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MAGNETIC TECHNOLOGIES

Market Outlook

for Ferrite, Rare Earth and other Permanent Magnets

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- Permanent magnets are ubiquitous, critical products that support our standard of living and quality of life in manifold ways.

- First a quick introduction to Arnold – the company I've worked for since 1992.
- Arnold's history in magnetics and magnetic materials extends back to 1895 and has included almost every commercially supplied permanent and soft magnetic product.
- Today Arnold is focused on: SmCo, Alnico and bonded permanent magnets; precision thin metals – both magnetic and non-magnetic; magnetic assemblies for motors, magnetic levitation, sensing and separation technologies; and most recently we have responded to customer requests to develop and supply ultra-high performance permanent magnet motors for select applications.

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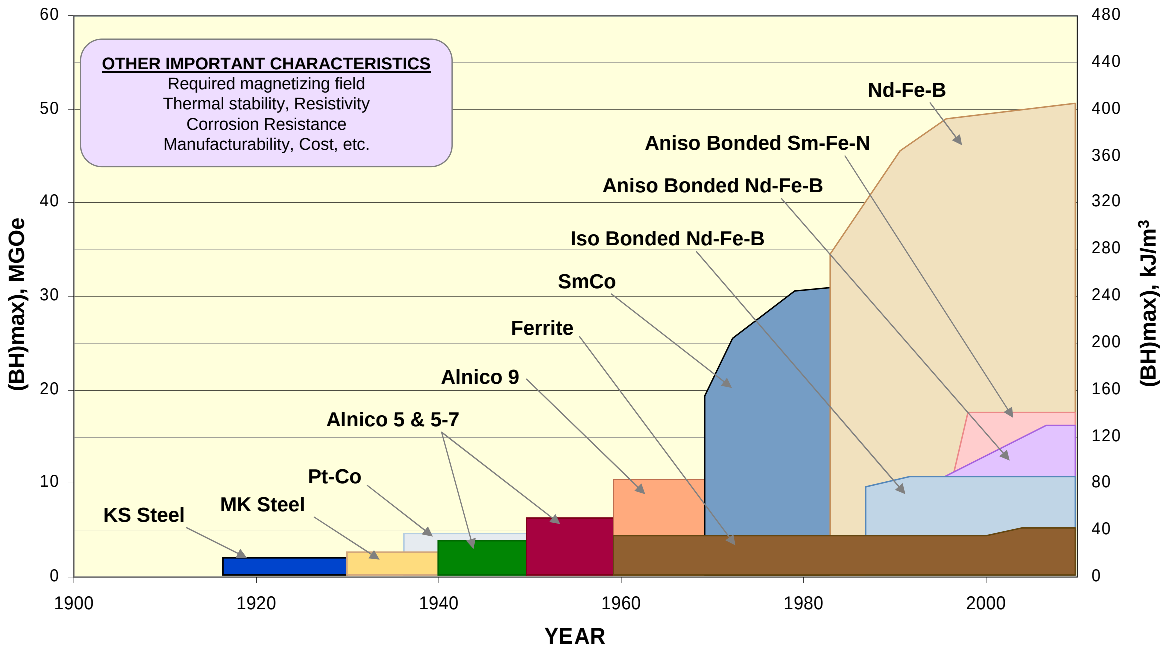
- Here are the five subject areas we'll cover today.

Improvement in Magnet Strength



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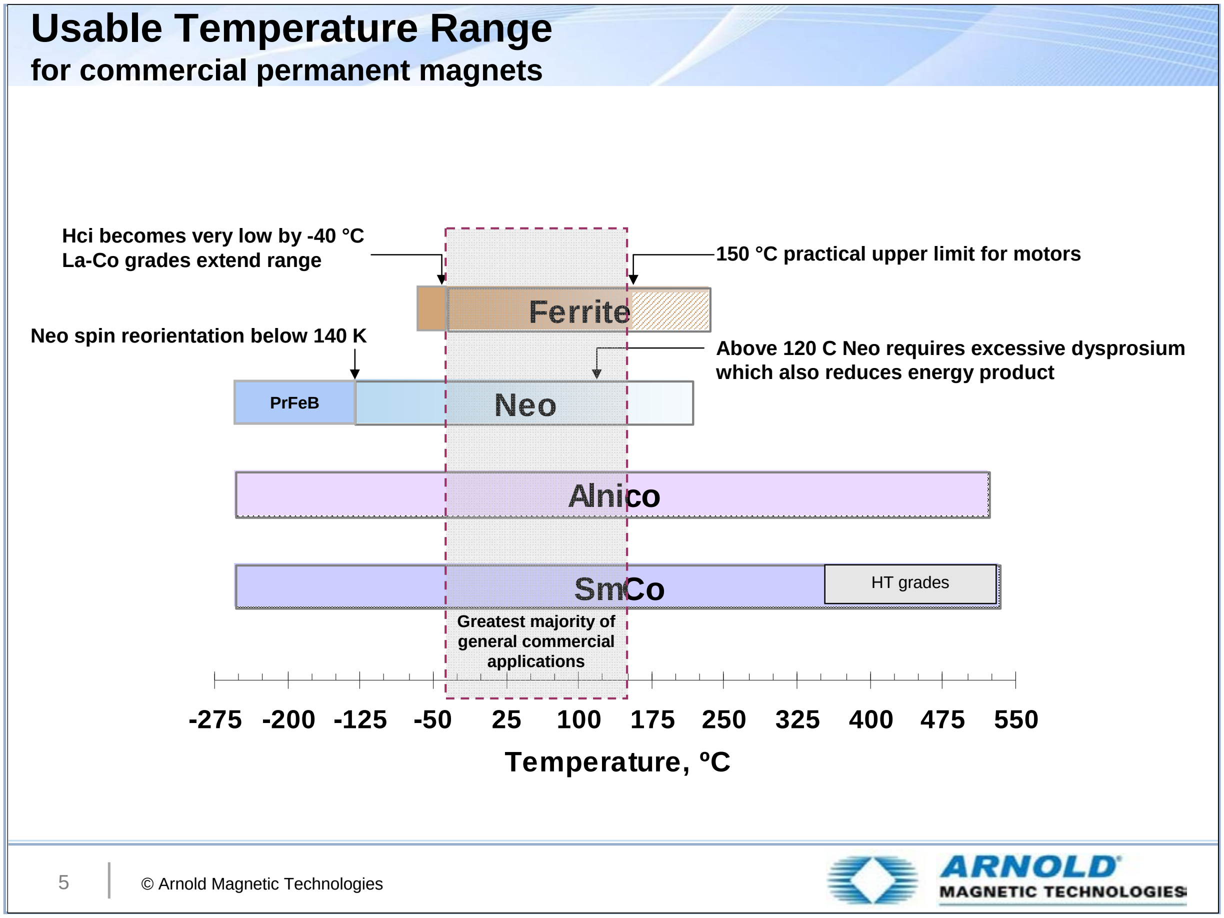
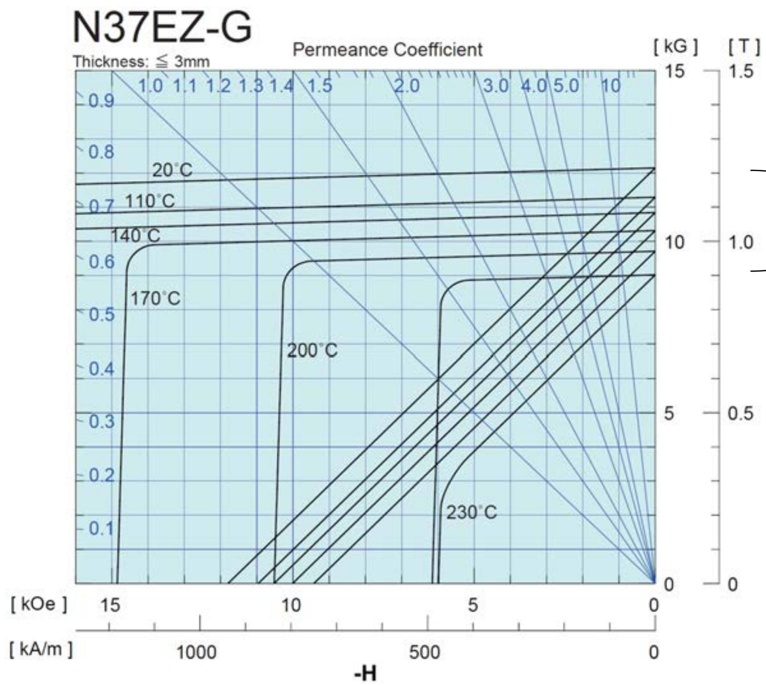
- One of the most well known magnet figures of merit is energy product.
- A chart presentation of energy product development over time graphically emphasizes the improvements.
- By the way, all the materials in this chart are still used in selected applications where their combination of price and performance is superior to the others.
- For example, even though ferrite magnets are far weaker than the rare earths, they continue to dominate in sales on a weight basis representing over 85% of permanent magnets sold in the free world.
- However, the focus on device low weight and small size has driven up usage of rare earth magnets so that neo magnets now represent over half of all magnet sales on a dollar basis.



- Magnetic performance is not constant – as temperature changes so do key material parameters.
- Each of the four commercially important materials can be effectively utilized over a limited temperature range.
- Neo (NdFeB) magnets are limited to above 140 K and their high temperature performance is compromised by loss of resistance to demagnetization.
- Ferrite magnets exhibit lower flux output with increasing temperature so that by 150 degrees Celsius, flux output is reduced by 25 percent.
- However, both Alnico and SmCo can be used from near absolute zero to over 500 degrees Celsius.

