Biohydrogen Production from Renewable Organic Wastes

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Project Team:

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Represented by:
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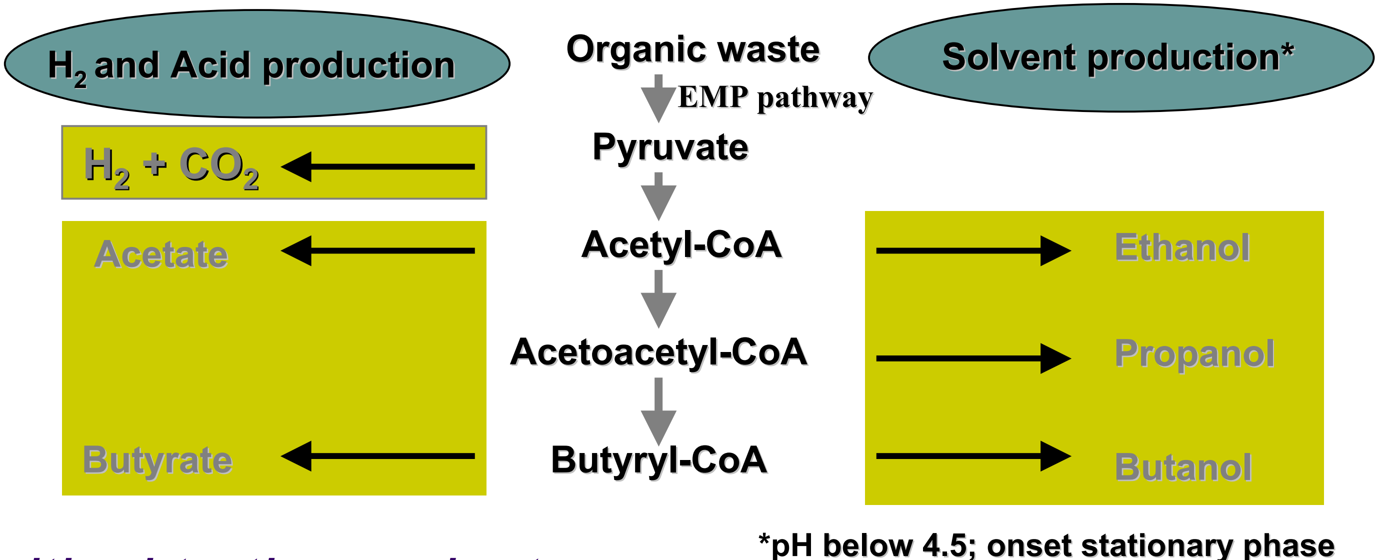
Cost Sharing Partners:	**Role:**
Iowa Energy Center	Provides Pilot Testing Facility
EcoFuels Corporation	Marketing & Commercialization

Industrial Partners:	
Smithfield Foods, Inc.	Wastes Stream Provider
Excel Corporation	Wastes Stream Provider
Universal Entech, Inc.	Marketing/Commercialization

Project Goal

- Develop **Anaerobic Fermentation Process** to convert **negative value organic wastes** (a renewable source) into **hydrogen-rich gas**, which can be used as a fuel source or as a raw material for industries that utilize hydrogen



Goals critical to the project:

- To identify and understand the **physiology of microbial populations (software)** to maximize hydrogen yield

- To **design and develop bioreactor (hardware)** to favor the growth of these microbial population

Approach

- Evaluate technical and practical **feasibility of sustainable hydrogen production** in continuous flow bioreactors using different organic waste stream

- Investigate different strategies for **selective growth of hydrogen producing bacteria** (e.g., heat selection, pH control, reactor configuration)

- Apply **nucleic acid based techniques - Terminal Restriction Fragment Length Polymorphism (T-RFLP)** for microbial identification and quantification

Project Timeline

Tasks	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
First Year (10/1/2000 - 09/30/2001)												
Task 1. Optimization of H_2 Production with Synthetic Waste Streams												
1-1 Enrichment of H_2-producing bacteria												
1-2 Influence of environmental factors												
Report												
Second Year (10/1/2001 - 9/30/2002)												
Task 2. Process Optimization of Continuous-flow Reactor												
2-1 Enhancement of hydrogen yield through heat treatment of seed sludge												
2-2 Identification and quantification of H_2-producing bacteria												
Report												
Third Year (10/1/2002 - 9/30/2003)												
Task 3. Study with Real Waste Streams												
Task 3-1a Lab-scale study using compartmentalized and two-stage sequential reactors												
Task 3-1b Pilot-scale demosntration project to study hydrogen production efficiency												
Task 3-2 Full-scale plant evaluation of hydrogen production	*Subject to funding availability*											
Task 3-3 Microbial community characterization												
Final Report												

