Catalytic Hydrothermal Gasification

Solving Two Problems at Once—Renewable Energy and Clean Disposal of Wet Wastes

Catalytic Hydrothermal Gasification (CHG) is a proven process which efficiently converts wet organic matter into methane/carbon dioxide in a single step—essentially "catalytic thermo-chemical digestion" with much higher yields than anaerobic digestion.

In the production of algal fuels, CHG produces a second high-value fuel stream from the residuals left after extraction of lipids, doubling the total fuel energy produced.

CHG AND NAABB

- Feedstock is organic material made into slurry
  - Most algae make ideal feedstocks—easy to prepare and easy to gasify
  - Can gasify either whole algae or algae biomass after lipids are extracted (Lipid-Extracted Algae or LEA)
- Reactions are fast (< 1 hour) and complete (>99%)
- Yield is ~0.4 liters of methane per gram dry solids
- Process developed over 30-year period at PNNL

OUTPUT VALUES FOR 1 T/D DRY WEIGHT ALGAE*

ITEM	QUANTITY/DAY	PRICE/UNIT	ANNUAL VALUE
Electricity	1,600 kWh/d	$0.12/kWh	$67,200
CO_2	0.81 t/d	$19/t	$5,386
Nitrogen (NH_3)	16 t/y	$231/t	$3,696
Potash	9 t/y	$875/t	$8,109
Process Heat	7.2 MMBtu/d	$6.00	$14,841
TOTAL			$99,232

Note: No value assigned to phosphorus because processing cost to recover fertilizer not yet known.

ANNUAL TOTAL OF OPEX AND CAPEX	$55,587

Note: No cost assigned to algae LEA feedstock; unit size 10,000 m³/d net methane output.

ANNUAL PROFIT/TON/DAY DRY ALGAE LEA	$43,645

**Assumes commercial-scale unit.*

ALGAE SAMPLES TESTED

ALGAE NAME	TYPE	YEAR	SOURCE
Spirulina	Cyanobacteria	2009	Genifuel
Mixed Species	Algae, Diatoms, Cyanobacteria	2009	Genifuel
Chara	Macroalgae	2010	Palmer Labs
Nannochloropsis	Algae	2010	Solix
Unknown	Diatom	2010	HRBP (Celana)
Nannochloropsis*	Algae	2011	Solix LEA
Dunaliella*	Algae	2011	TAMU Pecos

**Note: 2011 testing is still in process.*

LARGER-SCALE CHG SYSTEMS

Mobile Unit

Skid-Mount System

CLOSED-LOOP NUTRIENT CYCLE

- A key advantage of CHG is nutrient recycle
- Nutrients are recovered from the algae biomass and can be recycled to the growth ponds (or PBR)
  - Nitrogen, phosphorus*, potassium (NPK), and micro-nutrients (iron, copper, zinc, etc.) are recovered
- Carbon dioxide can also be recycled
  - Sterile output water is saturated with CO_2
  - Recovered CO_2 can also be sparged into growth ponds

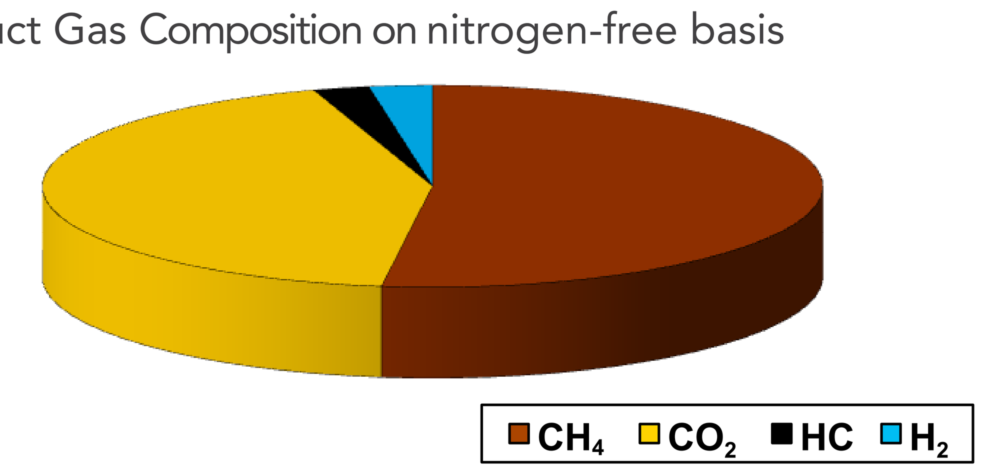
**P recovered in separated mineral*

CONTRIBUTION OF CHG TO ALGAE BIOFUELS

- Energy in the methane produced from gasification of LEA equals the energy in the algal lipids, assuming 25% lipid content, 75% LEA biomass
- Assuming the methane is immediately used to make electricity, then under reasonable price assumptions the methane will increase the total algal fuel value by 60%