HRE-Diffused Grades e.g. Shin-Etsu N37EZ-G

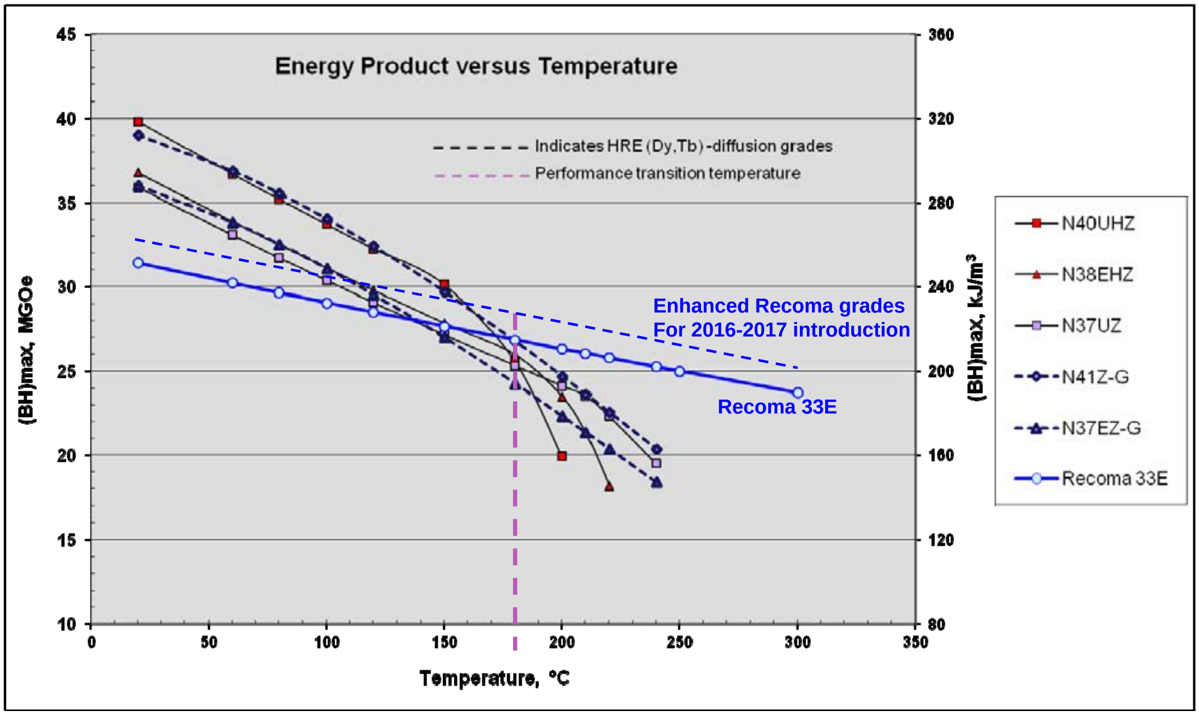


26% reduction in Br;
45% reduction in energy product

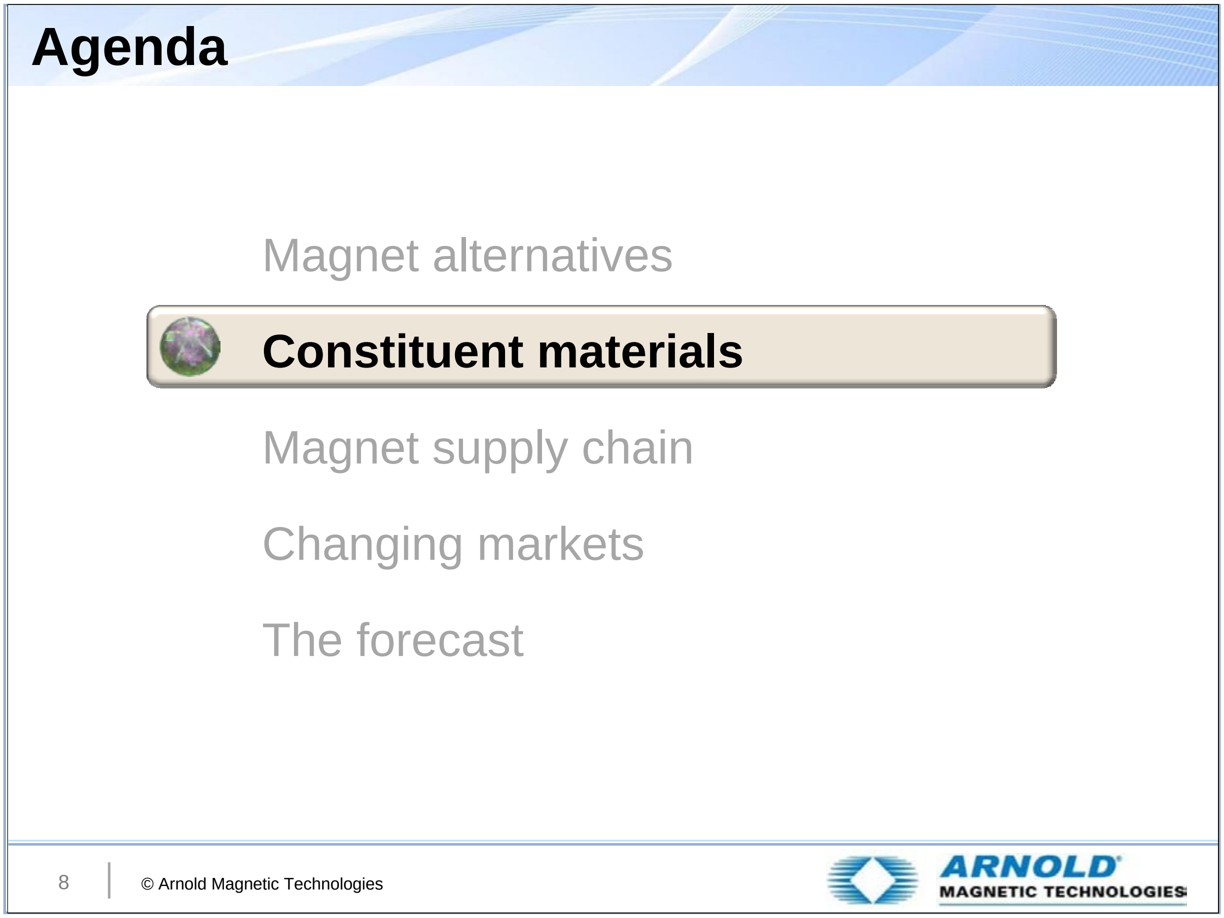
In contrast, SmCo 2:17 experiences less than 8% reduction in Br; less than 16% reduction in energy product

- The recently developed technology of diffusing heavy rare earth into the grain boundary of Neo magnets has provided a dramatic increase in resistance to demagnetization. However, Neo loses significant flux output with increasing temperature and from 20 to 230 degrees there is a 26% reduction in Br which equates to a 45% reduction in energy product – energy product changes approximately as the square of the change in Br.
- SmCo, on the other hand, is a true high temperature-capable magnet material, losing only 1/3 as much as Neo.

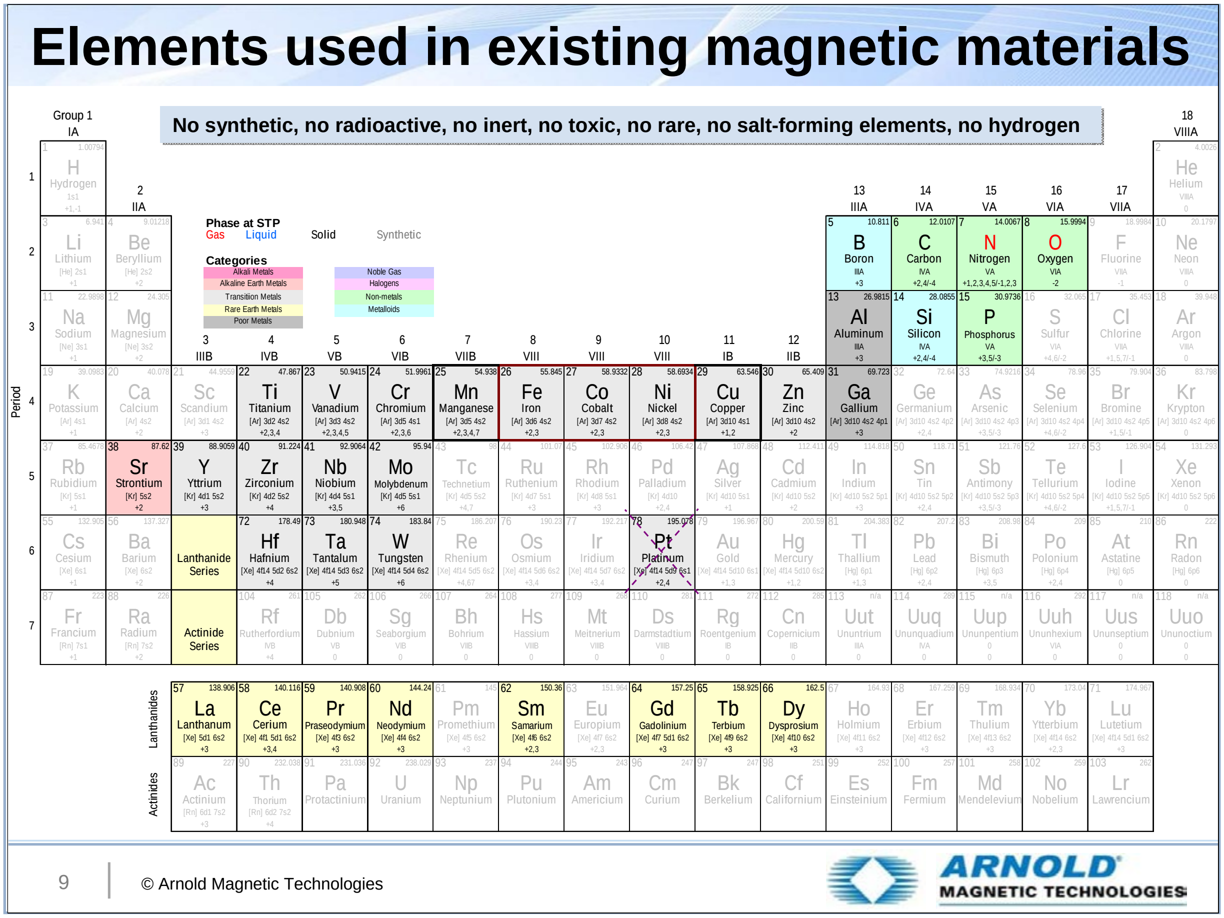
Product Comparison – Energy Product



- This chart exemplifies the difference in change in energy product as a function of temperature for several grades of Neo and for SmCo.
- Above 150 degrees, SmCo outperforms Neo in both energy product and resistance to demagnetization.



- To better enable us to understand the market surrounding magnets it is advantageous to see what materials, i.e. elements, go into magnets.



- This copy of the periodic table has numerous elements "grayed-out".
- These include the radioactive, rare, synthetic, inert, salt-forming and other elements that do not contribute to making a good magnet product.
- We're down to 36 elements with which to make magnet materials.
- Let's ask a question: what elements have been used over the last 150 years to make magnetic materials?