Milestones

- **Task 1: Optimization of H_2 Production with Synthetic Waste Streams**
  - **1-1** Enrichment of H_2-producing bacteria (completed)
  - **1-2** Influence of environmental conditions (completed)

- **Task 2: Process Optimization of Continuous-flow Reactor**
  - **2-1** Enhancement of hydrogen yield through heat treatment of seed sludge (completed)
  - **2-2** Identification and quantification of H_2-producing bacteria (completed)

- **Task 3: Study with Real Waste Streams (in progress)**
  - **3-1a** Lab-scale study using compartmentalized and two-stage sequential batch reactors (50% completed)
  - **3-1b** Pilot-scale demonstration project to study hydrogen production efficiency
  - **3-2** Full-scale plant evaluation of hydrogen production
  - **3-3** Microbial community characterization

Status of Progress

Task 1: Optimization of H_2 Production with Synthetic Waste Streams

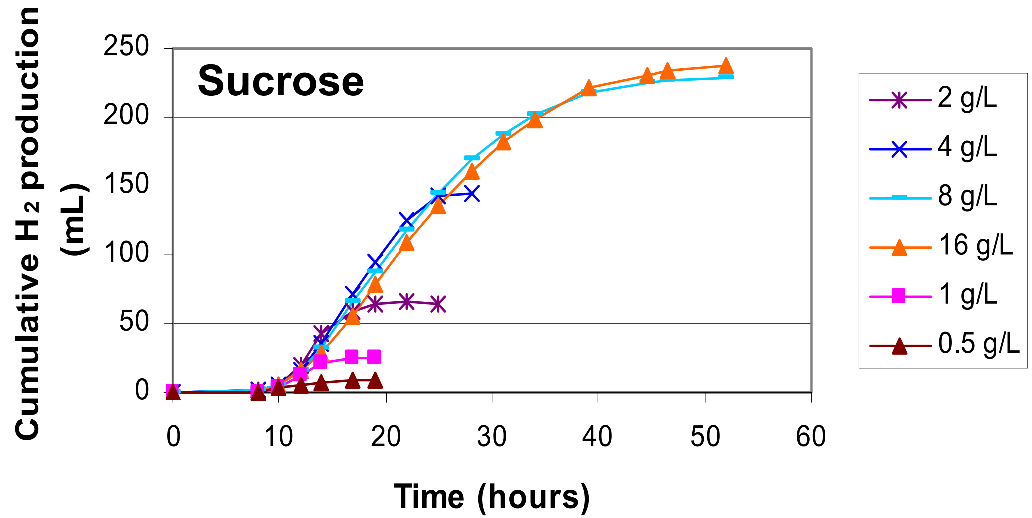
- pH of 5.5 and substrate concentration of 7.5 g COD/L - optimal for start-up
- Inocula rich in hydrogen-producing bacteria are readily available, e.g., compost, soybean soil, potato soil, anaerobic sludge
- Conversion efficiency of 20% (based on COD) with H_2 content of biogas of 55 - 82% was achieved with sucrose, starch, nonfat-dried milk, and commercial dog food
- Determination of important kinetic parameters

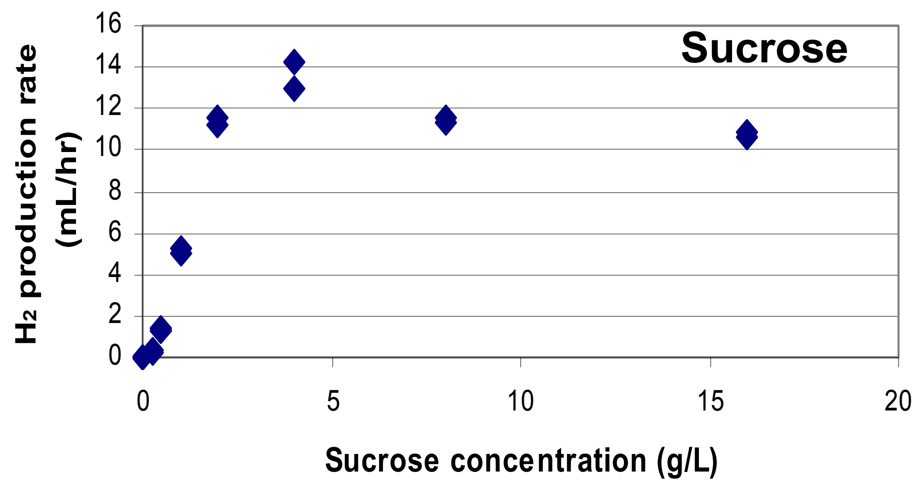
Status of Progress

Task 1: Optimization of H_2 Production with Synthetic Waste Streams (continue)

Biokinetic Study:

