Hydrogen Stations
- JHFC Activities in FY2008 -

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Jinichi TOMURO
(tdd325@enaa.or.jp)
Engineering Advancement Association of Japan

Framework of JHFC Project

Japan Hydrogen & Fuel Cell Demonstration Project

JHFC Project

Subsidized by METI

METI

JARI — FCV Demonstration Study

ENAA — Hydrogen Infrastructure Demonstration Study

METI : Ministry of Economy, Trade and Industry
JARI : Japan Automobile Research Institute
ENAA : Engineering Advancement Association of Japan

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Outline of JHFC2

Vehicles	Hydrogen FCV's, ICE vehicles and other small carriers
Fuel Supply	Compressed gaseous hydrogen and liquid hydrogen
Project terms	FY2006 - 2010
Project budget	FY2006 1,300 million JPY FY2007 1,800 million JPY FY2008 1,300 million JPY

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JHFC Japan Hydrogen & Fuel Cell Demonstration Project

Objectives of JHFC2

1. To clarify remaining issues under the actual using conditions

2. To collect data to develop regulations, codes and standards

3. To formulate and implement public relations and educations for dissemination and promotion

4. To verify the energy savings (fuel economy) and environmental impact

5. To identify technology and policy trends

of FCV's, fuel cell powered small vehicles and hydrogen ICV's as well as hydrogen infrastructures

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Features of JHFC 2

Fleet tests by third parties

Increase of hydrogen users (not limited to FCV's but small FC carriers and hydrogen ICV's)

Area extension (metropolitan Tokyo, Nagoya and Osaka)

Operation of FC buses and hydrogen station in Centrair Airport region

Operation of FC wheel chairs, FC carts and FC-assisted bicycles and operation of hydrogen stations for them in Osaka region

Participating Vehicles

Toyota FCHV

Nissan X-TRAIL FCV

Honda FCX

Daimler-Chrysler F-Cell

GM Hydrogen3

Toyota / Hino FCHV-BUS

Suzuki MRwagon-FCV

Mazda RX-8 Hydrogen RE*

* New ICV participants in JHFC2

FCV: Fuel Cell Vehicle

ICV: Internal Combustion engine Vehicle

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Japan Hydrogen & Fuel Cell Demonstration Project

Participants

8 automobile manufacturers and 16 energy or infrastructure companies are participating JHFC2.

Automobile manufacturers

- TOYOTA
- NISSAN
- DAIMLERCHRYSLER
- GM
- HINO
- SUZUKI
- mazda

***Energy or Infrastructure* companies**

- ENEOS
- Iwatani
- TOKYO GAS
- TAIYO NIPPON SANSO The Gas Professionals
- JAPAN AIR GASES
- Nippon Steel Corporation
- KURITA
- SINANEN
- ITOCHU ENEX CO.,LTD.
- TOHO GAS
- THE KANSAI ELECTRIC POWER CO.,INC.
- OSAKA GAS
- KURIMOTO
- JOMO

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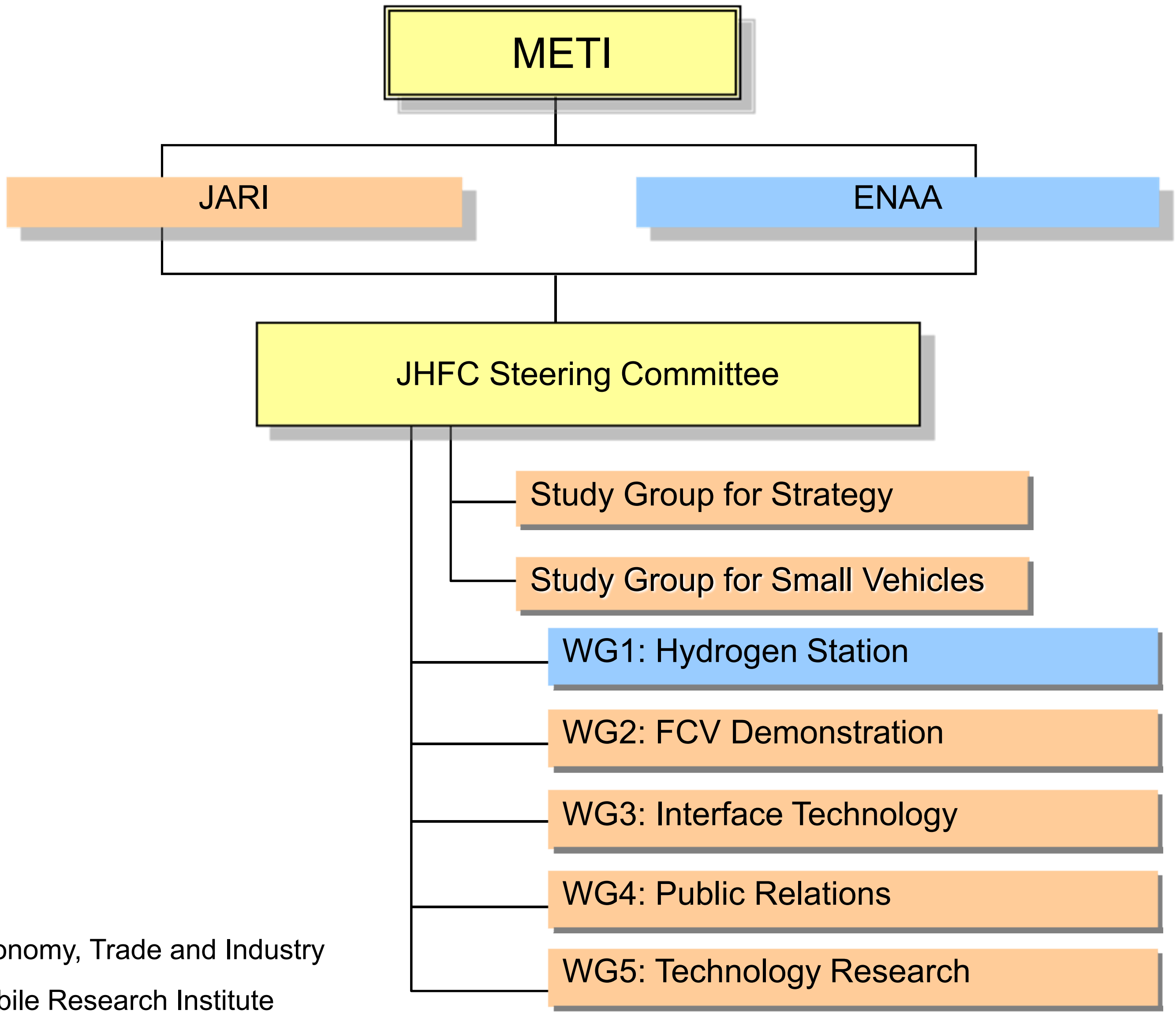
FY2007 JHFC Organization



METI: Ministry of Economy, Trade and Industry

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General Issues
for
Demonstration of Hydrogen Stations

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General Issues for Demonstration of Hydrogen Stations

In regard to FCV's etc. and hydrogen infrastructure:

- To clarify remaining issues under the actual conditions of use
- To demonstrate effectiveness and issues of storage and operation at higher pressures such as 70 MPa
- To collect data to develop regulations, codes and standards
- To formulate and implement public relations and education for dissemination and promotion
- To verify the energy savings (fuel economy) and environmental impact
- To identify technology and policy trends

This presentation discusses topics related to hydrogen stations.

Operation of Hydrogen Stations

Operation of Hydrogen Stations

- **11 JHFC hydrogen stations and liquid hydrogen production facility have been operated safely.**
- **JHFC hydrogen stations cumulatively supplied 42,658 kg hydrogen with 16,969 refuelings during the period from December 2002 to December 2008.**
- **70 MPa facilities were added to 4 stations (Senju, Asahi, Daikoku, Kasumigaseki (mobile)) and started operation.**

Senju Station will be further modified so that the vehicle might be able to be refueled at a flow rate as high as 2.0 kg/min by changing piping materials and so on.

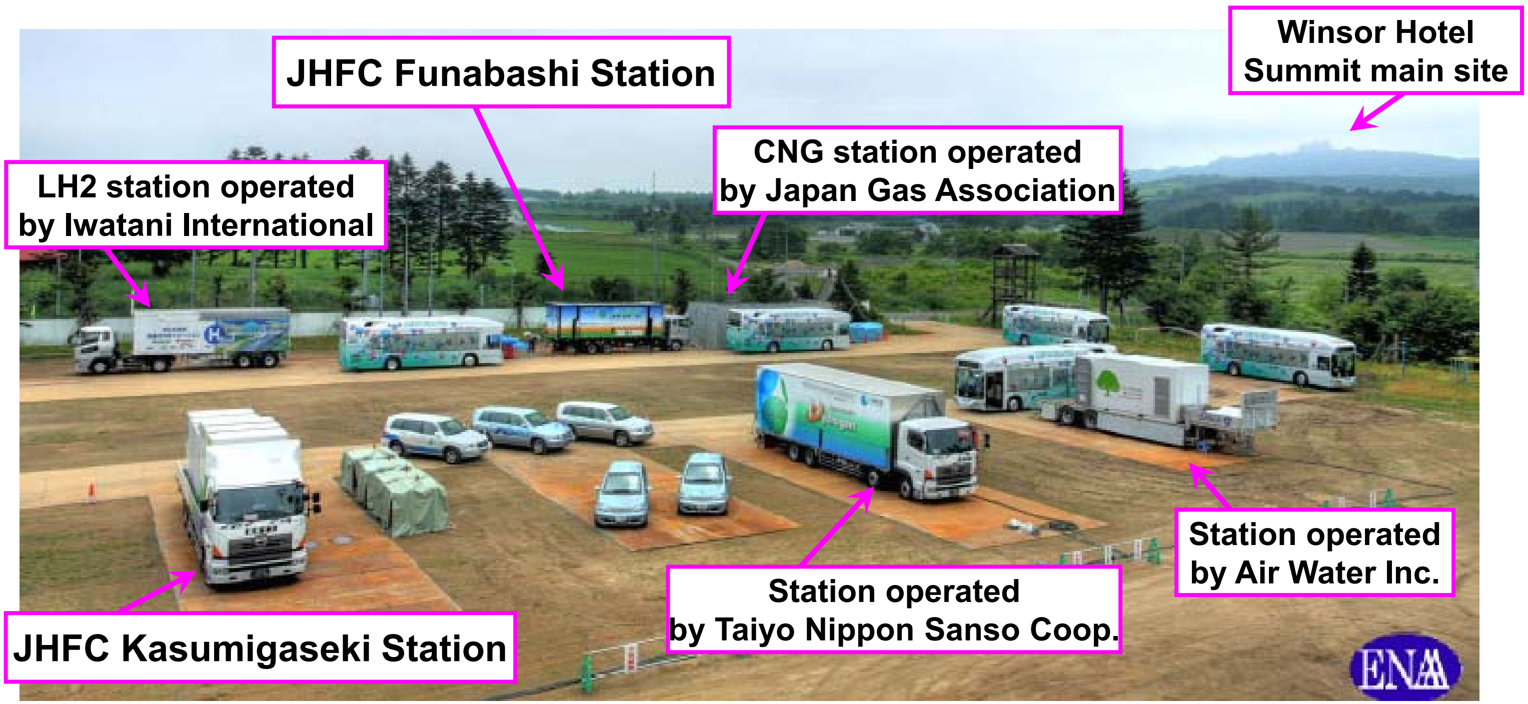
Funabashi station (mobile) was renovated as a 70 MPa station, but was assigned to operate for Kasumigaseki station due to vehicles' demand.

Topics

Mobile Hydrogen Stations refueled hydrogen to FC buses and FCV's for G8 Hokkaido Toyako Summit.

44 refuelings, 264 kg of H_2 for 5 FC Buses
33 refuelings, 66 kg of H_2 for 10 FC passenger vehicles

This operation demonstrated effectiveness of mobile stations even for the heavy duty vehicles such as FC buses. A very large demonstration for a worldwide famous event.



Mobile Station Complex, a joint project of Ministry of Foreign Affairs of Japan and JHFC, consisting of five hydrogen stations and a CNG station. This operated from June 26 to July 11, 2008 at the play ground of the former elementary school in the town of Toyako.

70 MPa Facility Addition

70 MPa Facility Addition

In order to extend driving range, 70 MPa on-board storage for FCV is beginning to be considered worldwide. 70 MPa hydrogen stations are necessary to support demonstration of such FCV's.

70 MPa facilities were added to 4 existing JHFC hydrogen stations.

Specification of JHFC 70 MPa Stations

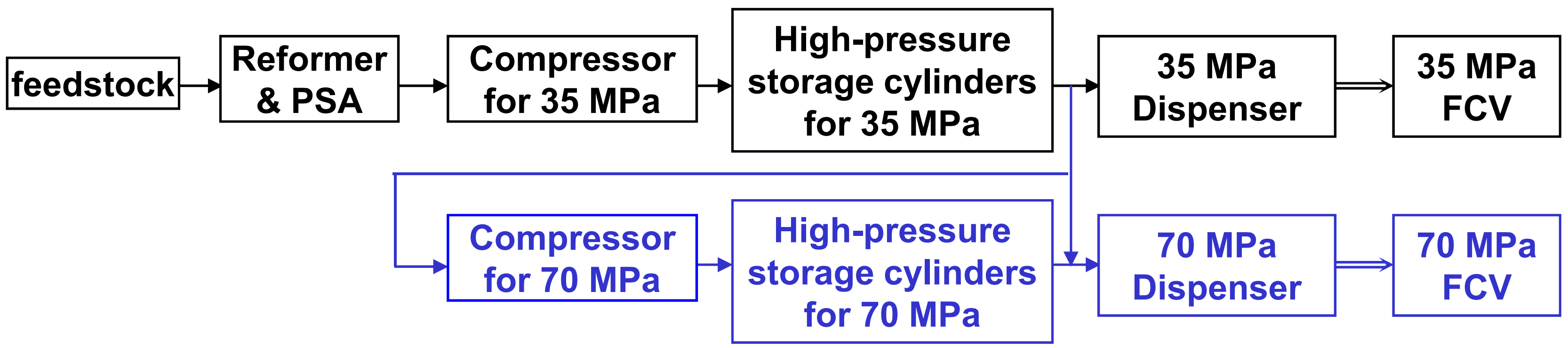
Station	Senju	Asahi	Kasumigaseki (mobile)	Daikoku
Refueling pressure	70 MPa			
Refueling capacity	1 passenger vehicle			3 passenger vehicle
H_2 storage cylinders for 70 MPa	Yes			No
Flow rate (kg/min)	0.1 - 2.0	0.1 - 0.85	0.1 - 0.85	0.1 - 0.3
Refueling protocol	Several protocols to be tested			
H_2 pre-cooling	-20 C	-5 C	-5 C	No

Concept of 70 MPa Facility Addition

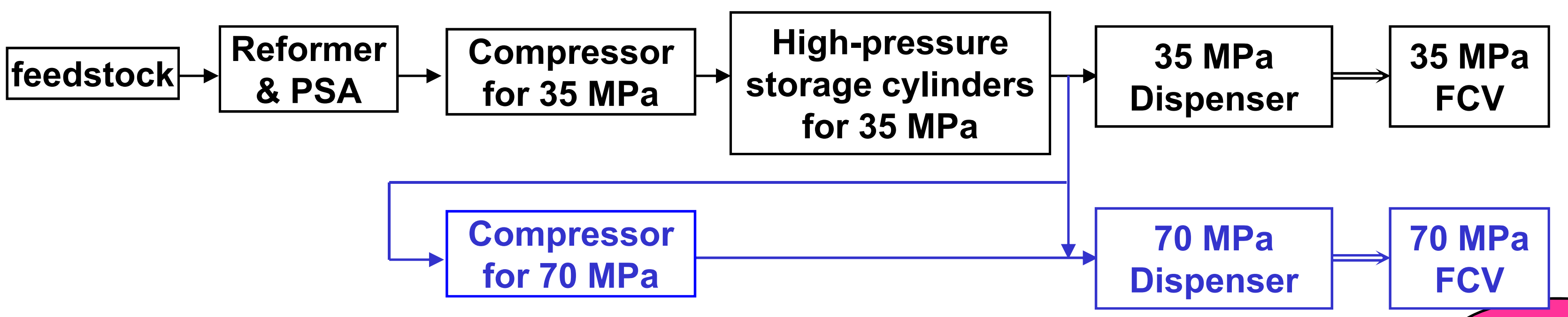
70 MPa facilities were added to 4 existing JHFC stations.

