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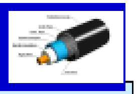

Study on 1 GW Class Hybrid Energy Transfer Line of Hydrogen and Electricity

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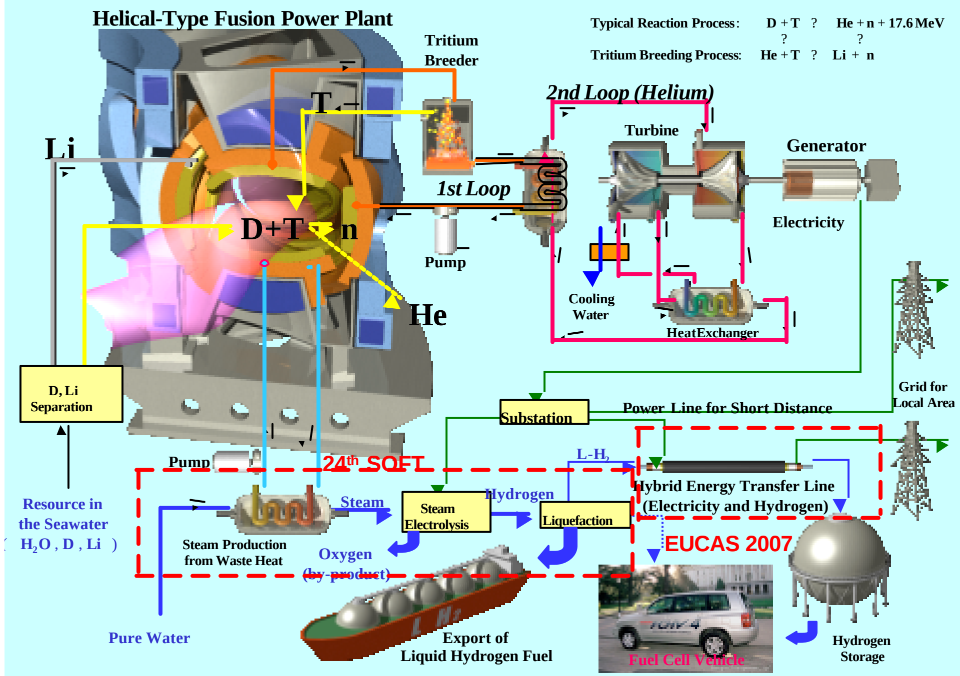
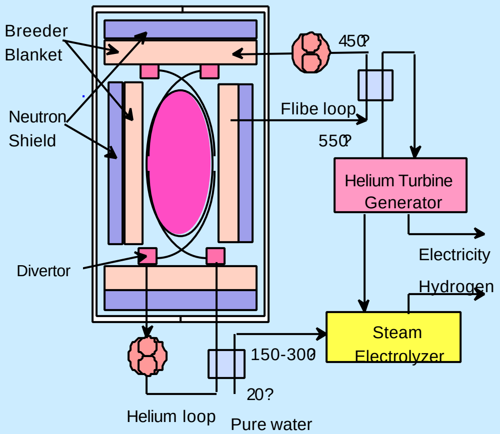
Helical-Type Fusion Power Plant with Electrolyzer



Dedicated Hydrogen Production by 1 GWe



Gaseous hydrogen of 700 tons/day can be produced by using electric power of 1 GW. The steam of 6,354 tons/day at more than 150 ºC is necessary.

In the FFHR, about 450 MW of thermal power is delivered via the scrape-off layer plasma to the divertors with double-null structure. The divertor may be one of the potential heat sources for the high-temperature electrolysis.

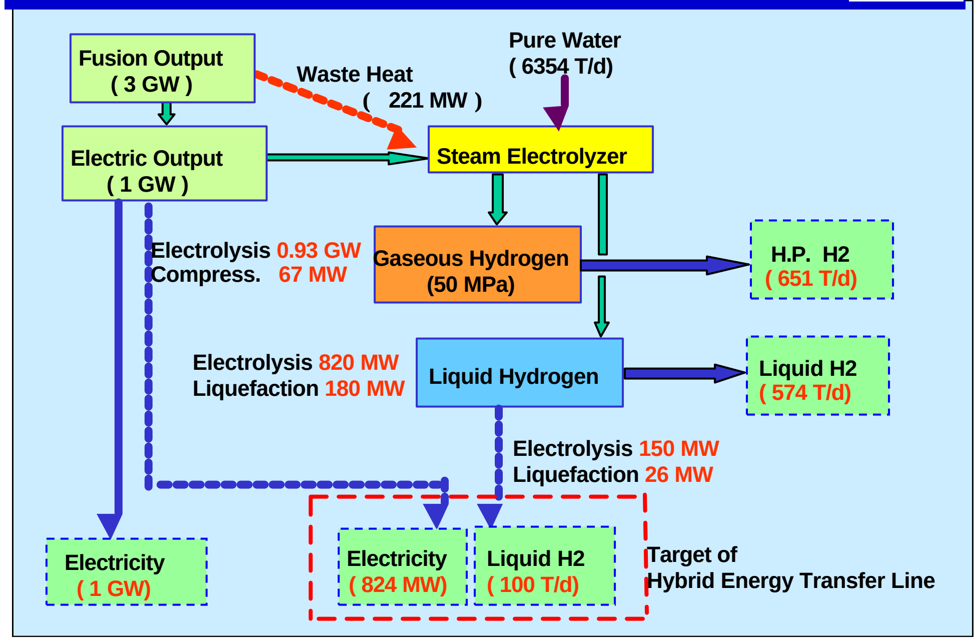
Table Required heating power to produce the steam of 6,354 tons per day.

