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

<table>
<thead>
<tr>
<th>Usage</th>
<th>Fuel cell type</th>
<th>$\text{H}_2$ demand by 2030 ($10^9\text{Nm}^3/\text{y}$)</th>
<th>$\text{H}_2$ supply from by-products ($10^9\text{Nm}^3/\text{y}$)</th>
<th>Alternative fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell vehicle</td>
<td>PEFC</td>
<td>17</td>
<td>37</td>
<td>-</td>
</tr>
<tr>
<td>Stationary fuel cell</td>
<td>PEFC/SOFC</td>
<td>29</td>
<td></td>
<td>Natural gas, Coal gas</td>
</tr>
</tbody>
</table>

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.
# Capital Rate

<table>
<thead>
<tr>
<th>Item</th>
<th>Off-site Equipments</th>
<th>On-site Equipments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Time (y)</td>
<td>10.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Depreciation (%)*</td>
<td>9.0</td>
<td>11.3</td>
</tr>
<tr>
<td>Property Tax (%)</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Insurance (%)</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Repair (%)</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Remuneration (%)</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>General Control Fee (%)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Capital Rate (%/y)</td>
<td>17.5</td>
<td>19.8</td>
</tr>
</tbody>
</table>

*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)

Cost target 1:
Cost of the steam reforming of methane

Cost target 2:
Refueling cost of gasoline

Here the capacity of station is assumed to be 300 Nm³/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 cost: 1.8 ¥/Mcal

Ammonia plant*
- capital cost: 27 G¥
- capacity: 200,000 m³/h

Hydrogen production cost = 12.8 ¥/Nm³

CO₂ fixation cost: 30 $/t-CO₂ & 120 ¥/$

Hydrogen production cost = 15.8 ¥/Nm³; 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)

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

Cost target 1; 15.8 ¥/Nm³
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)
Cost Comparison for Electrolysis

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

<table>
<thead>
<tr>
<th>Thermal Power (MWt)</th>
<th>Generation Cost (Yen/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.9</td>
</tr>
<tr>
<td>15</td>
<td>34.28</td>
</tr>
<tr>
<td>30</td>
<td>32.48</td>
</tr>
<tr>
<td>60</td>
<td>31.06</td>
</tr>
<tr>
<td>100</td>
<td>30.20</td>
</tr>
<tr>
<td>300</td>
<td>28.77</td>
</tr>
<tr>
<td>600</td>
<td>28.11</td>
</tr>
<tr>
<td>1000</td>
<td>27.71</td>
</tr>
<tr>
<td>3000</td>
<td>27.04</td>
</tr>
</tbody>
</table>

Cost target 1; 15.8 ¥/Nm³
# Delivery Cost

<table>
<thead>
<tr>
<th>Shipping facility</th>
<th>Capital cost</th>
<th>Capital rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trailer</strong></td>
<td>18 M¥/trailer</td>
<td>19.5 % (10 years)</td>
</tr>
<tr>
<td>Power of 0.65 based on the capital cost data*</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tank lorry</strong></td>
<td>51 M¥/lorry</td>
<td>33.0 % (4 years)</td>
</tr>
<tr>
<td><strong>Pipeline</strong></td>
<td>360 M¥/km</td>
<td>17.5 % (10 years)</td>
</tr>
<tr>
<td>Booster; 33.6 k¥/(Nm³/h)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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*

\[ Y = A \times X^{-B} \]

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% → 22.19 ¥/Nm³
- labor fee: 8.4 M¥/man → Gas station; 15 ¥/Nm³

*NEDO, NEDO-WE-NET-0101(2002)
Cost Target 2

Assumption
- 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 ¥/Nm³
Hydrogen Supply Cost for IS Method

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

Cost target 2: 41.8 ¥/Nm³

[Diagram showing cost variation with delivery distance]
Hydrogen Supply Cost for Electrolysis

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

Cost target 2; 41.8 ¥/Nm³

![Cost vs Delivery Distance Chart]

- refueling
- delivery
- production

Delivery distance (km)

Cost (Yen/Nm³)
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.

<table>
<thead>
<tr>
<th>Therma l power</th>
<th>Cost</th>
<th>Delivery distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS method</td>
<td>Heat: 1.29 ¥/kWt/h</td>
<td>&lt;200 km (η=0.5)</td>
</tr>
<tr>
<td>&gt;3000 MWt</td>
<td></td>
<td>&lt;250 km (η=0.55)</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>Electricity: 3 ¥/kWe/h</td>
<td>&lt;50 km (1000 MWt)</td>
</tr>
<tr>
<td>&gt;1000 MWt</td>
<td></td>
<td>&lt;200 km (3000 MWt)</td>
</tr>
</tbody>
</table>