Different 70 MPa Refueling method

(1) Cascade (Senju, Asahi, Kasumigaseki(mobile))



(2)Cascade and Compressor (Daikoku)



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Opening Celemony of JHFC 70 MPa Stations

Mr. Kawahara from METI celebrated the opening.

70 MPa FCV's (Toyota, Nissan, Suzuki)

JHFC Senju Hydrogen Station

Start refueling of 70 MPa hydrogen

Held at 13:00-14:00 on Sep. 12, 2008 at JHFC Senju Station.
Guests from METI, NEDO &c. and 35 press people attended.
Technical presentation and refueling demonstration followed test-ride.

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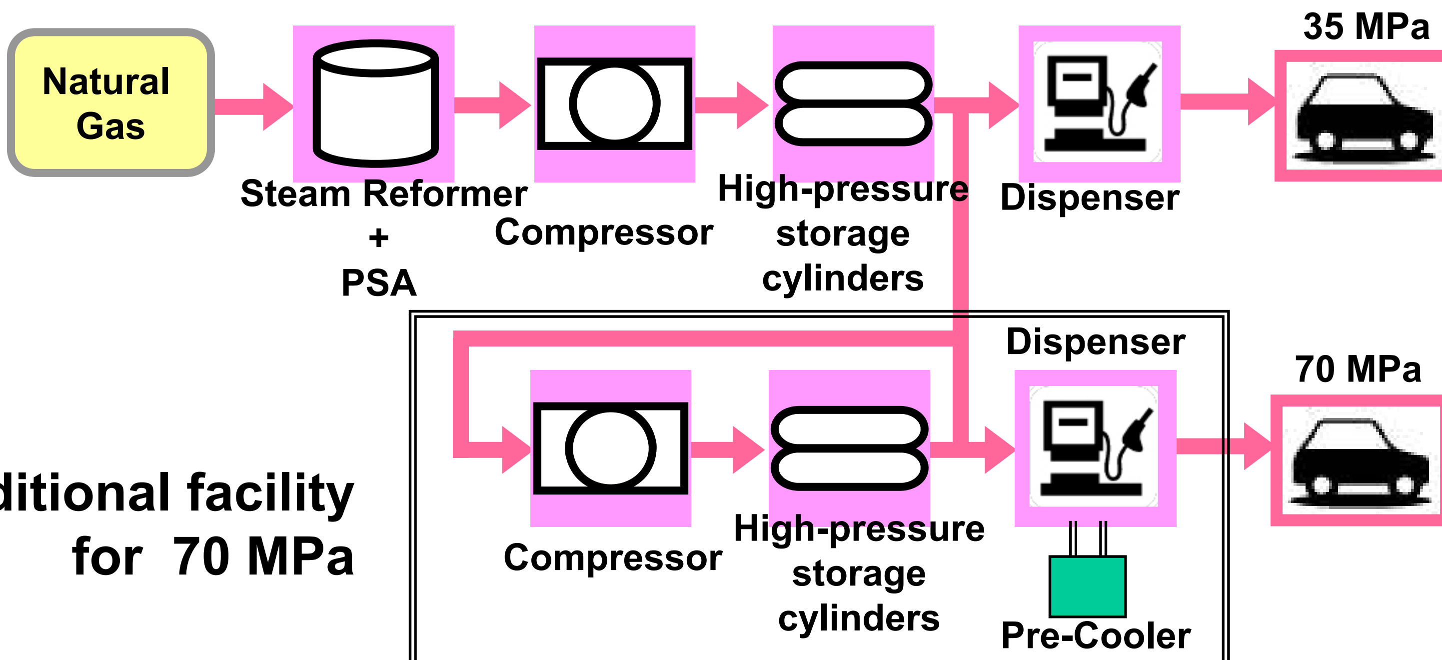
Senju Hydrogen Station 70 MPa Facility Addition

Operation started on Sep. 12, 2008



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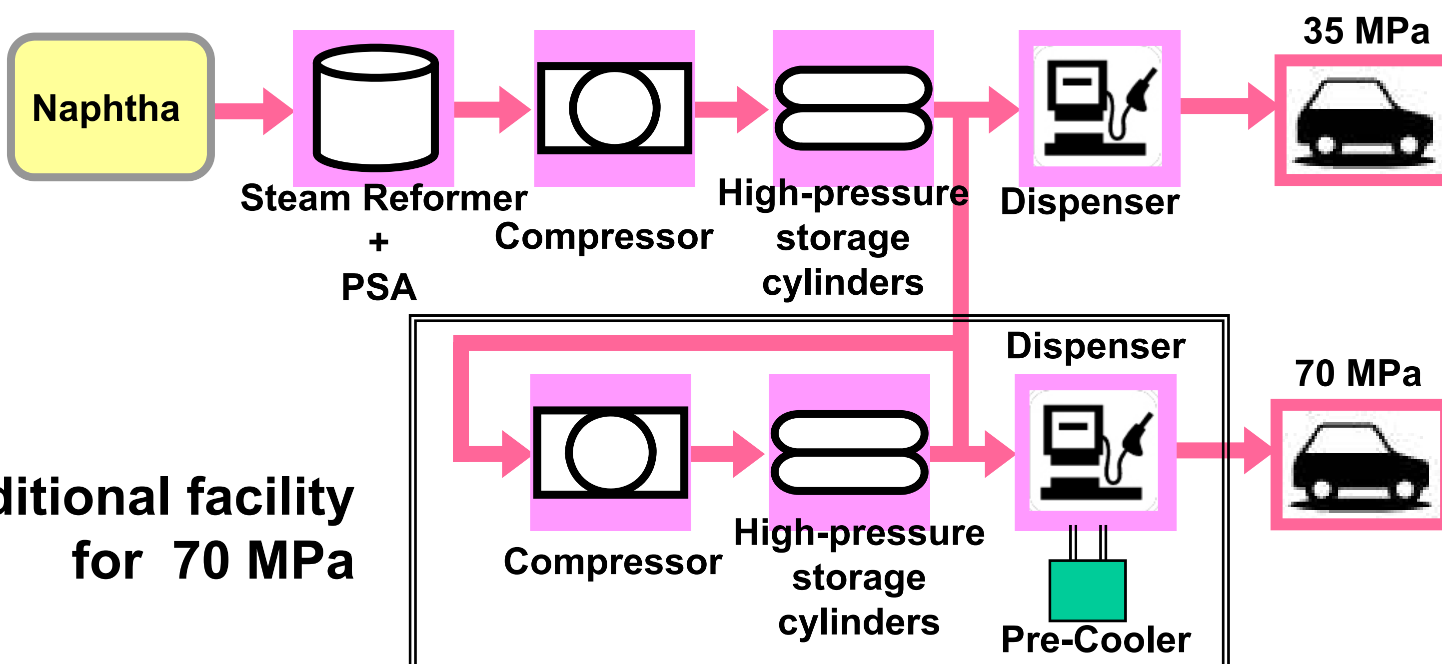
Asahi Hydrogen Station 70 MPa Facility Addition

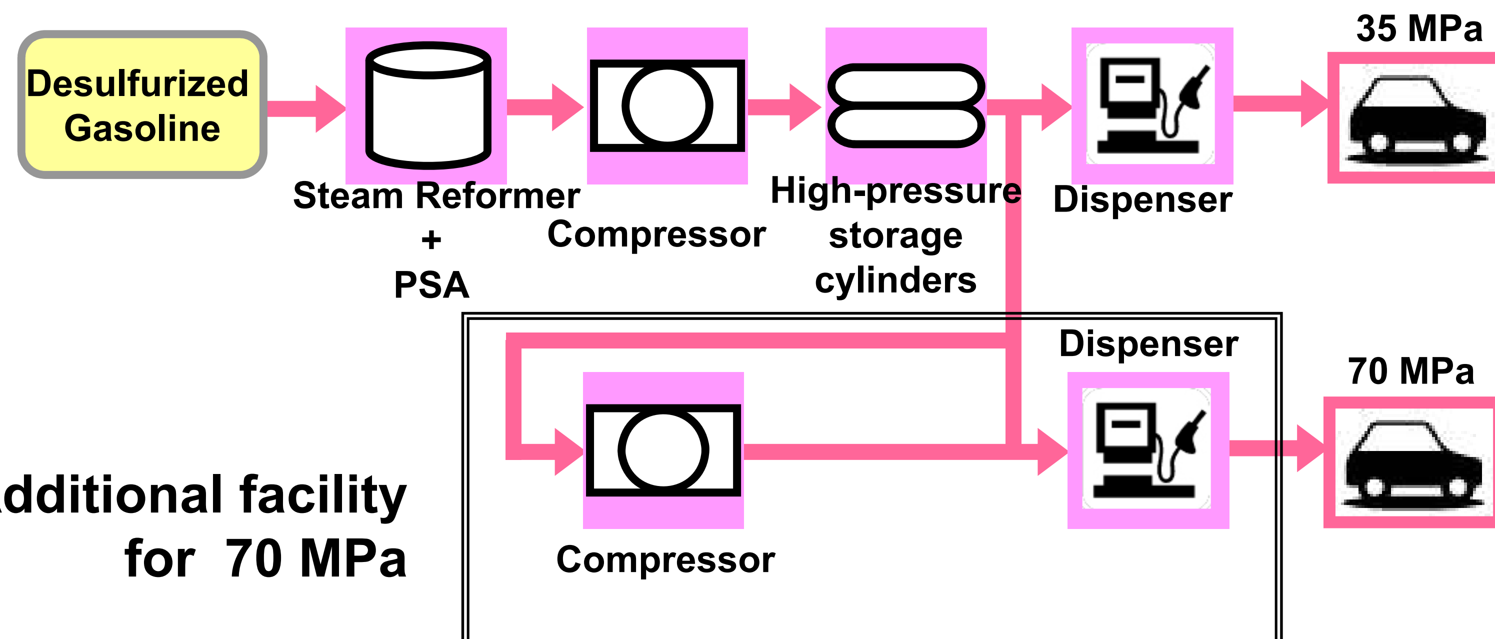
Operation started on Feb. 2, 2009



Additional facility for 70 MPa

Daikoku Hydrogen Station 70 MPa Facility Addition

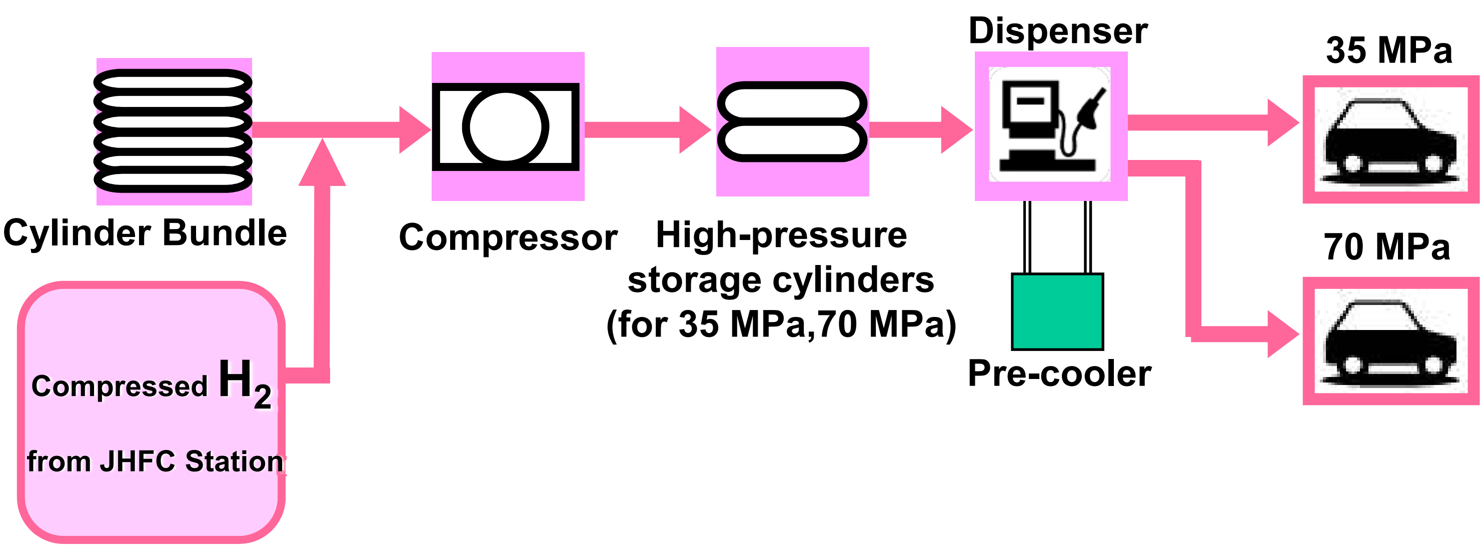
Operation started on Dec. 1, 2008



Additional facility for 70 MPa

Kasumigaseki Hydrogen Station (re-locatable) 70 MPa Facility Addition

Operation started on Feb. 2, 2009



Funabashi station (mobile) was renovated as a 70 MPa station, but was assigned to operate for Kasumigaseki station due to vehicles' demand.

