WG1: Hydrogen Infrastructure WG

Vice Chairperson
  Prof. Masanori Monde (Saga University)
Leader
  Kenichiro Saito (JX Nippon Oil & Energy Corporation)
Role of Hydrogen Infrastructure WG

JHFC’s Targets

1. Targets for hydrogen infrastructure
   ① Review and proposals of future commercialized infrastructure models
   ② Operation of hydrogen infrastructure under actual condition of use and clarification of tasks involved
   ③ Drawing up of specific plans for verifying safety of hydrogen infrastructure and reexamining regulations

2. Targets for fuel cell vehicles
   ④ Operation of fuel cell vehicles under actual condition of use and clarification of tasks involved
   ⑤ Verification of energy saving effects (fuel efficiency) and environment impact reduction effects

3. Targets for common areas shared by vehicle and infrastructure
   ⑥ Review of measures to be taken for all issues that should be addressed jointly between the vehicle and infrastructure fields

4. Targets for dissemination of results/public relation/globalization/local validation
   ⑦ Public relation and educational activities
   ⑧ Identification and proposal of overseas technologies and policy trends
   ⑨ Review ideal local validation methods

5. Proposals for technical tasks and next phase demonstrations to start dissemination in 2015
1. Commercial Infrastructure Model Sub WG

- Review on infrastructure standard specifications for the initial phase of propagation (2015-)

2. Safety & Regulation Sub WG

- Defining the agenda for reviewing safety, codes, and regulations (By who, By when, What kind of data...)

3. Hydrogen Infrastructure Demonstration Sub WG

- Operation and data acquisition of JHFC hydrogen station
- Extract tasks related to hydrogen refueling
1. Formulation of Commercial Infrastructure Model
2. Definition of Agenda for Safety and Regulation Review
3. Hydrogen Station Operations and Safety
4. Evaluation of Efficiency and Hydrogen Fuel
5. Summary
Review of Commercial Infrastructure

2015 ~

Start to spread FCV/Hydrogen Station (Initial Phase; Early Commercialization)

Transition period till full scale commercialization is realized

Proposals for hydrogen infrastructure in Initial Phase

→ Proposal of tasks for the implementation

2009 efforts

1. Review of hydrogen station specifications in initial phase
2. Review of facility costs of each hydrogen station, and hydrogen costs in initial phase
2010 Efforts

2010 Review items

Review of Onsite ST costs

(2009 review)

(Review of hydrogen costs)

Review of Offsite ST costs

Re-review of hydrogen ST costs

- Storage cylinder
- Skidding
- Peakless

Review of hydrogen costs (Onsite)

Review of hydrogen costs (Offsite)

Review of Offsite hydrogen production and transportation costs

Basic conditions (COCN* report)

(*Council on Competitiveness – Nippon)

<table>
<thead>
<tr>
<th>FCV conditions</th>
<th>Number of Units</th>
<th>5000 ~15500Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly Hydrogen Demand</td>
<td>475t</td>
<td>FCV fuel consumption: 100km/kg hydrogen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FCV mileage (average): 9500km/year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FCV hydrogen quantity per refueling: 4.8kg</td>
</tr>
</tbody>
</table>

| Hydrogen station conditions | Pressure | 35MPa and 70MPa |
|                            | Scale    | 300Nm³/h ** Commercial (FCV 1340Units/1ST) |
|                            |          | 100Nm³/h Mobile stationary type |
|                            | Filling Method | Cascade and Direct filling |

Onsite × Offsite

35MPa × 70MPa

300Nm³/h × 100Nm³/h

Cascade filling × Direct filling

→ Review of basic hydrogen stations

** FCV refueling: 5.6cars/h, FCV refueling peak: 11.2cars/h (1hour)

Basic specifications
Review of Offsite Hydrogen Station

Offsite Hydrogen Production / Transportation Infrastructure Specifications and Costs were reviewed.

- Increased hydrogen production ➔ Reduced costs
- Cost reduction as a result of scale-up

Increased transportation load ➔ Increased costs
Little scale-up effects

- Review optimization of load/costs
- Same Hydrogen costs as Onsite are expected in delivery to several ten stations.
Review of Hydrogen Station Costs

2009 review
Reduction of equipment costs

Increase raw material costs

Improvement of equipment efficiency

Review of Safety distance reduction

Onsite
Hydrogen production

Offsite
Hydrogen transportation

Dispenser 70MPa

Compressor
Pre-cooler -40°C

For 45MPa composite transportation cylinder

For 80MPa composite Storage cylinder

Skidding/Packaged → Reduction of construction work costs

Review of safety coefficient → Reduction of number

70MPa
Communication
Road

Trailer

Storage cylinder
Hydrogen station, Construction costs for hydrogen production / transportation

<table>
<thead>
<tr>
<th>Costs (×100 million yen)</th>
<th>Hydrogen station</th>
<th>70MPa, 300Nm³/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cascade filling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current → initial phase</td>
</tr>
<tr>
<td>Station construction costs</td>
<td>Onsite</td>
<td>10 → 4.2</td>
</tr>
<tr>
<td></td>
<td>Offsite</td>
<td>8.2 → 3.3</td>
</tr>
<tr>
<td>Construction costs for hydrogen production/transportation (Per station)</td>
<td>Onsite</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Offsite</td>
<td>1.5 → 0.9</td>
</tr>
<tr>
<td>total construction costs (initial phase: 2015-2020)</td>
<td>Onsite</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>Offsite</td>
<td>4.2 (×100 million yen)</td>
</tr>
</tbody>
</table>

- Onsite and offsite construction costs are more or less the same.
- The construction costs of cascade filling and direct filling will be less different.
Hydrogen Costs

