Applications of Produced Water in Biodiesel Production and Distribution

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Presentation outline

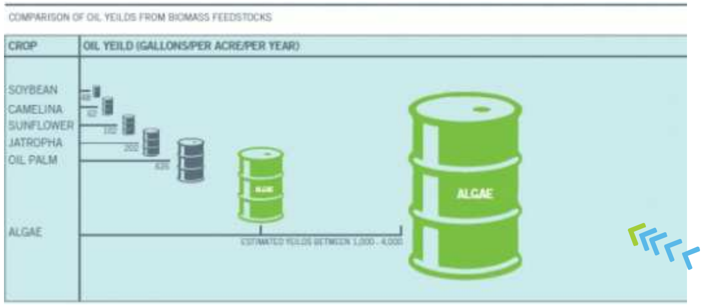
Motivation – Produced water

- Salty water trapped in the reservoir rock and brought up along with oil or gas during production
- These waters exist under high pressures and temperatures
- It can contain very minor amounts of chemicals, oil, and metals
- Every year in the United States about 800 billion gallons of produced water is brought to the surface along with oil and gas and about 98% of this water is routinely disposed as a waste product
- However, these large quantities of saline water have great potential value for algal biofuel production
- Scientists recently were successful in conducting the first pilot-scale test of algae growth using water from an oil-production well in Jal, New Mexico

