Algae-to-fuel: integrating thermochemical conversion, nutrient recycling and wastewater

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Our legacy of world-changing innovations

- First telerobotic surgical system
- New drug for lymphoma
- Ultrasound for medical diagnostics
- First ARPANET and internetworking nodes
- First computer mouse
- Treatment for drug-resistant malaria
- Emmy Awards for HDTV and more
- Created Siri (acquired by Apple)

U.S. Dept. of Education 2010 technology plan

- $540 million annual revenues
- 2,100 staff members
- 21 locations worldwide
Energy-related projects, Chemistry and Materials Lab

• Hydrothermal liquefaction of algae (EERE)
• CO$_2$ capture technologies (NETL)
  - Chilled ammonia
  - AC-ABC high P
  - Falling bead solid sorbent
  - Fixed solid sorbent
  - Mixed salt
• Selective recovery of metals from geothermal brines (EERE)
• Solar grade silicon (commercial licenses)
• Titanium metals production (ARPA-E)
• Containerless natural gas storage (ARPA-E)
• Vanishing electronics / silicon air battery development (DARPA)
• Alane (AlH$_3$), hydrogen storage for fuel cells (DOE)
• Low energy nuclear reaction (commercial client)
• Selective separation of ethanol from gaseous streams
ALGAE TO FUELS
Algae to fuels

Not shown for simplicity: additional inputs (i.e. solvents), outputs (i.e. water) and separation operations
Algae to fuels - pros

- Renewable fuel, low C footprint
- “High impact” (cfr. DE-FOA-0000811)
- Does not compete with land for food
  - Non-arable land
  - PBRs in the ocean
- High growth rate
- Contains a fraction of lipids: high C/O ratio, reduced functionality
Algae to fuels - challenges

- Algae is very diluted in water
  - Energy penalty for dewatering
  - Not economical for pyrolysis or gasification. OK for hydrothermal

- Costs pile up easily (isn’t this always the case?)
  - Capital: cents on liners for raceways, thickness of PBRs
  - Operating: moving water, CO₂,…
  - Location is very important: realistic resource assessment is needed

- Contains a fraction of proteins
  - Aromatic heterocycles formed during thermochemical conversion

- They require fertilizers
  - Food vs. fuel?

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Algae to fuels - nutrients and sustainability

- Some nutrients needed to grow microalgae to grow all transport fuel for EU (2010):
  - 25 million tons of N
  - 4 million tons of P
  - Values above: twice the amount of fertilizer produced in EU

- Residual source of nutrients
  - Wastewater as source of N, P,...
  - Agricultural runoffs

- Recycling of nutrients
Algae to fuels - wastewater: N calculations

- N in wastewater: organic nitrogen, ammonia, nitrite, and nitrate
- Typical N concentration in wastewater *
  - 85 mg/L of N (strong)
  - 40 mg/L of N (medium)
- Maximum amount of algae achievable **
  - 1.2 g/L (dry basis)
  - 0.56 g/L (dry basis)
- Wastewater helps, but it is not sufficient
- Potential output ***
  - San Francisco: 8600 kg N/day → 5.7 million Gal / year
  - DC: 56000 kg N/day → 37 million Gal / year

** Assumptions: all N being used, 7 wt% N in algae
*** Assumptions: C/N (wt) = 6.7, C efficiency = 65%, fuel modeled as dodecane
HYDROTHERMAL LIQUEFACTION WITH RECYCLING OF NUTRIENTS
Algae to fuels - HTL

- Biomass/water mixtures are heated to 200-350 °C in closed systems to form biocrude oil.
- N-rich compounds are extracted in the water phase during the low-temperature step (also C)
- N, C and other nutrients from the aqueous phase can be recycled for production of biomass.
- US 2014/0275299
Algae to fuels - recycling of nutrients (N)

- HTL1 aqueous phase was the sole source of N (blue line).
- Biomass concentration was higher than cultures with no N source and similar to cultures with excess nitrate.
- 47% of N from HTL1 aqueous phase was consumed during algae growth.
- Optimization is needed (operated at excess N)
Algae to fuels - recycling of nutrients (C)

- C source (blank, green line): 1 g/L NaHCO3
- C sources (blue lines): 1 g/L NaHCO3 + HTL1 aqueous phase (dilution factors were x35 and x70)
- Cultures with recycled C grew faster than blank
- Results show that algae can grow mixotrophically using recycled C.
Algae to fuels - recycling of nutrients (C)

- Sole N source: HTL1 aqueous phase
- Sole C source: HTL1 aqueous phase
- Biomass growth rate and final concentration increase with high dosage of nutrients
- Results show that algae can grow heterotrophically using recycled N and C
- 85% of C in aqueous phase was consumed (preliminary result)
HTL + WWT =
Other feedstocks

- Large amounts of wet organic residues are being wasted.
- Opportunity: some wet wastes have a significant heating value that can be recovered in the form of liquid fuels
  - Biosolids: 3.9 million dry tons of biosolids were wasted in 2014.
    - Potential impact: 780 million Gal of gasoline
  - Manure: 60 million tonnes available in the US
    - Potential impact: 66 million Gal of gasoline
- Example: Analysis of biosolids from local wastewater treatment plant after anaerobic digestion
  - Lipid content (Soxhlet extraction using Folch method): 18 wt%
  - Elemental analysis: 45 wt% C, 7 wt% H
- Hydrothermal liquefaction (HTL): recognized as highly promising technology
- Several scenarios combining biosolids, algae and nutrient recycling. Stay tuned...
Thank You

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