- Specific growth rate, μ
  = 0.10 hr^{-1}
- Half velocity constant, Ks
  = 1.00 g sucrose/L
- Yield, $Y_{H/X}$ (L H_2/g VSS)
  = 0.183





Status of Progress

Task 1: Optimization of H_2 Production with Synthetic Waste Streams (continue)

Biokinetic Study:

- Specific growth rate, μ

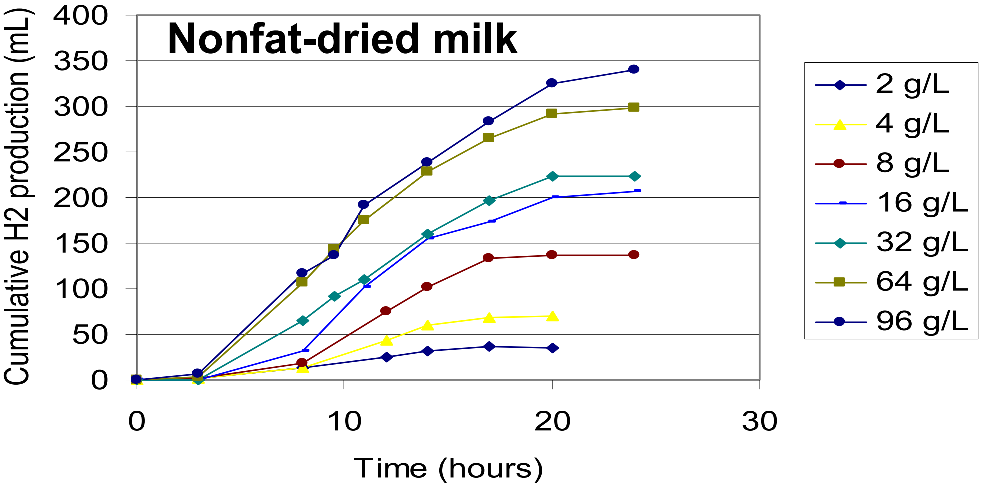
  $= 0.176\ hr^{-1}$

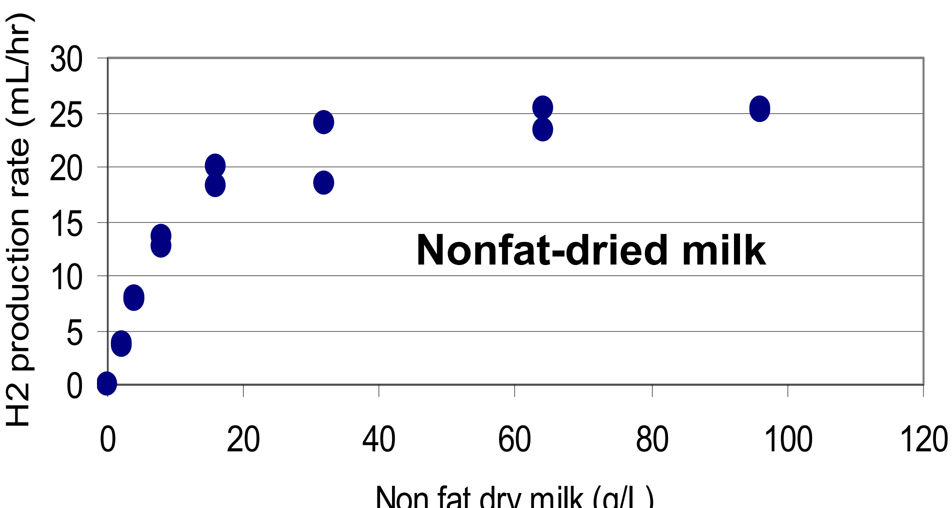
- Half velocity constant, Ks

  = 9.40 g NFDM/L

- Yield, $Y_{H/X}$ (L H_2/g VSS)