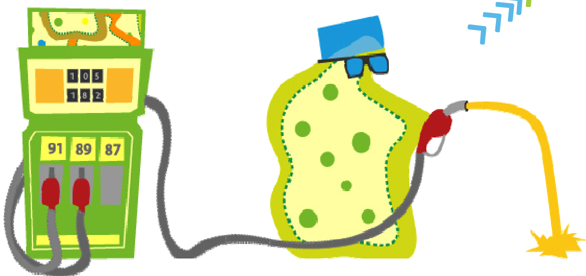
Advantages

Higher growth rates & productivities

CO_2 capture



Higher oil yield



Algae biofuel

Grown on non-arable land
and using produced water

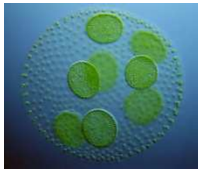
No sulfur, non-toxic & biodegradable

Food vs. fuel

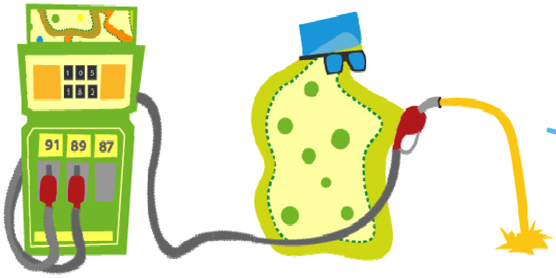
Challenges

High capital, operating & production costs

Relatively new technology

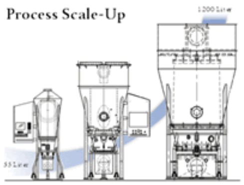


Variety of algae strains



Algae biofuel

Lack of optimal design of cultivation systems

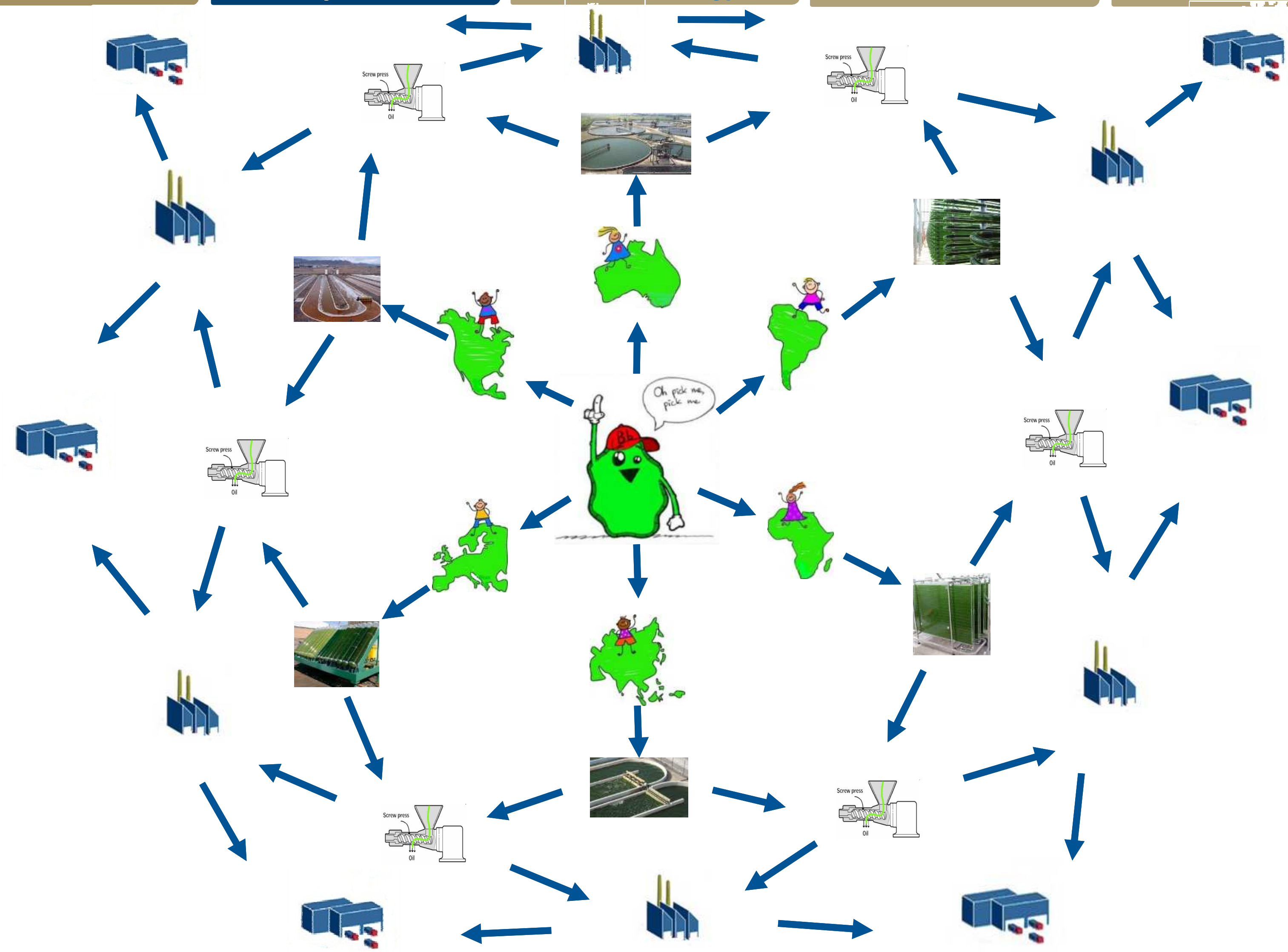


Difficulty in scaling up

Biodiesel Production

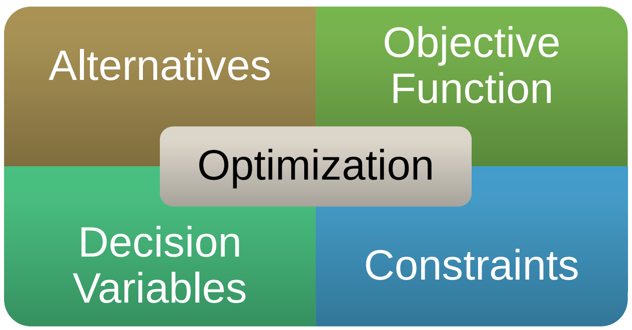
1. Selection of Algae Species ›››› Varying oil content and specific growth rates
2. Selection of Location ›››› Influences climatic conditions and sunlight
3. Algae Cultivation
4. Harvesting
5. Drying
6. Extraction
7. Transesterification

Research Objective



Optimization

Optimization focuses on finding the best solution from a set of available alternatives subject to constraints.



