Japan-US Workshop on
Fusion Power Plants and Related Advanced Technologies

Non-Nuclear Hybrid Concept with Fuel Production

Mar. 16, 2009
The University of Tokyo, Kashiwa

S. Konishi, M.Ichinose,J.Hatsuda and Y. Yamamoto
Kyoto University

Why Fuel?

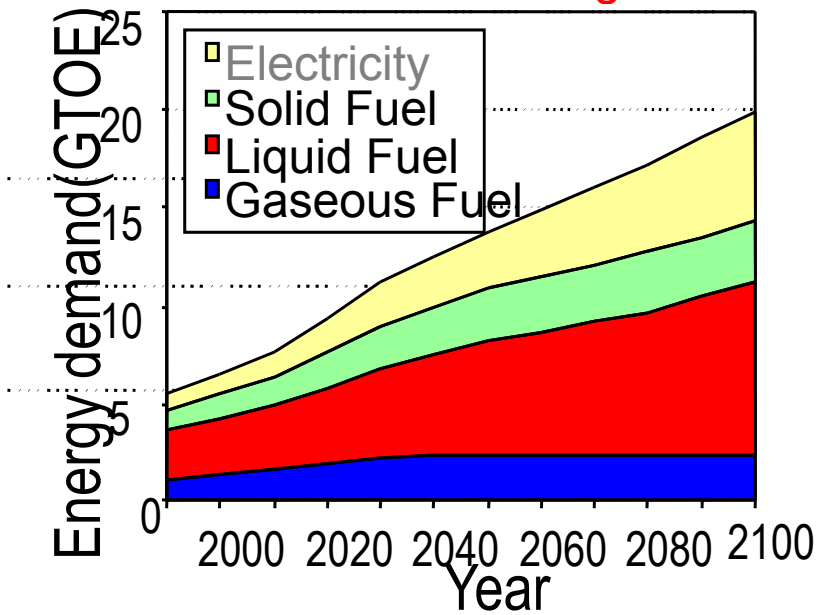
Can fusion respond to the expectations?
- global warming
- oil price change

Automobile

Aircraft

- Future fuel use:hydrogen
  - Fuel cells for automobile
  - aircrafts and ships
- Current/near future fuel:oil
  - gasoline can be substituted by HV,FCV
  - Diesel and jet fuel will not.
  - Existing infrastructure and technology (engine).
  - replacing fossil reduces CO_2 emission significantly.

Market 4 times larger



Example of Outlook of Global Energy Consumption by IPCC92a

Hydrogen Production by Fusion

Fusion can provide high temperature heat with advanced blanket options (DCLL etc.)

- Applicable for most of hydrogen production processes

There may be competitors…

As Electricity

- renewables, LWR

As high temperature heat

-IS process :HTGR(950C)

-biomass decomposition: HTGR

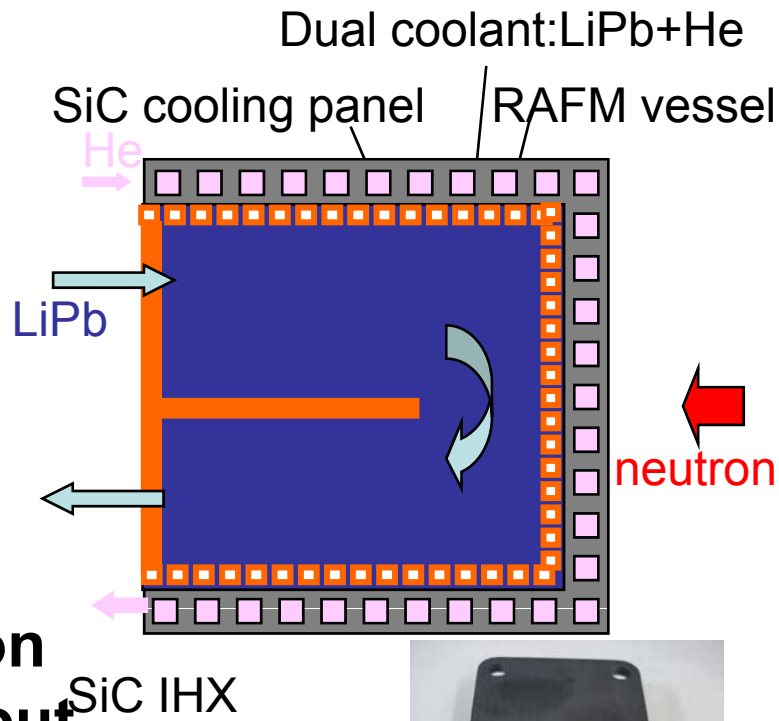
High Temperature
Fusion requires
Application process
IHX
Brayton cycle
Hydrogen production
cogeneration

Substitute fewer than electricity source

Concept of "Realistic" L i P b – S i C

1) LiPb-RAFM blanket with SiC cooling panel

- SiC cooling panel isolates RAFM vessel from LiPb
- LiPb extract heat at 900 degree.
- hot liquid metal to provide heat for chemical processes.



2) SiC Heat Exchanger program demonstrates the technical feasibility

- **active cooling enhances insulation and enables over 900 degree output.**

→high temperature, low pressure, high heat capacity liquid metal as secondary heat transfer medium.

Fuel Production with Fusion

Institute of Advanced Energy, Kyoto University

Fusion Energy （Heat, 900℃）

biomass + H_2O → H_2、CO

endothermic

cellulose: $(C_6H_{10}O_5)_{n/6} + n/6H_2O \rightarrow nH_2 + nCO$ – 136n [kJ]

lignin: $(CH_{1.4}O_{0.3})n + 0.7nH_2O \rightarrow 1.4nH_2 + nCO$ –136n[kJ]