Hydrogen costs in initial phase (2015 ~ 2020) ≈ 80 yen/Nm³ (900 yen/kg)

- Sharp drop in fixed costs for both onsite type and offsite type
- For variable costs, raw material costs may increase
Analysis of Cost Changes

Onsite 300Nm³/h 70MPa Cascade filling

- Decrease in area: -1.0Yen/Nm³
- Decrease operation staff: -2.7Yen/Nm³
- Use of CFRP storage cylinder (Review of safety coefficient): -23.8Yen/Nm³
- Reduction of reformer cost: -8.9Yen/Nm³
- Reduction of compressor cost: -2.6Yen/Nm³
- Reduction of storage cylinder cost: -7.7Yen/Nm³
- Reduction of dispenser cost: -3.8Yen/Nm³
- Reduction of pre-cooling cost: -0.6Yen/Nm³
- Reduction of construction work cost: -4.3, -1.2Yen/Nm³
- Improvement of equipment efficiency: -5.3Yen/Nm³
- Increase raw material cost: 9.6Yen/Nm³

\[ \Delta 28 \text{ yen/Nm}^3 \]

More or less the same

\[ \Delta 28 \text{ yen/Nm}^3 \]

Use of composite vessels had large effects of costs reduction in cascade filling

(Current hydrogen costs 138 yen/Nm³⇒ in initial phase(2015-2020) 82 yen/Nm³)
Summary Review of Commercial Infrastructure

1. Initial phase hydrogen station facilities specification/cost review Implemented
2. Offsite infrastructure hydrogen production/transportation facilities specifications/costs review Implemented
3. Hydrogen costs review based on regulations review, technological progress/mass production effects Implemented

Review of effects
- Use of composite storage cylinder, review of safety coefficient
- Review of distance regulations, review of operation staff
- Review of skidded and packaged facilities

In initial phase (2015-2020)
Construction costs per station: Approx. $3.6 \times 10^8$ yen (70MPa, 300Nm³/h)
Hydrogen costs: Approx. 80 yen/Nm³

Future tasks:
- Steady progress of regulations review, facilities costs reduction / improvement of equipment efficiency
  → Same level as overseas package station
- Review of full refueling hydrogen station based on overseas refueling standards
1. Formulation of Commercial Infrastructure Model
2. Definition of Agenda for Safety and Regulation Review
3. Hydrogen Station Operations and Safety
4. Evaluation of Efficiency and Hydrogen Fuel
5. Summary
### Progress of Hydrogen Station Regulation Review

<table>
<thead>
<tr>
<th>Before review (example)</th>
<th>2005 -2008</th>
<th>2009 -Future</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>35MPa station</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Safety distance</td>
<td>• Safety distance</td>
<td></td>
</tr>
<tr>
<td>• Multi station not permitted</td>
<td>• Multi stations permitted</td>
<td></td>
</tr>
<tr>
<td>• Only industrial (exclusive) areas</td>
<td>• Semi-industrial, commercial and semi residential areas allowed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Insufficient storage</td>
<td></td>
</tr>
<tr>
<td><strong>Situation same as before 35MPa station review</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Conspicuous 70MPa station cases</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel design coefficient ⇒ Stricter regulation compared to overseas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For pipes, Japan requires 4 times stronger, while other countries require 3 times stronger,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For 70MPa, pipes with thicker rim and more expensive steel are required.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>→ Smaller bore increases pressure loss. Flow rate is not maintained</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>70MPa station</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Review Sub WG objectives and tasks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Organize legal issues with large influence on dissemination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Define agenda for revising regulations (Who, Till When, What Data)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establish a hydrogen infrastructure that provides safe and inexpensive hydrogen timely, at the right place.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Prereq:</strong> Ensured safety (refueling)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Implement storage cylinders at basement or on the roof? Compact, etc.
### Key tasks in review of regulations related to hydrogen infrastructure

**Basic Concept of Key Rank**

- **Special A:** Items that will significantly interfere with the spread of infrastructure if they are not revised by 2015
- **A:** Items that will interfere with the commercial operations, such as high cost, if they are not revised by 2015
- **B:** Items that may become mandatory in the spread process

<table>
<thead>
<tr>
<th>Rank</th>
<th>Key Task</th>
<th>Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special A</td>
<td>Establishment of 70MPa law</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>• Revision of safety distance</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>• Revision of safety administrator resident obligations</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>• Permission to build next to gas stations</td>
<td>Fire Service Law</td>
</tr>
<tr>
<td></td>
<td>• Expand area for building hydrogen stations</td>
<td>Building Standards Law</td>
</tr>
<tr>
<td></td>
<td>Increase usable steel material</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>Review design standards (pressure-resistance safety coefficient)</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>Increase in range of compound vessels in vessel regulations (for transportation)</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>Increase hydrogen storage quantity in urban areas</td>
<td>Building Standards Law</td>
</tr>
<tr>
<td></td>
<td>Review inconsistencies in safe distance between CNG and hydrogen stations</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td>A</td>
<td>Extension in open inspection cycle, and simplification of safety inspections</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>Increase range of compound vessels (for stations)</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>Further review of safe distance</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>Permission on unmanned warm air operations of reformers</td>
<td>Fire Service Law</td>
</tr>
<tr>
<td></td>
<td>Review explosion-proof performance</td>
<td>High Pressure Gas Safety Act</td>
</tr>
<tr>
<td></td>
<td>Install high pressure storage cylinders and compressors on canopies</td>
<td>High Pressure Gas Safety Act /Fire Service Law</td>
</tr>
<tr>
<td>B</td>
<td>Parallel installation of dispensers</td>
<td>Fire Service Law</td>
</tr>
<tr>
<td></td>
<td>Refueling of FCVs on public roads</td>
<td>High Pressure Gas Safety Act /Road Traffic Law</td>
</tr>
<tr>
<td></td>
<td>Review of standard temperature/adjustments with overseas trends</td>
<td>High Pressure Gas Safety Act</td>
</tr>
</tbody>
</table>

**Results:** Listed a total of 17 key tasks. Promoted common awareness between related parties, and prompted start of specific activities.
JHFC “Safety and Regulations Review Committee”
Selection of [17 key tasks], setting of road map (draft)

Setting of road map and scenario for realizing this, involving both public and private sectors

Activities were started by the following policies.

