PURPOSE

Bio-inspired Hydrogen and BioHydrogen (microbial) production processes have been active fields of basic and applied research for many years, with significant R&D programs currently carried out around the world. Task 21 is carrying out collaborative research activities in areas, which include H_2 production using in vitro, biomimetic, and artificial photosynthetic systems; photosynthetic microbes; dark bacterial fermentations; biological/enzymatic fuel cells; and integrated combinations of these technologies. The overall objective is not only to sufficiently advance basic and applied science in these areas of research over a five-year period, but also to evaluate these technologies from the perspective of economics and sociology. A five-year period is considered to be sufficient time to initiate a significant directed research program, set metrics for evaluation of the developmental status and promise of this field of research and technology, and achieve some major advances.

FRAMEWORK SUMMARY

The Task covers the following 5 subtasks: A. Bio-inspired systems (i.e., identify and develop promising applications of biomimetic, in vitro, and artificial photosynthetic H_2-producing processes); B. Dark biohydrogen fermentation systems (i.e., increase achievable H_2 production from substrates above the currently achievable yields; C. Basic studies for light-driven biohydrogen production (demonstrate potential practical processes for conversion of water or organic substrates to H_2 with solar energy input); D. Biological electrochemical systems (identify and develop promising applications of microbial/enzymatic electrochemical cells for H_2-production processes); and E. Overall analysis (determine how to introduce bio-inspired hydrogen and biohydrogen processes as new technologies in support of the coming H_2 society; analyze technologies from the economic, technological, and societal point of view).

MEMBERS

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Italy	De Philippis, Roberto
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Japan	Tomiyama, Masamitsu
Japan	Wakayama, Tatsuki
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Korea	Kim, Dong Hoon
The Netherlands	Stams, Fons
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COUNTRY	NAME
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United States	Seibert, Michael
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TASK 21

BIO-INSPIRED HYDROGEN AND BIOHYDROGEN

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VITAL STATISTICS

Term

Phase 1: 2010-2013

Phase 2: 2013-2015

Members

Canada
Finland
France
Germany
Italy
Japan
Korea
The Netherlands
Norway
Sweden
Turkey
UK
USA

Expert Participants

26 experts from 13 countries

2010 Meetings

September 17-18, 2010
Famagusta, North Cyprus
February 28-March1, 2011
Singapore

ACTIVITIES AND RESULTS IN 2010

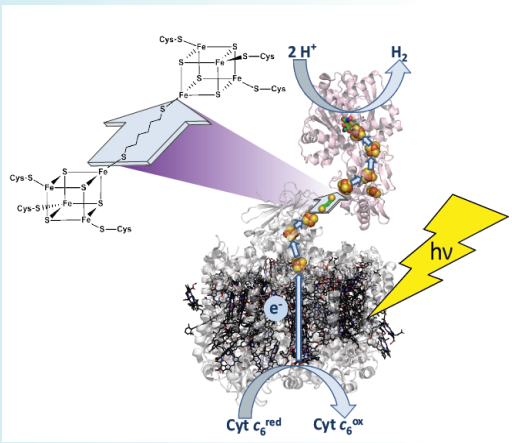
PROGRESS AND ACCOMPLISHMENTS

Subtask A. Bio-inspired H_2-producing Systems

Two catalyst systems that mimic the activities of [FeFe]- and [NiFe]-hydrogenases (Hydrogenases—the enzymes that microbes use to release H_2 gas) were developed in Sweden and France, respectively. The first was an [FeFe]-hydrogenase active-site model complex and H_2 production was linked to a light-driven process. The second, involving attachment of a nickel bisdiphosphine–based mimic of a [NiFe]-hydrogenase enzymes onto multi-wall carbon nanotubes resulted in a high–surface area material with high stability, high catalytic activity under the strongly acidic conditions, and very good H_2 oxidation properties (e.g., it could be used to replace platinum in a fuel cell).

Two examples of progress with bio-hybrid (composed of both biological and synthetic components) systems from the USA are (i) the spontaneously assembly of [FeFe]-hydrogenases (H_2ase) with (nc-CdTe) nanoparticles, which upon illumination promote H_2 production and (ii) the use of a synthetic molecular wire, attached through Fe/S coordination bonds to both the FB Fe/S cluster of isolated photosystem I (PSI) complex and to the distal Fe/S cluster of an [FeFe]-H_2ase. The molecular wire tethers the two biological centers allowing electrons to tunnel from PSI to the [FeFe]-H_2ase at a rate rapid enough to see H_2 photoproduction (see figure to the left, Golbeck, USA).

