Technology evaluation of zero-carbon power generation systems in Japan in terms of cost and CO$_2$ emissions

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Outline

• Introduction
   Technology issues toward zero CO$_2$ emission power generation system.

• Methodology
   RE tech. scenarios and optimal multi-regional power generation model.

• Results and discussions

• Conclusions
CO$_2$ emissions in Japan by sectors (2013 FY)

Energy consumption: 1.37 GJ/y
Power generation: 1,090 TWh/y
CO$_2$ emission from energy sector in Japan 1.24 Gt-CO$_2$/y

- Passenger transportation 11%
- Freight transportation 7%
- Household 5%
- Office 3%
- Steel 10%
- Chemical 2%
- Ceramic 2%
- Agriculture, forestry, fisheries 1%
- Other 6%

Power generation 53%
CO₂ emission reduction targets

LCS Technology scenarios

Indicators of technology (Cost, utility rate, parameters in operation)

Elec. Demand

Demand curve

Power generation model (Cost minimized)

Constraints eq.

Capacity constraints (Capacity, rate of output change)

Fluctuation constraints (Operating reserve, LFC, Inertia)

Transmission constraints (cap and energy loss of trans)

Storage system constraints (Pumped hydro, battery, H₂)

Regional constraints (conditions of climate and location)

Supply and demand balance

Regional balance

Seasonal balance

Output & cap. of power generation systems

Cap. of storage systems

Fuels

Capacity of transmission

Total cost of electricity system, CO₂ emissions
Platform for Design & Evaluation of LCT ("Modeling Tool")

Automated process design support system developed by LCS.

- PFD with mass & energy balance
- Equipment selection & sizing
- Equipment cost & weight
- Production cost & CO2 emissions
- Raw materials, utilities cost
- Environmental load
- Environmental load

- PV
- Battery
- FC
- Wind Power
- Med-sized hydraulic
- Geothermal
- Woody biomass
- Biogas
- CCS

![Graph showing cost vs. weight and power vs. cost/weight relationship with equations and coefficients]
Multi-regional power generation model

Storage sys.
- Battery
- Pumped hydro
- Hydrogen
  (Electrolysis, H₂ turbine)

Demand curve

Power generation with fluctuation
- PV
- Wind power

Load following power plants
- LNG
- Oil
- Hydro (ROR, Pumped)
- Hydrogen turbine
- Battery output

Base load plants
- Coal
- Nuclear
- Hydro (Run-of-the-river)
- Biomass
- Geothermal

* LFC: Load frequency control, GF: Governor-free control

(Average output of summer days, 2050 scenario)
Grid system and the issues

Elec. Com. In Japan
Installed Generation Capacity
At the end of 2012 FY

- Hokkaido: 7 GW
- Tohoku: 17 GW
- Tokyo: 66 GW
- Hokuriku: 8 GW
- Chubu: 33 GW
- Kansai: 35 GW
- Chugoku: 12 GW
- Shikoku: 7 GW
- Kyushu: 21 GW
- Okinawa: 2 GW

- Short term:
  Governor Free,
  LFC (Load frequency control)
- Long term: hourly, seasonal
- Grid system stability
  (a generator is considered synchronized to the grid)

60Hz / 50Hz

- LFC
  10 min
- GF
  Sec. to Min.
Important R & D items for future bright system

- Thinner Si-wafer by new slicing tech
- CIGS tandem by high speed process
- Organic compound tandem

Current status

Improved existing tech.

Future product

**Prospects of PV System Cost**

- **mono-crystalline Silicon solar cell** (module efficiency 17%, wafer thickness 180μm)
- New thin film Organic, Perovskite etc.
- Thin-film compound semiconductor solar cell (CIGS)
  - (20%, 150 μm)
  - (15%)
- Module Cost
  - (18%)
- **Future**
  - (20–25%, 50 μm)
  - (20–30%)

**Stand**

- BOS
- Power conditioner

**Power conditioner**

**Thin-film compound semiconductor solar cell (CIGS)**

(13%)
## RE technology scenarios

<table>
<thead>
<tr>
<th>Case, Technology level**</th>
<th>Capacity factor*</th>
<th>Power Cost [Yen/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A Tech.2015</td>
</tr>
<tr>
<td>PV</td>
<td>11%</td>
<td>16.0</td>
</tr>
<tr>
<td>Wind</td>
<td>23%</td>
<td>14.1</td>
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<tr>
<td>Geothermal</td>
<td>70%</td>
<td>12.5</td>
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<tr>
<td>Geothermal HDR*</td>
<td>70%</td>
<td>-</td>
</tr>
<tr>
<td>Biomass</td>
<td>70%</td>
<td>33.6</td>
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<tr>
<td>Hydro</td>
<td>54%</td>
<td>10.8</td>
</tr>
<tr>
<td>Battery (system cost)</td>
<td>-</td>
<td>19 Yen/Wh</td>
</tr>
</tbody>
</table>

*The capacity factors are calculated within the model. Standard capacity factors are used to estimate power cost that shows in this table.

