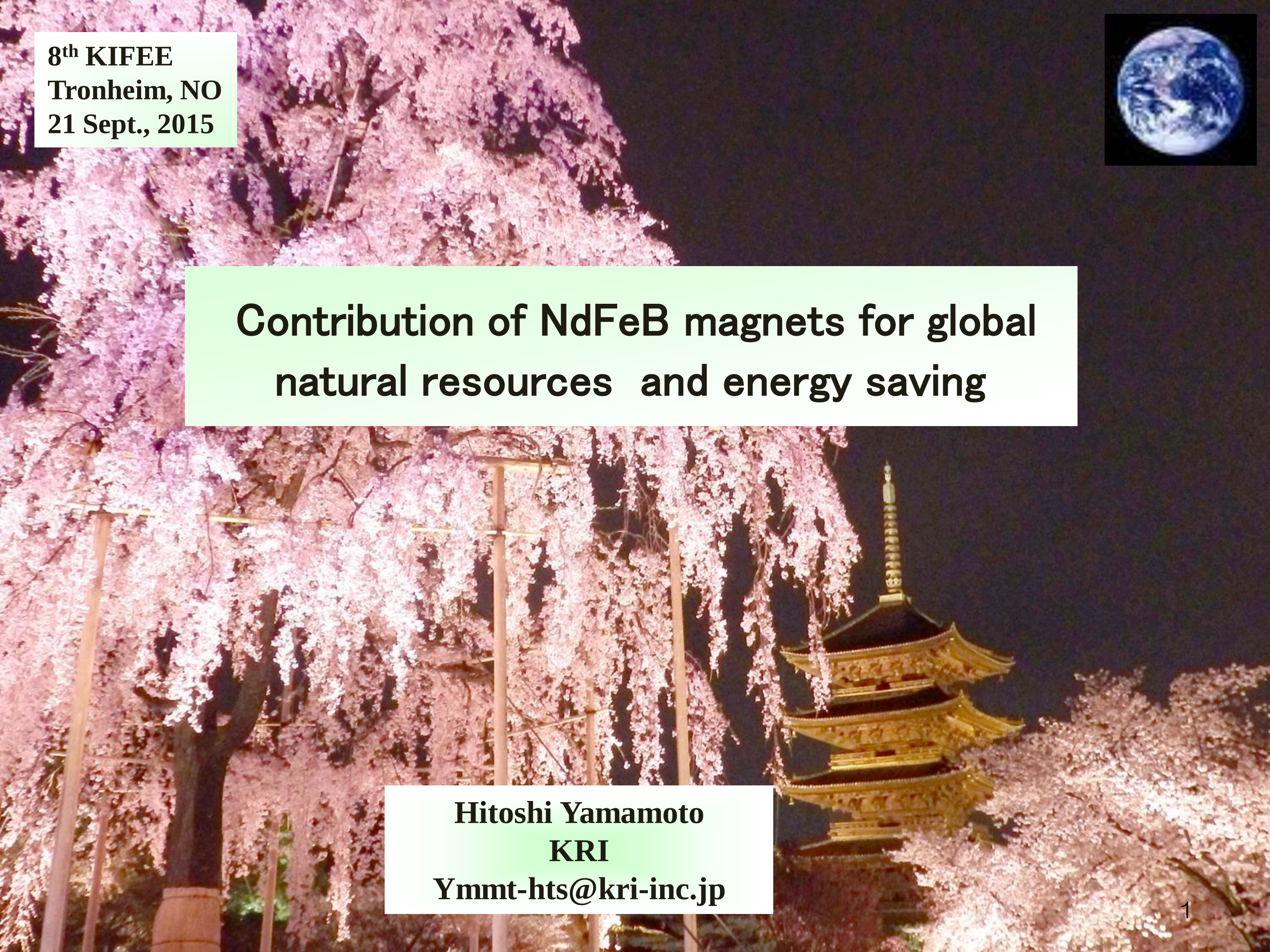


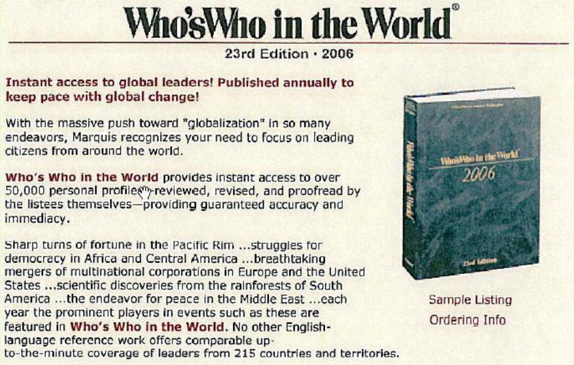
8th KIFEE
Tronheim, NO
21 Sept., 2015

Contribution of NdFeB magnets for global natural resources and energy saving

Hitoshi Yamamoto
KRI
Ymmt-hts@kri-inc.jp

Brief introduction of myself

KRI



Who'sWho in the World®

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Sample Listing

Ordering Info

Hitoshi Yamamoto

NdFeB magnets

Working in magnet industry over 30 years including R&D of NdFeB and SmCo magnets, engaged in national PJ related with magnets and marketing activities in USA

A research member in invention of NdFeB magnets in 1983
Patent of NdFeB magnets and application; over 120 patents

Nominated in a dictinary “Who’s who in the world”（2006）

IEC/TC68 convenor of permanent magnets （1998-2002, 2006-2008）

Stayed in USA； California（1989-2005）、Illinois（2003-2006）
Language； TOEIC SCORE ８２５／９９０（2007） English semi-1st（1996）
French； APEF French 3rd grade （2001）

Gorham Conference

KRI

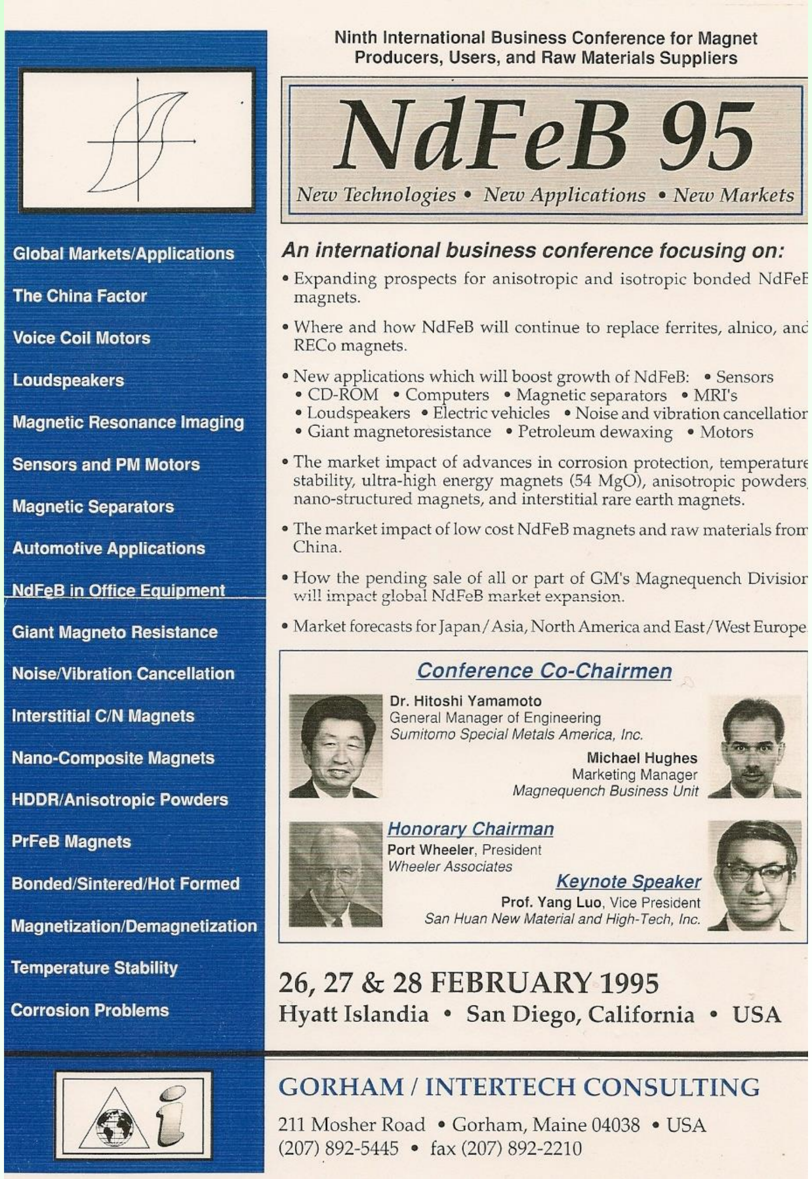
What is Gorham onference?

It is the

"Prestigious International Conference focusing NdFeB Technology and Global Business Opportunities"

Presentation Career

1. 1991 (London)
2. 1992 (Orland,FL)
3. 1994 (Orland,FL)
4. 1995 (San Diego,CA)
   * also co-chaired
5. 1997 (Chicago, IL)
5. 2004 (Detroit,MI)



Ninth International Business Conference for Magnet Producers, Users, and Raw Materials Suppliers

NdFeB 95

New Technologies • New Applications • New Markets

Global Markets/Applications
The China Factor
Voice Coil Motors
Loudspeakers
Magnetic Resonance Imaging
Sensors and PM Motors
Magnetic Separators
Automotive Applications
NdFeB in Office Equipment
Giant Magneto Resistance
Noise/Vibration Cancellation
Interstitial C/N Magnets
Nano-Composite Magnets
HDDR/Anisotropic Powders
PrFeB Magnets
Bonded/Sintered/Hot Formed
Magnetization/Demagnetization
Temperature Stability
Corrosion Problems

An international business conference focusing on:

- Expanding prospects for anisotropic and isotropic bonded NdFe magnets.
- Where and how NdFeB will continue to replace ferrites, alnico, an RECo magnets.
- New applications which will boost growth of NdFeB: • Sensors • CD-ROM • Computers • Magnetic separators • MRI's • Loudspeakers • Electric vehicles • Noise and vibration cancellatio • Giant magnetoresistance • Petroleum dewaxing • Motors
- The market impact of advances in corrosion protection, temperatur stability, ultra-high energy magnets (54 MgO), anisotropic powders nano-structured magnets, and interstitial rare earth magnets.
- The market impact of low cost NdFeB magnets and raw materials fro China.
- How the pending sale of all or part of GM's Magnequench Divisio will impact global NdFeB market expansion.
- Market forecasts for Japan/Asia, North America and East/West Europe

Conference Co-Chairmen

Dr. Hitoshi Yamamoto
General Manager of Engineering
Sumitomo Special Metals America, Inc.

Michael Hughes
Marketing Manager
Magnequench Business Unit

Honorary Chairman
Port Wheeler, President
Wheeler Associates

Keynote Speaker
Prof. Yang Luo, Vice President
San Huan New Material and High-Tech, Inc.

26, 27 & 28 FEBRUARY 1995
Hyatt Islandia • San Diego, California • USA

GORHAM / INTERTECH CONSULTING
211 Mosher Road • Gorham, Maine 04038 • USA
(207) 892-5445 • fax (207) 892-2210

Global Warming, CO_2

Brief introduction of KRI

Establishment of KRI

In 1987, KRI, Inc. (formerly Kansai Research Institute, Inc.) was established with a full investment by Osaka Gas Co., Ltd. In July, 2003, the company changed its name to KRI, Inc..

