Cost Evaluation for Centralized Hydrogen Production

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Background

- The next fuel should be
  environment-friendly,
  lasting available, and
  economically advantageous.
- Hydrogen is a promising fuel. The ideal source is water.
- Water can decompose by thermo-chemical methods or electrolysis.
- Nuclear power can provide both heat and electricity.

Hydrogen Usage

Usage	Fuel cell type	H_2 demand by 2030 ($10^9 Nm^3/y$)	H_2 supply from by-products ($10^9 Nm^3/y$)	Alternative fuel
Fuel cell vehicle	PEFC	17	37	-
Stationary fuel cell	PEFC/ SOFC	29		Natural gas, Coal gas

Mass production of hydrogen using nuclear power for fuel cell vehicles was considered.

Objective

- To optimize thermal power of a nuclear plant for hydrogen production by comparing
  - cost of water decomposition with that of steam reforming of methane, and
  - refueling cost for transportation with that of gasoline.

Cost Evaluation Method

Hydrogen supply cost = Production cost
+ Delivery cost
+ Refueling cost

Cost = Fixed cost + Variable cost
where
Fixed cost = (Capital Cost*) x (Capital Rate)
Variable cost = Fuel Cost (such as methane, water)
+ Utilities (such as electricity and water)
+ Labor Cost
[Variable cost = (Capital Cost) x (Capital Rate)]

*A plant construction fee was excluded because of wide variability depending on a construction site.

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Capital Rate

Item	Off-site Eqipments	On-site Equipments
Life Time（y）	10.0	8.0
Depreciation（%）*	9.0	11.3
Property Tax（%）	1.4	1.4
Insurence（%）	0.6	0.6
Repair（%）	3.0	3.0
Remuneration（%）	2.5	2.5
General Control Fee（%）	1.0	1.0
Capital Rate（%/y）	17.5	19.8

*Assuming a remaining capital cost of 10 %

Comparison of Cost

Hydrogen Supply Cost = Production Cost + Delivery Cost + Refueling Cost at station

-IS method
-Electrolysis

-Trailer
-Tank lorry
-Pipeline

as a function of thermal power of nuclear plants (15-3000 MWt)

<u>Cost target 2;</u>
Refueling cost of gasoline

<u>Cost target 1;</u>
Cost of the steam reforming of methane

Here the capacity of station is assumed to be 300 Nm^3/h, which is equivalent to one third of thermal energies sold at a gasoline stand. The efficiency of a fuel cell vehicle is about three times higher than that of a gasoline vehicle.

Hydrogen Production Cost by Steam Reforming

Assumption

- operation rate; 90 %
- utility fee; 1.6 %
- labor fee; 0.7 %
- methane; 1.8 ¥/Mcal

Ammonia plant*

- capital cost; 27 G¥
- capacity; 200,000 m^3/h

Hydrogen production cost = 12.8 ¥/Nm^3

CO_2 fixation cost; 30 \$/t-CO_2 & 120 ¥/\$

Hydrogen production cost = 15.8 ¥/Nm^3 ; Cost target 1

*NEDO, NEDO-WE-NET-9731, 1998

Hydrogen Production Cost for IS Method

IS plant*

capital cost; 79 G¥

capacity; 4200 mol/s

Assumption

(capital cost) = A*(production rate)$^{0.65}$

operation rate; 90 %

labor fee; 0.7 %

water; 200 ¥/t

cost of heat; 2.00 ¥/(kWt)/h [=5.9(¥/kWe/h)*0.34(kWe/kWh)]

1.29 ¥/(kWt)/h [=3(¥/kWe/h)*0.43(kWe/kWh)]

*Brown, L.C., *et. al*., GA-A24266(2003)