Government Revitalization Unit >
Regulations and Systems Reformation >
Green Innovation WG (16 themes)

⑦ Re-examination of regulations related to fuel cell vehicles and installation of hydrogen stations
Activities related to drawing up of specific roadmap (Outline)

◆ April 2010
Launch of promotion team normally called “Leader Group” which list up 17 key tasks specifically

JHFC review group members participate in leader meeting

Collaborated by JHFC WG1 Review Committee

◆ June 2010
Promotion of review of regulations by cabinet

Survey of actual conditions of regulations abroad
Provide hydrogen infrastructure demonstration data

- Preparation and revision of commentary and description drafts
- Changes in definitions for classifying importance of 17 items

... NEDO projects
(Related to review of standards)

◆ December 2010
Provide regulations review work table and indicate specific work details
Objective

- Japan uses larger design coefficients than Europe and the U.S., which have caused the following problems.
  - Difficult to import and use overseas products.
  - Difficult to reduce hydrogen station construction costs.
  - Pipes and valves are thick and large, which causes problems in terms of operability and performance.
- Review ministerial ordinances and exemplified standards, etc. to enable construction of hydrogen stations using design coefficients similar to the U.S. and Europe.

【Legal measures】
Revision of High Pressure Gas Safety Act, general laws (ordinances), and specific laws (ordinances), and exemplary standards.
Current situation of regulations

- In the U.S. and Europe, design coefficients * ) smaller than Japanese standards are used.

<table>
<thead>
<tr>
<th></th>
<th>Storage cylinder</th>
<th>Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>3.5 ~ 4</td>
<td>4</td>
</tr>
<tr>
<td>U.S./Europe</td>
<td>2.4 ~ 3.5</td>
<td>3</td>
</tr>
</tbody>
</table>

* ) The greater the value, thicker the pipe,

Expected effects

- Reduction of hydrogen station costs using overseas products.
- Improvement of performance required (refueling speed), and construction of satisfactory hydrogen stations.
1. Formulation of Commercial Infrastructure Model
2. Definition of Agenda for Safety and Regulation Review
3. Hydrogen Station Operations and Safety
4. Evaluation of Efficiency and Hydrogen Fuel
5. Summary
14 hydrogen stations are operated safely.

Hydrogen refueling results by December 2010 (For details, refer to the reference materials)

April to December 2010  JHFC cumulative
Dispensed H₂  2,510 kg  52,447 kg
No. of refueling  1170 times  21,039 times

Operates at high availability of 95.7% (JHFC station average in April to December 2010: Percentage of number of days unintended stopping did not occur.

Dispensed hydrogen per refueling during 2008 and 2010 of 70MPa vehicles was about 1.4 times that of 35MPa vehicles.
(1) There were no report of human and physical damage (A) minor malfunctions which did not affect operations (B2): 53% malfunctions affecting operations (B1): 17% malfunctions of accessories (B3): 12% human error (C): 4%

(2) By major equipment, malfunctions were: Hydrogen production equipment 31%, dispenser 28%, compressor 15%

(3) By cause, operation methods and aging degradation accounted for 67%, technical causes for 18%, management causes 15% many malfunctions were from operation methods & degradation from aging
1. Formulation of Commercial Infrastructure Model
2. Definition of Agenda for Safety and Regulation Review
3. Hydrogen Station Operations and Safety
4. Evaluation of Efficiency and Hydrogen Fuel
5. Summary
Definition of Station Efficiency

Energy for hydrogen generation, compression, refueling.

Energy of product ($H_2$ gas) fed to fuel tank. ($E_H$)

$$\eta = \frac{\text{Energy of product (H}_2\text{ gas) fed to fuel tank. (E}_H\text{) \text{ }} \text{$}}{\text{Whole energy input to hydrogen station (E}_0 + \Sigma e_n\text{)}}$$

35 MPa, 70 MPa
25 °C
<table>
<thead>
<tr>
<th>Station Name</th>
<th>Production Method</th>
<th>35MPa efficiency HHV (LHV) %</th>
<th>70MPa efficiency HHV (LHV) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asahi</td>
<td>Naphtha reforming</td>
<td>66.0 (58.9) %</td>
<td>63.1 (56.2) %</td>
</tr>
<tr>
<td>Daikoku</td>
<td>Desulfurized Gasoline reforming</td>
<td>63.1 (56.5) %</td>
<td>61.4 (54.9) %</td>
</tr>
<tr>
<td>Senju</td>
<td>Natural Gas reforming</td>
<td>64.0 (60.0) %</td>
<td>62.1 (58.0) %</td>
</tr>
<tr>
<td>Centrare</td>
<td></td>
<td>64.6 (60.5) %</td>
<td>—</td>
</tr>
<tr>
<td>Osaka</td>
<td></td>
<td>63.2 (59.0) %</td>
<td>—</td>
</tr>
<tr>
<td>Sagamihara</td>
<td>Alkaline Water Electrolysis</td>
<td>70.9 (60.5) %</td>
<td>—</td>
</tr>
<tr>
<td>Kawasaki</td>
<td>Methanol reforming</td>
<td>74.3 (70.7) %</td>
<td>—</td>
</tr>
<tr>
<td>Kyushu-Univ.</td>
<td>PEM Water Electrolysis</td>
<td>43.1 (36.8) %</td>
<td>—</td>
</tr>
</tbody>
</table>

- 70MPa Efficiency drops 2 – 3 points due to high pressure compressor and pre-cooler
- Efficiency of Methanol reforming is higher due to lower reforming temp. and its property.
- Lower Efficiency of PEM W.E. to be caused by indivisual low performance (normally above 60~70%).