Osaka Gas company

The Osaka Gas Group consists of 140 affiliated companies employing over 20,000 people.
The sales ;1,500,000,000,000 yen. (1trillion 500billion Yen)
The profit ; 110,000,000,000 yen. (110billion Yen)

KRI Offices

KRI

フェロ&ピコシステム研究部
部長

工学博士 山 本 日 登 志

株式会社 ＫＲＩ

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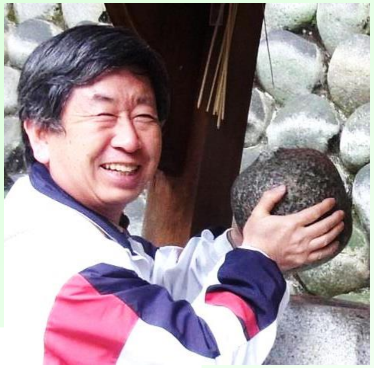
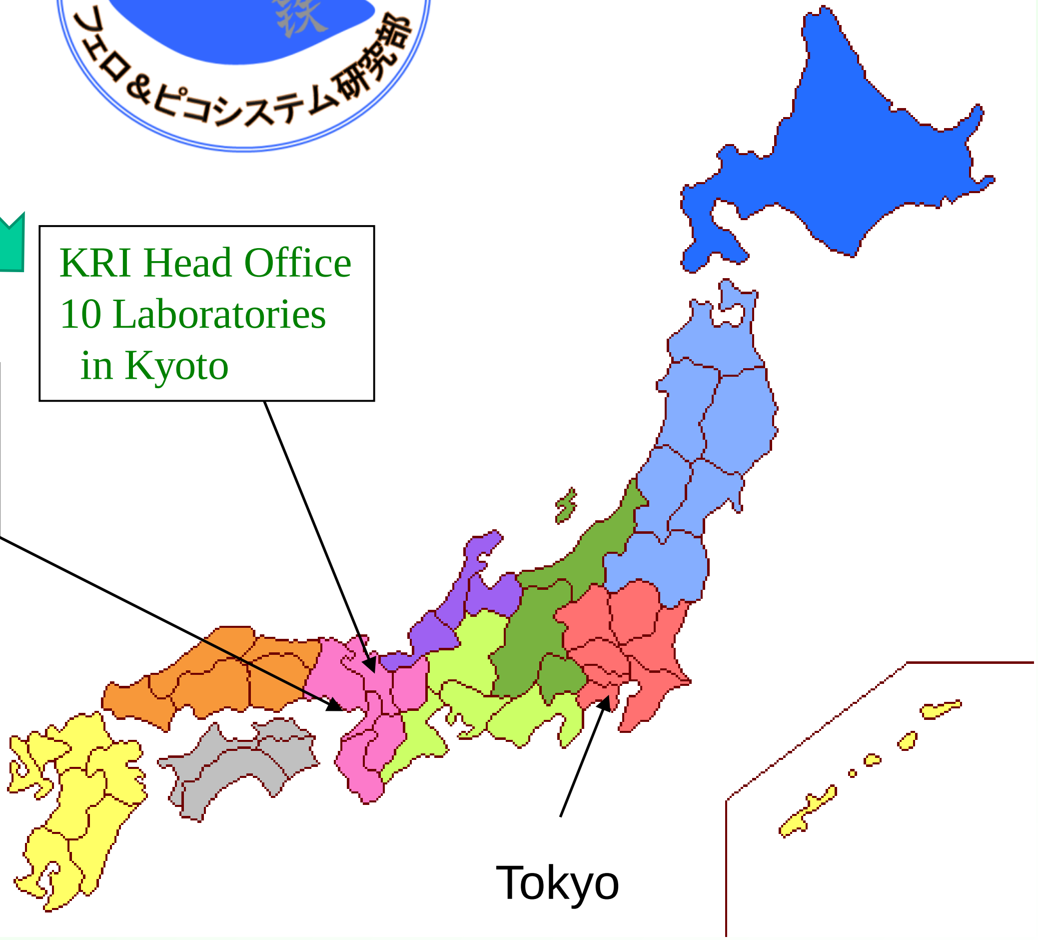
京都市下京区中堂寺南町134
京都リサーチパーク
e-mail : ymmt-hts@kri-inc.jp
URL : http://www.kri-inc.jp

Phone 080-2442-9009 (直通)
(075)322-6832
Fax (075)315-3095

Recycled Paper

I am here in Kyoto office

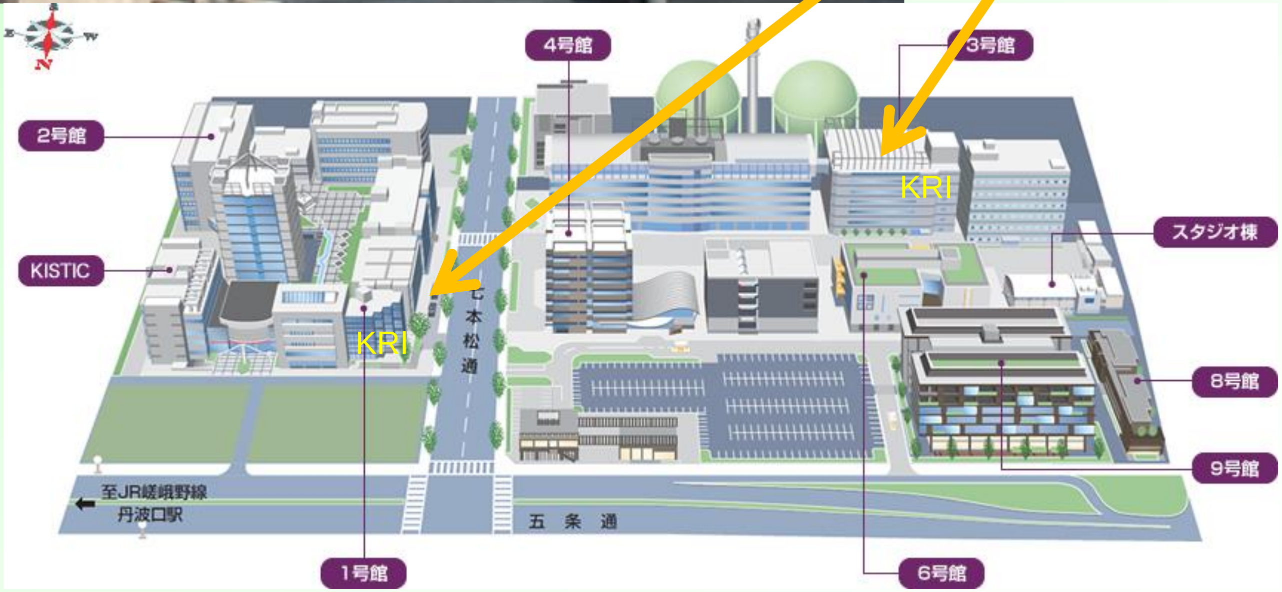




KRI Head Office
10 Laboratories
in Kyoto

KRI Osaka Office
5 Laboratories
in Osaka

KRI Head Office
10 Laboratories
in Kyoto



KRI Mission

KRI is a contract research company combinning the functions of a real research and development, and advanced analysis.

Our funded researchs are ;

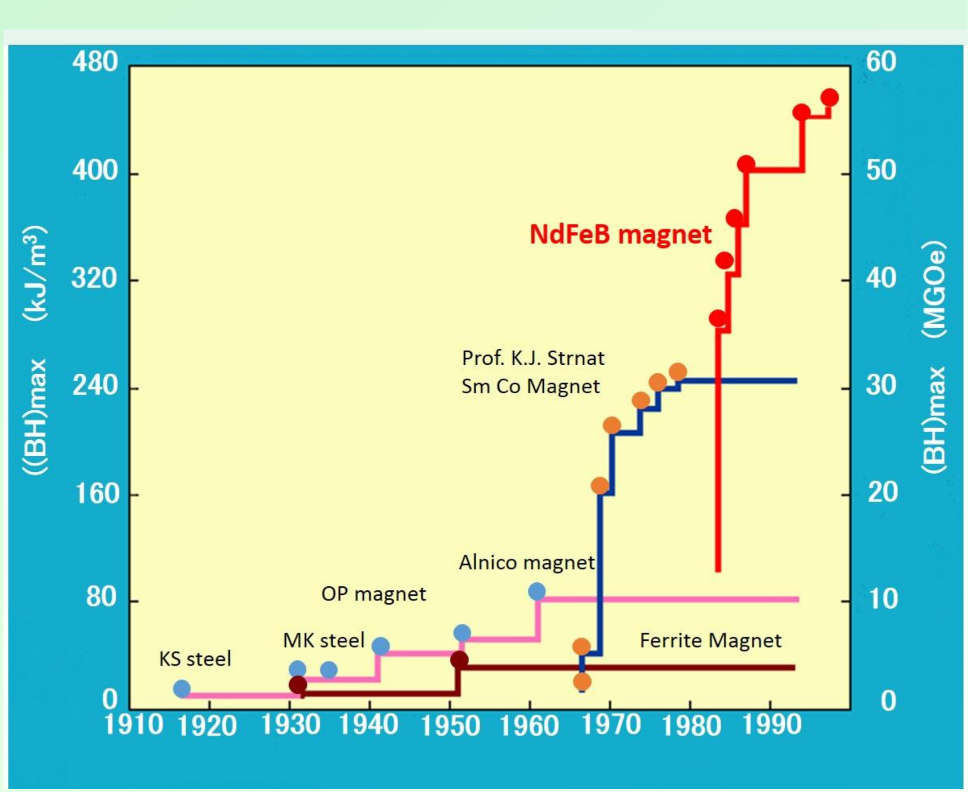
①material technologies,
②environmental technologies
③energy devices

KRI supports business and R&D to get innovative values, intellectual properties and fruitful collaboration partnership.

Why magnet is much attention in Japan?
This is coming back……

History of Permanent Magnet

Prof. Kotaro Honda
Inventor of KS steel
“father of permanent magnet”