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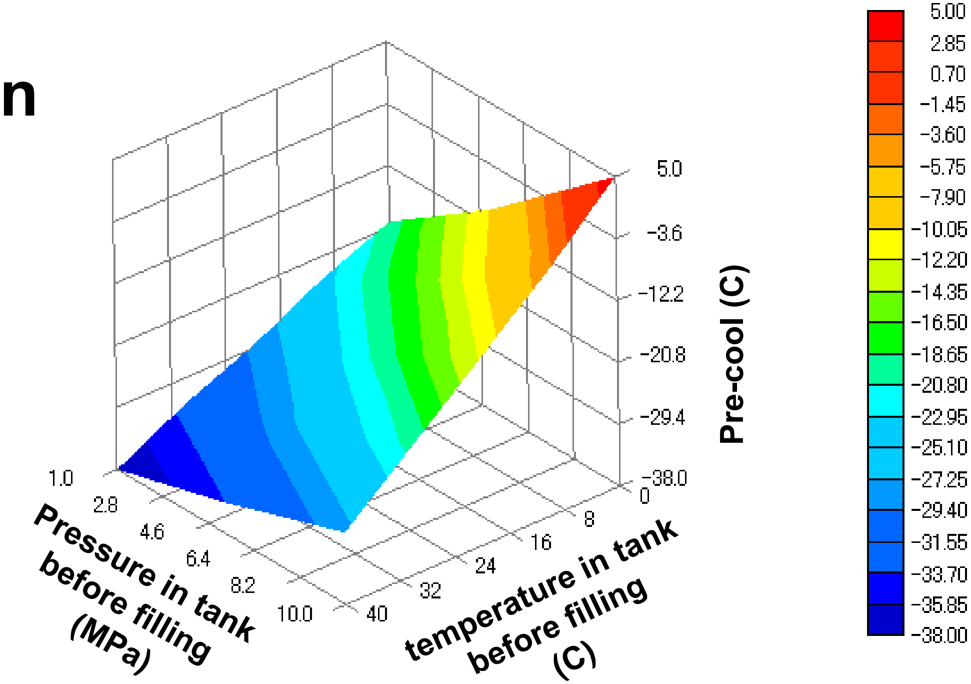
Pre-Cooling System Analysis (1)

Temperature rise of hydrogen

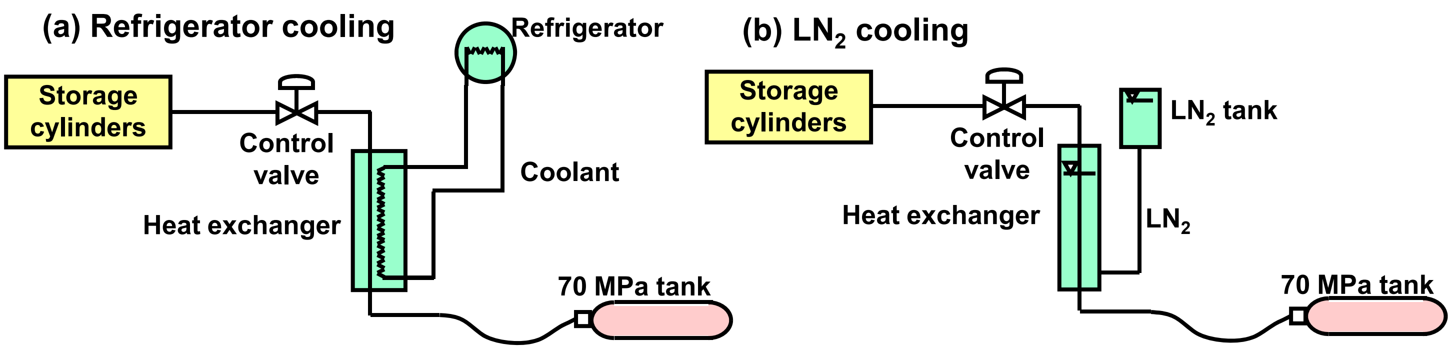
Relation among pre-cooled H_2 temperature, initial pressure, initial temperature and temperature after fulfilling has been estimated.

Optimal pre-cooling system will be further investigated.



Example: Fulfill for 3 minutes

Pre-cooling method



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Pre-cooling System Analysis (2)

Behavior of cooled nozzle

Before actual refueling, effect of ice and condensed water at the cooled nozzle surface was surveyed.

1. Objective : To confirm hazardous behavior by ice and/or condensed water at the nozzle surface after refueling pre-cooled H_2.

2. Method : To observe the state of ice and/or condensed water after pre-cooled H_2 at -5 to -20 C flows through the nozzle for a certain period.

3. Results : Although ice is observed at the nozzle surface, they found no detaching trouble and hydrogen leakage.

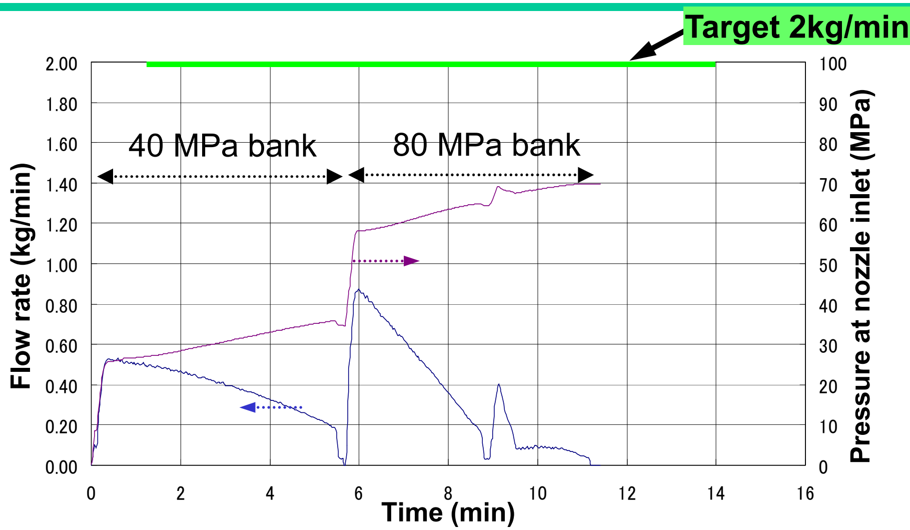
Tested nozzle

Ice at the nozzle surface

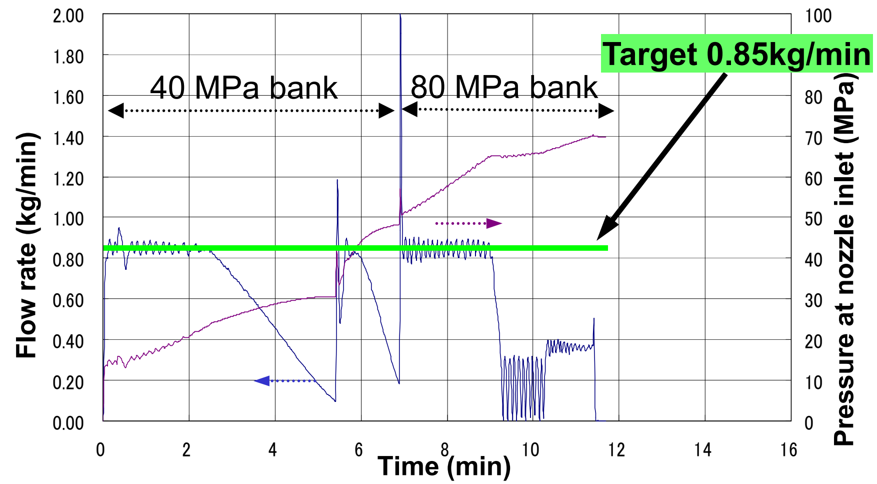
Condensed water

Results were also confirmed by the actual 70 MPa refueling with pre-cooling.

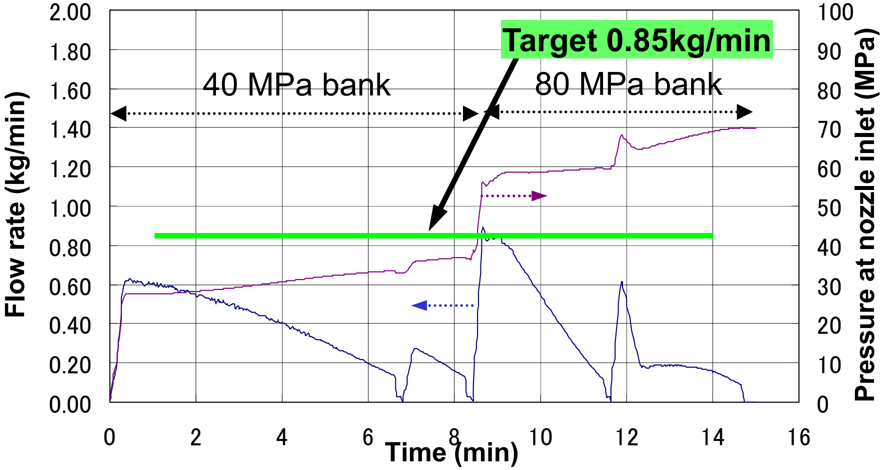
70 MPa Refueling



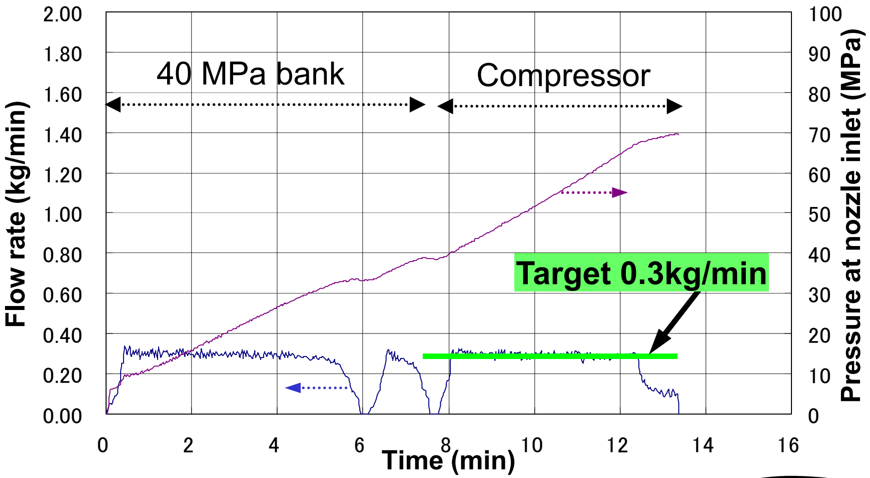
Senju station
(to 125 L tank Oct. 7, 2008)



Kasumigaseki station (mobile)
(to 100 L tank Jan. 14, 2009)



Asahi station
(to 160Ltank Jan. 21, 2009)



Daikoku station
(to 125 L tank Dec. 9, 2008)

70 MPa Hydrogen Stations Overseas

There are two major methods to refuel 70 MPa hydrogen; Cascade and Cascade + Compressor.
Both stations below used Cascade + Compressor, cascade filling up to 35 MPa followed by compressor direct filling up to 70 MPa.

Dispenser
for 35 & 70 MPa

Dispenser nozzle
for 70 MPa

Berlin, Germany(CEP)

Dispenser nozzle for
70 MPa

Dispenser
for 35 & 70 MPa

Stavanger, Norway(HyNor)

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Summary of 70 MPa Facility Addition

70 MPa facilities were added to 4 existing JHFC hydrogen stations (Senju, Asahi, Daikoku, Kasumigaseki) and their operation started.

4 JHFC 70 MPa stations cumulatively refueled hydrogen to FCV's over 50 times up to the end of December 2008 and are safely operated.

Senju Station will be further modified so that the vehicle might be able to be refueled at a flow rate as high as 2.0 kg/min by changing piping materials.

Further collection of 70 MPa refueling data will be continued for

- developing regulations, codes and standards
- finding operating issues
- investigating appropriate filling pressure.

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Estimation of Onboard Tank Volume (35 MPa)

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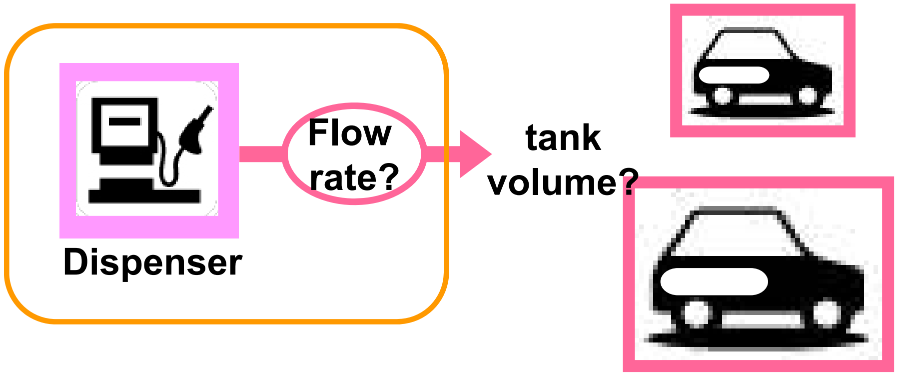
Estimation of Onboard Tank Volume(35 MPa)

Objective: to establish common and safe filling procedure by using estimated volumes of various tanks onboard. (Currently, different FCV's requests different flow rates.)



Large flow rate for small tank
=>temperature goes too high.

Small flow rate for large tank
=>takes too long a time.

Method: to estimate tank volume by filling a small amount of H_2 and evaluating pressure rise.

Last year:

using equation of state for ideal gas, PV=mRT

resulted accuracy : 15% (not very accurate)

=> more accurate estimation is required

Improved Estimation

Equation of state $PV=zmRT$

introducing compressibility factor, z, for real gas

Amount of H_2 filled $\Delta m=V(P_2/z_2T_2- P_1/z_1T_1)/R$

$$V= R\Delta m /(P_2/z_2T_2- P_1/z_1T_1)$$

$R\Delta m$: known

P_1/z_1T_1: known

z_2, T_2 : unknown

z_2 is a function of P_2 and T_2

-> T_2 prediction will give accurate V

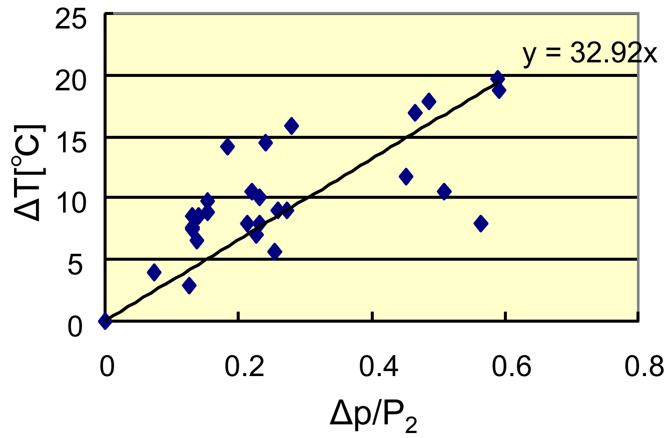
Prediction of gas temperature in the tank after filling a small amount of H_2 is essential.

Estimation of Gas Temperature in the Tank

Before filling

Gas temperature in the tank is expected to be similar to the ambient temperature.

When the pressure is low, mass of gas in the tank is small and no significant effect of initial gas temperature from the energy point of view.



After filling of a small amount of H_2

Heat release can be neglected due to the short period of time.

Enthalpy increase is proportional to the amount of filled H_2.

