SRI International

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

Presented by Jordi Perez

Bioenergy 2015

June 24th 2015

Our legacy of world-changing innovations


First telerobotic surgical system

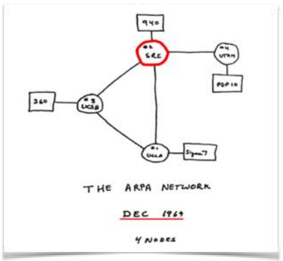
New drug for lymphoma

.com
.gov
.org

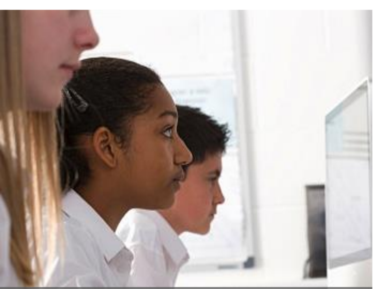
First assigned domain names


First computer mouse


Ultrasound for medical diagnostics



First ARPANET and internetworking nodes


U.S. Dept. of Education 2010 technology plan

Treatment for drug-resistant malaria


Emmy Awards for HDTV and more

Created Siri (acquired by Apple)

$540 million
annual revenues

2,100
staff members

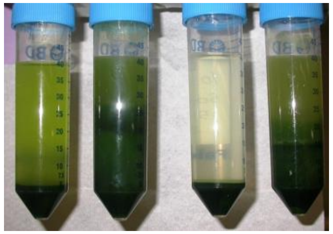
21 locations
worldwide

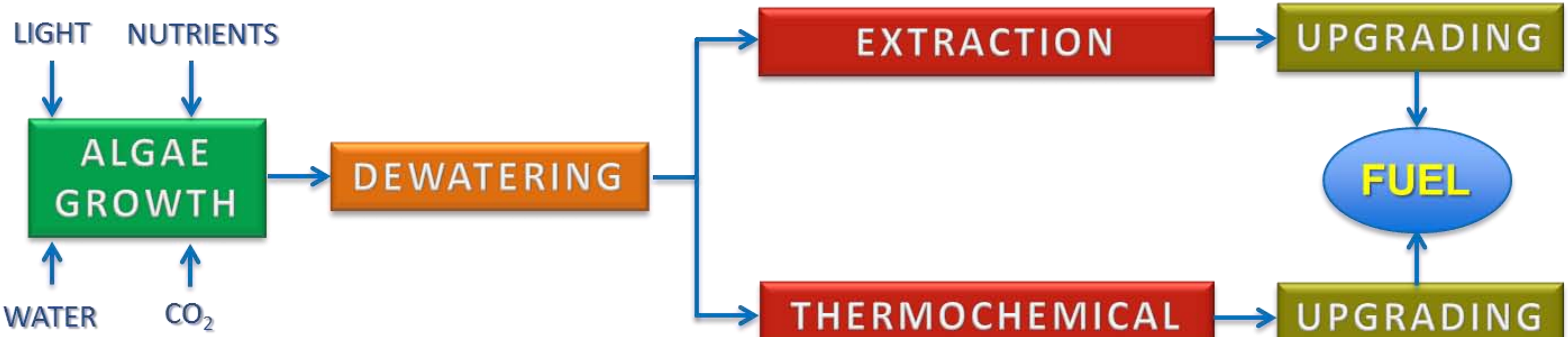
Energy-related projects, Chemistry and Materials Lab

- 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

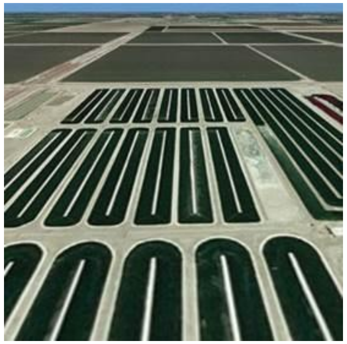
ALGAE TO FUELS

Algae to fuels



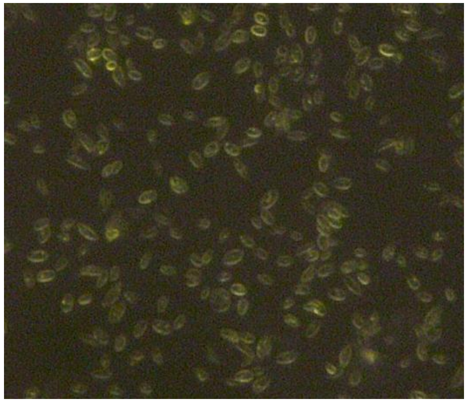


Not shown for simplicity: additional inputs (i.e. solvents), outputs (i.e. water) and separation operations



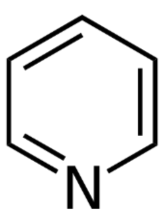
Algae to fuels - pros

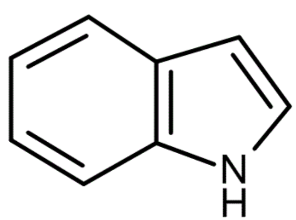
- Renewable fuel, low C footprint
- "High impact" (cfr. DE-FOA-0000811)
- Does not compete with land for food
  - Non-arable land
  - PBRs in the ocean
- High growth rate
- Contains a fraction of lipids: high C/O ratio, reduced functionality



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, CO_2,…
  - 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?





