Algal Scaling

- 1500 bbl/day – amount needed to integrate with refinery
- 25,000 L, 90 \( m^2 \) of solar area: 1-3 kg algae/wk (~3 g/m\(^2\)/day)

\[ \Rightarrow 7700 \text{ acres} \]
\[ \Rightarrow 110 \times 10^6 \text{ gallons water/h} \]
Biofuels: Other Platforms

• **Plant oil based routes**
  - Technology for conversion of plant oils such as soybean oil or palm oil well established
  - Conversion technology not capital intensive
  - Costs driven by cost of the plant oil which typically high
  - Soybean oil today is $1200 per tonne, that leads to over $4.00/gallon feedstock component in total cost of biodiesel
  - Raises questions concerning competition for food
Biofuels: Other Platforms

- **Other Fermentation Routes**
  - Synthetic biology used to modify yeast or other organisms to make specific products
  - Similar to fermentation, feedstock is sucrose
  - Cost of Brazilian raw cane sugar gives of order $3 per gallon of diesel hydrocarbon product (rough estimate)
  - Problems with microorganism survival and productivity

- **Catalytic conversion of other plant products**
  - Early stages of development
  - Need to find abundant plant products that are cheap
  - Technology not clear for estimate base
Co-Product Options

Despite consuming a small fraction of US oil compared with fuel, petrochemical products are worth more:

- Liquified refinery gases 2.3%
- Miscellaneous products 0.4%
- Still gas 4.1%
- Asphalt and road oil 3.0%
- Petroleum coke 5.0%
- Waxes 0.1%
- Lubricants 1.0%
- Special naphthas 0.2%
- Residual fuel oil 3.8%
- Heavy fuel oil 6.1%

\[\sim \$375bn\]

Petrochemicals 3.4% Including: naphtha, ethane, ethylene, other oils

\[\$385bn\]

Fuels 70.6% Including: motor gasoline, aviation gasoline, kerosene-type jet fuel, diesel

\[\sim \$375bn\]

Pre-tax value of petrochemical products, such as plastics, cosmetics, pesticides, detergents, paints and adhesives (excluding pharmaceuticals)

\[\sim \$385bn\]

Pre-tax value of transport fuels

Diverse product framework

NSF Engineering Research Center for Biorenewable Chemicals
Research Overview

- Biocatalysis and Microbial Engineering
  - Enzyme Engineering
  - Pathway Optimization
  - Strain Selection
- Chemical Catalysis
  - Catalyst Engineering
  - Catalyst Optimization
  - Catalyst Selection
- Life Cycle Analysis
  - Biocatalysis
  - Fatty Acids
  - Chemical Catalysis
  - α-Olefins

Testbeds

Renewable Carbon → Biorenewable Chemicals
General Framework

Fermentation

Fatty Acid and Polyketide Metabolism

Biocatalysis

Fatty Acids
3-en-2-one
3-keto Fatty Acids
Ring Pyrones
Ether Fatty Acids
Ester Fatty Acids

Chemical Catalysis

α-Olefins
Dienes
Branched-enes/ins
Ring Structures
Ethers
Esters

Polymerization

Polyolefins
Synthetic Rubbers
Resins/Styrenes
Polystyrenes/Nylons
Biodegradables
Biodegradables
Fast Pyrolysis

Corn stover (~1.5 GJ m⁻³)
Gas (~6 MJ kg⁻¹)
Bio-oil (~22 GJ m⁻³)
Biochar (~21 MJ kg⁻¹)

Cellulose

Gas
H₂, CO, CH₄, CO₂

Bio-oil

Biochar