Economical feasibility of the biomass-fusion hybrid concept

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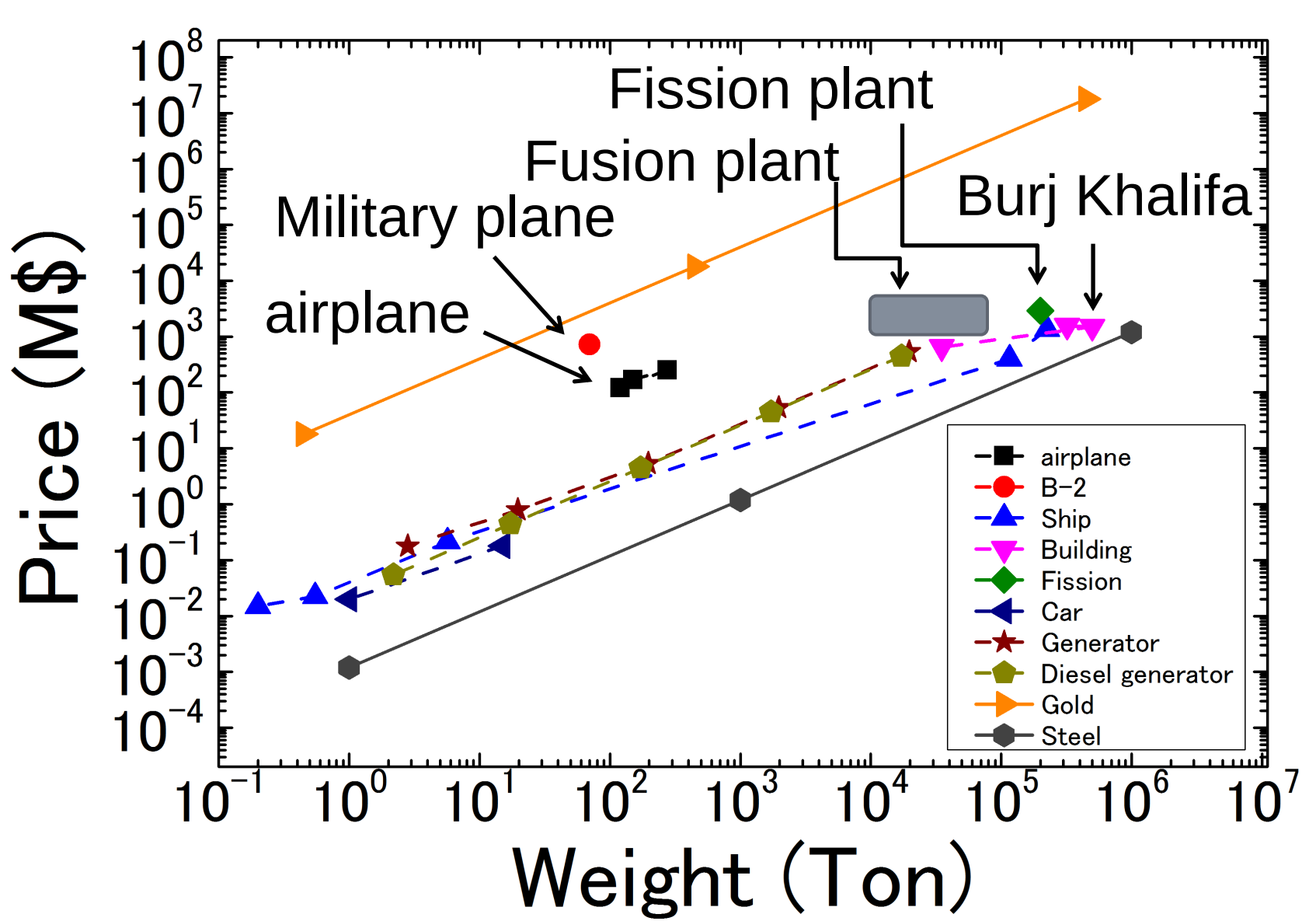
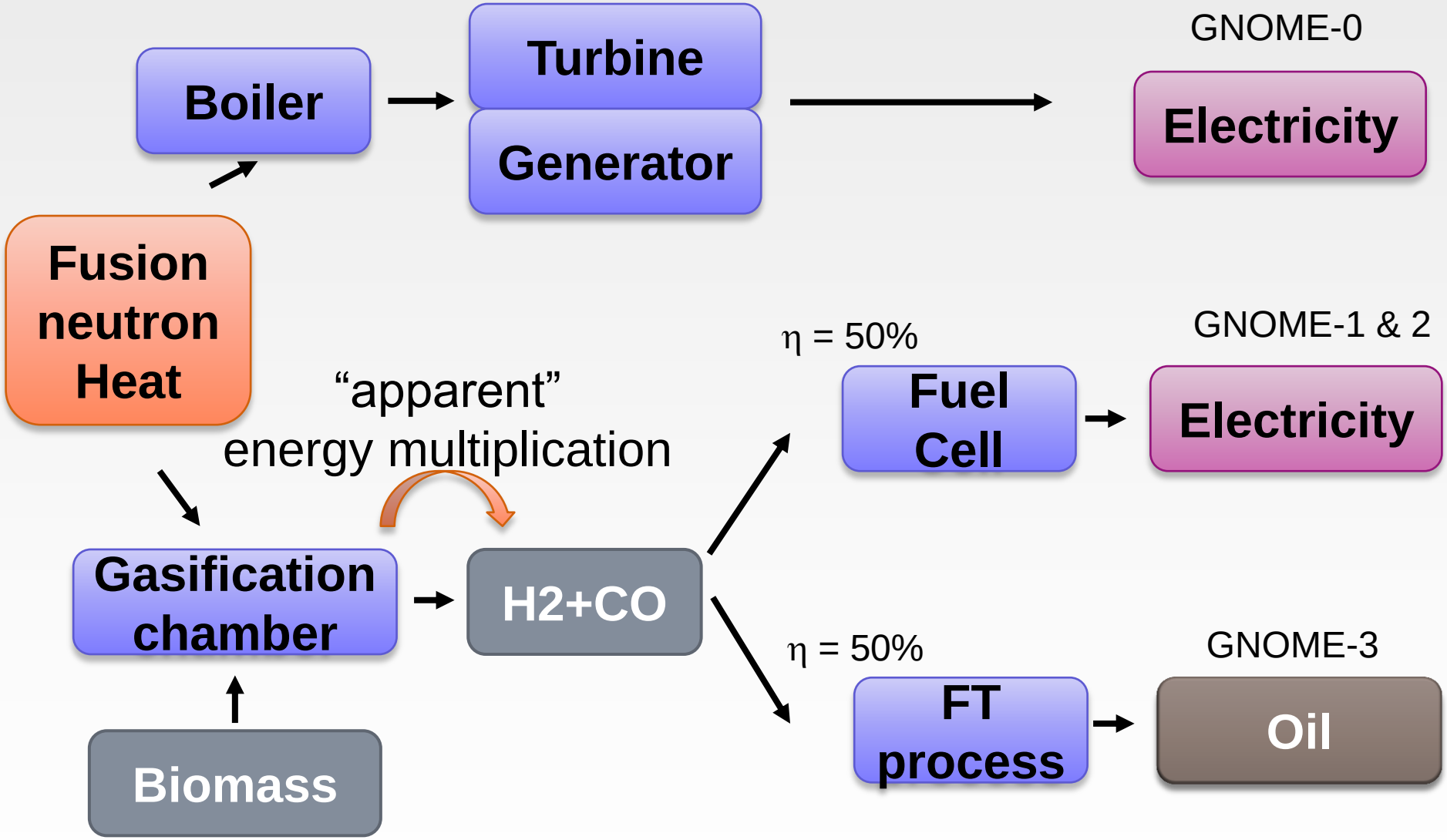
Weight vs Cost



