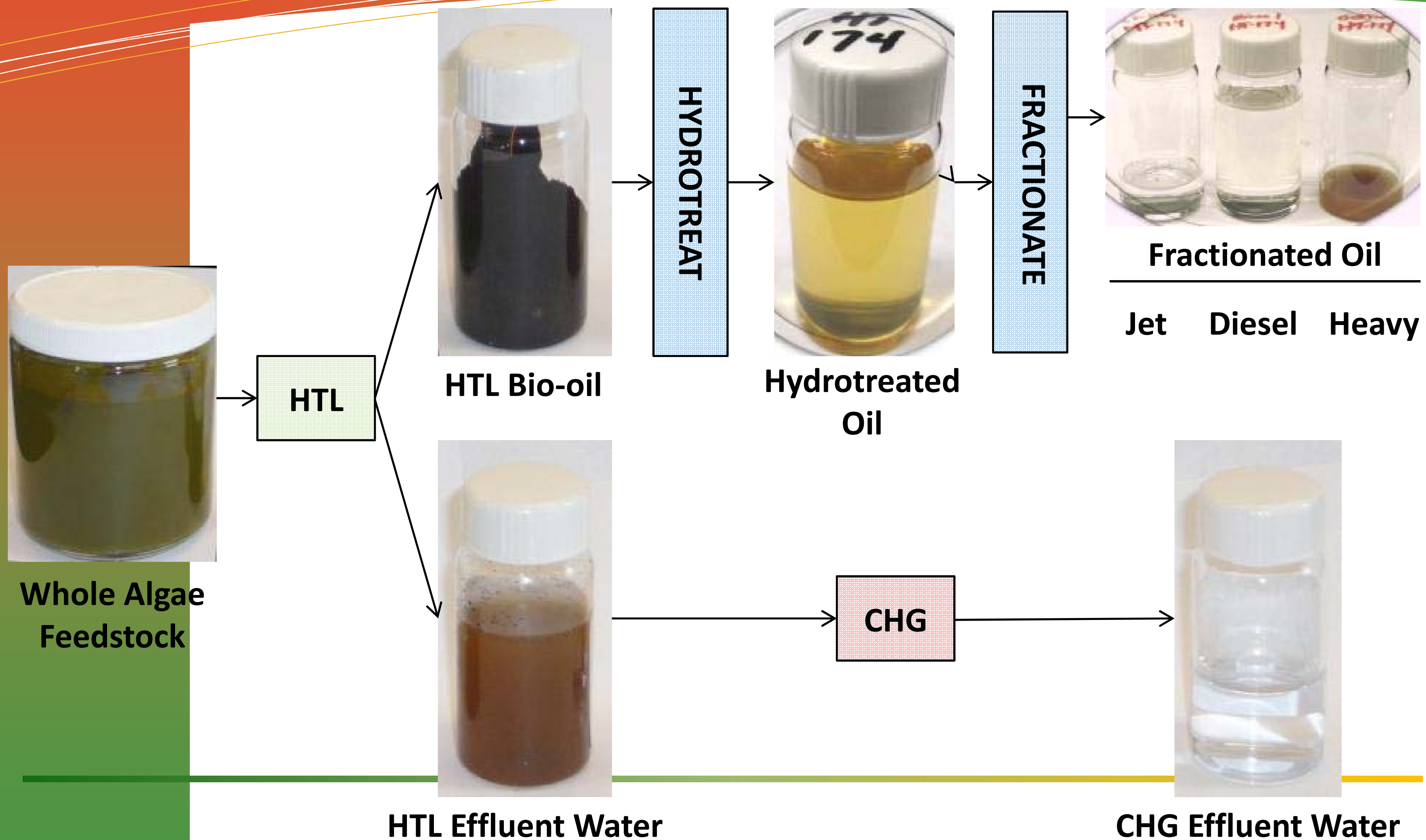
Cost Effective?

- NAABB Improved Case



- Based on our analysis
- 100% Probability of Success with 40% Decrease in CAPEX and OPEX

Combined HTL & CHG Conversion of Whole Algae



Chemical/Physical Characterization of Jet Fuel from HTL Conversion

Parameter	Jet A	Jet A1	Jet Fuel From HTL Algal Bio-Oil #1	Jet Fuel From HTL Algal Bio-Oil #2
Density (g/L)	775 - 840	775 - 840	786.3	780.2
Freeze point (°C) max	-40	-47	-45.8	-57
Flash Point (°C) min	38	38	61.2	59.6
Distillation 10% Recovered Temp (T10) °C max	205	205	167.8	167
50% Recovered Temp (T50) °C	Report	Report	207.4	203.6
90% Recovered Temp (T90) °C	Report	Report	244.6	242.2
Final Boiling Point (°C) max	300	300	273.2	272

AISIM = NAABB Algal Integrated Simulation Modeling

Statistical Data Analysis of Field Data
Applied Production Analysis (APA)

Graphic Information Systems Based Resource Assessment Model
Biomass Assessment Tool (BAT)

Scaling and Logistics of Algae Production Facilities
Algal Logistics Model (ALM)

