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

Biomass Hybrid Concept and Its High Temperature Blanket

Feb. 22, 2011
NIFS, Gifu, Japan

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Introduction

Background

Fusion energy MUST respond to immediate expectation for global environmental and energy problem.

Fusion technology is far from maturity as energy plant.

⇨ Fusion needs an ENGINEERING machine

- -to be immediately constructed with current technology
- -to be possible to show the net energy output by fusion

Objectives

to propose a possible next step option
to be immediately start,
to be justified as an option in carbon-free energy systems, and
to provide engineering maturity for fusion technology.

Expected Fusion Role (if possible)

Environmental

Not only carbon-free, but reduces carbon dioxide emission to replace fire powered stations is needed, not to compete with fission or renwerables.

Providing substute fuels are more important than electricity

Electricity systems

Renewables (solar, wind) will increase, and large stations are required to stabilize the grid.
Dispersed power (battery, fuel cells) will increase.
Large starting power and unit capacity are not welcome.

⇨ Fusion must find its time and place

Fuel Production Energy Balance

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Fusion Energy（Heat, 900℃）

8.2MJ

Biomass (1kg) + 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]

24.2MJ

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

Fischer-Tropsch reaction

hydrogen

Carbon Neutral

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

Waste /usable

Synthetic oil (Diesel)

15.6MJ

Substitute of OIL (0.5 litter)

Fusion Energy Balance

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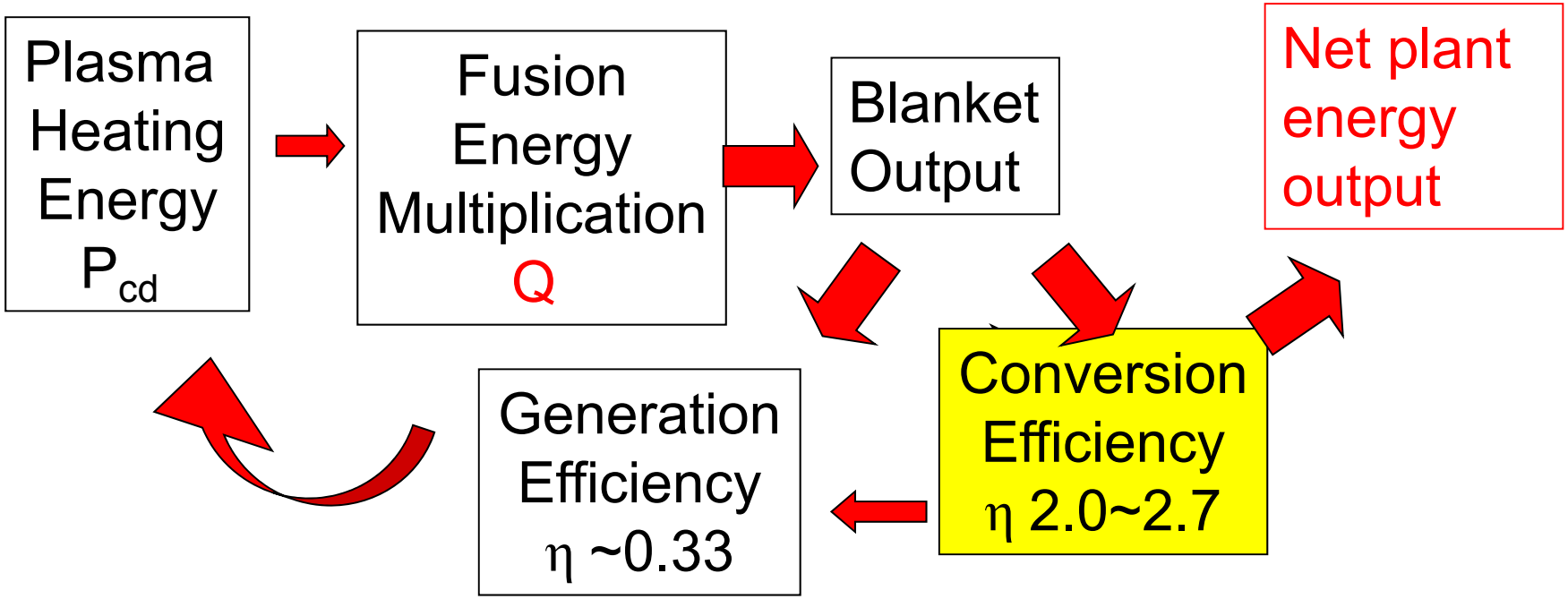

○Large Q (>20) needed for DEMO because of poor generation efficiency.

○If fusion plant is used for fuel production, only a fraction is regarded to be converted to electricity for plasma heating.

Energy Conversion efficiency

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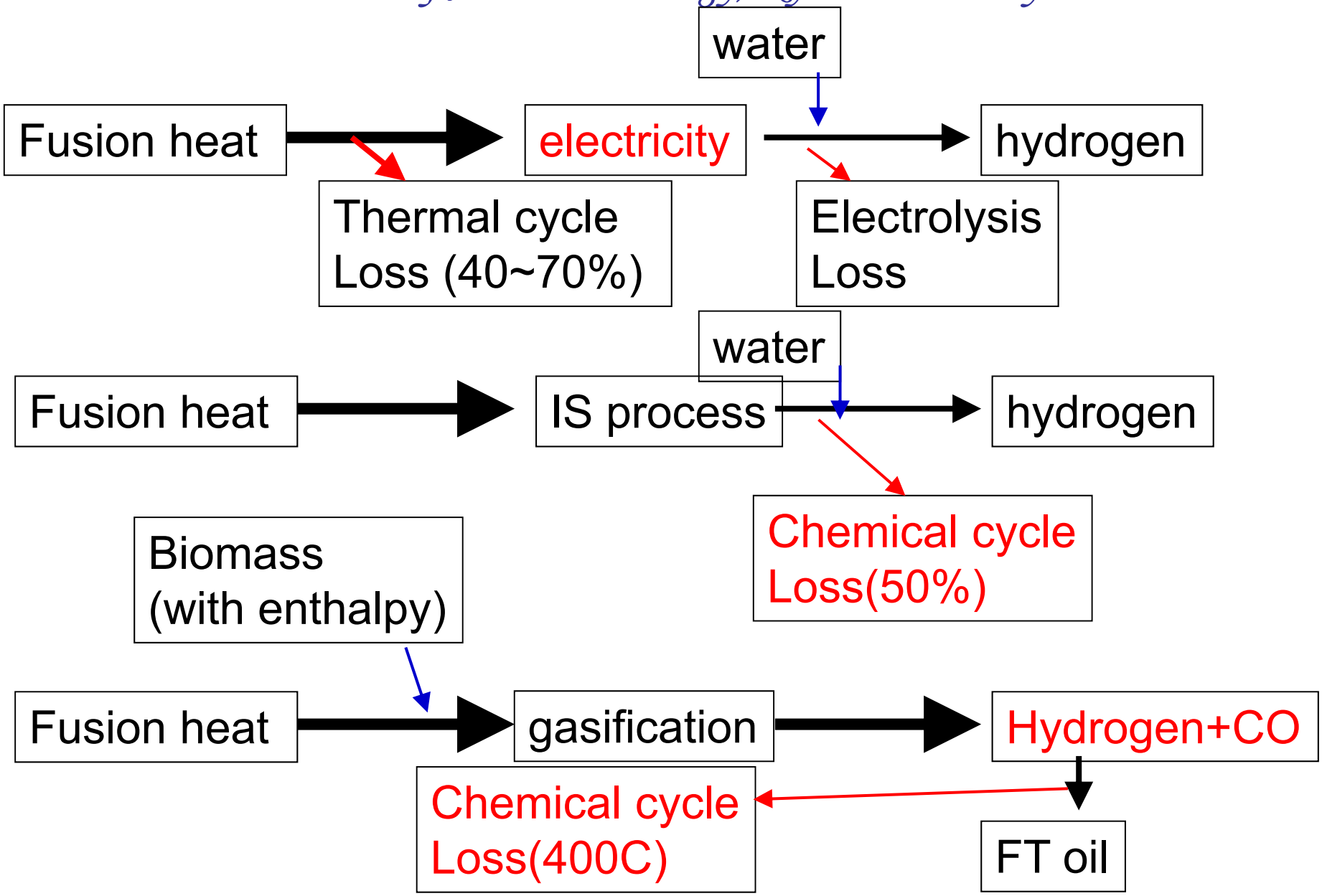

Biomass Hybrid Concept

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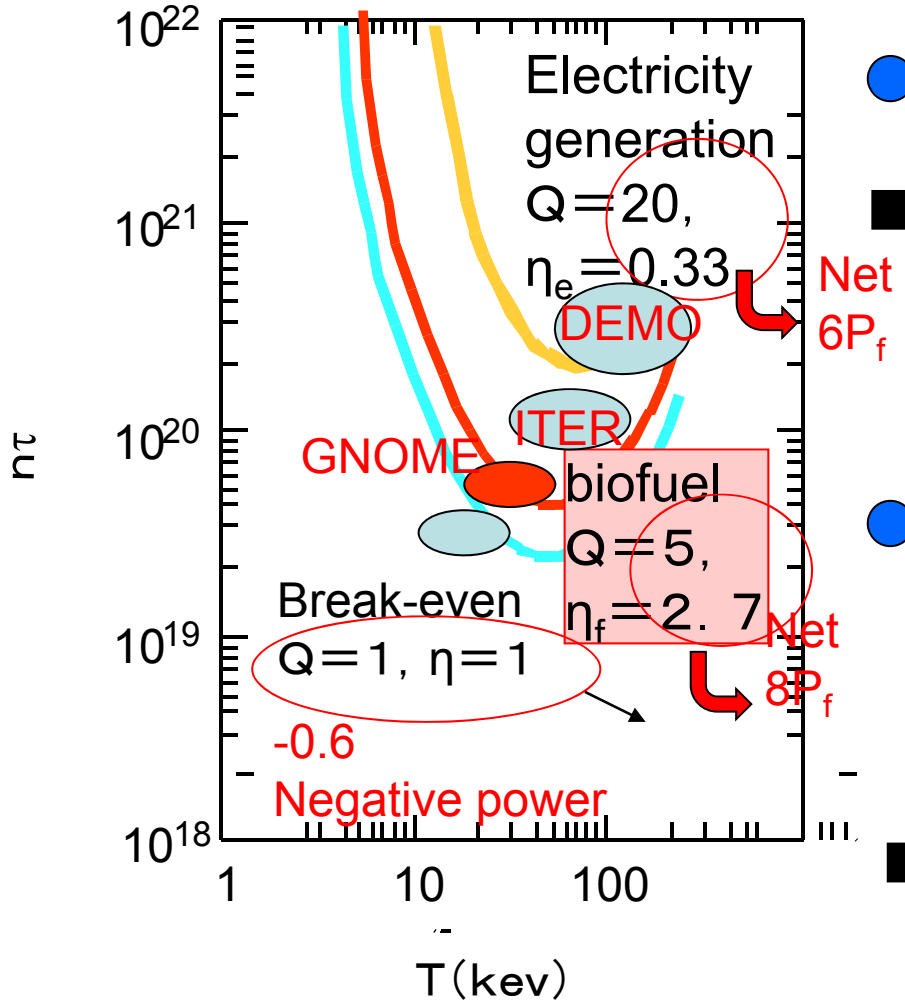

- High Plasma Q not required

➡ **Driven and pulsed operation is acceptable**

- High output temperature is required for gasification efficiency is required

➡ High temperature blanket To be developed.