Shift Reaction $CO + H_2O \Leftrightarrow H_2 + CO_2 + 32$ [kJ] → Waste heat

hydrogen

Carbon Neutral

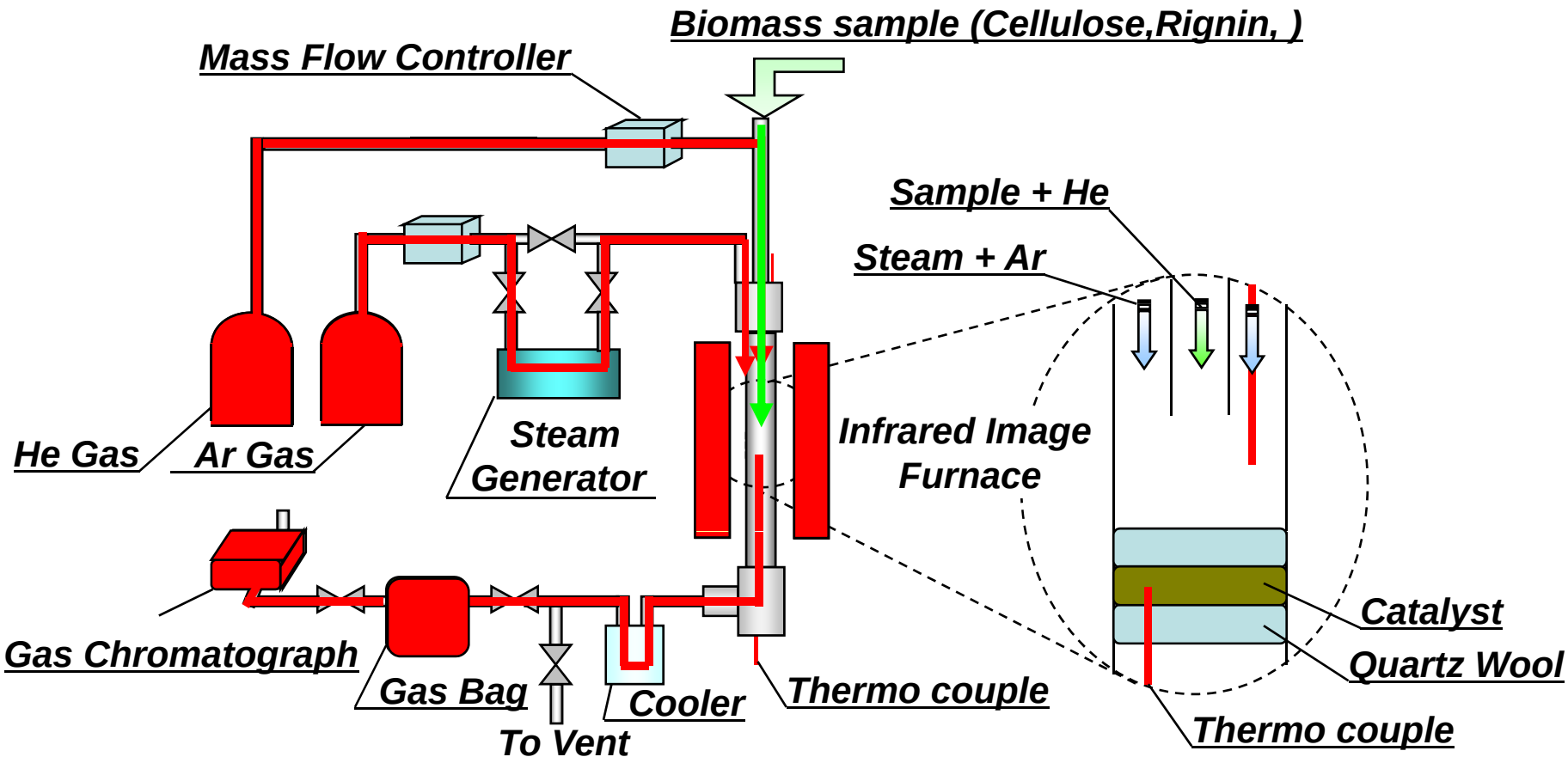
Fischer-Tropsch reaction

$2H_2 + CO \rightarrow -CH_2- + H_2O + 160$ [kJ]

Synthetic oil (Diesel)

Carbon Neutral fuel !

Experimental apparatus

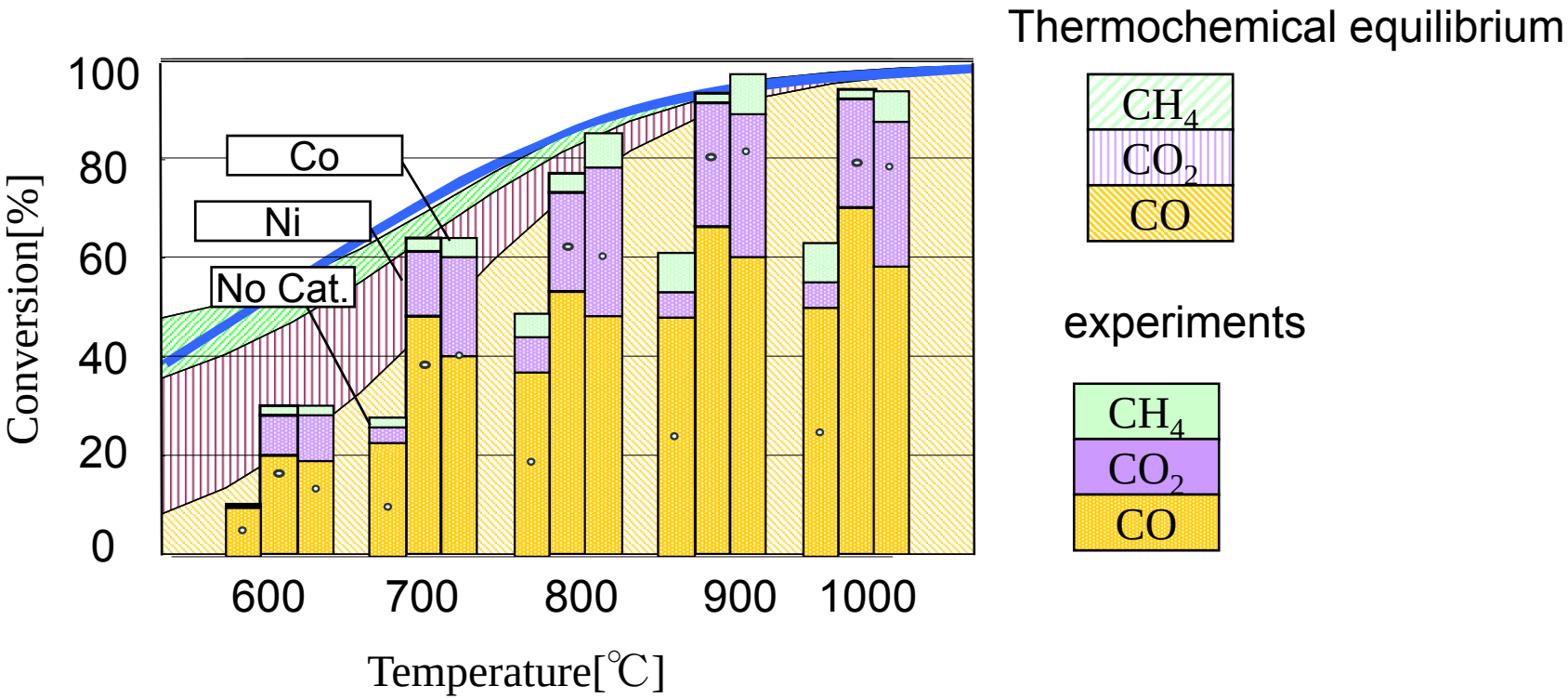


Ob

Gasification of Cellulose with Catalysts

Institute of Advanced Energy, Kyoto University

>95% carbon was converted to C1 gases with Ni.

