O6-4 REPM2025

Development of an active magnetic refrigerator for hydrogen liquefaction

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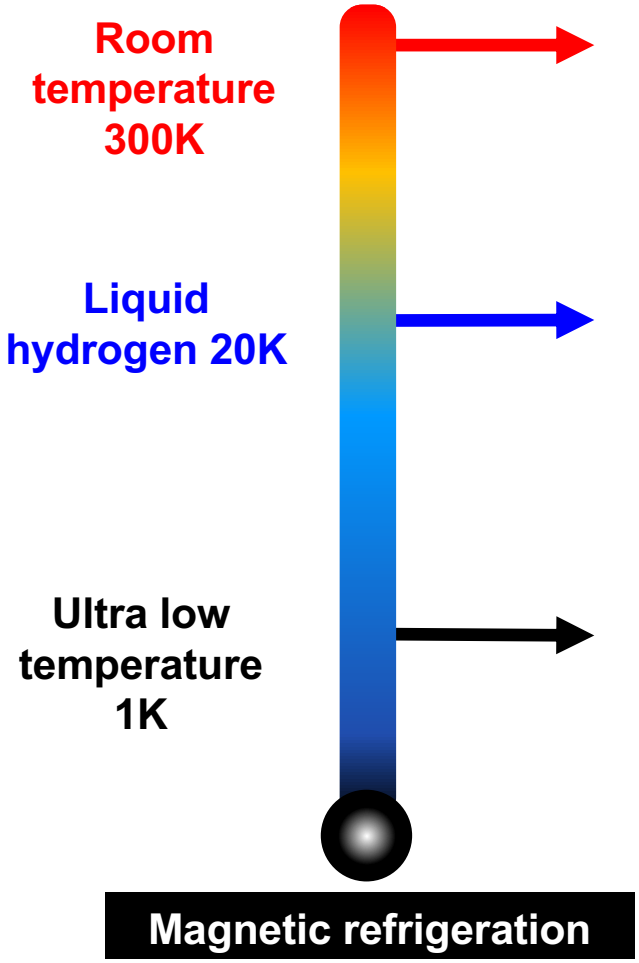
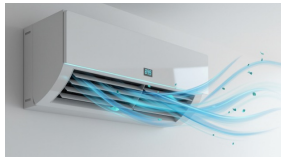
Date: July 29, 2025
Place: Tsukuba, Japan

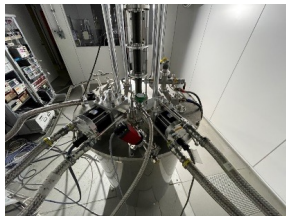
Application of magnetic refrigeration conducted in NIMS



