Ammonia as energy carrier of the renewable energy; thermodynamic consideration

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- At present ammonia is mostly formed through reforming of natural gas (CH4). 1000 ton per day plant is said to consume about 35 GJ of natural gas to produce 1 ton ammonia (22.5 GJ of enthalpy). About 50% of extra energy is wasted. If 1 ton ammonia is produced through water electrolysis, 22.5 GJ of electricity is necessary theoretically. Here again, extra electric energy must be wasted. The author discusses roughly how the efficiency depends upon the process size and the renewable energy cost.

Back ground

- Cost of renewable energy varies over the world .
- The sun belt area and windy area can supply economic energy.
- (Example; 3cent/kWh thorough wind at Patagonia)
- The cost is high at the populated area.
- (Example; 13cent/kWh through waste woods, 22cent/kWh through wind in Japan)
- **[Thus renewable energy must be stored and transported to industrialized countries such as Japan: Energy carrier project]**
- Renewable energy is turned to H2 then to NH3 (or methyl cyclohexane) and carried to industrial area, and used.

Energy carrier: Organization

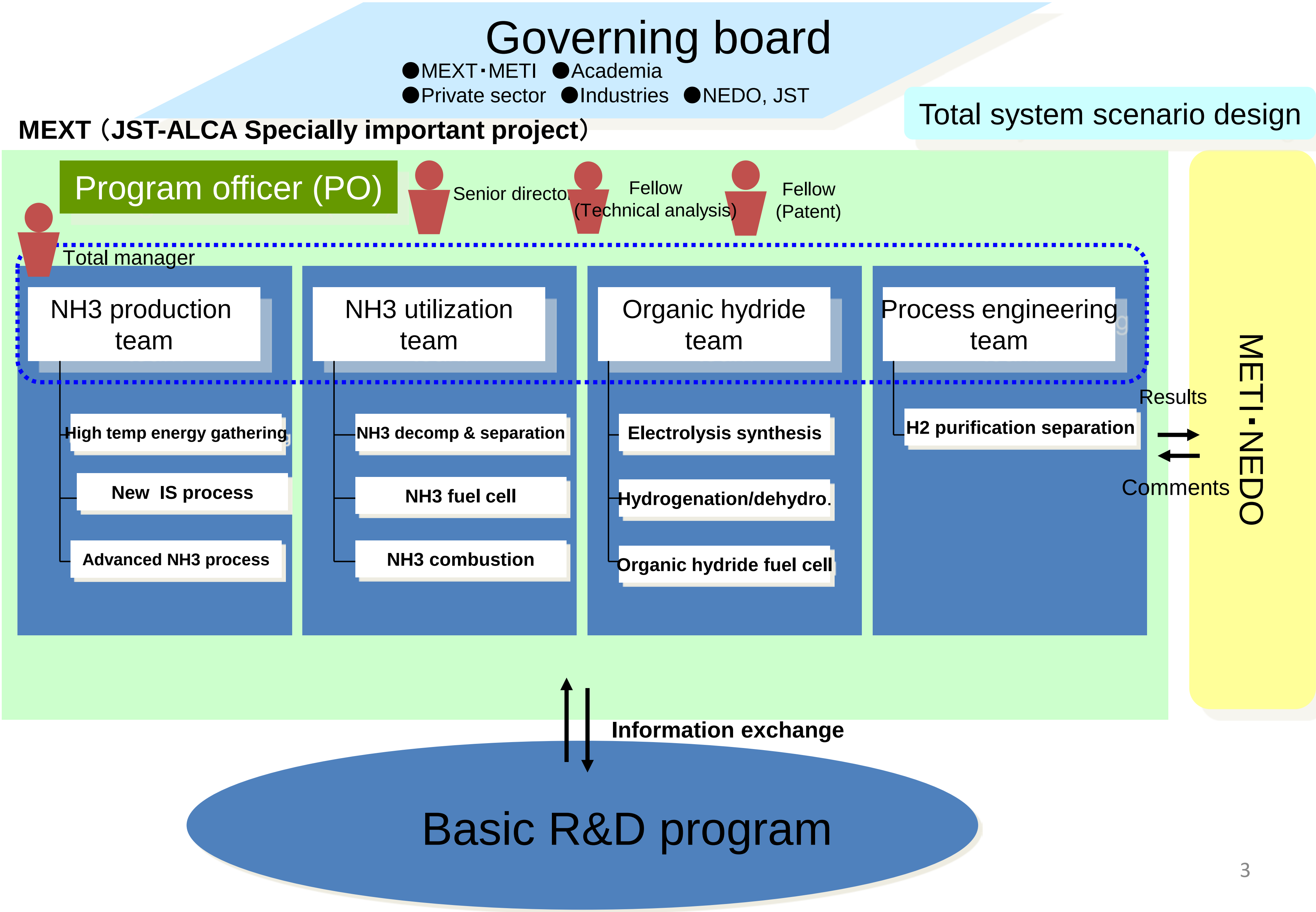
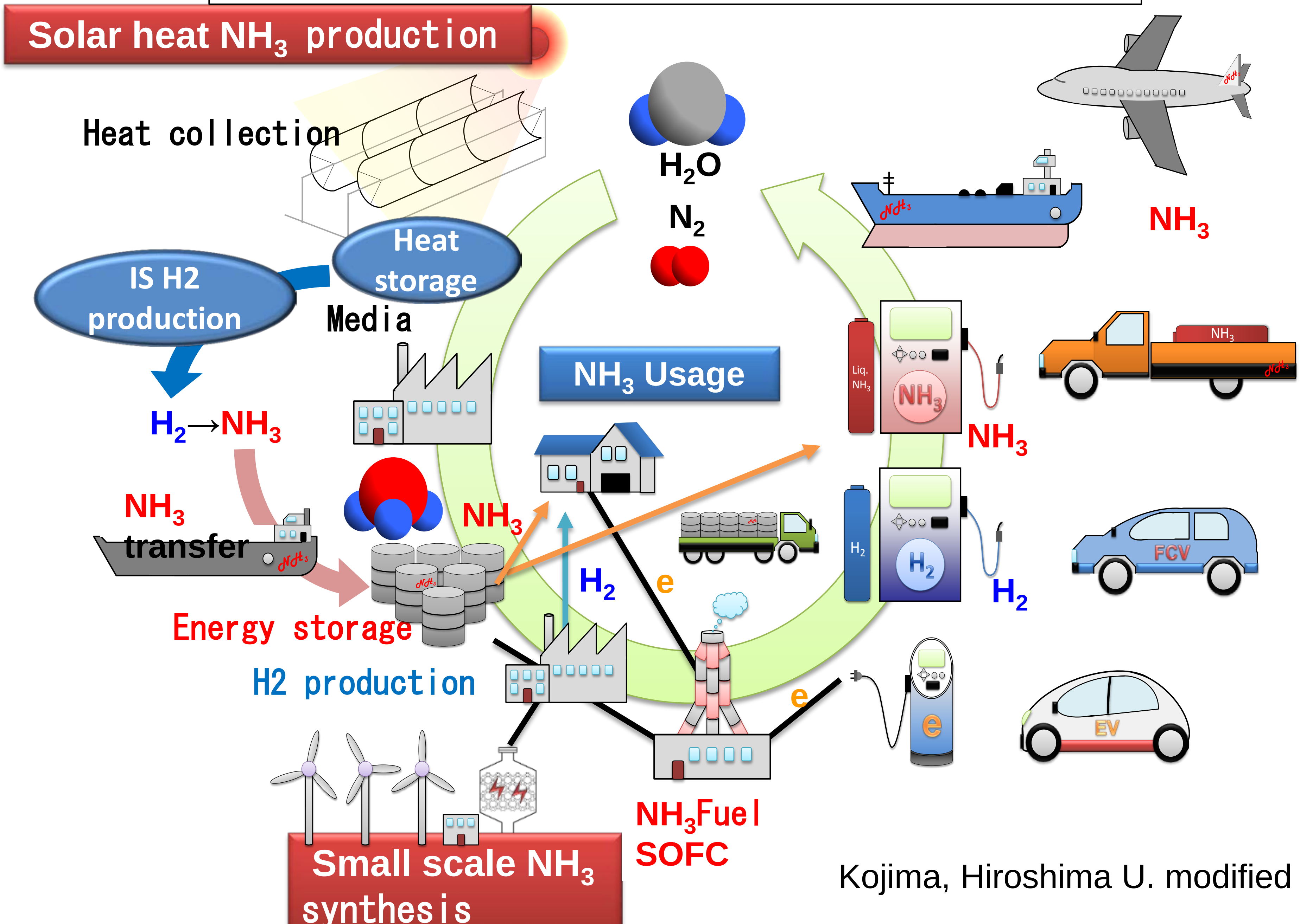