Blanket for Biomass process

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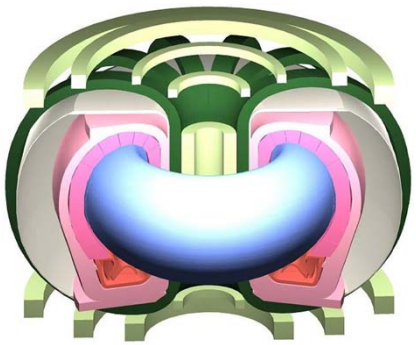
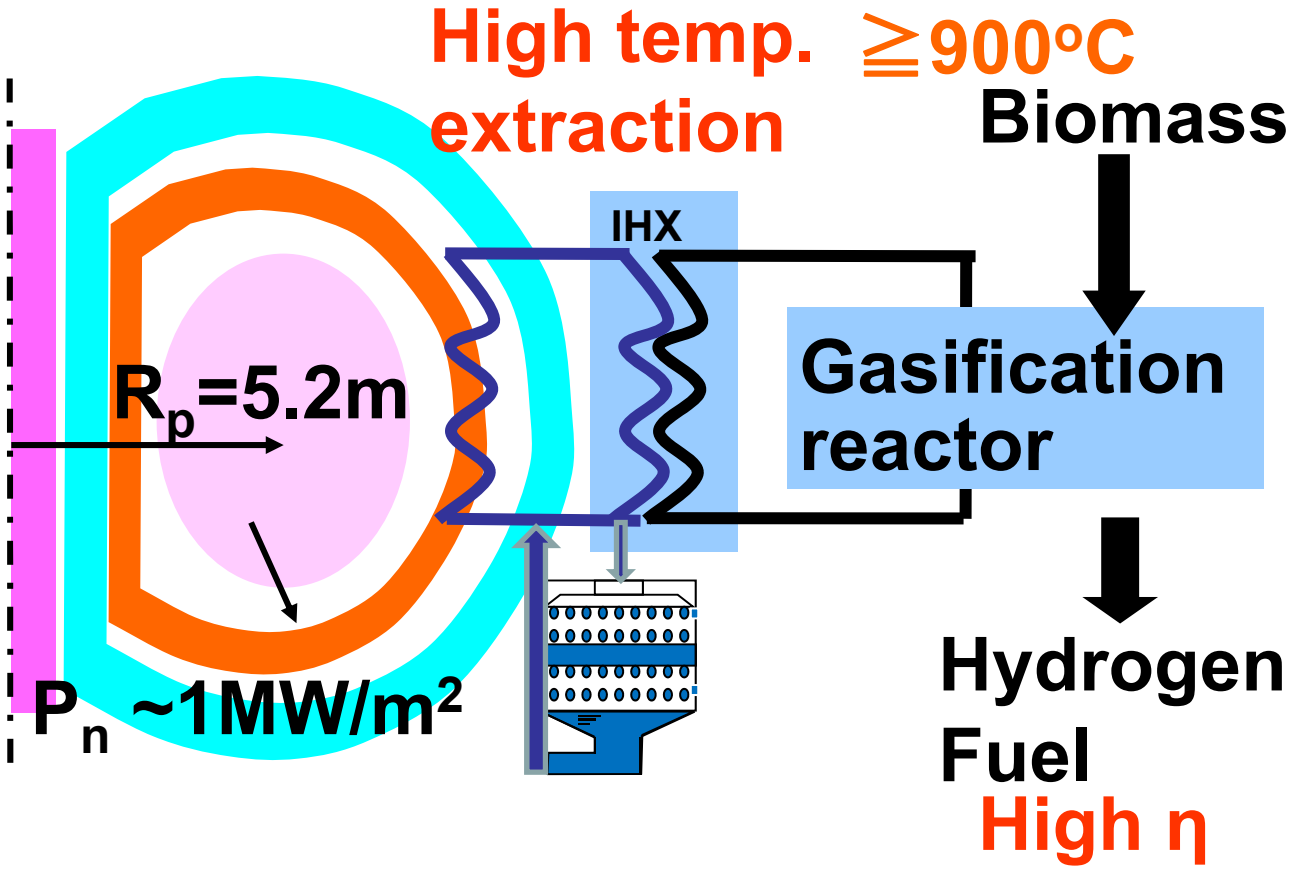
Fusion-biomass hybrid reactor for fuel production

Small

- Major radius
- Neutron wall load





Pb-17Li blanket with SiC cooling panel

Tokamak Parameters

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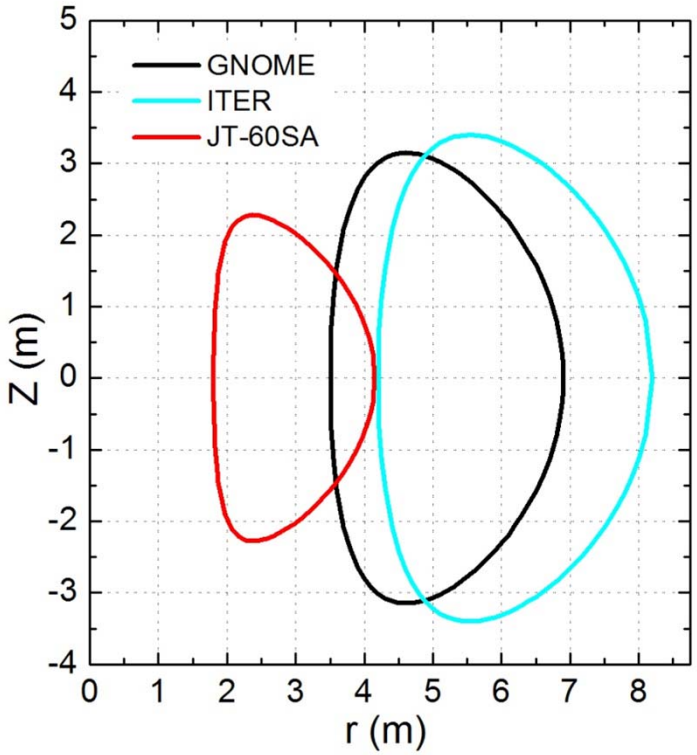
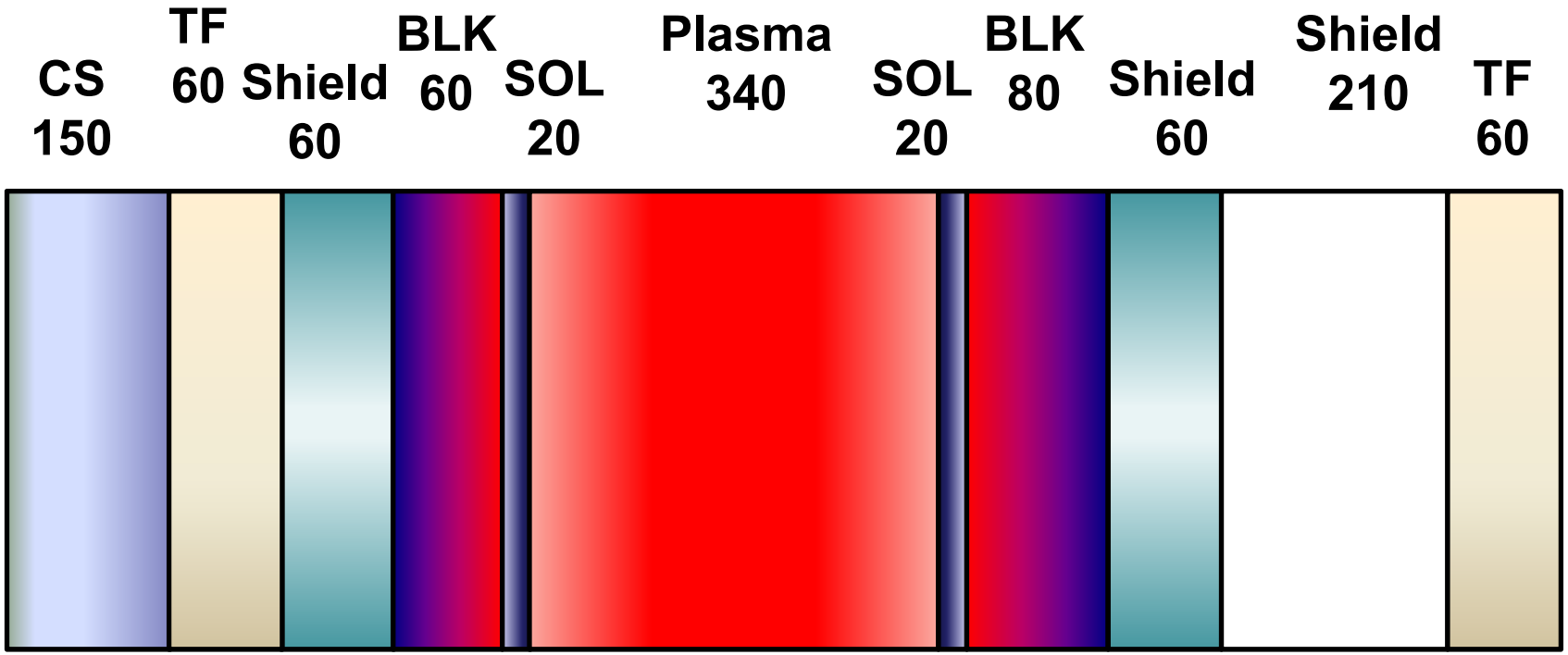
		ITER	GNOME
Major radius	R_p	6.2 m	5.2 m
Minor radius	a_p	2 m	1.7 m
Aspect ratio	A	3.1	3.1
Plasma volume	V_p	837 m^3	547 m^3
Plasma current	I_p	15 MA	10.4 MA
Toroidal field	B_t	5.3 T	4.4 T
Electron temperature	$\langle T_e \rangle$	8.9 keV	13 keV
confinement	HH_{y2}	(1.0)	1.4
Normalized beta	β_N	(1.5)	3.1
Greenwald density	f_{GW}	(0.7)	0.54
Fusion power	P_{fus}	500 (250) MW	324 MW
Current drive	P_{CD}	73 (20) MW	61 MW
Neutron flux	P_n	0.57 MW/m^2	0.48



Radial build



Neutron flux average 0.7 MW/m^2 (max 1.4 MW/m^2)

Neutron fluence (< 0.1MeV) to the CS reaches 1×10^{22} n/m^2 a reaches in 40 years

No vacuum vessel. Cryostat is regarded as boundary.