Elements in Existing Magnetic Materials

	Major constituents						Minor constituents				Comments
Soft Magnetic Materials											
Iron	**Fe**										Low carbon mild steel
Silicon Steel	**Fe**						**Si**				Si at 2.5 to 6%
Nickel-Iron	**Fe**	Ni									Ni at 35 to 85%
Moly Permalloy	Ni	**Fe**					Mo				Ni at 79%, Mo at 4%, bal. Fe
Iron-Cobalt	**Fe**	Co					V				23 to 52% Co
Soft Ferrite	**Fe**	**Mn**	Ni	Zn			O				Oxygen dilutes, required for structure
Metallic Glasses	**Fe**	Co	Ni				**B**	**Si**	**P**		Amorphous and nanocrystalline
Permanent Magnets											
Co-Steels	**Fe**	Co									
Alnico	**Fe**	Ni	Co	**Al**	Cu		**Ti**	**Si**			
Platinum Cobalt	**Pt**	Co									
Hard Ferrites	**Fe**	**Sr**									Oxygen dilutes; Ba no longer used
SmCo	Co	Sm	(Gd)	**Fe**	Cu	**Zr**					Sm is underutilized; excess supply
Neodymium-iron-boror	**Fe**	Nd	Dy	(Y)	**B**	Co	Cu	Ga	**Al**	Nb	
Cerium-iron-boron	**Fe**	Nd	Ce	B							Limited use in bonded magnets
SmFeN	**Fe**	Sm	**N**								Nitrogen is interstitial; stability issue
MnBi	**Mn**	**Bi**									Never commercialized
MnAl(C)	**Mn**	**Al**					Cu	**C**			Not successfully commercialized

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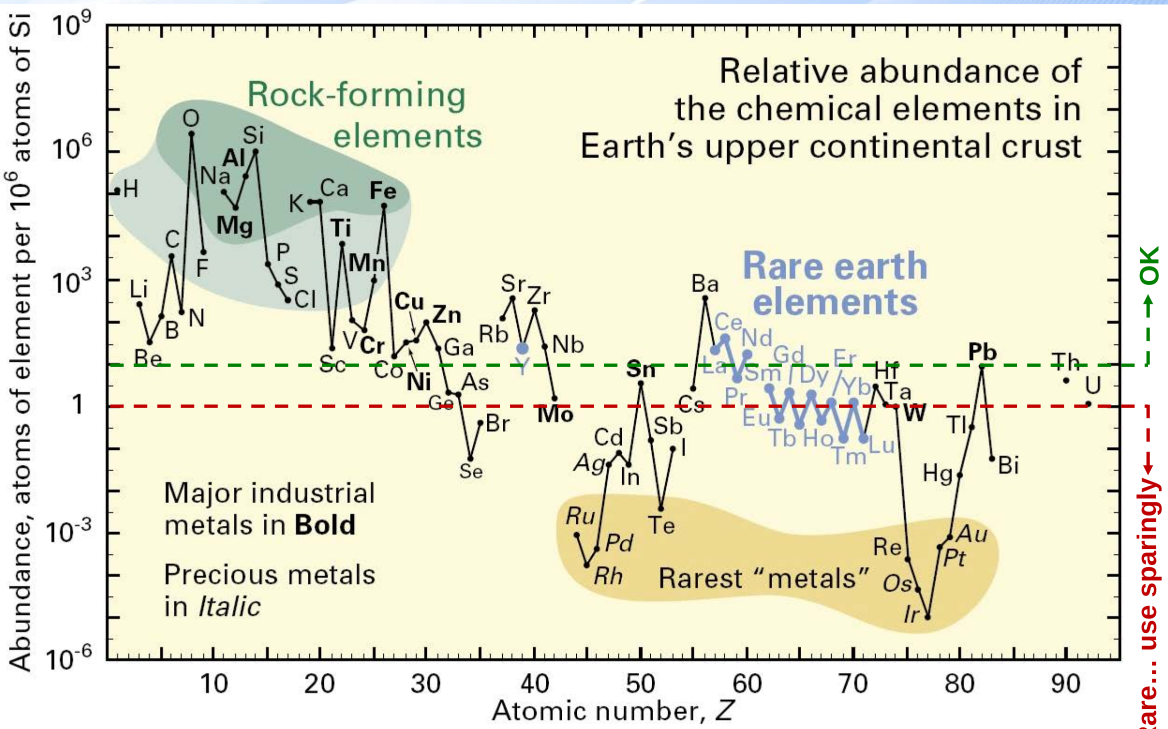
- This list contains most (though not all) common magnetic materials and the elements used to make them.
- These are the same elements selected on the periodic table.
- Elements shown here in red are too rare for practical use in all but very special applications.
- Elements in light green may be used, but are better consumed in modest percentages.
- Those in bold-face green are abundant and readily available.
- Take a good look and then we'll move to the next slide showing them in a chart created by the USGS showing elemental abundance.

Relative abundance of the elements



Source: http://pubs.usgs.gov/fs/2002/fs087-02/

- Placement of the green and red dashed lines is based on experience with elements in known magnetic materials.
- For example, note that PtCo is a fairly good permanent magnet material, but because Pt is truly rare, it is very expensive and PtCo magnets are seldom used.
- And if PtCo were used in larger quantities, the price of Pt would respond by rising dramatically.

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Balancing Supply and Demand

- Balance of supply and demand within the market and the supply chain into the magnet market is key to preventing disruptive pricing changes.

International Trade is Complex

Quality & Cost of Infrastructure: Tooling, electricity, process gases, raw materials and supplies

IP: Patent protection

Value Added Tax

Science Education and R&D

Tariffs: Export and Import

Currency Exchange Rates

CoDB: Cost of Doing Business (Licenses, financial reporting, OSHA, ability to hire/fire, etc.

Quotas: Production and Export

Strategic & Defense Sensitivity

Educated Labor Force

Cost of capital

Political: Int'l Negotiations

Shipping: Cost and Duration (inventory carrying charges)

Technical Leadership

Return on Investment (ROE, ROA, ROI)

Political: Job Creation or Loss

Supply chain dependability

Environmental needs

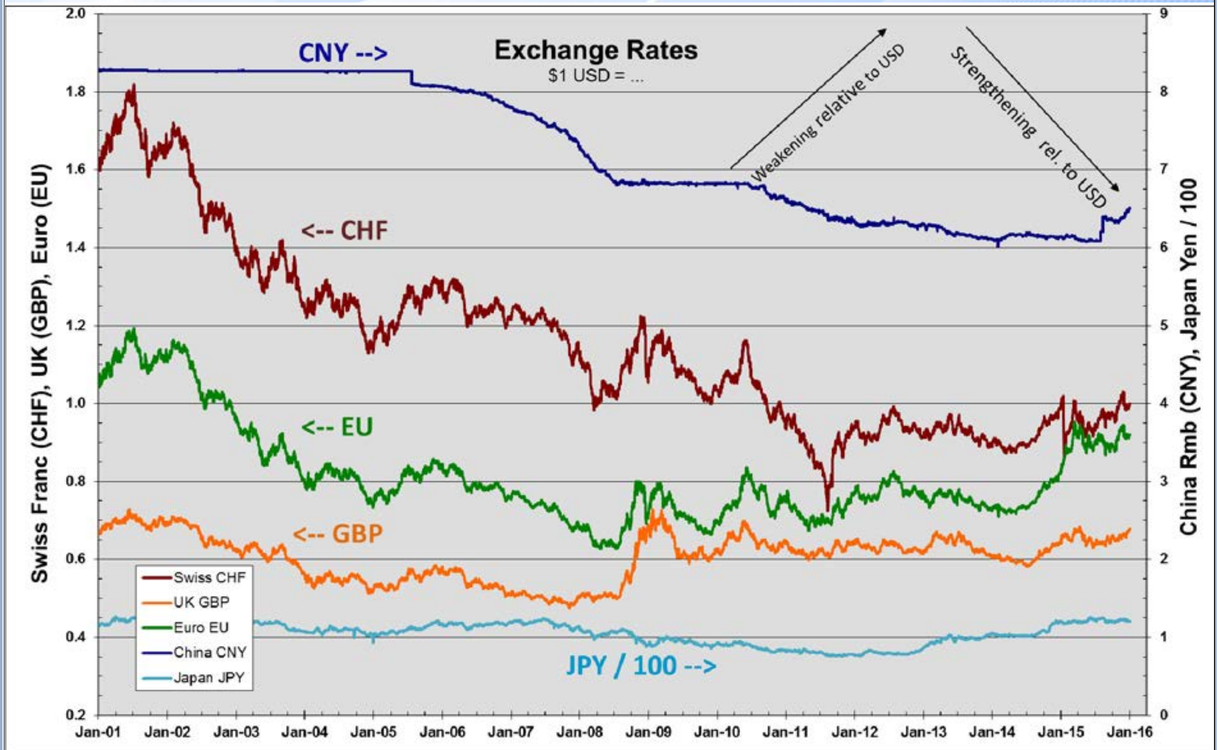
Corporate Tax Rate

Rule of Law

Government intervention

- Supply-demand balance is difficult enough within localized regions, but across country boundaries and large distances, it is a true challenge.
- These are just some of the issues faced in trying to maintain stability and consistency of supply and price in both the short and long term.

Currency Exchange



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- One challenge, which is almost totally out of our control, is management of exchange rates for supply of raw materials, sale of product and domiciling of profits.
- For example, the shift in exchange rates for the Yuan versus the dollar and the Euro versus the dollar, between 2005 and 2014, showed 25% strengthening.

Raw Material Sourcing – comparing REEs & Cobalt

Rare Earths

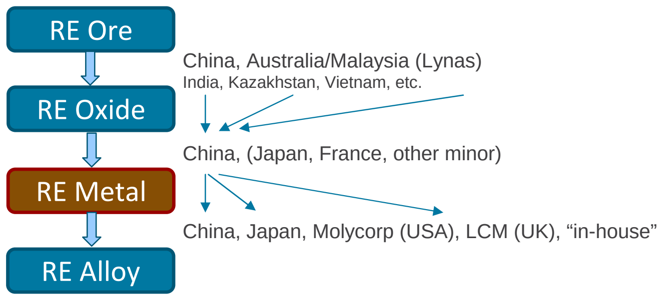

Figure 42: Estimated number of facilities and REO separation and refining capacity by country

Country	Estimated Number of Facilities	Estimated TREO Production Capacity (tonnes)	Current Rare Earth Products Yielded	Estimated Capacity Utilization (%)
China	59+	320,000	83% Separated REOs, mixed REOs	33%
Brazil	1	2,000	Separated REOs, mixed REOs	8%
Estonia	1	3,000	Separated REOs	90%
France	1	9,000	Separated REOs	25%
India	2	2,500	Mineral concentrates	80%
Kazakhstan	1	4,000	RE chloride	0%
Malaysia	2	22,600	Separated REOs, mixed REOs, mineral concentrates	45%
Russia	1	4,000	Separated REOs, RE chloride, RE carbonate	60%
U.S.	1	20,000	Separated REOs	75%
Vietnam	2	2,500	Separated REOs, mixed REOs, mineral concentrates	9%

Adamas Intelligence - Rare Earth Market Outlook - October 1, 2014

Cobalt

Country	2011 Mine Production Metric tonnes Co-contained	2011 Refinery Production Metric tonnes Co content
Australia	3,850	4,720
Belgium	-	3,187
Botswana	149	-
Brazil	3,500	1,613
Canada	7,071	6,038
China	6,800	43% 35,000
Congo (Kinshasa)	55% 60,000	3,083
Cuba	4,000	-
Finland	535	10,441
France	-	354
India	-	1,299
Indonesia	1,600	-
Japan	-	2,007
Madagascar	500	-
Morocco	2,159	1,788
New Caledonia	3,240	-
Norway	-	3,067
Philippines	2,200	-
Russia	6,300	2,337
South Africa	1,600	840
Uganda	-	661
Zambia	5,400	5,756
Zimbabwe	86	-
Totals	**109,000**	**82,200**

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- Diversity of material supply is also important.
- Why did REEs experience such an increase in pricing in 2011 while cobalt did not? Perhaps the answer lies in the supply chain's ability to react to market needs.
- Converting REO to metal is a constraint-point in the REE supply chain.
- There are few facilities outside China with the capability of processing rare earths on a commercial scale.
- On the other hand, cobalt is widely available – not to say that a disruption in the Republic of the Congo (ROC) wouldn't have an impact on supply and pricing, but the market would be able to adjust relatively more quickly and effectively than for the current rare earth metal supply where China capacity is 83+ percent of the world total.

