Astronautics ~200w intégration
(B2C – Consumer Appliances)
B2C & AC (AC 3KW Demo)

Cooltech 200-400w intégration
(B2I – Médical Appliances)
Focused on B2C & B2B

Camfridge 35~50w
(B2C – Fridge unit)
B2C units exclusively

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solutions for europe
natural refrigerants
19 & 20 April, 2016 – Barcelona

Demonstrators
(Published Results)
35w~3kW

EU Regulations
ELICiT B2C
MagFreeG B2B

Updated to also include
MRS OEM Status @ MAY 2016

Magneto-caloric Consulting @ MoveOnn Inside
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Informed on MRS

Metallic Refrigerant Suppliers
3 EU trademarks todate
+40°C /'Ambient Temperature'

MRS – Magneto-caloric Refrigeration Systems

MRS : A natural refrigerant technology

Status of sector since Brussels : April 2015

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Timothy Lorkin

Chairman – Industry Sub-Working Group (I-SWG)

www.iifiir.org

MoveOnn Inside
Informed on MRS

P164064-2

MRS – Magneto-caloric Refrigeration Systems

ATMOsphere EUROPE
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Presented as

Industry SWG Chairman

IIR-IIF Magneto-caloric Working Group
I-SWG or Industry Sub-Working Group

Timothy Lorkin

Magneto-caloric Consulting @ MoveOnn Inside
Lorkin.MOI@gmail.com
+33 (0) 607 956 198

Informed on MRS

To be discussed

1. Relative to Compressor systems
2. Caloric refrigeration – Industrialization

   Today — Magneto-caloric & 2020 Refrigeration

   Future — Elasto & Electro Caloric A/C & Solid-state

3. Challenges Standards & Regulations

Will not be discussed

Application specific information

4. Status : MRS OEM developers May '16

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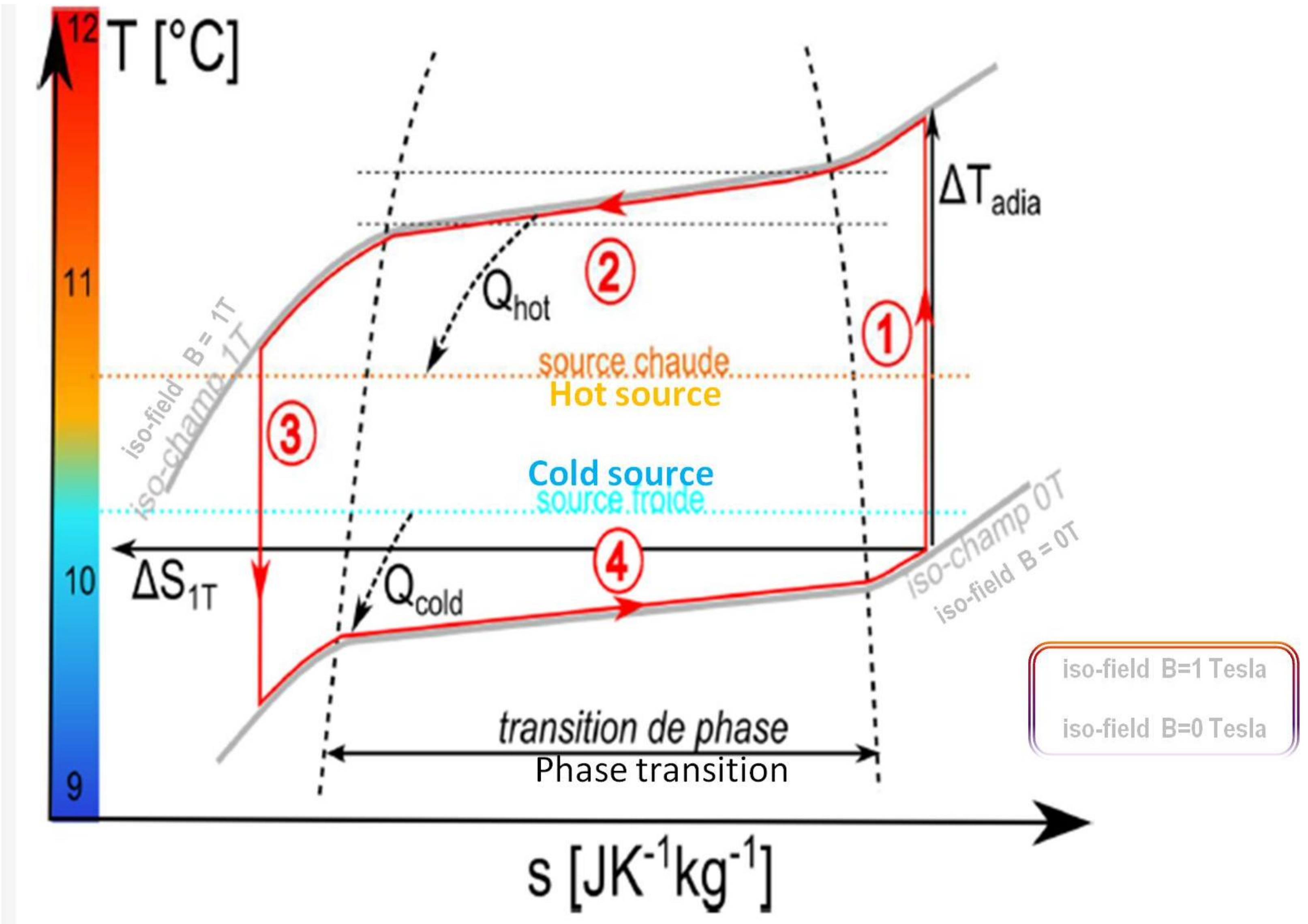
Active Magnetic Regenerative cycle
Basic BRAYTON cycle

#1

B='0' Tesla B='1' Tesla

Applied Quantum Physics

Electron 'Energy'	absorbed	←→	released
Magnetic constraints	1 Tesla	←→	0 Tesla
Metalic Refrigerant	Heats	←→	Cools
Caloporter Fluid	transfers energy to / from HEX		