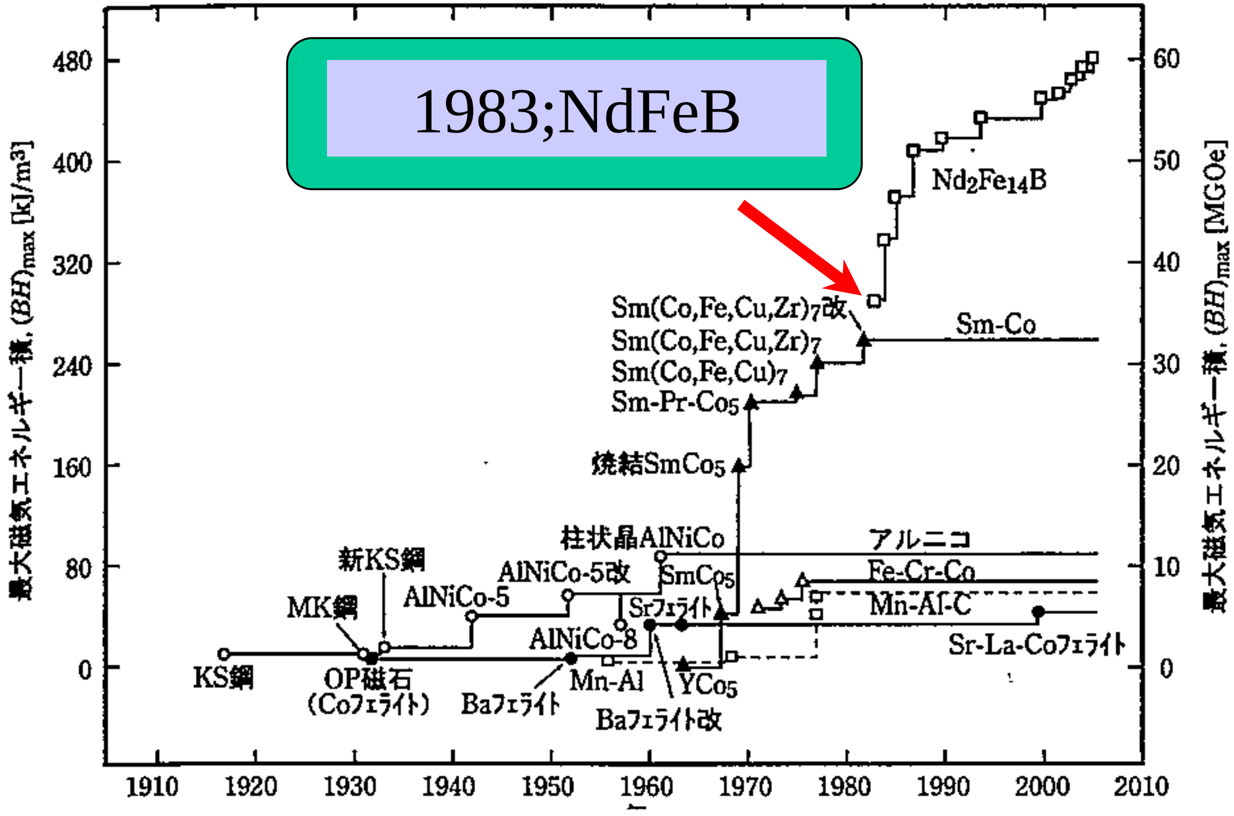


Dr. Masato Sagawa
Inventor of Nd magnet

Prof. Tokuhichi Mishima
Inventor of MK steel

Prof. Yogoro Kato (left) &
Prof. Takeshi Takei
Inventor of OP magnet and current ferrite magnet

Invention of NdFeB magnet



1983;NdFeB

Is “rare earth element” really rare ?

World Rare Earth Production, Deposit and Resources

KRI

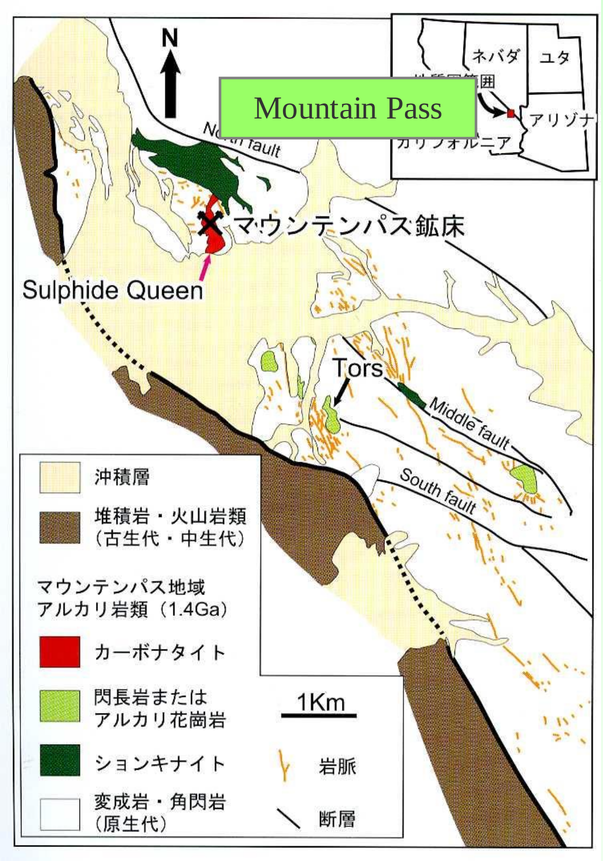
	Mine Production		Deposit	Resources
	2004	2005		
China	95,000	98,000	27,000,000	89,000,000
CIS	2,000	2,000	19,000,000	21,000,000
USA	none	none	13,000,000	14,000,000
Australia	none	none	5,200,000	5,800,000
India	2,700	2,700	1,100,000	1,300,000
Malaysia	250	250	30,000	35,000
Thailand	2,200	2,200	NA	NA
Others	none	none	22,000,000	23,000,000
Total	102,000	105,000	88,000,000	150,000,000

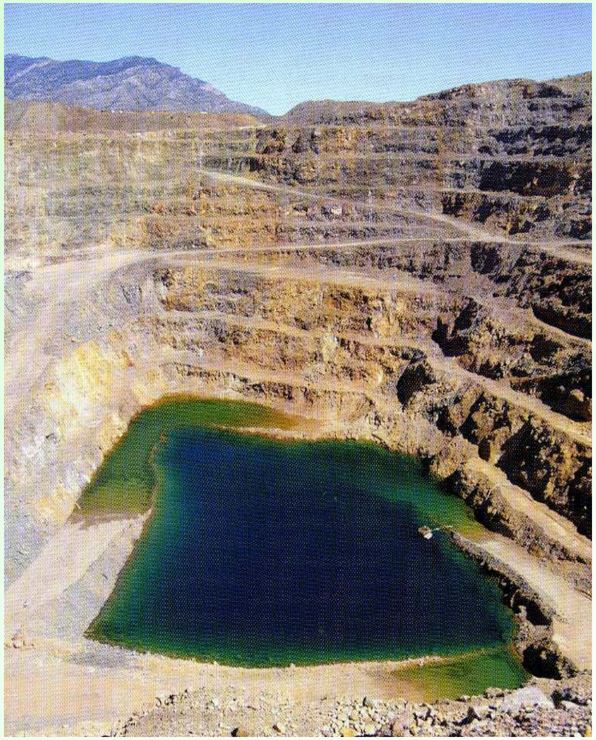
USGS Mineral Summaries, January 2006

Deposit/Production = 838 years !

Ref; AIST(Advanced Industrial Science and technology) Ph D Yasushi Watanabe

Rare earth mining
Mountain Pass (Arizona, USA)





* Report of Ishihara, Murakami (2006)

Ref; AIST(Advanced Industrial Science and technology) Ph D Yasushi Watanabe

Important Elements for NdFeB

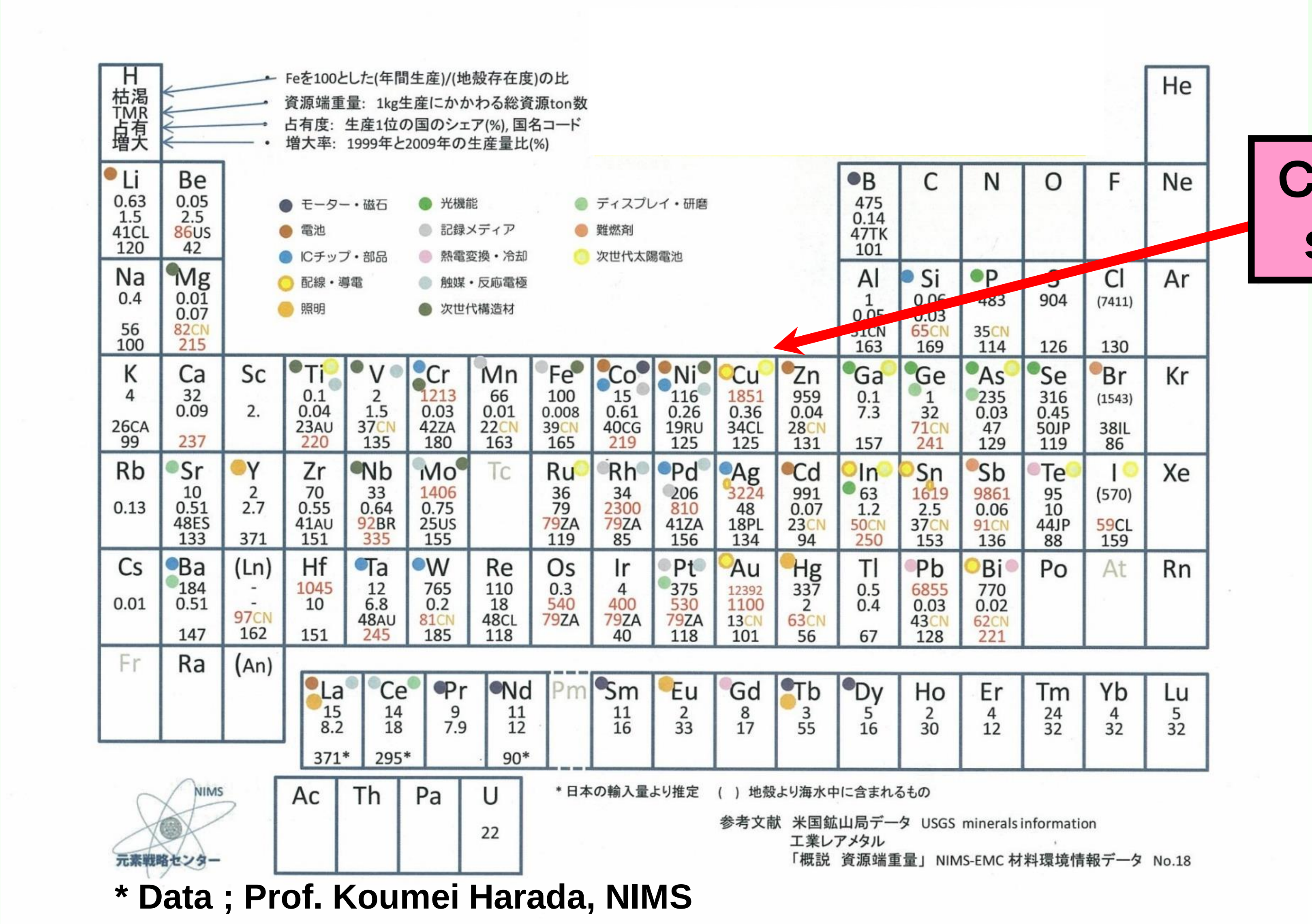
KRI

	Monazaite	Bastonasaite	Zenotime	Ion-Absorption
La_2O_3	21.50	33.20	1.24	1.82
Ce_2O_3	45.80	49.10	3.13	0.37
Pr_2O_3	5.30	4.34	0.49	0.74
Nd_2O_3	18.60	12.00	1.59	3.00
Sm_2O_3	3.10	0.79	1.14	2.82
Eu_2O_3	0.80	0.12	0.01	0.12
Gd_2O_3	1.80	0.17	3.47	6.85
Tb_2O_3	0.29	0.02	0.91	1.29
Dy_2O_3	0.64	0.03	8.32	6.67
Ho_2O_3	0.12	0.01	1.98	1.64
Er_2O_3	0.18	0.00	6.43	4.85
Tm_2O_3	0.03	0.00	1.12	0.70
Yb_2O_3	0.11	0.00	6.77	2.46
Lu_2O_3	0.01	0.00	0.99	0.36
Y_2O_3	2.50	0.09	61.00	65.00

(Wt %)

Sustainable element table

Which element will be short on the earth ?