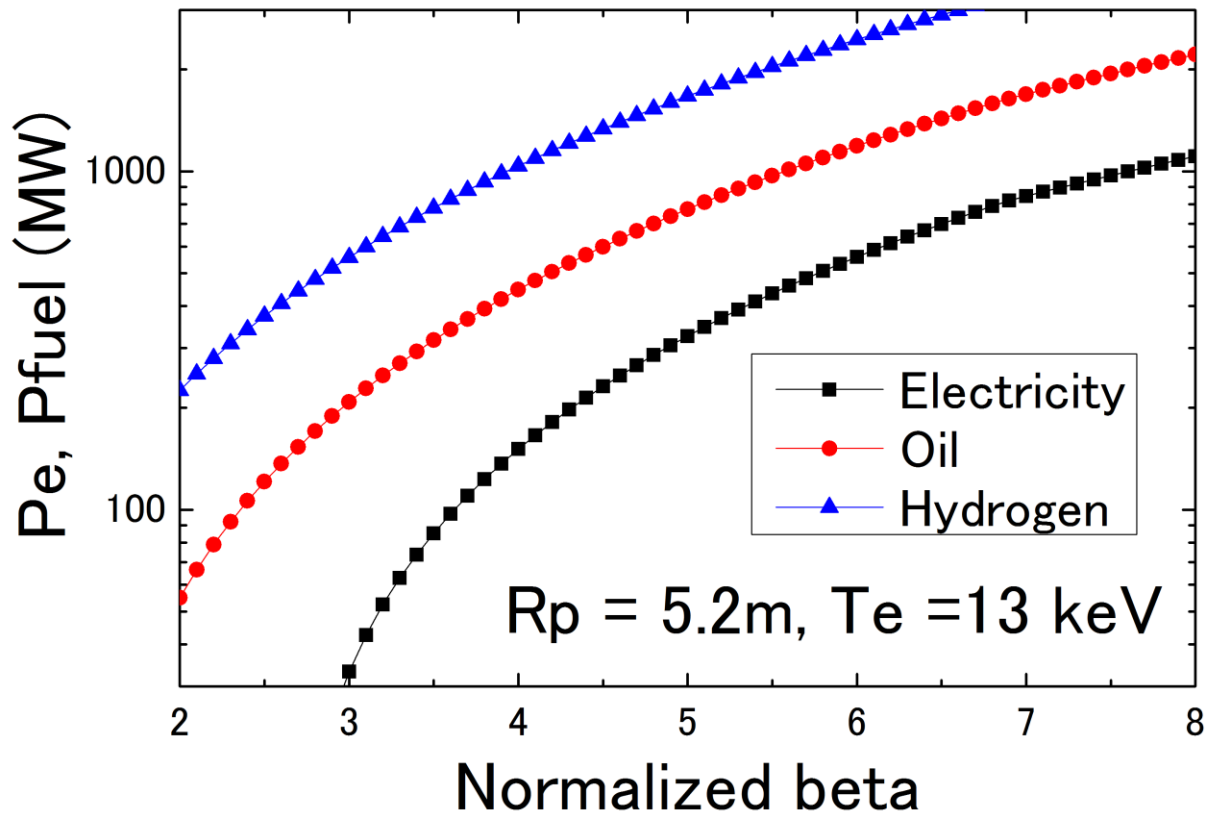
Biomass-fusion hybrid concept



The biomass-fusion hybrid concept can be a cheaper option

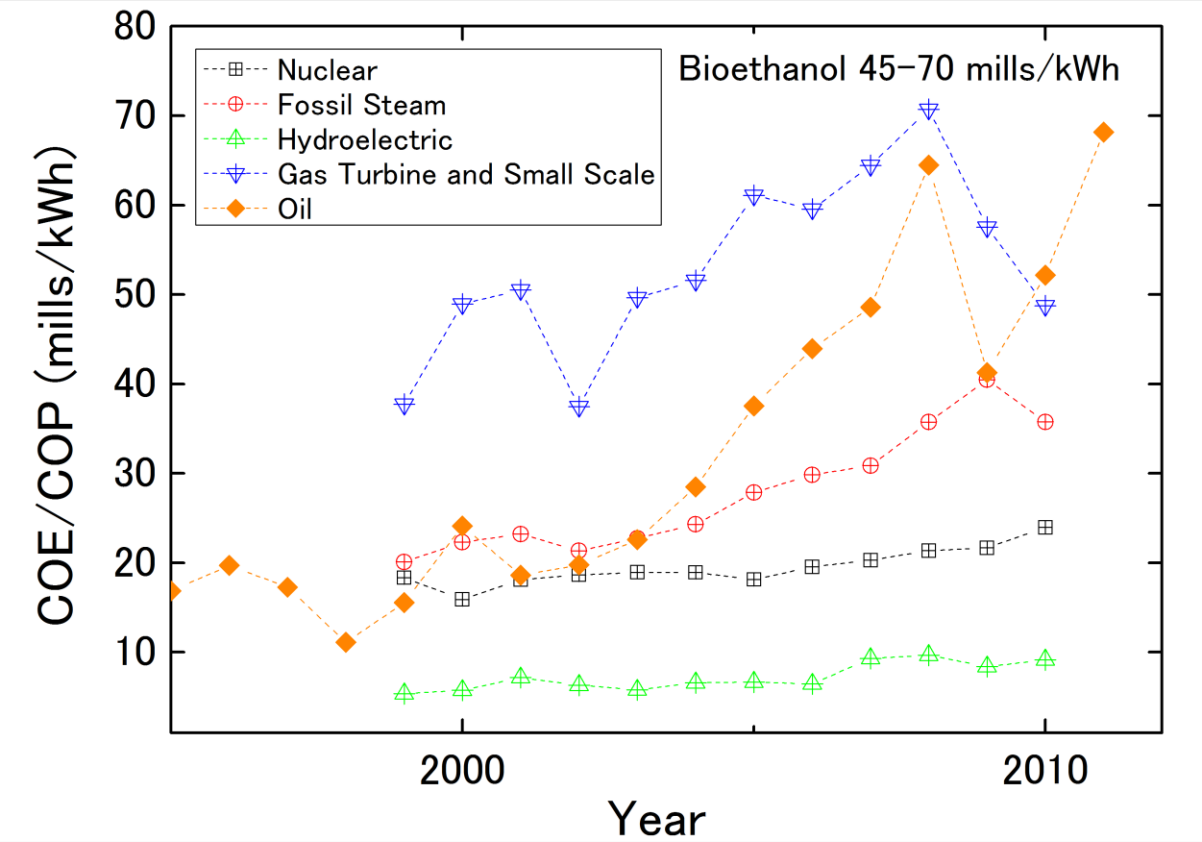
Energy conversion efficiency makes difference.