Note: These efficiencies not include the energy for starting, stopping, and standby of station functions. Include hydrogen generation, compression, and refueling per 1 kg hydrogen.
Breakdown of Energy Consumption

On-site type hydrogen stations

- Percentage of heating value of feedstock for H2 generation: Approx. 80～90%
- Percentage of power for compression: Approx. 5～10%
<table>
<thead>
<tr>
<th>Off-Site</th>
<th>Station Name</th>
<th>Production Method</th>
<th>35MPa efficiency HHV (LHV) %</th>
<th>70MPa efficiency HHV (LHV) %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kasumigaseki</td>
<td>High pressure hydrogen storage</td>
<td>—</td>
<td>96.2(95.3)%</td>
</tr>
<tr>
<td></td>
<td>Funabashi</td>
<td></td>
<td>96.0(95.3)%</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Kansai Airport</td>
<td></td>
<td>99.9(99.9)%</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Ariake (moved)</td>
<td>Liquid hydrogen storage</td>
<td>73.0(70.8)%</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Nikko</td>
<td>High pressure hydrogen storage</td>
<td>89.6(88.0)%</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Kita-kyushu</td>
<td></td>
<td>88.4(86.7)%</td>
<td></td>
</tr>
</tbody>
</table>

• Offsite type’s Efficiency is higher than On-site type because it stores hydrogen manufactured outside (no need for hydrogen generation).

• Kansai Airport receives 40MPa hydrogen, so compression is not required there.

• Liquid hydrogen storage: Power consumption for collecting BOG※s causes lower efficiency than other off-site type stations.

※BOG: Boil Off Gas

Note: These efficiencies not include the energy for starting, stopping, and standby of station functions. Include hydrogen generation, compression, and refueling per 1 kg hydrogen.
Breakdown of Energy Consumption

Off-site type hydrogen station

- Energy consumption for H2 generation, compression, refueling per 1kg-H2 [MJ(1000J)]
  - Pre-cool
  - Compression(70MPa) / LH2 Pump※3
  - Compression(35MPa) / BOG Collection (35MPa)※2
  - Utilities
  - HeatingValue: HighPress.H2 / Liquid H2※1

※1 ～ 3: in case of Ariake Station(moved)

Off-site type Hydrogen Station

- Percentage of power for compression: Approx. 5%
  (Ariake station is about 20% because of BOG collection and compression.)
Prediction of Station Efficiency in the Future

When results of other NEDO projects are applied to the future stations. Prediction of improvement in efficiency based on Natural gas steam reforming.

<table>
<thead>
<tr>
<th>Production method</th>
<th>35MPa Efficiency (LHV)%</th>
<th>70MPa Efficiency (LHV)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas reforming</td>
<td>64.0 (60.0)% → 78.3 (73.2)%</td>
<td>62.1 (58.0)% → 76.8 (71.8)%</td>
</tr>
</tbody>
</table>

※ The improvement prediction is calculated based on the actual average value measured in January and September 2009 at Senju.

Breakdown of efficiency improvement

- **Hydrogen production efficiency (natural gas steam reforming & PSA purification):**
  60~65%HHV (Senju results) ⇒ 80%HHV expected

- **Overall adiabatic efficiency of compressor:**
  52% (Senju 70MPa results) ⇒ 73% expected

**Note:** These efficiencies not include the energy for starting, stopping, and standby of station functions. Include hydrogen generation, compression, and refueling per 1 kg hydrogen.
Hydrogen Fuel Constituents

Continue to measure impurities level in hydrogen and check that JHFC standards and ISO international standards (draft) are satisfied. (Including CO continuous analysis) ⇒ Closely connected to devising of international standards (NEDO project)

<table>
<thead>
<tr>
<th></th>
<th>JHFC stations measured value / Draft ISO standard value / Analysis determination limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Mode value 0.01 ppm 0.2 ppm 0.01 ppm</td>
</tr>
<tr>
<td>Total sulfur</td>
<td>Mode value 0.0001 ppm 0.0004 ppm 0.0001 ppm</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Mode value 0.001 ppm 0.1 ppm 0.001 ppm</td>
</tr>
<tr>
<td>Moisture</td>
<td>Mode value 0.5 ppm 5 ppm 0.5 ppm</td>
</tr>
<tr>
<td>Particulates</td>
<td>0.040～0.055 mg/kg 1 mg/kg 0.0004 mg/kg</td>
</tr>
</tbody>
</table>

In addition, data on total hydrocarbons (methane), formaldehyde, formic acid, oxygen, argon, nitrogen, helium, methanol, acetaldehyde, acetone was also accumulated.