Blanket Structure

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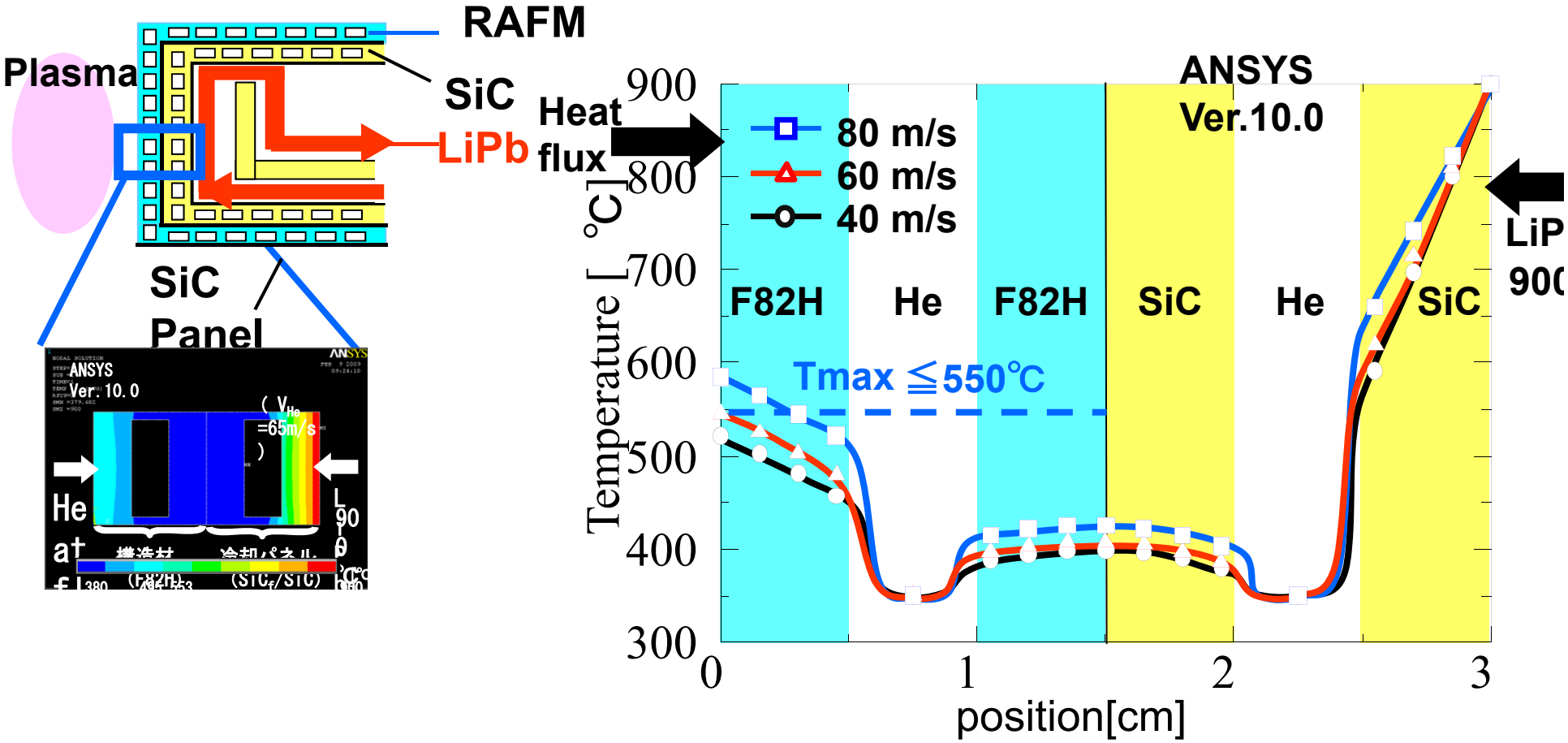

LiPb-RAFM blanket with SiC cooling panel

- Actively cooled SiC panel to control heat transfer
- isolate outer RAFM vessel structure
- obtain high temperature LiPb for heat

SiC/SiC cooling panel

Blanket parameters	
Heat flux to the FW	0.2 MW/m^2
Neutron flux from the plasma	0.5 MW/m^2
Boundary temperature at the LiPb/SiC interface	1000 ^oC
He temperature at F82H channel	350 ^oC
He temperature at SiC channel	850 ^oC
Heat transfer coefficient of He coolant at F82H channel	10000 $W\ m^{-2}\ K^{-1}$
Heat transfer coefficient of He coolant at SiC channel	7000 $W\ m^{-2}\ K^{-1}$
Thermal conductivity of F82H	33.3 $W\ m^{-1}\ K^{-1}$
Thermal conductivity of SiC	20 $W\ m^{-1}\ K^{-1}$

SiC cooling panel

- Actively cooled SiC panel to control heat transfer
- isolate outer RAFM vessel structure
- obtain high temperature LiPb for heat

Fabrication R&D for SiC cooling panels

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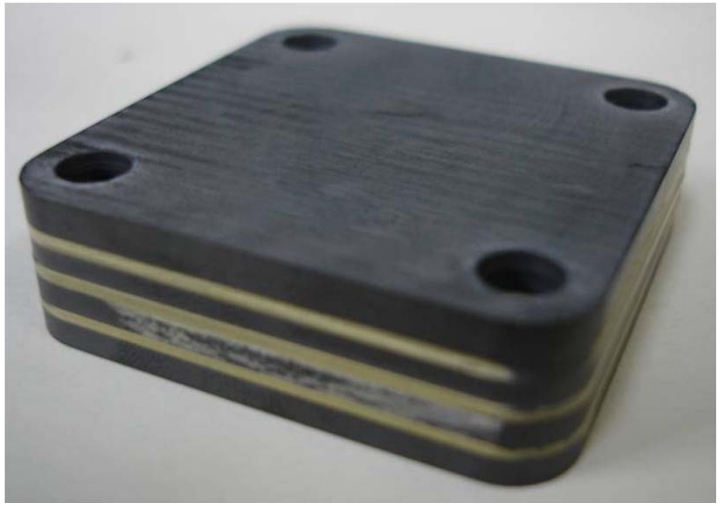

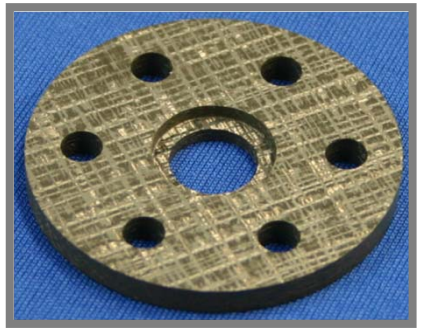

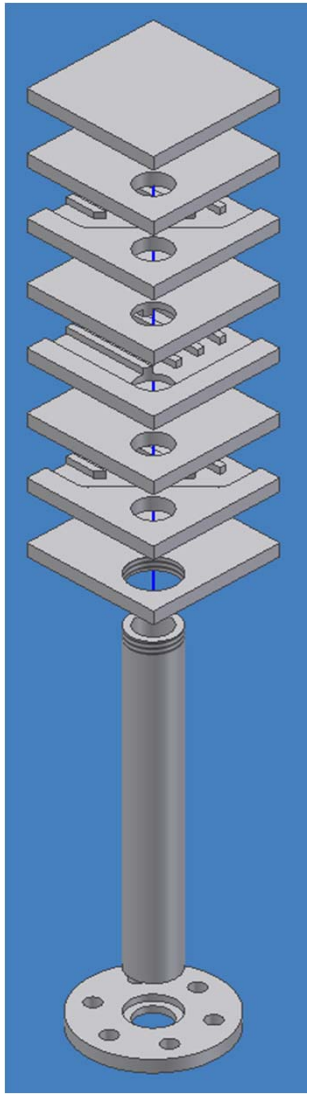

LiPb circulated >900°C

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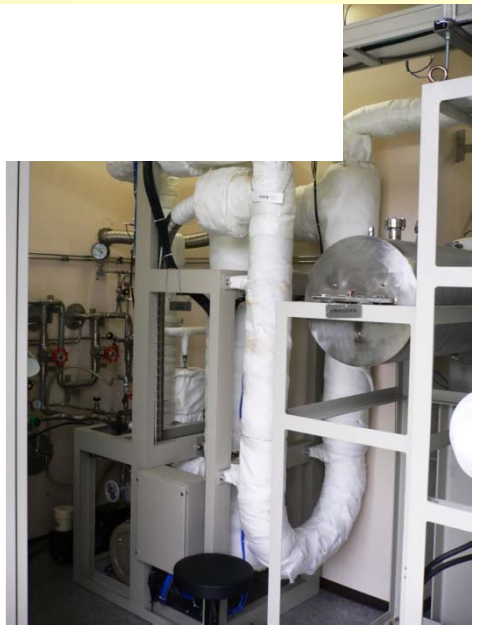
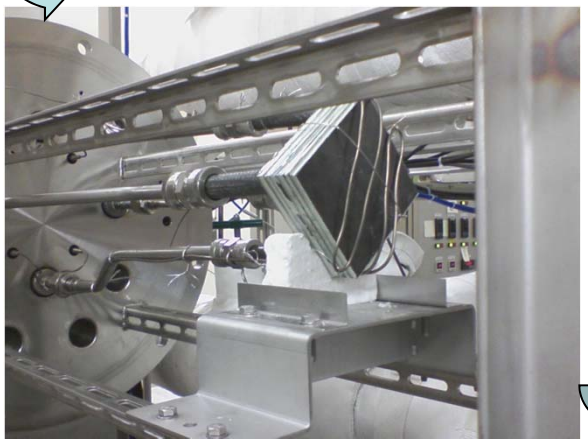
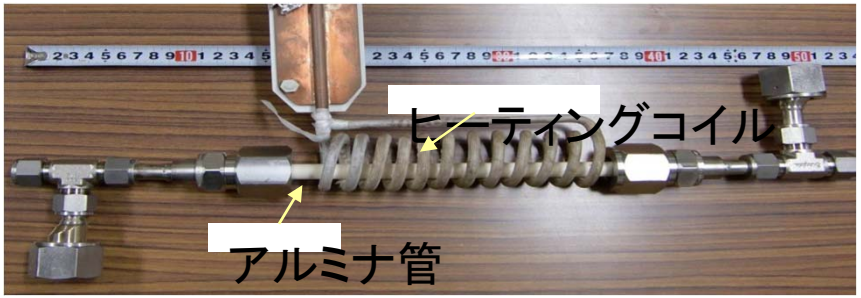
Loop operated >900 ° C
Only in the test vessel