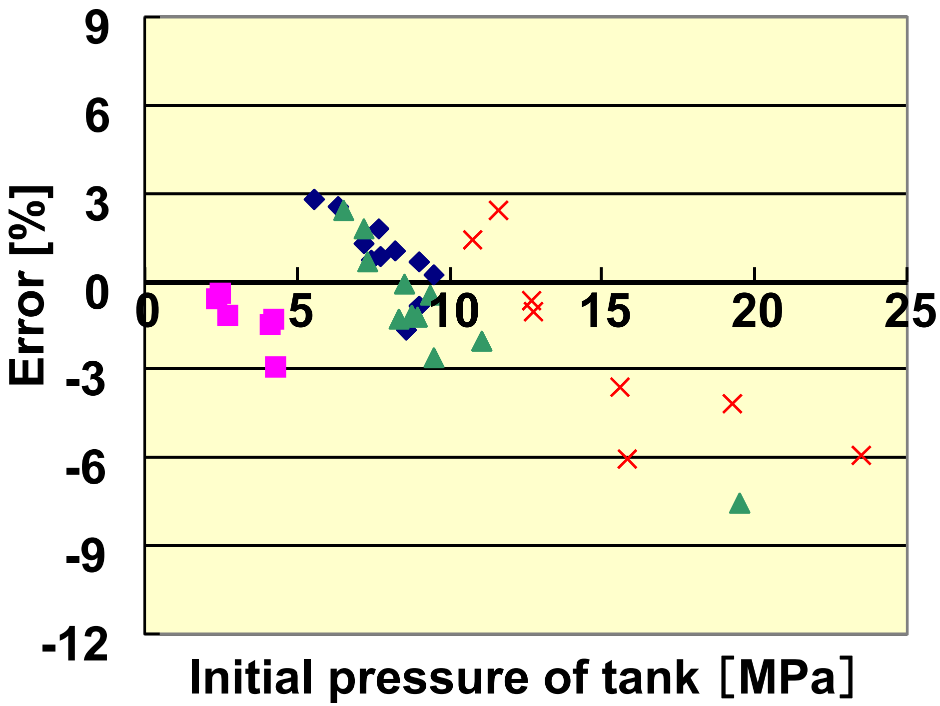
Temperature rise can be expressed as follows.

$$\Delta T=\alpha \Delta p/P_2$$

Empirical equation from test results at Senju Station became

$$\Delta T=33\Delta p/P_2$$

Summary of Onboard Tank Volume Estimation



Mark indicates FCV model.

Accuracy of volume estimation : within 3%

Higher initial pressure tends to increase error (Volume is underestimated.
-> safety side and acceptable.)

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Efficiency Evaluation and Cost Estimation of Hydrogen Stations

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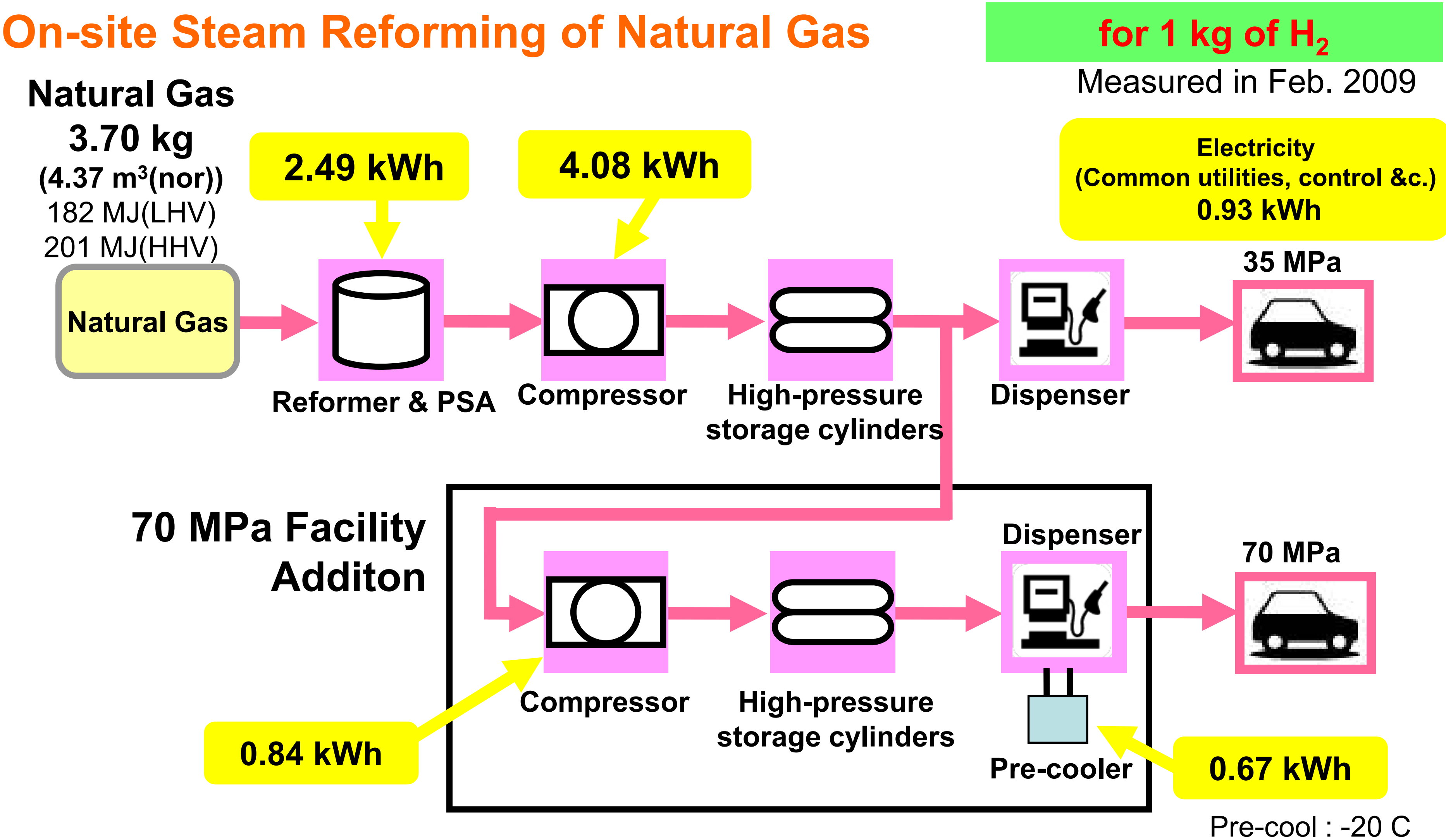
Senju Station (70 MPa, with pre-cooling)

On-site Steam Reforming of Natural Gas



Actual operating data will be further collected and evaluated in different seasons and for different pre-cool temperatures.

Senju Station (70 MPa, with pre-cooling)

On-site Steam Reforming of Natural Gas

Energy consumption per 1 kg H_2

Input	Consumption	Input Energy in MJ	
		LHV	HHV
Natural Gas	3.70 kg 4.37 m^3(nor)	182 MJ	201 MJ
Electricity	9.01 kWh	32.4 MJ	

Calculated Energy of Product H_2 : 128 MJ/kg(LHV), 150 MJ/kg(HHV)

(70 MPa gauge, 298K)

Efficiency = 59.7 %(LHV)
64.2 %(HHV)

For 35 MPa
60.7 % (LHV)
65.2 % (HHV)
see Appendix for detail

Previous Cost Estimation and Cost Evaluation in FY2008

Summary of previous hydrogen cost estimation

Natural Gas Reforming type Hydrogen Station (300 m^3(nor)/h)

Result of estimation for H_2 production

Construction Cost:	600 million yen (35 MPa), 700 million yen (70 MPa)
H_2 production Cost:	110 – 170 yen/m^3(nor)

Estimated H_2 cost is 3 - 4 times higher than the METI target cost of 40 yen/m^3(nor) in 2020. Further study to reduce H_2 cost is necessary.

Cost evaluation in FY2008

Preliminary evaluation of construction cost in 2015 – 2020.

R&D and deregulation expected by that time is taken into account.

Joint project by JHFC WG1 members as well as equipment manufacturers.

Final issue is to evaluate H_2 cost, but only to evaluate cost of equipment greatly affecting hydrogen stations.

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Assumptions for Cost Evaluation

Assumptions:

100,000 FCV's, 50 Hydrogen Stations

Station type :	On-site
H_2 production capacity :	27 kg/h (300 Nm3/h)
Onbord tank capacity :	5 kg-H_2/passenger vehicle
Remaining H_2 at refueling :	1 kg-H_2/passenger vehicle
Maximum refueling frequency :	20 vehicles/h (80 kg-H_2/h)

Parameters

Refueling pressure :	35, 44, 50, 70 and 88 MPa
Refueling period (fulfill) :	3, 5, 10 min
Refueling method :	Cascade or Cascade + Compressor

Firstly, current costs were evaluated.

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Current cost of Major Components

	Current cost (million yen)	Parameter*) dependence
Reformer	150 – 186	No
Compressor	50 – 110	Yes (strong)
High-pressure storage cylinders	39 -	Yes (very strong)
Dispenser	15 -	Yes (fairly strong)
Pre-cooler	17 -	Yes (fairly strong)
total	roundly 300 -	Yes (250 million yen difference between 35 MPa and 70 MPa stations)

Construction, piping and wiring costs are extra.

*)parameter : filling pressure, filling period, filling method

Results cannot be directly compared with those previously disclosed in the JHFC product.

Further cost reduction is definitely necessary.

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Cost Reduction Feasibility

Reformer	Simplified system, reduction of parts Target is 50% of current cost.
Electrolizer	Key components (electrode, separator), power supply, rectifier
Compressor	Cylinder type, oil-driven booster, &c.
High-pressure storage cylinders	Large-scale cylinder, mass production through standardization, cost reduction using material other than steel, number reduction through the combination of cascade and compressor-drive filling.
Dispenser	Target is 50% of current cost.
Common (parts & equipments)	Imported parts, similar equipment widely used
Others	Layout optimization, cost reduction of general installation at the site.

Investigation to be continued.

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Hydrogen Quality

Product Hydrogen Analysis

Hydrogen supplied by JHFC stations has been precisely analyzed to confirm impurities in it.

Station	Mar. '04	Mar. '05	Sep. '05	Feb. '07	Dec. '07	Dec. '08
Daikoku	o	o	o	o	o	o
Asahi	o	o	o	-	o	-
Senju	o	o	o	o	o	o
Kawasaki	o	o	o	o	o	o
Ome	/	o	o	o	/	/
Hadano => Ichihara	/	o	o	o	o	o
Seto-North	/	o	o	/	/	/
Seto-South => Centrare	/	o	o	o	o	o
Sagamihara	/	o	o	o	N_2	N_2
Ariake	/	o	o	o	-	-
Tsurumi	/	o	o	/	/	/
Osaka	/	/	/	/	o	o

Notes

o : all species analyzed **N_2 : N_2 only** **- : undone** **/ : not operating**

Results have been reported at JHFC Seminar every year.
Results of FY2008 is reported in detail in the appendix.

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Summary of Gas Analysis

	Species	Results		JHFC	ISO/TC197 TS
H_2				99.99%	99.97 %
impurities	CO	mostly at its worst	< 0.01 ppm 0.18 ppm	1 ppm	0.2 ppm
	CO_2	mostly in a few occation	< 0.01 ppm 1 ppm	1 ppm	2 ppm
	O_2	in all cases	< 0.01 ppm	2 ppm	5 ppm
	N_2		85 – 0.03 ppm	50 ppm	100 ppm
	Ar		7.26 – 0.03 ppm	---	100 ppm
	He		9 – 3 ppm	---	300 ppm
	Hydrocarbon		0.99 – 0.05 ppm	1 ppm	2 ppm
	H_2O		24 – 0.5 ppm only once for every station when H_2O exceeded 5ppm	---	5 ppm
	Sulfur compounds	in all cases	< 0.0001 ppm	---	0.004 ppm
	HCHO	in all cases	< 0.01 ppm	---	0.01 ppm
	HCOOH	in all cases	< 0.01 ppm	---	0.2 ppm
	NH_3	in all cases	< 0.001 ppm	---	0.1 ppm

Results indicated that hydrogen supplied by JHFC stations almost meets ISO/TC197/WG12 TS (Technical Specification).

Safety of Station Operation

Safety Learning (FY2008)

Date	Content	Hydrogen Leakage
May '08	Pressure rise due to the ambient temperature change resulted in alarm.	No
May '08	Malfunction of valve.	No
May '08	Operation became unstable due to the reforming catalyst degradation.	No
May '08	Too low an output voltage from UPS disabled emergency water spray.	No
May '08	Abnormal temperature of reformed gas at the exit of heat exchanger.	No
Jun. '08	Water condensation at the valve driving assembly due to the malfunction of the dryer for instrument air.	No
Jul. '08	Malfunction of flame detector caused emergency shutdown.	No
Jul. '08	Alarm relating to lubricating oil of the compressor	No
Jul. '08	CO analyzer became unstable due to the secular change of infrared lamp.	No
Jul. '08	Malfunction of the sensor for water treatment of steam reformer.	No
Jul. '08	Malfunction of sequencer module for steam reformer.	No
Jul. '08	Water leak from the strainer of the water treatment unit.	No
Nov. '08	Malfunction of air-driven valve caused alarm.	No
Nov. '08	After the maintenance, valve mode was not properly restored.	No
Nov. '08	Dust in the instrument air caused valve malfunction.	No
Dec. '08	Malfunction of the touch panel for the dispenser controller.	No
Dec. '08	Malfunction of valves of feedstock compressor.	No

Safety learning in FY2007 or older was listed in the material of JHFC Seminar for the respective year.
(JHFC Seminar materials can be downloaded at http://www.jhfc.jp)

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Safety Learning : Example (1)

Performance of heat exchanger inside the hydrogen producer became less effective.

1. What happened:
   The temperature of reformed gas at the exit of heat exchanger became too high.

2. Possible causes and measures:
   The cooling water line inside the heat exchanger seemed to be plugged by
   aragonite($CaCO_3$)
   magnesian calcite($(Ca,Mg)CO_3$)
   hemimorphite($Zn_4Si_2O_7(OH)_2 \cdot H_2O$)
   &c.

   Proper water treatment and monitoring will be investigated.

Plugged part
inside heat exchanger

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Safety Learning : Example (2)

Hydrogen leak from compressor

1. Status : A small leakage of hydrogen was found at the diaphragm head sealed by O-ring. The operating pressure is 40 MPa.

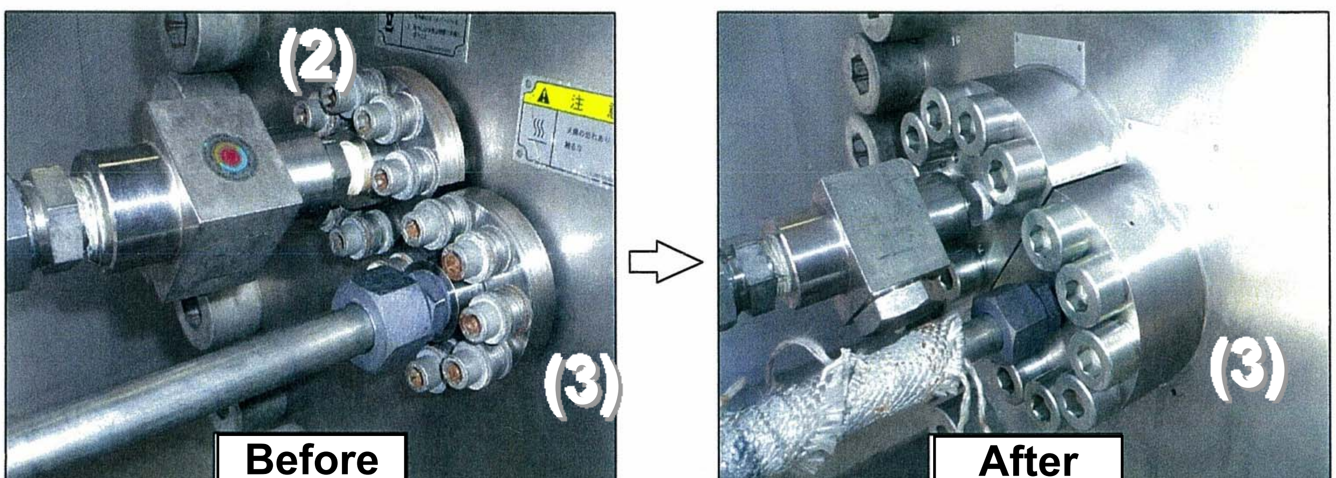
2. Cause : O-ring damage was due to vibration of the compressor

3. Measures: Sealing assembly and surrounded parts were rebuilt to exclude the vibration effect.

   New design of O-ring sealing assembly. (not shown)

   New structure to prevent loosening of bolts shown at (2).

