Rationale – Why biohydrogen?

Bio-Hydrogen is promising

- Using hydrogen as fuel leads to **remarkable reduction in CO2 emission** and in fossil resources dependence.
- Most experts predict **hydrogen society** as the final solution of global energy problems.
- Bio-hydrogen is a **clean and green technology** providing the most environmental-compatible, sustainable and renewable way of producing hydrogen.
- Asian countries possess the **world-leading biohydrogen technology** representing a dense population in biohydrogen R&D.
- Asian countries are **abundant in biomass resources**, indicating the high competitiveness and urgent demands in developing biohydrogen technology.
The **purpose** of the project

- **Aims**
  - The APEC Research Center to develop an *advanced technology of bio-hydrogen* production and to *organize a platform* for the experts of bio-hydrogen technology from the APEC member economies.

- **when and where :**
  - Set up a *website*.
  - Organizing a *symposium*.
  - A *non-food feedstock bio-hydrogen pilot plant* is for research and training courses at FCU.
The keys objectives (1)

- To develop the advanced technology of bio-hydrogen production (new generation).
  - To identify suitable non-food feedstock (e.g., agricultural waste)
    - as the substrate for the bioprocess. The feedstock will be focused on non-food biomasses that are dominantly produced in the region of APEC member economics.
- To innovate a high rate biohydrogen production system,
  - including bacterial screening, cultivation, bioreactor design, optimum operation, scale-up technology, biogas purification, applications of high value-added liquid products, reuse of organic wastes, as well as the molecular monitoring techniques on the biohydrogen bioprocess.
The **keys objectives (2)**

- **To offer the facilities in the research center**
  - such as laboratories open to the students from the APEC member economies *for short-term study or visiting*.

- **To organize a symposium**
  - for the biohydrogen technology experts from the APEC member economics
  - to extend and expand the biohydrogen technology to the APEC member economics
Dissemination of Technology Output

Biomass

Biohydrogen production system

Electric supply system

Hydrogen storage system

Hydrogen car
FCU Biohydrogen Research Team

- **Prof. Chiu-Yue Lin’s Lab**
  Depart of Environmental Engineering and Science, FCU

- **Prof. Shu-Yii Wu’s Lab**
  Depart of Chemical Engineering, FCU

- **Prof. Ping-Jei Lin’s Lab**
  Depart of Chemical Engineering, FCU

- **Prof. Chun-Hsiung Hung’s Lab**
  Depart of Environmental Engineering, NCHU

- **Prof. Jo-Shu Chang’s Lab**
  Depart of Chemical Engineering, NCKU
Ways of producing biohydrogen

<table>
<thead>
<tr>
<th>BioH₂ System</th>
<th>H₂ Rate</th>
<th>Size of BioReactor to Generate:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1.5 kW</td>
</tr>
<tr>
<td>Direct Photolysis</td>
<td>0.07 mmoles H₂/hr/L</td>
<td>512,000 L</td>
</tr>
<tr>
<td>Indirect Photolysis</td>
<td>0.335 mmoles H₂/hr/L</td>
<td>107,165 L</td>
</tr>
<tr>
<td>CO-water Shift</td>
<td>96.0 mmoles H₂/hr/L</td>
<td>374 L</td>
</tr>
<tr>
<td>Photo Fermentation</td>
<td>150.0 mmoles H₂/hr/L</td>
<td>239 L</td>
</tr>
<tr>
<td>Dark Fermentation</td>
<td>350.0 mmoles H₂/hr/L</td>
<td>102 L</td>
</tr>
</tbody>
</table>
H2 Production Concept

Complex Organics (non-food feedstock) → Monors (sugars, aminoacids…) → VFAs + alcohol + H₂ + CO₂ → CH₄ + CO₂

- Hydrolysis
- Methanogenesis
- Acidogenesis
The evolution for biohydrogen technology at FCU

Since 1998~

<table>
<thead>
<tr>
<th>Batch Test Basic Research</th>
<th>Continuous reactor</th>
<th>High rate reactor</th>
<th>The pilot plant system</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NSC Project, 150 mL)</td>
<td>(NSC and FCU Projects, 2 L)</td>
<td>(BOE and FCU Projects, 10 L)</td>
<td>(BOE and FCU Projects, 400 L)</td>
</tr>
</tbody>
</table>