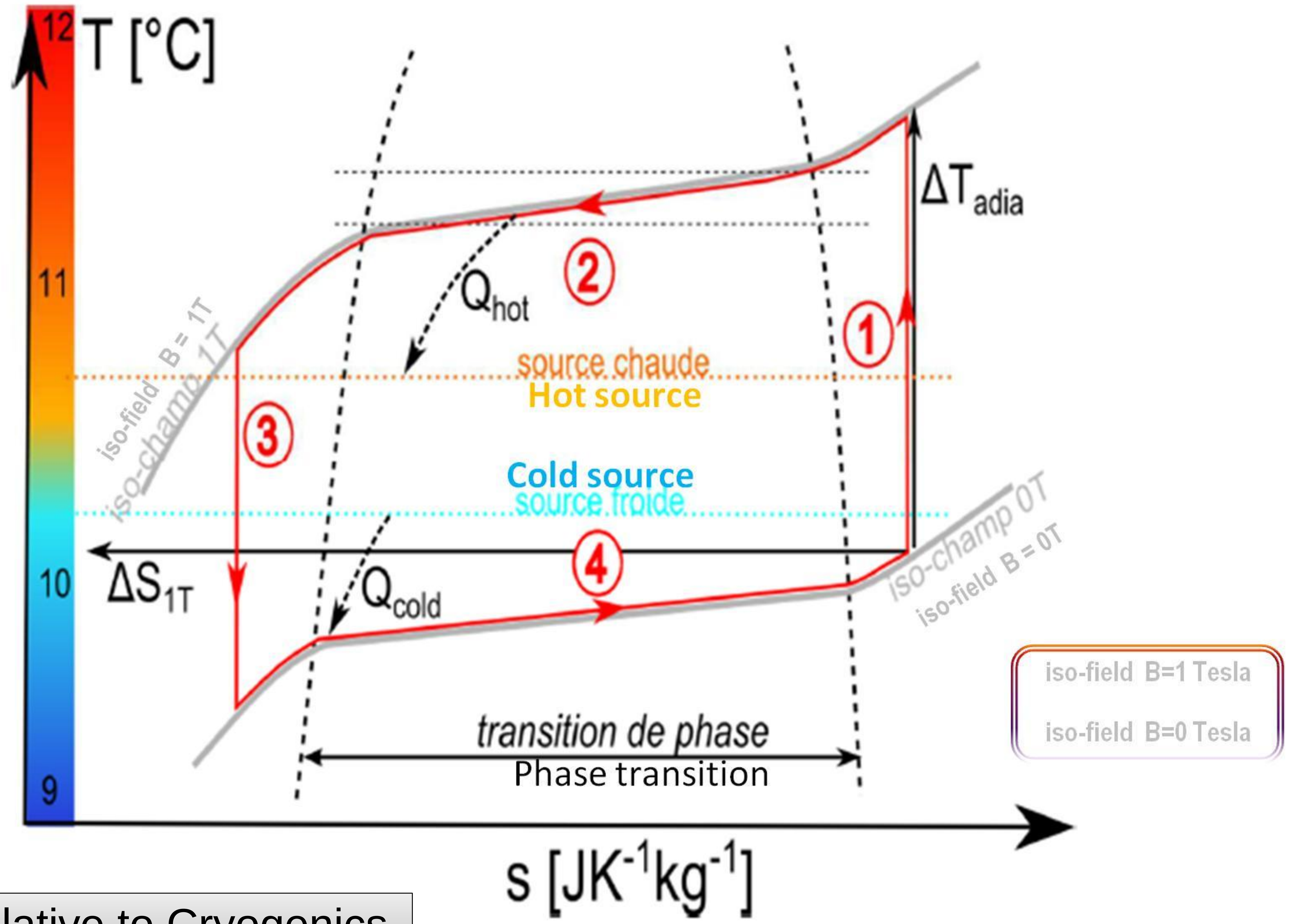


Diagrams - Delft Technical University G2E Lab Grenoble

Active Magnetic Regenerative cycle
Basic BRAYTON cycle

#1

B='0' Tesla B='1' Tesla



Ambient or 'High' Temperature (~±40°C), relative to Cryogenics

Active Magnetic Regenerative cycle

Basics of Magneto-caloric refrigeration

#1

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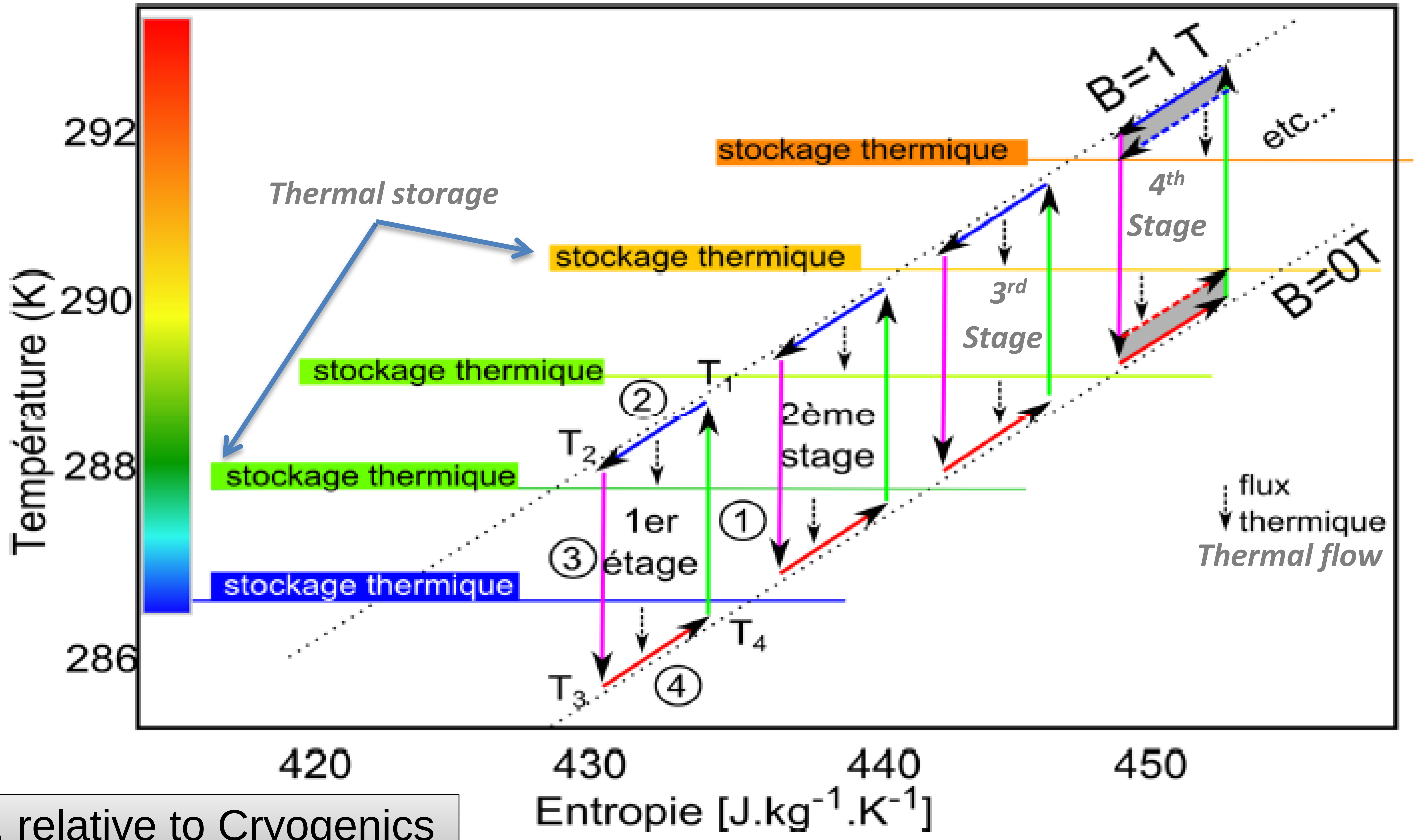
B='0' Tesla B='1' Tesla



Ambient or 'High' Temperature (~±40°C), relative to Cryogenics

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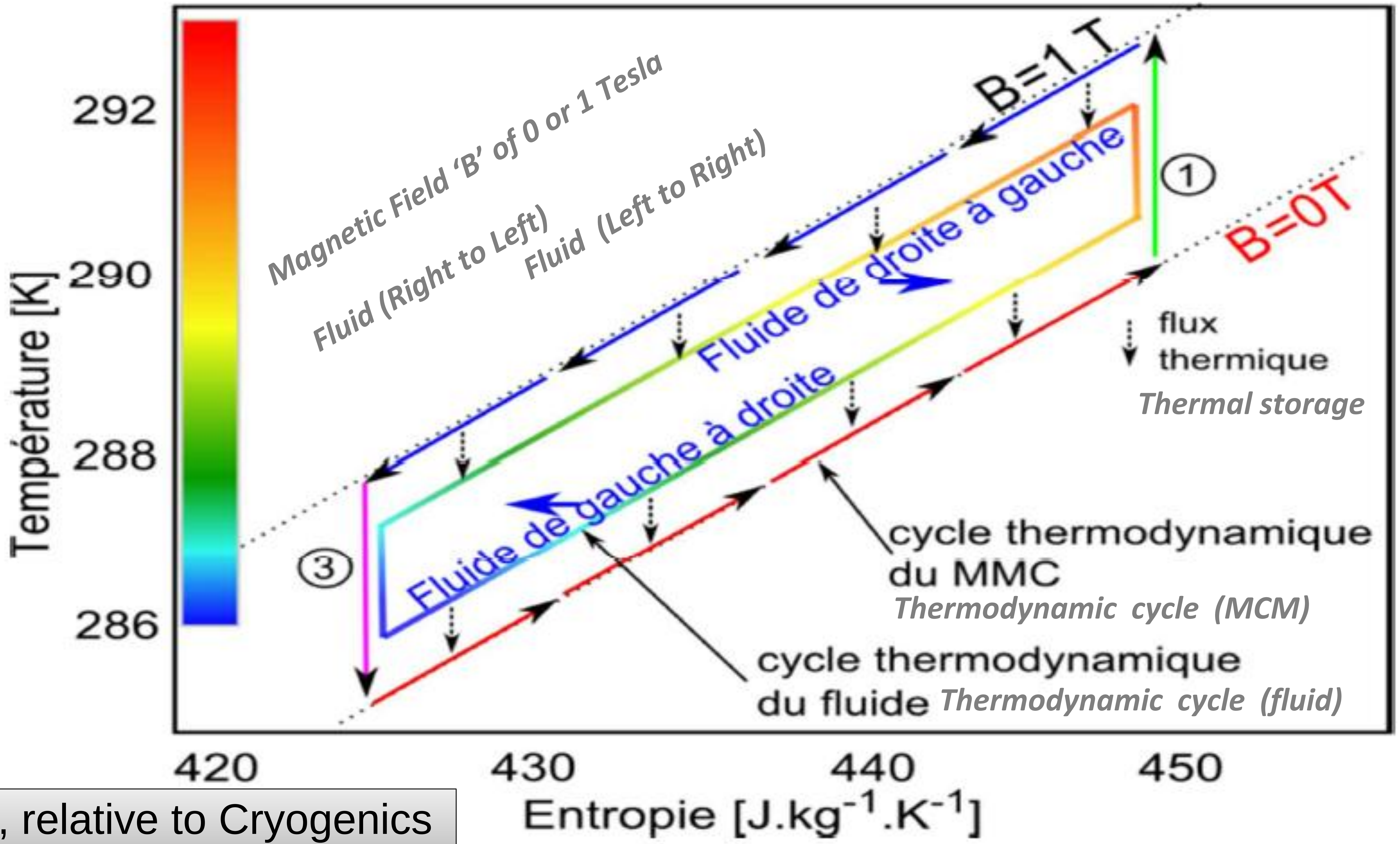
Active Magnetic Regenerative cycle

Basics of Magneto-caloric refrigeration #1

B='0' Tesla B='1' Tesla



Ambient or 'High' Temperature (~±40°C), relative to Cryogenics

Caloric refrigeration
Industrial MRS Systems

Today Magneto-caloric Refrigeration & 2020 (Public domain information / Conferences)

Magneto-caloric	Astronautics, Camfridge, Cooltech, GE Appliances*, Samsung*	Companies	Trade shows, presented public demonstration systems with industrialisation objectives
	France*, Germany, Denmark, Japan, Brazil (Company names available)	Other Industrialising companies / Academic groups	@ Conferences development systems under test
	Academic Laboratories Globally	Academic	'Fundamental' advances System level & Metallic Refrigerant

* SME OEM developer & fundraising / Advanced research groups

Power : 35W~3kW 'Ambient' MRS Demonstrator systems, Trade Shows etc
Sectors : Consumer, Industrial Refrigeration, Medical, HVAC