Sintered (Dense) Magnet Producers

China totally dominates production of raw materials for and manufacture of permanent magnets. They are also, by far, the largest market for magnets.

	China	Japan & Korea	USA	Europe
ALNICO	Atlas Magtech Chengdu Amoeba China Hope Magnet HPMG Shanghai Dao Ye **Many others**	Pacific Metals	Arnold T&S	SG Magnets Ltd Magnetfabrik Bonn Magneti Ljubljana
FERRITE	Anshang Dekang BGRIMM DMEGC Dongyang Gelin Jiangmen **>50 more**	Hitachi SsangYong TDK Ugimag	Hitachi TDK	Magnetfabrik Bonn Magnetfabrik Schramburg
SmCo	Arnold Chengdu Mag Mat'l TianHe Tiannu Group **>20 more**	Hitachi Shin-Etsu TDK	(Arnold) EEC	Arnold Magnetfabrik Bonn Magnetfabrik Schramburg Vacuumschmelze
NdFeB*	Anhui Earth-Panda AT&M BGMT Ningbo Jinji San Huan Thinova Yantai Zhenghai Yunsheng **>250 more**	Daido Hitachi Shin-Etsu TDK	(Hitachi)	Magnetfabrik Bonn (not licensed) Magnetfabrik Schramburg Magneti Ljubljana (not licensed) Vacuumschmelze (Neorem)

*the 8 listed companies are licensed to sell into the USA

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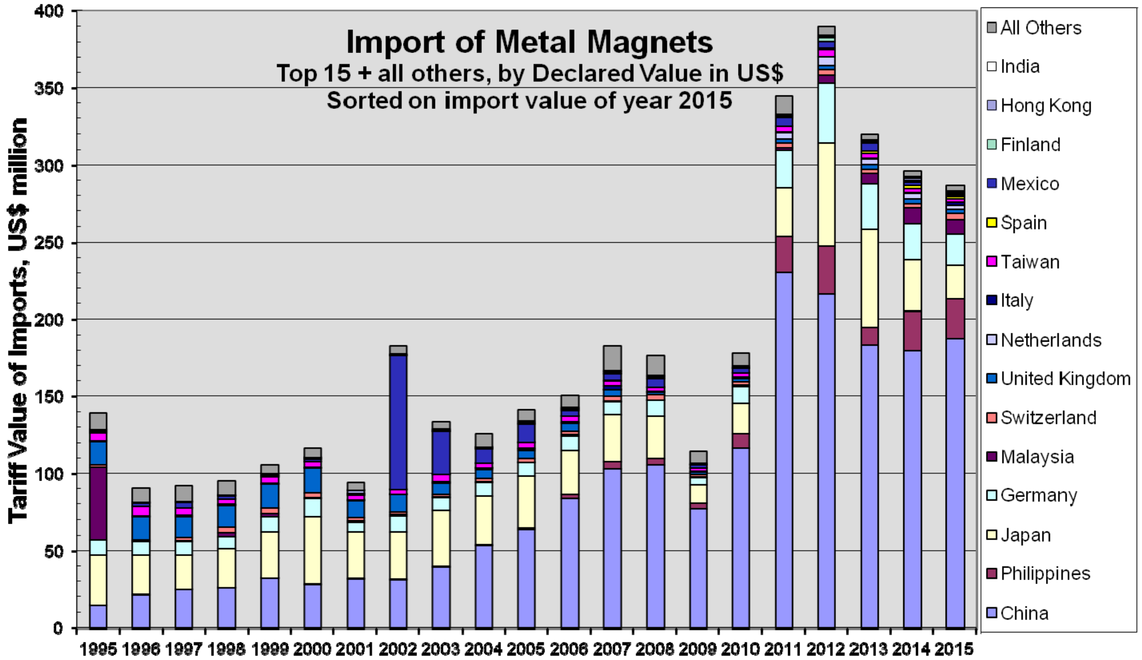
- Downstream from the raw material supply are the manufacturers.
- This listing shows manufacturers of the four most common permanent magnet materials accurate as of January 2016.
- Chinese companies produce over 80% of each of the magnet materials and the Chinese economy consumes the greatest portion domestically, building the magnets into products for use domestically (within China) and for export – products such as motors, appliances, and consumer electronics.
- Although there are few manufacturers of permanent magnets in north America, there are many companies that purchase magnets and pass them on to customers in the US and Canada.
- Magnet distributors typically just buy and resell while fabricators add value to the purchased magnets through machining and assembly.
- What quantity of magnets are purchased by these USA-located fabricators and distributors?

ITC data on metal magnet imports



Imports of NdFeB into the USA in 2015 ~$250 million, only ~3% of global on-record NdFeB production

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- The US ITC (International Trade Commission) keeps statistics on imports into the USA for many products including metal magnets.
- These are metal alloy materials that are, or are intended to be, used as magnets. (Magnets within products are not included).
- The metal magnet types include Neo, SmCo, FeCrCo, alnico, Vicalloy and similar materials.
- Neo magnets represent the greatest percentage of product both on a weight and dollar basis.
- The country list to the right of the chart is shown in the same sequence as the right-most bar of the chart with China at the bottom and “all other” at the top.
- The chart shows the country of importation, but not the country of origin. For example, there are no manufacturers of metal magnets in the Philippines or Malaysia. Are magnets funneled through these countries to avoid import tariffs?
- The values shown are US dollars and are the claimed value of the imported product, not the potential sales value within the USA.

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- Factors which make tracking of the magnet market difficult are:

1) So much of the market is now within China

2) China has a large number of manufacturers and

3) the market is not stable – it is changing – let's see how this is so.

Ferrite magnet use

Greater than 88% of all permanent magnets on a weight basis.

Motors - Automotive	18%	**70% in motors**
Motors - Appliances	13%	
Motors - HVAC	13%	
Motors - Industrial & Commercial	12%	
Motors - All Other	5%	
Loudspeakers	9%	
Separation Equipment	5%	
Advertising & Promotional Products	5%	
Holding & Lifting	5%	
MRI	3%	
Relays & Switches	1%	
All Other - Miscellaneous	11%	

Sources: Numerous including Benecki, Clagett and Trout, personal communications with industrial partners, conferences, suppliers, etc.

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- For ferrite, about 70% of all ferrite magnets are used in motors. This number has not changed much over time.

Rare Earth magnet use

2010 data last updated June 2014

Greater than 65% of all permanent magnets on a $$ basis.

Motors, industrial, general auto, etc	24.0%	●
HDD, CD, DVD	16.3%	●
Electric Bicycles	8.4%	●
Transducers, Loudspeakers	8.1%	●
Magnetic Separation	4.6%	
MRI	3.9%	
Torque-coupled drives	3.3%	
Sensors	3.1%	
Generators	3.0%	●
Hysteresis Clutch	2.8%	
Air conditioning compressors and fans	2.4%	●
Energy Storage Systems	2.3%	●
Wind Power Generators	1.9%	●
Gauges	1.5%	
Magnetic Braking	1.5%	
Relays and Switches	1.3%	
Pipe Inspection Systems	0.9%	
Hybrid & Electric Traction Drive	0.8%	●
Reprographics	0.6%	
Wave Guides: TWT, Undulators, Wigglers	0.3%	
Unidentified and All Other	6.6%	

● Motor-type applications = 67%

Sources: Numerous including: Benecki, Clagett and Trout; Roskill; Kingsnorth; personal communications with industrial partners, conferences, suppliers, etc.

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- About 67% of Neo magnets are used in motors – about the same as for ferrite.
- There are several more applications for rare earth magnets, especially Neo, due to improved temperature stability and much higher energy output.
- The market for Neo magnets, however, is undergoing large change.

Major and Developing Uses of Neo Magnets

- HDD (Global): mature products
  - Magnet total weight consumed in 2015 is estimated = **7,500 tonnes**
- Hybrid and electric cars & trucks (Global): in growth phase
  - Estimates of between 6 and 10 million hybrids to be manufactured in 2020
  - Each hybrid vehicle utilizes an average of 2 kg of neo magnets in drive and other sensor and motor applications: electric power steering, electric brakes, e-Turbo, speakers, etc.
  - Total neo magnet usage in 2015 = **7,000** rising to **17,000 tpa** in 2020
- Wind turbines (Global): generation IV permanent magnet generators ramping up
  - Between 200 (hybrid) and 500-600 kg (direct drive) neo magnets per MW output
  - Replacement of a 500 MW (average-size) coal-fired power plant would require ~275 tonnes of neo magnets
  - Global 2015 consumption = **8,500 tonnes**
- EB (electric bicycles) (primarily in Asia): large and growing application
  - 65-350+ grams of neo magnets per EB
  - 20 million sold in China in 2009; forecast growth to 60 million per year globally in 2018
  - Annual neo magnet usage = **6,000** rising to **>15,000 tpa** by 2018
- Air Conditioning (primarily southeast Asia and India)
  - In rapid growth phase
  - Use permanent magnet reluctance type motors to achieve ~20% efficiency gains
  - Neo in 2014= **>4,000 tonnes**

- Acoustic transducers
  - More than 1.8 billion cell phones currently connected use speakers and vibrator motors
  - Speakers in transportation – more than 280 million speakers per year
  - Speakers, ear buds, headphones = **>4,500 tpa**