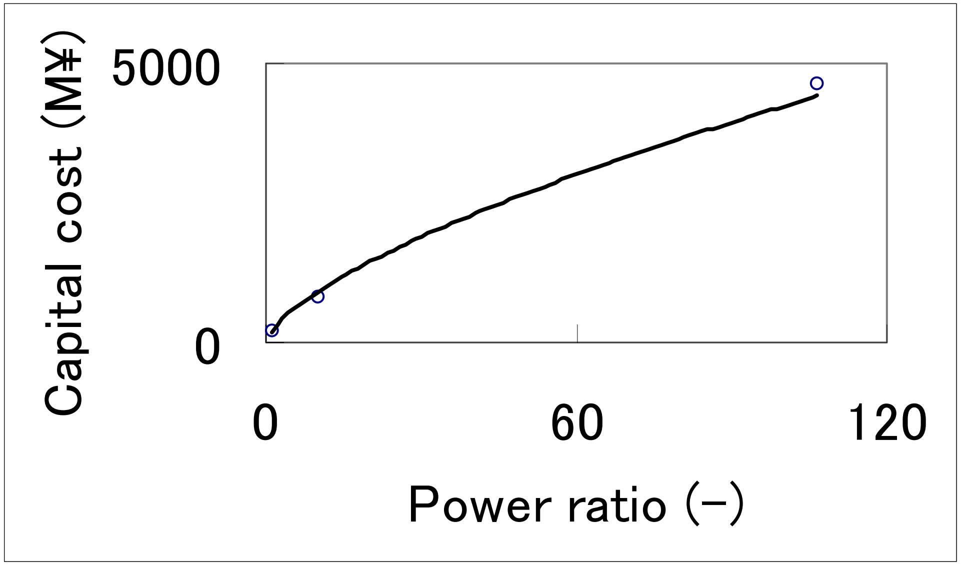
Cost Comparison for IS Method

- Thermal power >3000 MWt
- Thermal efficiency of IS method > 0.5
- Heat cost < 1.29 ¥/kWt/h (3 ¥/kWe/h)

Thermal Power (MWt)	Thermal Efficiency ; 0.45 Heat Cost(Yen/kWh)			Thermal Efficiency ; 0.5 Heat Cost(Yen/kWh)			Thermal Efficiency ; 0.55 Heat Cost(Yen/kWh)		
	2	1.65	1.29	2	1.65	1.29	2	1.65	1.29
15	49.73	46.97	44.14	46.88	44.40	41.85	44.48	42.23	39.90
30	42.62	39.86	37.03	40.03	37.55	34.99	37.85	35.60	33.28
60	37.04	34.28	31.45	34.65	32.17	29.62	32.65	30.40	28.08
100	33.72	30.96	28.12	31.45	28.96	26.41	29.55	27.30	24.97
300	28.29	25.53	22.70	26.22	23.73	21.18	24.50	22.24	19.92
600	25.80	23.04	20.20	23.82	21.33	18.78	22.17	19.92	17.59
1000	24.31	21.56	18.72	22.38	19.90	17.35	20.79	18.53	16.21
3000	21.89	19.13	16.30	20.05	17.57	15.01	18.53	16.27	13.95

Cost target 1; 15.8 ¥/Nm^3

Hydrogen Production Cost for Electrolysis



Electrolysis plant*

-capacity; 300, 3000, 32000 kWe

-PEM electrolysis

Assumption

(capital cost) = A∗(power ratio)$^{0.67}$

operation rate; 90 %

labor fee; 0.7 %

water; 200 ¥/t

*NEDO, NEDO-WE-NET-9908(2000)

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Cost Comparison for Electrolysis

- Thermal power > 600 MWt
- Electric cost < 3 ¥/kWe/h

Thermal Power (MWt)	Generation Cost(Yen/kWh)			
	5.9	5	4	3
15	34.28	30.41	26.11	21.81
30	32.48	28.61	24.31	20.01
60	31.06	27.19	22.89	18.59
100	30.20	26.33	22.03	17.73
300	28.77	24.90	20.60	16.30
600	28.11	24.24	19.94	15.64
1000	27.71	23.84	19.54	15.24
3000	27.04	23.17	18.87	14.57