Caloric refrigeration

Industrial MRS Systems

Today Magneto-caloric Refrigeration & 2020 (Public domain information / Conferences)

Magnets & Metallic Refrigerant	Metallic Refrigerant (Magneto caloric Materials) Manganese or Lanthanum based	Industrial Companies	Three EU companies* with trade marks (2015) other suppliers from China, USA & Japan
	Magnetic Systems	Industrial Companies	Existing producers, adapting to requirements
	EU, Regional &/or Global projects	Industrialising Academics	Rare earth reduction / avoidance
	Academic Laboratories Globally	Academic	'Fundamental' advances Materials with low/No Rare earth content

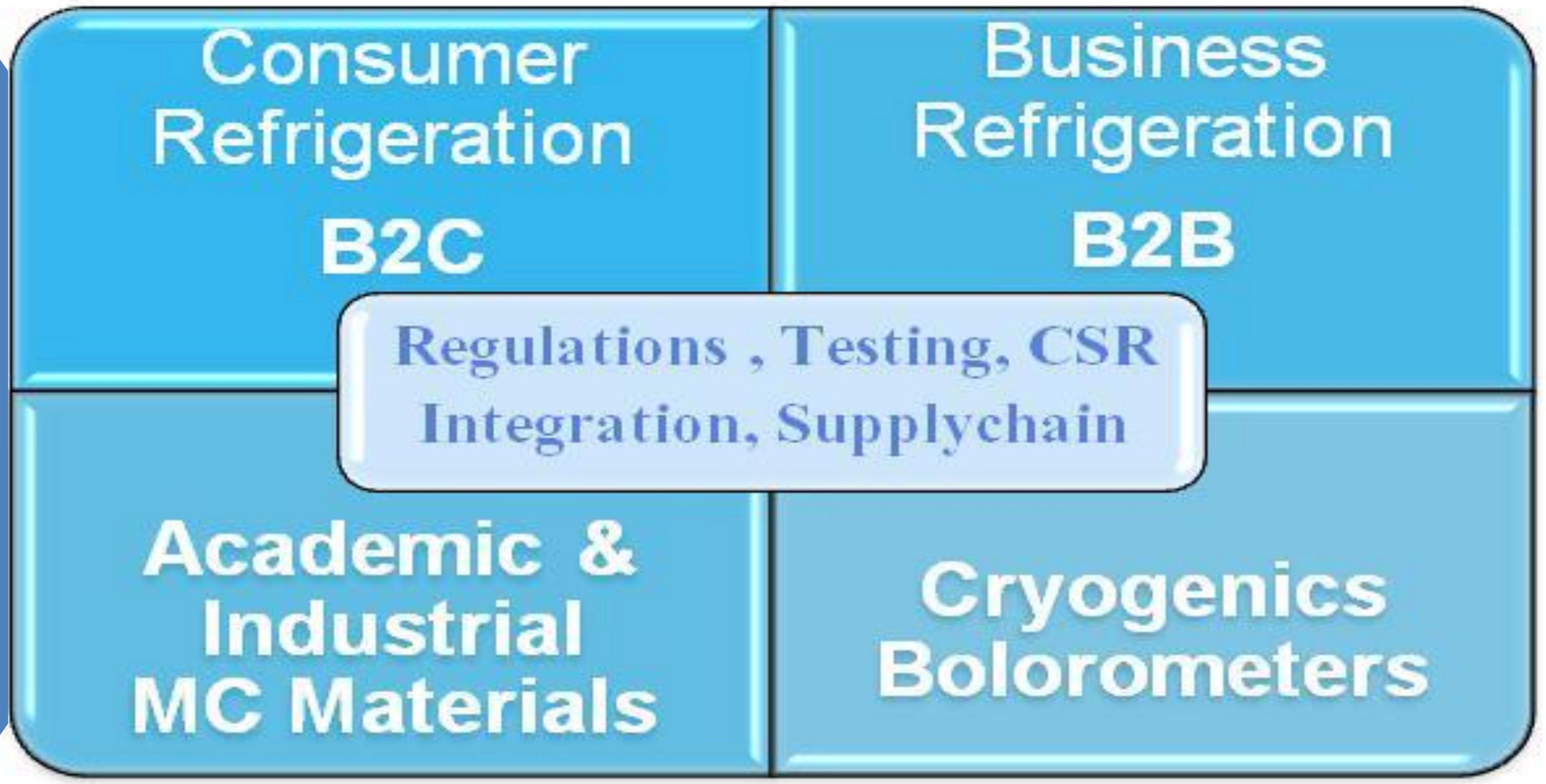
* Metallic Refrigerant, suppliers with existing global presence

Caloric refrigeration &IIR-IIF Indusrty SWG

#3

IIR-IIF ‘Industry’ Sub-working group (2014)

Timothy Lorkin (Chairman)	France	MoveOnn Inside (Consultant)
David Beers (Co-Chairman)	USA	GE Appliances
Pr. John Barclay	USA	Emerald Energy
Pr. Ekkes Brück	Holland	Delft Tech. University
Pierluigi Schisario	Italy	ARNEG S.A
Robert Hurley	UK	Retail Engineering Solutions (Consultant)



➔ Feedback to global Industrial & Academic ‘Expert circle’

‘Materials’ & ‘System’ Sub-working groups ➔ Academic (2006)

Caloric refrigeration Magneto-caloric MCM

Metallic Refrigerant (MCM)

EU Project : SSEEC – 2012

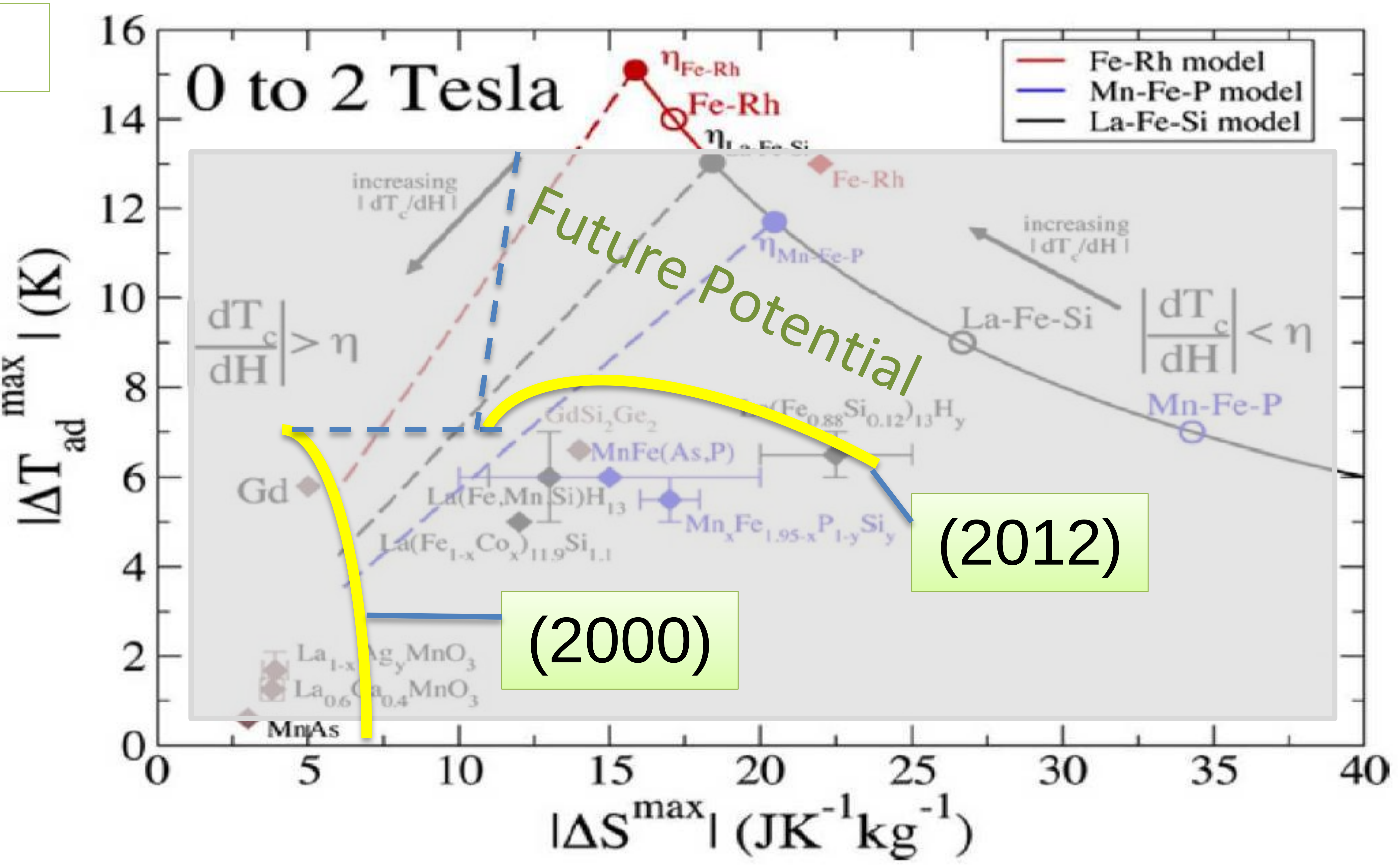
- REE reduction eg Magnets (Lifecycle & recycling)
- MCM limit & characterisation

MCM evolution potential

➔ Optimised for both ΔT & ΔS

➔ Multiple MCM families

➔ La & Mn families Industrialised (Three MCM trademarks in EU alone)



Karl G. Sandeman, Imperial college, Scr. Mater., 2012.