2015: 6.8 billion cell phones are connected

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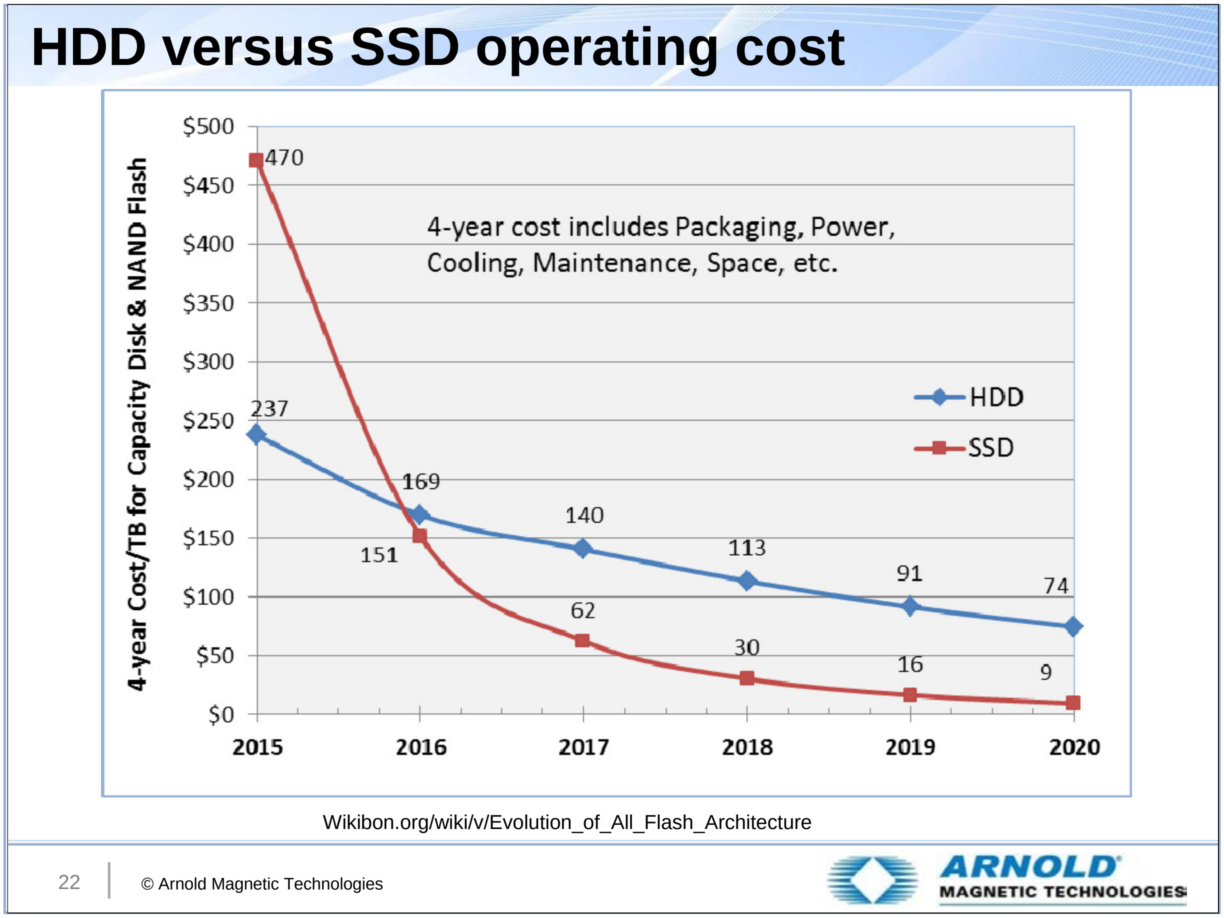
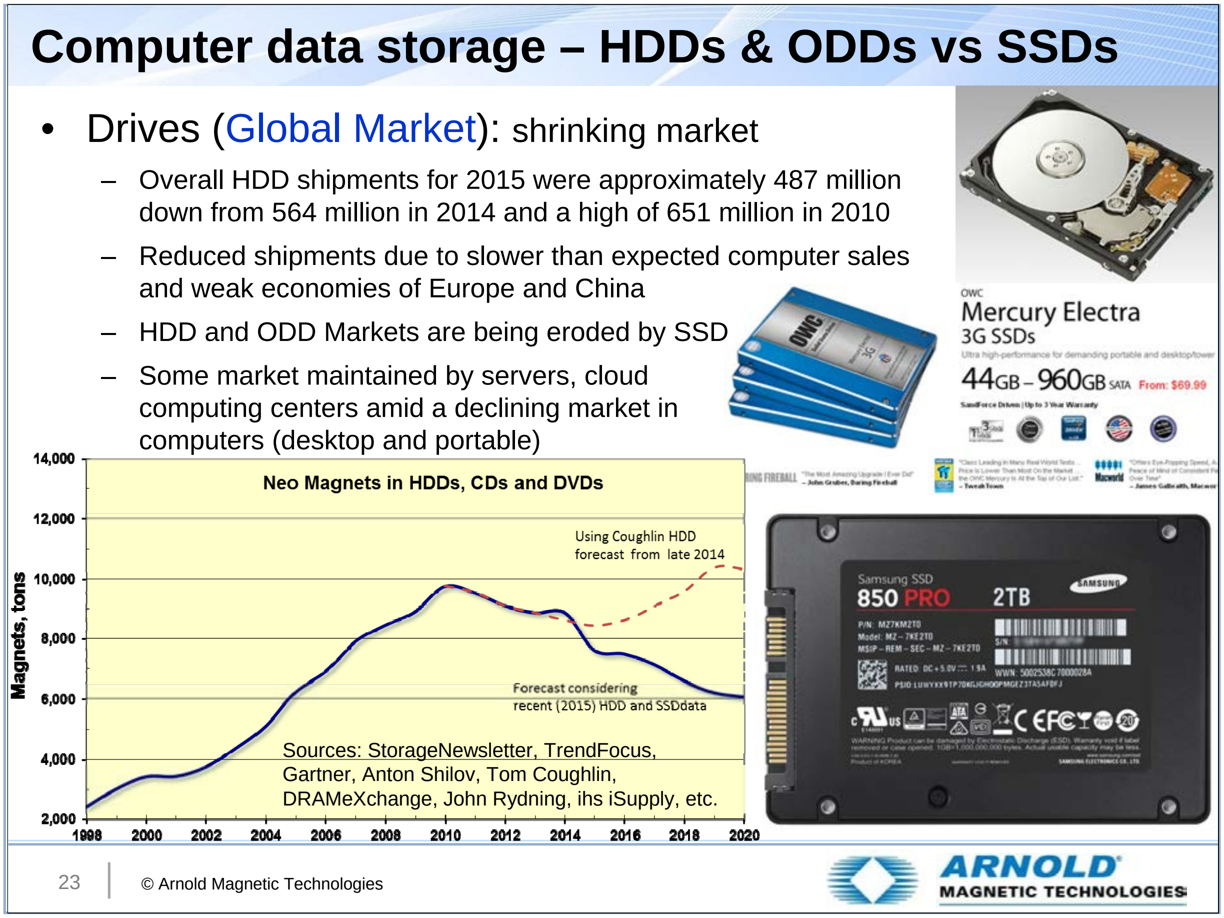
- The growth of and change in demand for magnet rare earth elements is and will be driven by many factors, not the least of which are these existing and new uses.
- Let’s examine a few in a bit more detail.



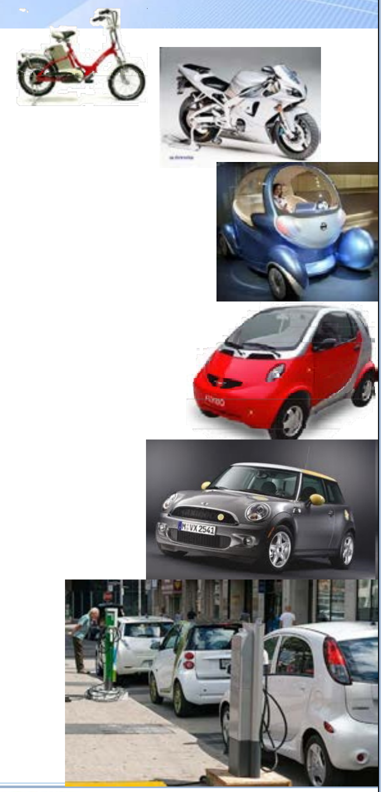
- Solid state memory (solid state drives, SSDs) have improved in performance and cost to where they often represent a viable alternative to HDDs.
- According to Wikibon, 2016 is a tipping year for the SSD-related competing information storage technologies.



- Neo magnets have been used in electronic devices such as hard disk drives, CDs and DVDs (optical disk drives, ODDs) where the magnet is used for driving the spindle motor, in the VCM for positioning the read/write head, and providing a clamping force (in some CDs and DVDs).
- Even though the amount used per drive is small, the huge quantity of devices requires large quantities of magnets.
- Importantly, these devices require little use of dysprosium.
- The HDD and ODD market is being eroded by expansion of SSD drives especially in portable devices.
- Continuing markets for HDDs are for servers and high end desktop systems.
- “The global demand for optical storage disc market is declining as a result of rapid adoption of new technologies such as cloud storage, Internet of Things (IoT) and Video on Demand. However, globally, increasing demand for archival solutions and positive outlook for the media and entertainment industry are expected to create a significant continuing demand for recordable optical discs. Increasing popularity of next generation optical disc for recording HD broadcasting, growing demand for content protection and widening application areas also act as factors supporting market growth.”
- There are competing opinions about the future of HDDs. Tom Couglin forecasts a resurgence; I see too many comments about a decline in usage and forecast a decline.

Alternative Powertrain Types

		Examples
HEV	**Hybrid Electric Vehicle** Uses both an electric motor and an internal combustion engine to propel the vehicle.	Prius
PHEV	**Plug-In Hybrid Electric Vehicle (PHEV)** Plugs into the electric grid to charge battery - is similar to a pure hybrid and also utilizes an internal combustion engine.	Plug-in Prius
EREV	**Extended Range Electric Vehicle (EREV)** Operates as a battery electric vehicle for a certain number of miles and switches to an internal combustion engine when the battery is depleted.	Volt
BEV	**Battery Electric Vehicle BEV)** Powered exclusively by electricity from it's on-board battery, charged by plugging into the grid	Leaf; Tesla Model S
FCEV	**Fuel Cell (Electric) Vehicle (FCEV)** Converts the chemical energy from a fuel, such as hydrogen, into electricity.	Honda FCX Clarity; Hyundai Tuscon



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- Transportation…
- There are many “alternative drive” types.
- This list shows most of them including one or more examples of each that are in production.
- Some use permanent magnet motors such as the Prius and Nissan Leaf, while some use induction motors such as the Tesla Model S.