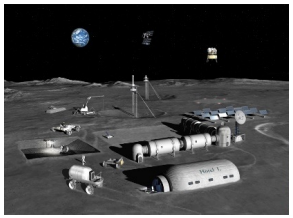
Air-conditioning



Hydrogen liquefaction

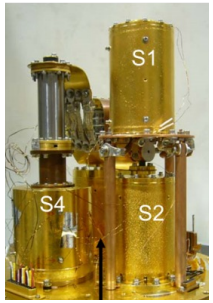


Space application

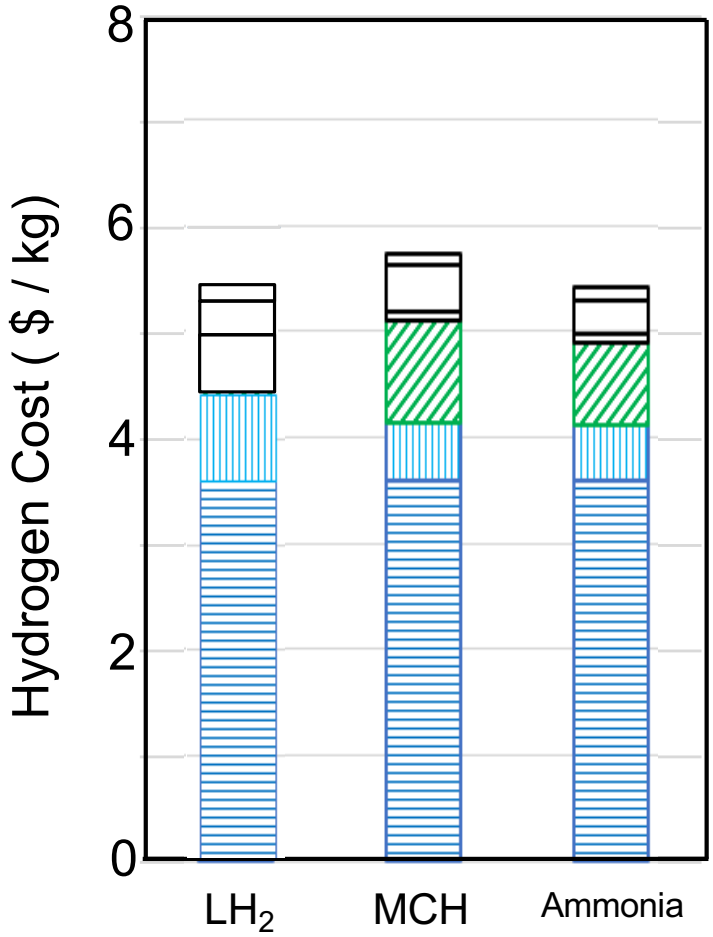


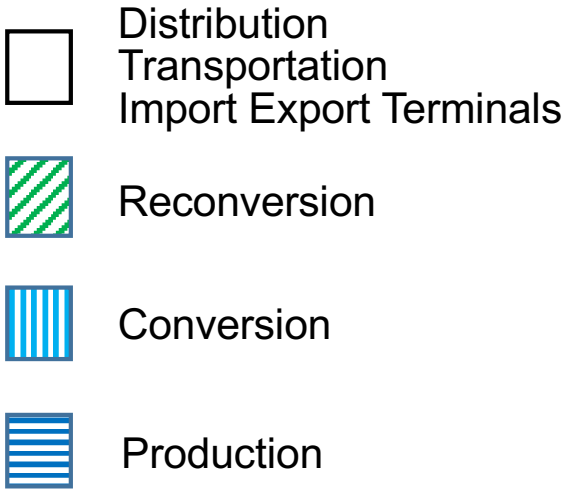
Quantum computers

Low temperature experiments



Comparison of hydrogen costs by 3 carriers



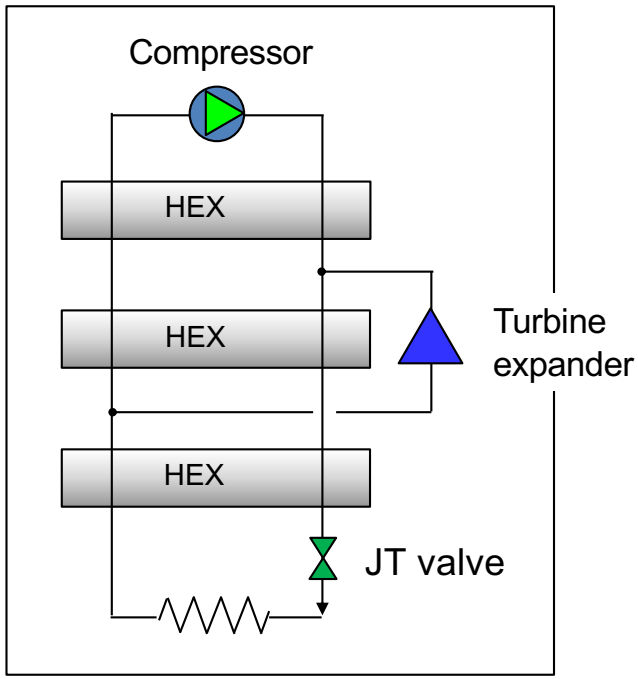


The calculation assumes Japan imports 100 tons/day of hydrogen from Australia in 2030.

IEA, “The Future of Hydrogen” (2019)

Conventional hydrogen liquefaction by vapor compression

Claude cycle



Vapor compression system requires a lot of energy.

→ Typical efficiency is about 25% (5 ton/day)

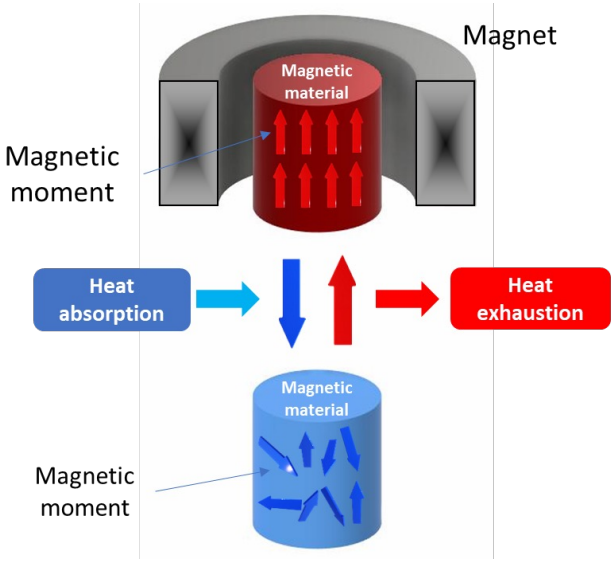
Principle of Magnetic Refrigeration

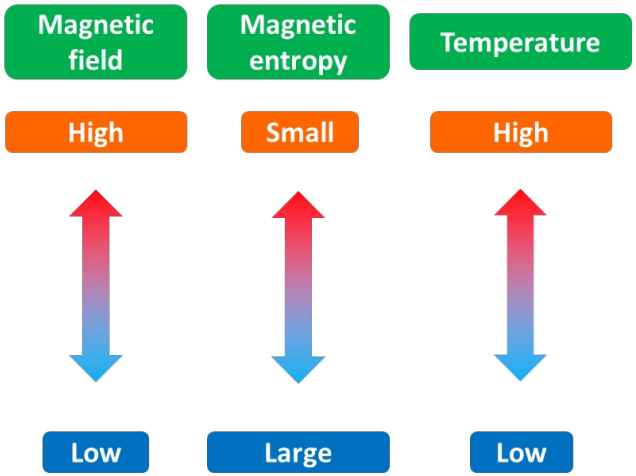
Magneto-caloric effect (MCE)

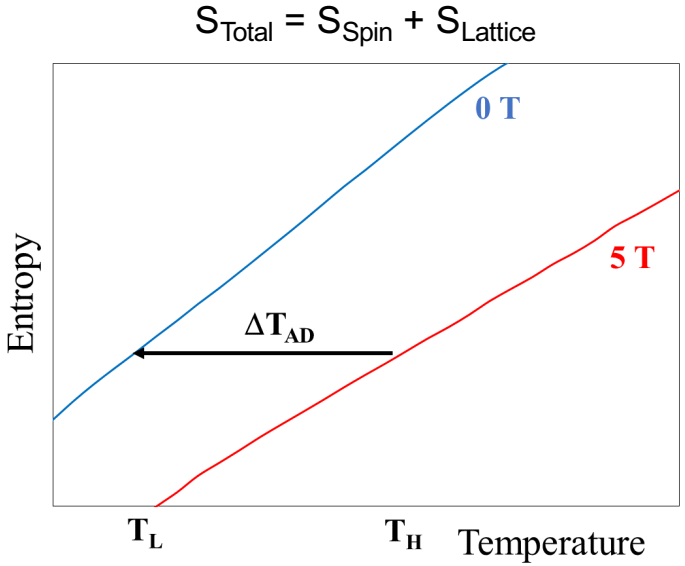
- Based on magnetic entropy change by applying magnetic field