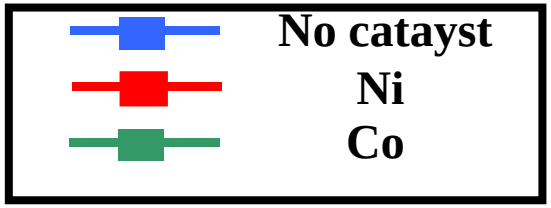


This conversion efficiency is practical level.

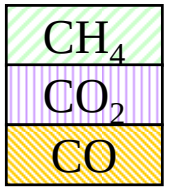
Gasification of lignin with Catalysts

Institute of Advanced Energy, Kyoto University

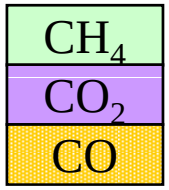
Lignin:
Typical content:(CH1.4O0.3)
Higher carbon content

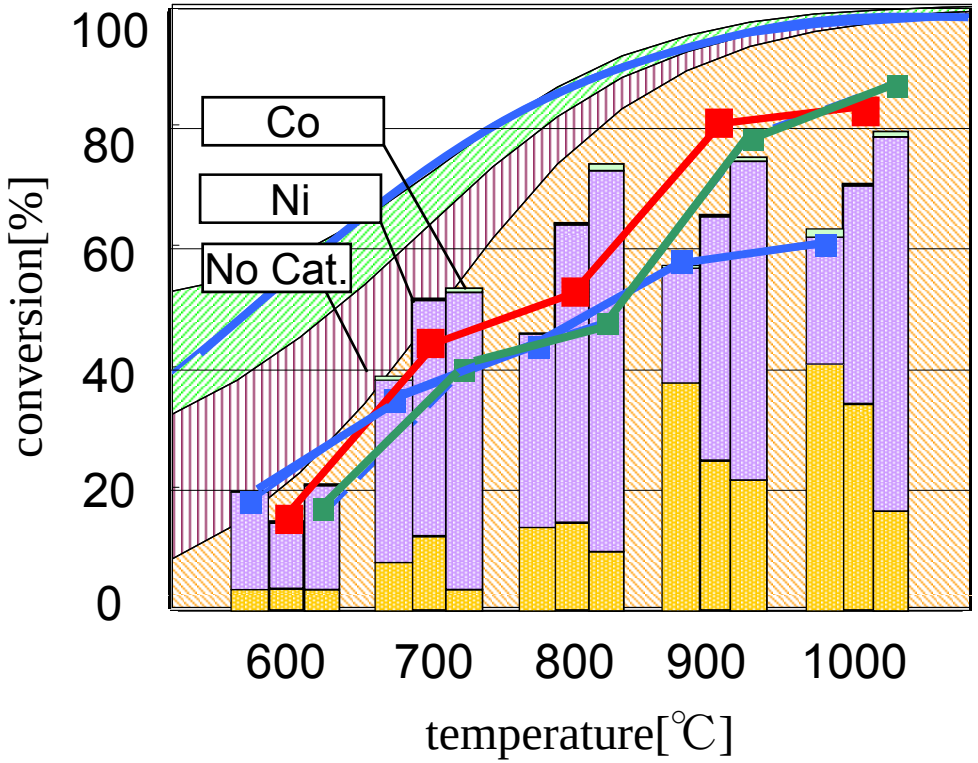


Thermochemical equilibrium



experiments





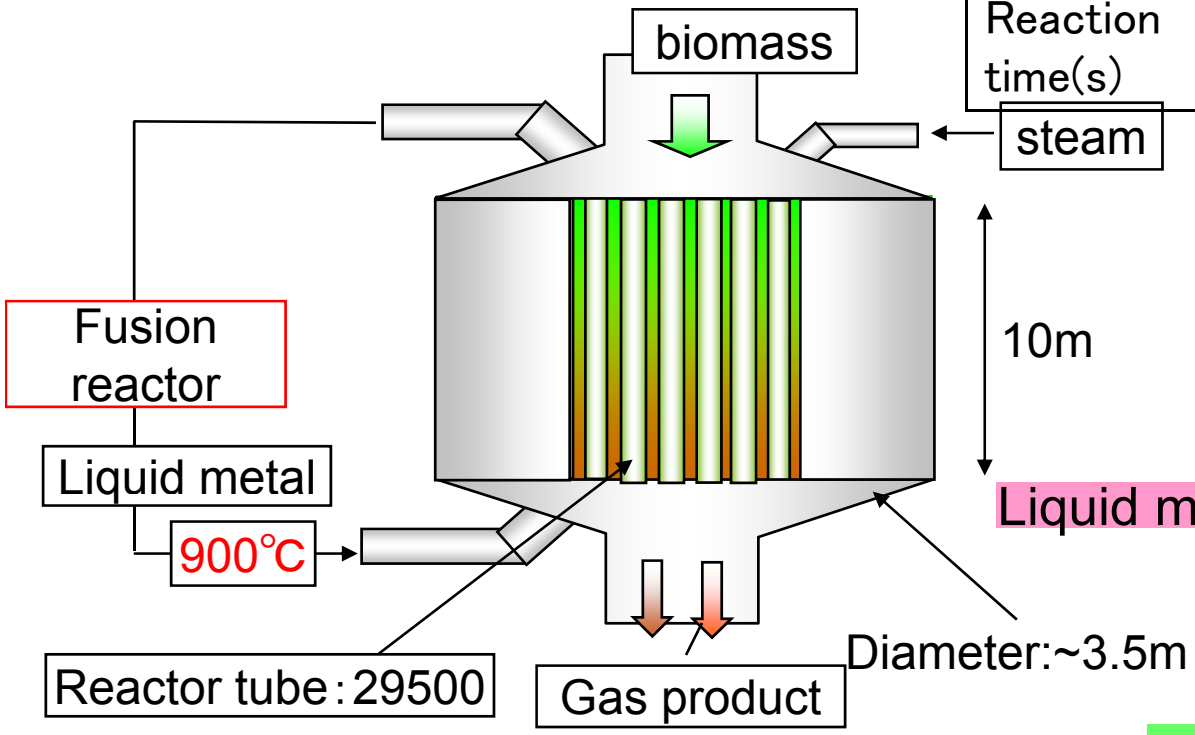
Ca,80% carbon was converted to C1 gases with Ni and Co.