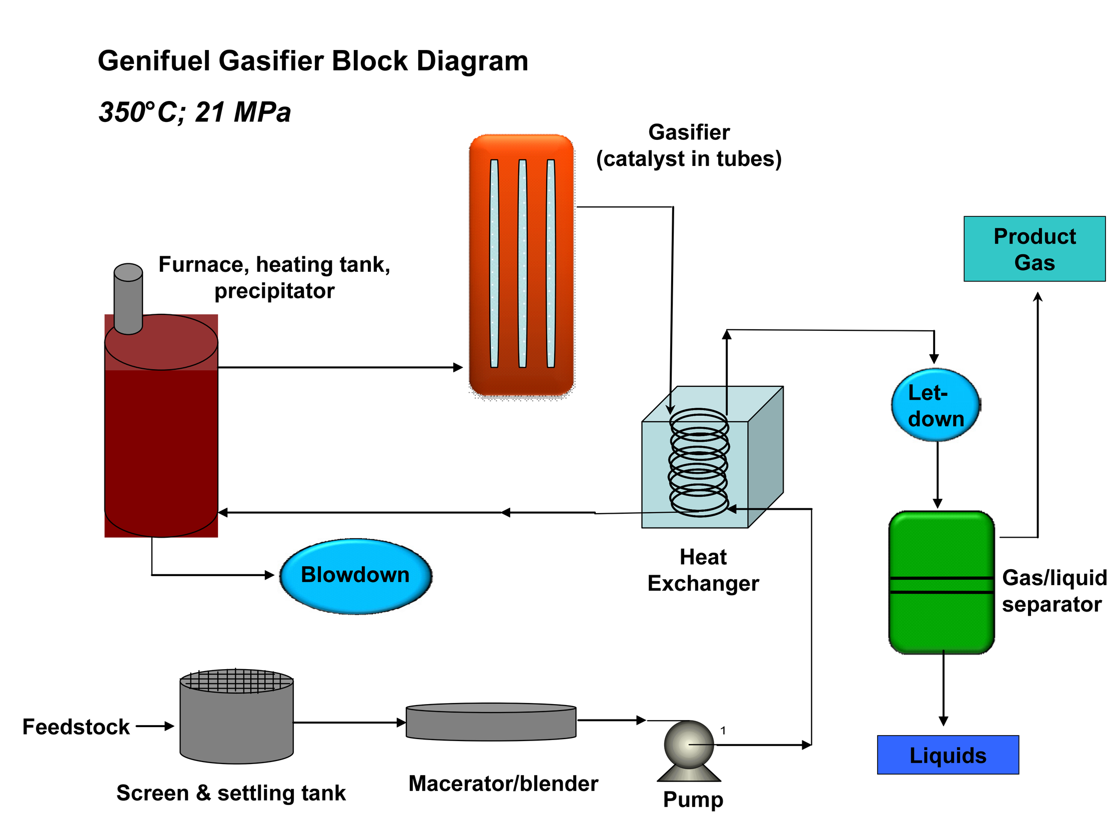
CONTINUOUS-FLOW PROCESSING RESULTS: ALGAE – SPIRULINA

Product Gas Composition on nitrogen-free basis

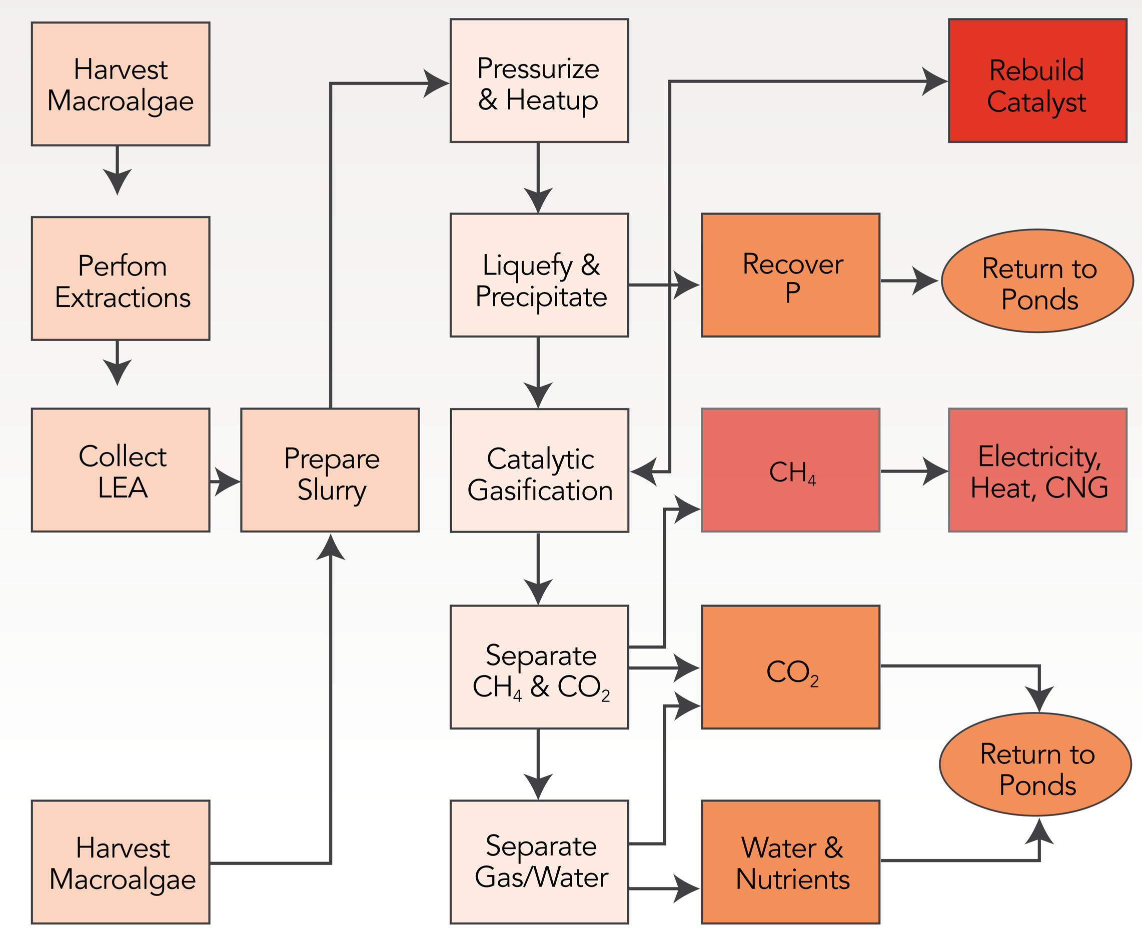


- COD reduced from 241,300 ppm (22.4 wt% DS) by 96.6%
- 8.3% ash
- 20.6 MPa, 1.4 LHSV @ 350°C, S scrub with Ru/C catalyst
- 1.2 L of a medium-Btu gas per gram carbon in aqueous
- 4.3% carbon loss with mineral

GENIFUEL GASIFIER BLOCK DIAGRAM



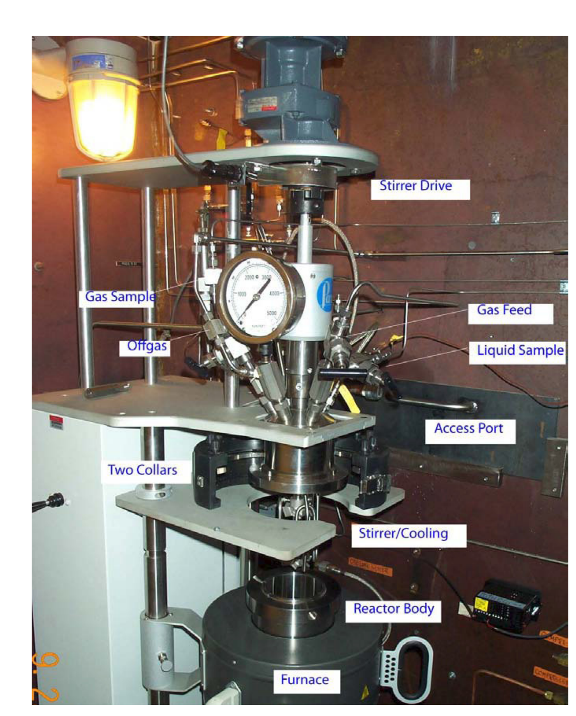
PROCESS FLOW DIAGRAM (INPUTS/OUTPUTS)



CHG POTENTIAL OUTPUT IN PERSPECTIVE

- If algae produced 10% of the US requirement for liquid transport fuels, production would be app. 20 billion gallons of algal lipids per year
- The algal biomass left after lipid extraction would be 207 million t/y dry weight
- This amount of algal biomass could produce 9% of the US production of electricity
  - Equivalent to more than 6X the amount of electricity from wind and solar combined (2009)
  - High-value electricity available any time

LABORATORY CHG SYSTEMS



ACKNOWLEDGEMENTS

NAABB National Alliance For Advanced Biofuels and Bio-products

U.S. DEPARTMENT OF ENERGY
OFFICE OF THE BIOMASS PROGRAM

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

A Joint Presentation of PNNL and Genifuel Corporation

Douglas C. Elliott and James R. Oyler

Genifuel