H
枯渇
TMR
占有
増大

- Feを100とした(年間生産)/(地殻存在度)の比
- 資源端重量: 1kg生産にかかわる総資源ton数
- 占有度: 生産1位の国のシェア(%), 国名コード
- 増大率: 1999年と2009年の生産量比(%)

● モーター・磁石
● 電池
● ICチップ・部品
● 配線・導電
● 照明
● 光機能
● 記録メディア
● 熱電変換・冷却
● 触媒・反応電極
● 次世代構造材
● ディスプレイ・研磨
● 難燃剤
● 次世代太陽電池

H 枯渇 TMR 占有 増大																	He
Li 0.63 1.5 41CL 120	Be 0.05 2.5 86US 42											B 475 0.14 47TK 101	C	N	O	F	Ne
Na 0.4 56 100	Mg 0.01 0.07 82CN 215											Al 1 0.05 31CN 163	Si 0.06 0.03 65CN 169	P 483 35CN 114	S 904 126	Cl (7411) 130	Ar
K 4 26CA 99	Ca 32 0.09 237	Sc 2.	Ti 0.1 0.04 23AU 220	V 2 1.5 37CN 135	Cr 1213 0.03 42ZA 180	Mn 66 0.01 22CN 163	Fe 100 0.008 39CN 165	Co 15 0.61 40CG 219	Ni 116 0.26 19RU 125	Cu 1851 0.36 34CL 125	Zn 959 0.04 28CN 131	Ga 0.1 7.3 157	Ge 1 32 71CN 241	As 235 0.03 47 129	Se 316 0.45 50JP 119	Br (1543) 38IL 86	Kr
Rb 0.13	Sr 10 0.51 48ES 133	Y 2 2.7 371	Zr 70 0.55 41AU 151	Nb 33 0.64 92BR 335	Mo 1406 0.75 25US 155	Tc	Ru 36 79 79ZA 119	Rh 34 2300 79ZA 85	Pd 206 810 41ZA 156	Ag 3224 48 18PL 134	Cd 991 0.07 23CN 94	In 63 1.2 50CN 250	Sn 1619 2.5 37CN 153	Sb 9861 0.06 91CN 136	Te 95 10 44JP 88	I (570) 59CL 159	Xe
Cs 0.01	Ba 184 0.51 147	(Ln) - - 97CN 162	Hf 1045 10 151	Ta 12 6.8 48AU 245	W 765 0.2 81CN 185	Re 110 18 48CL 118	Os 0.3 540 79ZA	Ir 4 400 79ZA 40	Pt 375 530 79ZA 118	Au 12392 1100 13CN 101	Hg 337 2 63CN 56	Tl 0.5 0.4 67	Pb 6855 0.03 43CN 128	Bi 770 0.02 62CN 221	Po	At	Rn
Fr	Ra	(An)															

La 15 8.2 371*	Ce 14 18 295*	Pr 9 7.9	Nd 11 12 90*	Pm	Sm 11 16	Eu 2 33	Gd 8 17	Tb 3 55	Dy 5 16	Ho 2 30	Er 4 12	Tm 24 32	Yb 4 32	Lu 5 32

Ac	Th	Pa	U 22

* 日本の輸入量より推定　( ) 地殻より海水中に含まれるもの

参考文献 米国鉱山局データ USGS minerals information
工業レアメタル
「概説 資源端重量」 NIMS-EMC 材料環境情報データ No.18

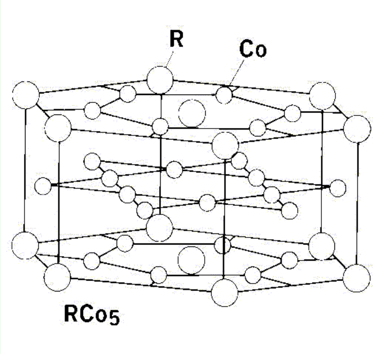
NIMS
元素戦略センター

Cu wil be short !!

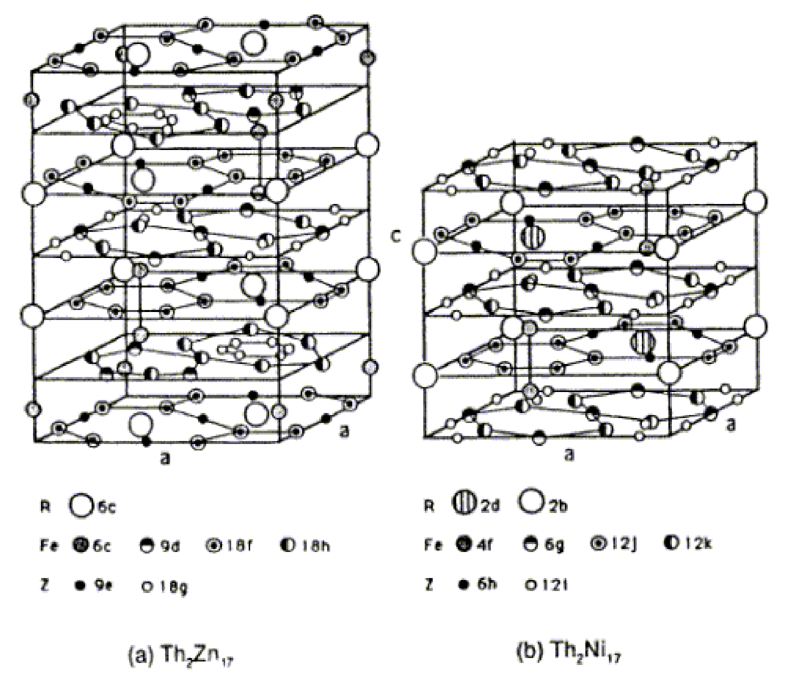
* Data ; Prof. Koumei Harada, NIMS

Basics of rare earth magnet

Crystallographic Strucfture of $SmCo_5$, Sm_2Co_{17} and $Nd_2Fe_{14}B$

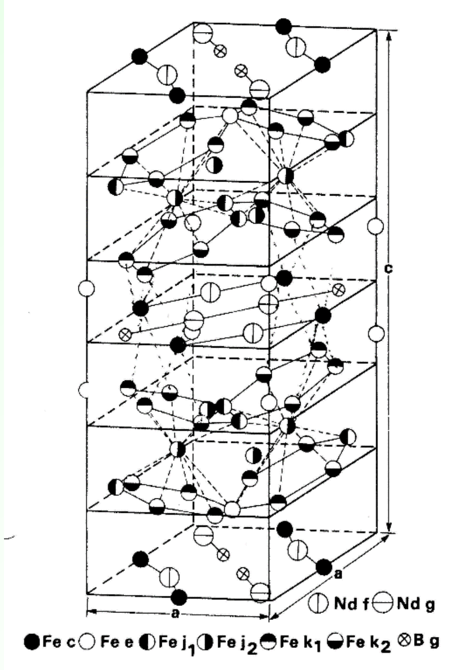


$SmCo_5$



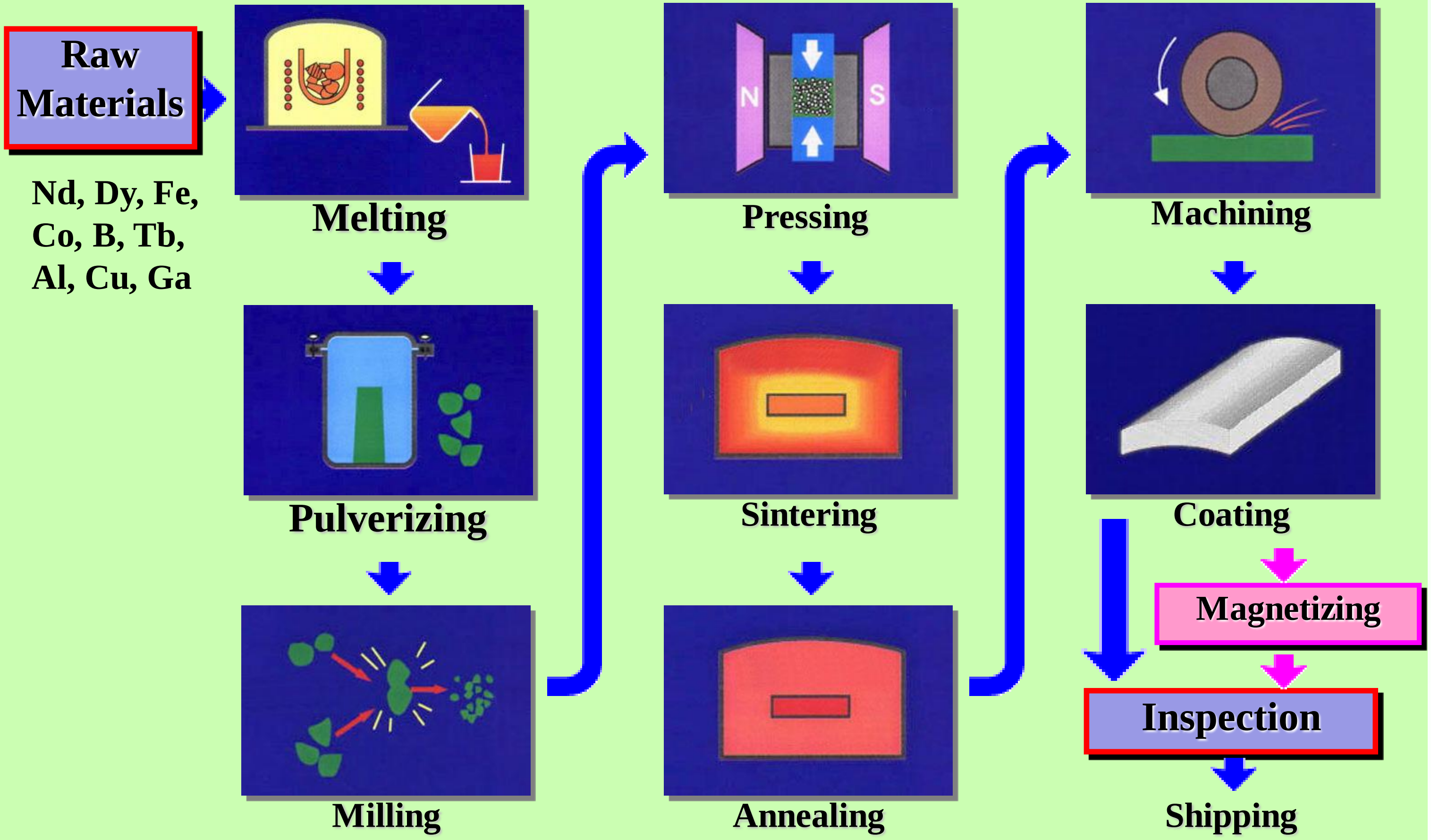
(a) Th_2Zn_{17} (b) Th_2Ni_{17}

Sm_2Co_{17}



$Nd_2Fe_{14}B$

Production process of NdFeB magnets



Raw Materials

Nd, Dy, Fe,
Co, B, Tb,
Al, Cu, Ga

- Melting
- Pulverizing
- Milling
- Pressing
- Sintering
- Annealing
- Machining
- Coating
- Magnetizing
- **Inspection**
- Shipping

How to improve magnetic properties

Br is

$$Br(T) \propto Is(T) \times \left(\rho / \rho_0\right) \times (1-\alpha) \times f$$

Br：residual magnetic flux、T：temperature、Is：saturation magnetization、ρ：sintered density、ρ_0：theoretical density、α：volume ration of nonmagnetic phase、f：crystal alignment degree