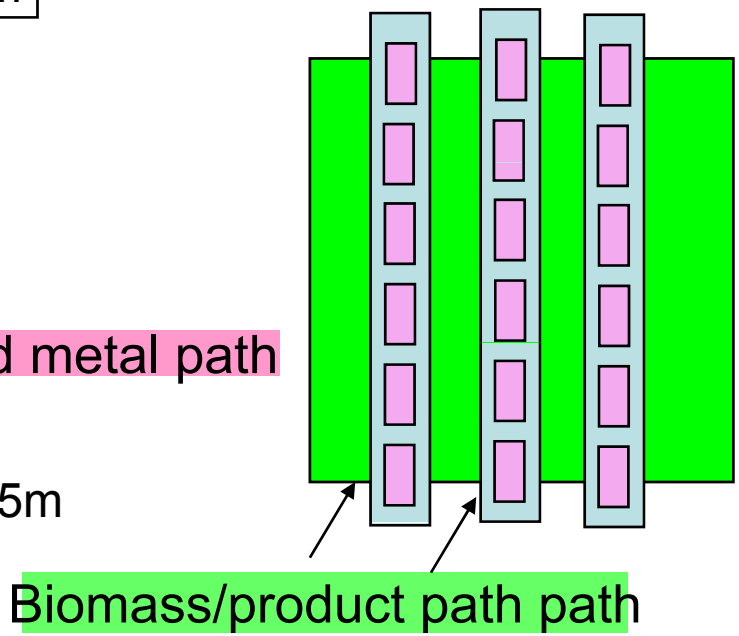
Concept of the reactor

Institute of Advanced Energy, Kyoto University

Assumed biamass:6Mton/year
(cellulose 70%,lignin 30%)

	cellulose	rignin
Reaction heat(kJ)	0.29	0.41
Reaction time(s)	60	60





Concept of the reactor

Fusion can produce Hydrogen

Institute of Advanced Energy, Kyoto University

Fusion generates hydrogen from biomass
free from heat cycle limit.

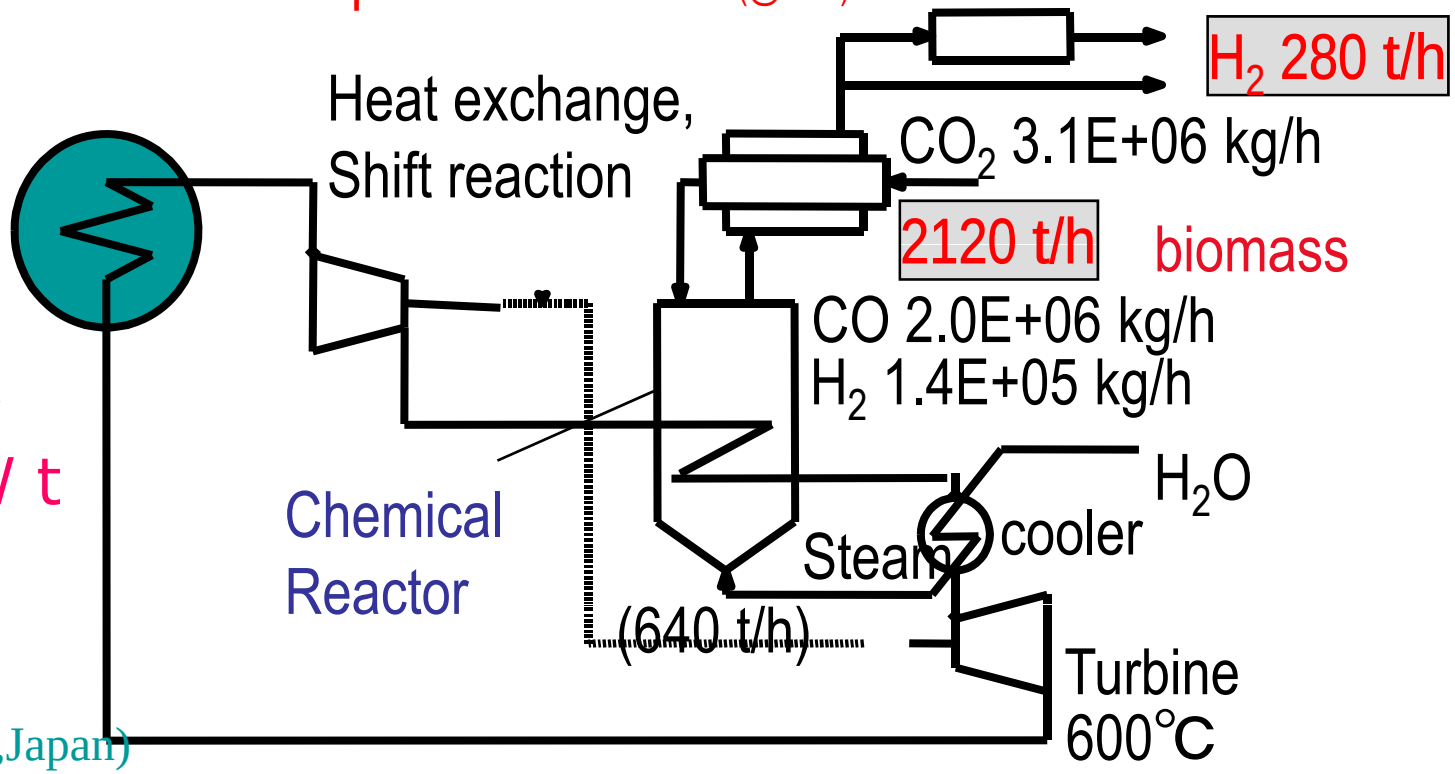
18.6Mt/y waste←60Mt/inJapan
Feeds 1.1M FCV /day or
17M FCV/year*

○Processing capacity

- 4240t／h biomass → 280t of H_2

○endothermic reaction converts both biomass and fusion into fuel.