Image of NH3 production and use



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Importance of sharing the basic concept: NH3 production is divided to 2; inevitable part (thermodynamics) and manageable part (excess energy)

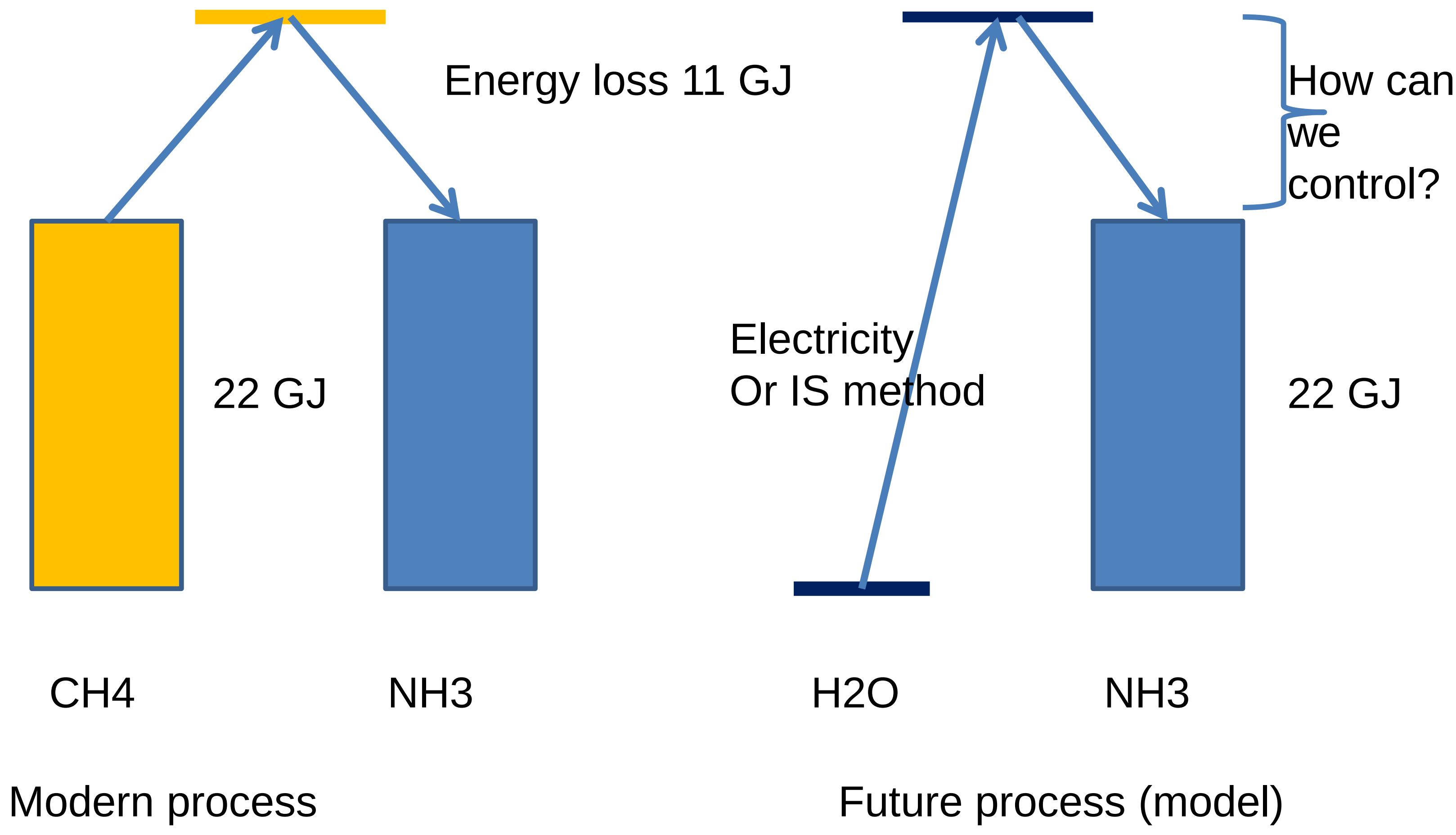
- A rough and simple estimation (to compete with the present resources)
- 2000t/d plant：400M$?
- NH3 sell price: 0.30$/kg, 300$/tNH3 ?
- Maintenance free operation, 30years: （300day/y) ?
- Total selling: 9000d＊300$/t＊2000t/d＝5400M$?

