Japan-US workshop on
Fusion Power Plants and Related Advanced Technologies
(With participation of EU?)

Hydrogen Production from Biomass with Fusion Heat
- Its feasibility and Impact

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Why Hydrogen?
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Market 4 times larger than electricity
Replaces fossil
(not possible for LWR, renewable)

• Future fuel use
  — Fuel cells for automobile
  — Aircrafts

• Dispersed electricity system
  — Cogeneration
  — Fuel cell,
  — Micro gas turbine

(could be other synthetic fuels)

Substitute fewer than electricity source

Example of Outlook of Global Energy Consumption by IPCC92a
Electricity and Synthetic fuels mutually converted

- Resources required for raw material and energy
- Substitution and competition with fossil occur

conversion efficiency?

Raw material  Energy  Conversion
Fusion can provide both high temperature heat with advanced blanket options (DCLL etc.)
- Applicable for most of hydrogen production processes

There may be competitors…

As Electricity
- water electrolysis, SPE electrolysis : renewables, LWR
- Vapor electrolysis : HTGR

As heat
- Steam reforming: HTGR(800C),
- membrane reactor: FBR(600C)
- IS process : HTGR(950C)
- biomass decomposition: HTGR

High Temperature Blanket needed, So IHX.
1) LiPb-RAFM blanket with SiC insert (DCLL)
   - SiC with low thermal conductivity used for FCI
   - thermal and electrical insulation
   - passive function limits output temp. ~700 degree.

2) SiC Heat Exchanger program and active cooling component
   - active cooling enhances insulation and enables over 900 degree output.

→ high temperature (high pressure) He, or high temperature lead as secondary heat transfer media.
To utilize carbon-free fusion energy, criteria are:

- **Endothermic**
  - as transformation of fusion energy
- **Reduce CO₂ emission**
  - Replacing fossil fuel with fusion
- **Market scale**
  - Large unit capacity

Electricity generation is a good option if fusion replaces fossil. Biomass hydrogen saves fossil and generates larger energy.
### Hydrogen conversion and Carbon gasification

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**Cellulose**

\[(C_6H_{10}O_5)_n + nH_2O \rightarrow 6nCO + 6nH_2\]

**Lignin**

\[(CH_{1.4}O_{0.3})n + 0.7nH_2O \rightarrow nCO + 1.4nH_2\]

- C + H_2O ⇌ H_2 + CO
- CO + H_2O ⇌ H_2 + CO_2
- C + CO_2 ⇌ 2CO
- 2CO + 2H_2 ⇌ CH_4 + CO_2
- C + 2H_2 ⇌ CH_4
- CH_4 + H_2O ⇌ 3H_2 + CO
- 2C + 2H_2O ⇌ CH_4 + CO_2

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**Hydrogen conversion**

\[
\text{Hydrogen conversion} = \frac{\text{Observed hydrogen}}{\text{Hydrogen by above reaction}} \times 100
\]

**Carbon Gasification**

\[
\text{Carbon Gasification} = \frac{\text{Gaseous carbon in CO,CO}_2,\text{CH}_4}{\text{Carbon in reactant}} \times 100
\]
Experimental apparatus

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Mass Flow Controller

Biomass sample (Cellulose, Rignin, )

Sample + He

Steam + Ar

Infrared Image Furnace

Catalyst

Quartz Wool

Biomass sample

He Gas

Ar Gas

Steam Generator

Gas Chromatograph

Gas Bag

Cooler

Thermo couple

Thermo couple

To Vent

Ob
Cellulose is completely gasified w/o catalyst, But conversion efficiency is limited.
Gasification of Cellulose with Catalysts
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>95% carbon was converted to C1 gases with Ni.

Thermochemical equilibrium

This conversion efficiency is practical level.
Conversion to hydrogen

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High hydrogen yield obtained with catalysts.
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Gasification of lignin with Catalysts

Lignin:
Typical content: (CH1.4O0.3)
Higher carbon content

Thermochemical equilibrium

<table>
<thead>
<tr>
<th>CH₄</th>
<th>CO₂</th>
<th>CO</th>
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</table>

experiments

<table>
<thead>
<tr>
<th>CH₄</th>
<th>CO₂</th>
<th>CO</th>
</tr>
</thead>
</table>

Ca, 80% carbon was converted to C1 gases with Ni and Co.
Measurement of heat adsorption
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SrCO₃ = SrO + CO₂ – 210.2 kJ

Heat adsorption calibrated by Known endothermic reaction

Temperature change in reaction

Heat absorption measurement

Apparent heat efficiency
- cellulose: 83%
- lignin: 80%

SrCO₃ = SrO + CO₂ – 210.2 kJ

Heat adsorption calibrated by Known endothermic reaction

Temperature change in reaction

Heat absorption measurement

Apparent heat efficiency
- cellulose: 83%
- lignin: 80%
Concept of the reactor

Assumed biomass: 6 Mton/year (cellulose 70%, lignin 30%)

<table>
<thead>
<tr>
<th></th>
<th>cellulose</th>
<th>rignin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction heat (kJ)</td>
<td>0.29</td>
<td>0.41</td>
</tr>
<tr>
<td>Reaction time (s)</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

Fusion reactor

He

Reacted tube: 29500

Diameter: ~3.5 m

Gas product

He path

Biomass/product path path

17 mm/20 mm
Fusion hydrogen production process

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Fusion reactor: 1530MW

H2 + \frac{1}{2}O_2 = H_2O + 286kJ

Hydrogen energy/fusion heat = 270%

CO + H_2O ⇌ H_2 + CO_2

Separator

H2O: 76kg/s
Biomass: 190kg/s
H2O: 55kg/s

CO2: 271kg/s
CH4: 4.5kg/s

Flow diagram from fusion to hydrogen
Fusion can produce Hydrogen

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Fusion generates hydrogen from biomass with efficiency if high temperature is achieved.