- 2.5GWt → 5.1GWe equivalent with FC(@70%)



(*assuming 6kg/day
or 460g/year, MITI,Japan)

Fuel Production with Fusion

Institute of Advanced Energy, Kyoto University

Fusion Energy （Heat, 900℃）

biomass + H_2O → H_2、CO

endothermic

cellulose: $(C_6H_{10}O_5)_{n/6} + n/6H_2O \rightarrow nH_2 + nCO$ – 136n [kJ]

lignin: $(CH_{1.4}O_{0.3})n + 0.7nH_2O \rightarrow 1.4nH_2 + nCO$ –136n[kJ]

Shift Reaction $CO + H_2O \Leftrightarrow H_2 + CO_2 + 32$ [kJ] → Waste heat

hydrogen

Carbon Neutral

Fischer-Tropsch reaction

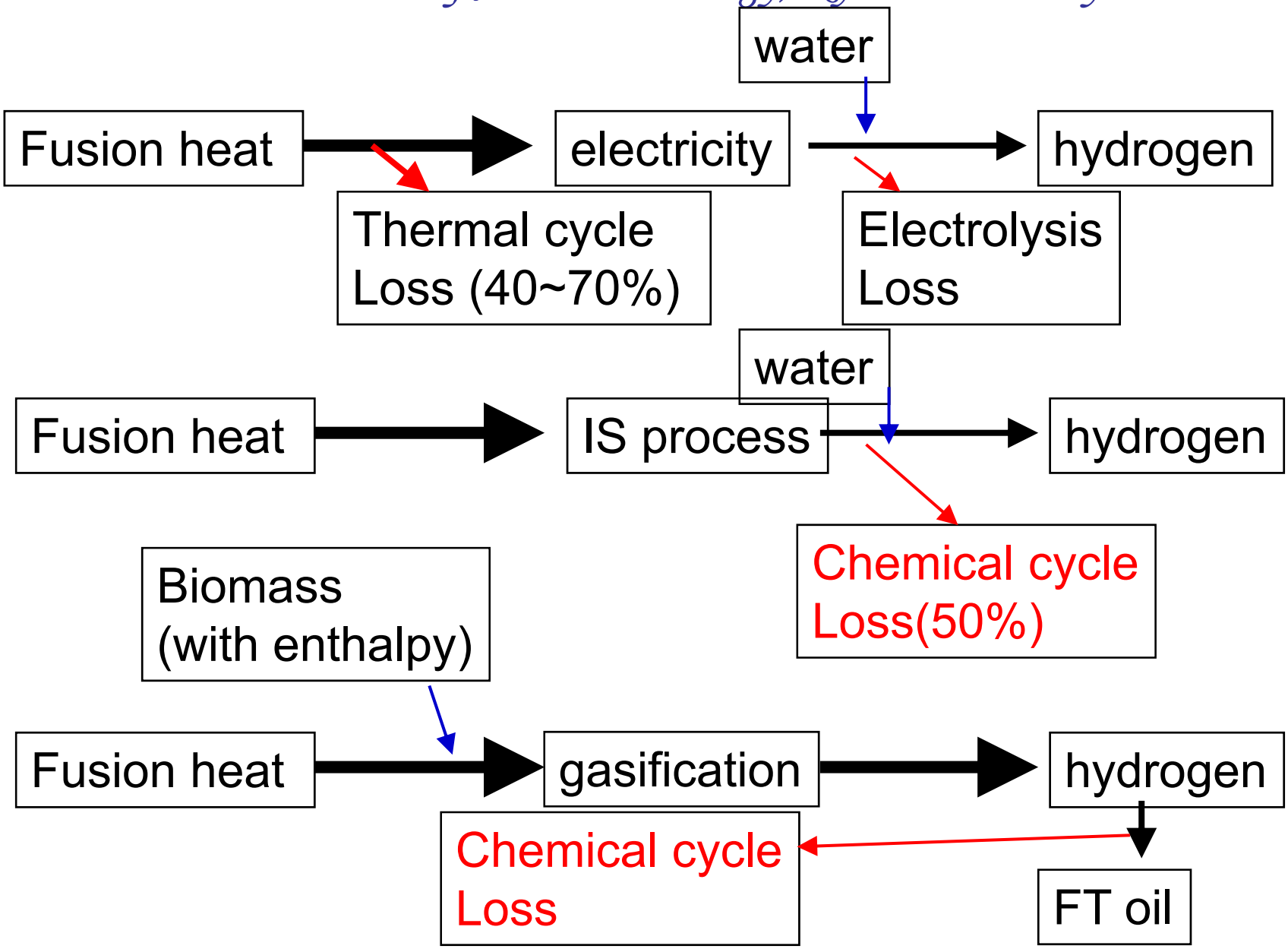
$2H_2 + CO \rightarrow -CH_2- + H_2O + 160$ [kJ]

Synthetic oil (Diesel)

Carbon Neutral fuel !