Steam Temperature (?)	150	200	250	300	350	400
Heat input requirement (MW)	198	206	213	221	229	237

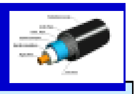
20 ? ≠ 100 ? : 24.7 MW
water ≠ steam : 165.5 MW

Cf.: Latent heat of water: 2250 kJ/kg, Specific heat of water: 4.2 kJ/kg· K, Specific heat of steam : 2.1 kJ/kg· K

Power Flow Diagram



Hybrid Energy Transfer Line (HETL)



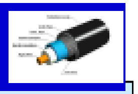
Merits of HETL:

- low energy consumption system for long transportation,
- low-voltage high-current system (for downsizing ac/dc converter),
- integrated energy transportation system which combines hydrogen fuel and SC power transmission.

Target parameters of hybrid energy transfer line.

Item	Values
Target distance	
total length to end user	1000 km
unit length between the cooling stations	10 km
Power Transmission	
Withstand voltage	+50 kV and -50 kV (100 kV)
rated current	dc 10 kA
Hydrogen Transportation	
capacity of transportation	100 ton/day (1.6 kg/s)
operation Temperature	17 – 24 K (@ 0.4 MPa)

SC Strand



Requirement for SC materials,

(1) expect the low-costs of material and cable production,
(2) perform the operation of 20 - 24 K in the limited area,
(3) expect the high current capacity with easy manufacturing processes.

Bi2223 Tape:	(?) mechanical property(?),
Bi2212 Rutherford cable:	(?) Complicated (Fig.1),
YBCO Tape:	(?) long cable (?),
MgB_2 Strand :	(?) low-costs, easy productivity (Fig.2)

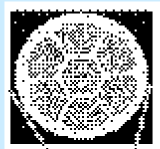


Fig.1 Bi2212
OD: 0.8 mm?
Showa-densen Review Vo.56, No.1, 2006 (in Japanese)

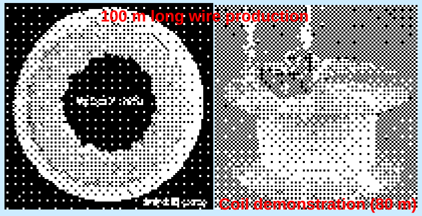


Fig.2 MgB2 Strand (outer diameter: 1.3 mm)
Kikuchi A, Hishinuma Y, Takeuchi T, Annual Conference of Cryogenic Society of Japan, May 2007, 1C-a09 (in Japanese).

I_C-B performance
500 A @2T (4.2 K)
260 A @3T (4.2 K)
140 A @4T (4.2 K)

→

Parameter for 10kA cable design;
Iop = 20 A @ 20 K
self-magnetic field : 0.12 T
number of strands : ~ 500

10 kA Class MgB_2 Cable

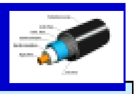


Table Design parameters of 10 kA class MgB2 cable.

Items	Design values
Operation Temperature	17 – 24 K
Materials of the SC strand	MgB_2
Diameter of the SC strand (and MgB2 core)	1.3 mm (0.5 mm)
Operation Current of strand (Core Jc)	20 A (~100 A/mm2)

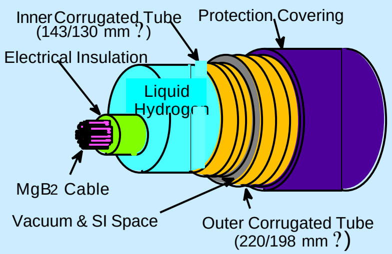
(1) Type A

Diameter of SC wires : 36.82 mm ?

Thickness of Electrical Insulation : 12 mm

Diameter of Cable : 61 mm ?