- Plant cost is below 10%: Running cost is exclusively important.
- Running cost owes energy (material).
- The energy is divided to two; thermodynamic and excess energy.

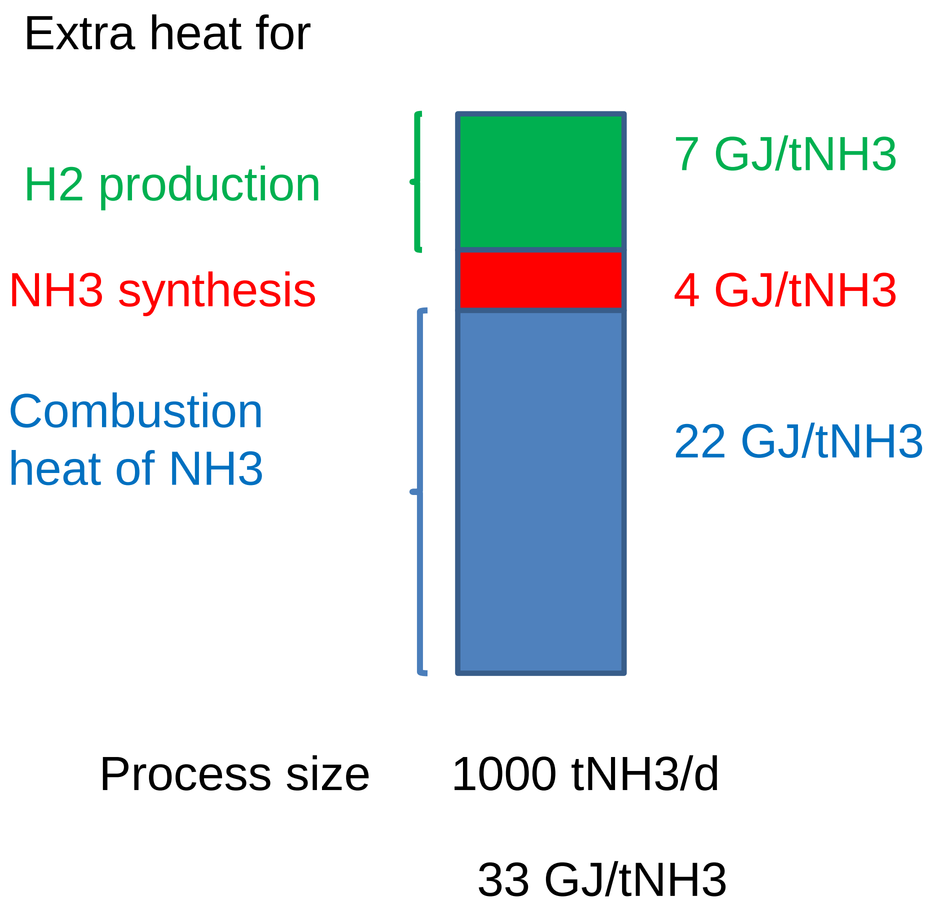
Thermodynamics of NH3 synthesis

- Synthesis from CH4, H2O, and air
- $7/16\ CH_4 + 5/8\ H_2O + 1/8\ O_2 + 1/2\ N_2 \rightarrow 7/16\ CO_2 + NH_3 +\ 6.9\ kJ$
- (0.4 GJ/t-NH3: 1.8% of NH3 combustion)
- NH3 combustion
- $NH_3 + 3/4\ O_2 \rightarrow 1/2\ N_2 + 3/2\ H_2O(l)\ \ + 382.6\ kJ$
- 22.5 GJ/t-NH3
- About 1.5 times energy (CH4), 34.5 GJ/t-NH3, is used for 1000 t/d plant.
- Synthesis from H2O electrolysis and air
- $3/2\ H_2O + 1/2\ N_2 \rightarrow NH_3 + 3/4\ O_2 - 382.6\ kJ$ (106.3Wh/mol)
- $½\ N_2 + 3/2\ H_2 \rightarrow NH_3$ $\Delta H = -46.1\ kJ$（2.7 GJ/t-NH3)

Comparison of NH3 source, CH4 or Electricity (or IS method)