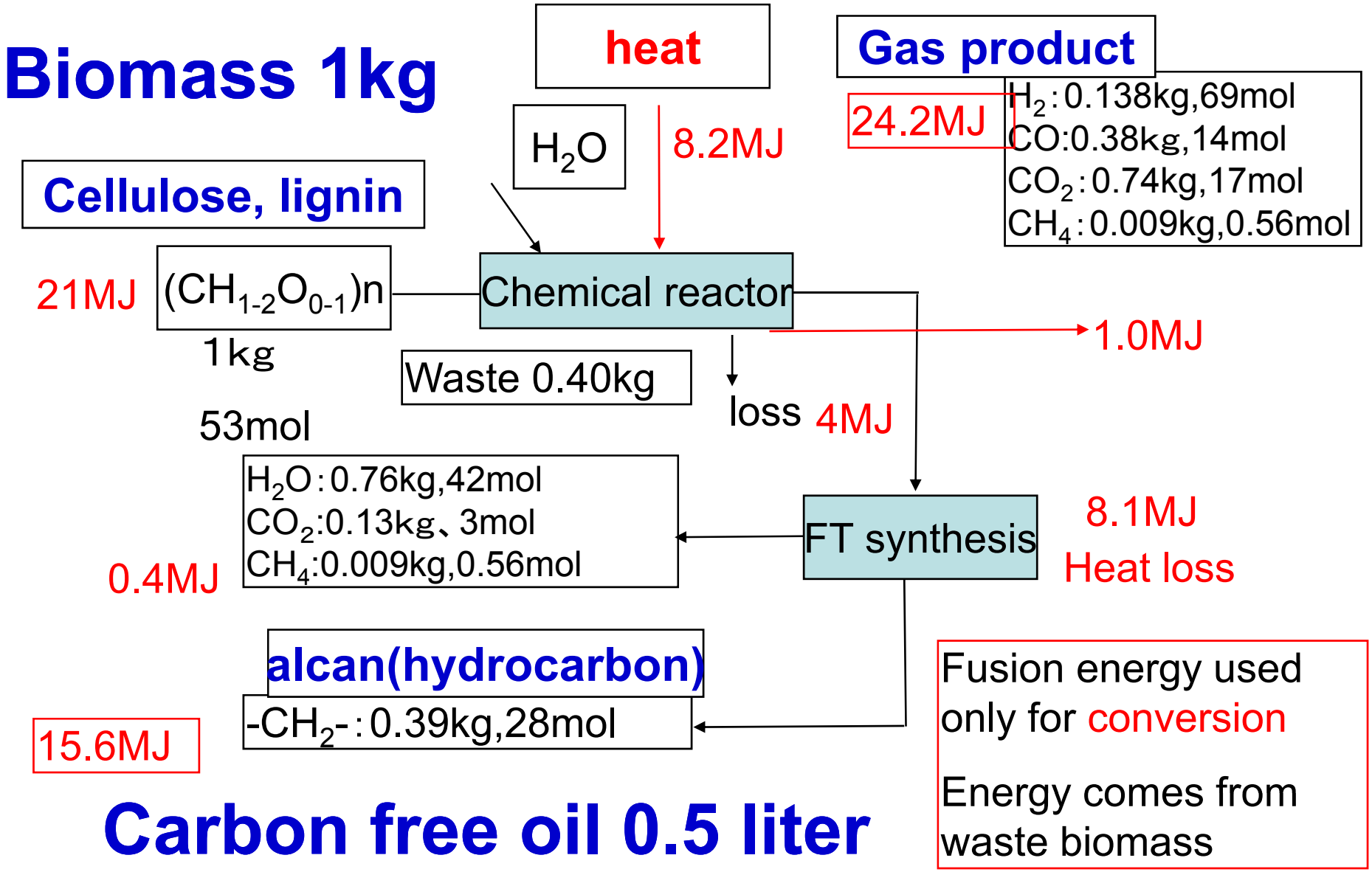
Energy Conversion efficiency

Institute of Advanced Energy, Kyoto University



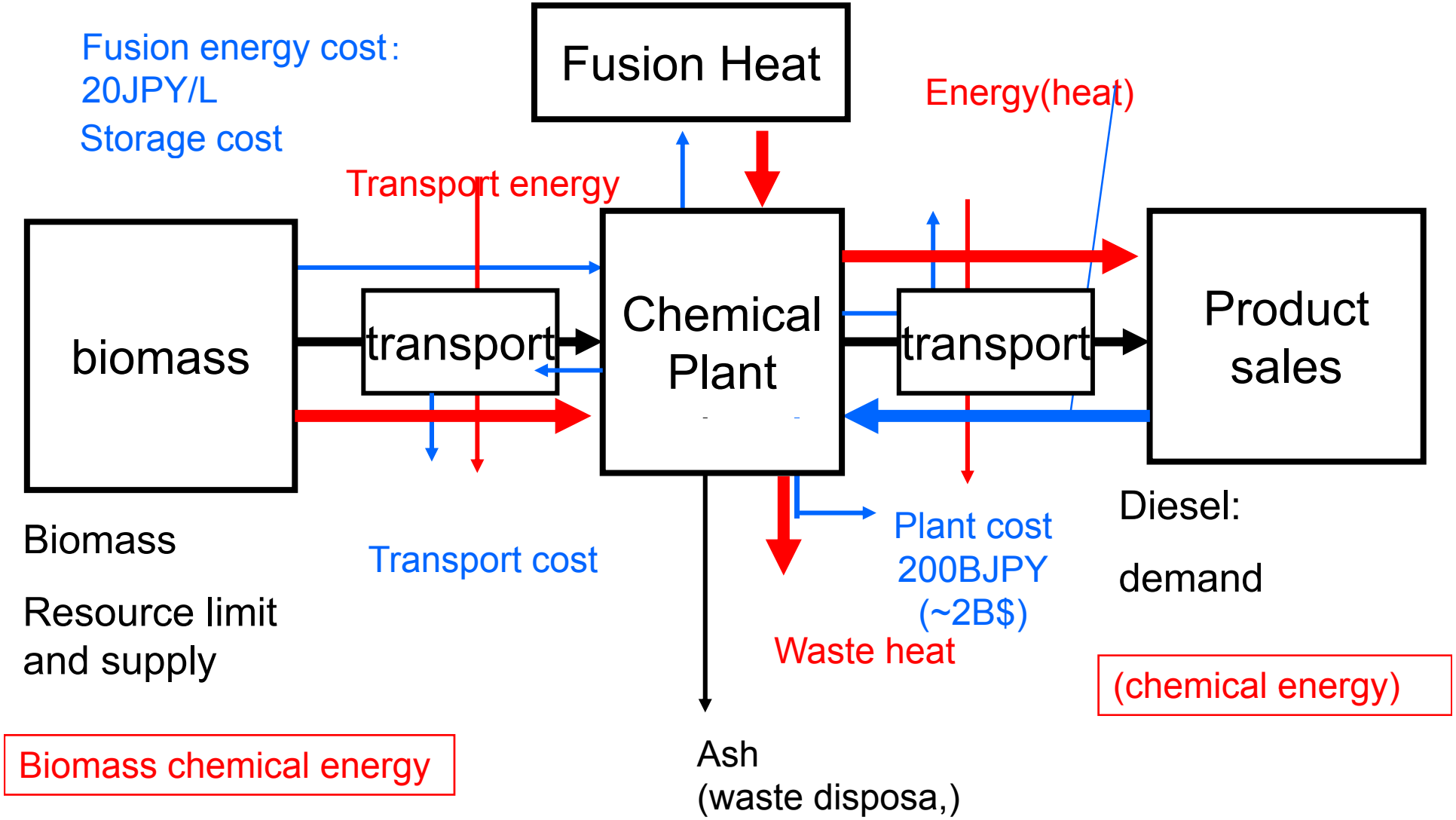