Apparent energy multiplication of 2 (hydrogen)or 1 (oil) is expected.



100 MW class reactor can be achieved with *R*p ~ 5 m and β ~ 3.

The biomass-fusion hybrid concept produce different products.



Crude oil

1 gallon = 130 MJ

Bio ethanol

1 gallon = 85.8 MJ

Electricity

1 kWh = 3.6 MJ

All units were converted into mills/kWh.

Energy prices are competitive.

US Energy Information Administration (2011)

The biomass-fusion hybrid concept requests some original features

- High-temperature system(blanket, pipe, HEX)
- Biomass gasification system ~ 1000 ^{o}C
- Oil conversion plant
- Fuel cell fee
- Fuel fee (12 mills/kWh)
- No Turbine

How does they affect COE/COP ?

Basics of Cost Analysis

Cost analysis

$$COE = \left\{ \frac{C_{\mathrm{ac}} + C_{\mathrm{om}} + C_{\mathrm{scr}} + C_{\mathrm{fuel}}}{8760 \times P_{\mathrm{e}} \times f_{\mathrm{av}}} + C_{\mathrm{dec}} \right\} \times F$$

(1.5) (1.0)

C_{ac}: accounting capital

C_{om}: maintaining

C_{scr}: periodic replace

C_{fuel}: fuel fee(D)

C_{dec}: Waste & shut down

P_e: Electricity output [MW]

f_{av}: utilization rate

F: 10th of a kind factor

$$\text{utilization rate} = \frac{\text{electricity output}}{\text{rated output} \times \text{time}} \times 100\ (\%)$$

$$\text{availablitiy rate} = \frac{\text{operation time}}{\text{time}} \times 100\ (\%)$$

Accounting Capital cost

$$C_{\mathrm{ac}} = C_{\mathrm{build-direct}} * f_{\mathrm{indirect}} * f_{\mathrm{interest}} * f_{\mathrm{pay\ back}}$$

(1.2) (1.1303) (0.05828)

C_{ac}: accounting capital

$C_{\mathrm{build\text{-}direct}}$: direct construction

f_{indirect}: in-direct fee ratio

f_{interest}: interest during construction

$f_{\mathrm{pay\ back}}$: capital recovery factor

From L. M. Waganer, “Fusion economics”, Nuclear Energy Encyclopedia, 2012

Direct building cost

$$C_{\text{build-direct}} = C_{\text{comp}} + C_{\text{CD}} + C_{\text{BOP}}$$

$C_{\text{build-direct}}$: direct construction

C_{CD}: Additional heating

C_{comp}: component cost

C_{BOP}: Balance of plant

$$C_{\text{comp}} = \Sigma\{c^{\text{d}}_{\text{material}} + c^{\text{d}}_{\text{manufacture}} + c^{\text{d}}_{\text{assembly}}\}[\$/\text{kg}] * W[\text{kg}]$$

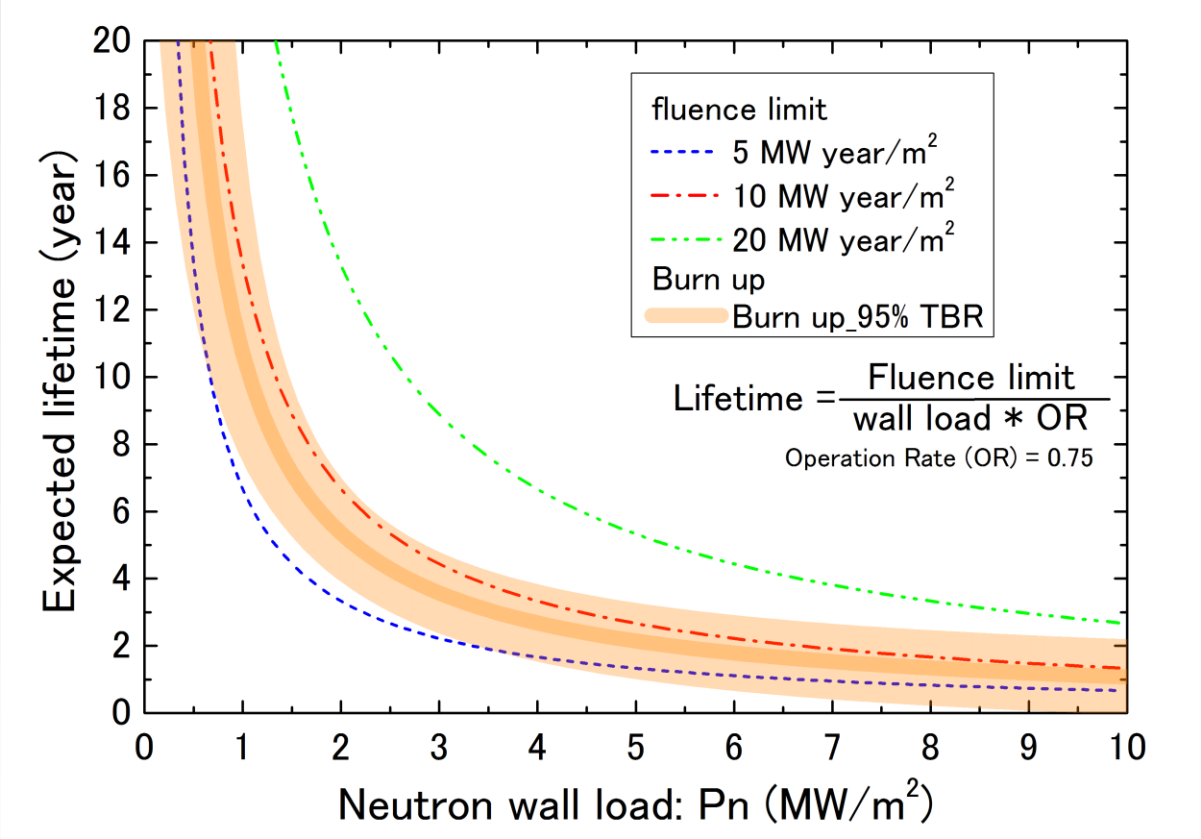
$$C_{\text{CD}} = c^{\text{CD}}\ [\$/\text{MW}] * P[MW]$$

$$C_{\text{BOP}} = C_{\text{building}} + C_{\text{other}}$$

$\propto V^{0.67}$

$\propto {P_{th}}^{0.6}$

Periodic replacement



Periodic replace:

$$C_{\mathrm{scr}} = C_{\mathrm{comp}}^{\mathrm{BLK}} * f_{\mathrm{scr}}^{\mathrm{BLK}} + C_{\mathrm{comp}}^{\mathrm{DIV}} * f_{\mathrm{scr}}^{\mathrm{DIV}}$$