Analysis results need to be accumulated from JHFC2 onwards as well.
1. Formulation of Commercial Infrastructure Model
2. Definition of Agenda for Safety and Regulation Review
3. Hydrogen Station Operations and Safety
4. Evaluation of Efficiency and Hydrogen Fuel
5. Summary
2010 Summary

1. Commercial Infrastructure Model Sub WG
   - Review various hydrogen infrastructure specifications in initial phase of dissemination
   - Evaluate hydrogen cost for various type of hydrogen stations

2. Safety & Regulation Sub WG
   More specific scenario for revision and implementation plans

3. Hydrogen Infrastructure Demonstration Sub WG
   - Summary of JHFC hydrogen station operations and data acquisition activities
   - Conclude and summarize final fiscal year regarding malfunction (durability), efficiency, cost, etc
Reference Materials
Total 13 hydrogen stations are in operation;
Tokyo: 7, Chubu: 1, Kansai: 2, Kyushu: 2,
Nikko: 1 (as of Dec.2010)

1) indicates the month/year when operation started.
2) Nikko and Kyushu are JHFC co-operative from 2009
# Operation Results (dispensed hydrogen (2))

Refueled quantity: kg

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kasumigaseki</td>
<td>Dec.'02</td>
<td>234</td>
<td>758</td>
<td>1007</td>
<td>883</td>
<td>694</td>
<td>886</td>
<td>716</td>
<td>706</td>
<td>343</td>
<td>6227</td>
</tr>
<tr>
<td>Daikoku</td>
<td>Mar.'03</td>
<td>65</td>
<td>354</td>
<td>597</td>
<td>511</td>
<td>409</td>
<td>406</td>
<td>472</td>
<td>543</td>
<td>157</td>
<td>3513</td>
</tr>
<tr>
<td>Asahi</td>
<td>Apr.'03</td>
<td>–</td>
<td>171</td>
<td>184</td>
<td>253</td>
<td>236</td>
<td>176</td>
<td>148</td>
<td>318</td>
<td>132</td>
<td>1619</td>
</tr>
<tr>
<td>Senju</td>
<td>May.'03</td>
<td>–</td>
<td>279</td>
<td>376</td>
<td>424</td>
<td>383</td>
<td>308</td>
<td>355</td>
<td>390</td>
<td>280</td>
<td>2794</td>
</tr>
<tr>
<td>Ariake</td>
<td>May.'03</td>
<td>–</td>
<td>1670</td>
<td>1540</td>
<td>736</td>
<td>515</td>
<td>1050</td>
<td>486</td>
<td>305</td>
<td>383</td>
<td>6684</td>
</tr>
<tr>
<td>Kawasaki</td>
<td>Aug.'03</td>
<td>–</td>
<td>50</td>
<td>104</td>
<td>98</td>
<td>116</td>
<td>156</td>
<td>213</td>
<td>401</td>
<td>169</td>
<td>1307</td>
</tr>
<tr>
<td>Tsurumi</td>
<td>Dec.'03</td>
<td>–</td>
<td>14</td>
<td>21</td>
<td>15</td>
<td>4</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>53</td>
</tr>
<tr>
<td>Hadano</td>
<td>Apr.'04</td>
<td>–</td>
<td>–</td>
<td>160</td>
<td>145</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>304</td>
</tr>
<tr>
<td>Sagamihara</td>
<td>Apr.'04</td>
<td>–</td>
<td>–</td>
<td>20</td>
<td>36</td>
<td>16</td>
<td>52</td>
<td>32</td>
<td>35</td>
<td>15</td>
<td>206</td>
</tr>
<tr>
<td>Ome &amp; Funabashi</td>
<td>Jun.'04</td>
<td>–</td>
<td>–</td>
<td>19</td>
<td>271</td>
<td>88</td>
<td>220</td>
<td>200</td>
<td>91</td>
<td>18</td>
<td>908</td>
</tr>
<tr>
<td>Seto-North</td>
<td>Feb.'05</td>
<td>–</td>
<td>–</td>
<td>445</td>
<td>5866</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>6312</td>
</tr>
<tr>
<td>Seto-South</td>
<td>Feb.'05</td>
<td>–</td>
<td>–</td>
<td>547</td>
<td>6183</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>6730</td>
</tr>
<tr>
<td>Centrair</td>
<td>Jul.'06</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>3075</td>
<td>4387</td>
<td>3793</td>
<td>2145</td>
<td>499</td>
<td>13899</td>
</tr>
<tr>
<td>Kansai Airport</td>
<td>Mar.'07</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>2</td>
<td>62</td>
<td>60</td>
<td>46</td>
<td>44</td>
<td>213</td>
</tr>
<tr>
<td>Osaka</td>
<td>Aug.'07</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>214</td>
<td>153</td>
<td>130</td>
<td>97</td>
<td>595</td>
</tr>
<tr>
<td>Ichihara*</td>
<td>Dec.'06</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>70</td>
<td>159</td>
<td>72</td>
<td>33</td>
<td>–</td>
<td>334</td>
</tr>
<tr>
<td>Nikko*</td>
<td>Sep.'09</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>61</td>
<td>50</td>
<td>110</td>
</tr>
<tr>
<td>Kitakyushu*</td>
<td>Sep.'09</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>211</td>
<td>169</td>
<td>380</td>
</tr>
<tr>
<td>Kyushu University*</td>
<td>Sep.'09</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>106</td>
<td>154</td>
<td>260</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>**</td>
<td>**299</td>
<td>**3294</td>
<td>**5019</td>
<td>**15420</td>
<td>**5607</td>
<td>**8076</td>
<td>**6701</td>
<td>**5521</td>
<td>**2510</td>
<td>**52447</td>
</tr>
</tbody>
</table>

* JHFC Co-Operative Hydrogen Station

** Total may vary from the simple sum of each station, due to essential figure.

In addition to above, cumulatively 30.8 kg of hydrogen has been supplied to small mobile vehicles by hydrogen cylinder stocker.
Operation Results (refueling number (1))

Refueling Number: Total 21039 times* (Dec. 2002 to Dec. 2010)

- Tokyo commuter bus
- EXPO2005 (Aichi)
- Centrair Airport boarding bus

Including JHFC Co-Operative Hydrogen Stations

Refueling Number per month (kg)

