Novel Two-Stage Process for Photobiological Hydrogen Production

Juergen Polle, Brooklyn College (Presenter)
John Benemann, Benemann Associates
David Brune, Clemson University
Ragaiy Zidan, Savannah River National Laboratory
Joseph Weissman, SeaAg, Inc.
Jian Yu, University of Hawaii
David Kyle, Advanced BioNutrition Corp.
(Project Principal Investigator).

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Overview

Timeline

- Project start date. Pending
- Project end date. tbd
- Percent complete 0%

Budget

- Total project funding DOE $4.28 million (awarded)
  Contractor share: $1.2 mill.
- Funding in FY04 None
- Funding for FY05 Pending

Barriers

This project will develop and verify the basic feasibility of photobiological hydrogen production in terms of the efficiency of both the photosynthetic and fermentation components of the process.

Partners

This project is a collaboration of six P.I.s and organizations (see next slide)

Project Partners (and tasks)

- Project Principal Investigator and Lead Organization:

Dr. David Kyle, Advanced BioNutrition Corp. (Task 4)

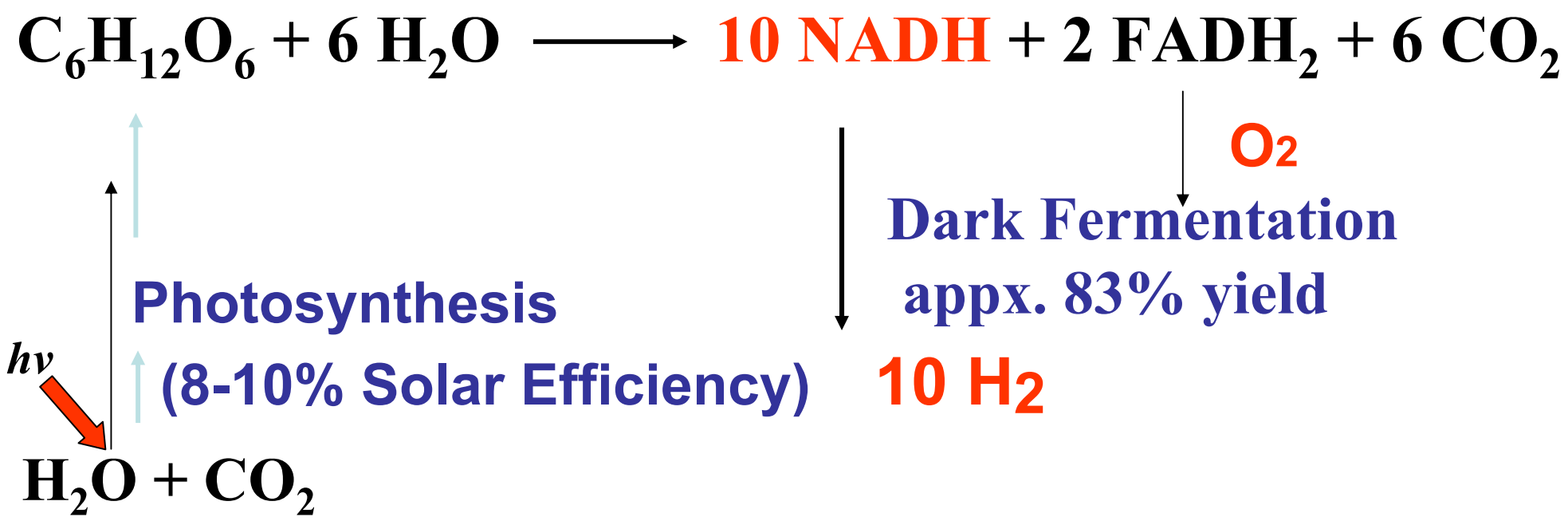
Other Co-P.I.s and Participating Organizations:

- Prof. Juergen Polle, Brooklyn College (Task 1)
- Prof. David E. Brune Clemson University, (task 5).
- Dr. Ragaiy Zidan Savannah River National Laboratory, Hydrogen Technology Section, (Task 6)
- Dr. Joseph Weissman SeaAg, Inc. (Task 2)
- Prof. Jian Yu University of Hawaii, Hawaii Natural Energy Institute, (Task 1).