Objective function

To minimize the production, operating and transportation costs of biodiesel

- Optimal algae cultivation systems
- Reliable supply chain network flow topology of production and distribution centers

Alternatives

- Algae Species – *I. galbana*
- Cultivation Units – Raceway Ponds
- Geographical Locations – USA
- Routes
- Means of Transportation – Trucks, Rails, Barges, and Pipelines

Alternatives - Locations

Supply

- Texas
- Mississippi
- Alabama
- Kentucky
- Georgia
- Oklahoma
- Virginia
- Arizona
- North Carolina
- South Carolina

Port

- Houston
- Gulf of Mississippi
- Mobile
- Paducah
- Savannah
- Tulsa
- Norfolk
- Phoenix
- Wilmington
- Charleston

Extraction

- Houston
- Gulf of Mississippi
- Mobile
- Paducah
- Savannah
- Tulsa
- Norfolk
- Phoenix
- Wilmington
- Charleston
- Houston
- Los Angeles
- Philadelphia
- Chicago
- Toledo

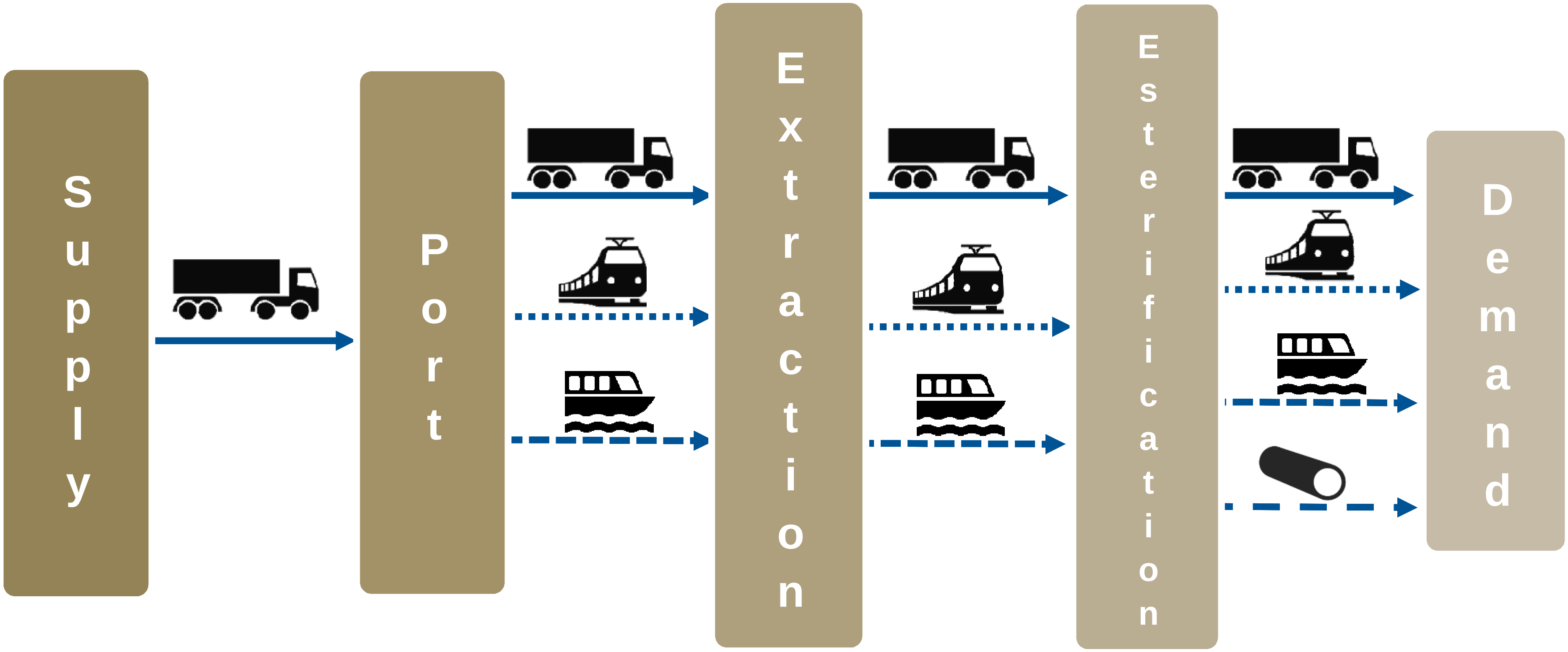
Transesterification

- Houston
- Gulf of Mississippi
- Mobile
- Paducah
- Savannah
- Tulsa
- Norfolk
- Phoenix
- Wilmington
- Charleston
- Houston
- Los Angeles
- Philadelphia
- Chicago
- Toledo