Peak flux ~ 1 MW/m^2 flux ➔ ~14 years

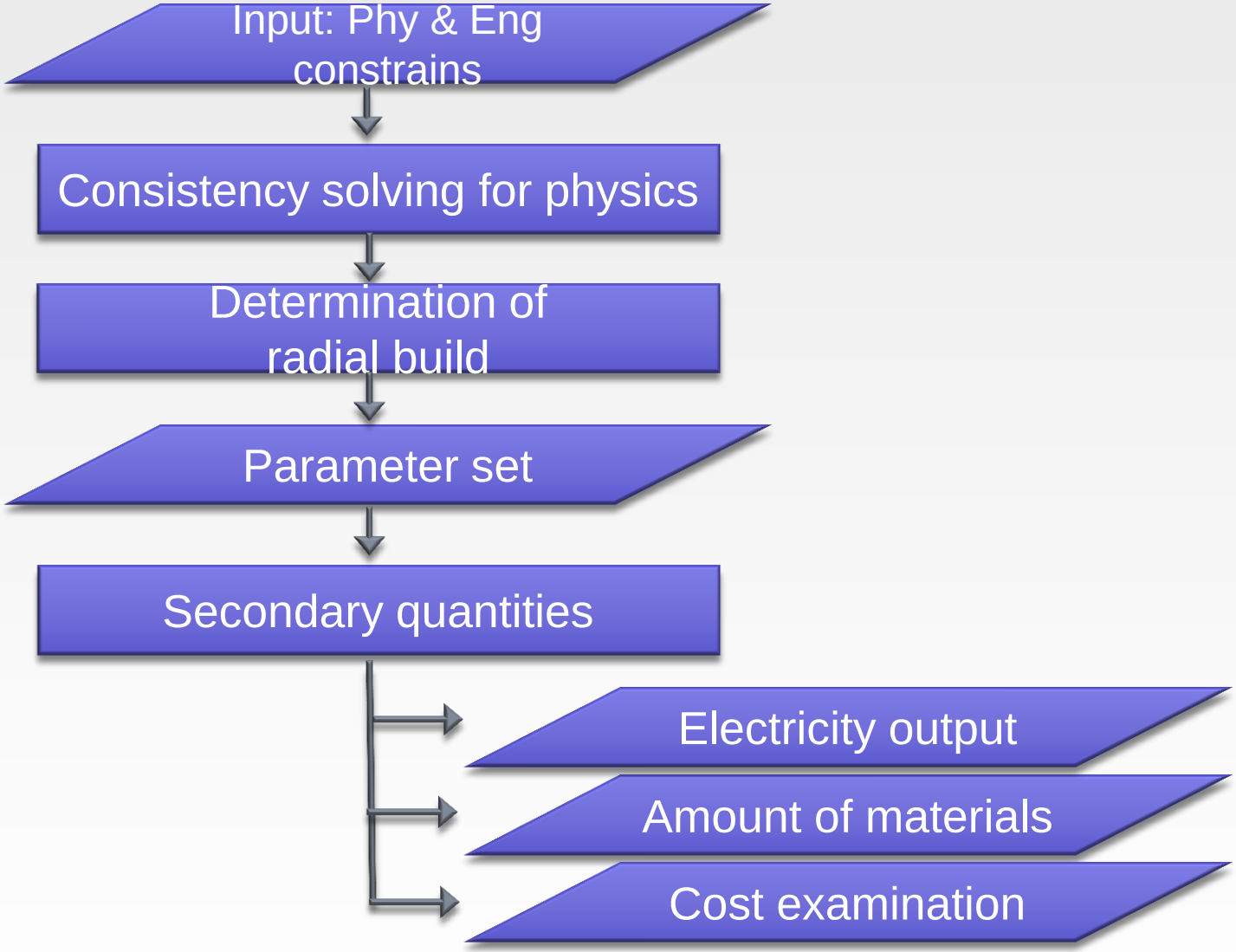
Cost estimations

GNOME parameter

		ITER	GNOME
Major radius	R_p	6.2 m	5.2 m
Aspect ratio	A	3.1	3.1
Current	I_p	15 MA	10.4 MA
Max field	B_{max}	11.8 T	11 T
Average temperature	$\langle T_e \rangle$	8.9 keV	13 keV
Density	f_{GW}	-	0.54
Bootstrap	f_{BS}	-	0.45
Fusion power	P_{fus}	500 MW	300 - 400 MW
Heating	P_{CD}	73 MW	85 MW
Neutron wall load	P_n	0.57 MW/m^2	~ 0.5 MW/m^2

Low power, low-*Q*.
Small *R*p.
12 TF coils. (Nb_3Sn)

Systems codes



CRIEPI code: FUSAC

Cost evaluations were taken for various options.

	Turbine	High temp. system	Biomass fuel	Fuel Cell	Oil plant	Product
GNOME-0	○					Electricity
GNOME-1		○	High	○		Electricity
GNOME-2		○	Cheap	○		Electricity
GNOME-3		○	High		○	Oil

FC, FT plant, HEX costs were applied to C_{other}.

$$C_{\text{BOP}} = \underbrace{C_{\text{building}}}_{\propto V^{0.67}} + \underbrace{C_{\text{other}}}_{\propto {P_{th}}^{0.6}}$$

Basic values used for the analysis

	Price ($)
Fuel cell	$40K*(Pfc(W)/700)^{0.6}$
FT plant	$C.I. / C.I._{1975} * 158K*P_{yearly}(ML)^{0.715}$
HEX	$M\&S/M\&S_{1975}* 4764*(P_{fus}(MW)/0.1)^{0.849}$
HEX-SiC	$C_{SiC}*Cost_{HEX}$
Turbine Generator	$240.3*(Pe(MW)/1200)^{0.83}$

Based on a commercial SOFC for household use.

Based on a commercial ethylene plant.