SiC module







IHX heat transfer from LiPb to He

Installed in 900 ° C vessel

LiPb/He dual coolant loop

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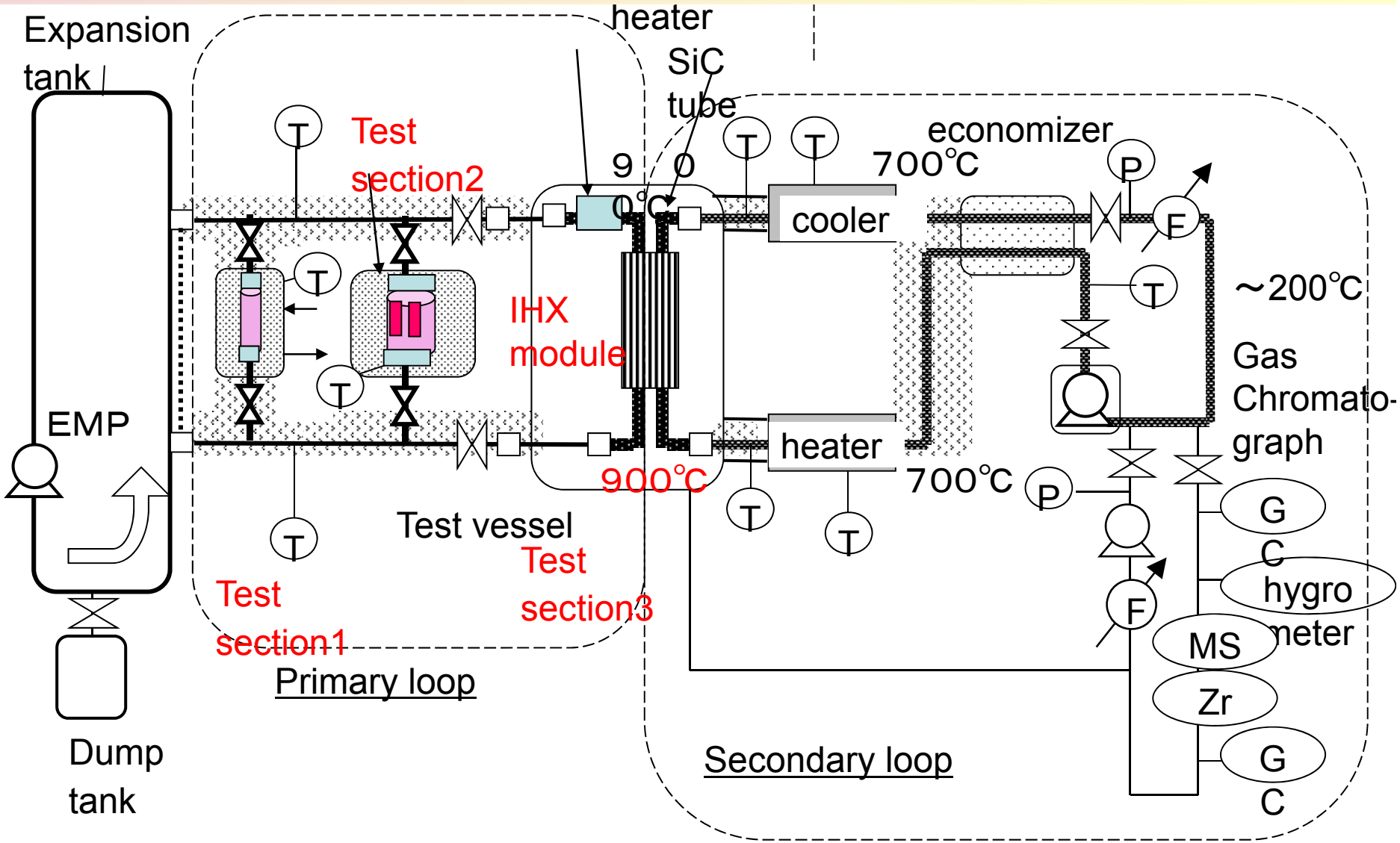

Heat transfer in SiC/LiPb module

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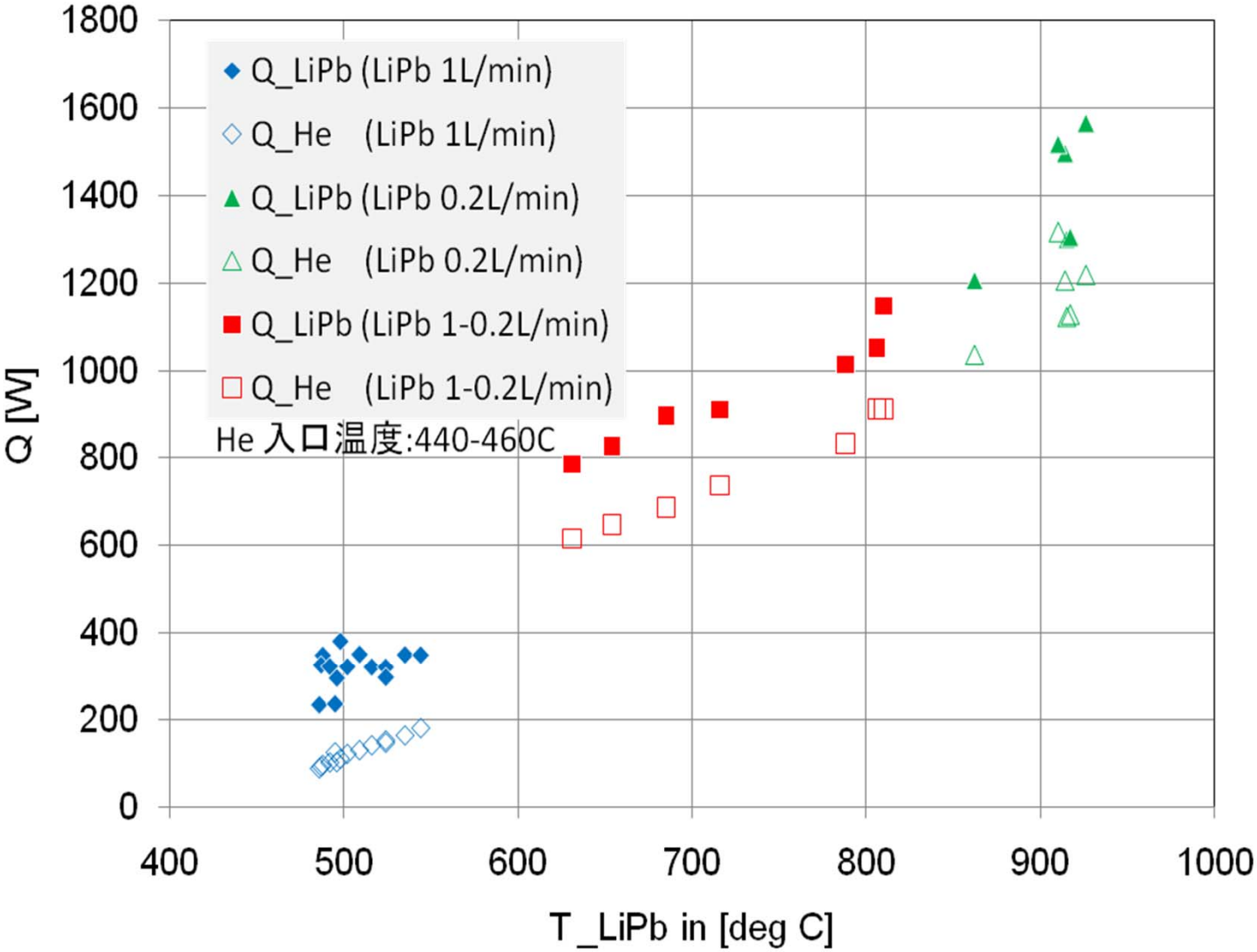

Concept of the biomass reactor

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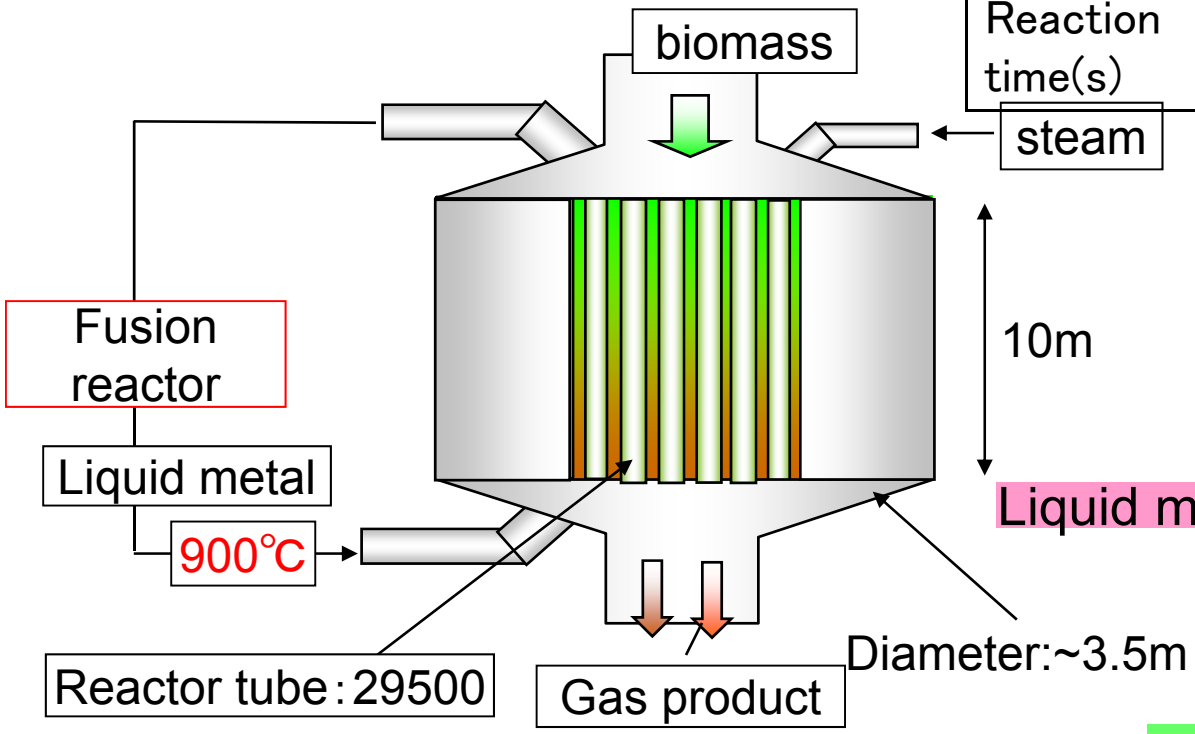
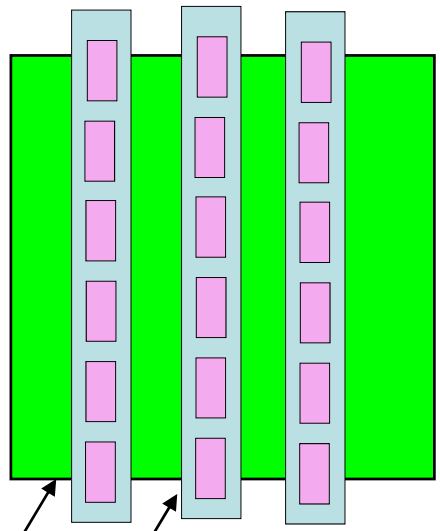
Assumed biamass:6Mton/year
(cellulose 70%,lignin 30%)