Demand

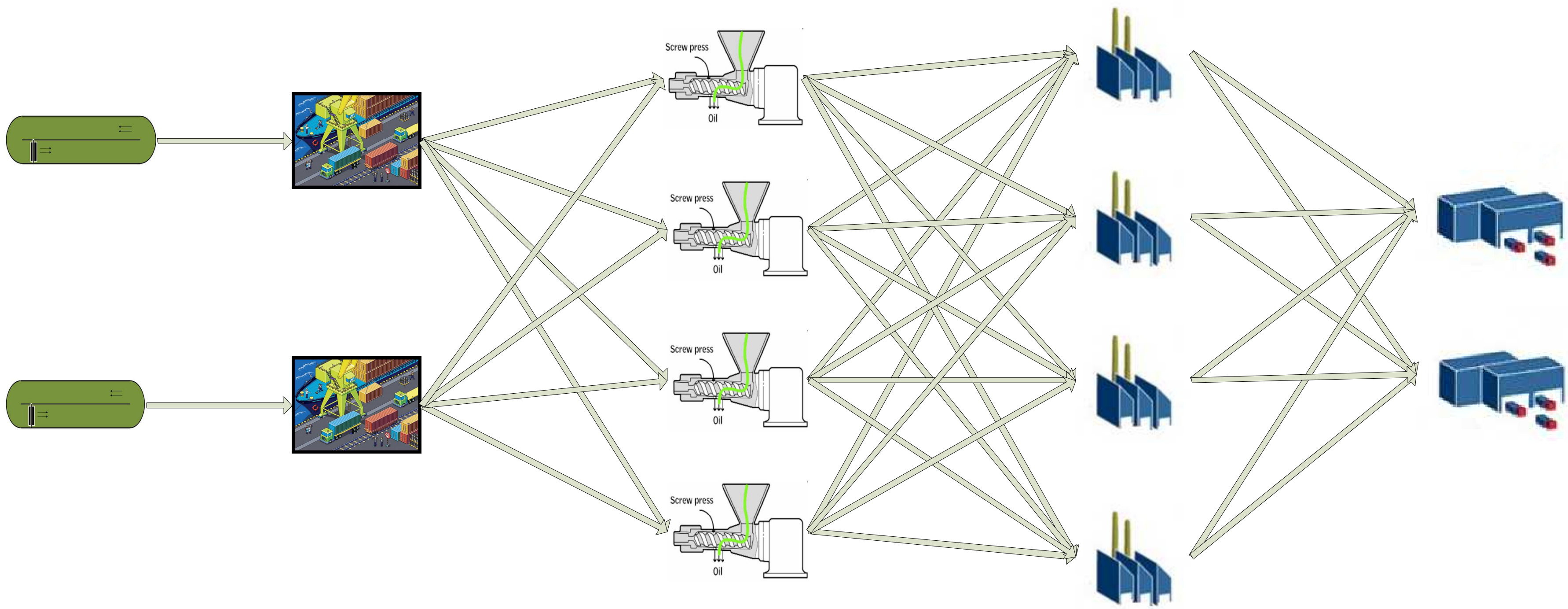
- Houston
- Los Angeles
- Philadelphia
- Chicago
- Toledo

Alternatives – Means of Transportation

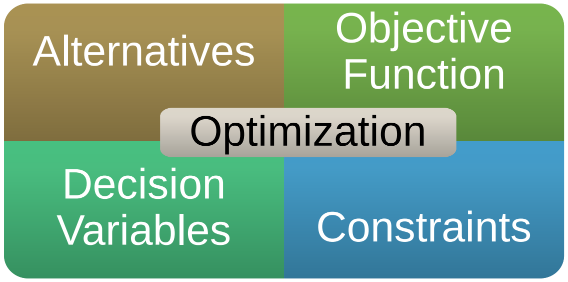


Alternatives - Routes

Supply → Port → Extraction → Transesterification → Demand



Decision Variables



Supply → DAProduced(Sloc), N_{Pond}(Sloc), TSA_{pond}(Sloc)

↓ $Transport_{Truck}$(Sloc,Ploc), N_{Truck}(Sloc,Ploc)

DATransported(Ploc) → **Port** → DAAvailable(Ploc)

↓ $Transport_{Truck,Rail,Barge}$(Ploc,Eloc), $N_{Truck,Rail,Barge}$(Ploc,Eloc)

DATransported(Eloc) → **Extraction** → AOProduced(Eloc)