  = 0.255



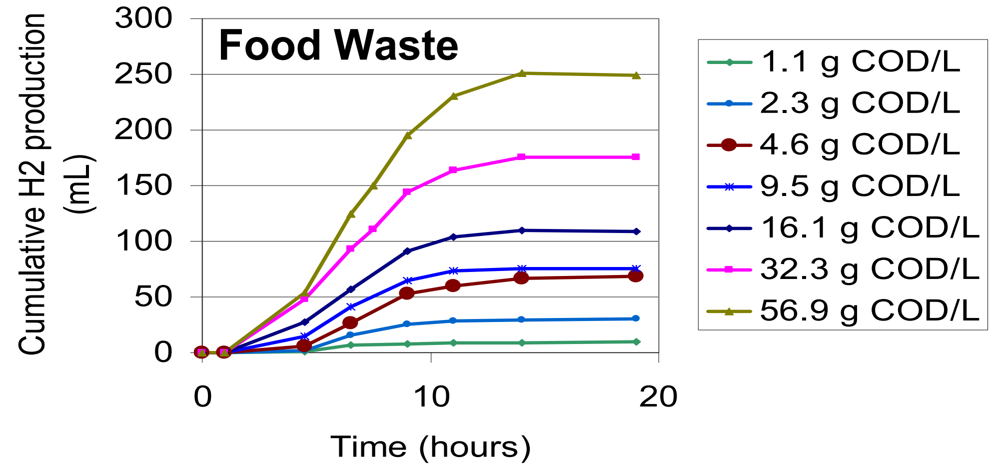


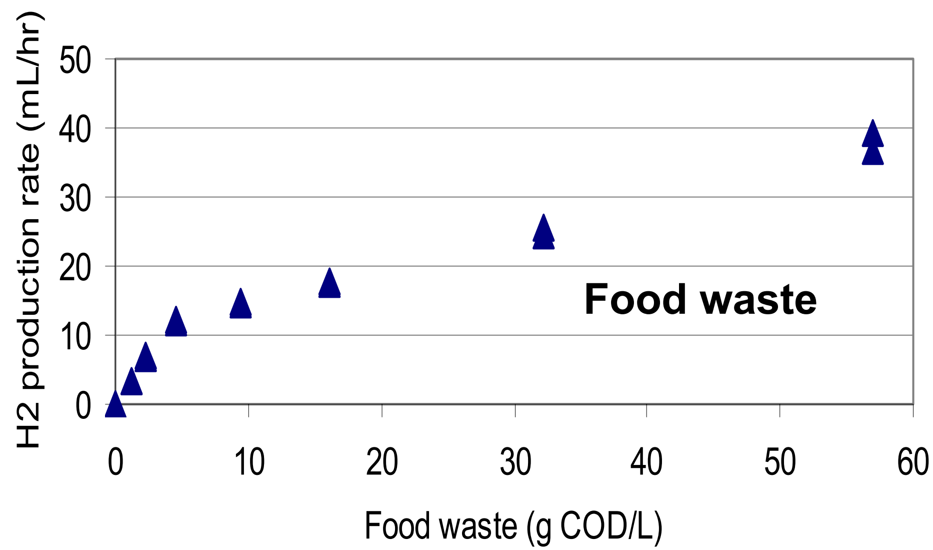
Status of Progress

Task 1: Optimization of H2 Production with Synthetic Waste Streams (continue)

Biokinetic Study:

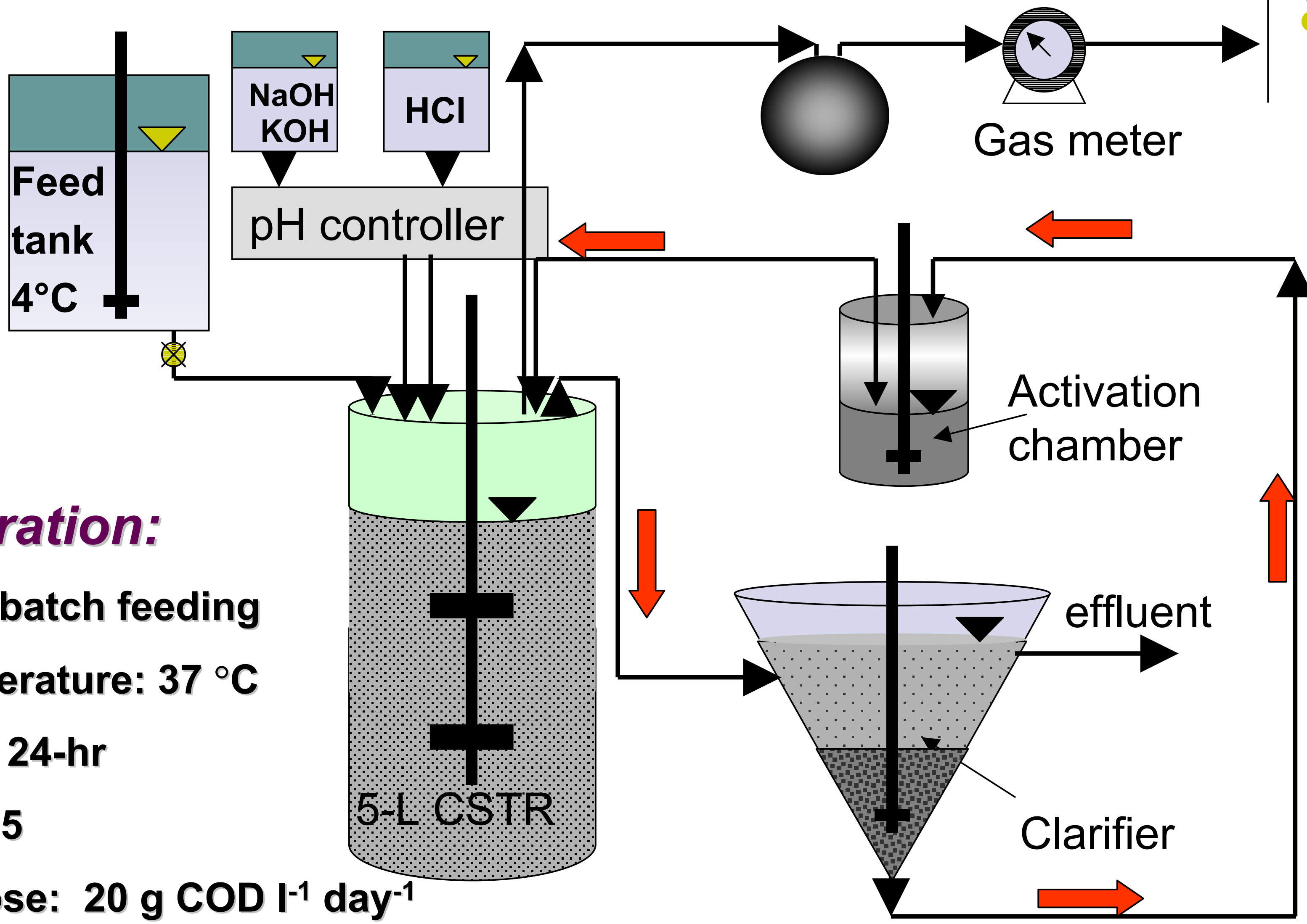
- Specific growth rate, μ
  = 0.215 hr^{-1}
- Half velocity constant, Ks
  = 7.00 g COD/L
- Yield, $Y_{H/X}$ (L H_2/g VSS)
  = 0.223