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



Concept of the reactor



Biomass/product path path

Hybrid Fusion power plant

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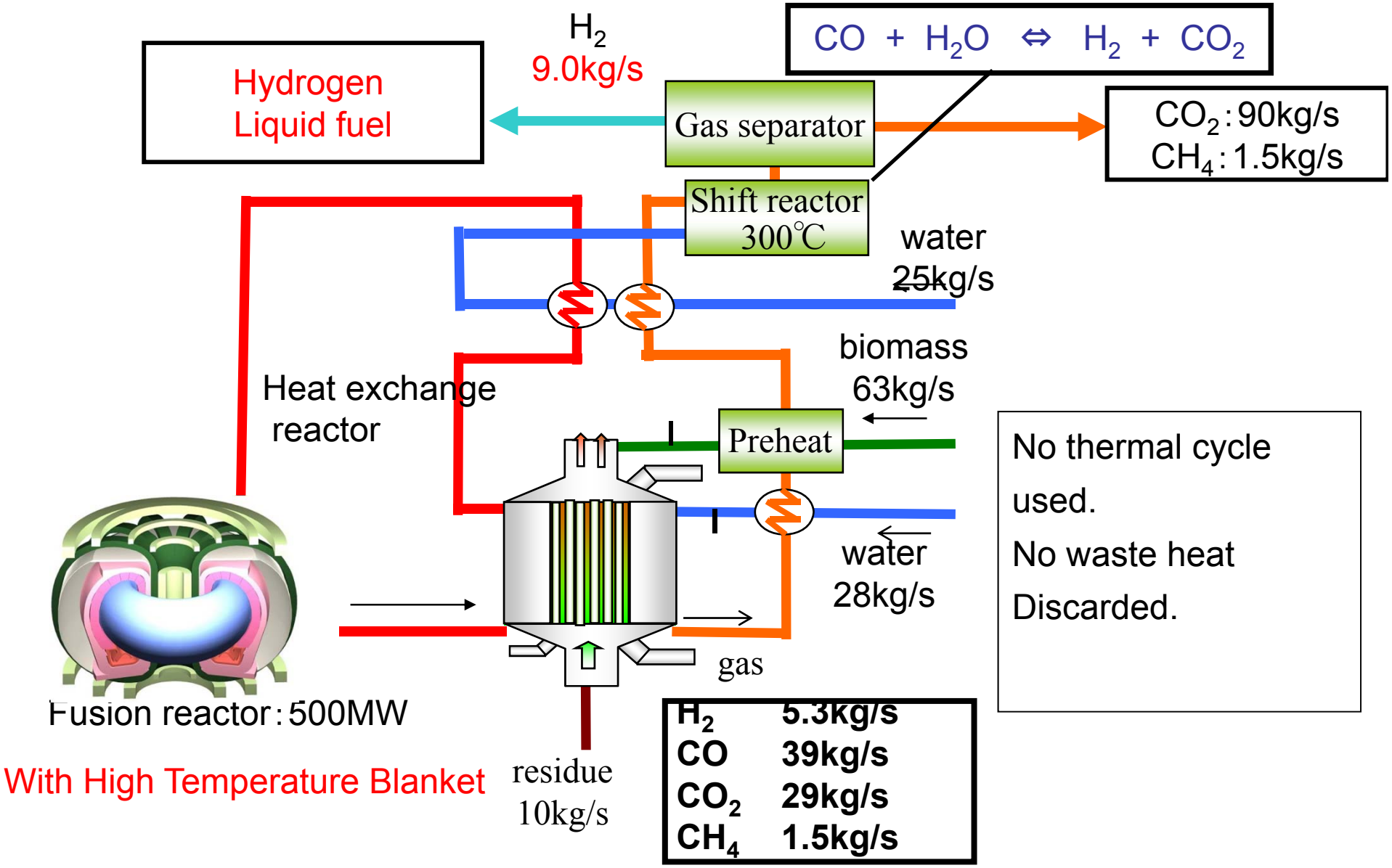

Gasification of Cellulose

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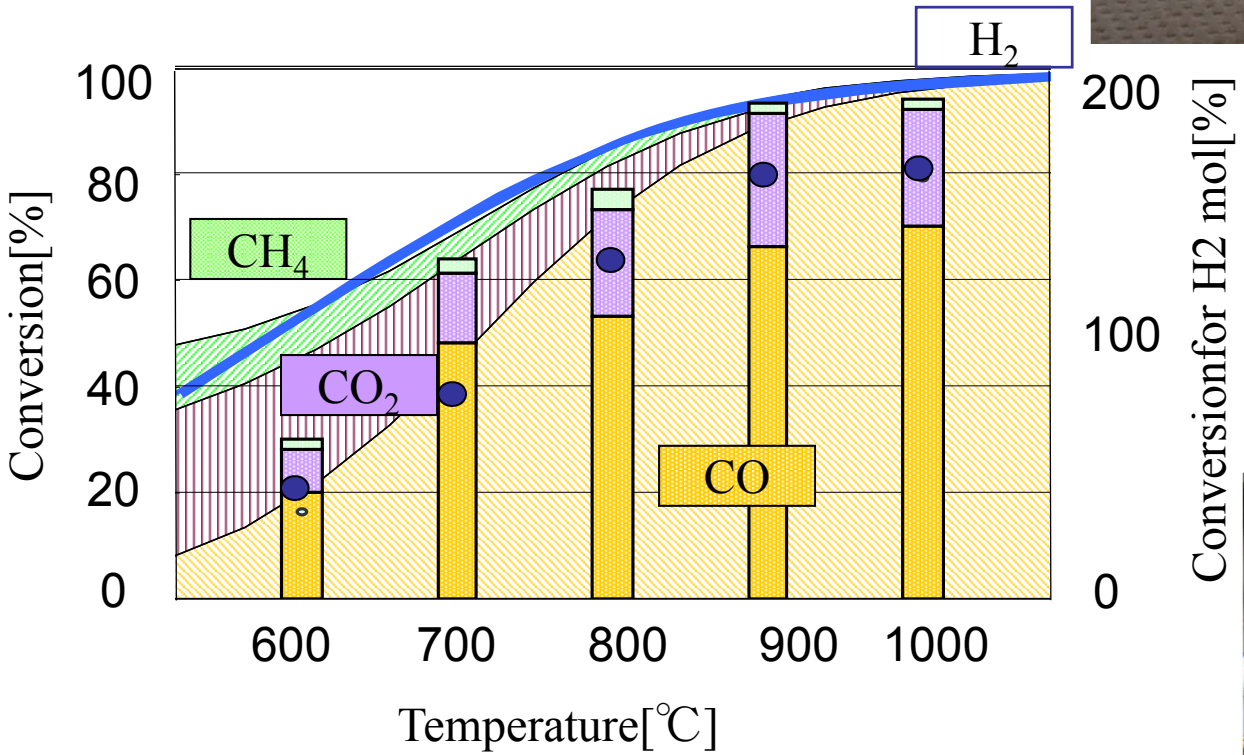
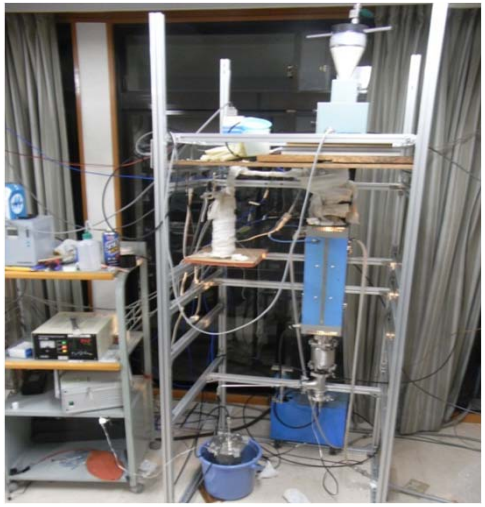
>95% carbon was converted to C1 gases and H2.

This conversion efficiency is practical level.





High temperature blanket is being developed .
(However, pressure and steady-state requirements are not.)

Tritium Balance in plant

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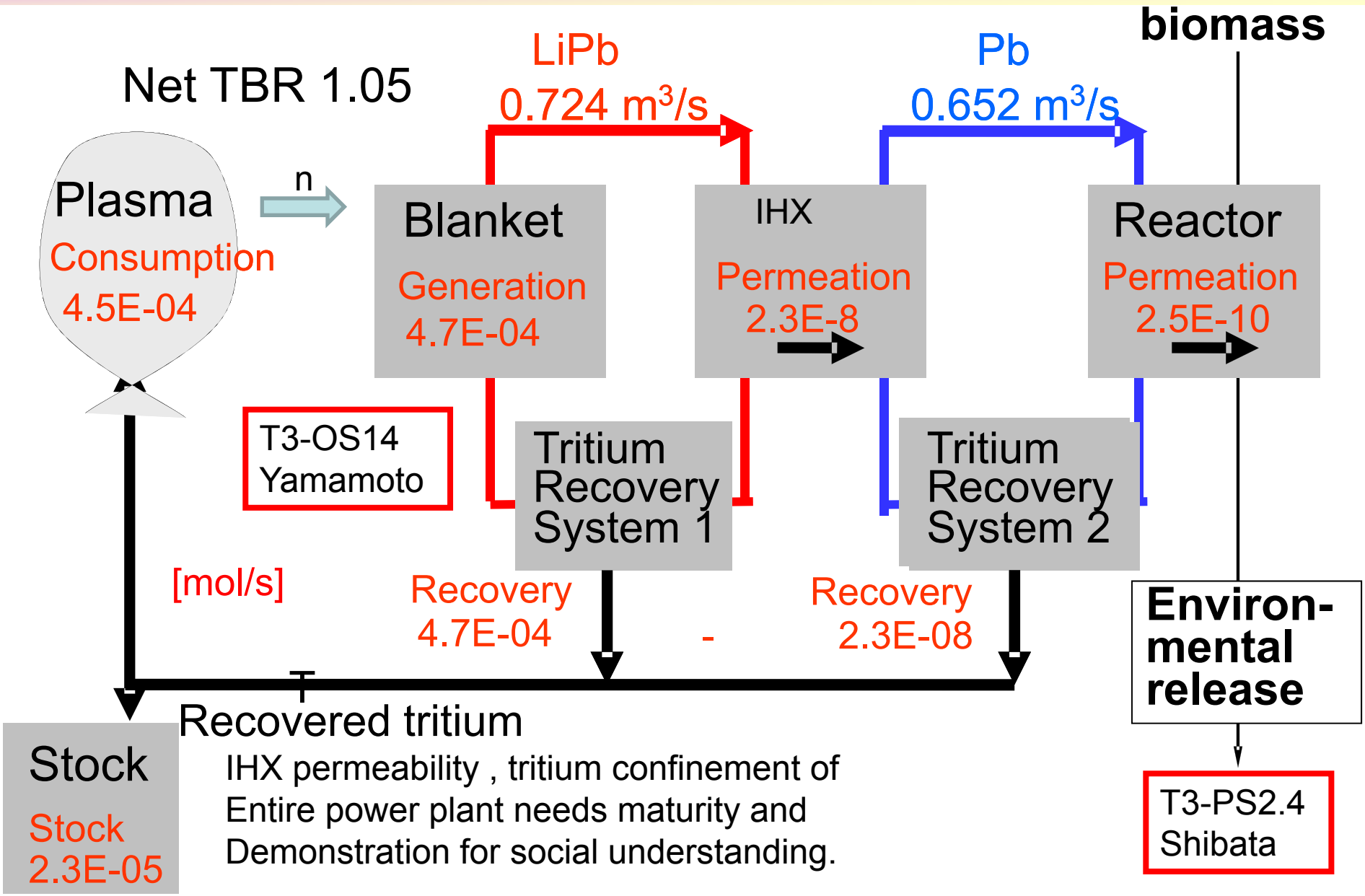

IHX permeability , tritium confinement of
Entire power plant needs maturity and
Demonstration for social understanding.