$\Delta H_{\$}$

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

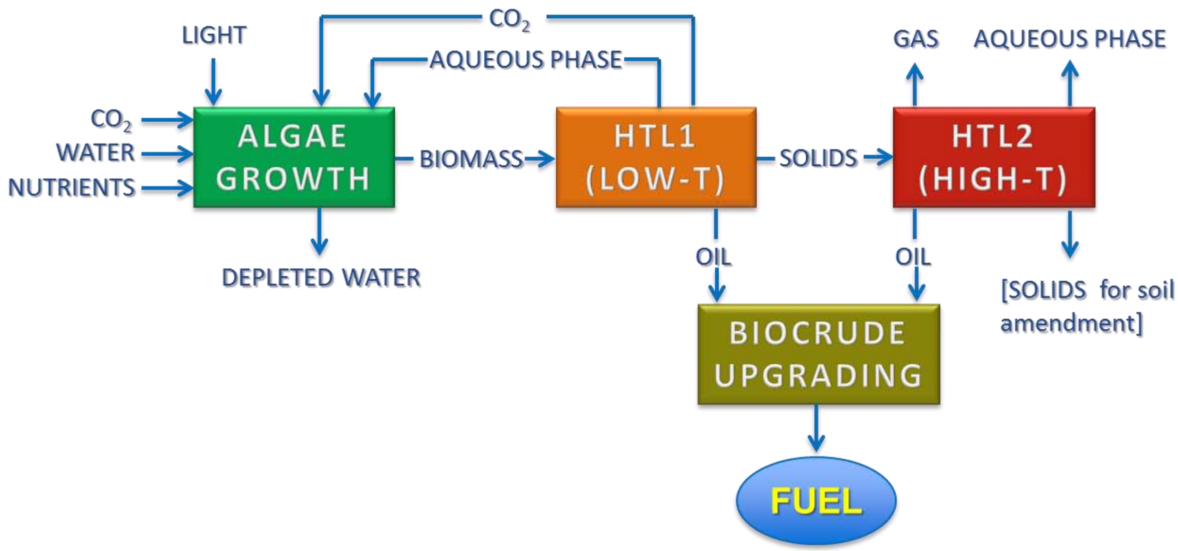
Algae to fuels - wastewater: N calculations

- 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

* Metcalf and Eddy (1991) Wastewater Engineering. Treatment Disposal Reuse, G. Tchobanoglous and F.L. Burton (Eds.), 1820 pp. New York: McGraw-Hill
** 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