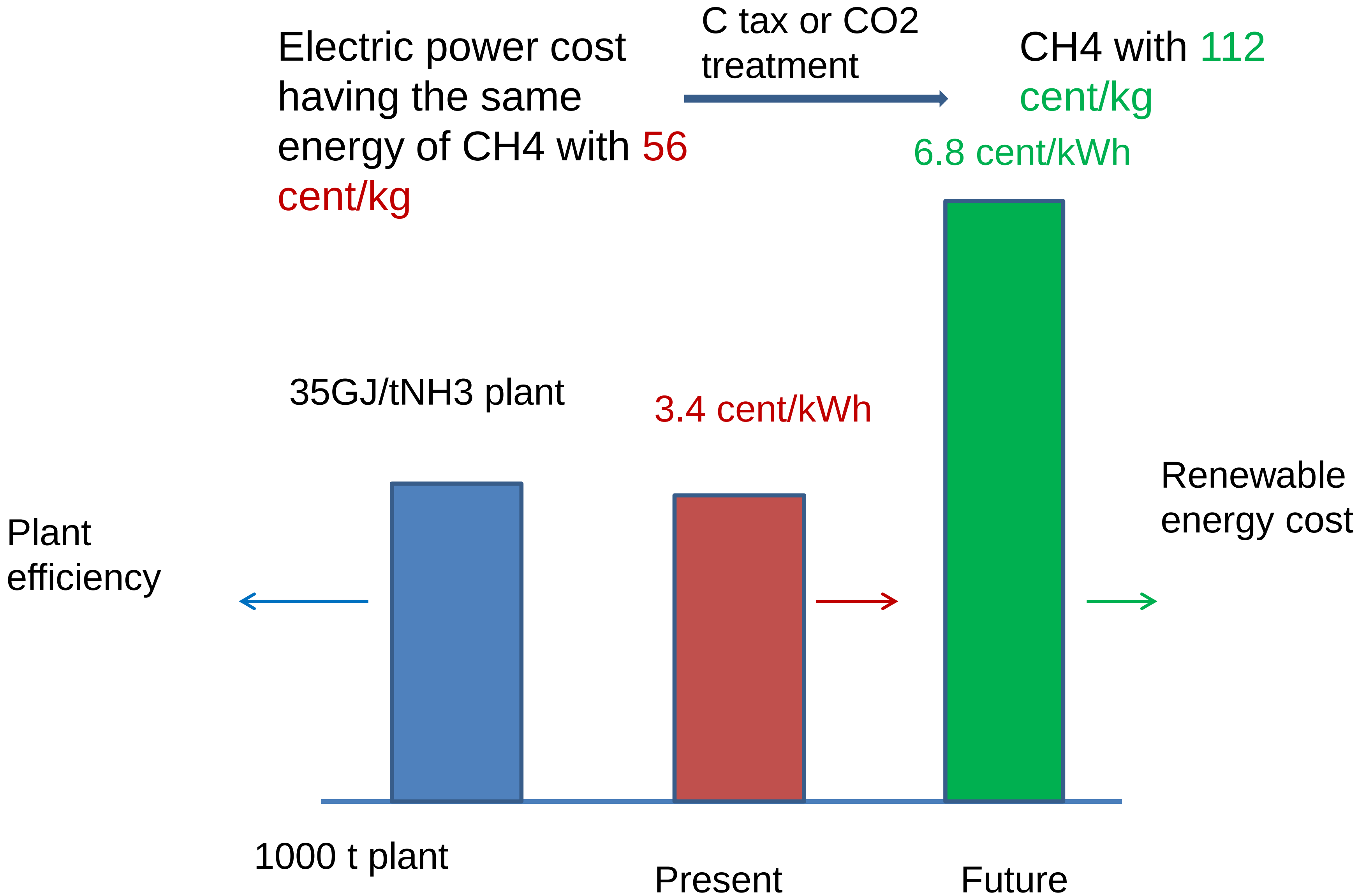


Only excess energy part is manageable for NH3 plant (either CH4 process or renewable energy process)



CH4 process is fully developed. This is the target for the renewable energy process at the natural gas production area.

Key is energy cost at renewable energy production site.