Advantages of Magnetic Cooling

- Reversible cooling cycle : Magnetic Carnot cycle satisfied theoretical efficiency
- Environmental safety : no use of Freon or any other refrigerants to produce CO_2







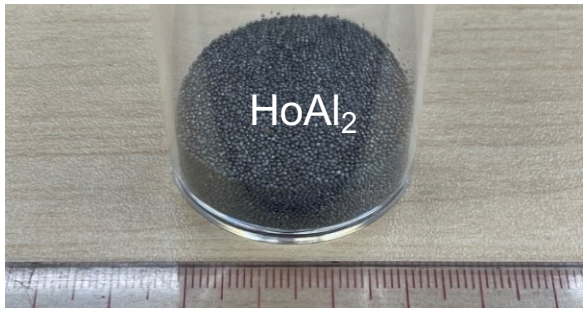
Magnetic refrigerant

Many candidate materials have been studied

Garnets, Intermetallic compounds (2nd order), First order materials

Fabrication

Spheres, thin plates



Garnet	$T_{c,N}$ (K)
$Gd_3Ga_5O_{12}$ (single)	0.8
$Gd_3Ga_5O_{12}$ (poly)	0.8
$Dy_3Al_5O_{12}$ (single)	2.5
$Dy_3Al_5O_{12}$ (poly)	2.5
$(Dy_{0.9}Gd_{0.1})_3Al_5O_{12}$ (pc	2.1
$Gd_3(Ga_xFe_{1-x})_5O_{12}$ (poly)	
$(Gd_xDy_{1-x})_3(Ga_xFe_{1-x})_5O_{12}$ (poly)	

Perovskite	
GdAlO3	4

RN	
DyN	21
GdN	62

R	
Dy	180
$Gd_{0.18}Dy_{0.82}$	195
$Gd_{0.36}Dy_{0.64}$	234
$Gd_{0.73}Dy_{0.27}$	266
Gd	293

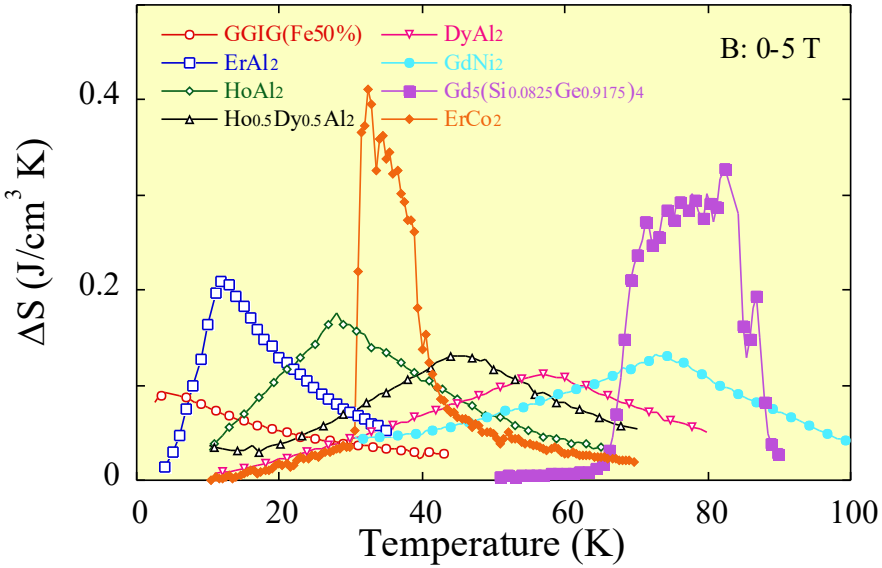
RAl_2	T_c (K)
$ErAl_2$	12
$Dy_{0.25}Er_{0.75}Al_2$	24
$Dy_{0.5}Er_{0.5}Al_2$	38
$Dy_{0.7}Er_{0.3}Al_2$	45
$DyAl_2$	63
$Dy_{0.5}Ho_{0.5}Al_2$	17
$HoAl_2$	27
$TbAl_2$	121
$GdAl_2$	182