Tritium Recovery Process

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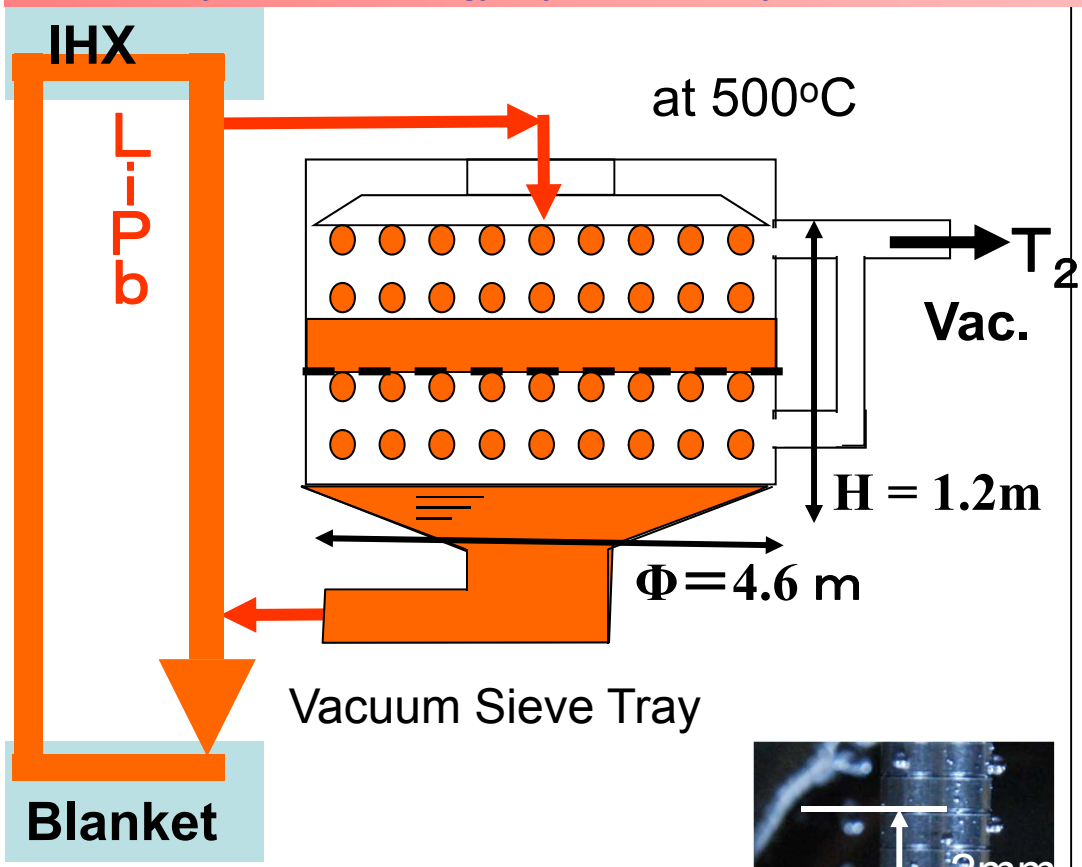
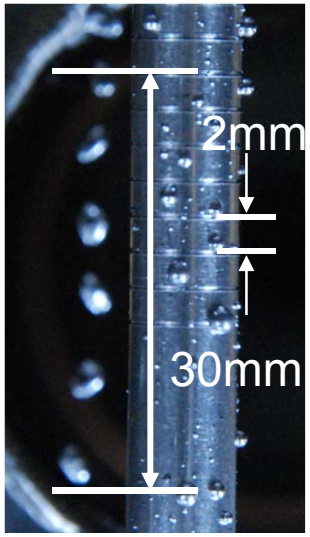


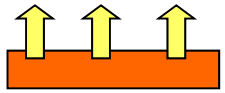


reruirement

- Inventory control
- Tritium in hydrogen product

Φ=4mm

$$\frac{M_t}{M_\infty} = 1 - \sum_{n=1} \frac{6}{n^2 \pi^2} \exp\left[-\frac{n^2 \pi^2 D}{r^2} t\right]$$



depth=√D

$$\frac{M_t}{M_\infty} = 1 - \sum_{j=0}^{\infty} \frac{8}{(2j+1)^2 \pi^2} \exp\left[-\frac{(2j+1)^2 \pi^2 D}{4 l^2} t\right]$$

→ **Recovery ratio 45%**

$M(t)$ [mol] : gas release

M_∞ [mol] : dissolved tas

D [$m^2\ s^{-1}$] : diffusion coefficient

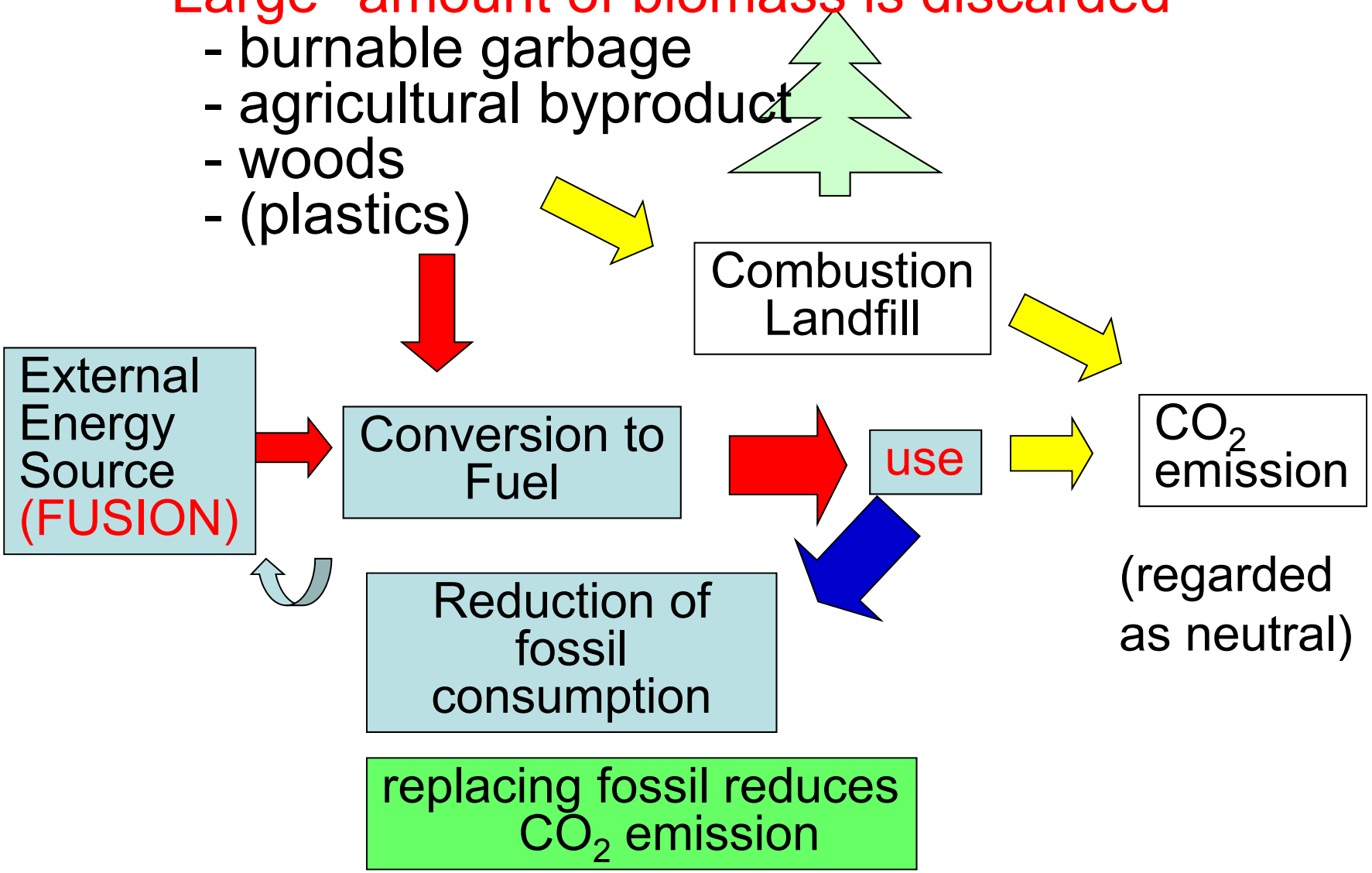
t [s] : time

r_0 [m] : radius of the droplet

l [m] : depth

Fusion-biomass hybrid as carbon recycle

Large amount of biomass is discarded
- burnable garbage
- agricultural byproduct
- woods
- (plastics)