   Unified flange structure to prevent vibration propagation at (3).



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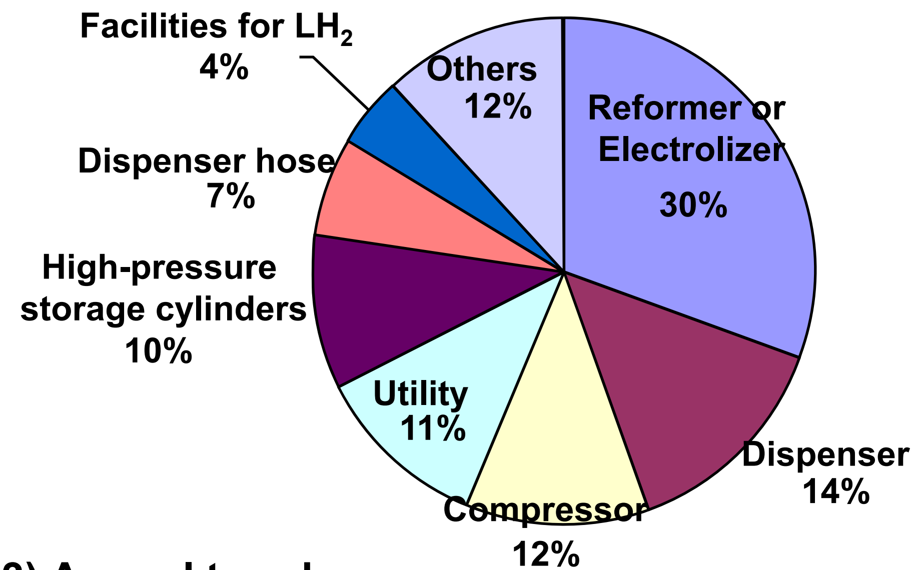
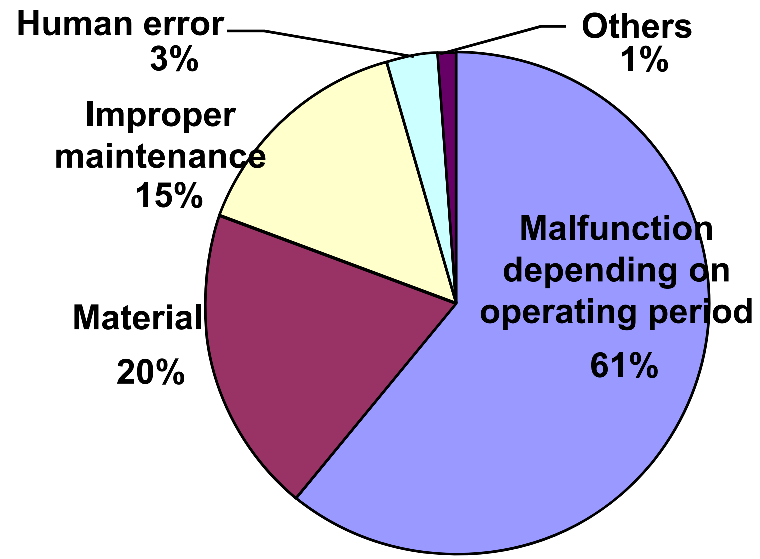
Safety Learning Analysis

JHFC hydrogen stations experienced 92 incidents and malfunctions for 3 years from FY2006 to FY2008.

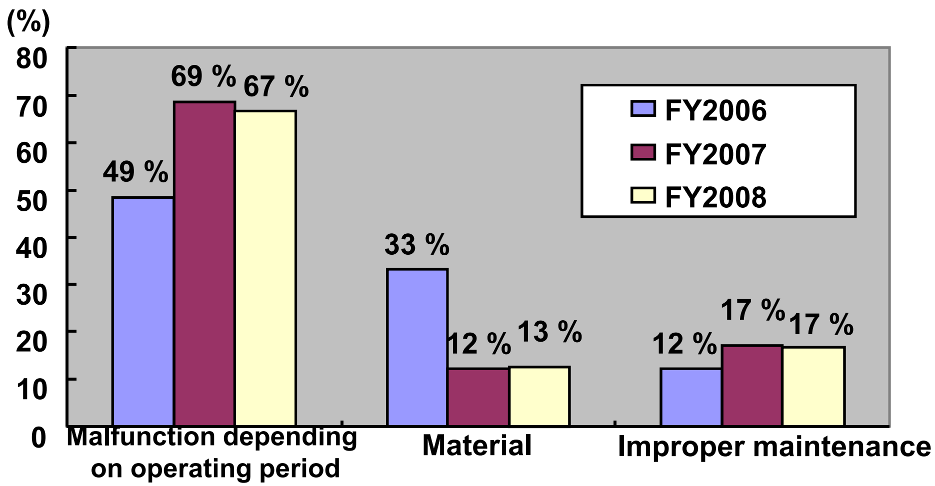
(1) Equipment



(2) Causes



(3) Annual trends



Further attentions should be paid especially for 70 MPa equipment.

Preliminary Feasibility Study for CCS

(Carbon Dioxide Capture and Storage)

Preliminary Investigation of CCS by PSA (1)

CO_2 recovery is an important issue for a hydrogen station with on-site reforming. Feasibility of CCS has been preliminarily investigated.

Commercial-scale hydrogen station with on-site hydrogen production.

System: Steam Reforming of Natural Gas

Production Capacity:	27 kg/h (300 Nm^3/h)
Hydrogen Purity:	99.99 %
Refueling Pressure:	35 MPa

Location of CO_2 capture

(1) CO_2 to be captured from PSA off-gas
(2) CO_2 to be captured from reformer burner flue gas

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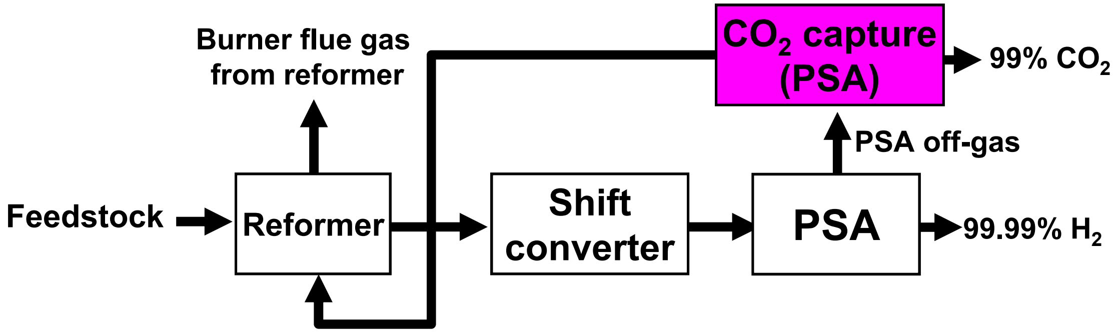
Preliminary Investigation of CCS by PSA (2)

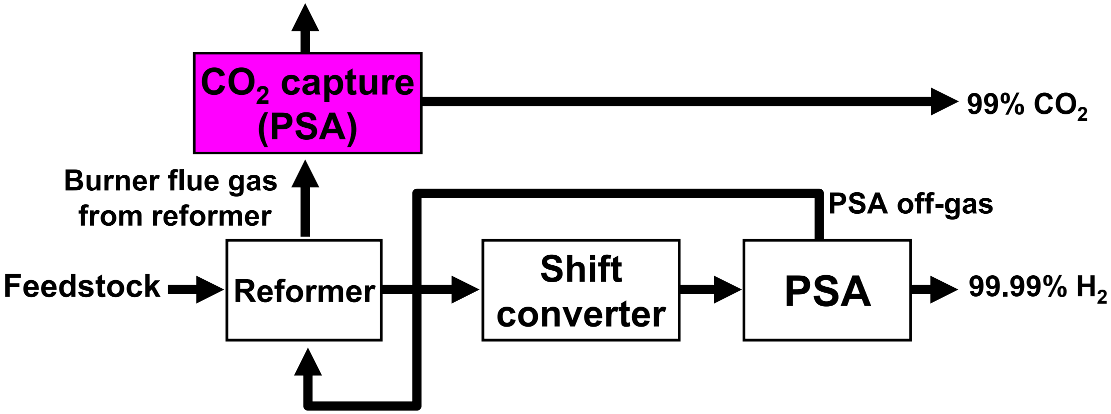
(1) CO_2 to be captured from PSA off-gas



CO_2 captured by PSA : 70 %
Overall CO_2 capture : 50 %

Capital cost for CCS : 35,000,000 yen
CCS cost (including depreciation)
12 yen/kg-CO_2
23 yen/Nm^3-H_2

(2) CO_2 to be captured from reformer burner flue gas



CO_2 captured by PSA : 50%
Overall CO_2 capture : 50%

Capital cost for CCS : 71,000,000 yen
CCS cost (including depreciation)
23 yen/kg-CO_2
44 yen/Nm^3-H_2

CO_2 capture from PSA off-gas was found feasible.

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Future Plan

Future Plan

Operation of 70 MPa stations to be continued and refueling data to be accumulated.

(Senju station will be further modified to realize higher flow rates.)

Operation of hydrogen stations and Information sharing of safety learning to be continued.

Efficiency evaluation and cost estimation in order to investigate appropriate filling pressure to be continued.

Survey for the station system in the future.

Further investigation for safety and deregulation.

Business model analysis for commercialization.

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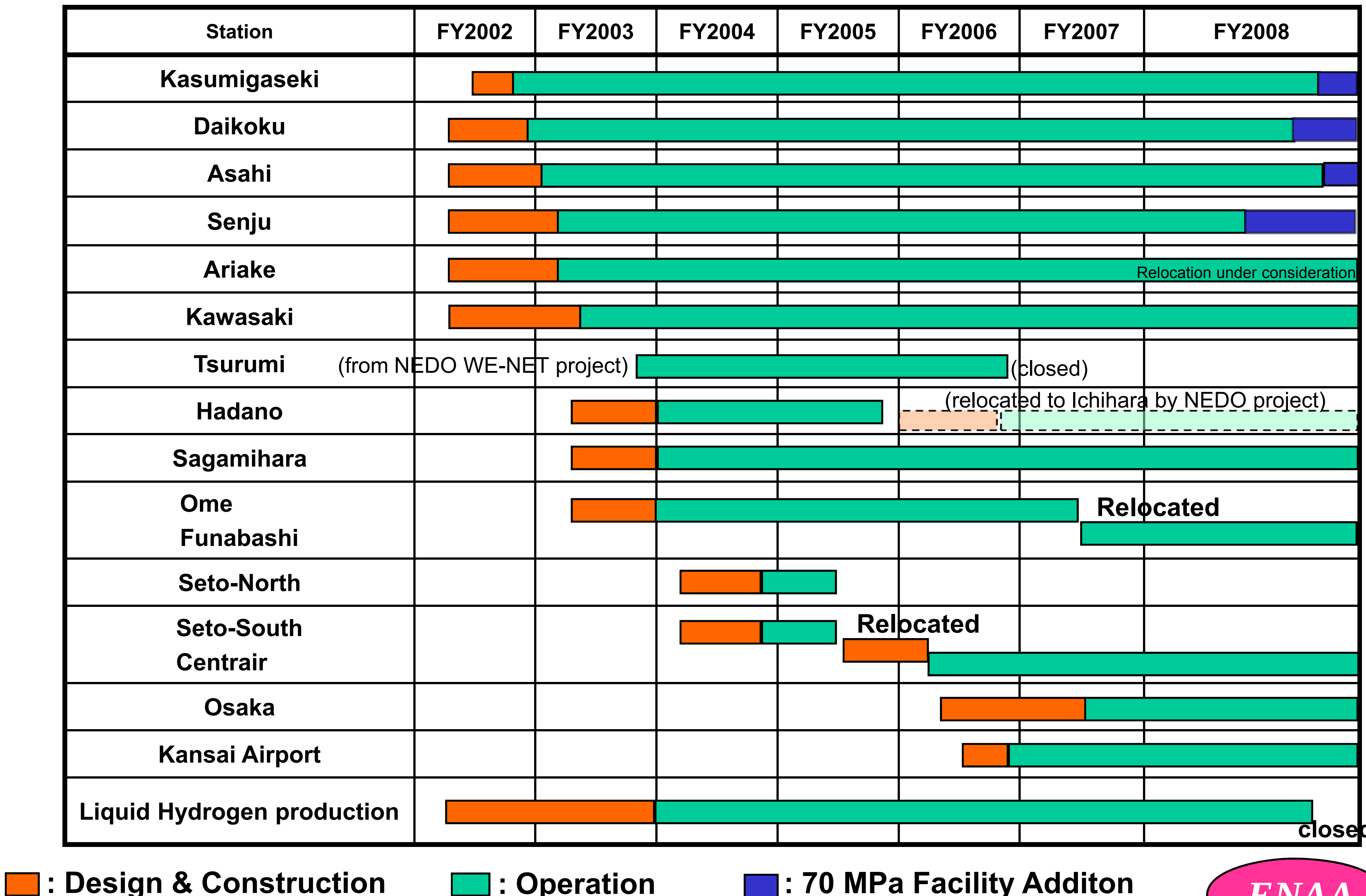
Summary

- JHFC stations have been operated safely and supplied cumulatively 42,658 kg hydrogen with 16,969 refuelings during the period from December 2002 to December 2008.
- 70 MPa facilities were added to 4 existing JHFC hydrogen stations (Senju, Asahi, Daikoku, Kasumigaseki) and their operation started. Senju Station will be further modified so that the vehicle might be able to be refueled at a flow rate as high as 2.0 kg/min by changing piping materials and so on.
- Improvement of accuracy of volume estimation of onboard tank has been investigated. The effect was confirmed during actual refueling.
- Efficiency of JHFC 70 MPa station with pre-cooling of hydrogen is evaluated.
  Investigation of major factors governing cost reduction is started.
- Precise analysis of impurities in hydrogen actually supplied by JHFC stations indicated almost satisfactory in regard to ISO/TC197 WG12 specification.