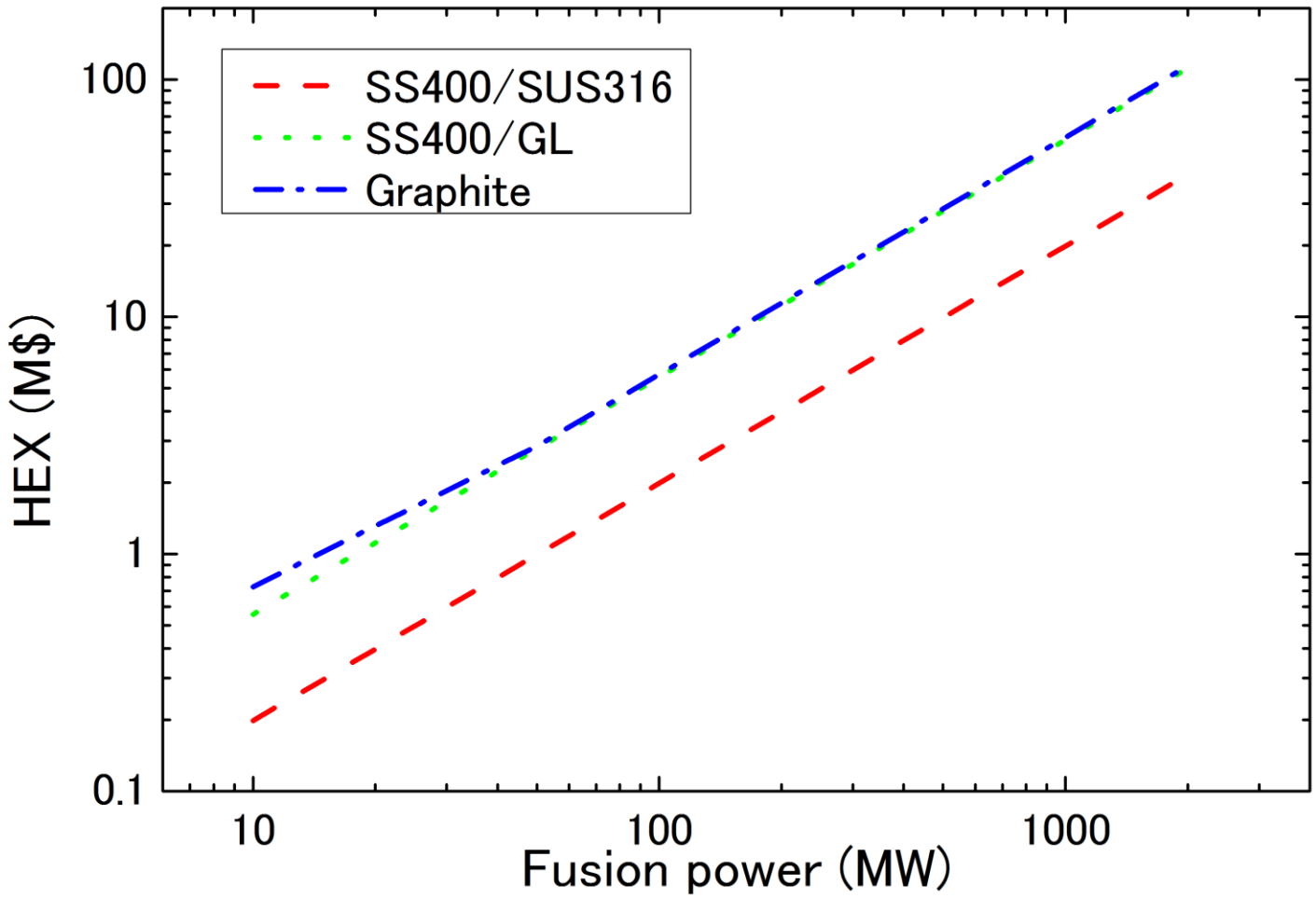
0.1 MW/m^2 limit at HEX (dx=1.0 cm, dT=25K, λ=40 W/m/K.) (scaling for < 500 m^2)

C_{SiC} = 4
(twice cost, two HEX)