Tritium Recovery Process

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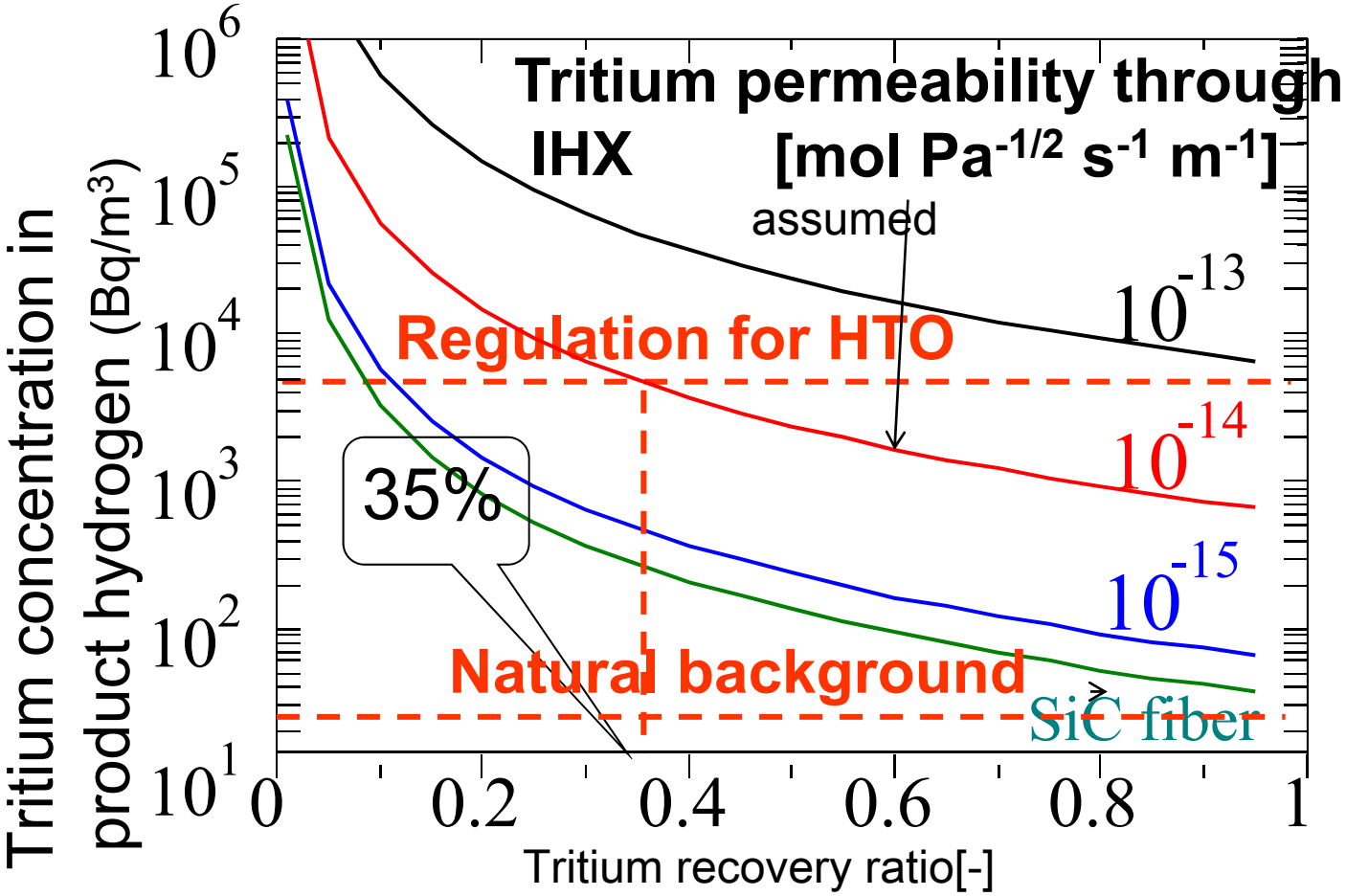


-Recovery ratio determined from the contamination of product.

-Requirement is a function of permeability through IHX

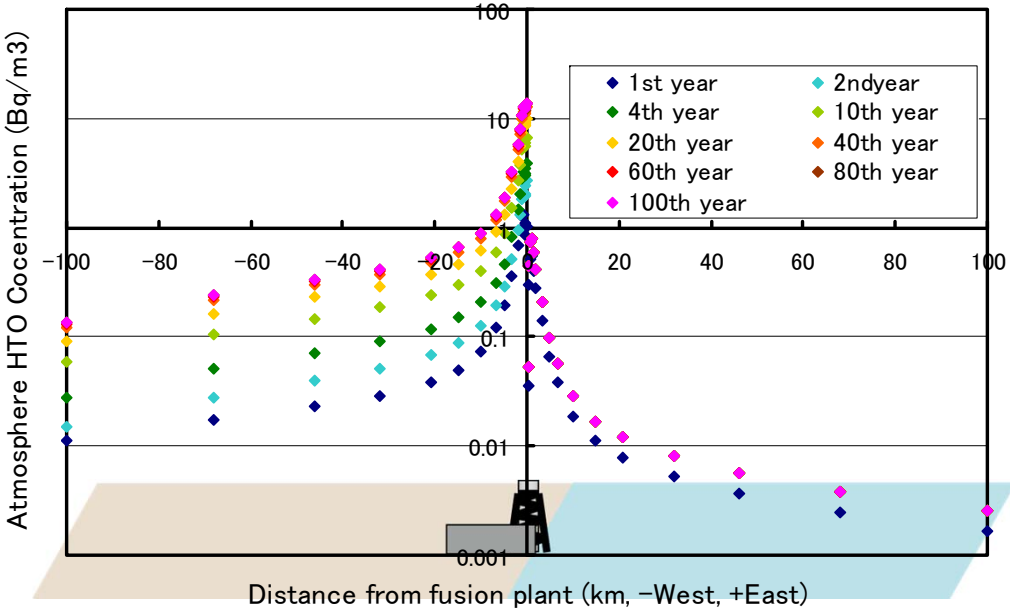
➡ Target recovery ratio >35% in the LiPb stream

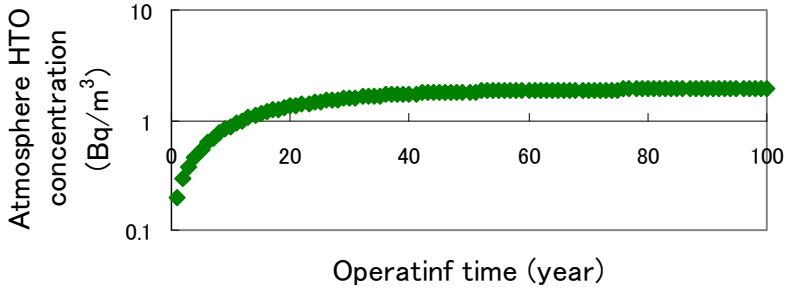
Yearly change of tritium concentration

Tutorial course

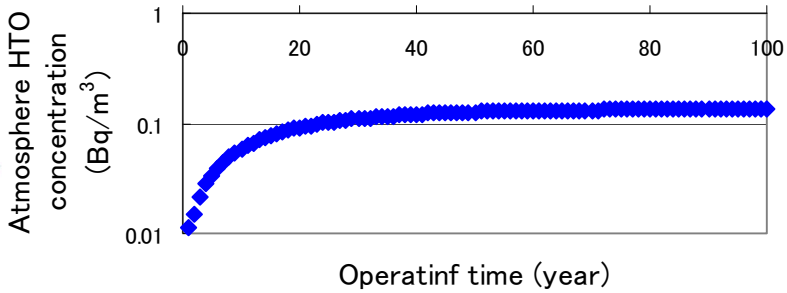
Change on the tritium concentration in the atmosphere during prolonged operation is analyzed.

Emission rate: 1.35×10^{14} Bq/year





5.7 km west



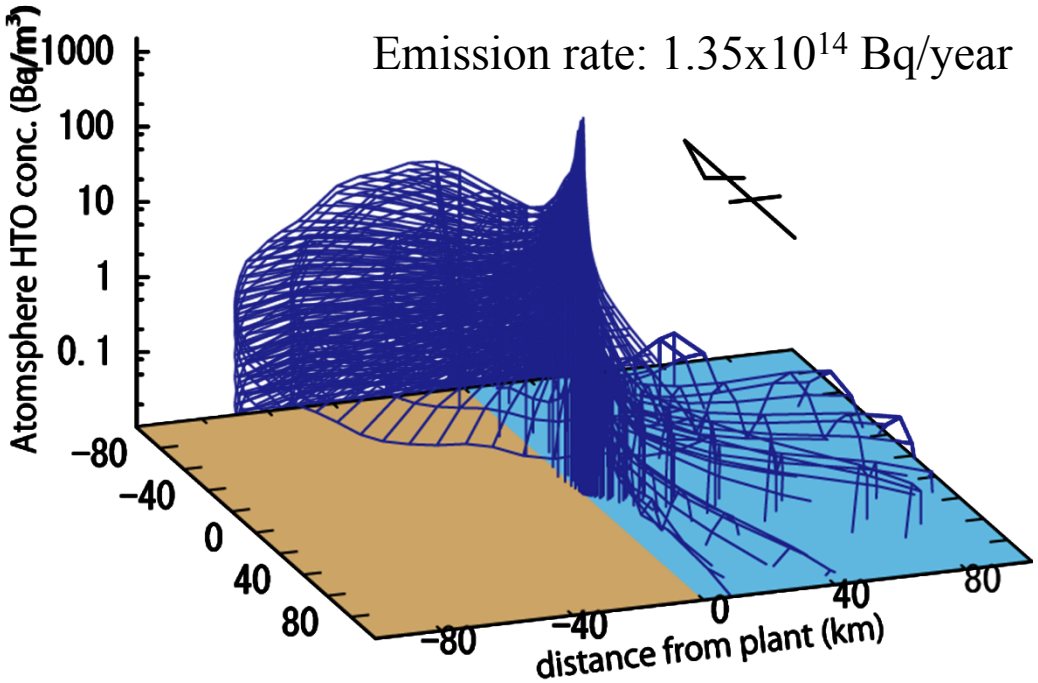
Atmosphere HTO concentration after 100 years operation.

100 km west

- Tritium concentration increase for about 60 years on land.
- Tritium concentration on the sea surface is low and dose not show accumulation

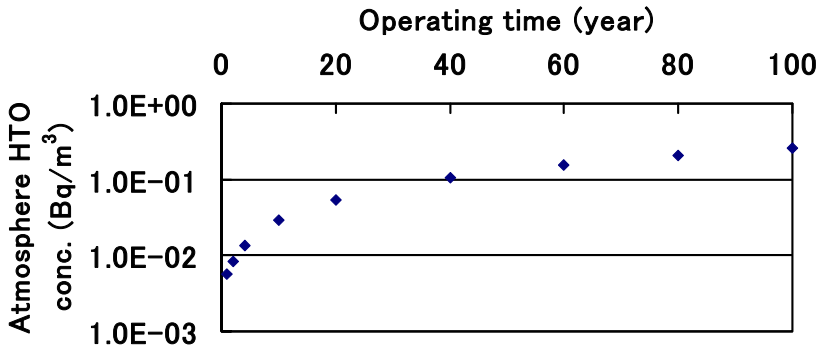
Accumulation in the environment

Annual emission accumulates in the environment

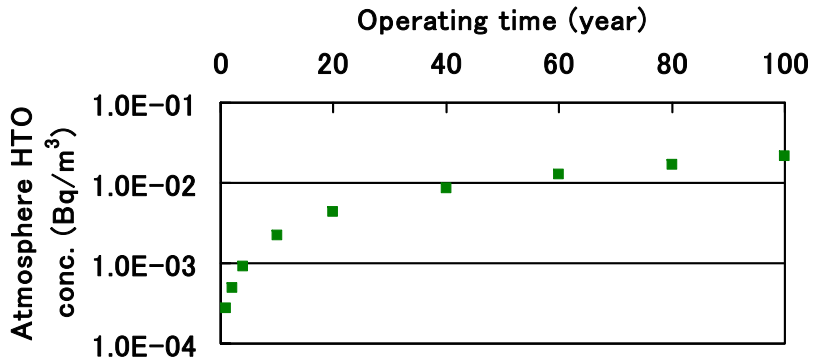


Emission rate: 1.35×10^{14} Bq/year

Operating time: 80 years



5.7 km west



100 km west

- Considerably increases for 20 years
- Still negligible from dose, but easy to detect.
  - If 100 plants operated 100 years?