Objectives

- This project will develop and demonstrate a two stage process for the production of hydrogen fuel from water using microalgae. The first stage will convert solar energy, water and CO_2 into storage carbohydrates. The second stage will convert these storage carbohydrates into H_2 fuel in a dark fermentation, with the CO_2 recycled between the stages. The microalgal cells will be reused and act as catalysis for this process.
- The objectives of this project are to demonstrate the feasibility of achieving high photosynthetic efficiencies in the first stage (approaching 10% of solar) and a high yield of H_2 production in the second stage (up to 10 H2 per mole of glucose).

Novel proposed Two Stage Photobiological Process:



For high yields will need genetically improved algal strains with high photosynthetic efficiency in carbohydrate storage and also high yields of dark fermentative H_2 production.
APPROACHES: **Reduce antenna size in photosynthesis and apply reverse electron flow with limited respiration**

Technical Approach

- The algal strains used in this research will be selected based on their ability to be mass cultured, the availability of genetic systems, their storage of carbohydrates and their H_2 fermentation capabilities. The selected strains will be improved genetically for photosynthetic efficiencies and fermentation yields.
- Microencapsulation technology from Advanced BioNutrition Corp. will be applied to allow the transfer and reuse of the algal cells between stages.
- The feasibility of the overall process will be demonstrated in outdoor tests for achievement of high solar efficiencies in the production of storage carbohydrates and by integrating the two stages in a prototype process operation.

Technical Accomplishments/ Progress/Results

- This project is currently in contract negotiations.
- The entire project team and other researchers met in February 2005 at Clemson University for a two day strategy session.

  Day one: Discussion of photosynthetic efficiencies and of . ongoing research by Dr. Joseph Weissman and Prof. Juergen Polle under a Phase II SBIR project (See Next two Slides)

  Day two: Discussion of H2 fermentations and of ongoing research by Dr. John Benemann and Prof. K.T. Shanmugam (University of Florida) under a Phase I SBRI project. (See below)
- The Clemson meeting resulted in several new directions for the experimental strategies for the project, including:

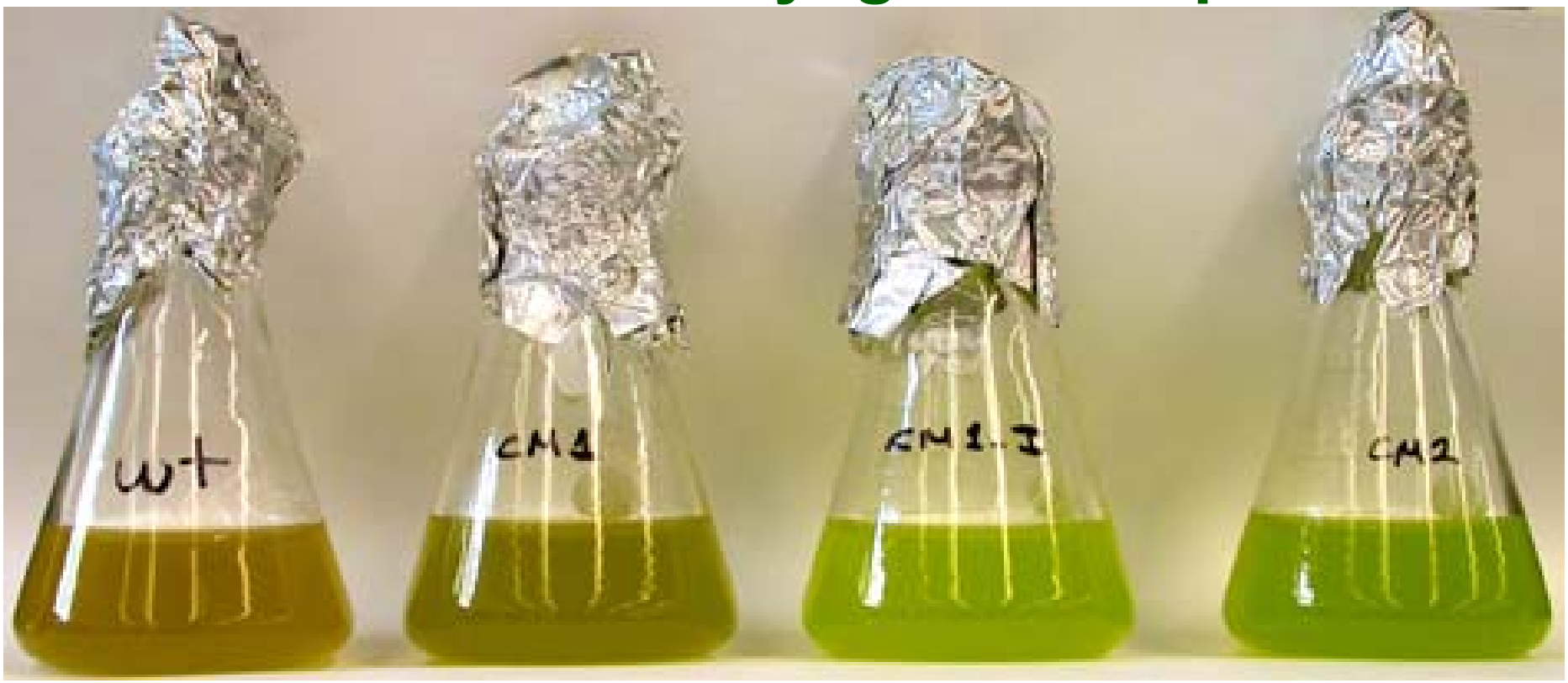
  - Use of selection techniques for development of strains with high photosynthetic efficiencies.
  - Application of microencapsulation techniques for long-term maintenance of the algal cells and their transfer between the two stages.