Status of Progress

Task 2: Process Optimization of Continuous-flow Reactor



Operation:

Semi-batch feeding

Temperature: 37 °C

HRT: 24-hr

pH: 5.5

Sucrose: 20 g COD l^{-1} day^{-1}

Heat treatment: 100 ^{0}C for 15 min

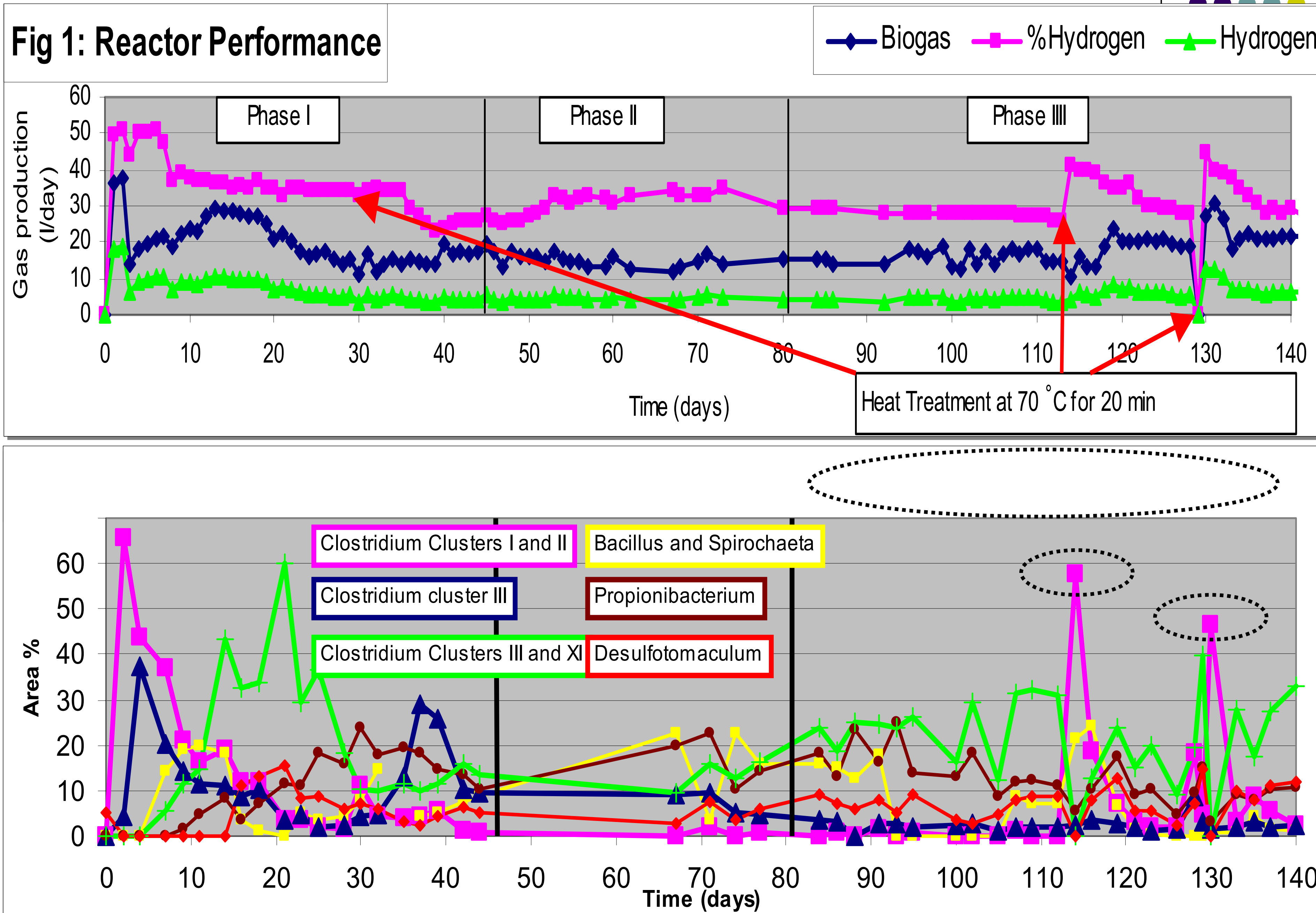


Fig 1: Reactor Performance
Biogas
%Hydrogen
Hydrogen
Phase I
Phase II
Phase IIII
Gas production (l/day)
Time (days)
Heat Treatment at 70 °C for 20 min
Clostridium Clusters I and II
Bacillus and Spirochaeta
Clostridium cluster III
Propionibacterium
Clostridium Clusters III and XI
Desulfotomaculum
Area %
Time (days)

Status of Progress

Task 2: Process Optimization of Continuous-flow Reactor (continue)

- Sustainable H_2 production was achieved by initial heat treatment followed by periodic heat treatment of reactor biomass