Pilot-scale hydrogen fermentation system

BioH2 Pilot Plant (400 L) in FCU
Appearance of BioH₂ Pilot Scale

- Feedstock and Nutrient mixing Tank
- Pretreatment Tank
- Automatic Control room
- 400 L fermentor and Gas/liquid separator
## Highly evaluation by international experts

<table>
<thead>
<tr>
<th>Affiliations</th>
<th>Victoria Univ., Canada</th>
<th>Glamorgan Univ., UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commentator</td>
<td>Levin et al. 2004</td>
<td>Hawkes et al. 2007</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comments</th>
<th></th>
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</table>
| • Using fixed-bed bioreactors containing an undefined consortium of mesophilic bacteria, FCU team observed rates of H2 synthesis **far greater than other studies.**  
  • The system reported **by FCU team** in particular appears **most promising.**  
  • A bioreactor of approximately 500 l would provide enough H2 to power a 2:5 kW PEMFC, while a bioreactor of approximately 1000 l would provide sufficient H2 to power a 5:0 kW PEMFC. |  
  • The highest volumetric hydrogen production rate **to our knowledge ever reported** is 15.09 (l/1/h) at 93% sucrose conversion, OLR 1708 g sucrose (l/d), in a novel continuously stirred granular sludge type reactor seeded with silicone-immobilised sludge **by FCU team.**  
  • If these rates could be maintained, the granulation approach to conversion of soluble simple sugars is **very promising.** |
Project outcomes

- The Steering Committee Meeting and kick-off Workshop of APEC Research Network for Advanced Biohydrogen Technology.
- The website has been established in Feng Chia University, Chinese Taipei. ([http://www.apec-bioH2.org](http://www.apec-bioH2.org))
- APEC biohydrogen newsletter has been published 4 issues.
- The 2010 APEC Advanced Bio-Hydrogen Technology Conference has been held at Feng Chia University, Taichung, on Nov 16th – 18th, 2010.
- The 2010 APEC Advanced Bio-Hydrogen Technology Short-term Training Course has been held at Feng Chia University, Taichung, on Nov 16th – 20th, 2010.
The 2010 steering committee meeting and workshop of APEC research network for advanced biohydrogen technology

- **Date and Venue**
  - February 3, 2010, Feng Chia University, Taichung, Chinese Taipei

- **Activities**
  - Advanced biohydrogen technology workshop
  - Visit biohydrogen production pilot plant and laboratory, and exchanged experiences.
  - Steering Committee Meeting
  - More than 150 industrial and commercial people, scientists and academia joined the workshop.
The website and the APEC biohydrogen newsletter

http://www.apec-bioh2.org

APEC biohydrogen newsletter
The 2010 APEC Advanced BioH2 Technology Conference

- **Date and Venue:** Nov. 15th – 20th, 2010, Feng Chia University, Taichung, Chinese Taipei

<table>
<thead>
<tr>
<th>Keynote speech</th>
<th>Coffee break</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Keynote speech" /></td>
<td><img src="image2.png" alt="Coffee break" /></td>
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</table>

<table>
<thead>
<tr>
<th>Banquet</th>
<th>Group photo</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Banquet" /></td>
<td><img src="image4.png" alt="Group photo" /></td>
</tr>
</tbody>
</table>
230 participants from 14 APEC members and 9 other countries

Presented articles

Keynote and invited: 28(21)
Oral presentation: 40(36)
Poster presentation: 53(50)
The 2010 APEC Advanced BioH2 Technology Short-term Training Course

- **Date and Venue:** Nov. 16th – 20th, 2010, Feng Chia University, Taichung, Chinese Taipei