Appendix

(Appendix)

Status – Hydrogen Stations



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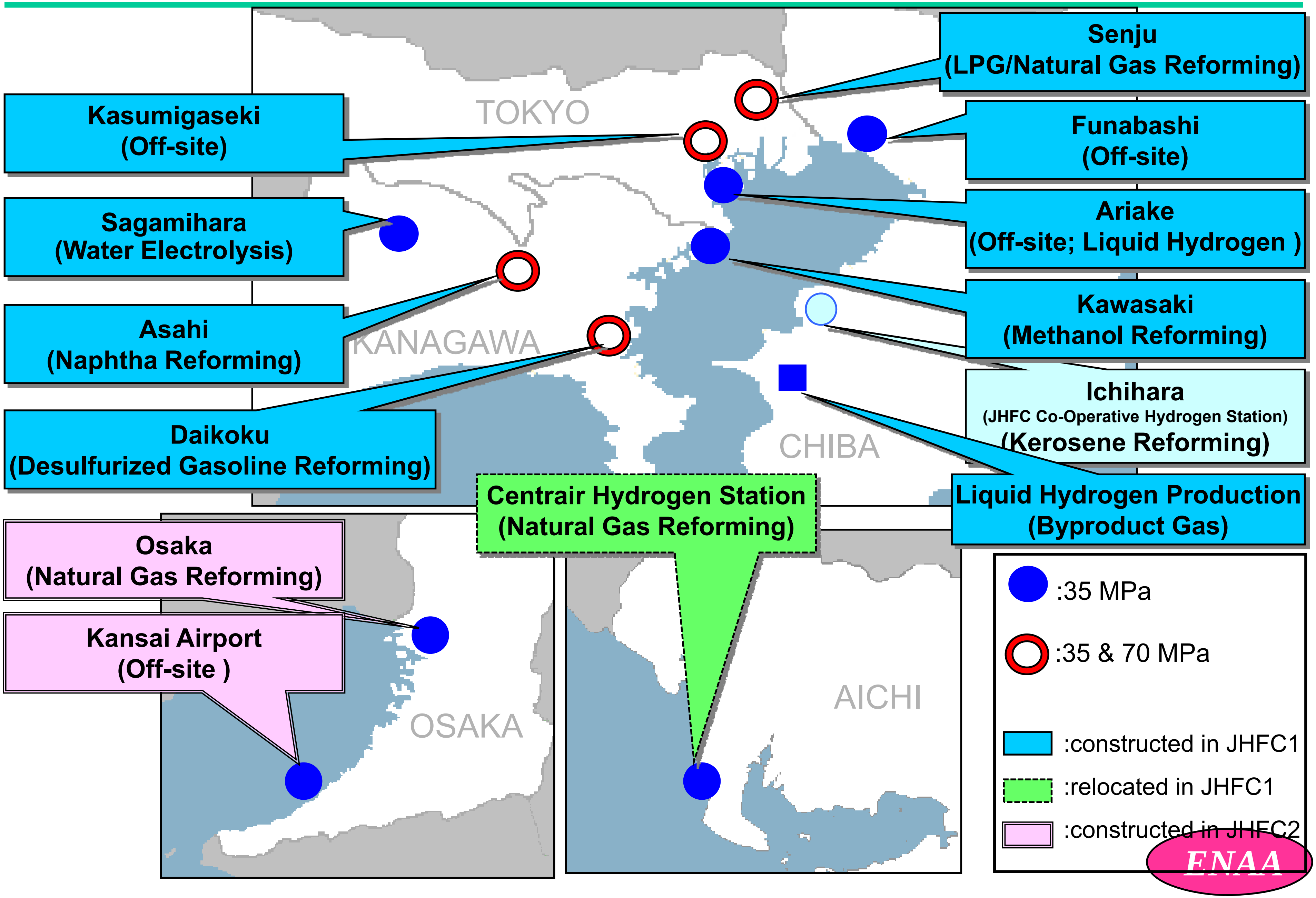
(Appendix)

Location of Hydrogen Stations

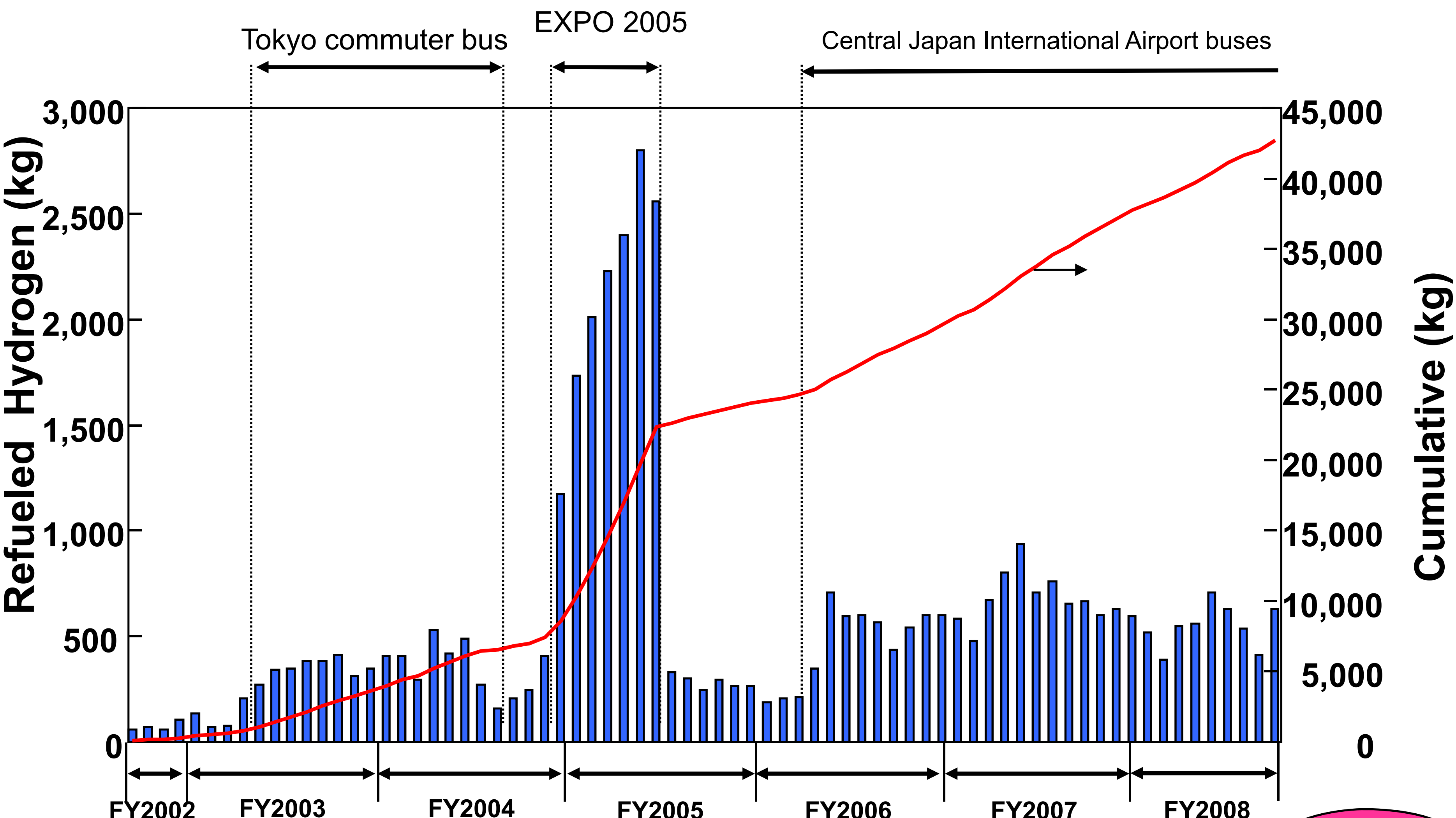


(Appendix)

Refueling – All JHFC Stations (1)

H_2 Refueling :42,658kg*(Dec. 2002 – Dec. 2008)

* Including Result of JHFC Co-Operative Hydrogen Station



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(Appendix)

Refueling – All JHFC Stations (2)

Refueled Hydrogen (kg)

Station	Opening	FY2002 (-Mar.'03)	FY2003 (Apr.'03-Mar.'04)	FY2004 (Apr.'04-Mar.'05)	FY2005 (Apr.'05-Mar.'06)	FY2006 (Apr.'06-Mar.'07)	FY2007 (Apr.'07-Mar.'08)	FY2008 (Apr.-Dec.'08)	Total**
Kasumigaseki	Dec.'02	234	758	1007	883	694	886	604	1962
Daikoku	Mar.'03	65	354	597	511	409	406	309	2651
Asahi	Apr.'03	-	171	184	253	236	176	65	1086
Senju	May.'03	-	279	376	424	383	308	240	2009
Ariake	May.'03	-	1670	1540	734	515	1050	396	5906
Kawasaki	Aug.'03	-	50	104	98	116	156	98	621
Tsurumi	Dec.'03	-	14	21	15	4	-	-	53
Hadano	Apr.'04	-	-	160	145	-	-	-	304
Sagamihara	Apr.'04	-	-	20	36	16	52	21	145
Ome &Funabashi	Jun.'04	-	-	19	271	88	220	187	785
Seto-North	Feb.'05	-	-	445	5866	-	-	-	6312
Seto-South	Feb.'05	-	-	547	6183	-	-	-	6730
Centrair	Jul.'06	-	-	-	-	3075	4387	2759	10221
Kansai Airport	Mar.'07	-	-	-	-	2	62	54	117
Osaka	Aug.'07	-	-	-	-	-	214	141	355
Ichihara *	Dec.'06	-	-	-	-	70	159	68	297
Total**		299	3294	5019	15419	5607	8076	4942	42658

* JHFC Co-Operative Hydrogen Station

** Total amount may slightly differ from the sum in the table above due to a significant figure rounding. Additional 20.5 kg of hydrogen supplied for metal hydride canister storages.

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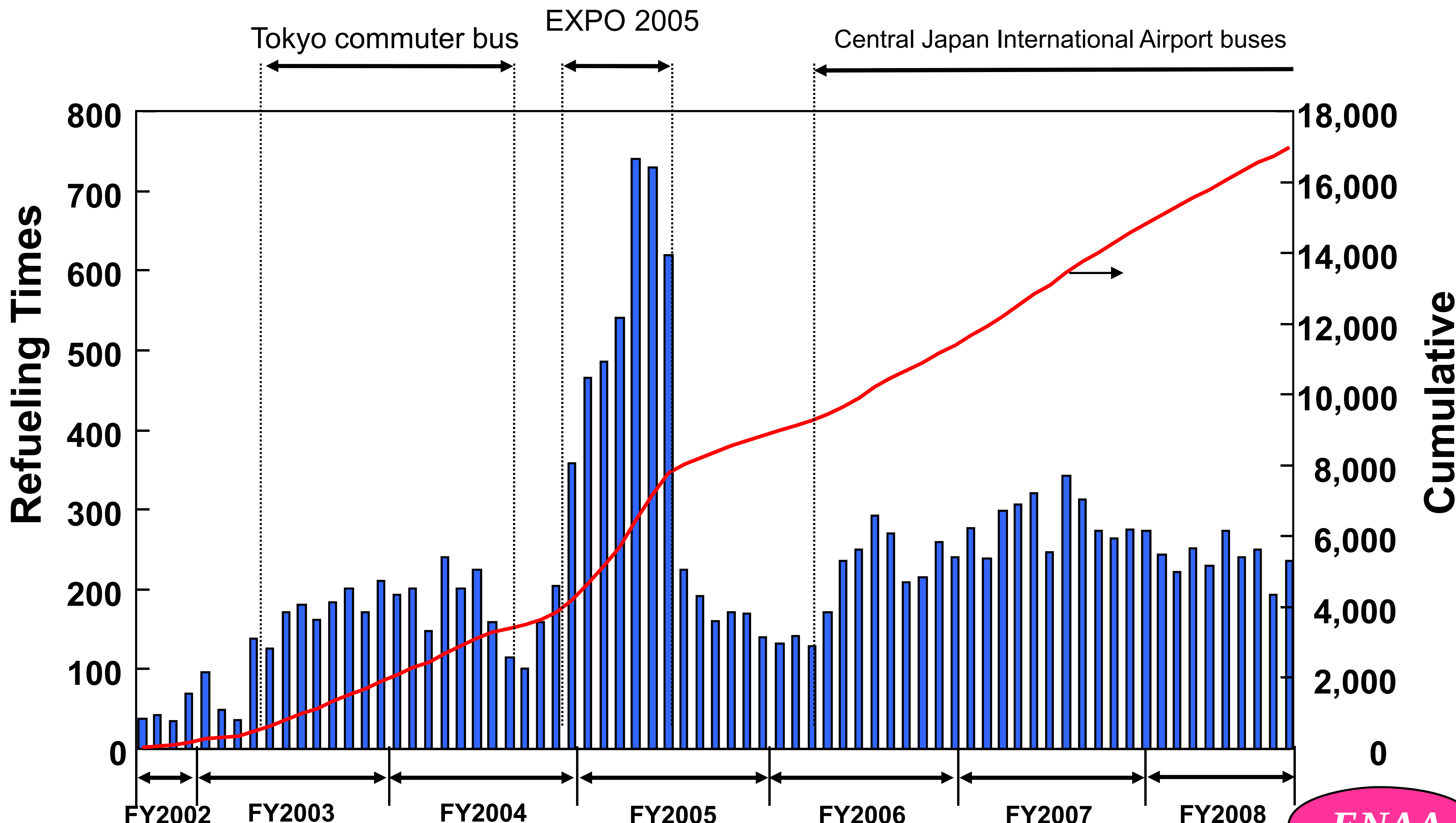
(Appendix)

Refueling – All JHFC Stations (3)

H_2 Refueling : 16,969 times* (Dec. 2002 – Dec. 2008)

* Including Result of JHFC Co-Operative Hydrogen Station



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(Appendix)

Refueling – All JHFC Stations(4)

Hydrogen Refueling Times

Station	Opening	FY2002 (-Mar.'03)	FY2003 (Apr.'03-Mar.'04)	FY2004 (Apr.'04-Mar.'05)	FY2005 (Apr.'05-Mar.'06)	FY2006 (Apr.'06-Mar.'07)	FY2007 (Apr.'07-Mar.'08)	FY2008 (Apr.-Dec.'08)	Total
Kasumigaseki	Dec.'02	136	379	466	462	486	640	403	1416
Daikoku	Mar.'03	48	316	466	388	275	316	206	2015
Asahi	Apr.'03	-	141	106	167	146	121	52	733
Senju	May.'03	-	246	298	313	263	210	131	1461
Ariake	May.'03	-	569	557	549	435	559	289	2958
Kawasaki	Aug.'03	-	60	66	72	74	114	70	456
Tsurumi	Dec.'03	-	15	16	12	3	-	-	46
Hadano	Apr.'04	-	-	107	106	-	-	-	213
Sagamihara	Apr.'04	-	-	17	32	17	41	19	126
Ome &Funabashi	Jun.'04	-	-	11	158	75	152	108	504
Seto-North	Feb.'05	-	-	88	1136	-	-	-	1224
Seto-South	Feb.'05	-	-	105	1244	-	-	-	1349
Centrair	Jul.'06	-	-	-	-	727	1020	657	2404
Kansai Airport	Mar.'07	-	-	-	-	1	40	36	77
Osaka	Aug.'07	-	-	-	-	-	114	116	230
Ichihara *	Dec.'06	-	-	-	-	48	101	52	201
Total		184	1726	2303	4639	2550	3428	2139	16969

* JHFC Co-Operative Hydrogen Station

Additional 183 times for metal hydride canister storages.