H_{cJ} is

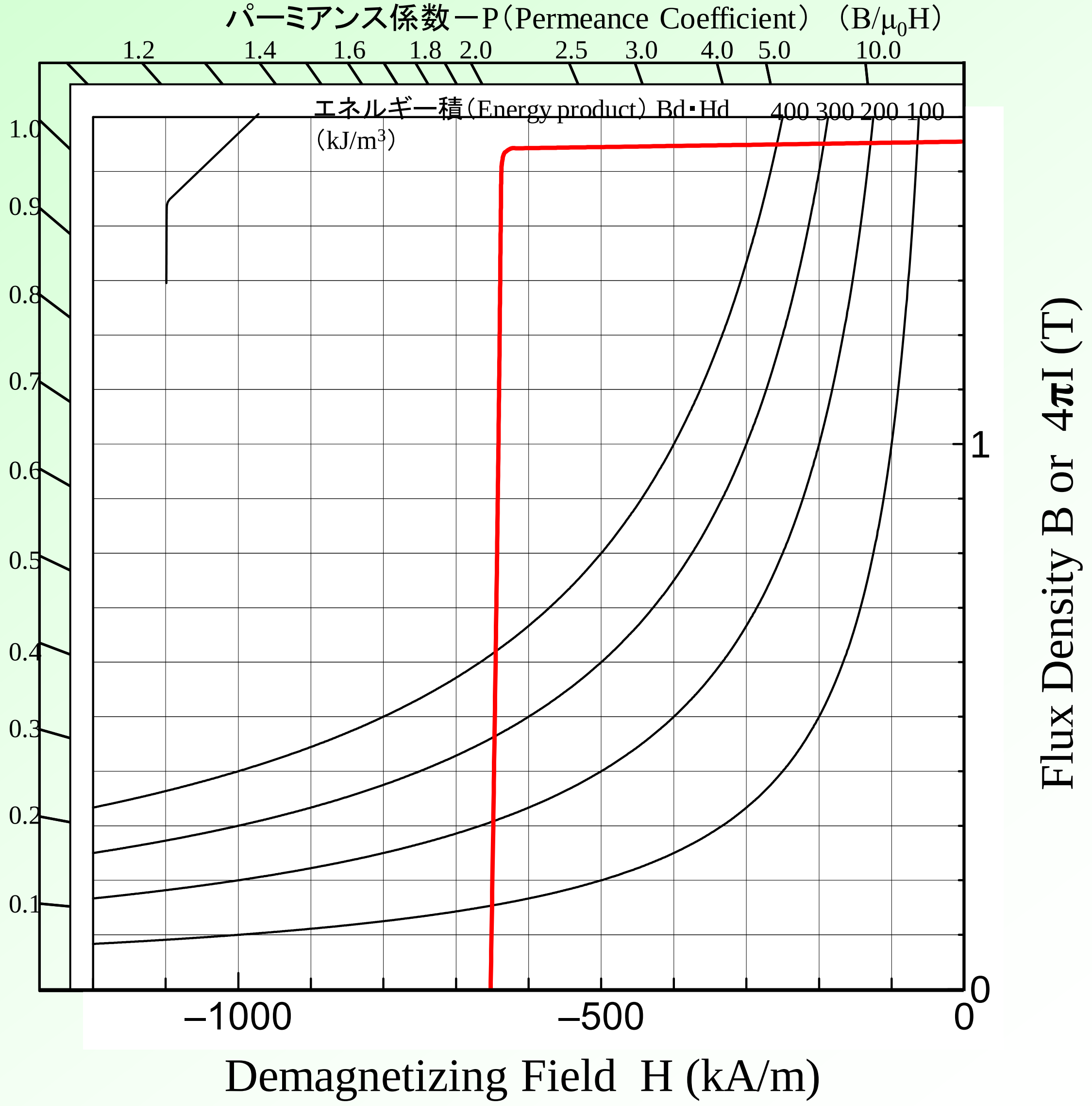
$$H_{cJ}(T) \propto 2 \times K(T)/Is(T) - N \times Is(T)$$

HcJ：coercivity、T：temperature、K：anisotropy constant、N：demagnetization factor

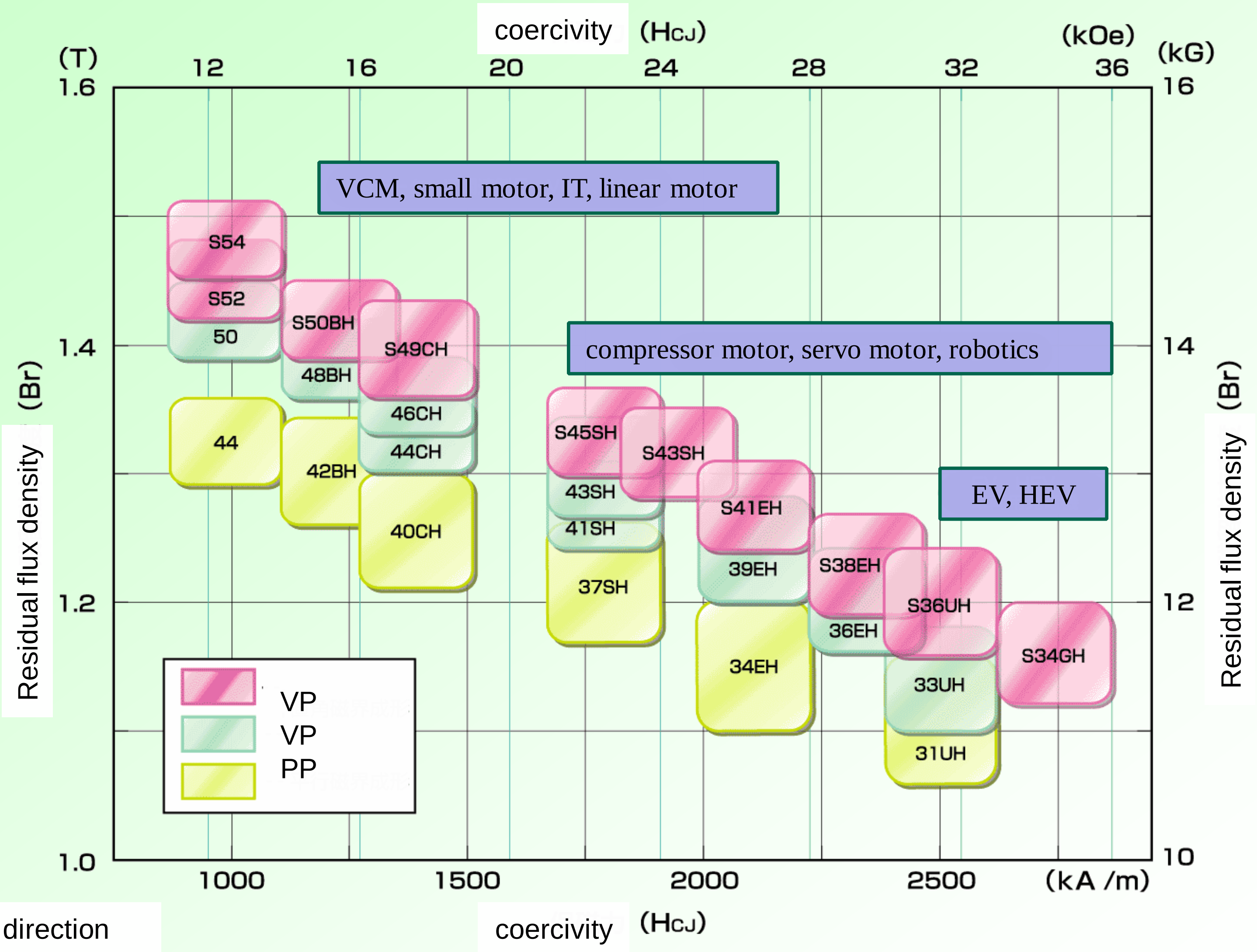
The Record Highest (BH)max in the World !!

KRI

Br	**;**	**1.555T** **(15.55kG)**
HcJ	**;**	**653kA/m** **(8.2kOe)**
(BH)max	**;**	**474kJ/m3** **(59.5MGOe)**

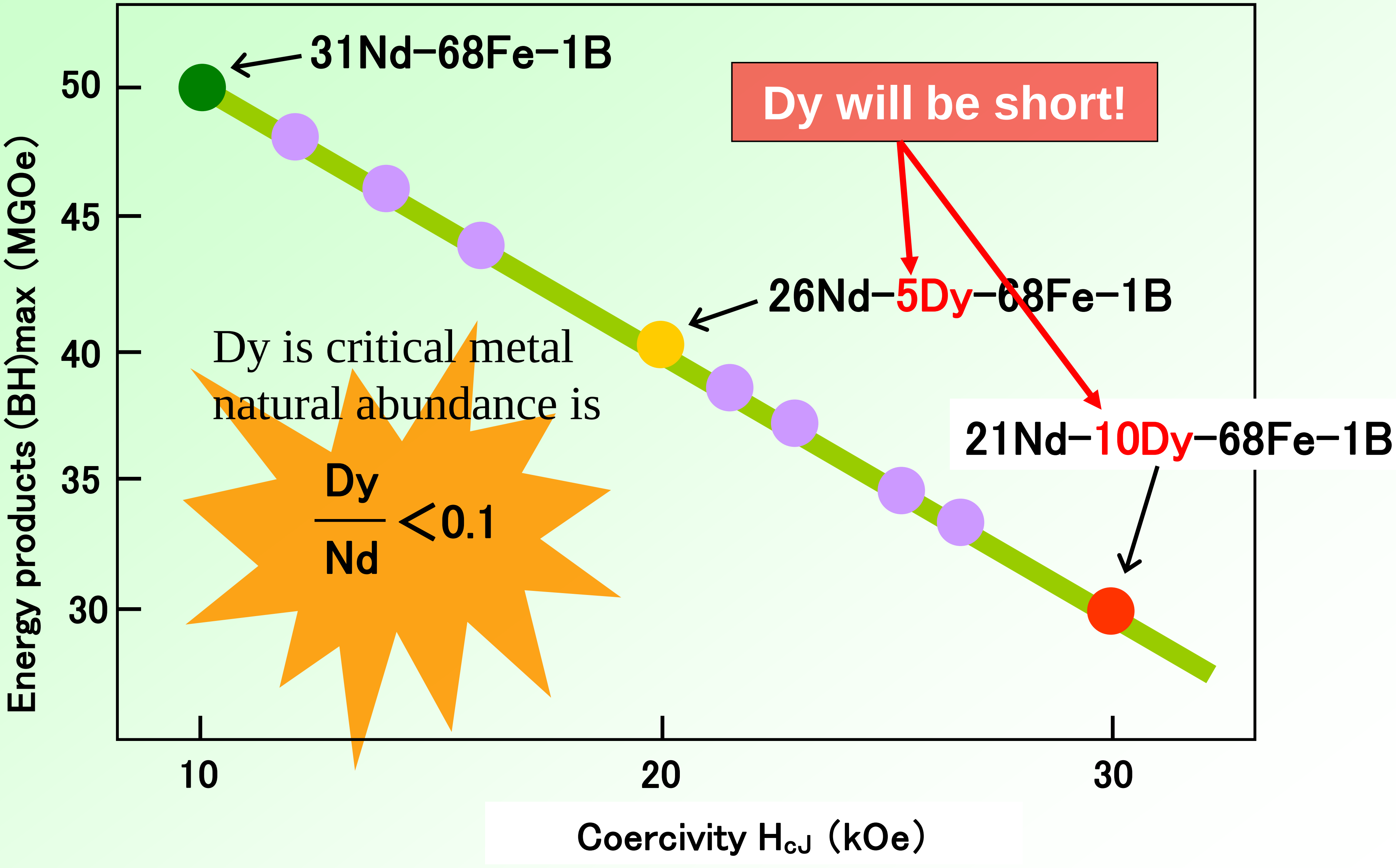


Typical magnetic properties of NdFeB



Pressing direction
VP: vertical pressing
PP; parallel pressing

NdFeB magnetic properties vs composition (wt%)



31Nd-68Fe-1B

Dy will be short!