Cost target 1; 15.8 ¥/Nm^3

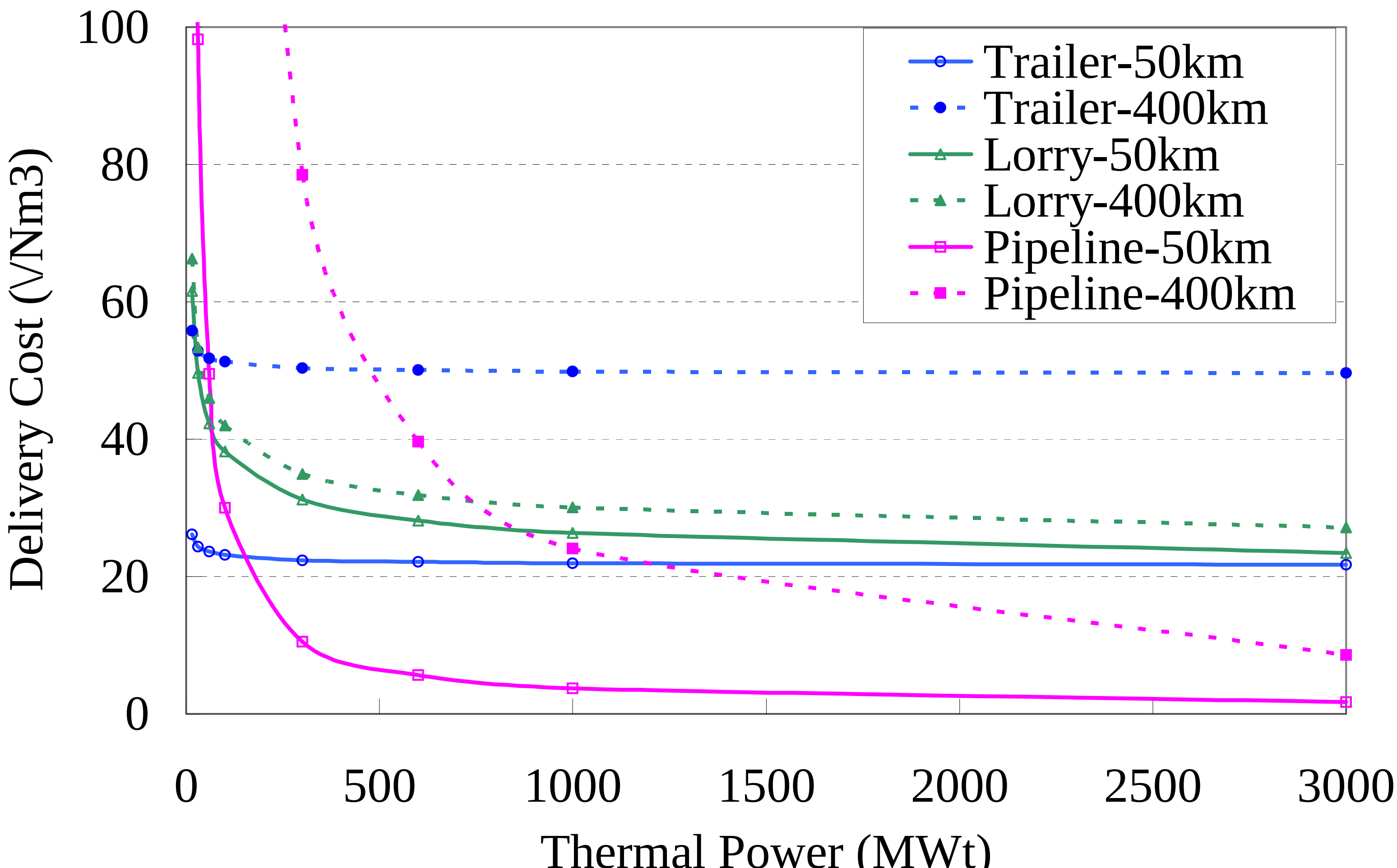
Delivery Cost

	Shipping facility	Capital cost	Capital rate
Trailer	Power of 0.65 based on the capital cost data*	18 M¥/trailer	19.5 % (10 years)
Tank lorry		51 M¥/lorry	33.0 % (4 years)
Pipeline	Booster; 33.6 k¥/(Nm^3/h)	360 M¥/km	17.5 % (10 years)

*NEDO, NEDO-WE-NET-0101(2002)

Cost Comparison for Delivery

- Trailer if distance < 50 km & thermal power < 100 MWt
- Pipeline for any distance if thermal power > 1000 MWt



Refueling Cost

Capital cost evaluation using a progress ratio*

$$Y = A*X^{-B}$$

where Y: station cost after X-1 stations has been constructed

A: cost of the first station

B: cost reduction ratio

Assumption

- X=10000 after 2030
- capital rate; 19.8 %
- labor fee; 8.4 M¥/man

→ 22.19 ¥/Nm^3

Gas station; 15 ¥/Nm^3

*NEDO, NEDO-WE-NET-0101(2002)