RNi_2	
$ErNi_2$	8.5
$HoNi_2$	13
$DyNi_2$	26.5
$GdNi_2$	73

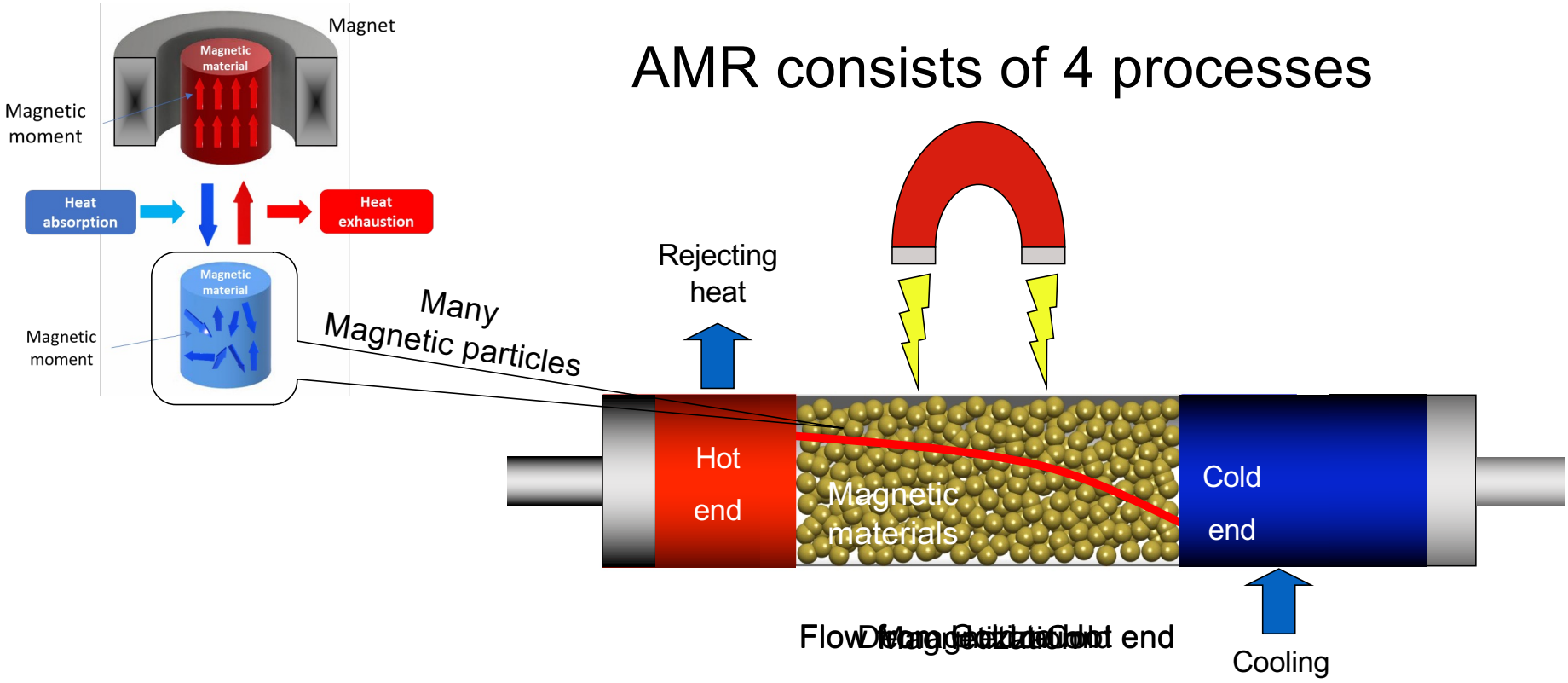
RCo_2	
$TmCo_2$	3.7
$ErCo_2$	32
$HoCo_2$	77
$DyCo_2$	137

$Gd_5(SiGe)_4$	$T_{c,N}$ (K)
Gd_5Ge_4	~20
$Gd_5(Si_{0.025}Ge_{0.975})_4$	~40
$Gd_5(Si_{0.06}Ge_{0.94})_4$	~50
$Gd_5(Si_{0.0825}Ge_{0.9175})_4$	75
$Gd_5(Si_{0.15}Ge_{0.85})_4$	90
$Gd_5(Si_{0.225}Ge_{0.775})_4$	120
$Gd_5(Si_{0.2525}Ge_{0.7475})_4$	135
$Gd_5Si_2Ge_2$	260

R_5Si_4	
Er_5Si_4	25
$(Er_{0.75}Dy_{0.25})_5Si_4$	~50
Ho_5Si_4	76
Dy_5Si_4	140
Tb_5Si_4	225
Gd_5Si_4	336