Electric power cost having the same energy of CH4 with 56 cent/kg
C tax or CO2 treatment
CH4 with 112 cent/kg
6.8 cent/kWh
35GJ/tNH3 plant
3.4 cent/kWh
Renewable energy cost
Plant efficiency
1000 t plant
Present
Future

Another problem: process size

- Solar energy density is low.
- The size of facility is limited.
- Assumption: manageable cost is related with -0.8 power of process size.
- Is the smaller process possible?

Wind farm Demark; 20x1MW (can be turned to 12 t-NH3 / d)

風力発電（デンマーク） with 25% effectiveness

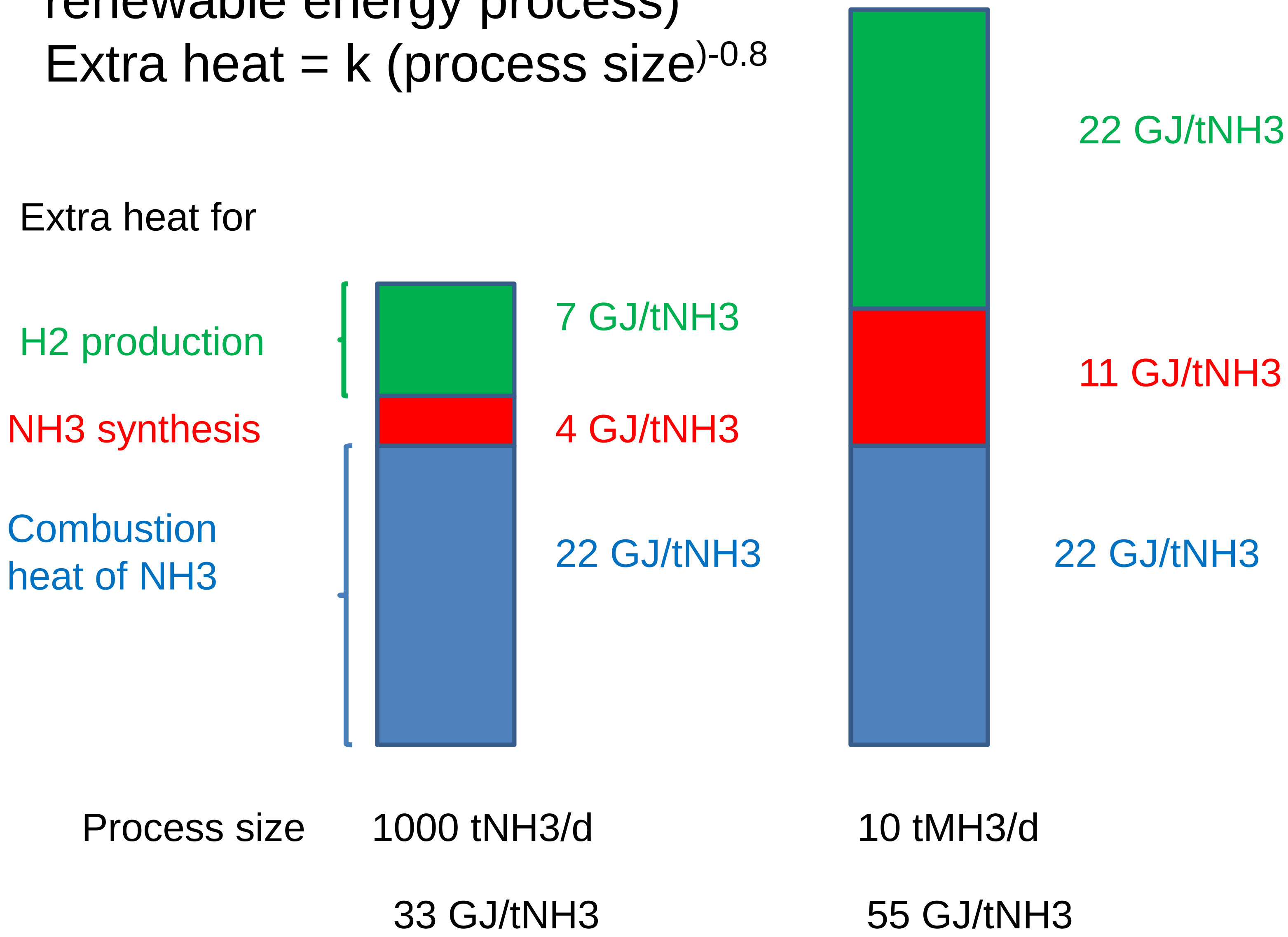
出典：○○○○

Wind > Electric power > Electrolysis of H2O > H2 > NH3 > Transported

Abdavi [Shrms 1] 100MW, Heated liquid media gathers 400-500C heat for steam.
60 t-NH3/d (assuming 25% efectiveness)