Future Energy Systems

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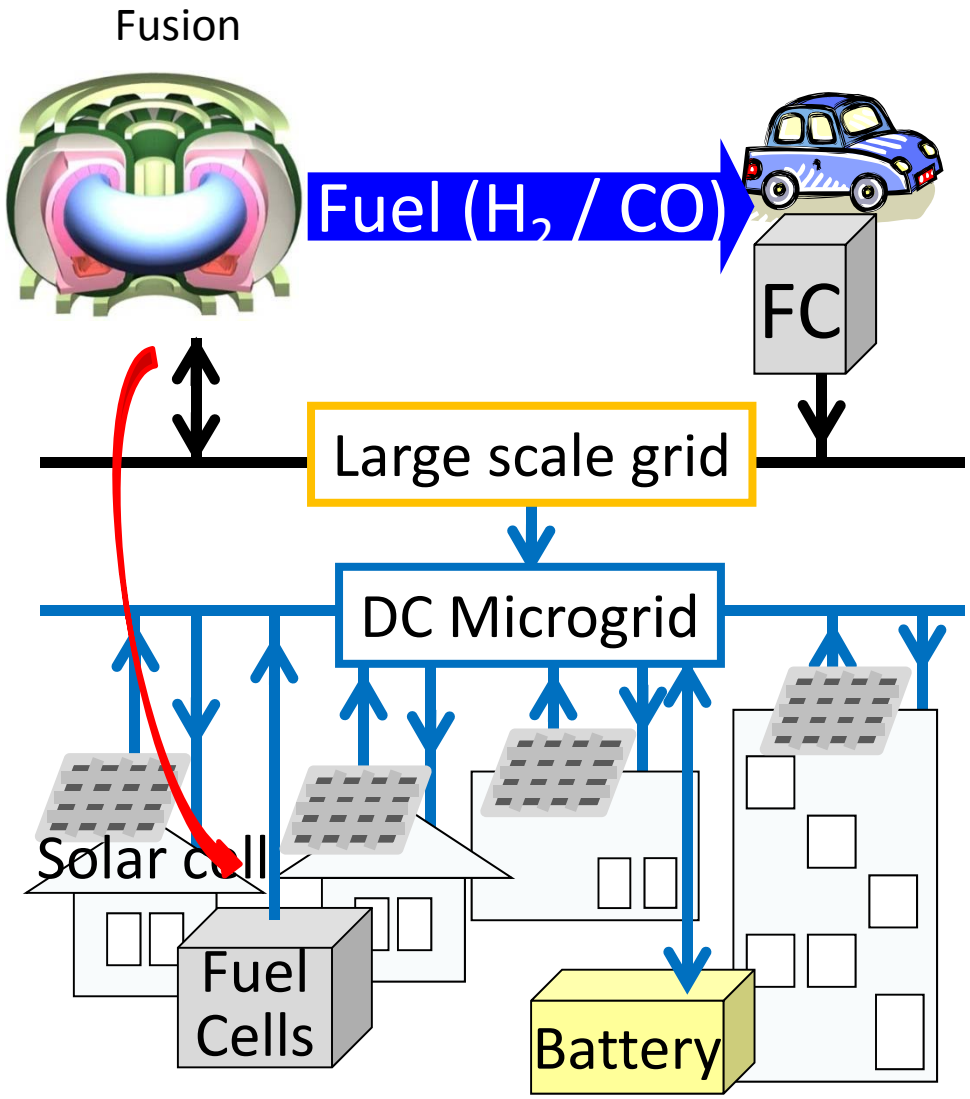

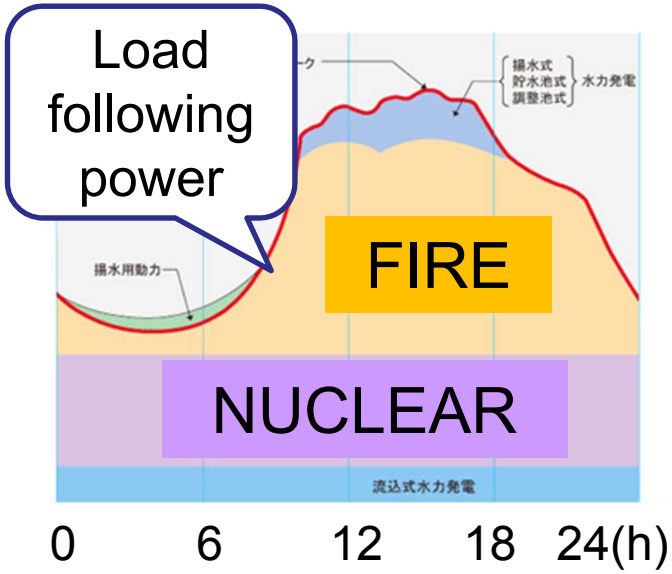

Electricity will be powered by Carbon-free sources

Day peak will be supplied by Battery and fuel cells.

Fusion and grid

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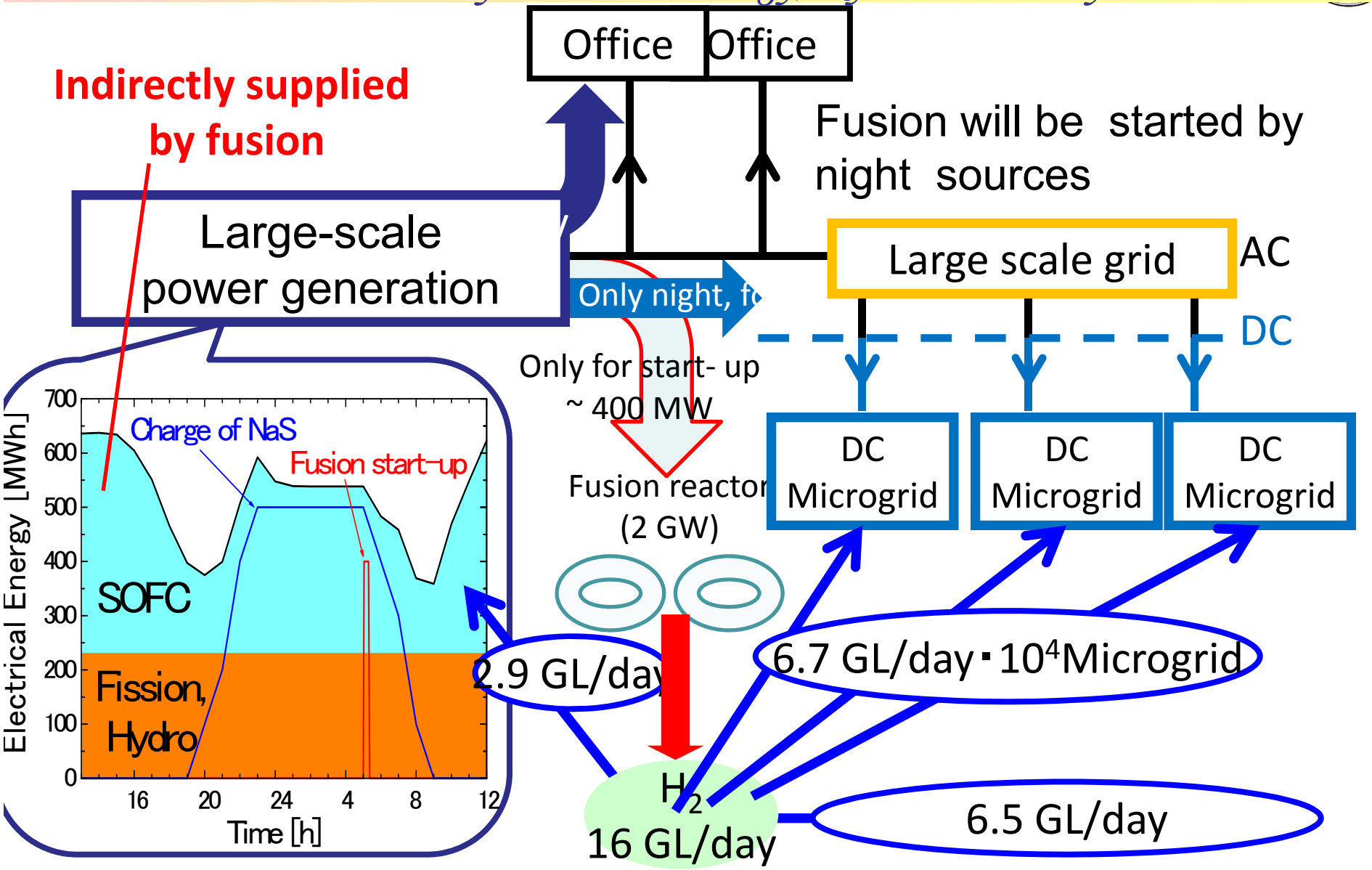

Fusion Energy Development

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1980 2000 2020 2040 2060

CDA88-90 ITER

EDA 92-01

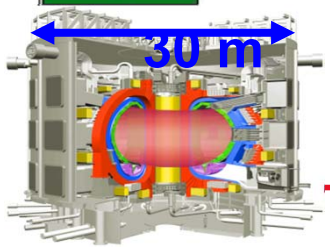
Const. Oper.

TBM

Competition to demonstrat

Fusion power

ITER(2010)



JA DEMO

Targetted to 2050 comercial electricity

→demonstration possible 2038

EU fast DEMO

"Plan B" of Fusion

Smaller than ITER

follows ITER construction

Oil product Demo before 2030

Bio Hybrid

Fusion as biomass hybrid

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

- small power generation has better market chance.
- cost requirements for the product (hydrogen, oil) may be easier (eventually. Depends on oil price and carbon tax)

○ Low Q plasma can generate net energy product

- realistic target with current plasma technology
- earlier requirements for plasma, divertor and first wall
- smaller plant of R=～5m scale
- smaller device, smaller cost and project risk and tritium needs

○High temperature blanket/divertor are realistic challenge

- SiC-LiPb blanket being developed.
- Biomass-hydrogen conversion in bench scale test.

Strategic consideration

○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.
- Fits the entire carbon-free energy systems better.

Conclusion

- Fuel production from biomass has larger market.
- Substituting Oil contributes CO_2 reduction
- Biomass-Fusion Hybrid will give a good chance for technology maturity of fusion power, and more attractive feature as energy
- Hybrid Device smaller than ITER and will not have to wait for ITER success.
- Applicable for ICF, stellarator and other confinements.

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