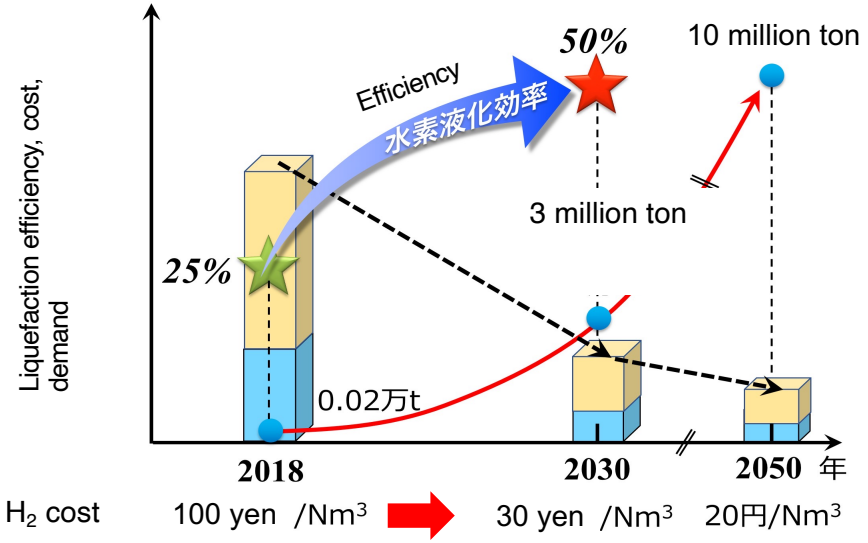
AMR cycle in real system

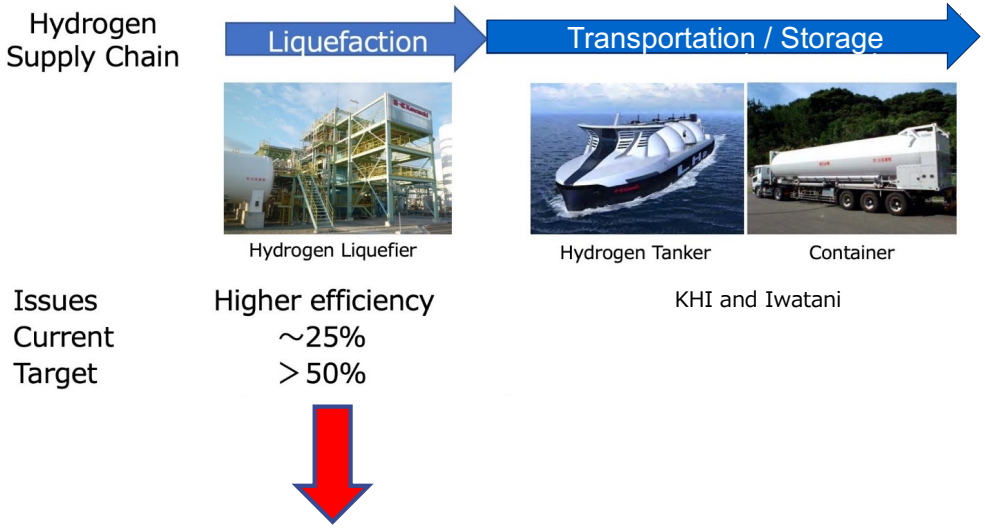


JST Mirai Project – Hydrogen liquefaction by AMR -

Background

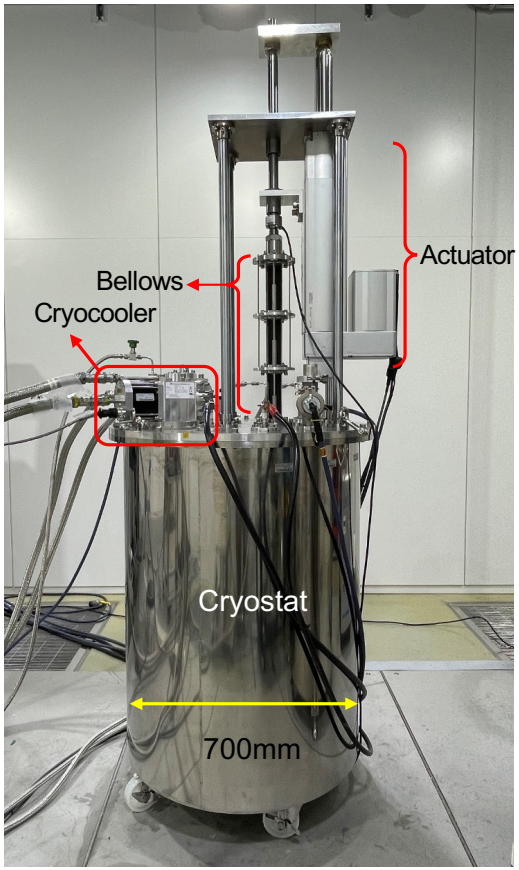
The Basic Hydrogen Strategy targets hydrogen consumption of 3M tons and cost of 30 yen/Nm^3 by 2030.