???Max.?Magnetic Field in a Cable : 0.12 T



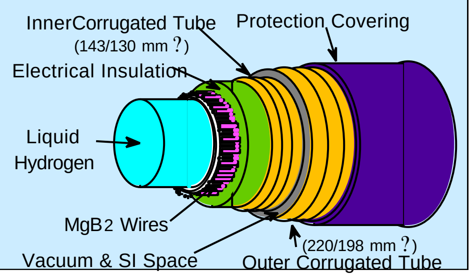
(2) Type B

Diameter of SC cable : 105/103 mm ?

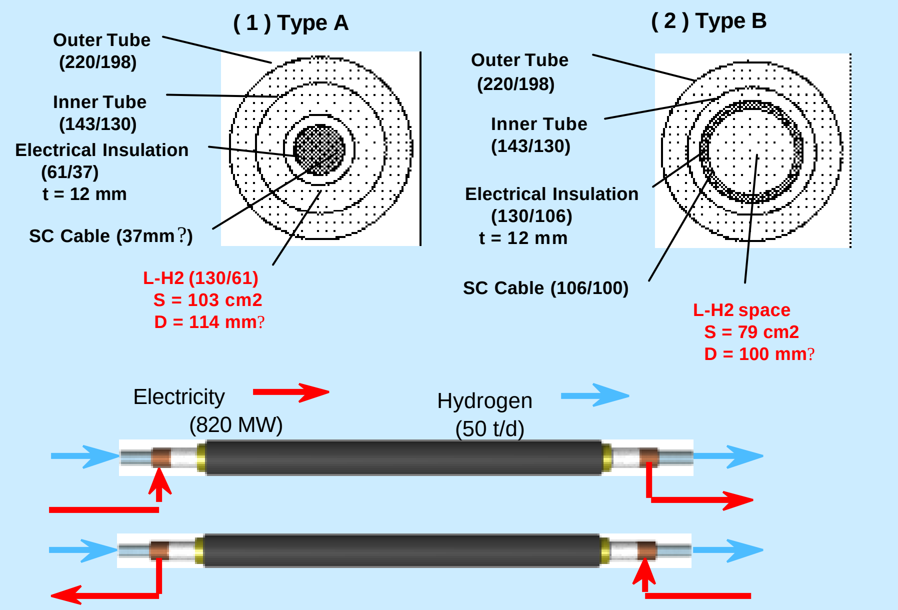
Thickness of Electrical Insulation : 12 mm

Diameter of L-H2 Channel : 100 mm ?

Max. Magnetic Field in a Cable : 0.04 T



Structure of HETL



Temperature and Pressure of L-H2

Pressure loss of 10 km long HETL is investigated as a function of temperature of pressurized hydrogen.

Assumption:

1) Inlet temperature: 17 K

2) Straight tube with smooth surface

3) Inner diameter: 100 mm?

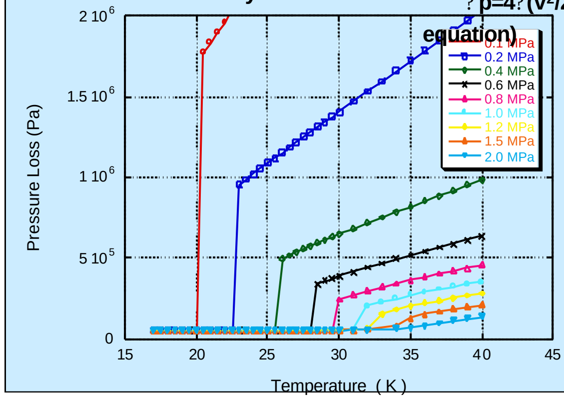
???Flow rate: 50 ton/day

friction factor: ?

???=0.032+0.221 Re^{-0237} (Nikuradse ' s equation)

pressure loss: ?p

?p=4?(v²/2)(L/D) (J/kg) (Fanning ' s equation)



When pressure increases, boiling temperature also increases.

0.1 MPa ≤ 20 K

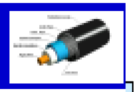
0.2 MPa ≤ 22.5 K

0.4 MPa ≤ 25.5 K

0.6 MPa ≤ 28 K

Pressurized hydrogen enables to,
1) expand operation temp. region,
2) absorb head loss of the route.

Structure of Cryogenic Envelope

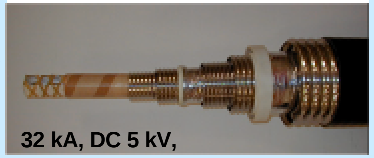


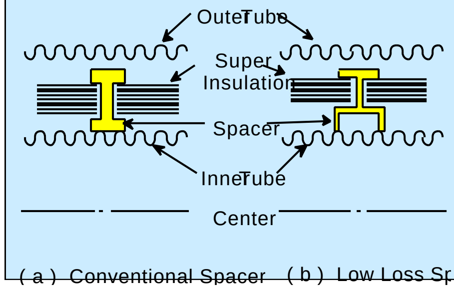
Heat Load of SC bus-line in LHD

2.8 ~ 2.9 W/m (300K ✍50K)
more than 7 months per year
ten years operations

Reduction of Heat Leak

- **Conduction : slender and long spacer**
- **Convection : high vacuum degree**
  (Purging with clean and dry gas before evacuation)
- **Radiation : increase in number of SI sheets**