Cumulative (kg)

2002 2003 2004 2005 2006 2007 2008 2009 2010

JHFC1 JHFC2

0 5000 10000 15000 20000 25000

700 600 500 400 300 200 100 0

Cumulative
### Operation Results (refueling number (2))

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kasumigaseki</td>
<td>Dec.'02</td>
<td>136</td>
<td>379</td>
<td>466</td>
<td>462</td>
<td>486</td>
<td>640</td>
<td>466</td>
<td>385</td>
<td>158</td>
<td>3578</td>
</tr>
<tr>
<td>Daikoku</td>
<td>Mar.'03</td>
<td>48</td>
<td>316</td>
<td>466</td>
<td>388</td>
<td>275</td>
<td>316</td>
<td>309</td>
<td>238</td>
<td>100</td>
<td>2456</td>
</tr>
<tr>
<td>Asahi</td>
<td>Apr.'03</td>
<td>–</td>
<td>141</td>
<td>106</td>
<td>167</td>
<td>146</td>
<td>121</td>
<td>84</td>
<td>131</td>
<td>68</td>
<td>964</td>
</tr>
<tr>
<td>Senju</td>
<td>May.'03</td>
<td>–</td>
<td>246</td>
<td>298</td>
<td>313</td>
<td>263</td>
<td>210</td>
<td>183</td>
<td>190</td>
<td>105</td>
<td>1808</td>
</tr>
<tr>
<td>Ariake</td>
<td>May.'03</td>
<td>–</td>
<td>569</td>
<td>557</td>
<td>549</td>
<td>435</td>
<td>559</td>
<td>335</td>
<td>168</td>
<td>195</td>
<td>3367</td>
</tr>
<tr>
<td>Kawasaki</td>
<td>Aug.'03</td>
<td>–</td>
<td>60</td>
<td>66</td>
<td>72</td>
<td>74</td>
<td>114</td>
<td>99</td>
<td>136</td>
<td>77</td>
<td>698</td>
</tr>
<tr>
<td>Tsurumi</td>
<td>Dec.'03</td>
<td>–</td>
<td>15</td>
<td>16</td>
<td>12</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>46</td>
</tr>
<tr>
<td>Hadano</td>
<td>Apr.'04</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>107</td>
<td>106</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>213</td>
</tr>
<tr>
<td>Sagamihara</td>
<td>Apr.'04</td>
<td>–</td>
<td>–</td>
<td>17</td>
<td>32</td>
<td>17</td>
<td>41</td>
<td>25</td>
<td>29</td>
<td>16</td>
<td>177</td>
</tr>
<tr>
<td>Ome &amp; Funabashi</td>
<td>Jun.'04</td>
<td>–</td>
<td>–</td>
<td>11</td>
<td>158</td>
<td>75</td>
<td>152</td>
<td>119</td>
<td>70</td>
<td>17</td>
<td>602</td>
</tr>
<tr>
<td>Seto–North</td>
<td>Feb.'05</td>
<td>–</td>
<td>–</td>
<td>88</td>
<td>1136</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1224</td>
</tr>
<tr>
<td>Seto–South</td>
<td>Feb.'05</td>
<td>–</td>
<td>–</td>
<td>105</td>
<td>1244</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1349</td>
</tr>
<tr>
<td>Centrair</td>
<td>Jul.'06</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>727</td>
<td>1020</td>
<td>882</td>
<td>607</td>
<td>3355</td>
</tr>
<tr>
<td>Kansai Airport</td>
<td>Mar.'07</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1</td>
<td>40</td>
<td>39</td>
<td>32</td>
<td>143</td>
</tr>
<tr>
<td>Osaka</td>
<td>Aug.'07</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>114</td>
<td>129</td>
<td>106</td>
<td>439</td>
</tr>
<tr>
<td>Ichihara *</td>
<td>Dec.'06</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>48</td>
<td>101</td>
<td>56</td>
<td>30</td>
<td>–</td>
</tr>
<tr>
<td>Nikko *</td>
<td>Sep.'09</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>43</td>
<td>35</td>
</tr>
<tr>
<td>Kitakyushu *</td>
<td>Sep.'09</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>103</td>
<td>86</td>
</tr>
<tr>
<td>Kyushu University *</td>
<td>Sep.'09</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>45</td>
<td>73</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>184</td>
<td>1726</td>
<td>2303</td>
<td>4639</td>
<td>2550</td>
<td>3428</td>
<td>2726</td>
<td>2313</td>
<td>1170</td>
<td>21039</td>
</tr>
</tbody>
</table>

* JHFC Co-Operative Hydrogen Station

In addition to above, hydrogen has been supplied cumulatively 347 times to small mobile vehicles by hydrogen cylinder stocker.
Results of Remodeling Senju 70MPa Station (1)

Remodeling was carried out targeting the average flow rate of 1.7 kg/min (5kg/3min).

Flow rate simulation was carried out prior to remodeling.

Enlargement of pipe inner diameter

<table>
<thead>
<tr>
<th>Enlargement</th>
<th>1φ2.5→6.4</th>
<th>2φ3.1→6.4</th>
<th>2φ3.1→4.8</th>
<th>2φ1.6→2.2</th>
</tr>
</thead>
</table>

Other reduction methods

<table>
<thead>
<tr>
<th>Other reduction methods</th>
<th>③Flow control valve Control software</th>
<th>②Divided into two parallels</th>
</tr>
</thead>
</table>

ΔP reduction

<table>
<thead>
<tr>
<th>ΔP reduction</th>
<th>1/43</th>
<th>1/18</th>
<th>1/46</th>
<th>1/3.8</th>
</tr>
</thead>
</table>

Notes: Figures in the figure indicate the time of remodeling

①: 1st remodeling (Feb 2009)
②: 2nd remodeling (Jun 2009)
③: 3rd remodeling (Feb 2010)
Results of Remodeling Senju 70MPa Station (2)

Achieved average flow rate of 1.7 kg/min (refueled 5kg in 3min).