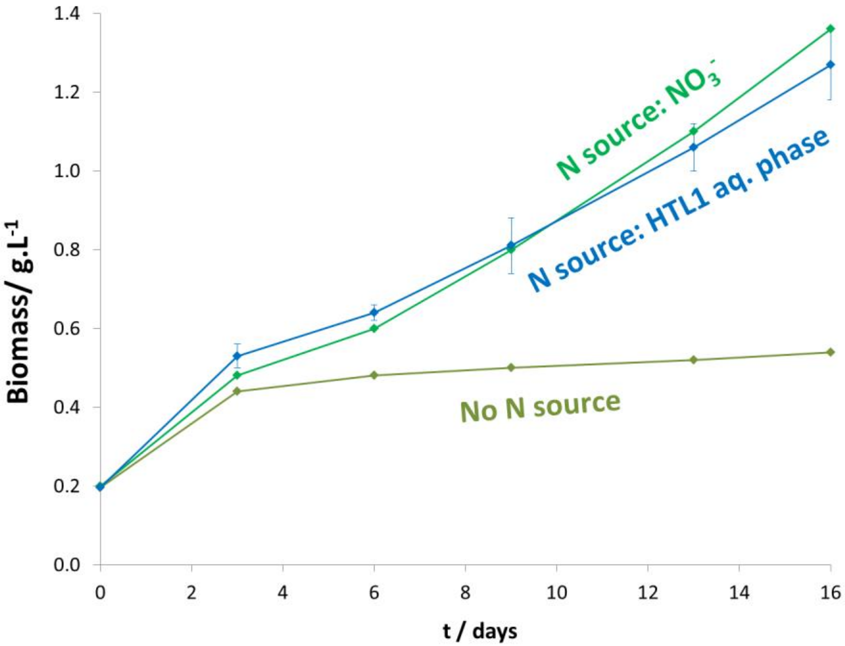
Algae to fuels - HTL



- 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

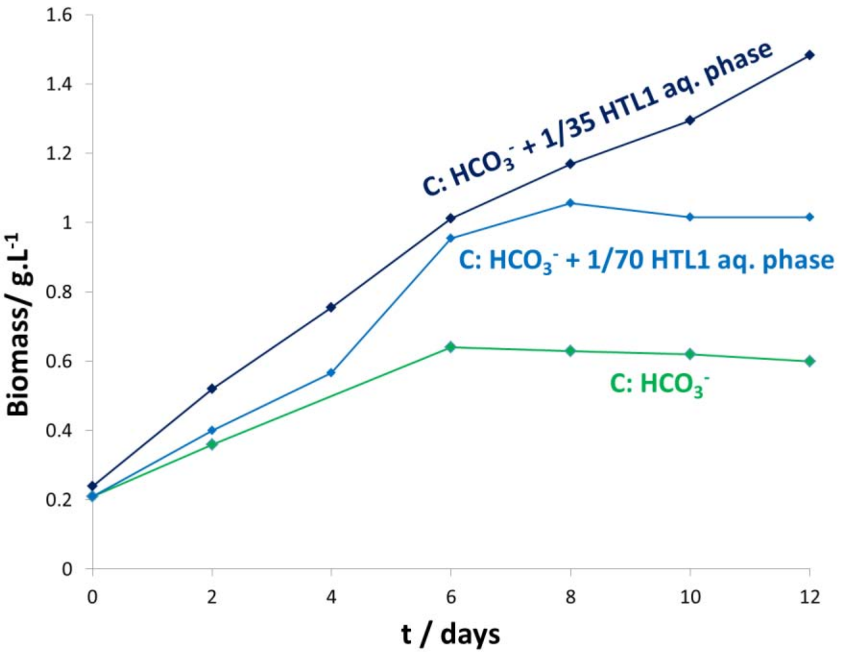
Algae to fuels - recycling of nutrients (N)

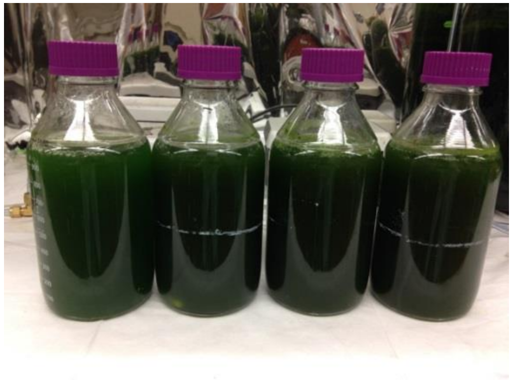
- HTL1 aqueous phase was the sole source of N (blue line).
- Biomass concentration was higher than cultures with no N source and similar to cultures with excess nitrate.
- 47% of N from HTL1 aqueous phase was consumed during algae growth.
- Optimization is needed (operated at excess N)



Algae to fuels – recycling of nutrients (C)

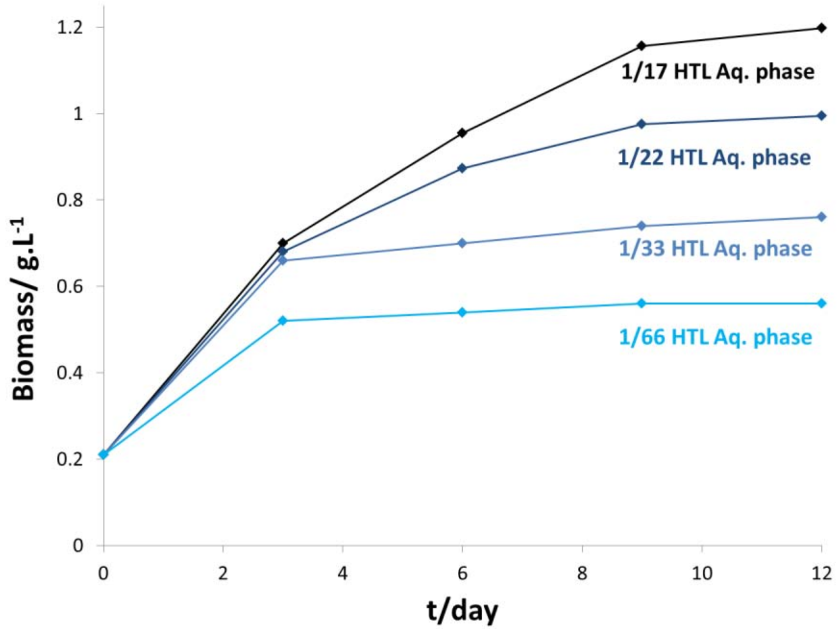
- C source (blank, green line): 1 g/L NaHCO3
- C sources (blue lines): 1 g/L NaHCO3 + HTL1 aqueous phase (dilution factors were x35 and x70)
- Cultures with recycled C grew faster than blank
- Results show that algae can grow mixotrophically using recycled C.





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)

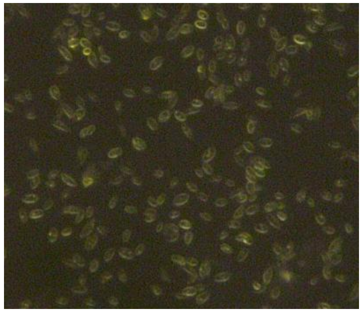


HTL + WWT =

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 <u>after anaerobic digestion</u>
  - 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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