- Hydrogen production showed positive correlation with clostridium cluster I and II associated with heat treated biofilm and not bulk biomass
- Repeated heat treatment caused a population shift in identified *Clostridium* populations:
  - Spore germination
  - Substrate competition

Status of Progress

Task 2: Process Optimization of Continuous-flow Reactor (continue)

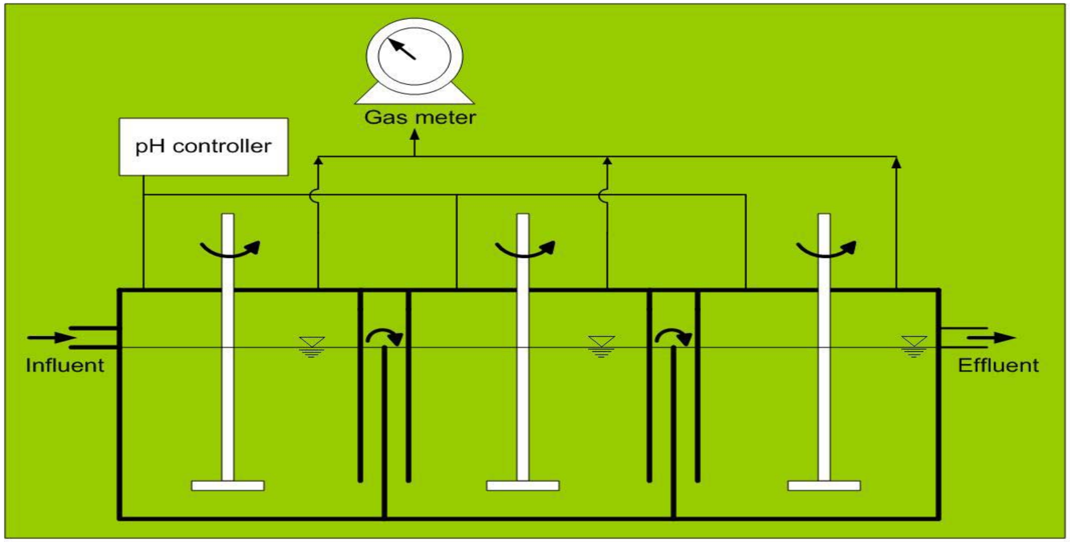
Table Anaerobic populations identified using T-RFLP analysis

1	*Clostridium cluster I & II*
2	*Bifidobacterium*
3	*Spirochaeta*
5	*Propionibacterium*
7	*Clostridium formicoaceticum (cluster XI), C.termitidis, C.aldrichii, C.cellobioparum (cluster III)*
8	*Brachyspira*
10	*C. stercorarium, C. thermolacticum (cluster III)*
11	*Desulfotomaculum*

Status of Progress

Task 3-1a: Study with Real Waste Streams (in progress)