Caloric refrigeration

Future Options

Future **Elasto & Electro Caloric** **Air-conditioning & Solid-state**

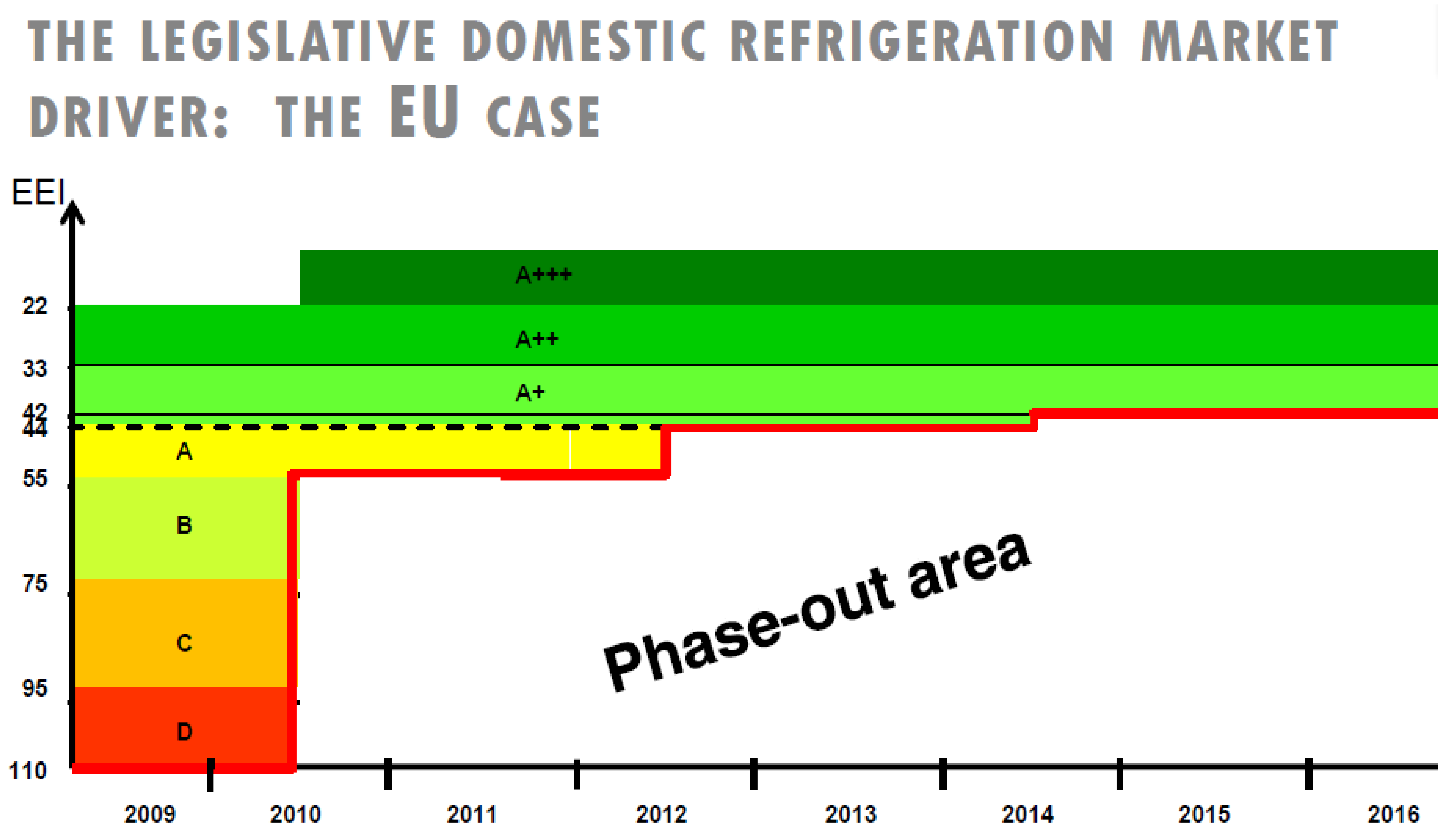
Elasto	USA & Switzerland	Industrialising PME & Academics	@ Conferences development systems under test
			Demonstrator AC systems ➔ 20°C air temperature drop
Electro	Academic Laboratories	Academic	'Fundamentals' Proof of concept

Challenges
- Exotic *Ambient or High EC* temperature materials
- Engineering (relative to Cryogenics)
- Power

Caloric refrigeration

Regulations : EU level support for Integration & International scope

- ELICiT (Camfridge – 2016)
- MagFreeG (Cooltech – 2017)



IIR-IIF 'Industry' Sub-working group

- Transversal standards (to establish..)
- Industrial oversight for MRS integration into EU Regulations

International Conferences & Industrial MRS

ICR2015 (Yokohama), ATMOsphere EU (Barcelona), CES & ASHRAE (USA)..

Caloric refrigeration
Standards & Regulations

IIR-IIF ‘Industry’ Sub-working group (Established Q4-2014)

- Transversal standards
  Workshops established in 2015
  Academia – Suppliers – MRS ‘OEM’ Developers
  2nd round September 2016 Thermag VII in Turin
  eg Metallic Refrigerant (MCM) Academic Round Robin → Industrial Supply Chain

- Industrial oversight for integration into EU Regulations
  Validating proposals via Global Experts, basis for EU integration (All Sectors)

Global MRS ‘Expert Circle’ CSO, Scientists..	Industrialising OEMS →	Astronautics, Camfridge, Cooltech ..
	Metallic Refrigerants →	Industrials & Academics
	System Development →	Industrial Adv. R&D, SME’s & Academics

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natural refrigerants

19 & 20 April, 2016 – Barcelona

Thank you very much!

Timothy Lorkin : MoveOnn Inside

MRS Engineering consulting

Email lorkin.moi@gmail.com

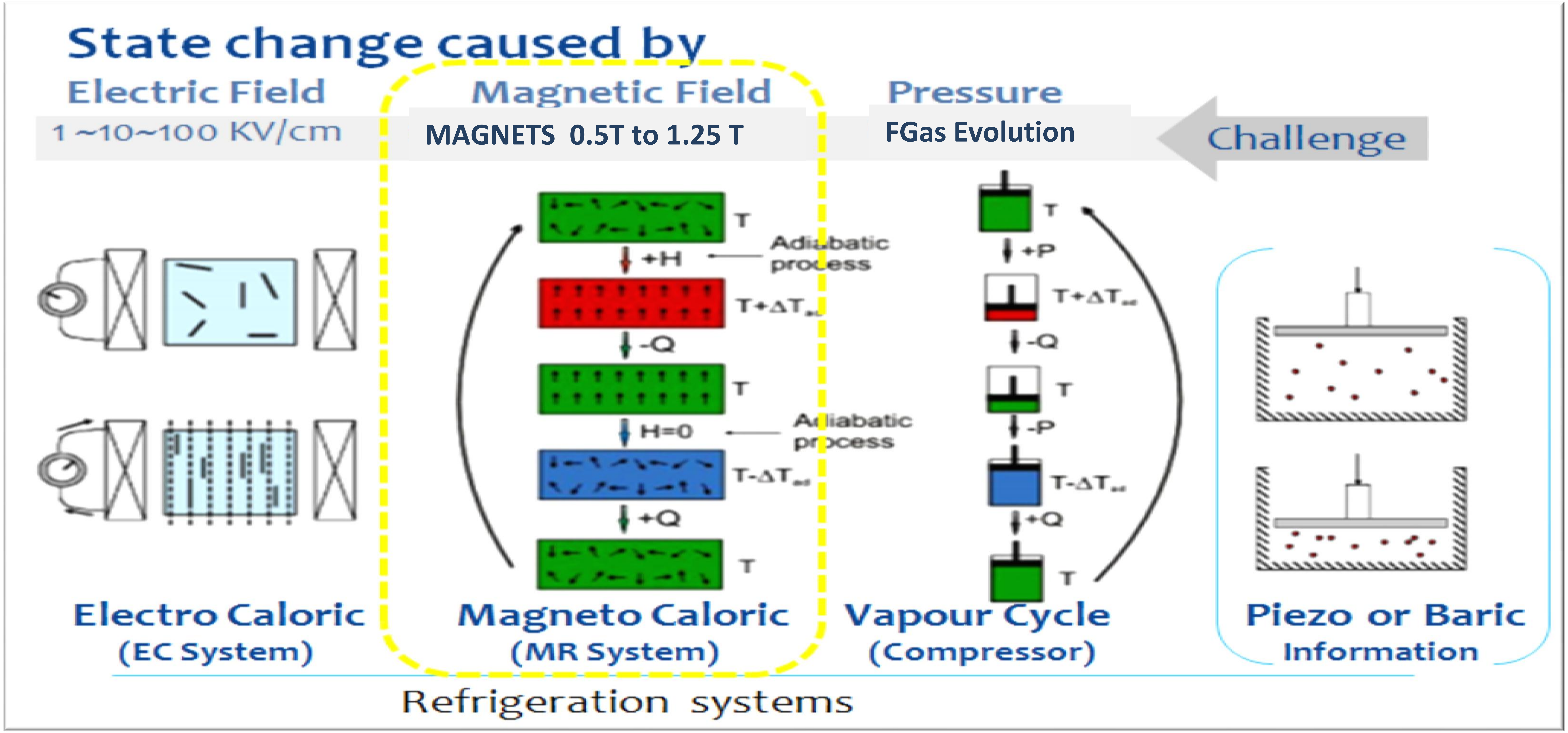
MoveOnn Inside

Informed on MRS

Caloric refrigeration

Compression Comparison

#4



MoveOnn Inside
Informed on MRS

ATMOsphere EUROPE solutions for europe natural refrigerants

IIR-IIF Sponsors
Caloric refrigeration Thermag conference series

The International Institute of Refrigeration (IIR), an independent intergovernmental science and technology based organization, promotes knowledge transfer of refrigeration technologies that improve quality of life in a cost effective and environmentally sustainable manner including:

- Food quality and safety from farm to consumer
- Comfort in homes and commercial buildings
- Health products and services
- Low temperature technology and liquefied gas technology
- Energy efficiency
- Use of non-ozone-depleting and low global warming refrigerants in a safe manner

iif iir www.iifiir.org

Sponsors of Magneto-caloric refrigeration (Ambient & Cryo)
Thermag conferences – Sept 2016 : Thermag VII in Turin

Acknowledgements

Delft Technical University	Pr Ekkes Bruck	
G2ELab Grenoble	Pr Afef Lebouc	Presentation AFF January 2016
NEEL lab Grenoble	Dr M Almanza	Eur.Phys Journal of applied Physics 71 1 2015
Imperial College London	Dr K Sandeman	Magnetocaloric materials: The search for new systems. (2012) Scripta Materialia 67(6):566 · Sept 2012

Annexes for internet document

#4

Information from publically declared MRS Development OEM's @ Thermag or Delft DDMC conferences

Following - ICR2015 workshop status or May 2016 Status

1~3 pages requested

Premiere of cutting edge cooling appliance

(4A)

(4B)

(4C)

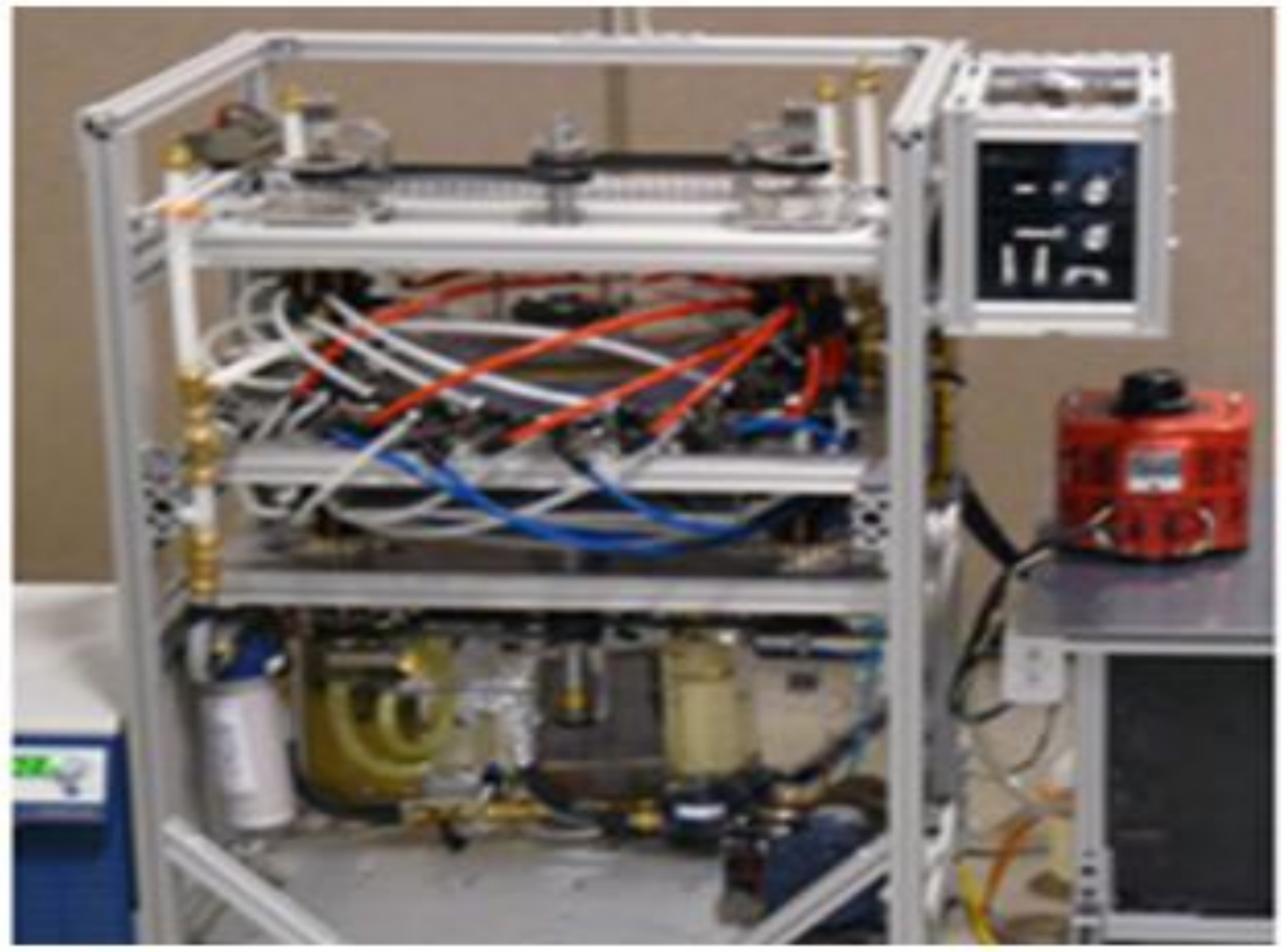
(4D)

(4E)

Symbols are Active website links
updated ICR2015 status will be available for May 2016