Change in refueling flow rate by remodeling (100ℓ tank)

Confirmed 5 kg/3min on actual vehicle → Achieved improvement of flow rate

Average flow rate after modifications

Before modification
0.4kg/min

1st modification
0.7kg/min

2nd modification
1.0kg/min

3rd modification
1.6kg/min

Note 1 1st bank 40Mpa class up to 2nd remodeling
Note 2 1st bank also 80Mpa class in 3rd remodeling
# Malfunction Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Disaster</td>
<td>Cases of human damages, physical damages</td>
</tr>
<tr>
<td>B. Equipment malfunctions</td>
<td></td>
</tr>
<tr>
<td>B1. Operational malfunctions</td>
<td>Malfunctions of equipment causing severe problems in the operation of stations other than A.</td>
</tr>
<tr>
<td>B2. Minor malfunctions not obstructing operations</td>
<td>Malfunction of hydrogen facility equipment other than B1</td>
</tr>
<tr>
<td>B3. Malfunctions of accessories other than hydrogen facilities</td>
<td>Malfunction of accessories, etc. (instrumentation air, cooling water, hydrogen facilities, etc.)</td>
</tr>
<tr>
<td>B4. Phenomenon preventing malfunctions</td>
<td>Phenomenon in which changes in facilities were detected and acted upon before malfunctions or problems occurred.</td>
</tr>
<tr>
<td>C. Human error</td>
<td>Problems cause by misoperations and inadequate maintenance, etc.</td>
</tr>
<tr>
<td>D. Survey reports, etc.</td>
<td>Knowledge from survey on facilities, not problems and malfunctions.</td>
</tr>
</tbody>
</table>
Problems of Key Equipment (By Categorization)

Percentage of key equipment (B1)
- Hydrogen production equipment: 25%
- Dispenser: 54%
- Compressor: 13%
- High-pressure storage cylinder: 4%
- Others: 4%

Percentage of key equipment (B2)
- Hydrogen production equipment: 44%
- Dispenser: 29%
- Compressor: 19%
- High-pressure storage cylinder: 4%
- Others: 4%

Percentage of key equipment (B3)
- Accessories: 84%
- Others: 16%

Percentage of key equipment (B4)
- Hydrogen production equipment: 23%
- Dispenser: 23%
- Compressor: 18%
- Accessories: 12%
- Others: 6%
- High-pressure storage cylinder: 18%

(2006～2010)
## Causes of Problems

<table>
<thead>
<tr>
<th>Factor</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative</td>
<td>Related to work guidelines or work procedures, or caused by improper work.</td>
</tr>
<tr>
<td>Operational factor</td>
<td>Caused by operation method, caused by changes or effects with years, or caused by accidental factors.</td>
</tr>
<tr>
<td>Technical factor</td>
<td>Caused by technical problems such as selection of material, structural design, etc.</td>
</tr>
</tbody>
</table>

### Percentage of cause

**Administrative factor**
- (2006~2010): 14.9%

**Operational factor**
- 66.9%

**Technical factor**
- 18.2%
Malfunction Case 1

Leakage from Compressor, discharge, absorption valves

1. Situation
   - Hydrogen gas alarm installed inside the building sounds directly after compressor is started. Facilities automatically stop after the alarm.

2. Cause
   - Polishing is carried out in the longitudinal direction on the joined face of the discharge and absorption valves which are metal touch.
   - Affecting also the temperature and vibration during operations, polishing marks form a leakage path from the center of the valve to the outer sealed area, resulting in leakage from the flange.

3. Measures/improvements
   - Polished the valve joined area in the Circumferential Direction and attached.
   - In the future, manufacturers are planning to use a polishing method with higher density in the circumferential direction.
Malfunction Case 2

Hydrogen manufacturing unit malfunction

1. State
   • Through open inspection of the reaction tube, check for damage of the aluminum ball, deformation of the reaction pipe, and cracks near the elbow.
   • Through the micro and fractured surface inspection of cracked area, check for intercrystalline cracks and striation.

2. Causes
   • The structure was one where thermal shrinkage at start/stop was absorbed by the up/down movements of the reaction pipe, however the up/down movements are impeded when the inner tube is covered by the catalyst and heat exchange alumina ball.
   • The repetition of start/stop in this state causes deformation of the top part of the inner tube, resulting in defects.

3. Measures/Improvements
   • Reduce the filling amount of the alumina ball to reduce covering of the inner tube.
   • Increase material strength to reduce inner tube deformation and damage.
Definition Of Energy

Electric energy: 3.6 MJ/kWh

Material energy: For high pressure gas, Estimated by Heating Value + Pressure Energy

Pressure energy of hydrogen gas ($E_{pf}$)

$$E_{pf} = R \times t_f \times \ln \left( \frac{p_f}{p_0} \right)$$

- $R$: Gas Constant (8.31510 J mol$^{-1}$ K$^{-1}$)
- $t_f$: Temperature of Hydrogen Gas (K)
- $p_0$: Atmospheric Pressure (101.325 kPa)
- $p_f$: Pressure of Hydrogen Gas (kPa)
# Potential Energy Of Hydrogen