26Nd-5Dy-68Fe-1B

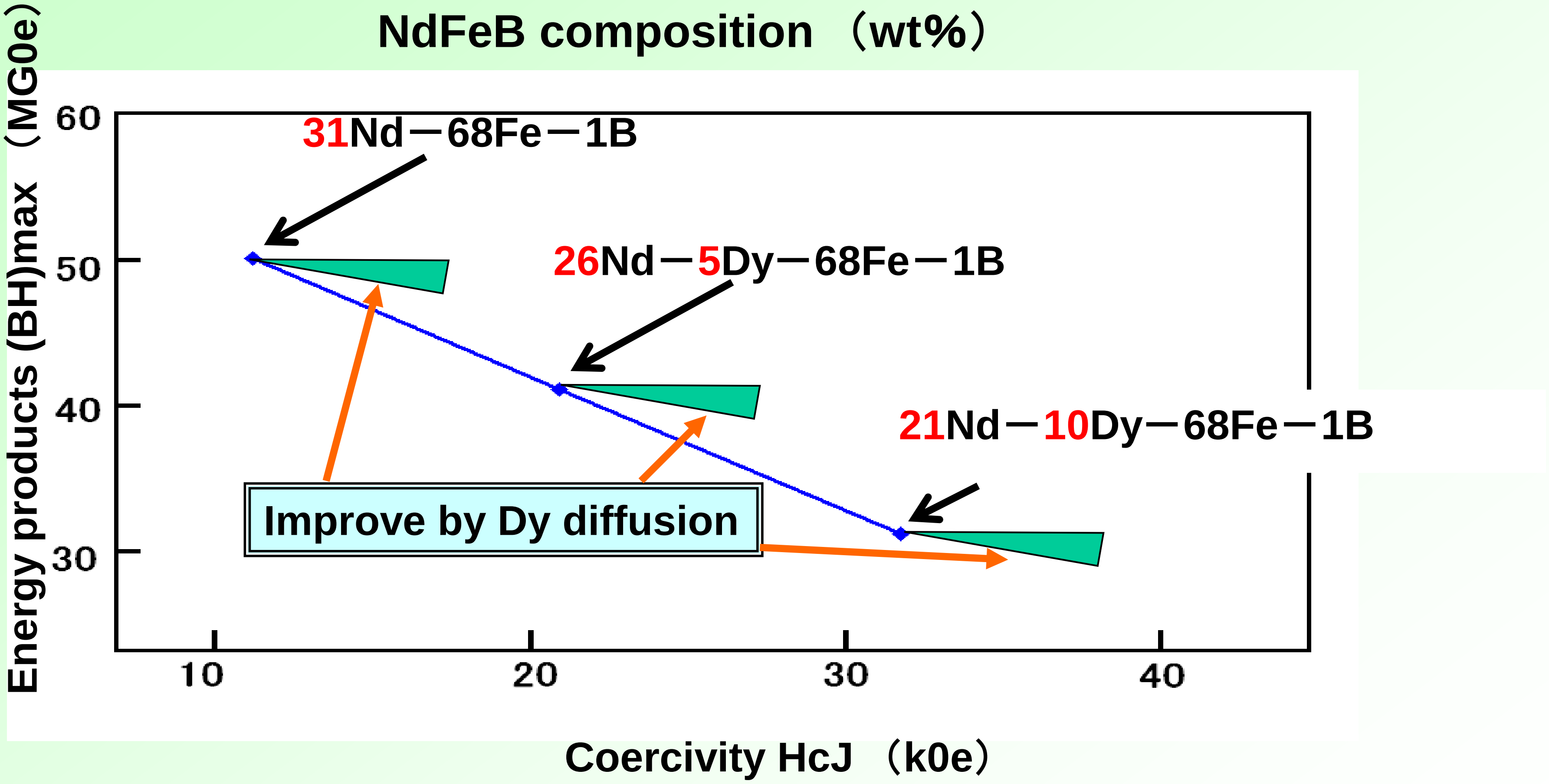
21Nd-10Dy-68Fe-1B

Dy is critical metal natural abundance is

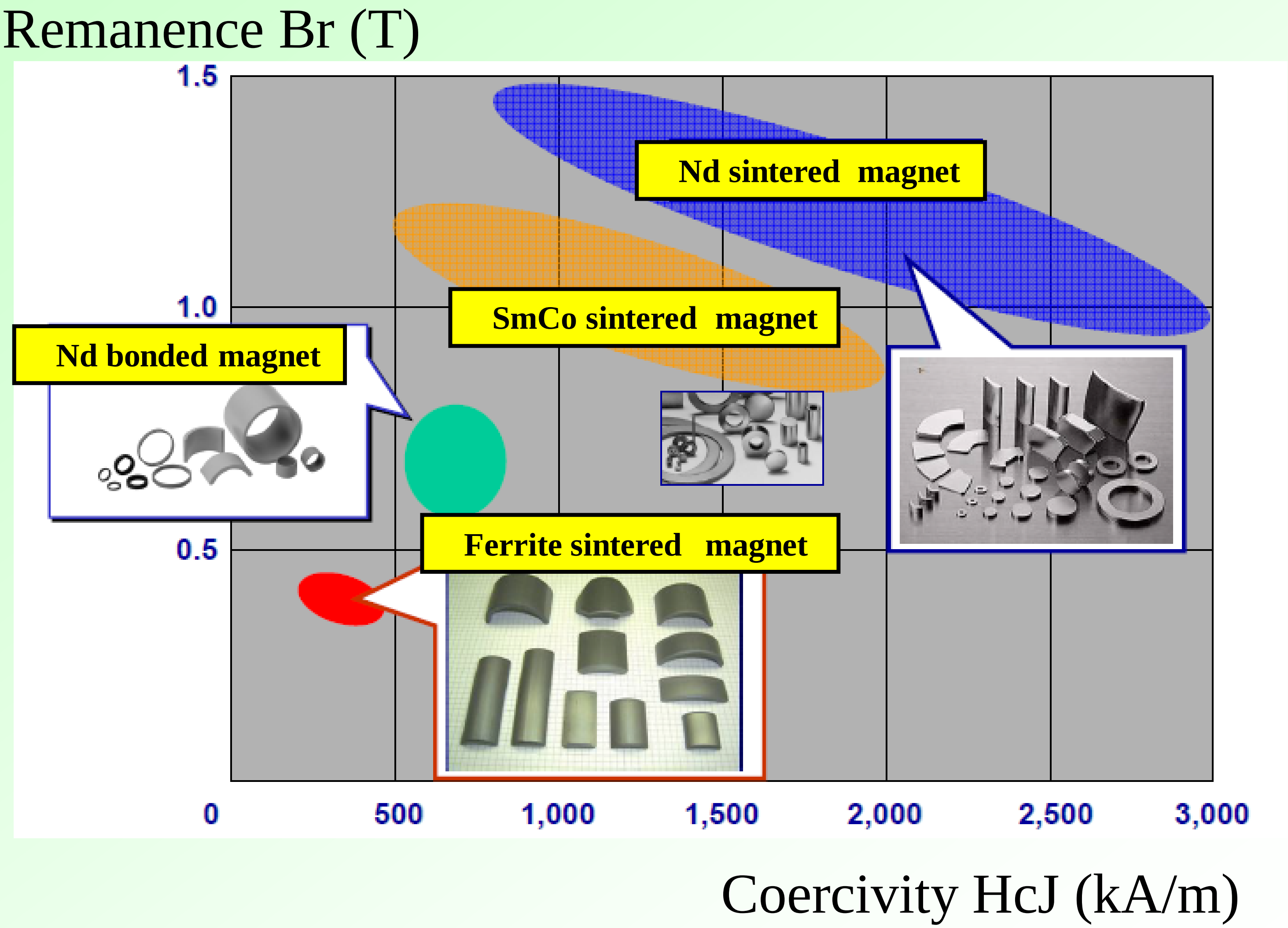
$\frac{Dy}{Nd} < 0.1$

Coercivity vs Dy content

NdFeB composition （wt%）



Typical magnet in mass-production



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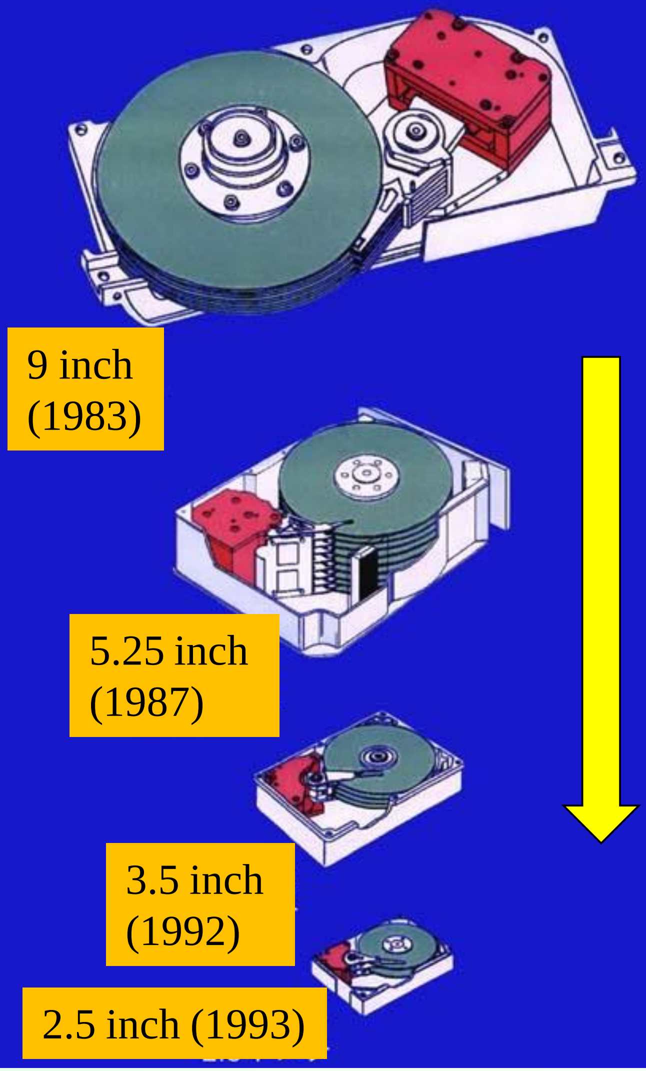
NdFeB applications

History of HDD (hard disk drive)



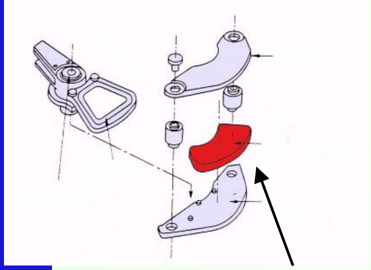
9 inch (1983)

5.25 inch (1987)

3.5 inch (1992)

2.5 inch (1993)