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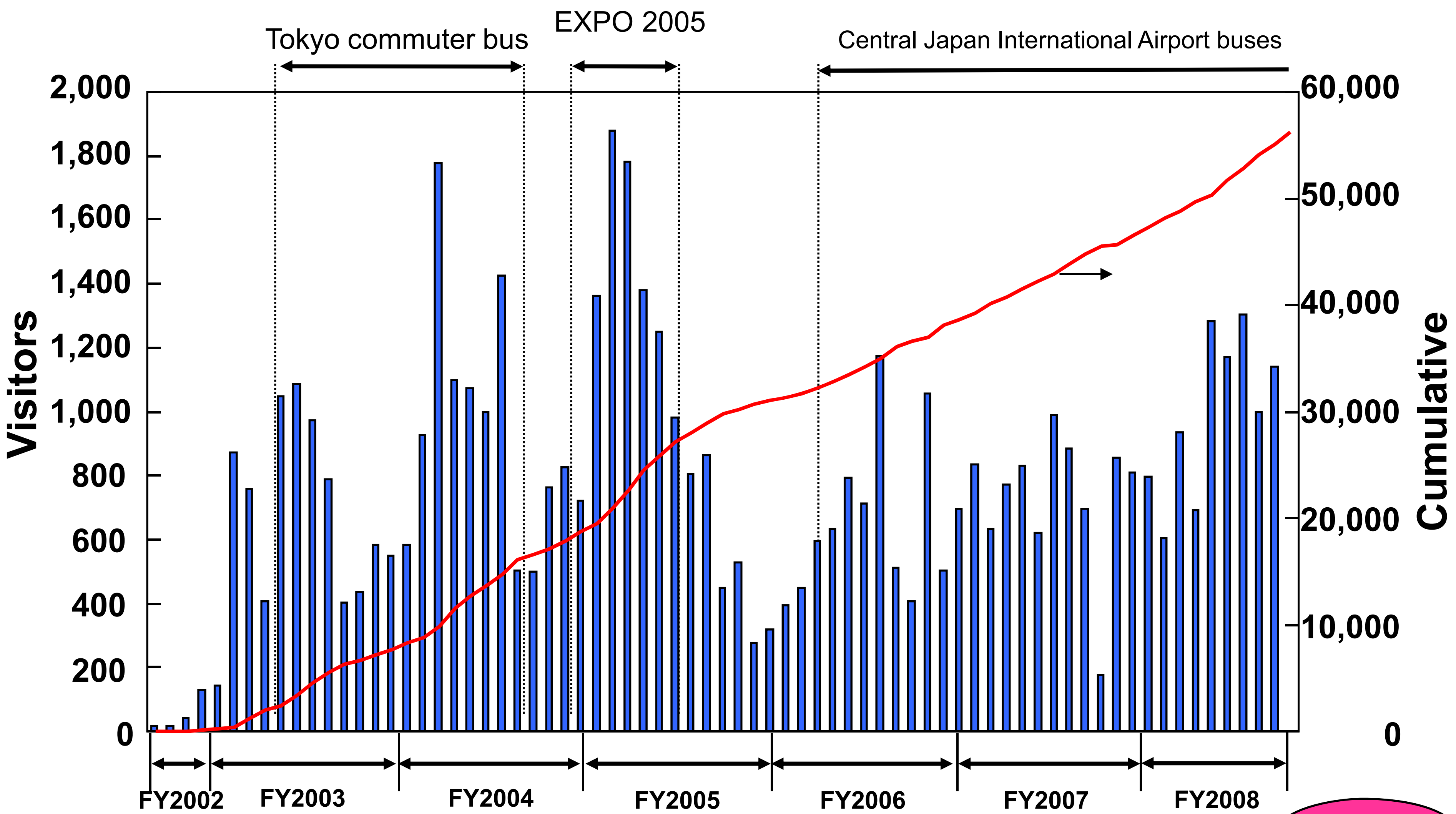
(Appendix)

Visitors to Hydrogen Stations (1)

56,267 Visitors* (Dec. 2002 – Dec. 2008)

* Including Result of JHFC Co-Operative Hydrogen Station



(Appendix)

Visitors to Hydrogen Stations (2)

Station	Opening	FY2002 (-Mar.'03)	FY2003 (Apr.'03-Mar.'04)	FY2004 (Apr.'04-Mar.'05)	FY2005 (Apr.'05-Mar.'06)	FY2006 (Apr.'06-Mar.'07)	FY2007 (Apr.'07-Mar.'08)	FY2008 (Apr.-Dec.'08)	Total
Kasumigaseki	Dec.'02	45	73	91	8	33	42	14	306
Daikoku	Mar.'03	36	1681	1977	1902	1892	2266	2485	12239
Asahi	Apr.'03	-	344	359	159	122	201	16	1201
Senju	May.'03	-	2026	4540	3294	2462	2184	2605	17111
Ariake	May.'03	-	3254	2578	2448	1058	454	394	10186
Kawasaki	Aug.'03	-	220	386	151	145	172	176	1250
Tsurumi	Dec.'03	-	32	82	39	13	-	-	166
Hadano	Apr.'04	-	-	499	230	-	-	-	729
Sagamihara	Apr.'04	-	-	198	81	30	56	57	422
Ome &Funabashi	Jun.'04	-	-	315	725	21	182	1169	2412
Seto (North & South)	Feb.'05	-	-	0	3236	-	-	-	3236
Centrair	Jul.'06	-	-	-	-	1478	1356	714	3548
Kansai Airport	Mar.'07	-	-	-	-	-	421	148	569
Osaka	Aug.'07	-	-	-	-	-	438	315	753
Ichihara *	Dec.'06	-	-	-	-	293	1024	822	2139
Total		81	7630	11025	12273	7547	8796	8915	56267

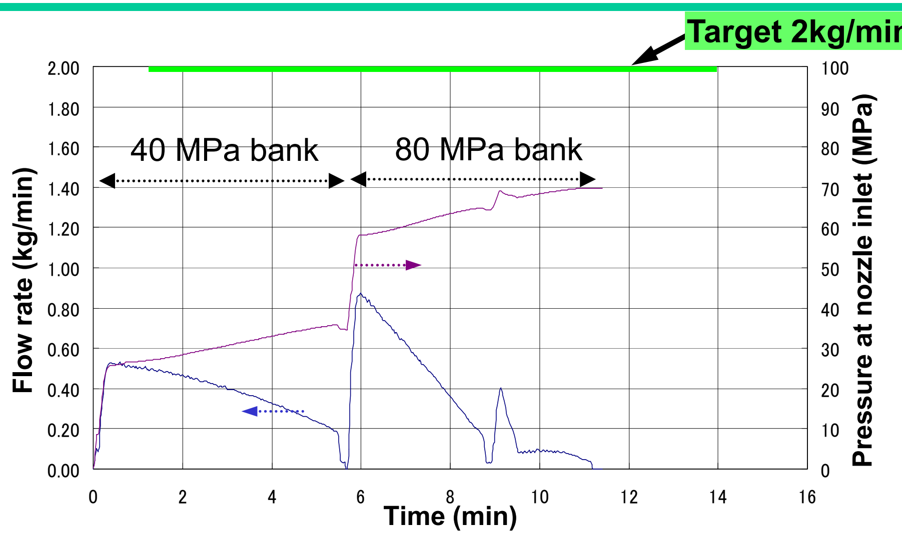
* JHFC Co-Operative Hydrogen Station

(Appendix)

70 MPa Refueling (1)

Results

- **Senju station:**
  Flow rates both from 40 MPa and 80 MPa banks did not reach targeted 2 kg/min.
- **Asahi station:**
  Flow rate from 40 MPa bank did not reach targeted 0.85 kg/min while flow rate from 80 MPa bank reached 0.85 kg/min.

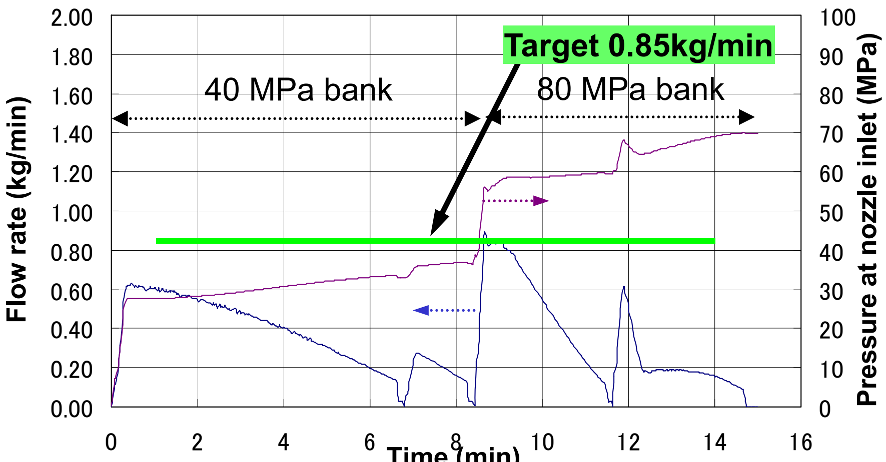


Senju station
(to 125 L tank Oct. 7, 2008)

Causes of low flow rates:

Lower strength of SUS316L compared to SUS316 made inner diameter too small though SUS316L is favorable from the stand point of hydrogen embrittlement.

Modification of existing station tended to result in high pressure loss by longer piping between high-pressure banks, dispenser and pre-cooler.



Asahi station
(to 160 L tank Jan. 21, 2009)

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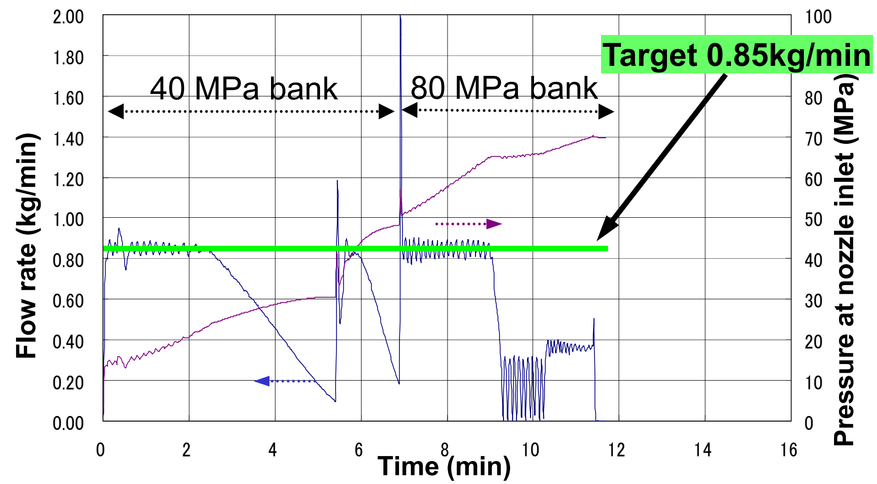
(Appendix)

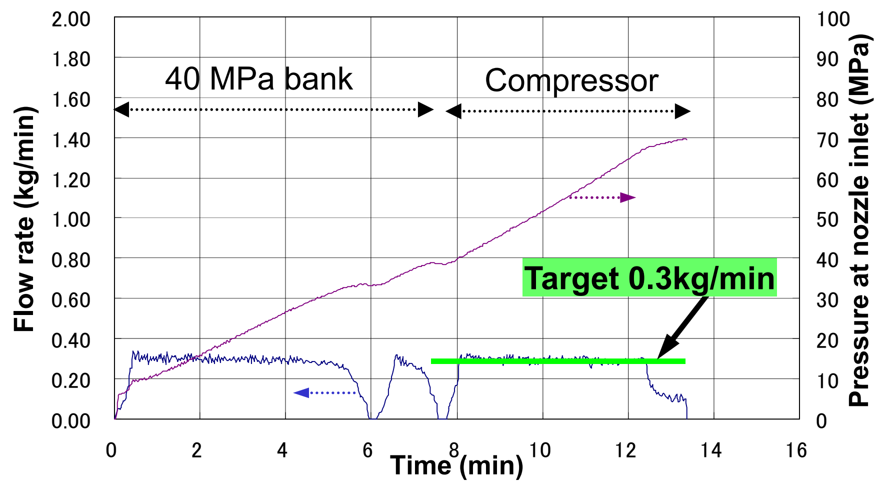
70 MPa Refueling (2)

Flow rates in Daikoku station and mobile station, reached targets, 0.85 kg/min and 0.3 kg/min, respectively.

Temperature of hydrogen supplied by mobile station slightly exceeded target and needs improvement.



Kasumigaseki station (mobile)
(to 100 L tank Jan. 14, 2009)



Daikoku station
(to 125 L tank Dec. 9, 2008)

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(Appendix)

How to increase 70 MPa refueling flow rates

(1) Decrease pressure loss

Material SUS316L → SUS316(higher strength widens inner diameter)

Piping Inner diameter 2.5 or 3.1 mm → 6.4 mm

Pre-cooler Inner diameter 3.1 mm → 4.8 mm

Refueling Nozzle Inner diameter 1.6 mm → 2.2 mm

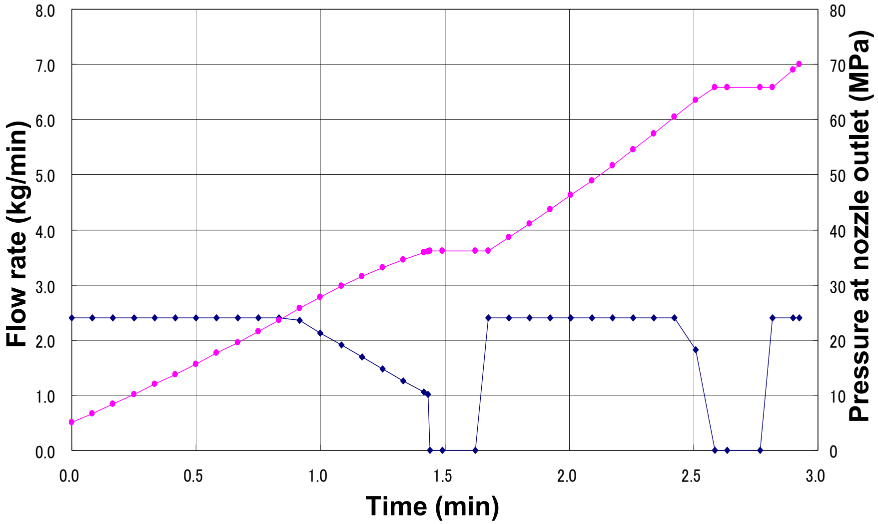
(2) Increase refueling potential

Pressure of banks 40 MPa → 41 MPa

80 MPa → 82 MPa

Volume of high pressure(82 MPa) bank

400 L → 800 L



Flow rate simulation after all improvement
(6kg H_2 for 3 minutes to 160 L tank, period similar to gas refueling)

Staged improvement

(1)Feb., 2009: 6.4 mm piping between banks and dispenser
slightly higher bank pressure