Year 2015 alternative power train sales (USA)

Manufacturer	Hybrid	PHEV	BEV	CNG	Diesel	Total	Total%
Accura	272	-	-	-	-	272	0.04%
Audi	97	-	-	-	11,765	11,862	1.81%
BMW	67	3,157	11,024	-	11,602	25,850	3.95%
Chrysler	-	-	-	-	57,462	57,462	8.77%
GM	4,587	16,417	2,629	-	3,282	26,915	4.11%
Fiat	-	-	4,516	-	-	4,516	0.69%
Ford	47,261	17,341	1,582	-	-	66,184	10.11%
Honda	20,483	64	2	486	-	21,035	3.21%
Hyundai	19,908	15	-	-	-	19,923	3.04%
Infiniti	6,544	-	-	-	-	6,544	1.00%
Jeep	-	-	-	-	3,790	3,790	0.58%
Kia	11,492	-	1,015	-	-	12,507	1.91%
Land Rover	-	-	-	-	1,357	1,357	0.21%
Lexus	36,331	-	-	-	-	36,331	5.55%
Mercedes	64	118	1,906	-	8,611	10,699	1.63%
Mitsubishi	-	-	115	-	-	115	0.02%
Nissan	2,245	-	17,269	-	-	19,514	2.98%
Porsche	-	1,570	-	-	3,585	5,155	0.79%
Smart	-	-	1,387	-	-	1,387	0.21%
Subaru	5,589	-	-	-	-	5,589	0.85%
Tesla	-	-	26,608	-	-	26,608	4.06%
Toyota	228,708	4,191	18	-	-	232,917	35.56%
Volkswagen	756	-	4,232	-	53,322	58,310	8.90%
Volvo	-	86	-	-	-	86	0.01%
TOTAL	**384,404**	**42,959**	**72,303**	**486**	**154,776**	**654,928**	**100.00%**
% of alt. fuel	**58.69%**	**6.56%**	**11.04%**	**0.07%**	**23.63%**	**100.00%**	
% of total Mkt	**2.22%**	**0.25%**	**0.42%**	**0.00%**	**0.89%**	**3.78%**	

Data source: www.hybridcars.com

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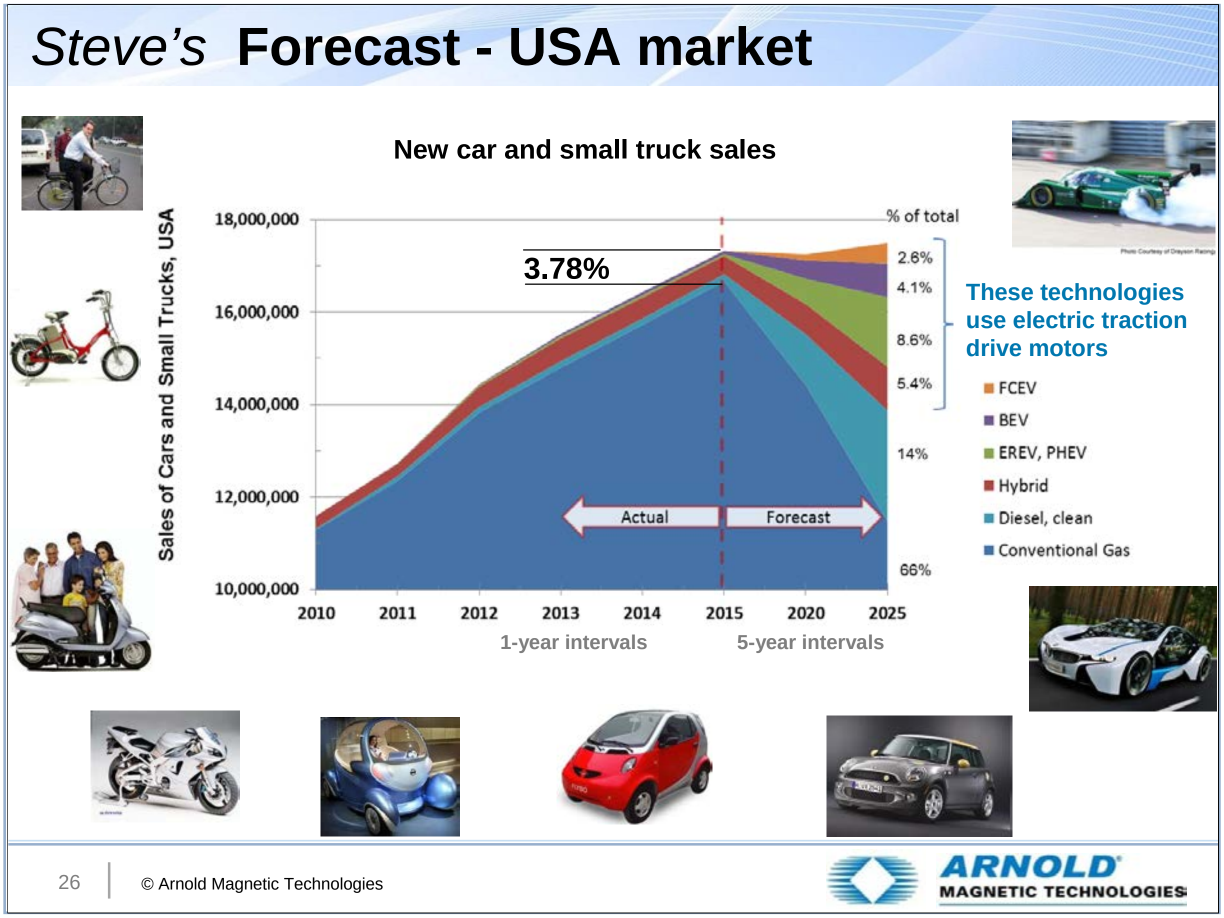
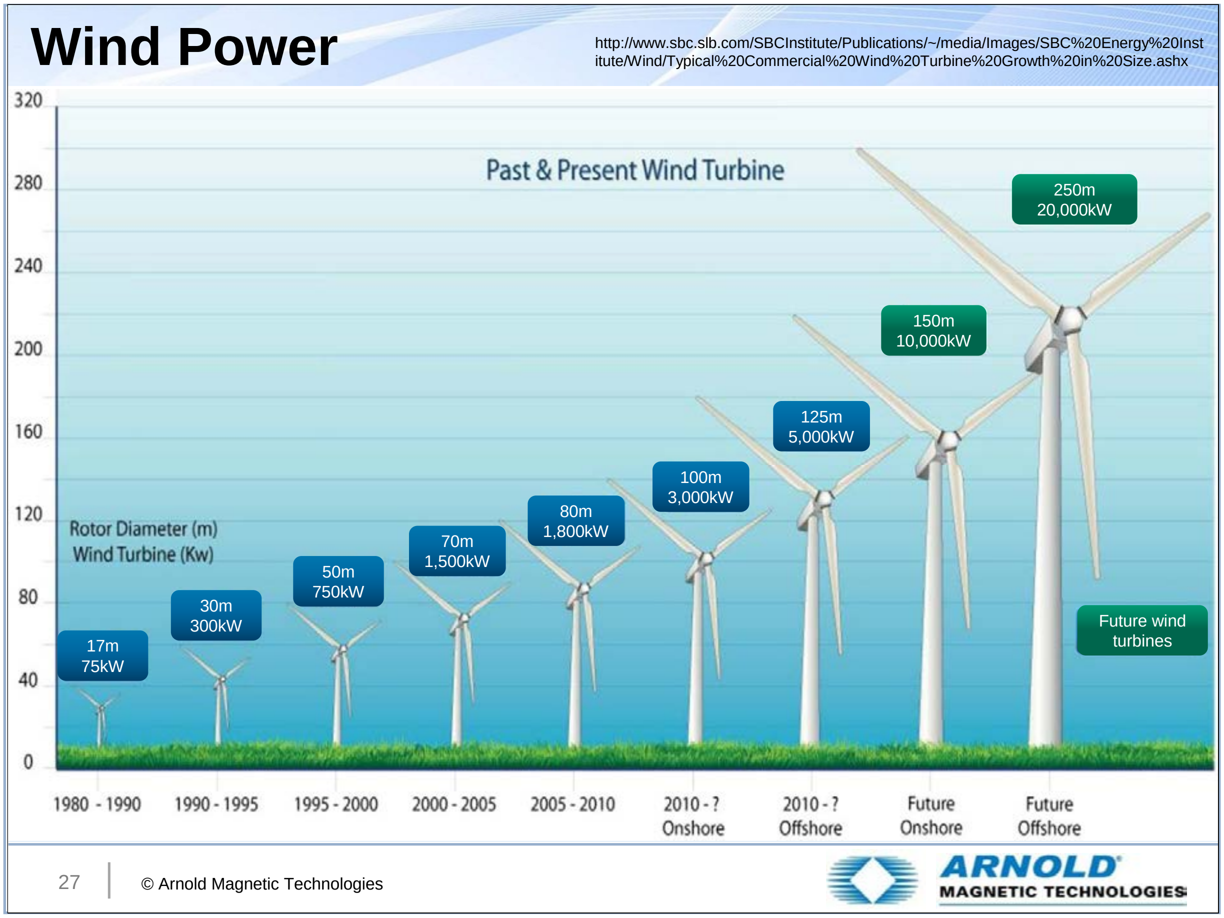
- Hybridcars.com tracks sales within the USA by drive type and manufacturer – shown here.
- EREVs (Chevy Volt) are included in the PHEV column in this table.
- Although Diesel is not an electric drive vehicle, it represents a significant shift in power sources.
- For year 2015, all of these alternate power sources represent only 3.78% of USA sales of new cars and small trucks.
- This is well below market forecasts and is due at least in part to lower oil and gasoline prices.



- In response to these overly optimistic forecasts, opinions have been sought regarding the development of the transportation industry.
- This chart is my attempt to show a consensus of the development of alternate drive systems by type and over time.
- Reasons why ICE (including clean diesel) will remain the primary source of tractive power, at least through 2025, are the technological advances being made to provide ever more efficient drive systems at modest price increase and using existing fuel distribution infrastructure with simultaneous "light-weighting" of the vehicles.
- Expansion in use of any type drive depends upon a range of factors including economic (e.g., gas prices), political (e.g., CAFÉ standards), and technical (e.g., greatly improved battery performance/cost).

- N.B.: the scale at the bottom is by year to 2015 and then by 5-year increments.



- Wind power is a renewable, "green" technology for producing electricity.
- The number of and size of installations continues to grow.
- The larger systems are targeted for off-shore use and the lower MW output towers primarily installed on land.

Why NdFeB Magnets – gearbox wear and failure

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- Direct drive generators using permanent magnets represent an alternative to geared induction generators.
- Direct drive offers lower noise, lower weight (reduced tower cost) and ...and lower maintenance !
- Permanent magnet generators permit reducing the gear box to 2-stage (from 3) for hybrid (medium speed geared) drives or eliminating it altogether in direct drive generator systems.