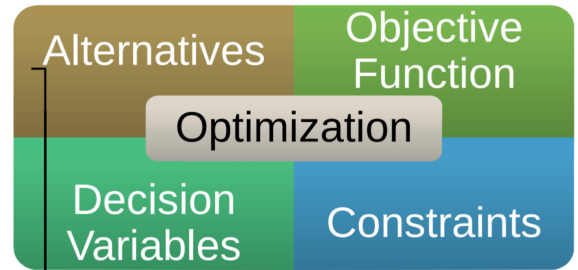
↓ $Transport_{Truck,Rail,Barge}$(Eloc,Tloc), $N_{Truck,Rail,Barge}$(Eloc,Tloc)

AOTransported(Tloc) → **Transesterification** → BDProduced(Tloc)

↓ $Transport_{Truck,Rail,Barge,Pipeline}$(Tloc,Dloc), $N_{Truck,Rail,Barge,Pipeline}$(Tloc,Dloc)

Demand

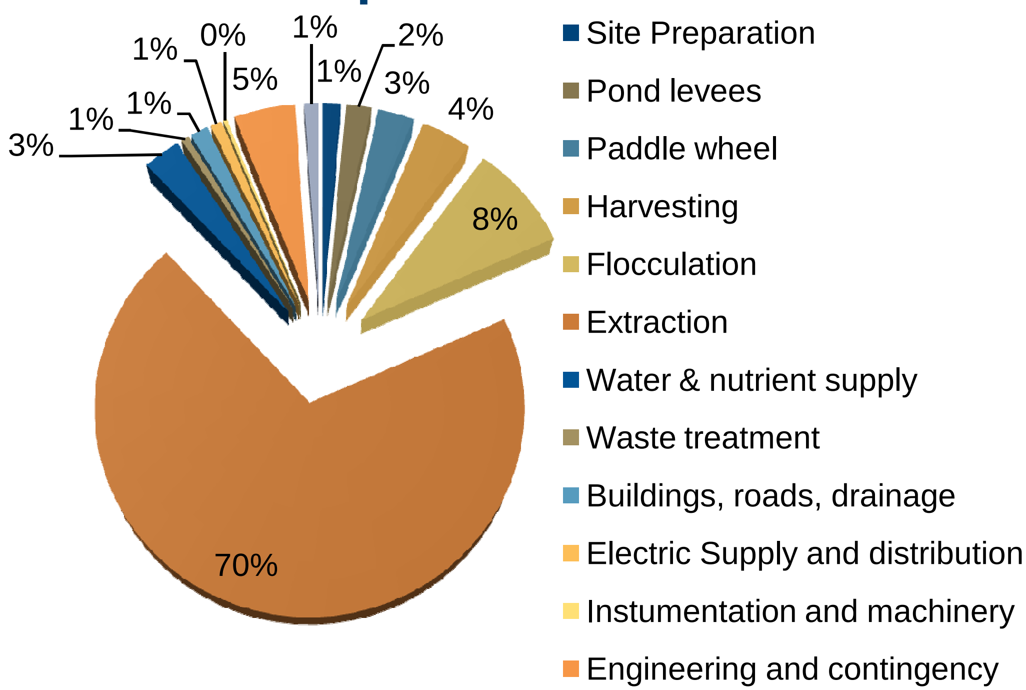
Objective Function



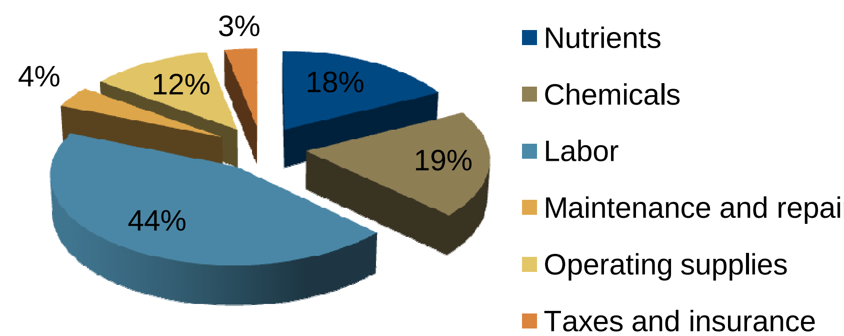
Min

$$Z = CpCt_{Pond\ +\ Ext\ +\ Trans} + TranportCt + \sum_{n=0}^{10} \frac{1}{(1+MARR)^n} \begin{bmatrix} ElecticCt \\ +WaterCt \\ +LandCt \\ +OpCt_{Pond\ +\ Ext\ +\ Trans} \end{bmatrix}$$