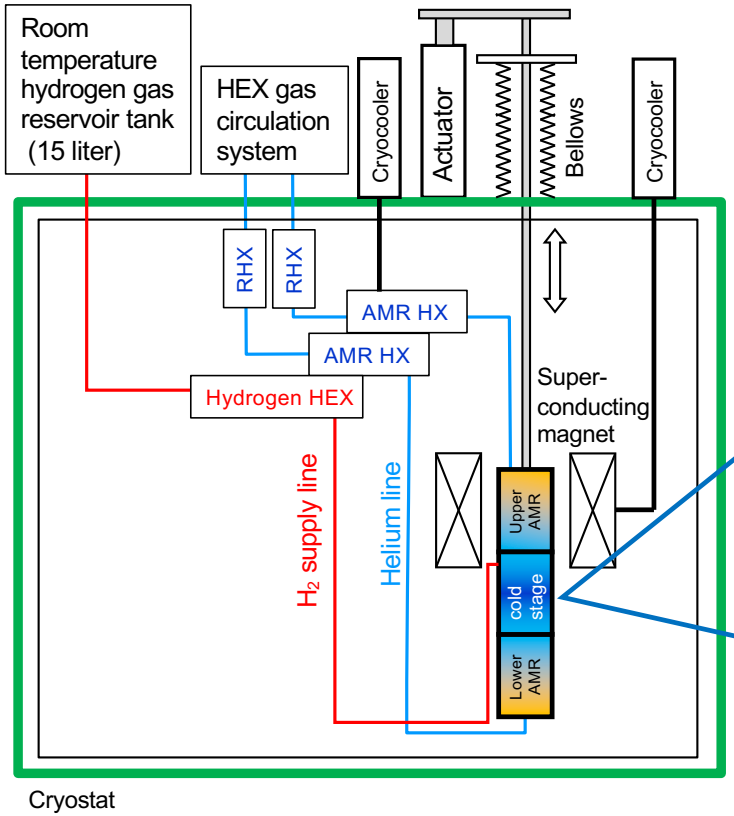


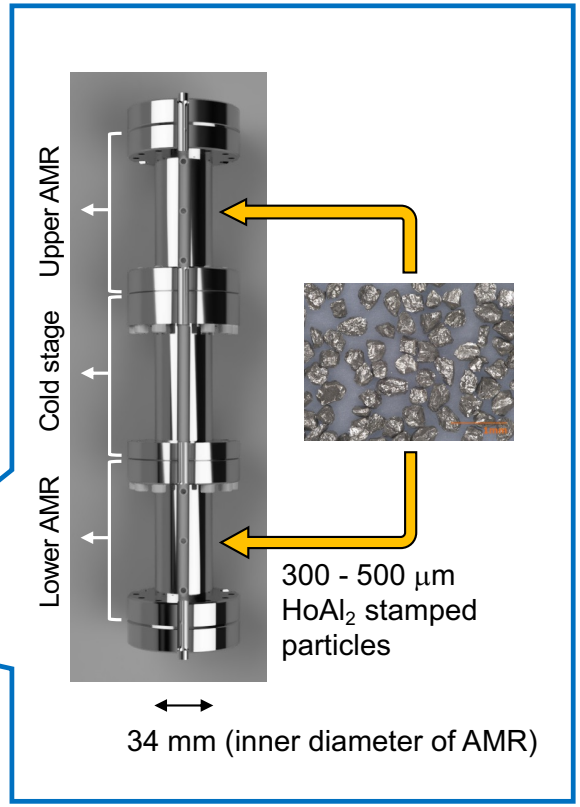


Highly efficient liquefaction

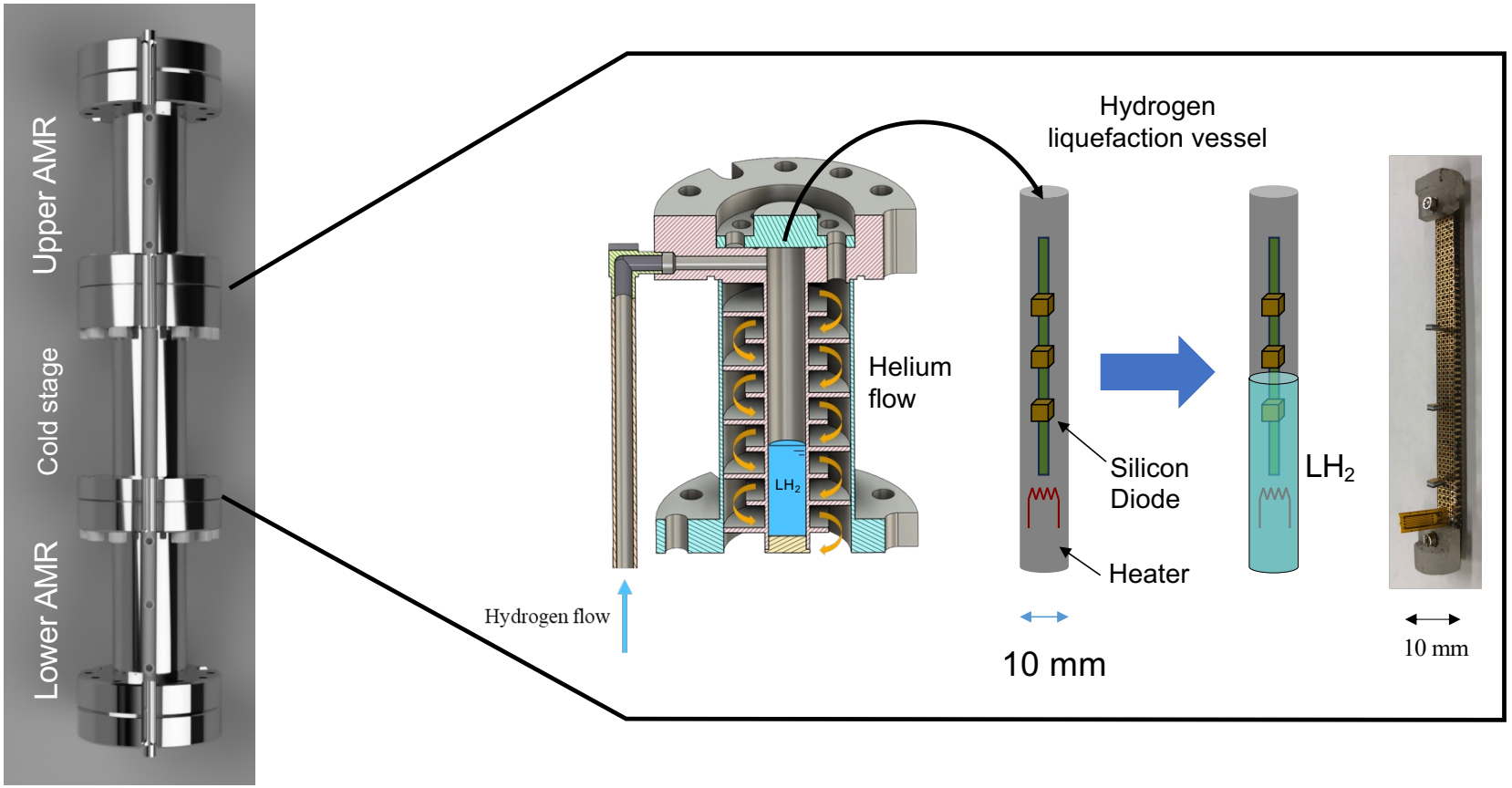
Picture and schematic of AMR for hydrogen liquefaction