Cost Target 2

<u>Assumption</u>

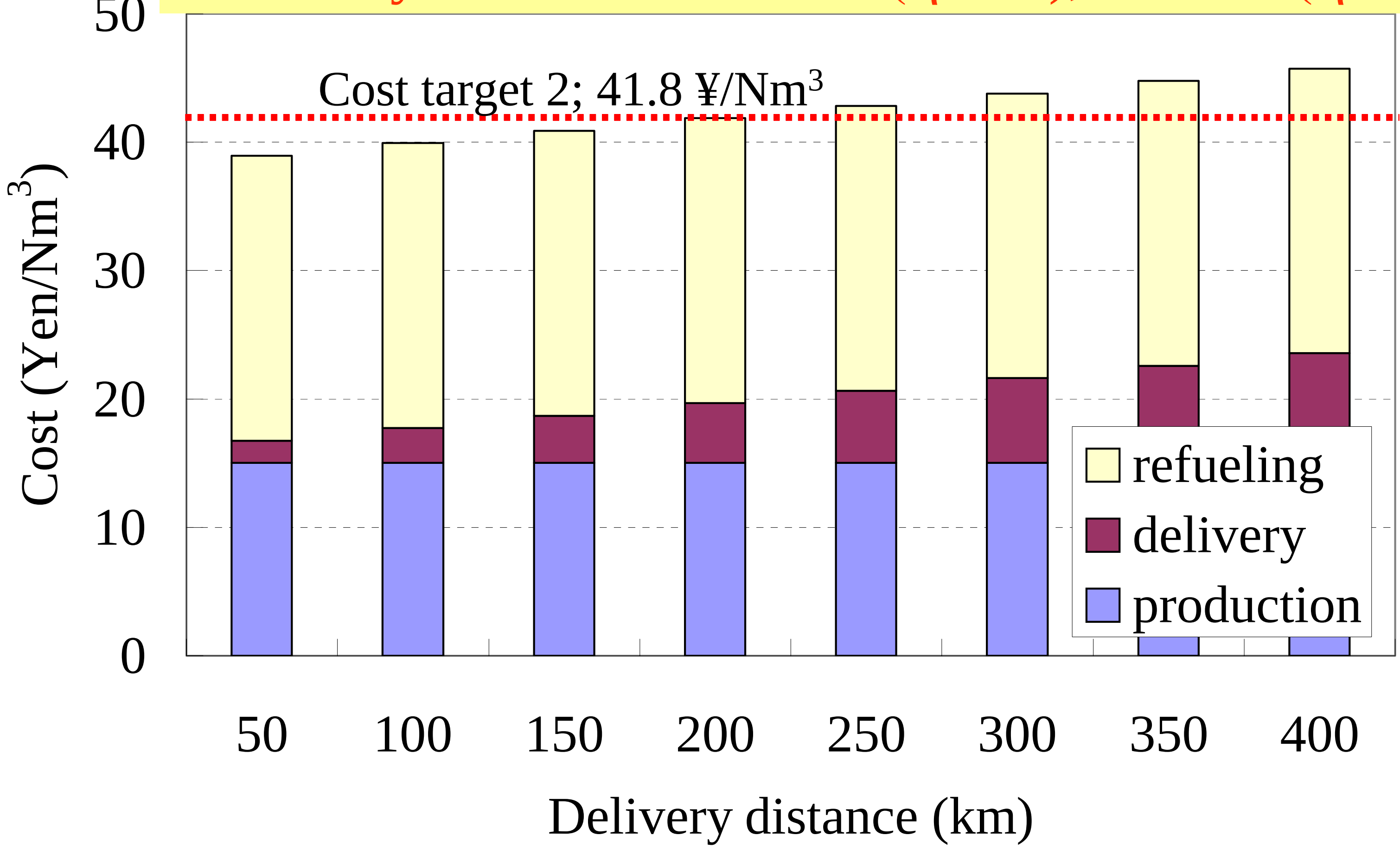
- gasoline cost; 100 ¥/L
- tax for volatile oils; 53.8 ¥/L
- efficiency of fuel cell vehicles; 2.5 times higher than gasoline cars