HARD DISK DRIVE



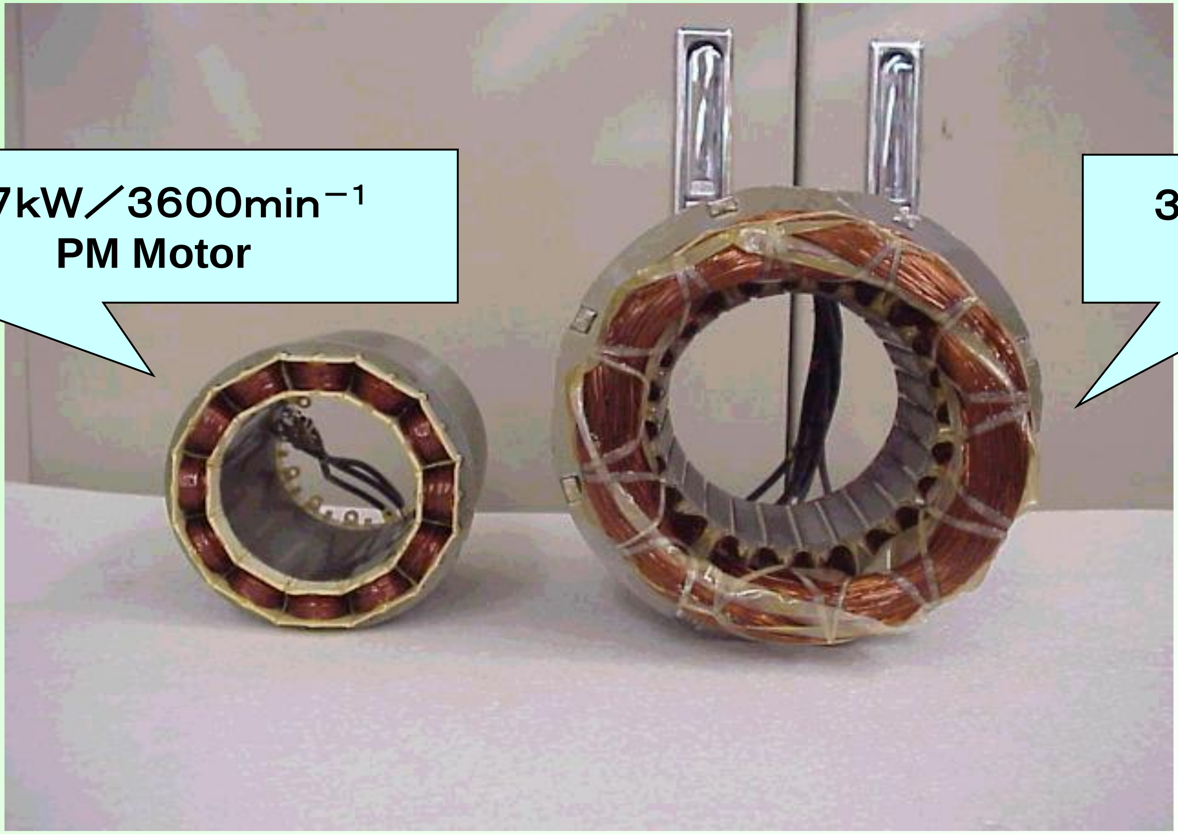
NdFeB

VOICE COIL MOTOR

HDD drastically decreased in size mostly due to the NdFeB magnet performance improvement.

50% of Electric Power is used for motors !

Size comparison between PM motor and conventional induction motor



3．7kW／3600min^{-1}
PM Motor

3．7kW－2pole
IM Motor

PM Motor
Volume; 50%

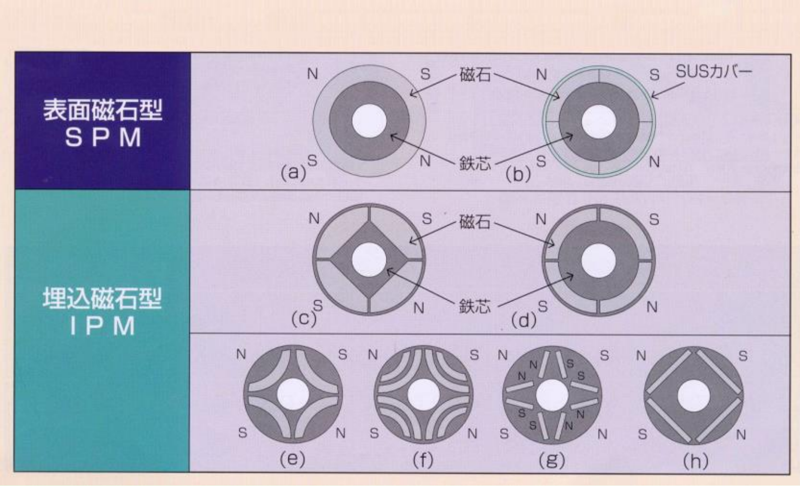
Induction Motor
volume ;100%

PM motors achieve small & compact size saving natural resources.

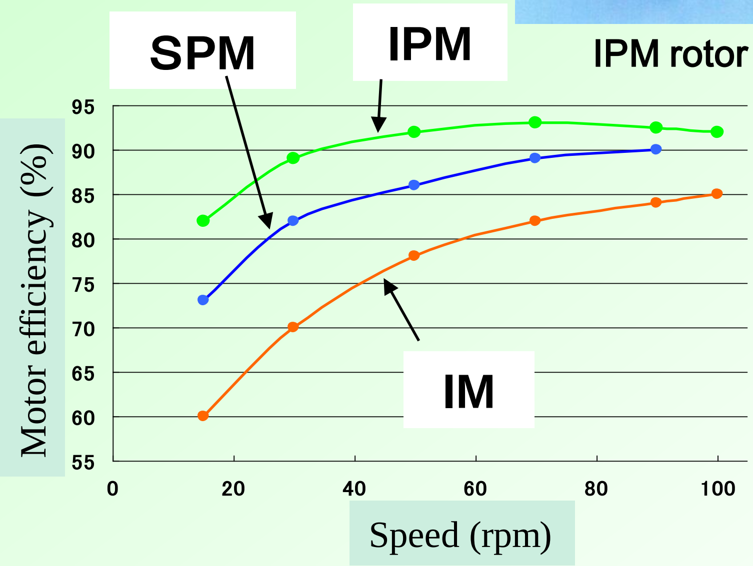
PM motor is more efficient than induction motor

Inverter air-con

IPM rotor



Different magnet position of SPM and IPM Motor



Comparison of Motor efficiency

IM ; Induction Motor

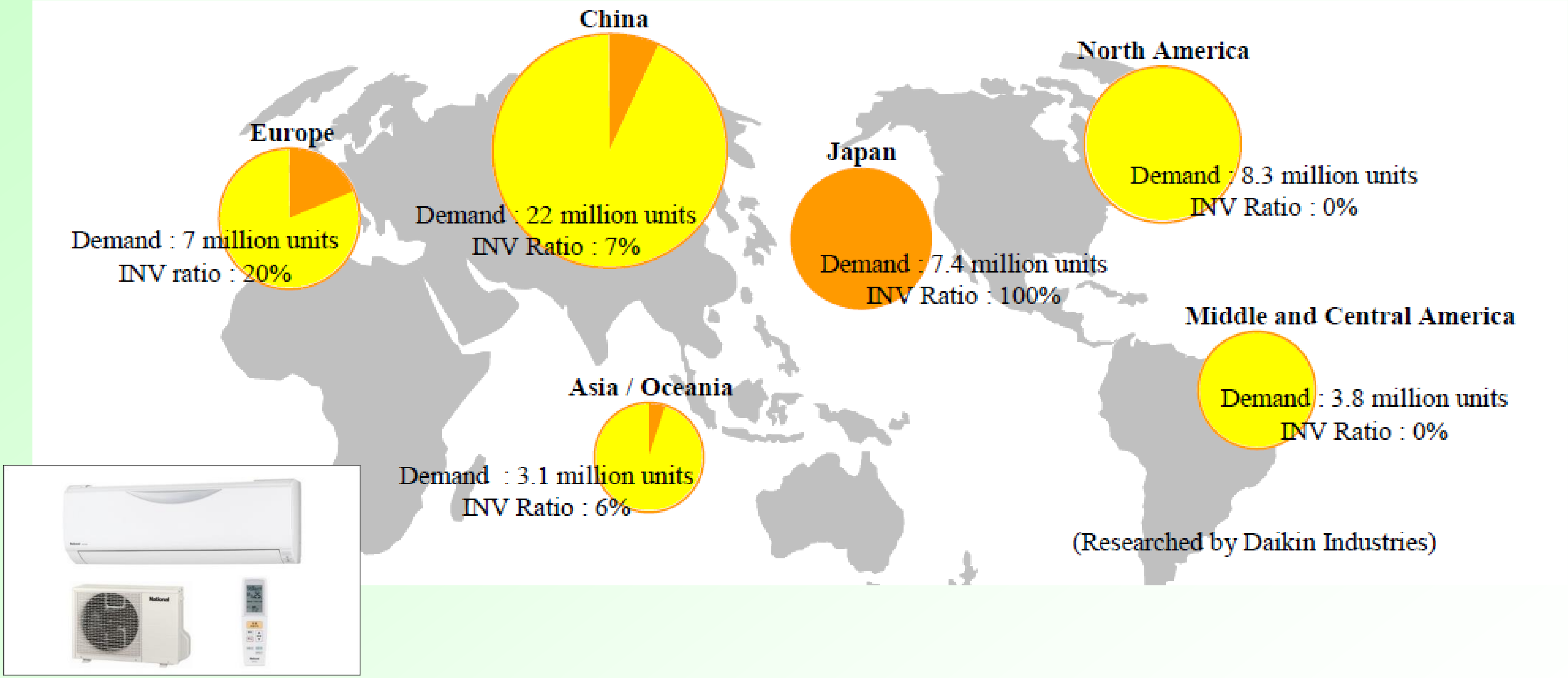
PM ; Permanent magnet motor

*SPM (Surface permanent magnet) ;

*IPM(Interior permanent magnet) ;

Japn is the top runner of inverter air-con using (PM)permanent magnet ;NdFeB magnet