Energy use of biomass conversion

Institute of Advanced Energy, Kyoto University



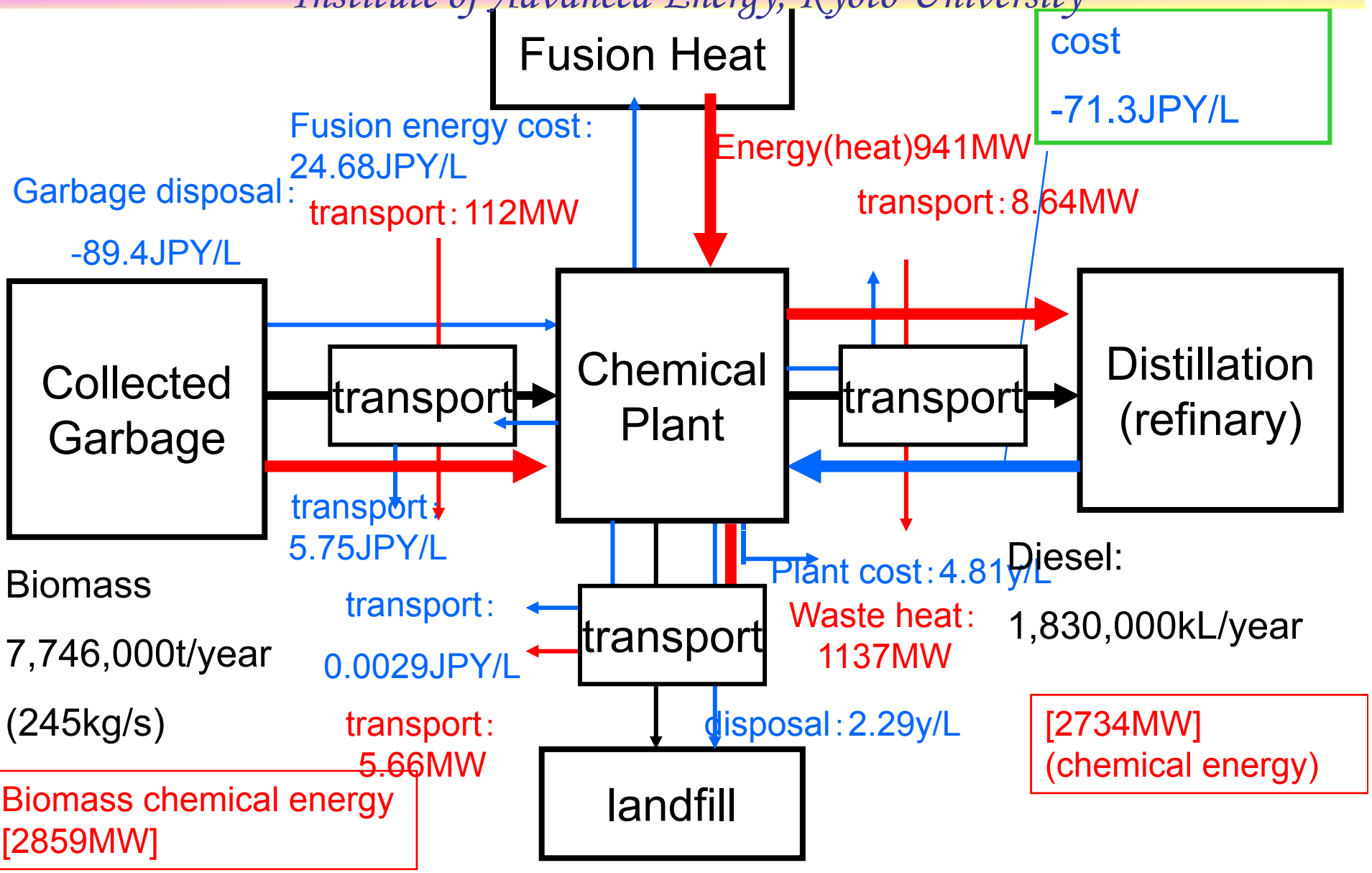
Supply chain constraint

Supply chain is more important for hybrid!