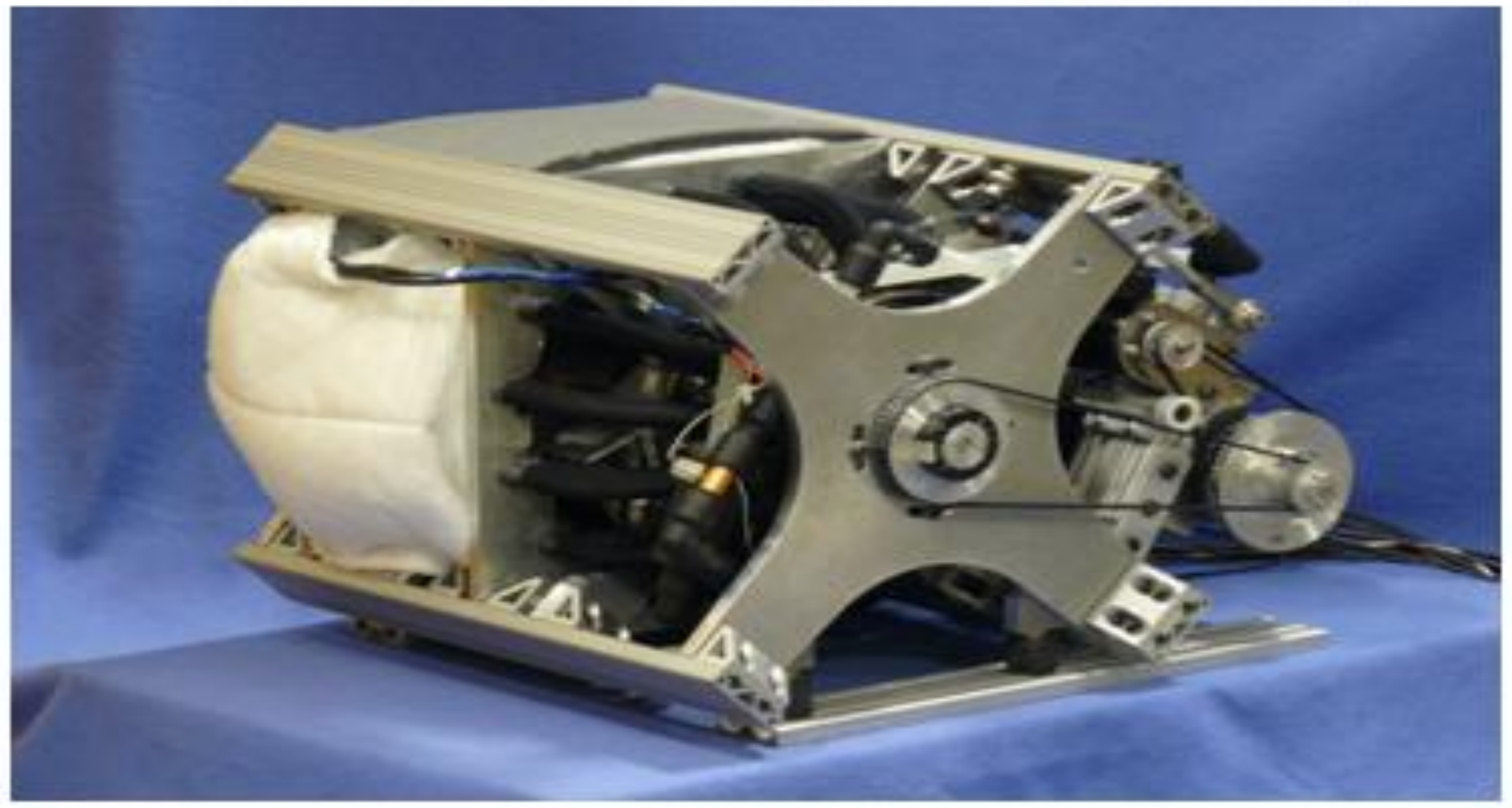
Astronautics Corporation of America

Magnetocaloric Heat Pump Systems



2001
10's Watts
Gadolinium MCM

2012
1000's Watts
$La(Fe,Si)_{13} H_y$ MCM



2015
Appliance Prototype
with BASF & Haier
MnFePSi MCM

Contact:
Dr. Steven L Russek
s.russek@astronautics.com
www.astronautics.com

Astronautics Corporation of America

Decades of Astronautics Know-How

Materials, Components & Systems

- ➢ Started with technology transfer from Los Alamos National Lab, inventors of the Active Magnetic Regenerator Cycle, in 1984
- **Key Milestones**
  - ✓ 1997 1st high efficiency room-temperature MHP (600 W, superconducting magnet)
  - ✓ 2001 1st permanent magnet room-temp MHP (50 W max, 21 C Span max)
  - ✓ 2005 1st demonstration of first-order MCM [LaFeSiH] in an MHP
  - ✓ 2006 Rotary-permanent magnet room-temperature MHP (100's W with Gadolinium MCM)
  - ✓ 2009 Successfully scaled up LaFeSiH MCM – Comprehensive understanding of MCMs
  - ✓ 2010 1st demonstration of layered bed with first-order MCM (400 W @ 10 c span)
  - ✓ 2012 Record performance metric of 168 W/T/liter (2400 W @ 11 C Span, 2.2 COP)
  - ✓ 2015 Demonstrated first appliance prototype at US Consumer Electronics Show

Current Focus

Cost Effective Magnetocaloric Heat Pumps (MHP)
High Performance Magnetocaloric Materials(MCM) & Beds
Low Field (~1 T) Permanent Magnets
Industrializing Product Design for Cost Effective Products
Evolving Supply Chain with Industrial Standards
Meet 2020 F-Gas Deadline

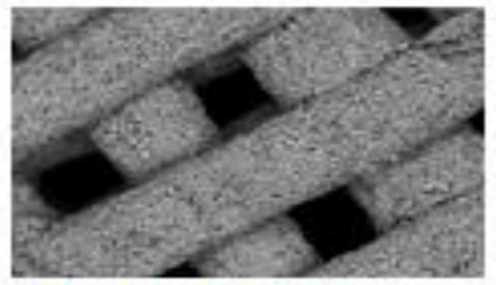
Astronautics Corporation of America

Comprehensive RD&E

Materials Development

Materials Science

Cost Effective Magnetocaloric Materials

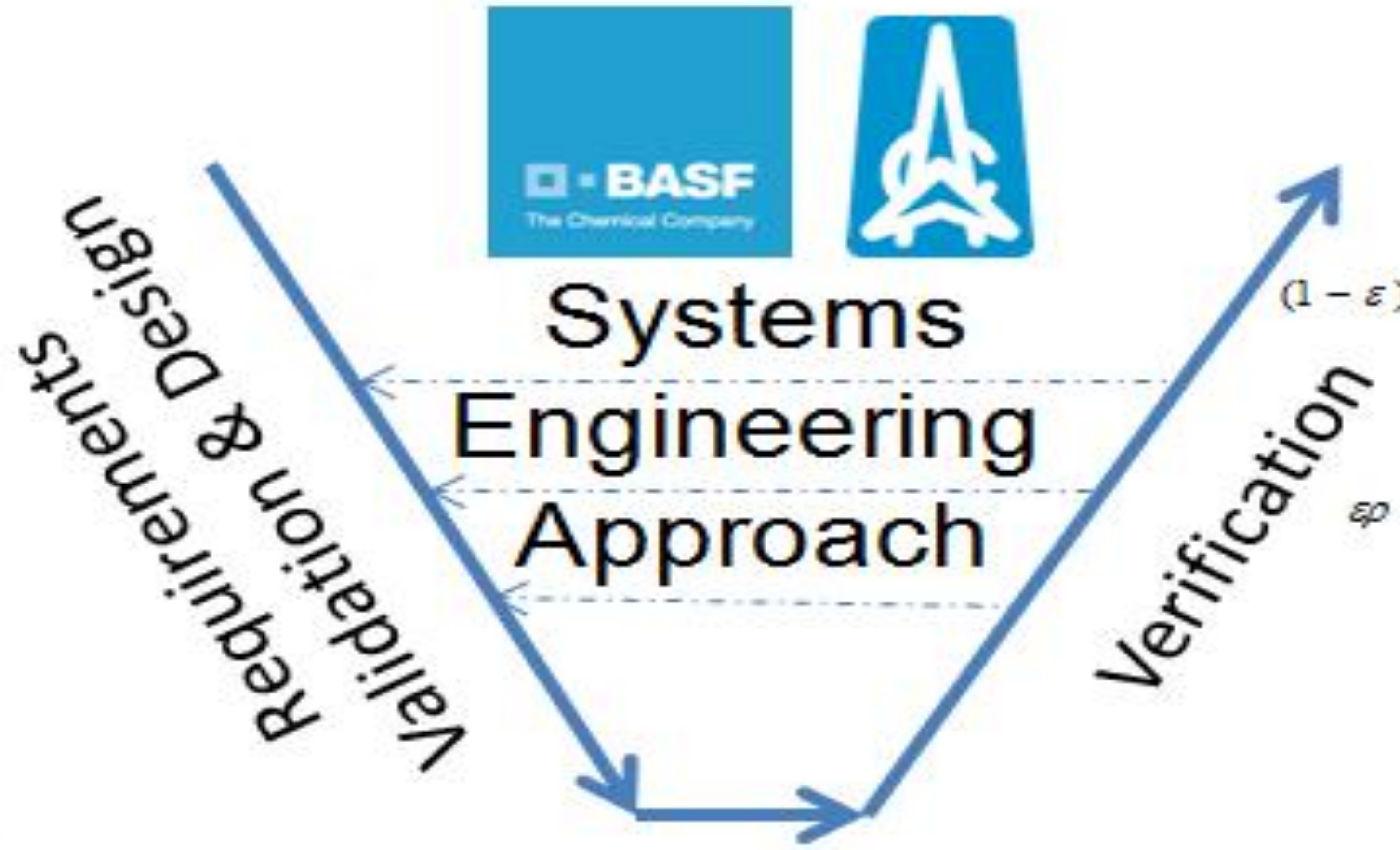


High Performance Shaped Magnetocaloric Beds

Modelling

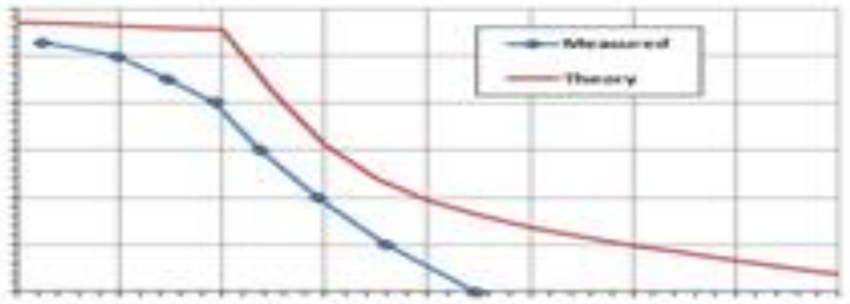
$$(1-\varepsilon)\rho_s C_s \frac{\partial T_s}{\partial t} = \frac{\partial}{\partial x}\left(k_{s,e}\frac{\partial T_s}{\partial x}\right) + ha(T_f - T_s) - (1-\varepsilon)\rho_s T_s \frac{\partial S}{\partial B}\frac{\partial B}{\partial t}$$

$$\varepsilon\rho_f C_f \frac{\partial T_f}{\partial t} = \frac{\partial}{\partial x}\left(k_{f,e}\frac{\partial T_f}{\partial x}\right) + ha(T_s - T_f) - \frac{\Phi\rho_f}{A} C_f \frac{\partial T_f}{\partial x} + F$$



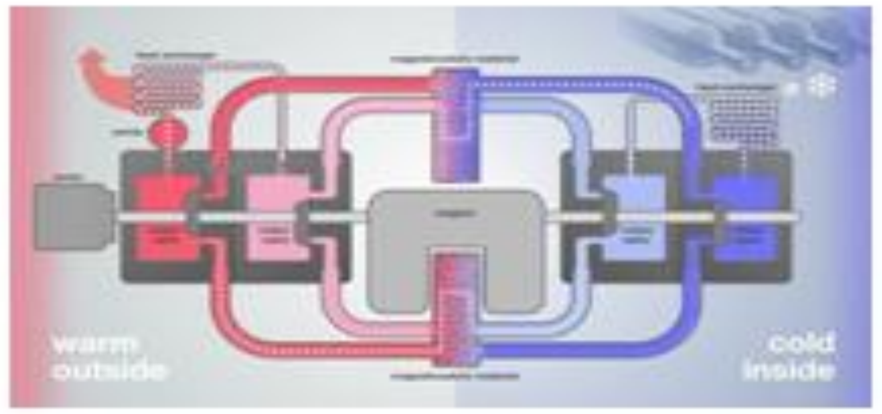
Engineering

Validation & Verifcation theory ➔ experiments ➔ Design Basis for Products



Prototypes to Products

Device Architectures



Focus: Cost-Effective, Efficient, Compact Magnetocaloric Heat Pumps

Astronautics Corporation of America

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Annexes for internet document

#4B

Magnetic cooling for today's appliances

Camfridge

World's smallest magnetic cooling solution.