Red; Inverter ratio

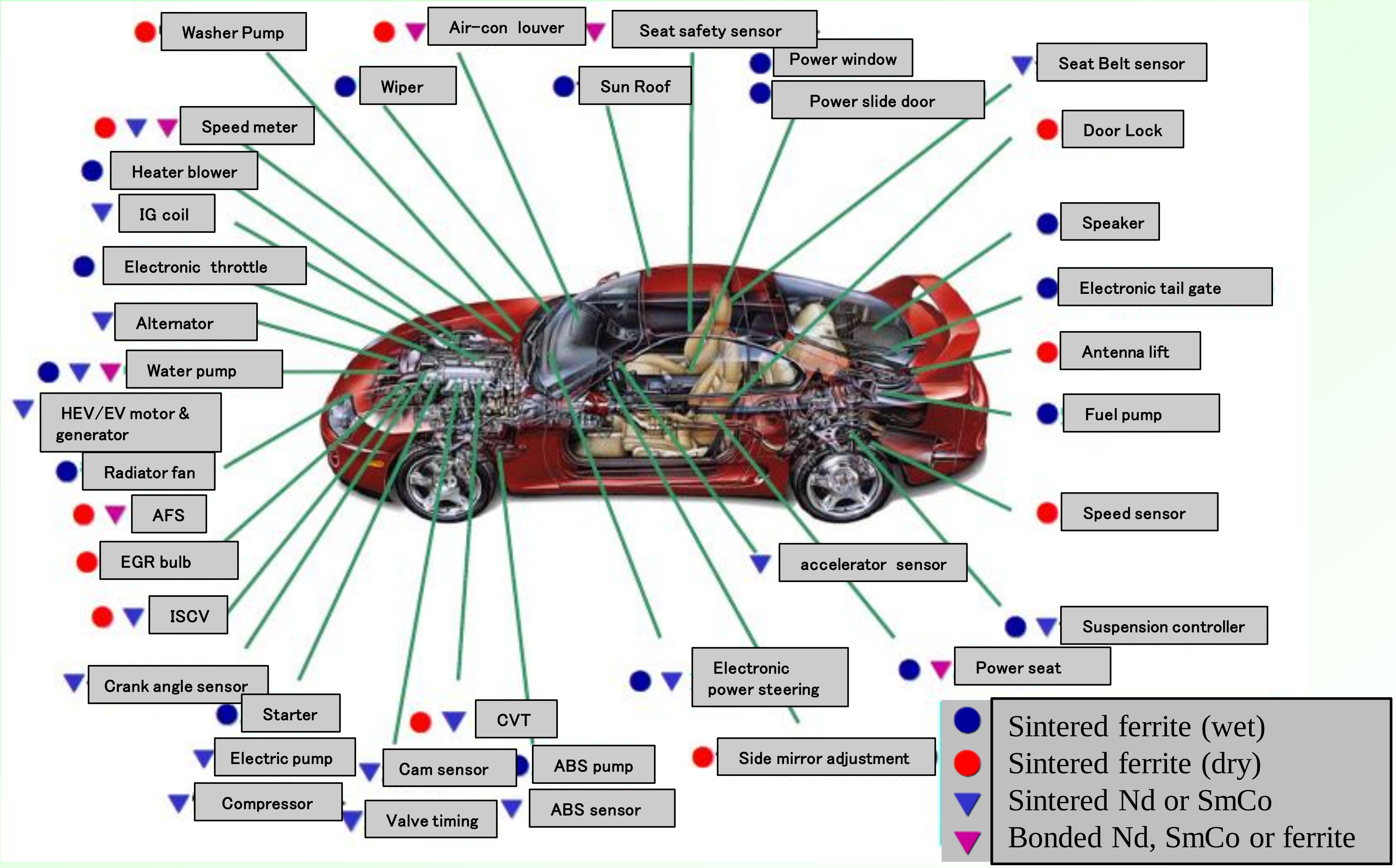


(Researched by Daikin Industries)

Inverter air-con can save electric power of 30-40% reduction level compared with conventional on-off air-con

Massive application of permanent magnets in a car

KRI



🔴 Washer Pump

🔴 🔻 Air-con louver

🔻 Seat safety sensor

🔵 Power window

▼ Seat Belt sensor

🔵 Wiper

🔵 Sun Roof

🔵 Power slide door

🔴 ▼ 🔻 Speed meter

🔴 Door Lock

🔵 Heater blower

▼ IG coil

🔵 Speaker

🔵 Electronic throttle

🔵 Electronic tail gate

▼ Alternator

🔴 Antenna lift

🔵 ▼ 🔻 Water pump

▼ HEV/EV motor & generator

🔵 Fuel pump

🔵 Radiator fan

🔴 🔻 AFS

🔴 Speed sensor

🔴 EGR bulb

▼ accelerator sensor

🔴 ▼ ISCV

🔵 ▼ Suspension controller

🔵 ▼ Electronic power steering

🔵 🔻 Power seat

▼ Crank angle sensor

🔵 Starter

🔴 ▼ CVT

▼ Electric pump

▼ Cam sensor

🔵 ABS pump

🔴 Side mirror adjustment

▼ Compressor

▼ Valve timing

▼ ABS sensor

🔵 Sintered ferrite (wet)

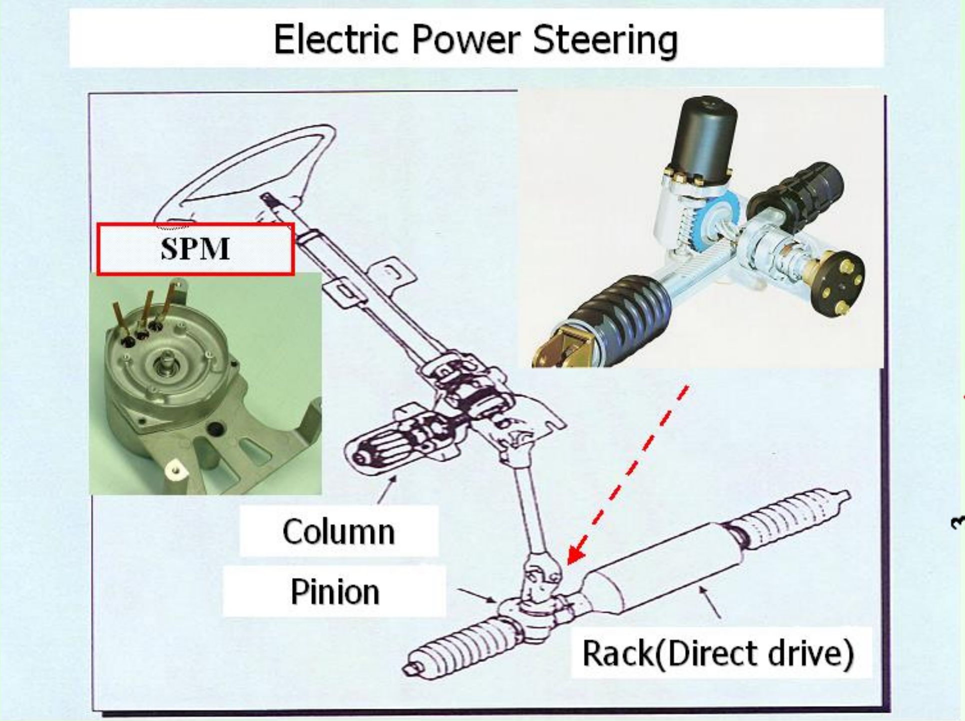
🔴 Sintered ferrite (dry)

▼ Sintered Nd or SmCo

🔻 Bonded Nd, SmCo or ferrite

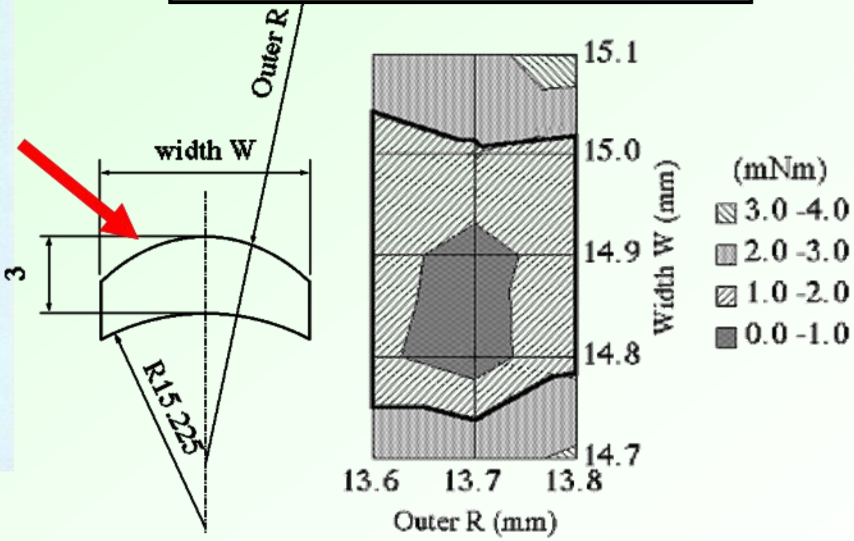
Memo; AFS; Active Front Lighting system, ISCV; Idle speed control valve, CVT; Continuoue variable transmission

Expanding EPS Applications



IC

Two-arc-radii segment



Low cogging by Two-arc-radii segment

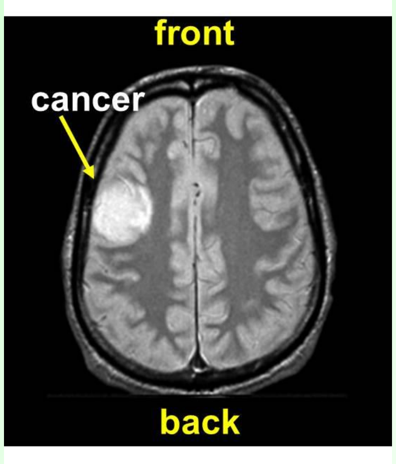
Future application; Wind mill generater

Type	Horizontal Type
Blade	3
Blade diameter)	15m
Hub height	22m
Rated power	40KW
Generator	**NdFeB magnet**
Rated speed	11m/sec

Permanent Magnet Type MRI

KRI

Superconductive type



Permanent Magnet type

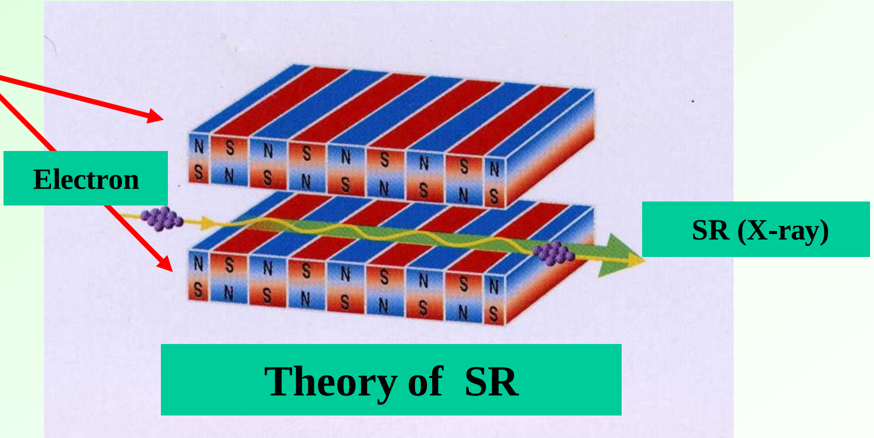
- First Mass-production in Japan in late 1980’
- Magnetic Field; 0.2-0.4 Tesla
- Weight; 10-20 Ton
- Compact (less than half space of SC type)
- Non running cost (No Helium etc)
- No magnetic shielding is necessary

Undulator/ Wiggler
for SR (Synchrotron radiation)

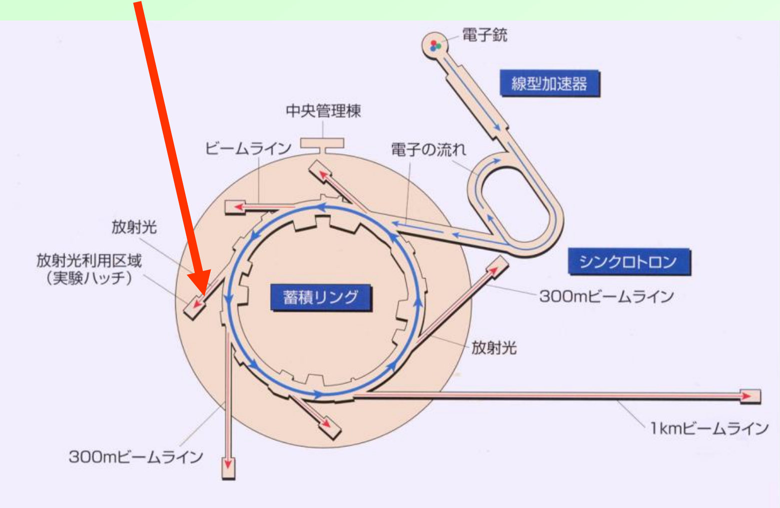
SPring-8;（Nishiharima）

Xray; x10^4 high density beam line

Two arrays of NdFeB magnets



Theory of SR



Undulator

Electron； accelerator → synchrotron ring
→storage ring → undulator in the beam line

In-vacuum type
NdFeB magnet undulator

Thank you

Tusen Takk　!

Contributing the "sustainable" earth through Nd magnets

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