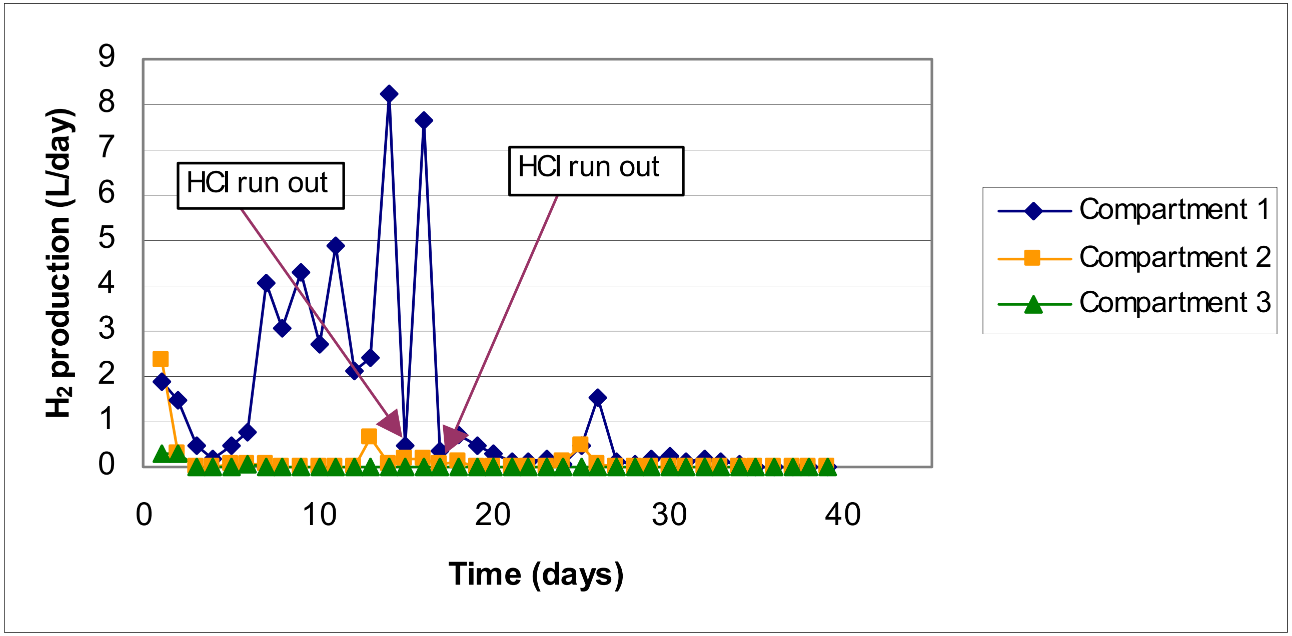
- Compartmentalized reactors (Anaerobic Baffled Reactor)
- Allow accumulation of hydrogen producers inside the reactor while maintain high organic loading rate and low HRT (favorable for hydrogen producers)
- Loading rate = 40 g COD/L/day and HRT = 9 hours



Status of Progress

Task 3-1a: Study with Real Waste Streams (in progress)

- 4 - 6 L H_2/day produced from day 7-14 of ABR operation
- Abrupt drop in hydrogen production on day 15 due to exhaust of acid that caused increase in pH to as high as 8.0
- Failure of pH controller for quick response to pH changes