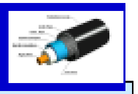




Heat load of 1 W/m
(target value)
Vacuum port: every 1 km
(cf. LPIA Cable: 600 m)

Reference: Schippl K, EUCAS2003,
***IoP Series Number* 181 (2004) 360-364.**

Temperature Rise after 10 km delivery



Assumption:

Pressure of liquid hydrogen : **0.4 MPa**

Flow rate of each line: **50 tons/day (1.6 kg/s)**

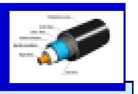
Parameters

Heat loads : 0.5 W/m, 1.0 W/m, 1.5 W/m, and 2.0 W/m

Table Calculation results of outlet temperature rise.

Temperature at Inlet (K)	Temperature at Outlet for Each Loss (K)			
	0.5 W/m	1.0 W/m	1.5 W/m	2.0 W/m
17.0	17.6	18.1	18.6	19.1
18.0	18.5	19.0	19.5	20.0
19.0	19.5	19.9	20.4	20.8
20.0	20.4	20.9	21.3	21.8
21.0	21.4	21.9	22.3	22.7
22.0	22.4	22.8	23.2	23.6
23.0	23.4	23.8	24.2	24.5

Power Consumption of Refrigerator



Power consumption of the refrigerator, *P*, can be estimated following equation.

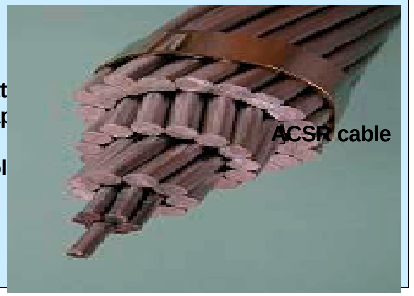
$$P \; ? \; W_L \frac{T_H \; ? \; T_L}{T_L} \frac{1}{?}$$

The refrigerator operates between *TH* (=300 K) and *TL* (=17 K).
W_L is refrigeration capacity, and ? is efficiency of the Carnot cycle.

Assumption:

T_H = 300 (K) , T_L = 17 (K)
??? ? = 0.25 (assumption)
W_L = 20 (kW) ;
(1 W/m for 10 km long two-way tubes)

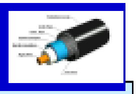
→ **P = 1.32 MW**



Power consumption of **1000 km long** HETL is estimat
This value is equivalent to 13.2 % to the transport cap

Cf. Joule loss of conventional 1GW class ACSR cabl
(2 kA, 275 kV) is about **230 MW**.

Conclusions

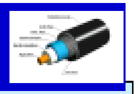


Applicability of 1 GW class hybrid energy transfer line of hydrogen and electricity is investigated. The results are concluded as follows;

- Power transportation capacity of the dc power line is 1 GW, and capacity of the liquid hydrogen transportation is 100 tons per day.
- To keep the liquid state of hydrogen anywhere in the unit section, the temperature and pressure of the inlet point were selected to 17 K and 0.4 MPa.
- When the heat leak into the liquid hydrogen is 1.0 W/m (expected value), the temperature at the outlet becomes 18.1 K.
- The total power consumption for the energy transfer system of 1000 km long becomes 132 MW. This value is equivalent to 13.2 % to the transport capacity of 1GW.

Thank you for your time and attention.

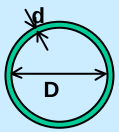
Bending strain of In-situ/MgB2



Not in published Data (@20K, 1T, Ic=84 A)
(Hishinuma A： private communication)

Definition of strain ??

??= (d/D) x 100 (%)



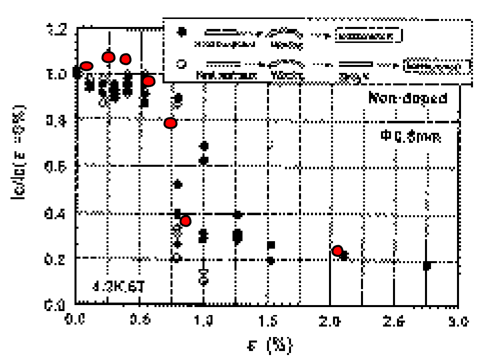


Fig. 2 Relationship between the normalized Ic and bending strain for MgB_2 mono-core wires at 4.2K and 6T.

Tanaka K et al, “ Bending strain of In-situ/MgB2 wire ”, Annual Conference of Cryogenic Society of Japan, May 2007, 1p-p22 (in Japanese).