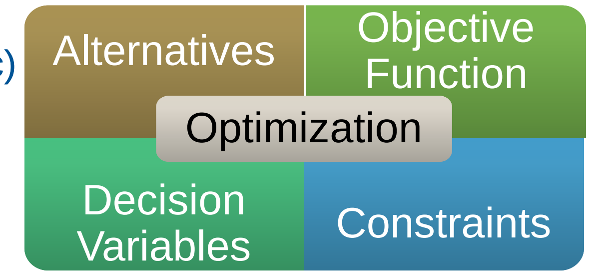
Capital Costs



Operating Costs



Constraints



Supply → DAProduced (Sloc), N_{Pond}(Sloc)

↓ $\text{Transport}_{\text{Truck}}$(Sloc,Ploc)

$$n_{pond} \times DA_{produced\ Sloc} \geq Transport_{Truck_{Sloc,Ploc}}$$

$$Transport_{Truck_{Sloc,Ploc}} = DA_{transported\ Ploc}$$

DATransported (Ploc) → Port → DAAvailable (Ploc)

↓ $\text{Transport}_{\text{Truck,Rail,Barge}}$(Ploc,Eloc)

$$DA_{transported_{Ploc}} = DA_{available_{Ploc}}$$

$$Dryalgae_{available_{Ploc}} \geq \sum_{Eloc} Transport_{Truck_{Ploc,Eloc}} + \sum_{Eloc} Transport_{Rail_{Ploc,Eloc}} + \sum_{Eloc} Transport_{Barge_{Ploc,Eloc}}$$

$$\sum_{Ploc} Transport_{Truck_{Ploc,Eloc}} + \sum_{Ploc} Transport_{Rail_{Ploc,Eloc}} + \sum_{Ploc} Transport_{Barge_{Ploc,Eloc}} = DA_{transported\ Eloc}$$

Constraints

Alternatives | Objective Function | Optimization | Decision Variables | Constraints

DATransported(Eloc) → **Extraction** → AOProduced(Eloc)

↓ Transport$_{Truck,Rail,Barge}$(Eloc,Tloc)

$$DA_{transported\ Eloc} = \frac{AO_{Produced\ Eloc}}{\eta_{extracction} \times OC_{species}}$$

$$AO_{produced\ Eloc} \geq \sum_{Tloc} Transport_{Truck_{Eloc,Tloc}} + \sum_{Tloc} Transport_{Rail_{Eloc,Tloc}} + \sum_{Tloc} Transport_{Barge_{Eloc,Tloc}}$$

$$\sum_{Eloc} Transport_{Truck_{Eloc,Tloc}} + \sum_{Eloc} Transport_{Rail_{Eloc,Tloc}} + \sum_{Eloc} Transport_{Barge_{Eloc,Tloc}} = AO_{transported\ Tloc}$$

AOTransported(Tloc) → **Transesterification** → BDProduced(Tloc)

↓ Transport$_{Truck,Rail,Barge,Pipeline}$(Tloc,Dloc)

$$AO_{transported\ Tloc} = \frac{BD_{Produced\ Tloc}}{3 \times \eta_{transesterification} \times \left(\frac{MW_{BD}}{MW_{lipid}}\right)}$$

Constraints

AOTransported(Tloc) → Transesterification → BDProduced(Tloc)