Life Cycle Assessment
GREET and SimaPro

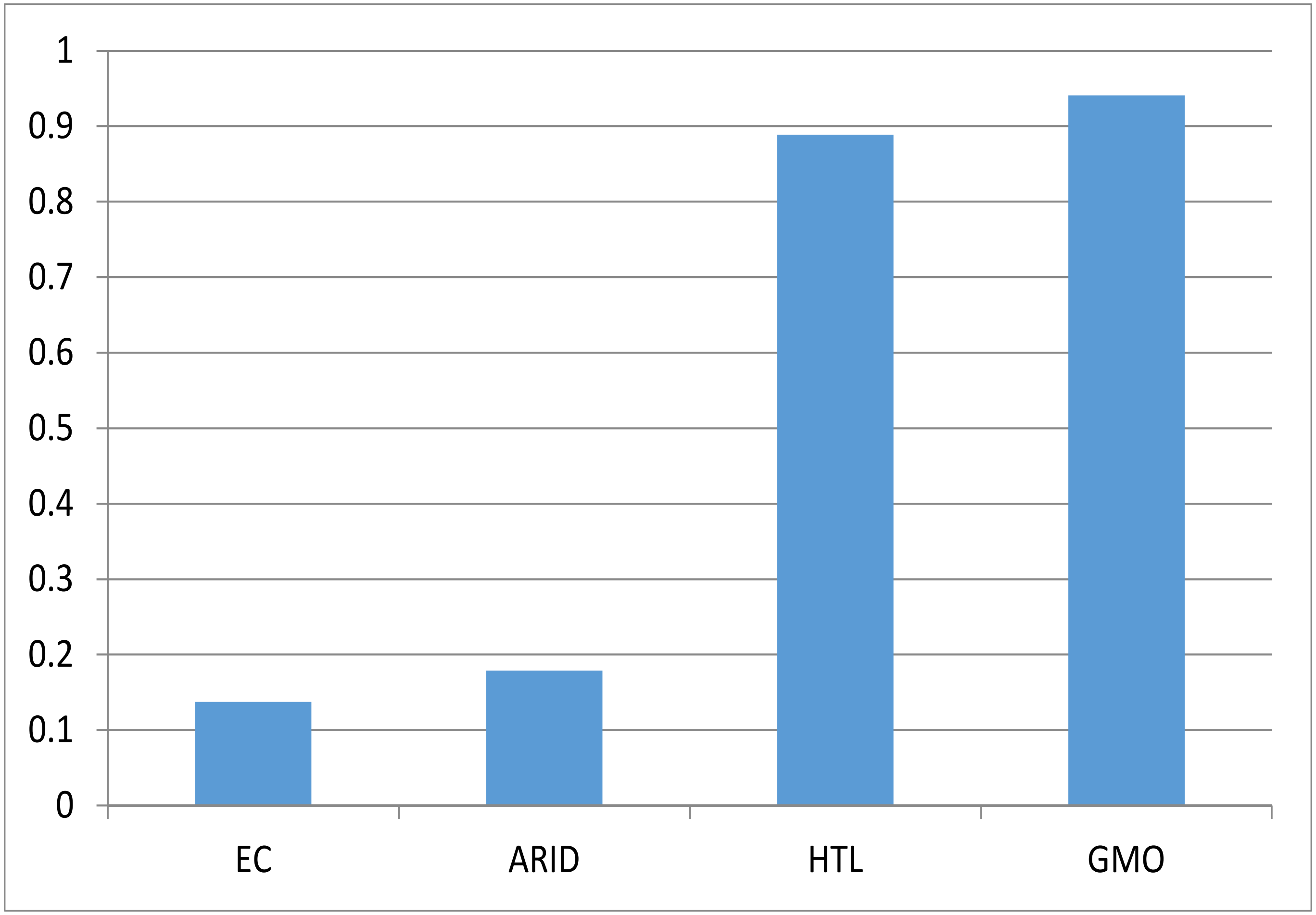
Techno-economic Analysis
Harmonized Techno-Economic Model and
Energy Limited Model of Algal Biofuel Production

Financial Feasibility Analysis
Farm-level Algal Risk Simulation Model (FARM)

Measures of Sustainability Generated by AISIM

- Risk Adjusted Profit
- Prob. of Success
- CAPEX/OPEX
- GHG Emissions
- Net Energy
- Land Use
- Marginal Cost
- Water Use Needs

Fractional reductions in total costs for producing algae crude oil for the NAABB innovations



LCA Analysis

Feedstock	Greenhouse Gas Emissions (kg CO_{2eq} / kg feedstock)
Algae (this work)	0.1 – 4.4
Corn	0.3 – 0.4
Soybeans	0.4 – 0.5
Jatropha	0.3
Camelina [54]	0.1 – 0.3

- UOP Ecofining ™ Process to jet fuel or diesel
- Harvesting and Extraction (H&E) Unit Operations
- Land-Use Change in Large-Scale-Algae Cultivation

RAFT
Regional Algal Feedstock Testbed

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Opportunities for Collaboration

- Production of algal biomass for a variety of applications
  - Fuel
  - Feed
  - High value Products
- Cultivation of genetically modified algae
- Design and implementation of integrated, controlled systems for cultivation, harvesting, and conversion.
- Optimization of algal productivity in impaired waters
- Culture diagnostics using molecular markers