Genetic Improvements for Increasing Solar Energy Conversion Efficiency by Microalgae Cultures.

Phase II DOE SBIR Project, SeaAg, Inc. (Dr. Joseph Weissman) and Brooklyn College (Dr. Juergen Polle)

We generated truncated chlorophyll antenna mutants of *Cyclotella* (a diatom) and *Tetraselmis* (unicellular green alga), microalgae used in commercial algae mass cultivation. These are being used to test the prediction that such strains will have higher productivities (solar conversion efficiencies) in outdoor cultivation (Polle et al., 2002).

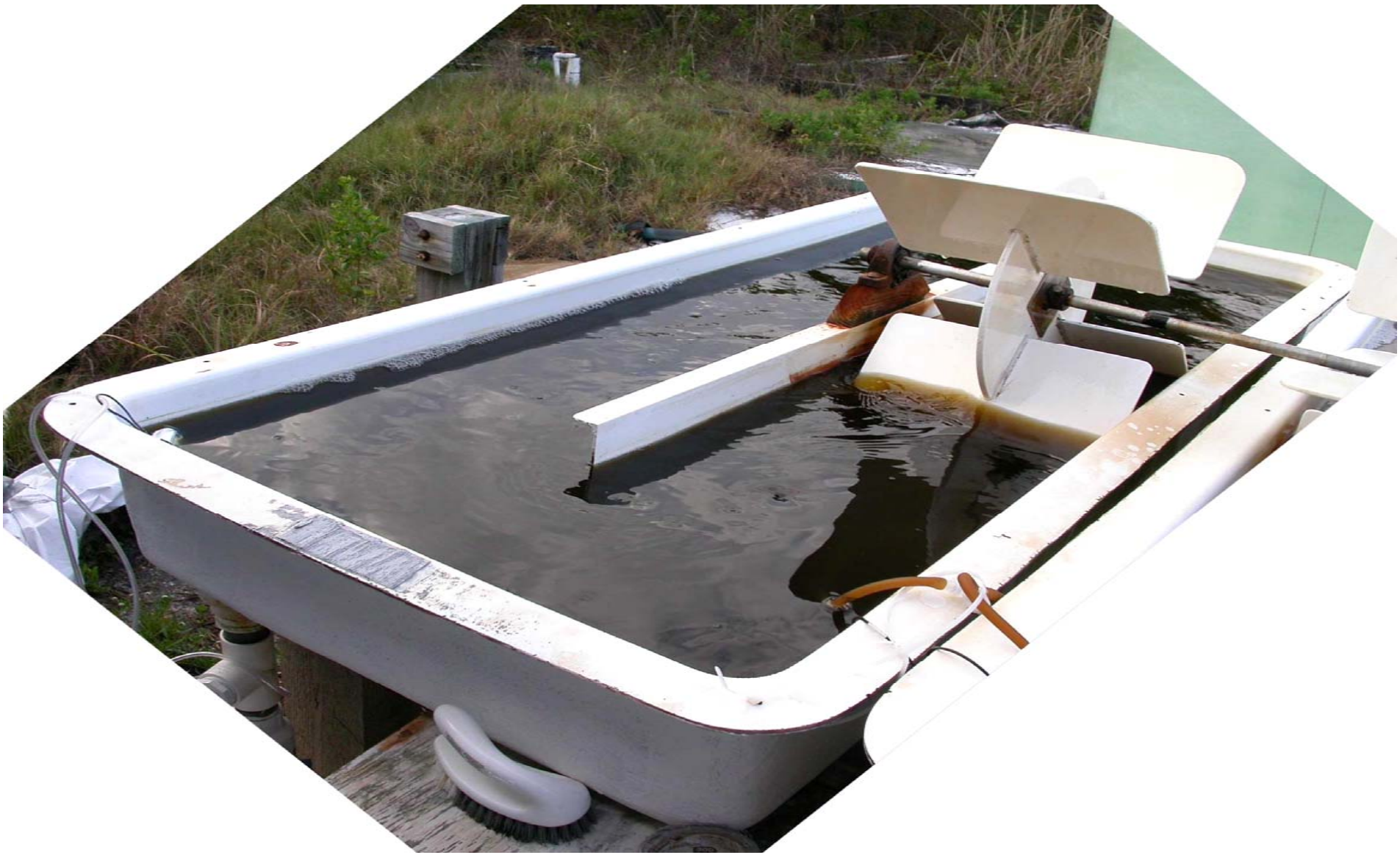
Comparing the phenotypes of *Cyclotella* wild type, CM1, CM1-1, and CM2 grown in liquid cultures under fluorescent daylight of ~50µE m^{-2} s^{-1}.



The olive-green color of mutant CM1 and green color of mutants CM1-1 and CM2 indicate changes in cellular pigments and loss of fucoxanthin. In all three mutants the Chl *a/c* ratios are 2-3 three fold higher than in he wild type cells