Same size and weight as a gas compressor. Gas-free.

Low pressure design, exploiting next-generation shaped refrigerant materials.

Designed to increase the efficiency of above 0°C appliances (e.g. larder fridge).

Up to 50W cooling power.

Designed to fit inside appliances without platform modification

Appliance optimisation in collaboration with Whirlpool (Elicit project) and Arcelik (Frisbee project).

Cemafroid is drafting (Elicit project) an extension to existing EU energy efficiency standards to cover magnetic refrigeration. Will help to enable market engagement.

Target cost for magnetic cooling engine <$100.

First commercially available appliances targeted for 2020.

Interior of an optimised appliance

Visit us at Thermag VI, Turin, September 11th – 14th 2016

Camfridge

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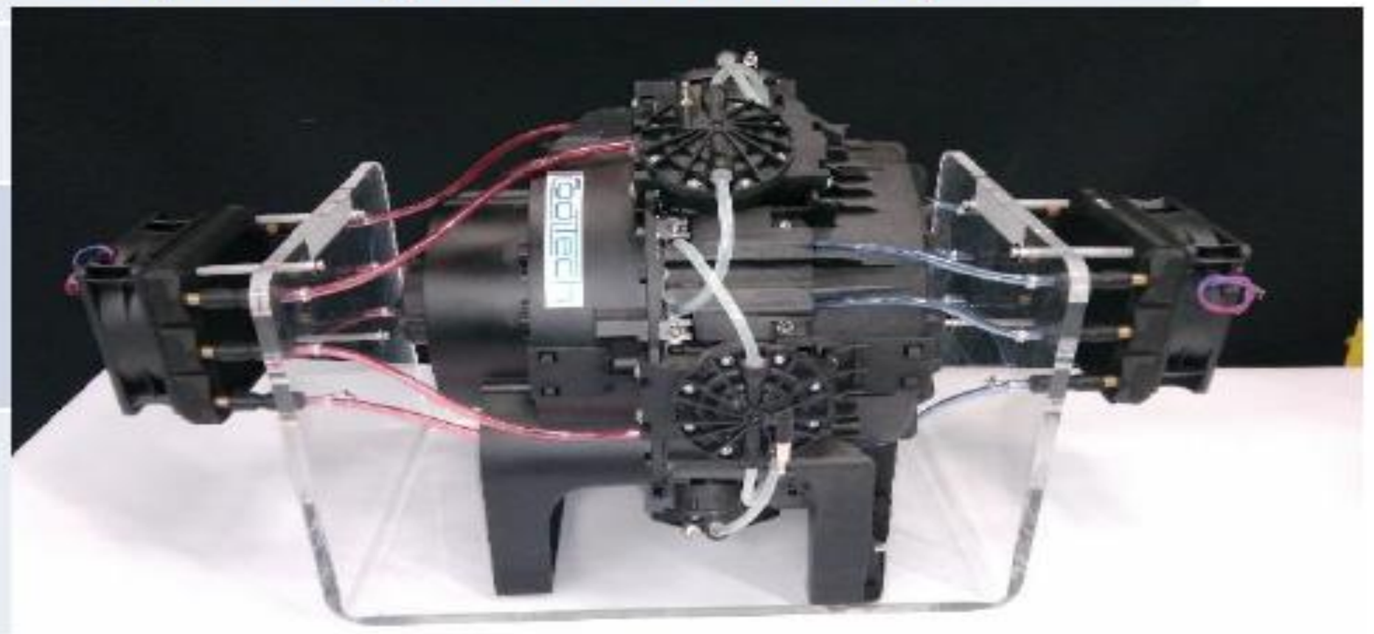
Annexes for internet document

#4C

Datasheet of the commercial device from Cooltech Applications

Item	Description
Architecture	• Double-stage rotary machine
Size	• Diameter: 260 mm • Length: 310 mm (400 mm with current motor) • Footprint: 260 x 310 mm (400 mm) < A3 format of sheet of paper
Weight*	• ~ 30 kg (not optimized yet)
Magnetic field	• ~ 1 T (emission: 0,5 mT at 10 cm – measured by the external Institute APAVE)
Cooling power	• From 200 up to 400 W @ span = 25 K with specific L/A HEX (max span with no load = 46 K)
Electrical consumption**	• Today 44 W with motor efficiency $\eta_{motor} \approx 0.85$ @ 2 Hz (including motor control box)
COP	• COP ≈ 6 (total consumption) • % COP Carnot > 55%
Heat transfer fluid temperatures (in exchange mode)	• T_{Hot}: +28°C (+34°C in progress) • T_{Cold}: -2 down to -5°C
Hydraulic distribution	• Adjustable liquid flow rate: 4 to 8 L/min • Recommended liquid flow rate: 6.5 L/min • Maximum internal pressure: 2.4 bars
Regenerator system	• Two stators with welded covers and housings (tested at 6 bars)
Motorization (interchangeable)	• With variable speed • N = 60 to 220 RPM @ 2 Hz
Optional integration	• Plate liquid/liquid heat exchangers



(*) without motor
(**) without pump, in the perimeter of the customer

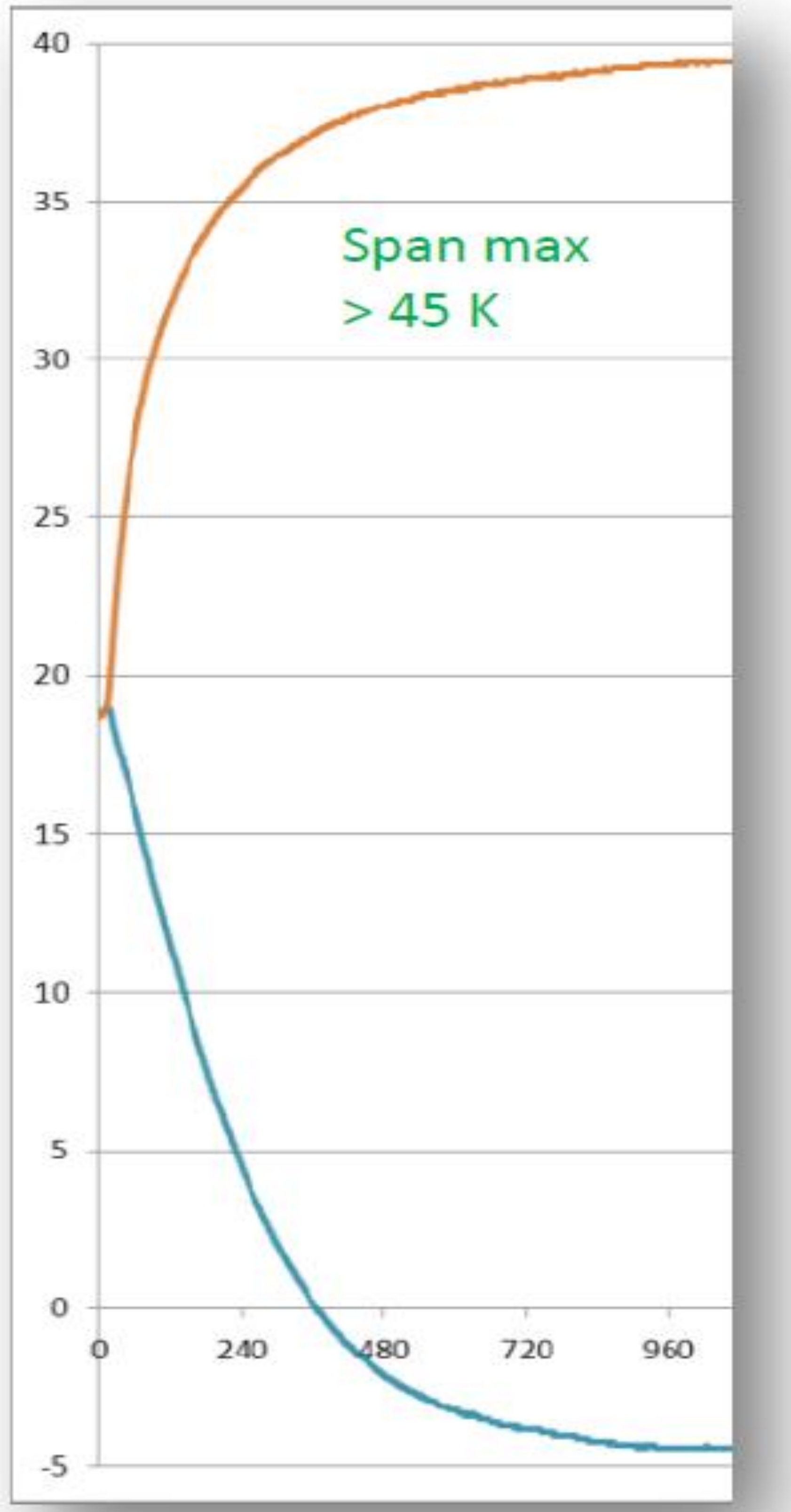
The system from Cooltech Applications (modular & scalable) is designed to use most of the alloys and is compatible to any future alloys