*C.I. : CEPCI $C.I._{1975}$=182.4, $C.I._{2009}$=539.6
$M\&S_{1975}$=444.3, $M\&S_{2007}$=1362.7

H. Saito “Cost handbook for the chemical plants.”
ARIES website

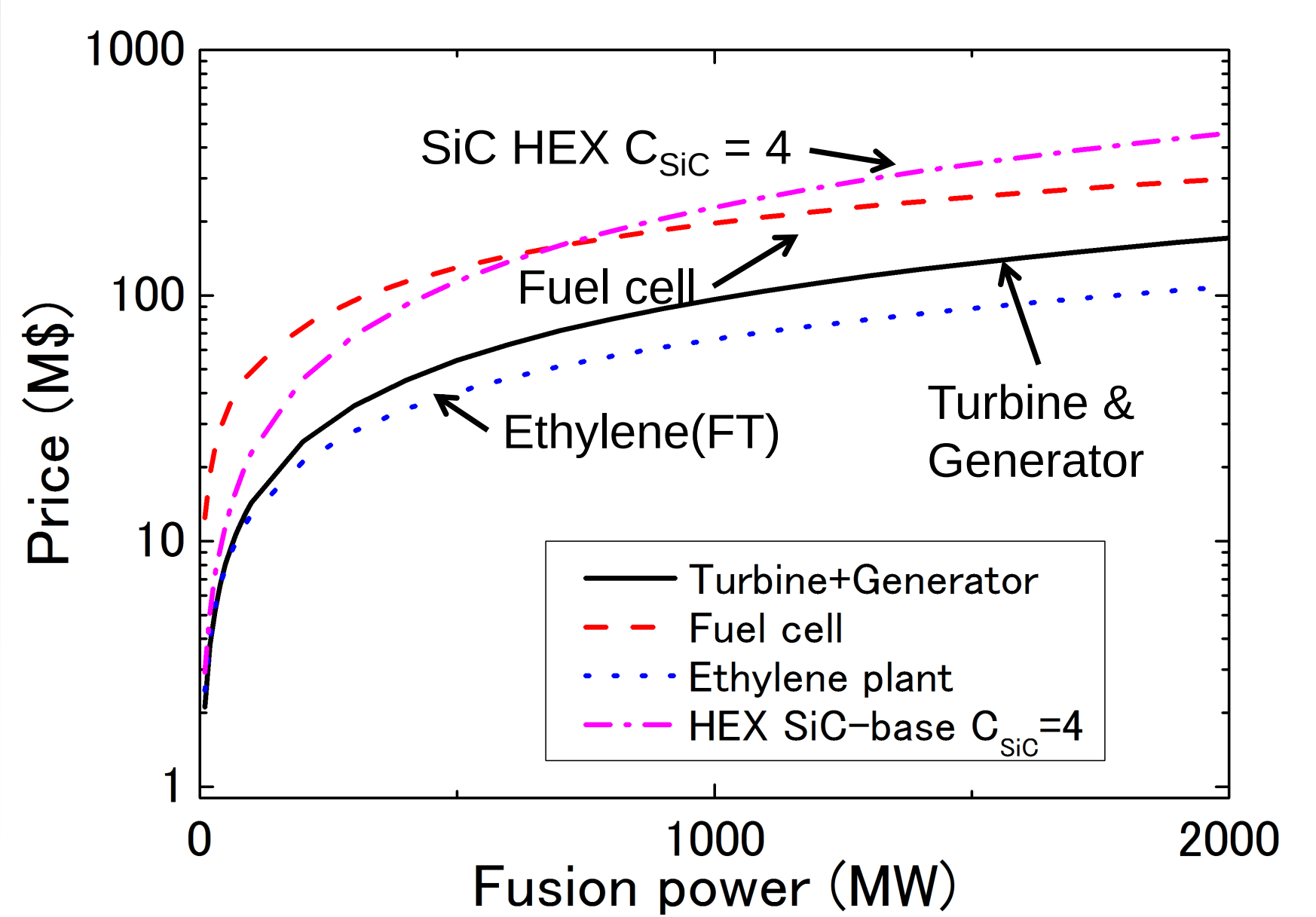
Cost of Heat Exchanger



http://www.ncmersen.jp/towerbessel/parts.html

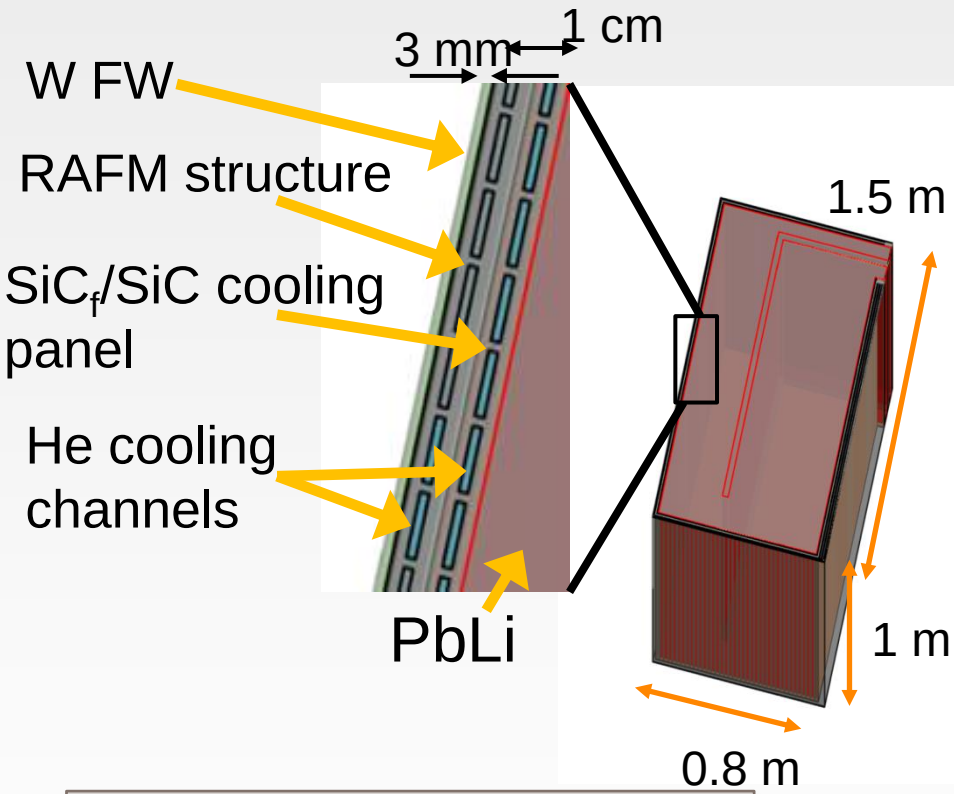
A patent for a Graphite HEX with a SiC surface layer does exist.
The patent says the HEX can handle up to 1273K.
JP 特空平 7-225095

Basic values used for the analysis



Blanket component price

Material	Volume (m^3)	Weight (kg)	Price (k$)
Tungsten	4.5×10^{-3}	87	10.4
F82H	3.5×10^{-2}	270	11.7
SiC_f/SiC	5.4×10^{-2}	170	99
He (8MPa)	2.5×10^{-2}	0.35	7.0×10^{-2}
PbLi	1.13	10000	88
Module	1.2	10500	200
total	370	3200 tonn	62 M$
Material / Total cost			50 %