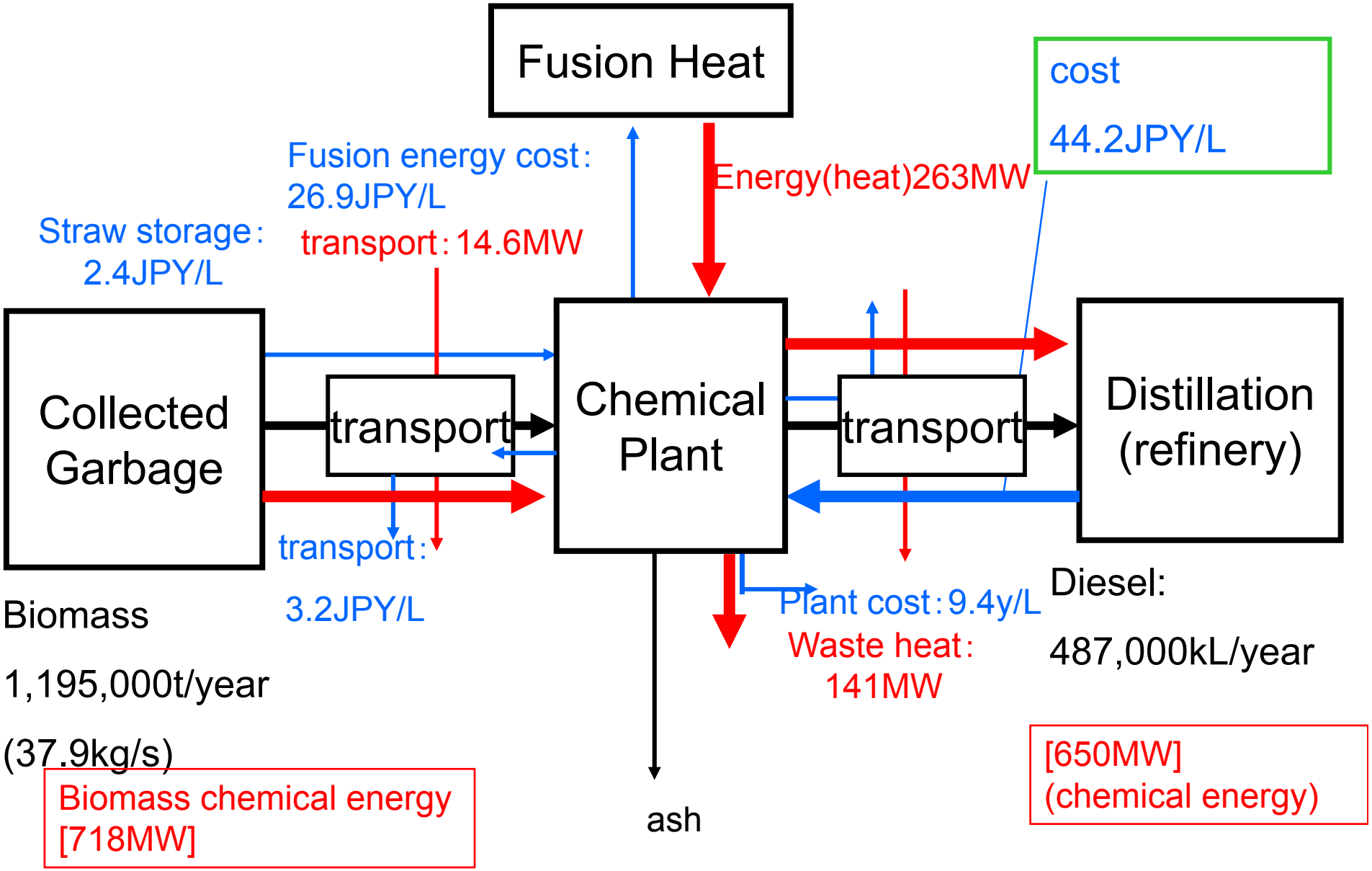
Case of Burnable Garbage

Institute of Advanced Energy, Kyoto University



Case of Agricultural Waste

Institute of Advanced Energy, Kyoto University



Case Study Summary

Institute of Advanced Energy, Kyoto University

	Garbage	Woody Biomass	Agriculture	Forestry
Cost(JPY/L)	-51.6	-42.66	44.16	50.1
Biomass production(t/year)	7,746,000	267,000	1,195,000	446,000
Diesel Product(kL/year)	2,045,000	114,000	487,000	191,000S
Required energy（MW)	941	61	263	101
Fusion energy efficiency	2.90	2.51	2.47	2.51
Total energy efficiency	0.70	0.64	0.65	0.63

・fusion energy efficiency＝product diesel chemical energy/fusion heat

・total energy efficiency＝ product diesel chemical energy/consumed energy

National Total

	garbage	agriculture	forestry	Woody waste
Waste total(t/year)	**38,067,000**	**14,650, 000**	**2,068, 000**	**1,497, 000**
Diesel production (kL/year)	**8,992, 000**	**4,819, 000**	**714, 000**	**517, 000**

Diesel total：**15,000,000kL/year**

	aircrafts	kerosene	diesel
Oil demand (kL/year)	**5,324,600**	**（24,382,000）**	**36,323,000**

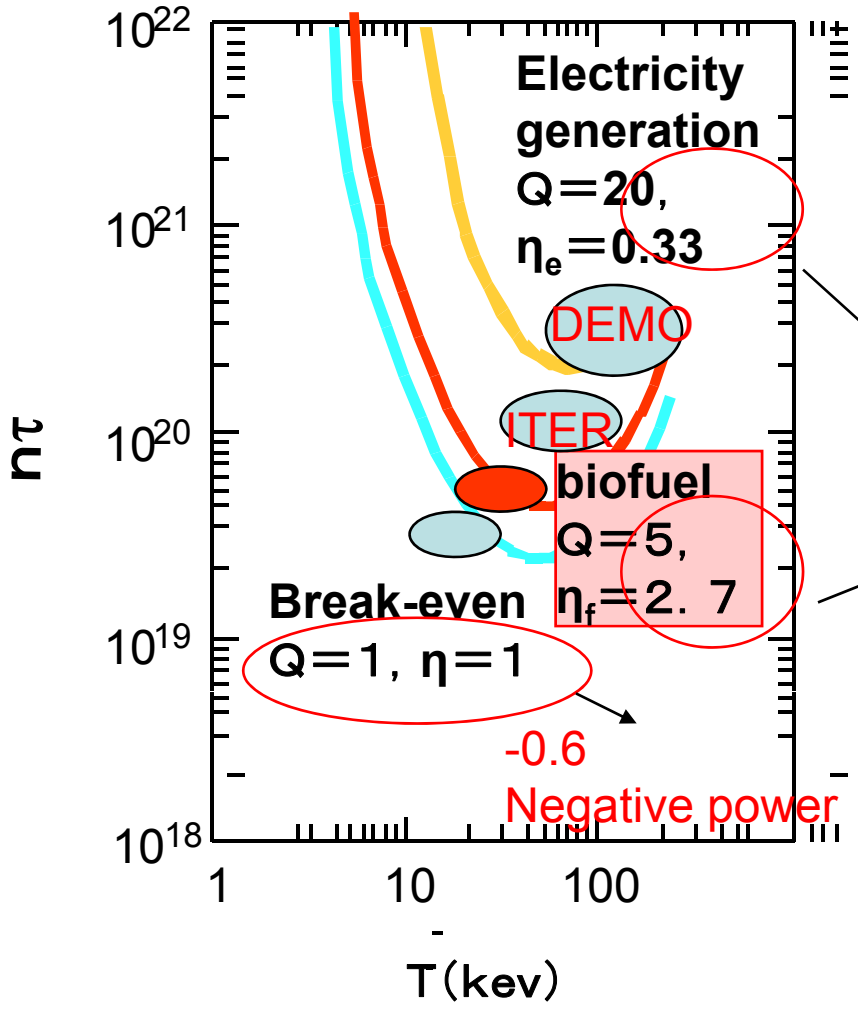
Transport demand：**42,000,000kL/year**

⇨ ・36% demand can be supplied

Replace fossil with carbon free fuel to recuce CO2 emission

Relaxed Lawson criterion and efficiency η

Institute of Advanced Energy, Kyoto University



(non-Nuclear Hybrid)

○High Plasma Q not required
- Positive plant energy balance
- larger energy efficiency

Net plant energy output

6 Practical energy generation

10 Larger than electricity

○Low Q plasma can be competitive
- possible marketing as oil fuel
- earlier introduction
- easier plasma requirements

○smaller plant→

Q＞5， R～4.5m scale？

Fusion –biomass non-nuclear hybrid

○Fusion plays minor, but inevitable contribution

- Serves as heat source for fuel production processes
- Fusion can improve in temperature by blanket development.
- There is few High temperature carbon-free heat
- Fusion has less limitation in resource, site, environment, and nuclear proliferation concern than fission.
  →suitable for deployment in developing countries.

○fuel application provides fusion a better chance.

- Eventually larger market than electricity
- Global demands for fuel and its supply capability.
- Fuel production does not require stable steady state.
- Blanket and energy plants can be developed independently.
- Possibly slower demand change than electricity.

Implication

○Fusion –biomass hybrid may demonstrate fusion energy earlier than pure fusion electricity.

- relaxed plasma requirement, such as low Q
- smaller reactor for smaller project cost and tritium need
- driven, possibly pulsed operation

- cost requirements for the product may be easier (eventually)

○small driven DEMO has a feature of component test facility

- development of in vessel components are major issue
- reliability and availability can gradually improve.
- staged development will be required for blanket and divertor
- energy production can be demonstrated in early operation.

Conclusion

- Fuel production from biomass at high temperature endothermic reaction is demonstrated at Kyoto University.

- Fuel production from fusion can respond to global environmental problem and energy market. with easier plasma requirement.

- Both experimental and design studies shows possible fuel production with high temperature blanket.

non-nuclear hybrid will give a good chance for technology maturity and better economy in CTF phase.

Fusion can respond to global environment and resource problem in the near future!