↓ $\text{Transport}_{\text{Truck,Rail,Barge,Pipeline}}(\text{Tloc,Dloc})$

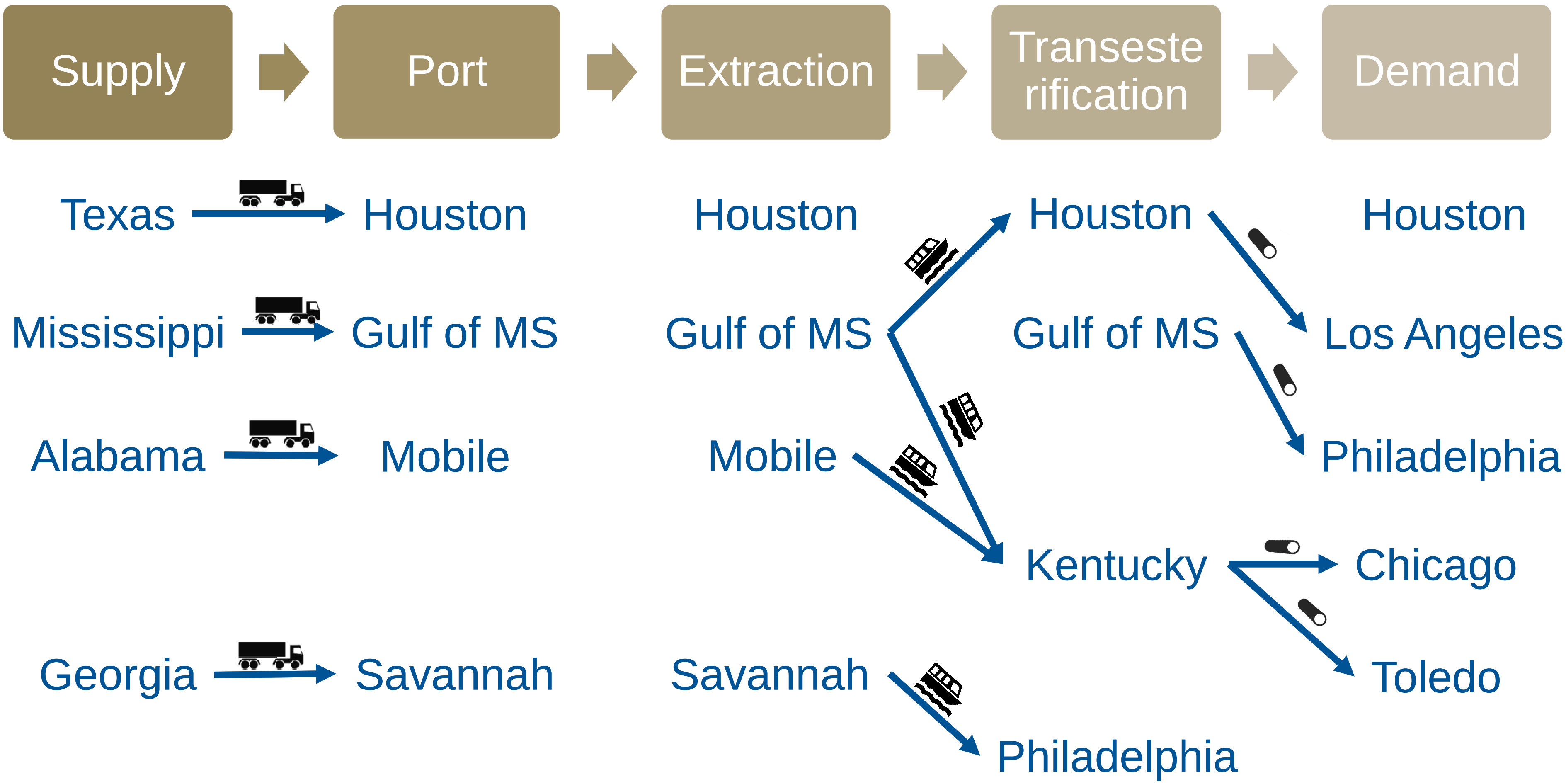
Alternatives | Objective Function | Optimization | Decision Variables | Constraints

$$BD_{produced_{Tloc}} \geq \sum_{Dloc} Transport_{Truck_{Tloc,Dloc}} + \sum_{Dloc} Transport_{Rail_{Tloc,Dloc}} + \sum_{Dloc} Transport_{Barge_{Tloc,Dloc}} + \sum_{Dloc} Transport_{Pipe_{Tloc,Dloc}}$$

$$\sum_{Dloc} Transport_{Truck_{Tloc,Dloc}} + \sum_{Dloc} Transport_{Rail_{Tloc,Dloc}} + \sum_{Dloc} Transport_{Barge_{Tloc,Dloc}} + \sum_{Dloc} Transport_{Pipe_{Tloc,Dloc}} \geq Demand_{Dloc}$$