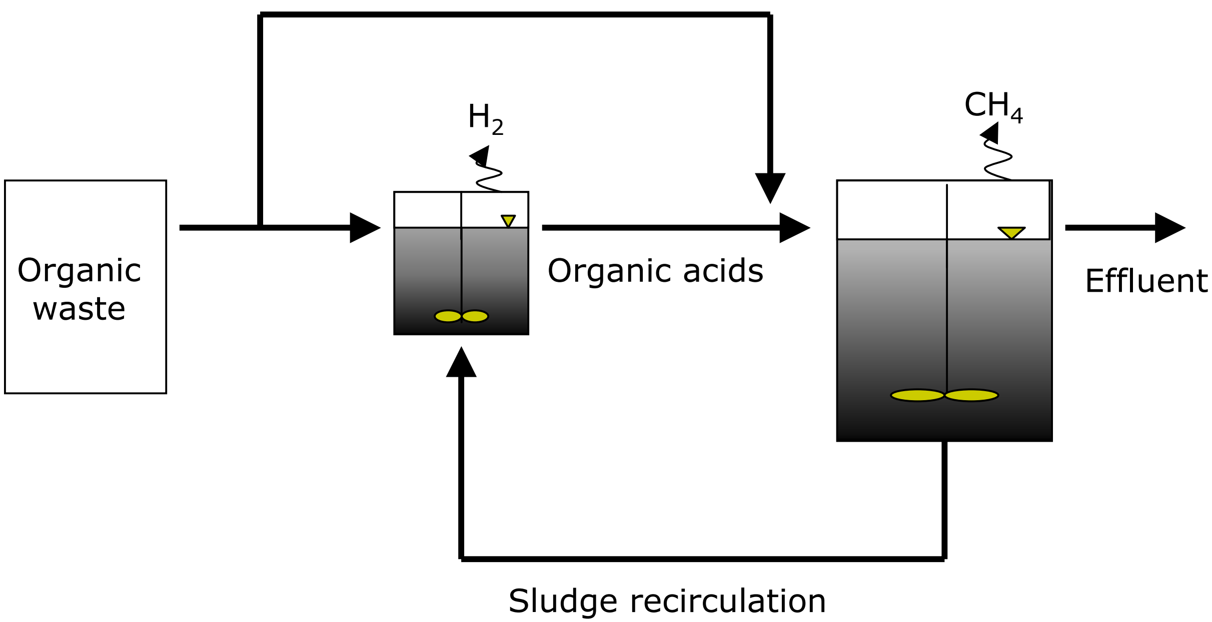


Status of Progress

Task 3-1a: Study with Real Waste Streams (in progress)

- Two-stage bioreactor: To maintain fresh microbial seed in hydrogen producing bioreactor to avoid degeneration

- To provide a favorable environment for the selective growth of hydrogen-producing bacteria in mixed microbial community: e.g. high organic loading, short hydraulic retention time, pH of 5.5



Future Work

Task 3-1b: Pilot-Scale Demonstration Project to Study Hydrogen Production Efficiency (subject to funding availability)

- Installation of pilot-scale bioreactor in IEC' BECON Facility, Nevada, IA
- Evaluation of design and critical operational parameters for hydrogen production in pilot-scale bioreactors using real waste

Task 3-2. Full-Scale Plant Evaluation (subject to funding availability)

- Evaluation of detailed design and operational guidelines for producing hydrogen from real waste

Future Work (continue)

With continuous research on process engineering and microbiology of biological hydrogen production, our research team intends to:

- **Design improved bioreactor** system that favors the selective growth of *Clostridium* cluster I and II
- Obtain operating parameters for efficient bioconversion of real waste stream: **high fructose corn syrup, corn stover, food waste, DDG** etc. to hydrogen
- Develop **nation's first biohydrogen pilot plant** using organic wastes

Cooperative Efforts

PI: Prof. Sung, Environmental Engineer at Iowa State University (ISU)
- Technology Transfer: The ISU patented TPAD to more than 20 commercial installations nationwide. The process won 1999 R&D 100 Award

Co-PI: Prof. Bazylinski, Microbiologist at ISU
- Graduate program committee member & consultant : H_2-producing cultures and sporulation

Co-PI: Prof. Raskin, Environmental Engineer at University of Illinois, Urbana-Champaign
- Expert in microbial community characterization using nucleic acid based techniques

Cost Sharing & Industrial Sharing Partners:
- **Iowa Energy Center** ($134K)**:** Providing Pilot Testing Facility in Nevada, IA
- **EcoFuels Corporation** ($20K), **Smithfield Foods, Inc., Universal Entech Inc. and Excel Corp.:** Marketing & Commercialization, Providing Waste Streams

Publications:

1. Duangmanee, T., Padmasiri, S., Simmons, J. J., Raskin, L. and Sung, S. (2002) Hydrogen production by anaerobic communities exposed to repeated heat treatment. *Water Environment Federation 74th Conference*, Chicago., IL.
2. Duangmanee, T., Chyi, Y. and Sung, S. (2002) Biohydrogen production in mixed culture anaerobic fermentation. *14th World Hydrogen Energy Conference*, Montreal, Canada.
3. Van Ginkel, S., Sung, S. and Lay, J. J.(2001) Biohydrogen production as a function of pH and substrate concentration.*Environmental Science & Technology*, 35:4726 - 4730.
4. Van Ginkel, S., Lay, J. J. and Sung, S. (2000) Biohydrogen production optimization using variable natural inocula. *Proceedings of Water Environment Federation 73rd Annual Conference*, Anaheim, CA.

Budget for 10/01/2002 to 12/31/2003

Total Budget: $ 195,000.00

Amount transferred in May (with no cost time extension up to Dec 31, 2003)
$ 115,000.00

Comments from previous review panel meeting

- Recommended that the work to be continued through development of the initial prototype system and the potential of this process for economic hydrogen production

- Pilot-scale demonstration not to be pursued – require more system optimization for higher hydrogen yield (4-6 moles H_2/mole substrate)

- The project should proceed with corn processing, rendering and other wastes

- Very good, simple process concept, very orderly experimental sequence and the work to date is very good