### Total Invited Speakers from APEC Members were 20.

<table>
<thead>
<tr>
<th>APEC Members</th>
<th>Invited Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA (3)</td>
<td>Veziroglu Turhan Nejat, Bruce Logan, Michael Seibert</td>
</tr>
<tr>
<td>Thailand (1)</td>
<td>Alissara Reungsang</td>
</tr>
<tr>
<td>Russia (1)</td>
<td>Vasily Borzenko</td>
</tr>
<tr>
<td>Korea (3)</td>
<td>Hang Sik Shin, Mi Sun Kim, Sunghoon Park</td>
</tr>
<tr>
<td>Japan (2)</td>
<td>Jun Miyake, Yu-You Li</td>
</tr>
<tr>
<td>Indonesia (1)</td>
<td>Dwi Susilaningsih</td>
</tr>
<tr>
<td>Canada (1)</td>
<td>Patrick C. Hallenbeck</td>
</tr>
<tr>
<td>China (1)</td>
<td>Guangyi Wang</td>
</tr>
<tr>
<td>Hong Kong, China (1)</td>
<td>Tong Zhang</td>
</tr>
<tr>
<td>Chinese Taipei (6)</td>
<td>Sheng-Shung Cheng, Duu Jong Lee, Jo-Shu Chang, Min-Ray Lin, Chun-Hsiung Hung, Ming-Der Bai</td>
</tr>
</tbody>
</table>

### Total Student participants from APEC Members were 65.

Viet Nam (8), Malaysia (5), Thailand (11), The Philippines (5), Indonesia (12), Chinese Taipei (16), Republic of Korea (8)
The Activities on 2010 APEC BioH2 Short-term Training Course

Group photo of students and lecturers
Technical tour to wastewater treatment plant
Pilot plant visiting in FCU
Lab visiting and operation
Applications

High COD Feedstock → Bio Fermentation Process → Lower COD Waste water → Aeration Facility

Hydrogen → Fuel Cell → Electricity

CO2 → Pressured Storage → Resale or On-site use
BioH$_2$ Process in the Conventional Wastewater Treatment Process

- **Wastewater** ➔ **Equalization** ➔ **UASB** ➔ **Activated Sludge**
- **Sedimentation** ➔ **Sludge Thickening** ➔ **Effluent**
- **H$_2$ fermenter** ➔ **Separator** ➔ **Purification** ➔ **H$_2$ Fuel cell (Electricity)**
- **CO$_2$ reuse**

**BioH$_2$ process**
video

Wastewater 9.1 billion tons by 2009 Nestlé

Agricultural wastes 1.07 billion tons by 2010 Global waste rice straw and rice husk

Fast-food waste 7 million tons by Coca-Cola

40 kg Wastewater
4 kg Agriculture waste
1440 ml Cola waste

= 750 L H2 = 1 kWh
Network with Asia BioHyLinks (ABHL)

**Members**
- China
- India
- Indonesia
- Japan
- Korea
- Malaysia
- Russia
- Singapore
- Chinese Taipei
- Thailand
- VietNam

**Aims**
- Annual Meeting
- Publication (IJHE or others)
- Technical Exchange of Researchers
2011 ICCE Conference in FCU
11th International Conference on Clean Energy (ICCE-2011)

- **Date:** November 2 - 5, 2011
- **Venue:** Feng Chia University, Taichung, Taiwan
- **Information Website:** [www.icce2011.org.tw](http://www.icce2011.org.tw)
- **Topics of interest include, but are not limited to:**

  - Hydrogen economy
  - Solar energy
  - Wind energy
  - Hydrogen and fuel cell
  - Geothermal energy
  - Hydropower
  - Ocean/tidal/wave energy
  - Biomass and biofuels

  - Waste-to-energy
  - Nuclear energy
  - Clean coal
  - Clean fossil fuels
  - Environmental remediation
  - Energy management
  - Energy policy

  - Energy awareness
  - Risk analysis
  - Economical appraisal
  - Energy conservation
  - Energy storage
  - Intelligent grids
  - Intelligent buildings

High quality papers will be selected and published in special issues of the *International Journal of Hydrogen Energy* and *Applied Energy Journal* and in other prestigious journals.
The 2011 Asian Bio-Hydrogen and Biorefinery Symposium (2011ABBS)

- **Date:** Oct. 14-16, 2011
- **Place:** Bogor, Indonesia
- **Information Website:** [http://www.asia-biohylinks.org](http://www.asia-biohylinks.org)
- **Topics of interest include, but are not limited to:**
  - Biomass to hydrogen and biochemicals
  - Molecular biology approaches
  - Biohydrogen by dark/photo fermentation
  - Bioreactor design
  - Biohydrogen applications
  - Biorefineries and its applications

High quality papers will be selected and published in special issue of the *International Journal of Hydrogen Energy.*
BioH2 Pilot Plant (400 L) in Feng Chia University Campus

Thank you for your attention