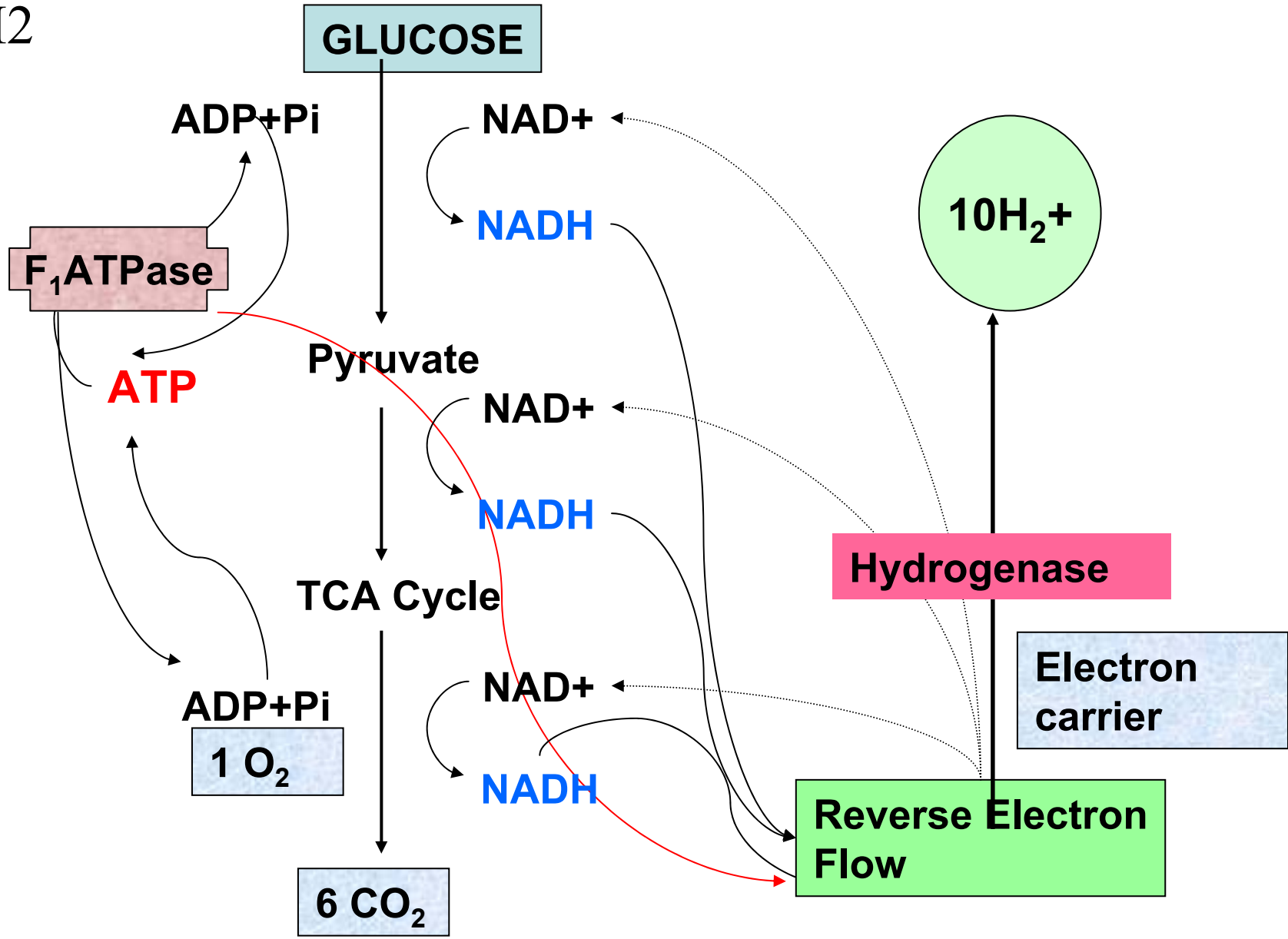
(Brooklyn College, under SeaAg, Inc., Phase II SBIR Project)

Experimental, outdoor raceway pond located at SeaAg, Inc., used in testing the cultivation of *Cyclotella* wild type and mutant strains



Re-engineered metabolism for high H_2 Yield

Schematic shows limited respiration to generate a minimum amount of ATP which couples to NADH oxidation to reduce an electron carrier and produce H2



Benemann and Shanmugam, SBIR Phase II Proposal

Future Work

The project proposal outlined the following six tasks:

- Task 1. Physiology of carbohydrate accumulation and H_2 production by algal cultures. (U. Hawaii. Dr. Jian Yu , P.I.)
- Task 2. Development of high solar conversion efficiency microalgal strains. (Brooklyn College. Dr. Juergen Polle, P.I.)
- Task 3. Efficient microalgae biomass production in outdoor ponds (SeaAg, Inc. Dr. Joseph Weissman, P.I.)
- Task 4. Increase H_2 production rates and yields in dark fermentations by microalgae. (Advanced BioNutrition Corp., Dr. David Kyle, P.I.)
- Task 5. Prototype process integration – demonstration efficiencies, stability, longevity. (Clemson University, Prof. David Brune, P.I.)
- Task 6. Techno-economic analysis of the two-stage photobiological H_2 production process. (Savannah River National Laboratory. Dr Ragaiy Zidan, P.I.).

Publications and Presentations

A Novel Photobiological Hydrogen Production Process

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13th Int. Cong. Photosynthesis, Montreal, Canada (Sep. 2004)

Hydrogen Safety

The most significant hydrogen hazard associated with this project is the potential for H_2 leakage and fire or explosion during process scale-up.

Hydrogen Safety

Our approach to deal with this hazard is to carry out a risk assessment and hazard mitigation plan prior to any scale up research.