(2)May-June, 2009: re-designed pre-cooler and refueling nozzle

(3)Dec., 2009: increase volume of high pressure bank

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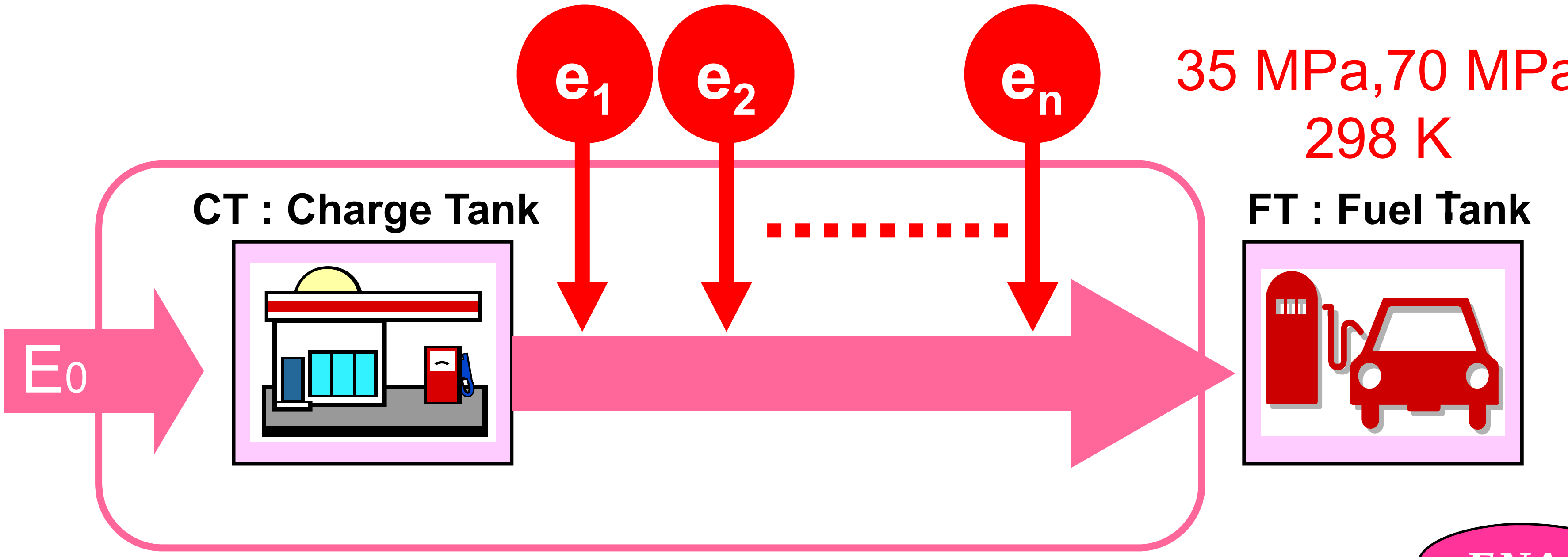
(Appendix)

Definition of Efficiency

$$\text{Efficiency} = \frac{\text{Energy of Product (} H_2 \text{ Fed to FT)}}{\text{Energy of Input } (E_0 + \sum e_n)}$$



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Definition of Energy

Electricity : 3.6 MJ/kWh

(Efficiency of power generation is not taken into account)

Energy of Gas : Heating Value + Energy of Pressure

Energy of Pressure (E_{pf})

$$E_{pf} = R * t_f * \ln(p_f/p_0)$$

Where,

R	Gas Constant	(8.31510 $Jmol^{-1}K^{-1}$)
t_f	Temperature of Gas	(K)
p_0	Atmospheric Pressure	(101.325 kPa)
p_f	Pressure of Gas	(kPa)

Energy of Product Hydrogen

Conditions

	Calculated Energy of H_2	
	LHV	HHV
70 MPa gauge (298 K)	**128** MJ/kg	**150** MJ/kg
	11.5 MJ/m^3(nor)	**13.5** MJ/m^3(nor)
35 MPa gauge (298 K)	**127** MJ/kg	**149** MJ/kg
	11.4 MJ/m^3(nor)	**13.4** MJ/m^3(nor)
0 MPa gauge (298 K)	**120** MJ/kg	**142** MJ/kg
	10.8 MJ/m^3(nor)	**12.8** MJ/m^3(nor)

(Appendix)

Efficiency of 35 MPa Hydrogen Stations (1)

On-site Reforming

Station	Feedstock	Efficiency % LHV (HHV)
Daikoku	Desulfurized Gasoline	58.7 (64.1)
Asahi	Naphtha	60.4 (66.2)
Kawasaki	Methanol	65.0 (68.8)
Hadano	Kerosene	54.6 (61.1)
Senju	LPG	58.7 (63.8)
	Natural Gas	60.7 (65.2)
Seto-South	Natural Gas	62.5 (66.7)
Centrair	Natural Gas	62.0 (65.6)
Osaka	Natural Gas	60.4 (64.7)

Efficiency from the feedstock to the fuel tank on the vehicle.
Electricity is regarded as 3.6 MJ/kWh. (No power generation efficiency is taken into account.)
Energy of gaseous material : heating value + energy of pressure

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(Appendix)

Efficiency of 35 MPa Hydrogen Stations (2)

Off-site

Station	System	Efficiency % LHV(HHV)
Tsurumi	High pressure H_2 storage	98.3 (98.6)
Seto-North	High pressure H_2 storage	89.8 (91.2)
Kasumigaseki (New Unit)	High pressure H_2 storage	95.8 (96.4)
Kasumigaseki (New Unit)	High pressure H_2 storage	94.1 (94.9)
Kansai Airport	High pressure H_2 storage	99.8 (99.8)

Efficiency from the feedstock to the fuel tank on the vehicle.
Electricity is regarded as 3.6 MJ/kWh. (No power generation efficiency is taken into account.)
Energy of gaseous material : heating value + energy of pressure

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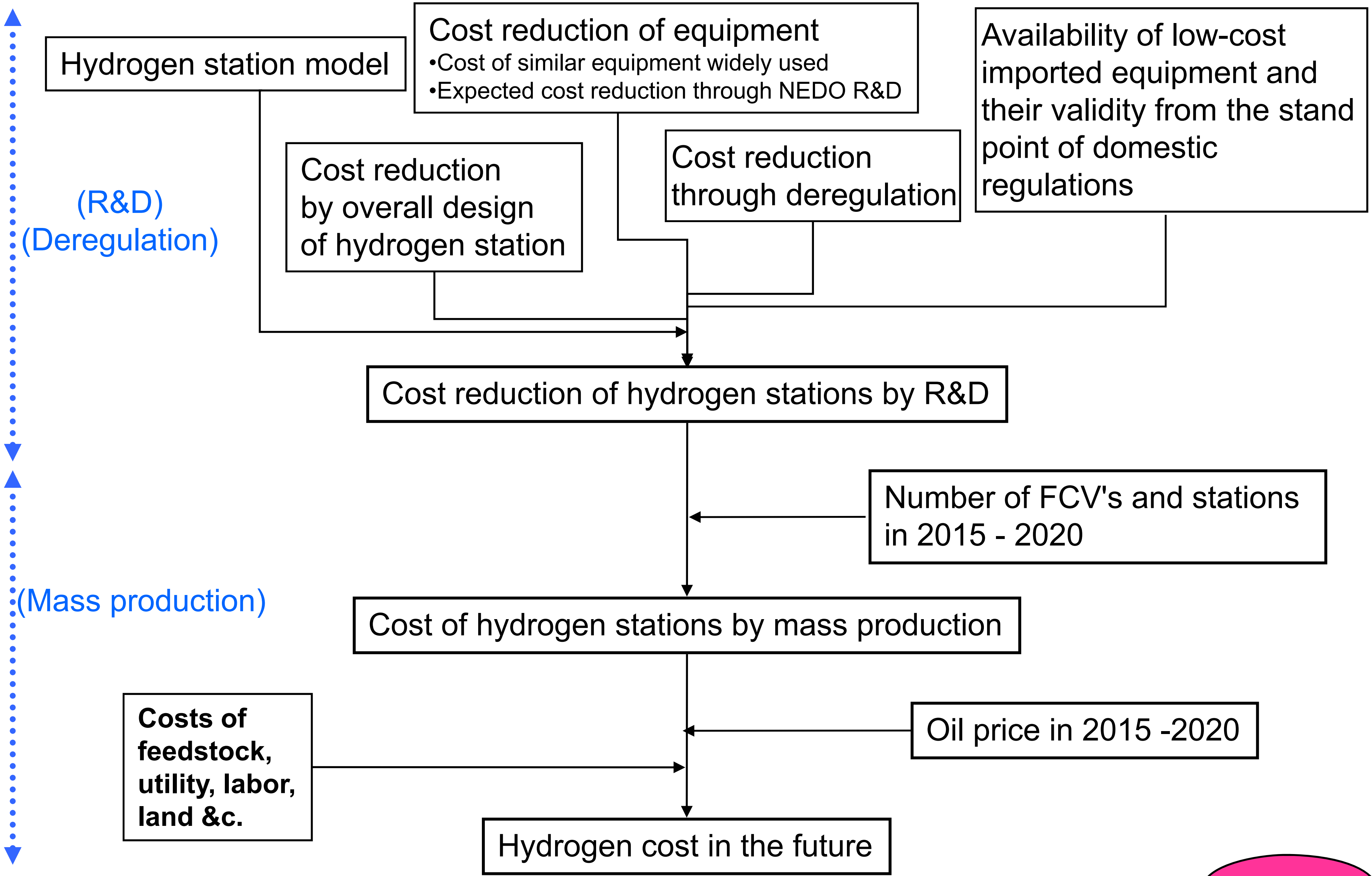
(Appendix)
Cost Reduction Survey in FY2008



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(Appendix)

ISO/TC197/WG12 Hydrogen Specification

ISO/TC197/WG12 approved TS (Technical Specification) of hydrogen for FCV's. Further work is under way to issue IS (International Standard).

		ISO/TC197 TS	JHFC
H_2		99.97 %	99.99%
impurities	CO	0.2 ppm	1 ppm
	CO_2	2 ppm	1 ppm
	O_2	5 ppm	2 ppm
	N_2	100 ppm	50 ppm
	Ar	100 ppm	---
	He	300 ppm	---
	Hydrocarbon	2 ppm	1 ppm
	H_2O	5 ppm	---
	Sulfur compounds	0.004 ppm	---
	HCHO	0.01 ppm	---
	HCOOH	0.2 ppm	---
	NH_3	0.1 ppm	---
	Total halogen	0.05 ppm	---

Note) --- indicates unspecified when JHFC Project started.

Reference : ISO/TC197/SC/WG12, ISO/PDTS 14687-2 (2006. 8.30)

(Appendix)

Precise Gas Analysis (Dec. 2008)

Impurity	Concentration in volume ppm								Analysis Method
	Ichihara kerosene	Daikoku De-S gasoline	Kawasaki methanol	Senju natural gas	Centrair natural gas	Osaka natural gas	Sagamihara water electrolysis	MDC	
CO	0.06	<0.01	<0.01	0.01	0.05	0.16	–	0.01	GC-FID
CO2	<0.01	<0.01	<0.01	<0.01	0.02	0.35	–	0.01	GC-MS
Methane	<0.05	<0.05	<0.05	<0.05	<0.05	0.19	–	0.05	GC-FID
Other Hydrocarbon [1]	0.13	<0.05	<0.05	<0.05	<0.05	0.40	–	0.05	GC-FID
Benzene	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	–	0.005	GC-MS
Sulfur [2]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	–	0.0001	IC
Methanol	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	–	0.01	GC-MS
Formaldehyde	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	–	0.01	DNPH/HPLC
Acetoaldehyde	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	–	0.01	DNPH/HPLC
Formic Acid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	–	0.01	IC
Acetone	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	–	0.01	DNPH/HPLC
Ammonia	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	–	0.001	IC
Water	<0.5	3.4	<0.5	<0.5	<0.5	0.74	–	0.5	Dew-point Meter
Oxygen	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	–	0.01	Trace Oxygen Meter
Argon	<0.03	1.13	<0.03	1.34	0.39	0.54	–	0.03	GC-MS
Nitrogen	0.04	24.6 [4]	0.32	6.91	10.9	2.05	26.9 [4]	0.03	GC-MS
Helium	<3	<3	<3	<3	<3	<3	–	3	GC-TCD
Halogen compounds [5] : F^-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	–	0.05	IC
Halogen compounds [5] : Cl^-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	–	0.05	IC
Halogen compounds [5] : Br^-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	–	0.05	IC

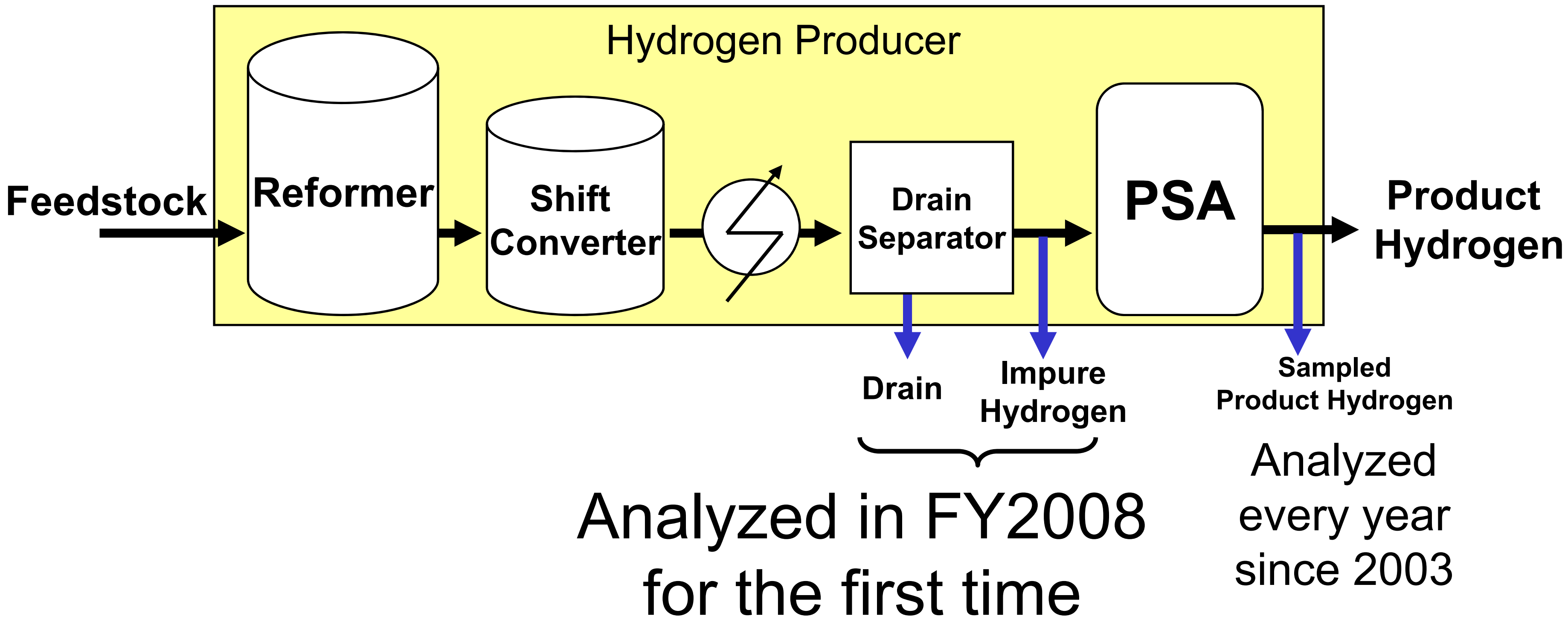
1) All Hydrocarbon concentrations are expressed as methane-equivalent.

2) All sulfur compounds are expressed as SO_4^{2-}–equivalent.

3) Each Halogen compound is expressed as F^-, Cl^-, Br^-.

4) Minimum Detectable Concentration

Gas Analysis



Impurities such as CH_3OH, CH_3COCH_3, NH_4^+, HCOOH, and aldehydes were detected.
Their concentrations were low and were easily removed by PSA.
Investigation will be continued.

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