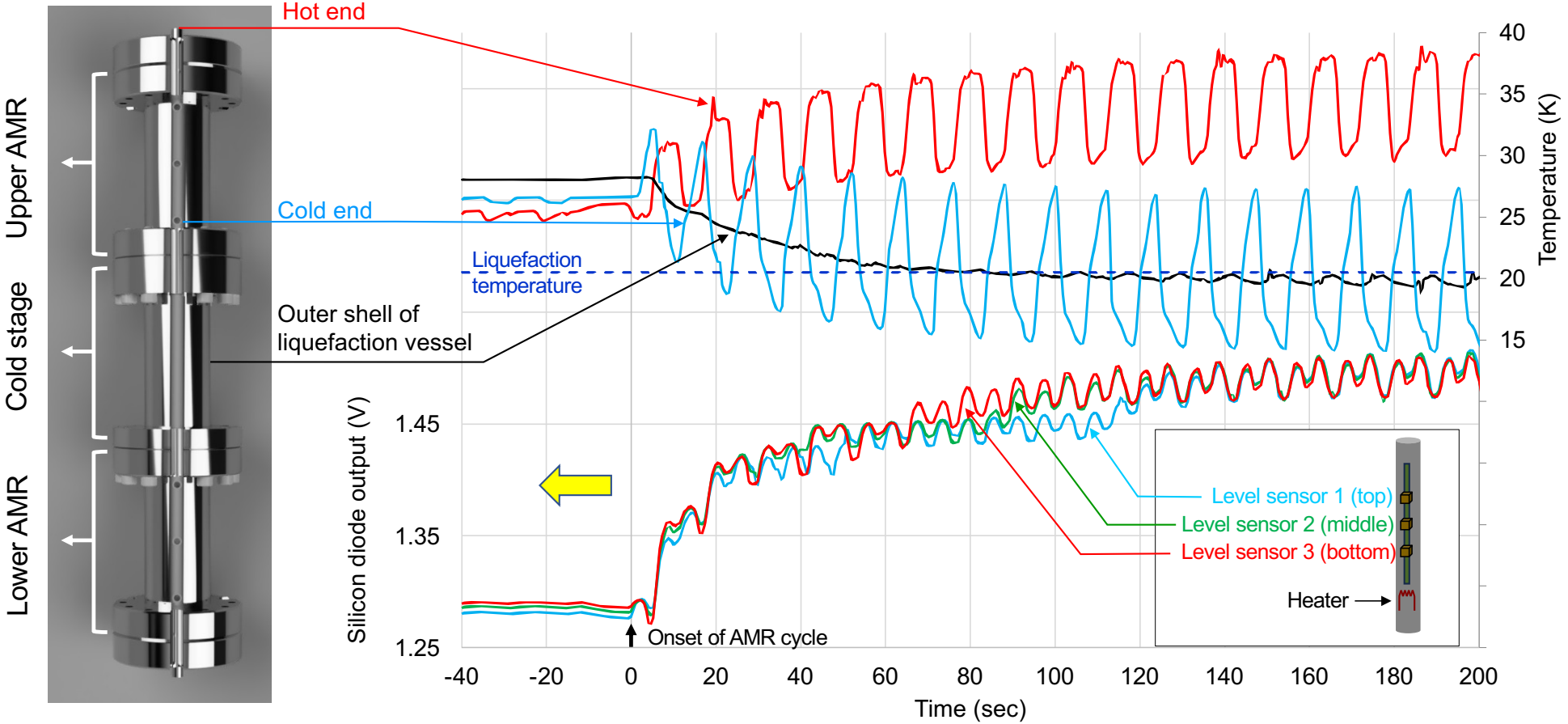




Liquid hydrogen vessel and liquid level sensors



AMR hydrogen liquefaction experimental result



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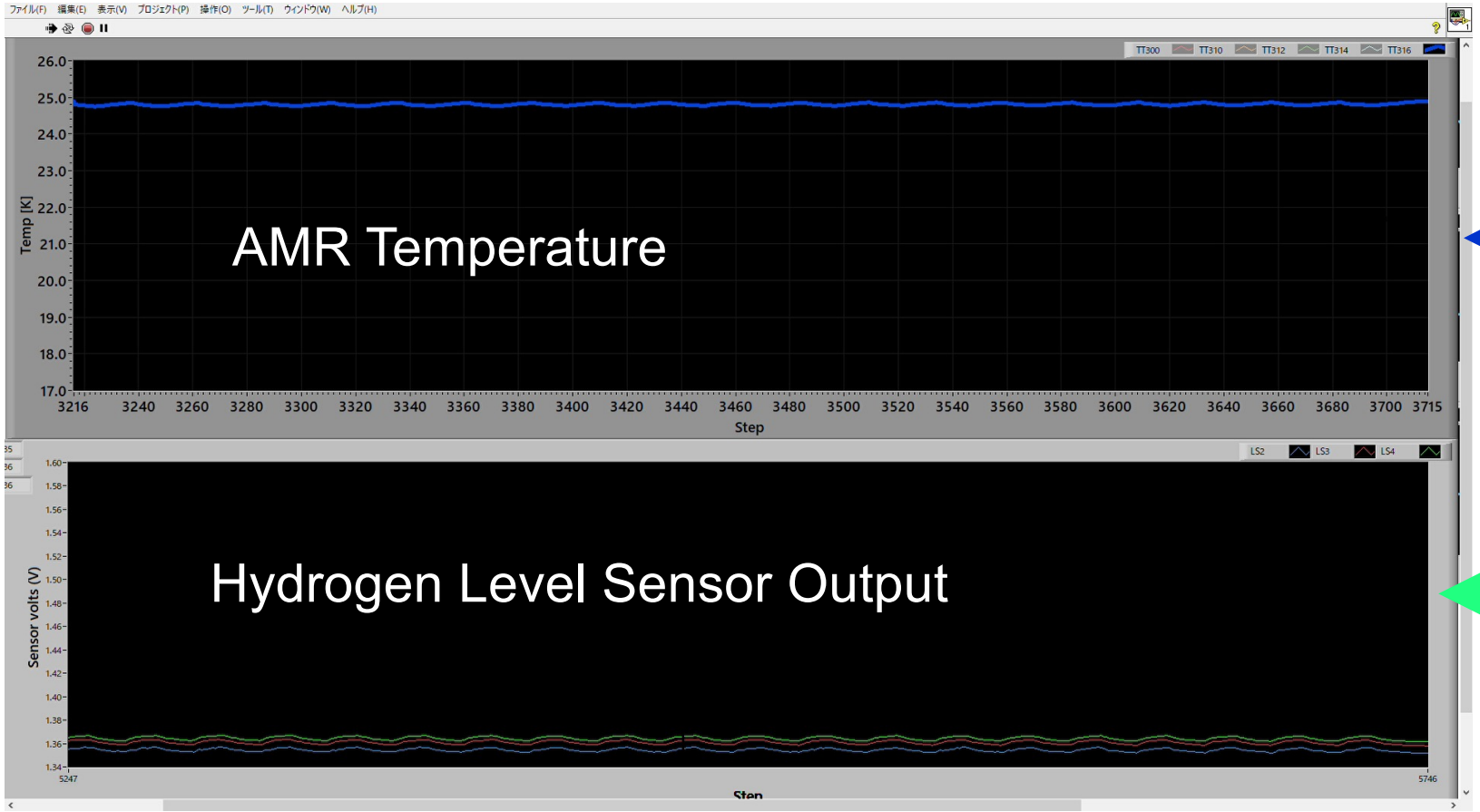
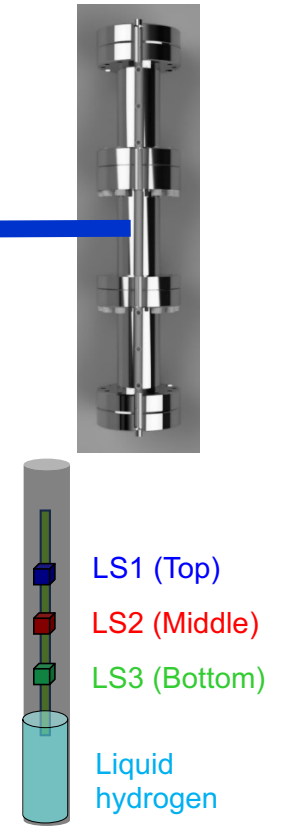
Hydrogen liquefaction experiment video