Offshore Turbine development

TOP TEN OFFSHORE TURBINES *The wind industry's biggest, heaviest and most expensive products compared and contrasted*

Model	IEC class	Power rating	Rotor diameter	Drive system	Noteworthy
MHI-Vestas V164-8.0MW (Denmark)	S	8MW	164m	MSG, PMG	Clever combination of evolutionary and innovative design features; flanged tube-shaped drivetrain, favourable 500-tonne head mass
Ming Yang SCD 6.0 (China)	IIB	6MW	140m	MSG, PMG	Innovative two-blade downwind turbine with compact semi-integrated drivetrain and single rotor bearing, focused at typhoon-prone markets
Siemens SWT-6.0-154 (Germany)	I	6MW	154m	DD, PMG	Single rotor bearing; largest rotor diameter in 6MW class, converter and transformer in nacelle; favourable head mass
Alstom Haliade 150-6MW (France)	I	6MW	150.8m	DD, PMG	Stationary main shaft (pin); "pure torque" principle decouples rotor-bending moments and generator drive torque
Siemens SWT-4.0-130 (Germany)	I	4MW	130m	HSG, IG	Evolutionary development and optimisation of SWT-3.6-120 model, which has been the offshore market leader for several years
Senvion 6.2M152 (Germany)	S	6.15MW	152m	HSG, DFIG	Developed from pioneering 5MW turbine introduced in 2004; prototype of more powerful model with longer blades installed in 2014
Areva M5000-135 (France)	S	5MW	135m	MSG, PMG	Extensive upgrade of M5000-116 introduced in 2004; features clever pioneering low-speed hybrid-drive design
Gamesa G128-5.0MW (Spain)	IB	5MW	128m	MSG, PMG	Pioneer tube-type drivetrain; builds on 2009's G128-4.5MW platform; new variant with 132m rotor diameter has been announced
Hyundai HQ5500/140 (South Korea)	I	5.5MW	140m	HSG, PMG	Sister product of Dongfang 5.5MW, co-developed with AMSC; Sinovel SL5000/SL6000 uses same AMSC product platform
Goldwind GW 6MW (China)	I	6MW	150m	DD, PMG	Specification not verified; initial design basis 5MW power rating

BDFIG Brushless doubly-fed induction generator
CGFRE Carbon & glass-fibre reinforced epoxy
DD Direct drive
DFIG Doubly-fed induction generator
EESG Electrically excited synchronous generator
GFRE Glass-fibre reinforced epoxy
HH Hub height
HSG/LSG High-speed geared/Low-speed geared
IG Induction generator
MSG medium-speed geared
PMG permanent magnet generator
PCVS Pitch-controlled variable-speed

Source: http://www.windpowermonthly.com/10-biggest-turbines

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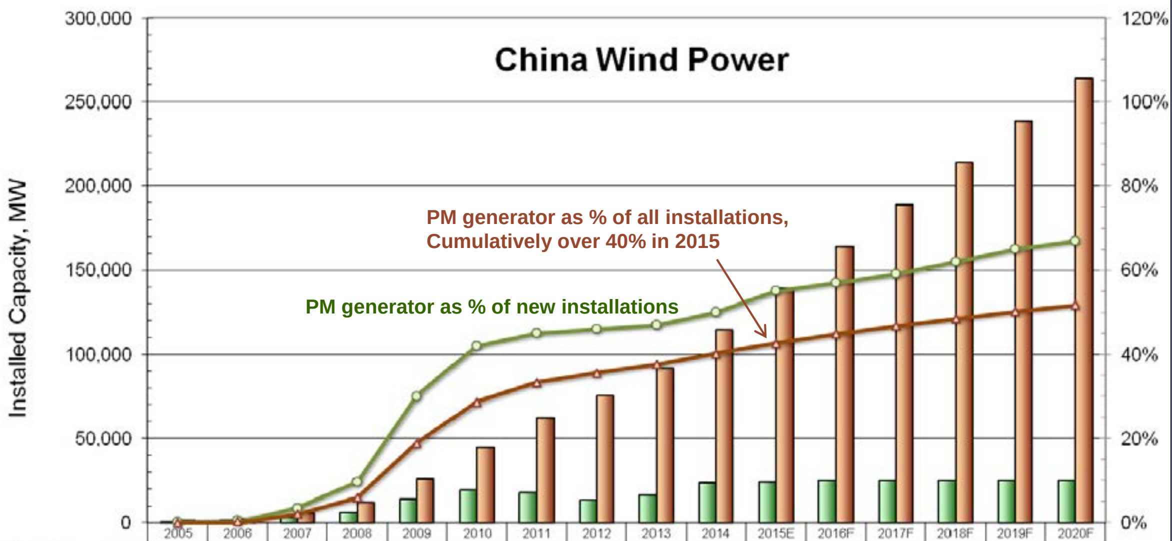
- The largest generators have been designed for use off-shore.
- Of the current top ten generators, 8 are PM type.
- The largest at the date of the referenced publication is the MHI-Vestas 8.0 MW generator.

China wind power generation: total and PM



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015E	2016F	2017F	2018F	2019F	2020F
Newly Installed Capacity (MW)	507	1,288	3,311	6,154	13,803	18,928	17,631	13,124	16,100	23,351	24,000	25,000	25,000	25,000	25,000	25,000
Cumulative Installed Capacity (MW)	1,272	2,559	5,871	12,024	25,828	44,733	62,364	75,324	91,424	114,763	139,000	164,000	189,000	214,000	239,000	264,000
PM Gen. as % of New Installations	0.1%	0.5%	3.5%	9.5%	30.0%	42.0%	45.0%	46.0%	47.0%	50.0%	55.0%	57.0%	59.0%	62.0%	65.0%	67.0%
PM Gen. as % of all Installed	0.0%	0.3%	2.1%	5.9%	18.8%	28.6%	33.2%	35.5%	37.6%	40.1%	42.6%	44.8%	46.7%	48.5%	50.2%	51.8%

Sources: GWEC; China Wind Energy Assoc.; numerous news stories

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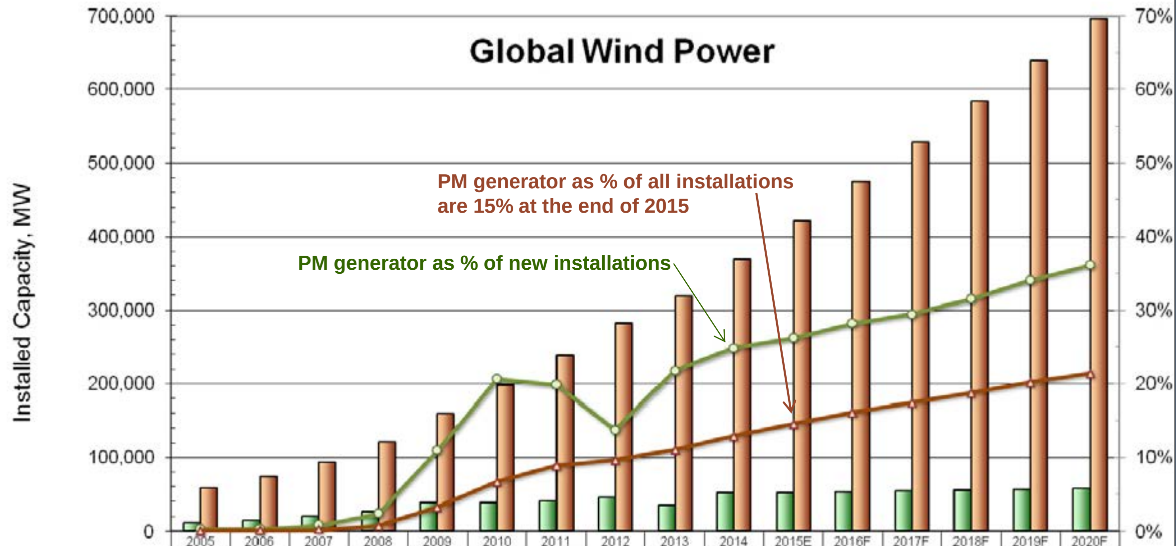
- Prior to 2005, China wind power installation was done on a limited basis by foreign companies.
- Between 2005 and 2010, the Chinese wind power industry became dominant.
- Probably due to the ready availability of Neo magnets within China, a large percentage of installations have been of the permanent magnet type – cumulatively through 2015, over 40%.

Global wind power generation: total and PM

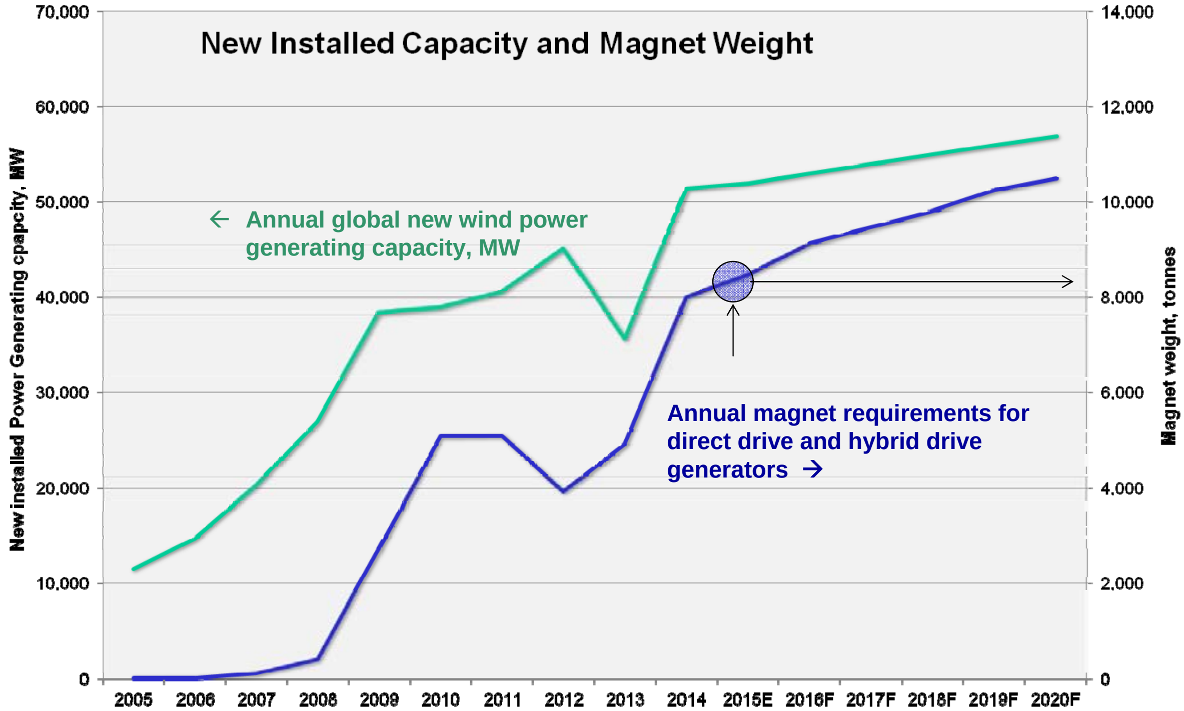


	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015E	2016F	2017F	2018F	2019F	2020F
Global new Installed capacity (MW)	11,531	14,703	20,285	26,952	38,478	38,989	40,637	45,161	35,708	51,477	52,000	53,000	54,000	55,000	56,000	57,000
Global Cumulative Installed (MW)	59,091	73,959	93,911	120,725	159,089	197,953	238,139	283,068	318,596	369,553	421,553	474,553	528,553	583,553	639,553	696,553
Global PM Gen. as % of New	0.3%	0.3%	0.8%	2.4%	11.0%	20.6%	19.8%	13.7%	21.7%	24.8%	26.2%	28.2%	29.5%	31.5%	34.0%	36.1%
Global Cum PM Gen % of cum installed	0.1%	0.2%	0.3%	0.8%	3.2%	6.7%	8.9%	9.7%	11.0%	13.0%	14.6%	16.1%	17.5%	18.8%	20.1%	21.4%

Sources: GWEC; China Wind Energy Assoc.; numerous news stories

- The same information on a global basis is presented here.
- On a global basis only 15% are permanent magnet type generators.
- Direct drive and hybrid drive permanent magnet generators represent less than 1% of generators in North America and the UK (England and Scotland) and only a slightly higher percentage in Europe.