- Processing capacity
  - 4240 t/h biomass → 280 t of H₂

- Endothermic reaction converts both biomass and fusion into fuel.
  - 2.5 GWt → 5.1 GWe equivalent with FC (@70%)

Fusion can produce Hydrogen

2120 t/h H₂, 280 t/h H₂

Fusion generates hydrogen from biomass with efficiency if high temperature is achieved.

- 18.6 Mt/y waste ← 60 Mt/in Japan
- Feeds 1.1M FCV/day or 17M FCV/year*

(*assuming 6 kg/day or 460 g/year, MITI, Japan)
Fusion heat → electricity → hydrogen
Thermal cycle
Loss (40~70%)

Fusion heat → IS process → hydrogen
Electrolysis Loss

Fusion heat → gasification → hydrogen
Chemical cycle
Loss (50%)

Biomass (with enthalpy)
Energy Efficiency
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- Amount of produced hydrogen from unit heat
  - Low temperature (300°C) generation
    → conventional electrolysis
  - High temperature (900°C) generation
    → vapor electrolysis
  - High temperature (900°C) → thermochemical production

<table>
<thead>
<tr>
<th>From 3GW heat</th>
<th>Efficiency</th>
<th>Electricity</th>
<th>Energy Consumption</th>
<th>Hydrogen Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>300C-electrolysis</td>
<td>33%</td>
<td>1GW</td>
<td>286 kJ/mol</td>
<td>25t/h</td>
</tr>
<tr>
<td>900C-SPE electrolysis</td>
<td>50%</td>
<td>1.5GW</td>
<td>231 kJ/mol</td>
<td>44t/h</td>
</tr>
<tr>
<td>900C-vapor electrolysis</td>
<td>50%</td>
<td>1.5GW</td>
<td>181 kJ/mol</td>
<td>56t/h</td>
</tr>
<tr>
<td>950C-IS process</td>
<td>~50%</td>
<td>1.5GW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>900C-biomass</td>
<td>270%</td>
<td>5GWeq</td>
<td>60 kJ/mol</td>
<td>340t/h</td>
</tr>
</tbody>
</table>
For hydrogen production, some energy sources provide limited options.

<table>
<thead>
<tr>
<th></th>
<th>renewables</th>
<th>LWR</th>
<th>fusion(HTGR)</th>
<th>FBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv. electrolysis</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Vapor electrolysis</td>
<td>×</td>
<td>×</td>
<td>O</td>
<td>×</td>
</tr>
<tr>
<td>IS process</td>
<td>×</td>
<td>×</td>
<td>O</td>
<td>×</td>
</tr>
<tr>
<td>Steam reforming</td>
<td>×</td>
<td>×</td>
<td>O</td>
<td>?</td>
</tr>
<tr>
<td>Biomass hydrogen</td>
<td>×</td>
<td>×</td>
<td>O</td>
<td>?</td>
</tr>
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Renewables (PV, wind, hydro) cannot provide heat. LPR temperature not suitable for chemical process.
### Use of Fusion Heat

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Blanket and generation technology combination requires more consideration.

<table>
<thead>
<tr>
<th>Blanket option</th>
<th>temperature</th>
<th>technology</th>
<th>efficiency</th>
<th>challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCPB</td>
<td>300 °C</td>
<td>Rankine</td>
<td>33%</td>
<td>proven</td>
</tr>
<tr>
<td>HCPB/HCLL</td>
<td>~500°C</td>
<td>Rankine</td>
<td>~40%</td>
<td>proven</td>
</tr>
<tr>
<td>Supercritical</td>
<td>500 °C</td>
<td>SCW</td>
<td>&gt;40%</td>
<td>available</td>
</tr>
<tr>
<td>DCLL</td>
<td>~700°C</td>
<td>SC-CO2</td>
<td>~50%</td>
<td>GEN-IV</td>
</tr>
<tr>
<td>LL-SiC</td>
<td>900°C</td>
<td>SC-CO2</td>
<td>50%</td>
<td>IHX?</td>
</tr>
<tr>
<td></td>
<td>900°C</td>
<td>Brayton</td>
<td>~60%</td>
<td>GEN-IV</td>
</tr>
<tr>
<td></td>
<td>900°C</td>
<td>bio-H2</td>
<td>&gt;&gt;200%</td>
<td>?</td>
</tr>
</tbody>
</table>

SiC-based intermediate heat exchanger is being developed.
Fusion has advantages for hydrogen systems.
- Serves various hydrogen production processes
- Fusion can improve in temperature by blanket development.
- High temperature application is suitable for hydrogen.
- Fusion has less limitation in resource, site, environment, and nuclear proliferation.
  → suitable for deployment in developing countries.

Hydrogen application provides fusion a better chance.
- Eventually larger market than electricity
- Global demands for fuel and its supply capability.
- Hydrogen requires both large scale source and remote supply. (Electricity and electrolysis)
- Blanket and energy plants can be developed independently.
- Possibly slower demand change than electricity.
Hydrogen production from biomass at high temperature endothermic reaction is demonstrated at Kyoto University.

Fusion plant will have to be designed and evaluated from socio-economic aspects, i.e., global environmental problem and energy market.

Both experimental and design studies show possible hydrogen production with high temperature blanket.