Future plan - Scaling-up of AMR

Scaling-up, and scaling up…

We are here

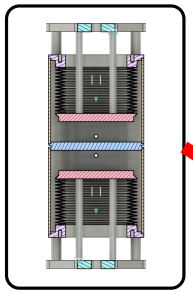
STEP 3
(2025～2027)

Target

Efficiency : 50%
Capacity :100 kg/day

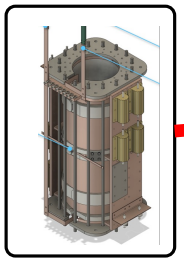
Large-scale AMR

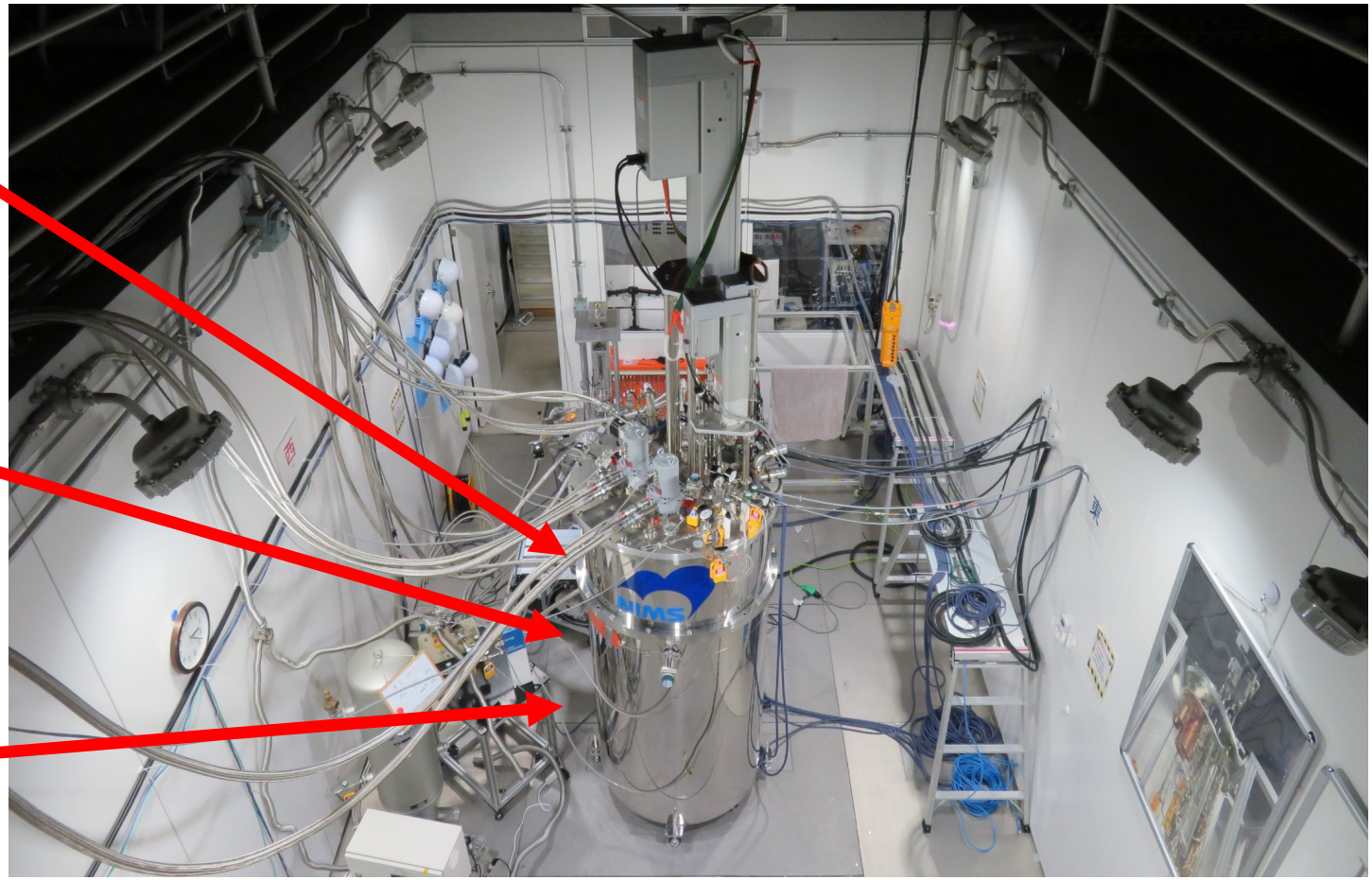
Newly developed cryogenic pump



Larger AMR vessel

Larger Superconducting magnet





The large-scale AMR has been assembled and has begun trial operations.

Summary

1) NIMS has developed an AMR for hydrogen liquefaction and successfully liquefied hydrogen.
2) The large AMR has been assembled and has begun trial operations.

Acknowledgements
This research was supported by the JST Future Society Creation Project "Development of Innovative Hydrogen Liquefaction System by Magnetic Refrigeration Technology" (JPMJMI18A3).