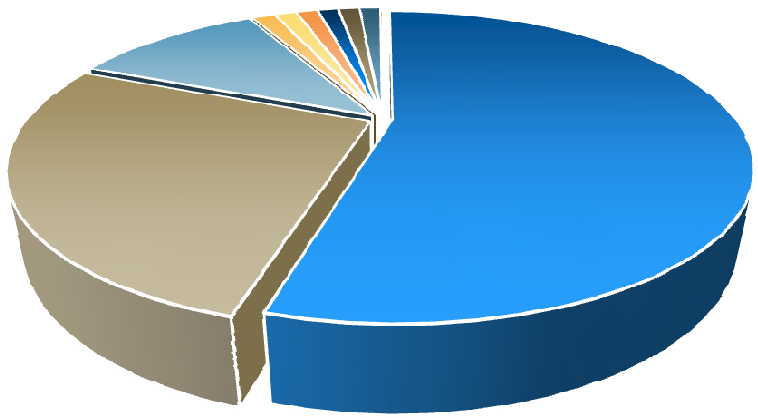
Alternatives | Objective Function | Optimization | Decision Variables | Constraints »»» **GAMS** (General Algebraic Modeling System) »»» **BARON**

Results

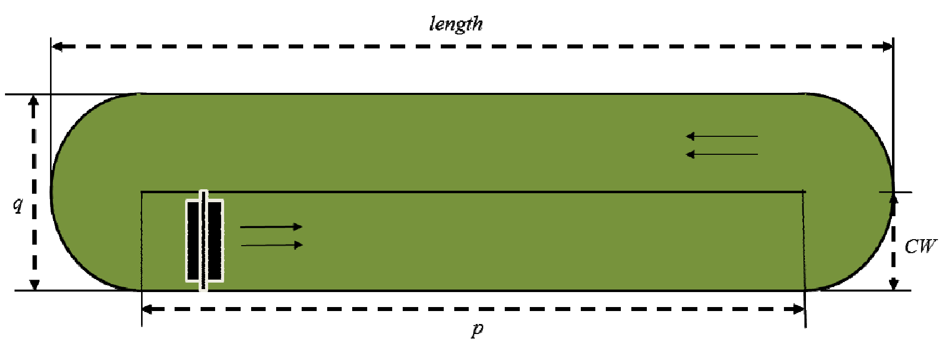

Supply
Port
Extraction
Transesterification
Demand
Texas
Houston
Mississippi
Gulf of MS
Alabama
Mobile
Georgia
Savannah
Houston
Gulf of MS
Mobile
Savannah
Houston
Gulf of MS
Kentucky
Philadelphia
Houston
Los Angeles
Philadelphia
Chicago
Toledo

Results

Production Costs

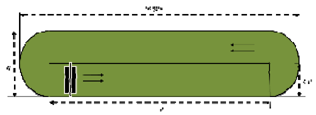
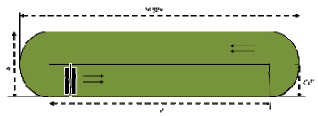
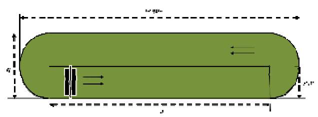
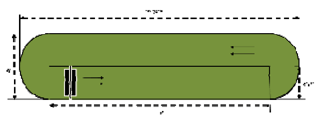


Raceway Pond Dimensions = Channel Depth = 1 m
Pond width = 3.5 m
Pond length = 300 m



Results

Supply

			$N_{Pond}(Sloc)$			$N_{Truck}(Sloc,Ploc)$
Texas		x	8.5000E6	=	8.5000E5 ha	3.7686E5
Mississippi		x	8.5200E6	=	8.5200E5 ha	7.5971E6
Alabama		x	8.8200E6	=	8.8200E5 ha	3.5821E5
Georgia		x	1.0665E7	=	1.0665E6 ha	4.3563E5

Conclusions

- A mathematical framework is developed to estimate the best combination of algae species, geographical location, and raceway pond geometry by combining experimentally validated temperature, irradiance, and algae growth models with optimization

- Model the network flow topology of algae oil distribution in the United states

Future directions

- Model the dynamic behavior of algae biomass cultivation using HYSYS simulation software

Acknowledgement

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- Department of Chemical Engineering, The University of Tulsa
- IPEC

THANK YOU

Questions???