## Potential energy of hydrogen (25°C basis)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Potential energy per 1 kg hydrogen gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Higher Heating Value basis (HHV)</td>
</tr>
<tr>
<td><strong>70 MPa (Gauge pressure)</strong></td>
<td></td>
</tr>
<tr>
<td>MJ/kg</td>
<td>150</td>
</tr>
<tr>
<td>MJ/Nm³</td>
<td>13.5</td>
</tr>
<tr>
<td><strong>35 MPa (Gauge pressure)</strong></td>
<td></td>
</tr>
<tr>
<td>MJ/kg</td>
<td>149</td>
</tr>
<tr>
<td>MJ/Nm³</td>
<td>13.4</td>
</tr>
<tr>
<td><strong>Atmospheric pressure</strong></td>
<td></td>
</tr>
<tr>
<td>MJ/kg</td>
<td>142</td>
</tr>
<tr>
<td>MJ/Nm³</td>
<td>12.8</td>
</tr>
</tbody>
</table>

- **Hydrogen unit conversion factor:** 0.0899 [kg/Nm³]
### Heating Value of Feedstock for Hydrogen Generation

<table>
<thead>
<tr>
<th></th>
<th>Unit conversion factor</th>
<th>Higher Heating Value (HHV)</th>
<th>Lower Heating Value (LHV)</th>
<th>HHV (Unit converted)</th>
<th>LHV (Unit Converted)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural gas (Kanto/Kansai)</strong></td>
<td>0.817 [kg/Nm³]</td>
<td>45.0 [MJ/Nm³]</td>
<td>40.5 [MJ/Nm³]</td>
<td>55.1 [MJ/kg]</td>
<td>49.6 [MJ/kg]</td>
</tr>
<tr>
<td><strong>Natural gas (Chubu)</strong></td>
<td>0.847 [kg/Nm³]</td>
<td>46.0 [MJ/Nm³]</td>
<td>41.4 [MJ/Nm³]</td>
<td>54.3 [MJ/kg]</td>
<td>48.9 [MJ/kg]</td>
</tr>
<tr>
<td><strong>Methanol</strong></td>
<td>0.796 [kg/L]</td>
<td>18.1 [MJ/L]</td>
<td>15.8 [MJ/L]</td>
<td>22.7 [MJ/kg]</td>
<td>19.8 [MJ/kg]</td>
</tr>
<tr>
<td><strong>Naptha</strong></td>
<td>0.723 [kg/L]</td>
<td>33.6 [MJ/L]</td>
<td>31.9 [MJ/L]</td>
<td>46.5 [MJ/kg]</td>
<td>44.1 [MJ/kg]</td>
</tr>
<tr>
<td>**Desulfurized gasoline *</td>
<td>0.733 [kg/L]</td>
<td>34.6 [MJ/L]</td>
<td>32.9 [MJ/L]</td>
<td>47.2 [MJ/kg]</td>
<td>44.9 [MJ/kg]</td>
</tr>
</tbody>
</table>

* For the heating value of desulfurized gasoline, the value of gasoline is adopted.
  - The station efficiency calculated in 2009 was based on the values above.
  - Ref.: Report of March 2006 “JHFC General Efficiency Review” (Edit by JHFC General Efficiency Review Committee・JARI) P.7
  - Condition of gas fuel: 0°C・1 atm (the previous STP condition)
  - Condition of liquid fuel: 15°C
Station Efficiency (Future/Flow Chart)

【Future】Natural gas reforming (70MPa/with pre-cooling)

When hydrogen 1.0 kg [ 11.1 Nm³ ] is supplied

Natural gas
3.04 kg (3.72 Nm³)
151 MJ(LHV)
168 MJ(HHV)

Electricity
2.41 kWh
3.12 kWh

(Breakdown)
40MPa compressor 2.80 kWh
80MPa compressor 0.32 kWh

Electricity (Utilities, etc.)
1.00 kWh

Urban gas

Hydrogen generator

40MPa compressor

40MPa storage cylinder

Dispenser

70 MPa

80MPa compressor
80MPa storage cylinder
Pre-cooling

Electricity
1.02 kWh

Power consumption of Pre-cooler (−40℃) not include starting and keeping up temperature.

70 MPa system

Hydrogen temperature : −40 ℃
Station Efficiency (Future/Details)

【Future】Natural gas reforming  (70MPa/with pre-cooling)

Station input energy per hydrogen 1 kg (Fuel tank)

<table>
<thead>
<tr>
<th>Type of energy</th>
<th>Energy input unit</th>
<th>Energy input unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LHV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HHV</td>
</tr>
<tr>
<td>Natural gas</td>
<td>3.04kg</td>
<td>151 MJ</td>
</tr>
<tr>
<td></td>
<td>3.72 Nm³</td>
<td>168 MJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>7.55 kWh</td>
<td>27.2 MJ</td>
</tr>
</tbody>
</table>

Potential energy of hydrogen gas: 128 MJ/kg (LHV), 150 MJ/kg (HHV)
(Hydrogen gas condition: Temperature 25°C, Pressure 70 MPa))

Energy efficiency $\eta$  71.8 % (LHV)
76.8 % (HHV)
Review on-site natural gas reforming 300Nm$^3$/h, 35MPa station

CO$_2$ capture PSA and CO$_2$ liquefaction unit is added for usual station.

300Nm$^3$/h-scale station  
Captured liquid CO$_2$ amount=110kg/h  
CO$_2$ capture ratio=50%

Change in hydrogen station energy efficiency  
68.2%(LHV)$\rightarrow$65.6%(LHV)  
(No CO$_2$ capture) (CO$_2$ capture)

Energy for CO$_2$ capture
CO$_2$ PSA unit cost: 35 million yen,
CO$_2$ liquefaction unit cost: 57.6 million yen
Hydrogen costs adding CO$_2$ capture units: 79 yen/Nm$^3$

CO$_2$ capture cost: approx. 32,000 yen/ton-liquidCO$_2$