Subtask B. Dark Biohydrogen Fermentation Systems

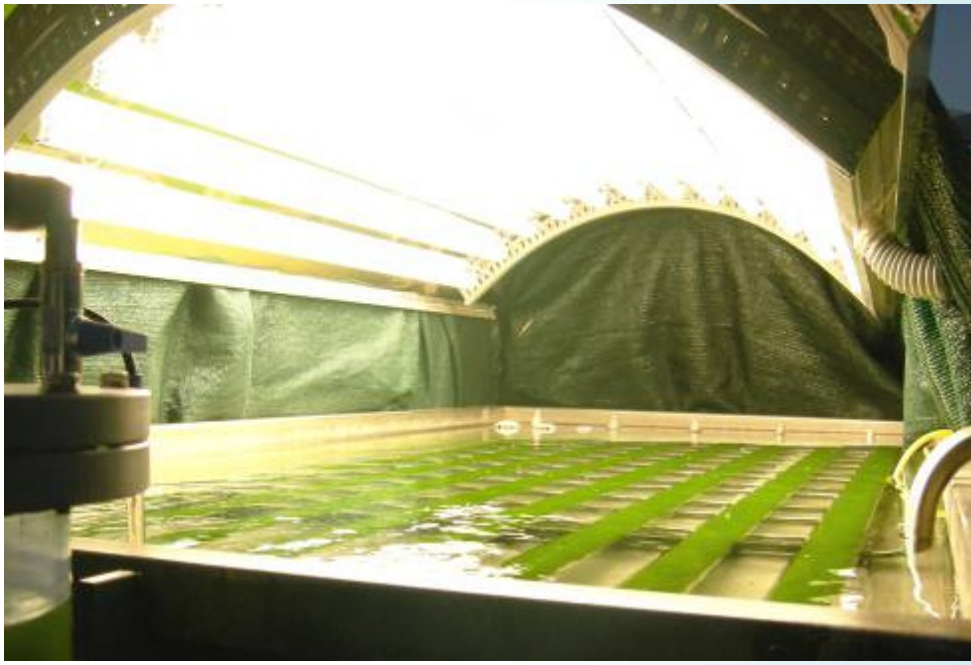


Researchers from (i) Canada developed a novel, on-line, recycle fermentation system that produced H_2 for over 70 days, (ii) Korea discovered one of the simplest microbial anaerobic systems described so far that produces H_2 using waste water containing formate, (iii) The Netherlands reported a new organism that has only two hydrogenases (an [FeFe]-H_2ase dependent on ferredoxin) and an NAD-dependent, [NiFe]-H_2ase), which makes this bacterium an ideal model organism for study; and (iv) Finland demonstrated microbial cultures producing H_2 with high rates and yields from cellulose and glucose at elevated operating temperatures (59–78°C) in a continuous, dark fermentation process.

A key milestone was also achieved by The Netherlands, which led HYVOLUTION, a 13-country EU/IEA HIA consortium (included 7 Task 21 countries) with the goal of developing an integrated, two-stage, dark fermentation/photofermentation system to convert waste biomass to H_2. Ending in December 2010, the Program successfully developed the projected H_2-production technology and reported base and long term case H_2 costs (19.95 and 6.14 €/kg). These costs were similar to those projected by the USA DOE Fuel Cell Technologies Program (www1.eere.energy.gov/hydrogenandfuelcells/pdfs/46674.pdf). This technology and similar technology developed in Japan has been made available to Malaysia and Indonesia, where the labor costs are much lower than those in developed countries.

Subtask C. Basic Studies of Light-driven BioH_2 Production

Examples of many technology advances in this area are: (i) Improvements in the O_2 tolerance of a [NiFe]-H_2ase through molecular engineering of the enzyme (France), (ii) development of pilot-scale photobioreactors (Turkey and Italy) for H_2 production by photosynthetic bacteria and algae (see the figure below, which is an outdoor, algal bioreactor, Torzillo, Italy), (iii) the green alga, *Chlamydomonas noctigama*, was found to express three genes under anaerobic conditions, all of which have strong resemblance to hydrogenases (this discovery by Norway provides more basic knowledge about diversity of hydrogenases since all other algae express only two hydrogenases), (iv) novel molecular biology tools have been developed by Sweden to regulate H_2 production in a cyanobacterium (*Nostoc* PCC 7120) by influencing the assembly process of an active hydrogenase and to design and engineer cyanobacteria using a standardised Synthetic Biology approach, and (v) Finland has screened 400 cyanobacterial strains from the country's fresh and ocean waters and established a national culture collection with 200 H_2-producing strains.



Subtask D. Biological Electrochemical Systems

Major decreases in the cost of the electrode materials used in microbial electrolysis cells (MECs), to significantly supplement the amount of H_2 that the dark fermentation of wastewater with reports of the replacement of platinum with low cost materials including Ni-alloy, and Ni powder (Canada, The Netherlands, and the USA). Furthermore, a detailed study of MEC operational parameters with real-life waste materials by the UK has led to the optimization of temperature and minimization of current regeneration times when high temperature regimes are incurred during abnormal operating conditions.

Subtask E. Overall Analysis

Two major analysis efforts have been completed. This first, an analysis of primary energy use in Japan, has led to a country-wide goal of 8% (non-hydro) renewable energy in place by 2030. Energy itself is not seen as much of a problem as the ability to deliver energy to the customer in the country. The second is a major report entitled "Technoeconomic Boundary Analysis of Biological Pathways to H_2 Production" (now freely available; see Subtask B above), which presents cost projections for a number of potential biological H_2-production technologies (USA).

OUTREACH AND COMMUNICATION

Summary of Strategy and Activities

Task 21 has been active in promoting research collaboration between member countries. Currently there are seven formal collaborations among member countries in addition to the just completed HYVOLUTION Program, which involved seven task countries. The most transparent means of outreach and communication is through the peer review literature and presentations at international meeting. Task meetings, whenever possible, are held as satellite meetings of large international conferences (the last two task meetings were held in conjunction with ICCE-2010 in North Cyprus and the Keystone Symposium on Biofuels in Singapore) of interest to task Experts. Task 21 has also been active in promoting new collaborations within four task countries, and help from several task countries has led to the design of new experimental approaches in other task countries.

Task websites

Task 21 maintains a private website for the benefit of all task experts. The site is a repository for country report presentations given at semi-annual task meetings, country and task semi-annual reports, task meeting minutes, lists of task publications, and other material that task Experts might find useful.