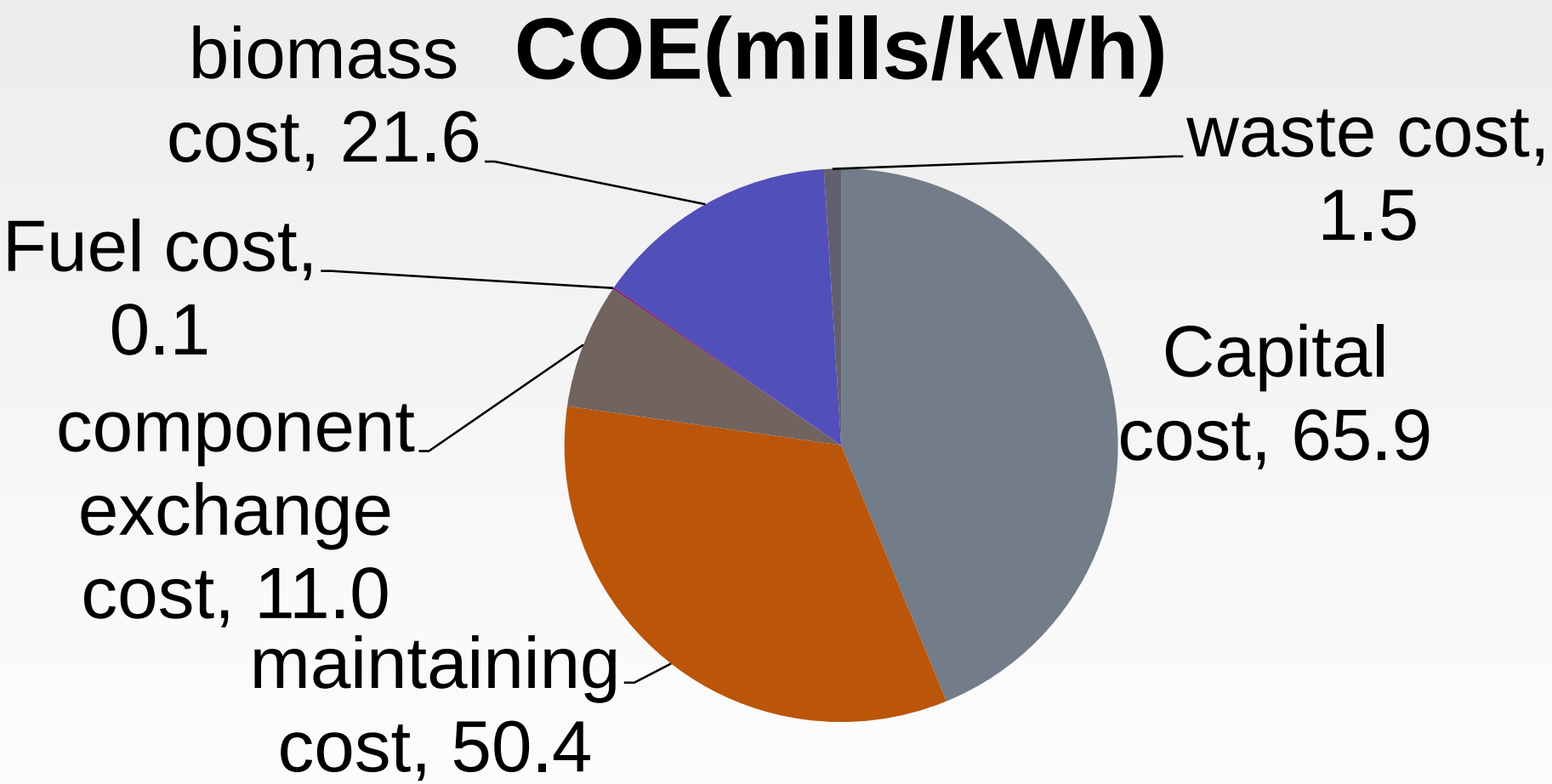


8.8 ton/m^3
39 $/kg
0.34 M$/$m^3$

Material cost base from ARIES website is used.

Result

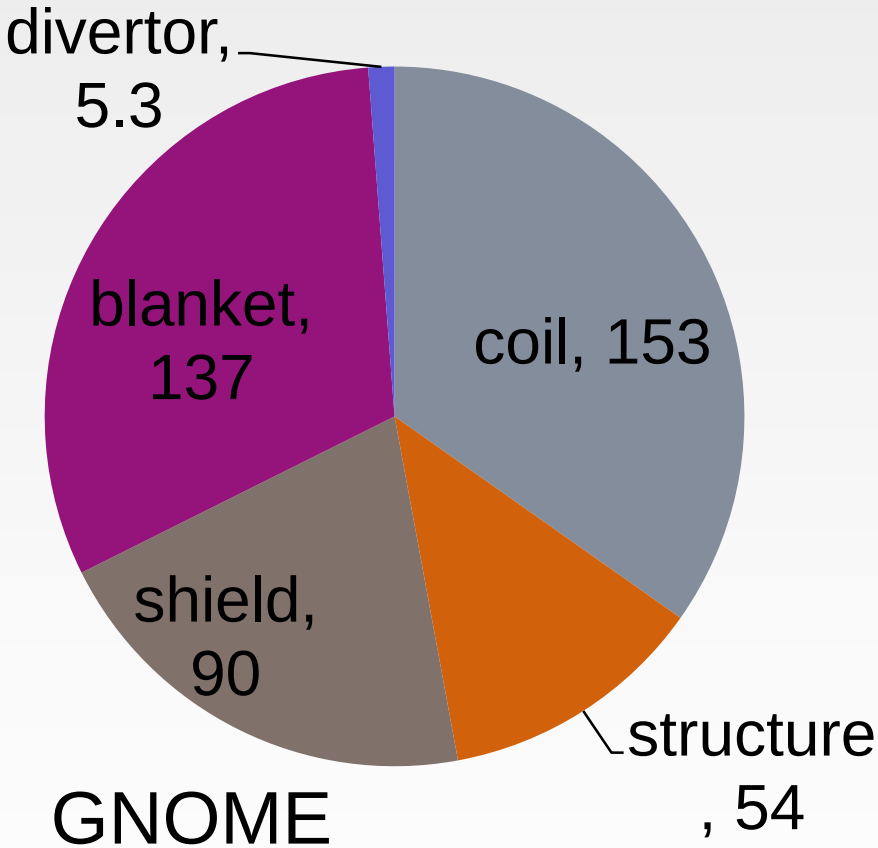
COE of GNOME with FC



COE = 150.598 mills/kWh with P_{fus} = 364 MW

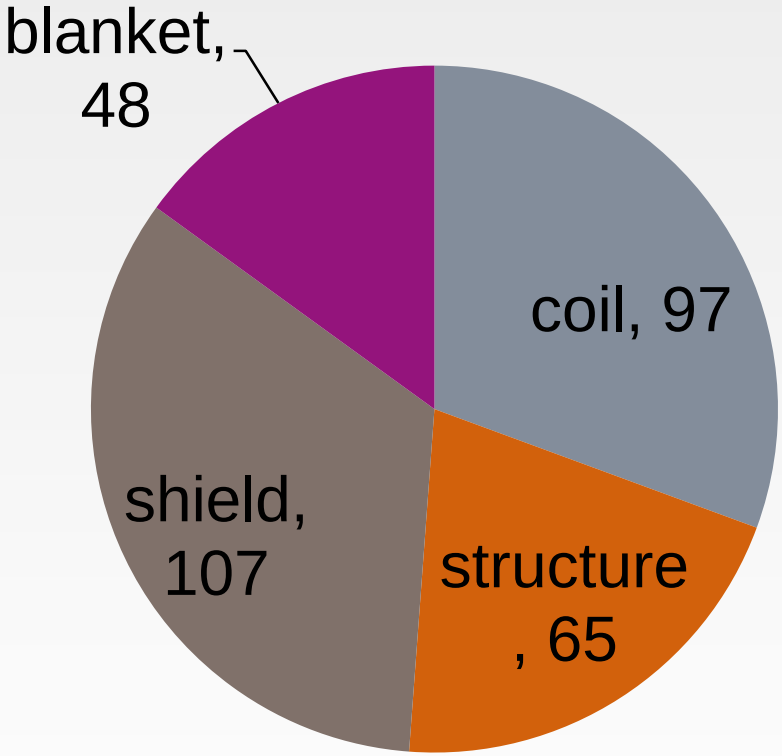
GNOME reactor weight & cost

Cost of reactor components(M$)