**A Tech level 2015; current technology, B Tech level 2020; improving technology, C Tech level 2030; developing technology

***HDR: Hot dry rock geothermal power is optional technology

110Yen = 1$
Result
Relationship between CO$_2$ reduction potential and power demand
— Effect of inertia force power ratio on CO$_2$ reduction rate —

Max. reduction of CO$_2$ emissions (Based on 2013)  HDR: Hot dry rock geothermal power
# Power Cost, zero CO₂ emission (Inertia regulation 50%, 25%)

<table>
<thead>
<tr>
<th>Case</th>
<th>2013</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>Power demand (TWh/y)</td>
<td>990</td>
<td>1000</td>
<td>800</td>
<td>1000</td>
<td></td>
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<tr>
<td>Inertia fraction</td>
<td>50%</td>
<td>25%</td>
<td>25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ reduction</td>
<td>565 Mt-CO₂/y</td>
<td>80%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>0</td>
<td>130</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Hydro power</td>
<td>94</td>
<td>0</td>
<td>130</td>
<td>130</td>
<td>130</td>
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<tr>
<td>LNG</td>
<td>285,697</td>
<td>317</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Coal,Oil</td>
<td>697</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>PV</td>
<td>9</td>
<td>0</td>
<td>595</td>
<td>555</td>
<td>692</td>
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<td>Wind power</td>
<td>5</td>
<td>524</td>
<td>402</td>
<td>344</td>
<td>559</td>
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<td>Geothermal</td>
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<td>211</td>
<td>12</td>
<td>12</td>
<td>12</td>
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<tr>
<td>Geothermal (HDR)</td>
<td>-</td>
<td>12</td>
<td>0</td>
<td>100</td>
<td>0</td>
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<tr>
<td>Biomass</td>
<td>-</td>
<td>31</td>
<td>22</td>
<td>31</td>
<td>29</td>
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<tr>
<td>Total</td>
<td>1190</td>
<td>1,225</td>
<td>1,160</td>
<td>1,172</td>
<td>1,422</td>
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<tr>
<td>H₂ Generation (TWh/y)</td>
<td>-</td>
<td>51</td>
<td>67</td>
<td>9</td>
<td>106</td>
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<tr>
<td>Battery output (TWh/y)</td>
<td>-</td>
<td>227</td>
<td>252</td>
<td>294</td>
<td>242</td>
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<tr>
<td>Battery Cap (GWh)</td>
<td>-</td>
<td>801</td>
<td>821</td>
<td>983</td>
<td>809</td>
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<tr>
<td>Gene. Cost (¥/kWh)</td>
<td>12.9</td>
<td>11.7</td>
<td>14.3</td>
<td>11.1</td>
<td>16.5</td>
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</table>
## Power Cost, zero CO₂ emission (Inertia regulation 25%)

<table>
<thead>
<tr>
<th>Case</th>
<th>5</th>
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<th>8</th>
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</thead>
<tbody>
<tr>
<td>Power demand (TWh/y)</td>
<td>1200</td>
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<tr>
<td>Inertia fraction</td>
<td>25%</td>
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<tr>
<td>CO₂ reduction</td>
<td>100%</td>
<td>98%</td>
<td>90%</td>
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</table>

<table>
<thead>
<tr>
<th>Generation Power (TWh/y)</th>
<th>Nuclear power</th>
<th>Hydro power</th>
<th>LNG</th>
<th>PV</th>
<th>Wind power</th>
<th>Geothermal</th>
<th>Geothermal (HDR)</th>
<th>Biomass</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>130</td>
<td>0</td>
<td>592</td>
<td>509</td>
<td>12</td>
<td>200</td>
<td>31</td>
<td>1,465</td>
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<tr>
<td></td>
<td>0</td>
<td>130</td>
<td>32</td>
<td>673</td>
<td>537</td>
<td>12</td>
<td>100</td>
<td>30</td>
<td>1,514</td>
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<tr>
<td></td>
<td>0</td>
<td>130</td>
<td>159</td>
<td>672</td>
<td>441</td>
<td>12</td>
<td>0</td>
<td>30</td>
<td>1,443</td>
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<tr>
<td>H₂ Generation (TWh/y)</td>
<td>24</td>
<td>43</td>
<td>29</td>
<td></td>
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<tr>
<td>Battery output (TWh/y)</td>
<td>156</td>
<td>297</td>
<td>308</td>
<td></td>
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<tr>
<td>Battery Cap (GWh)</td>
<td>643</td>
<td>920</td>
<td>1,013</td>
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<tr>
<td>Gene. Cost (¥/kWh)</td>
<td>12.1</td>
<td>12.9</td>
<td>11.7</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

(¥10/kWh = €85/MWh)
To construct a CO$_2$ zero-emission power generation system

1. Large-scale introduction of renewable energy, in particular, solar cell technology (30% eff.) to reduce plant area.

2. Storage batteries: 500 to 1000 GWh in order to alleviate short- and medium-term fluctuations and to integrate daily operations.

3. Electricity grid system reinforcement by at least 10 times the current level in order to use renewable energy in rural area.

4. The inertial force constraint has the greatest influence on power generation cost. Set the fraction of the electricity supply provided by inertial generators to 25%(half of the current).

5. Reduce power demand. On the other hand, when the demand for electricity increases, the introduction of a stable power source of 100 to 200 TWh (such as HDR) is indispensable.
Thank you for your attention

Center for Low Carbon Society Strategy,
Japan Science and Technology Agency

https://www.jst.go.jp/lcs/