Cooltech Applications

Annexes for internet document

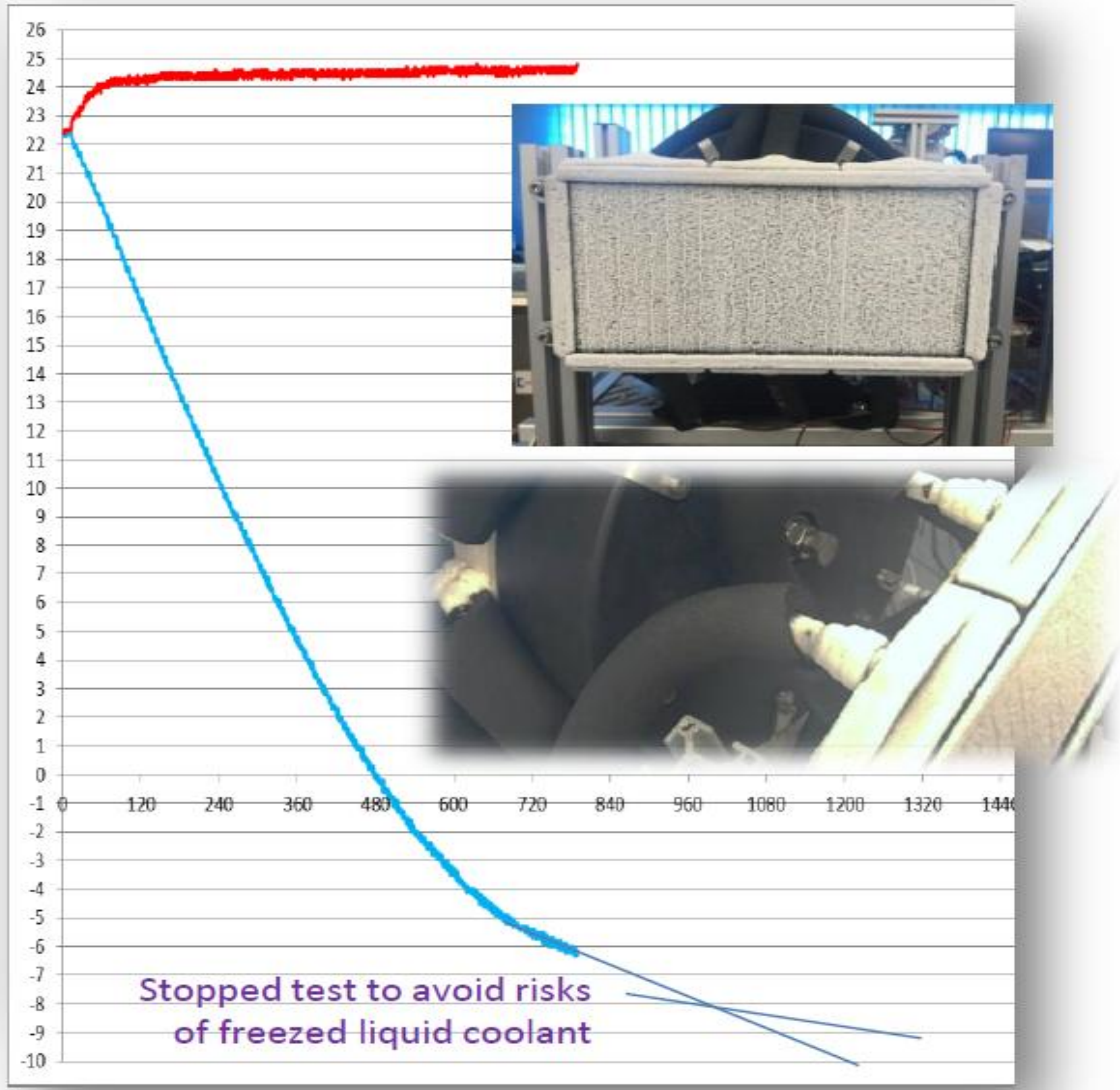
Validation tests on the commercial device from Cooltech Applications

Maximum span with no thermal load

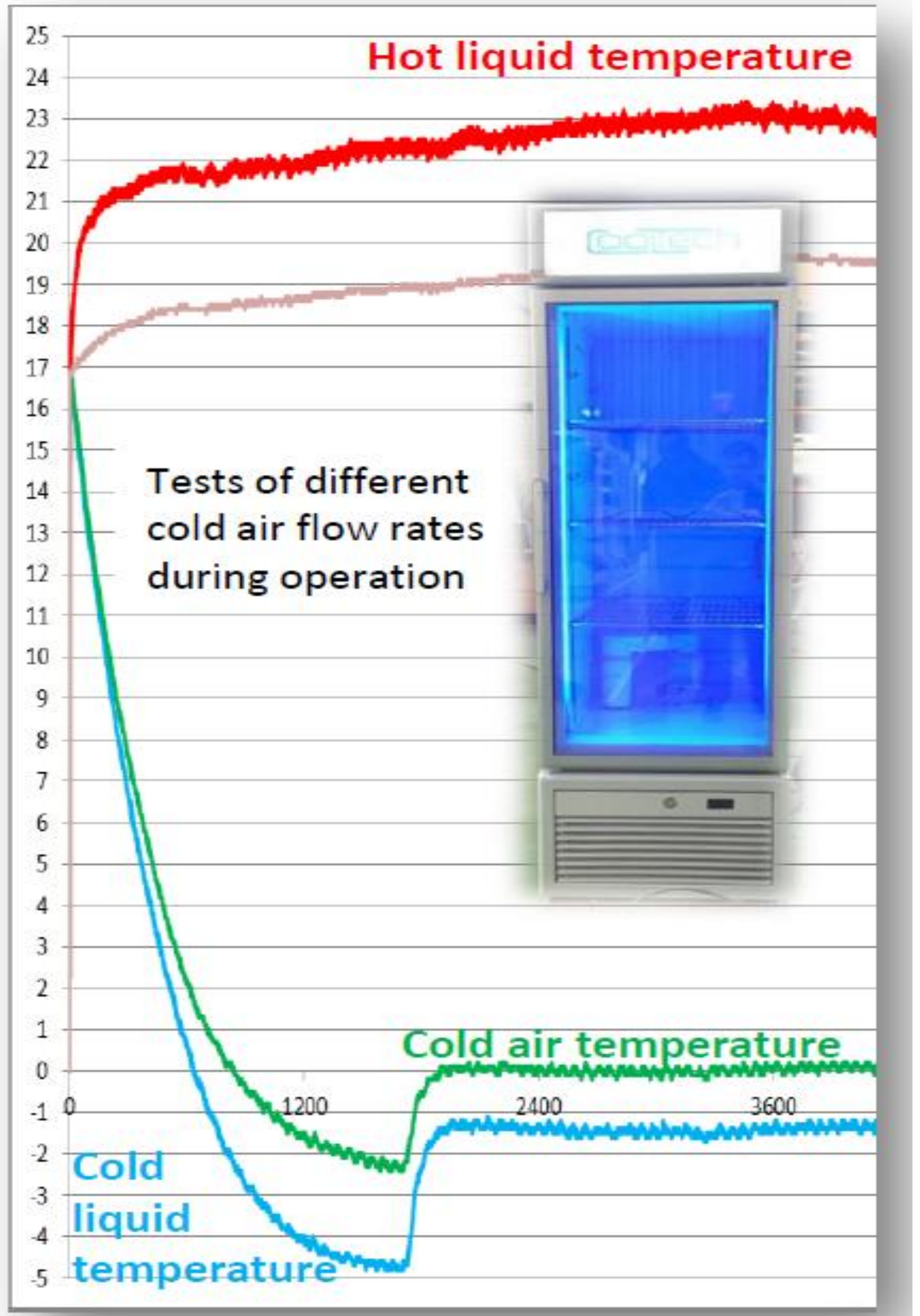


Negative temperatures tests

Freezing the cold heat exchanger and the connections



Integration project Cooltech Display Cabinet for End User



Cooltech Applications

Annexes for internet document

Information from MRS Development OEM's

General Electric Appliances, in conjunction with General Electric Global Research Centre has shown a sustained effort in development of Magneto-caloric Refrigeration since 2005. Having developed significant internal analysis and simulation capability we continue to prototype and experiment to accomplish significant milestones.

GE APPLIANCES

Status Q1 2016	Not willing yet to commit to a production configuration.
Future	Capable of & may soon build proof of concept prototypes for public demonstration, we have not yet reached the commercial commitment hurdle.
David Beers	" Our work continues toward meeting that hurdle."

Note GE Appliances sold to Haier - June 2016

#4E

The technical objective of the company NextPac, within the framework of a general activity of scientific research, engineering and technical studies, is the development of a new technology of ecological & climate compatible heat pump.

The medium-term commercial objective, is to propose a technological offer on this basis, and by means of industrial and commercial partners, to become integrated into the existing large heat pump and air conditioning market, which will have to be renewed before 2030 further to the new European regulations (revision of the regulations F-GAS) which is phasing down use of the HFC (Hydro-Fluoro-Carbons), which are on the basis of the current technologies in this domain.

Leaning on previous physical and mechanical studies, NextPac has started manufacturing a prototype requiring R&D mainly in the of the fluid mechanics, magneto caloric domains, and systems.

FOCUS on our presence at the congress THERMAG VI.

Here we presented a digital model allowing to demonstrate the thermal transfers in a magneto caloric regenerator which takes into consideration the oscillating flows in such systems.

The presentations made at the congress in Canada :

https://goo.gl/fhJr3e
https://goo.gl/3yyVtP