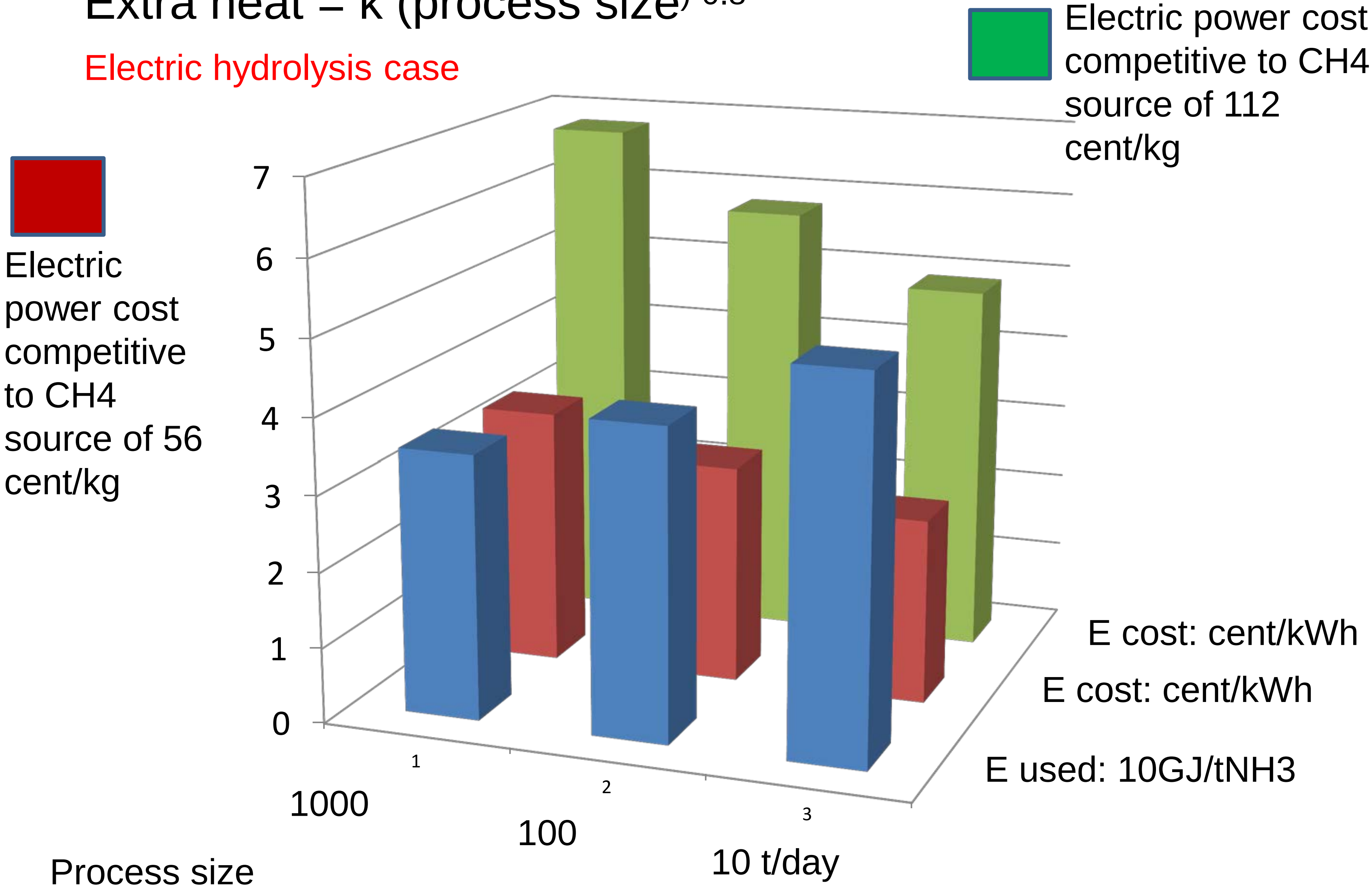
Scale effect NH3 plant (either for CH_4 process or renewable energy process)