↓

Cost target 2; 41.8 ¥/Nm^3

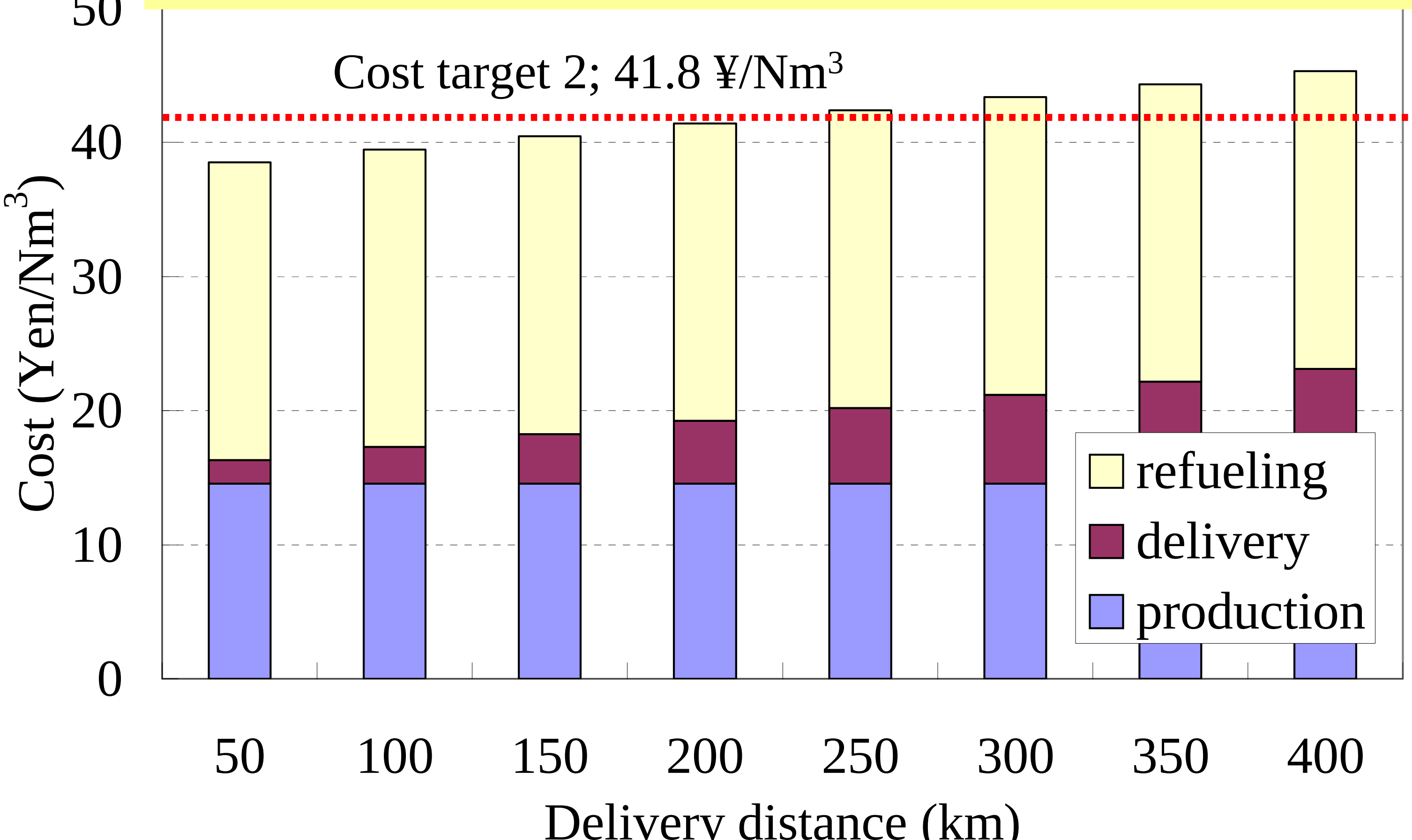
Hydrogen Supply Cost for IS Method

- Thermal power > 3000 MWt
- Heat cost < 1.29 ¥/kWt/h (3 ¥/kWe/h)
- Delivery distance < 200 km (η=0.5), 250 km (η=0.55)



Hydrogen Supply Cost for Electrolysis

- Thermal power > 1000 MWt
- Electric cost < 3 ¥/kWe/h
- Delivery distance < 200 km (3000MWt), 50 km (1000MWt)



Summary

The hydrogen supply cost was evaluated to optimize the thermal power of nuclear plants to compete gasoline for transportation. The hydrogen production cost by water decomposition was comparable to that by steam reforming of natural gas. The refueling cost, which would be more than 50 % of the supply cost, should be reduced. Necessary conditions are shown in the table.

	Therma l power	Cost	Delivery distance
IS method	>3000 MWt	Heat: 1.29 ¥/kWt/h	<200 km (η=0.5) <250 km (η=0.55)
Electrolysis	>1000 MWt	Electricity: 3 ¥/kWe/h	<50 km (1000 MWt) <200 km (3000 MWt)