GNOME

Total ~ 439 M$

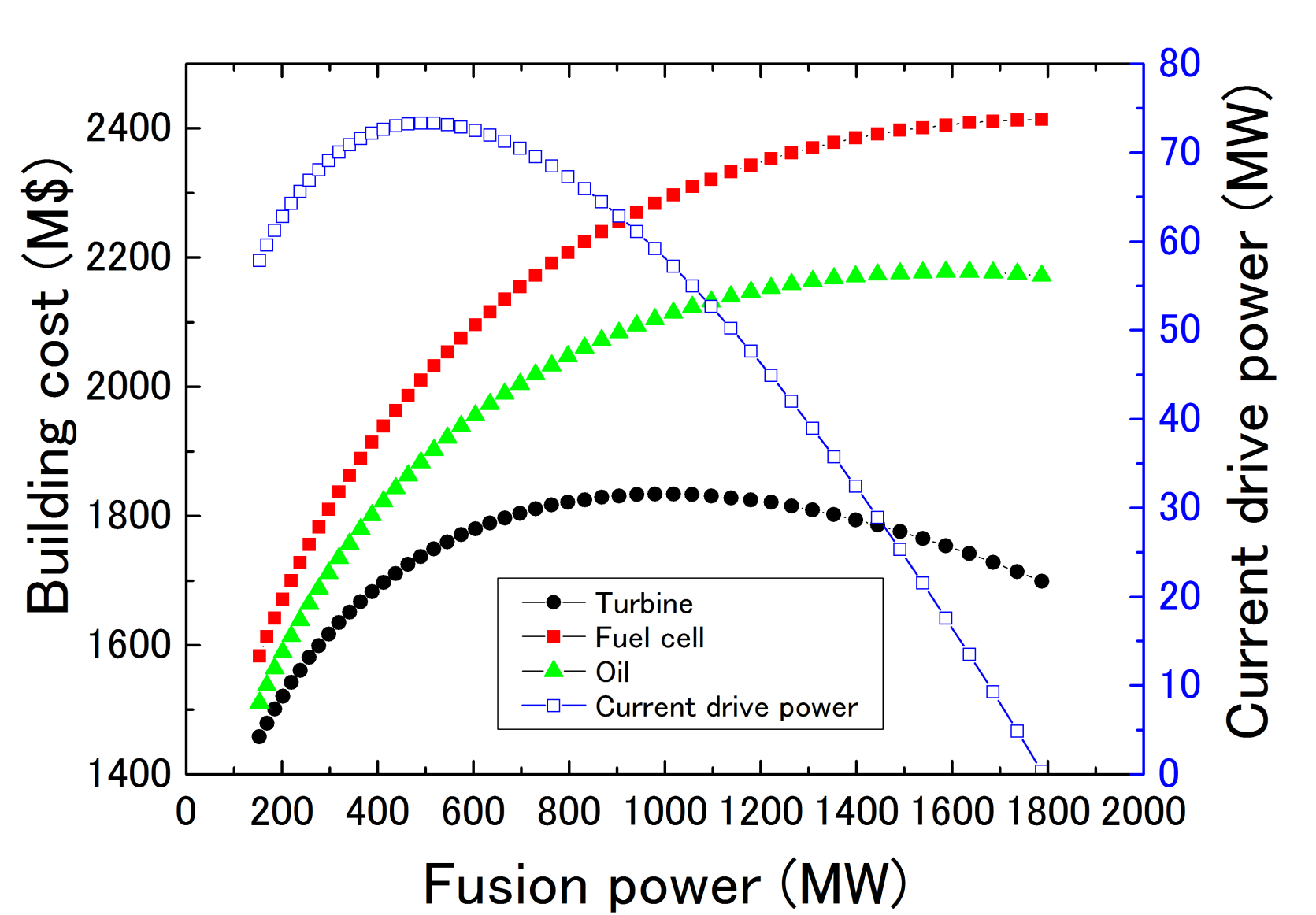


ARIES-ST

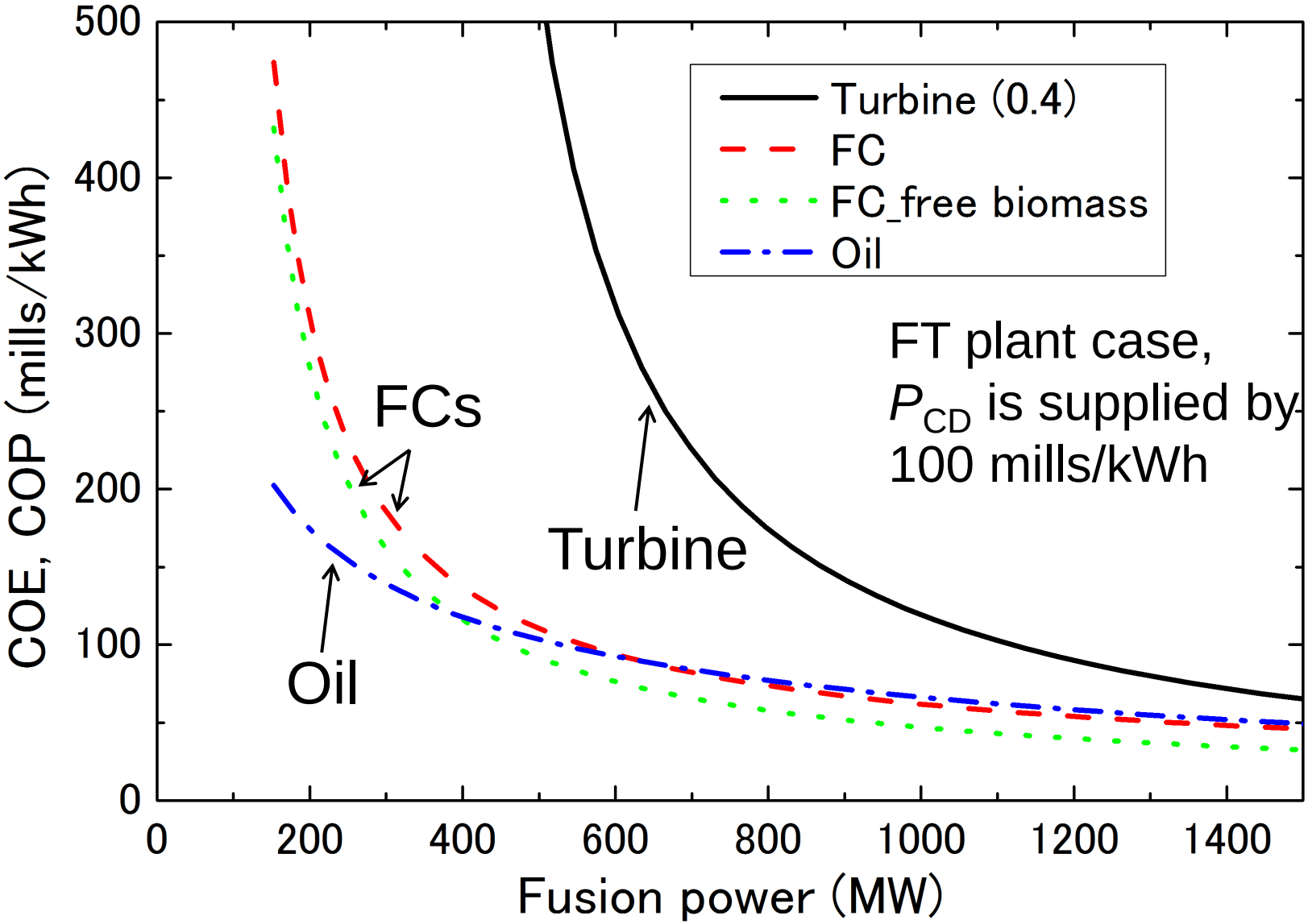
Total ~ 317 M$.

from ARIES website

Building cost



COE/COP analysis



Summary

- Cost estimation effort has been taken for the biomass-fusion hybrid concept.
- The concept shows economical feasibility than turbine particularly for a low fusion power devices.
- COP < 100 mills can be achieved with 500-1000 MW fusion power.