Extra heat = k (process size$)^{-0.8}$



Extra heat = k (process size)$^{-0.8}$

Electric hydrolysis case



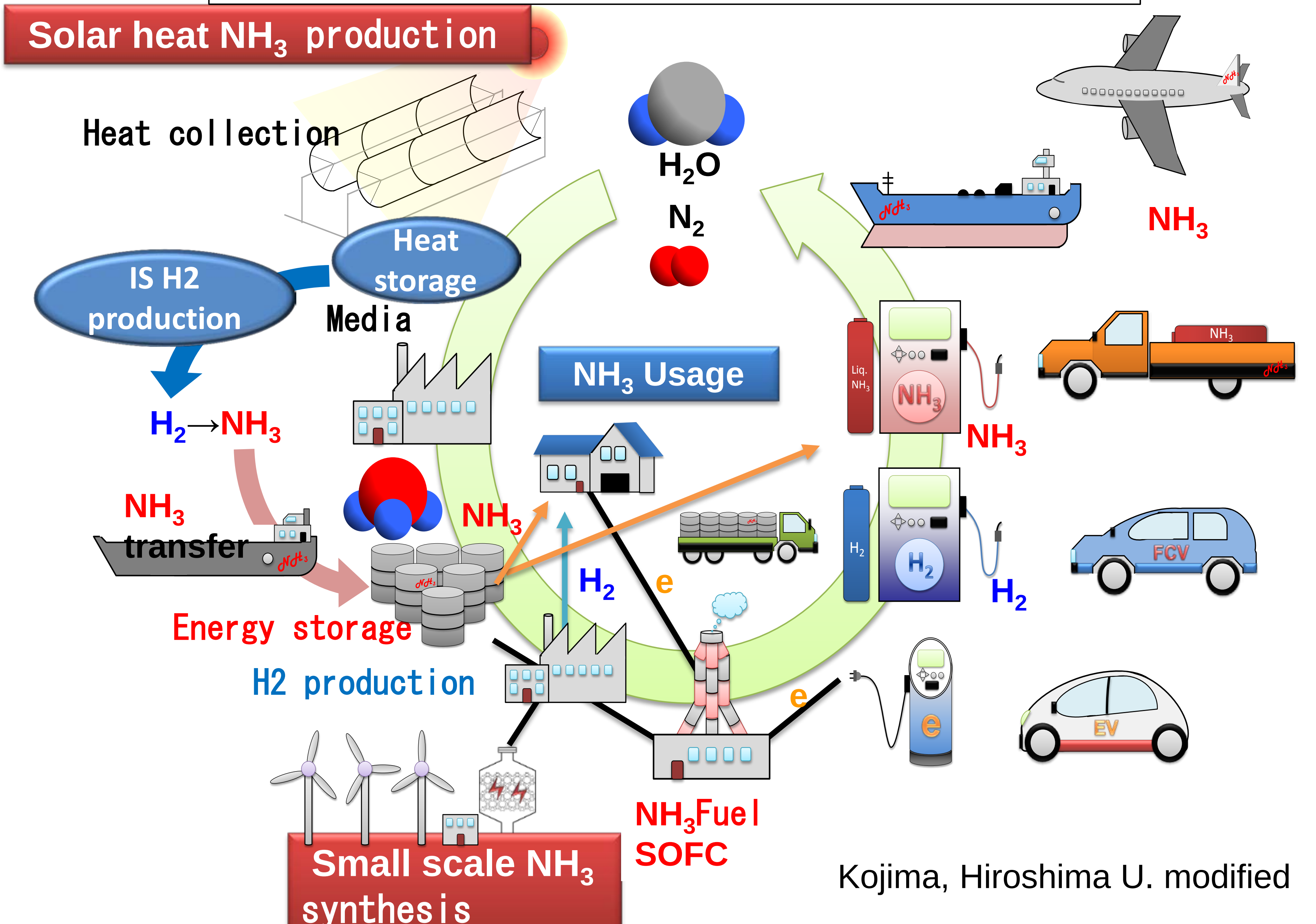
0.8 order; weak size effect

Solar or wind NH3 is economically possible under solar energy cost of 3-7cent/kWh if:

- The ammonia process (at the renewable energy site where N2 and H2 is separately produced) is developed competitive to the present natural gas process. (Remote area for fertilizer or industrial area as energy storage are already feasible.)

- More favorable; Renewable energy conversion technology is improved, and the cost get less.
- Fossil fuel is restricted further.

Image of NH3 production and use



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