Direct and hybrid drive generator, magnet requirements

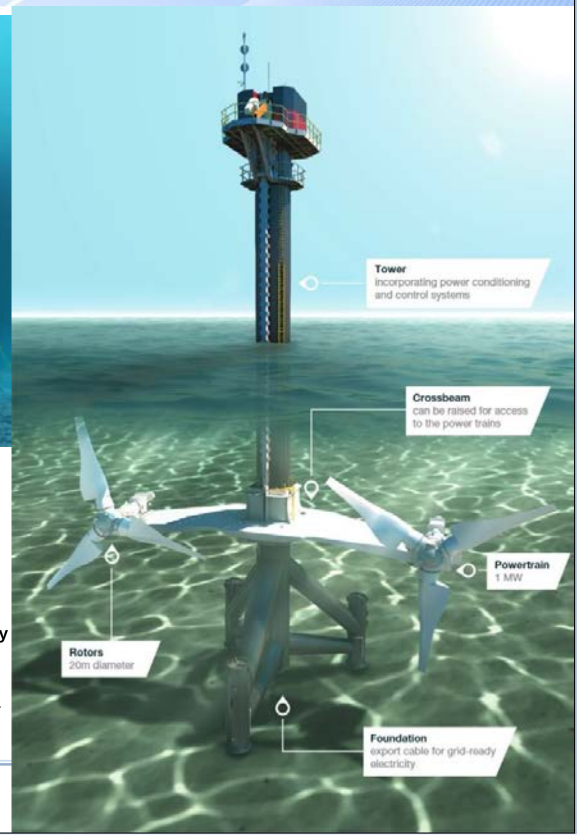


- Annual magnet requirements for this industry for 2015 are 8,500 tons of Neo.
- This is forecast to grow to >11,000 tons per year by 2020.
- Consumption of Neo in this market is highly dependent upon magnet price!

Tidal Power Generation

Atlantis AK1000, Scotland
http://www.lockheedmartin.com/us/products/wave-tidal-energy.html
...and
http://atlantisresourcesltd.com/

http://inhabitat.com/worlds-first-tidal-farm-successfully-installs-100-foot-subsea-turbine/



"SeaGen is the world's first large scale commercial tidal stream generator. It was four times more powerful than any other tidal stream generator in the world at the time of installation." - Wikipedia

http://www.marineturbines.com/sites/default/files/FINAL_MCT_Product_Brochure_8pp_Seagen_UPDATE_E_HIRes.pdf

info-mct.energy@siemens.com

In addition to wind power…

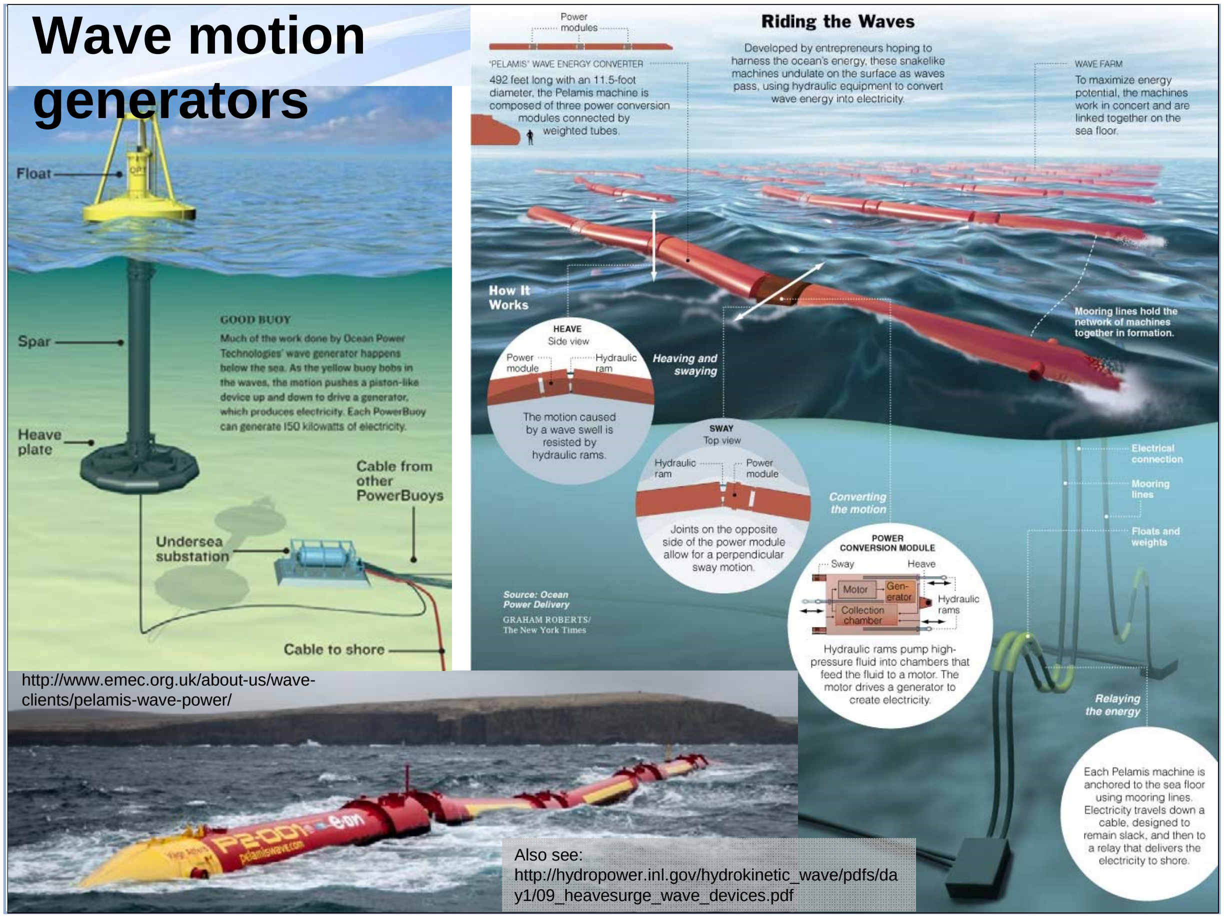
•Numerous companies are developing, testing and installing power generating facilities that depend on tidal current or wave motion.

•Water is far more dense than air, so higher output capacity is possible with smaller swept-area devices.

•The Atlantis AK1000 is pictured here prior to installation - testing has been completed and the unit decommissioned.

•SeaGen is a product of MCT which is now a wholly owned subsidiary of Siemens.

Wave motion generators



- In addition to the previously shown “propeller-type” generators, numerous other methods have and are being investigated to use movement of water to power electric generators including long undulating segments and bobbing buoys.
- These technologies are still immature, but likely to utilize rare earth permanent magnets due to the slow movement of wave motion.

- Some of the more conventional commercial small-magnet applications are shown here.
- For example, the “ear bud“ magnet is approximately 0.2 gram per ear bud. At a production quantity of 200,000,000 units, total mass is about 40 tons of magnets.
- While this may seem like a lot, several magnet companies can produce over 5,000 tons per year – 40 tons is therefore inconsequential to the overall market.
- Due to the small size of these devices, use of magnets other than rare earth magnets is not feasible.

Agenda

Magnet alternatives

Constituent materials

Magnet supply chain

Changing markets

The forecast

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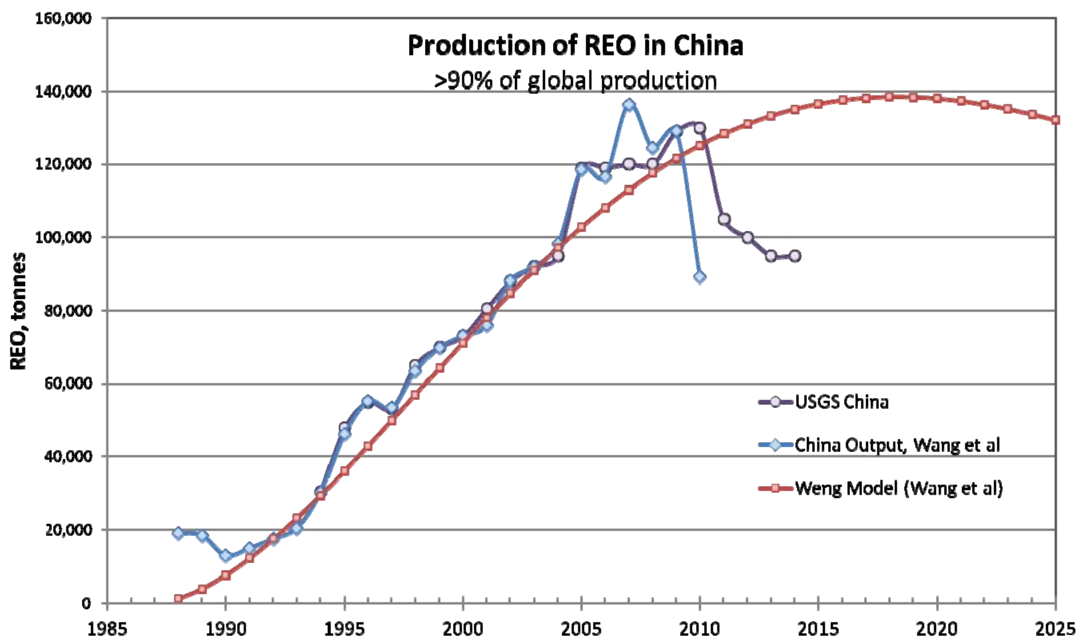
- Let's dust-off the proverbial crystal ball and see if we can forecast what is coming along for the magnet industry.

Production of REO



Sources: Many including USGS and
Production forecast of China's rare earths based on the generalized Weng Model and policy recommendations, Wang et al, 2015

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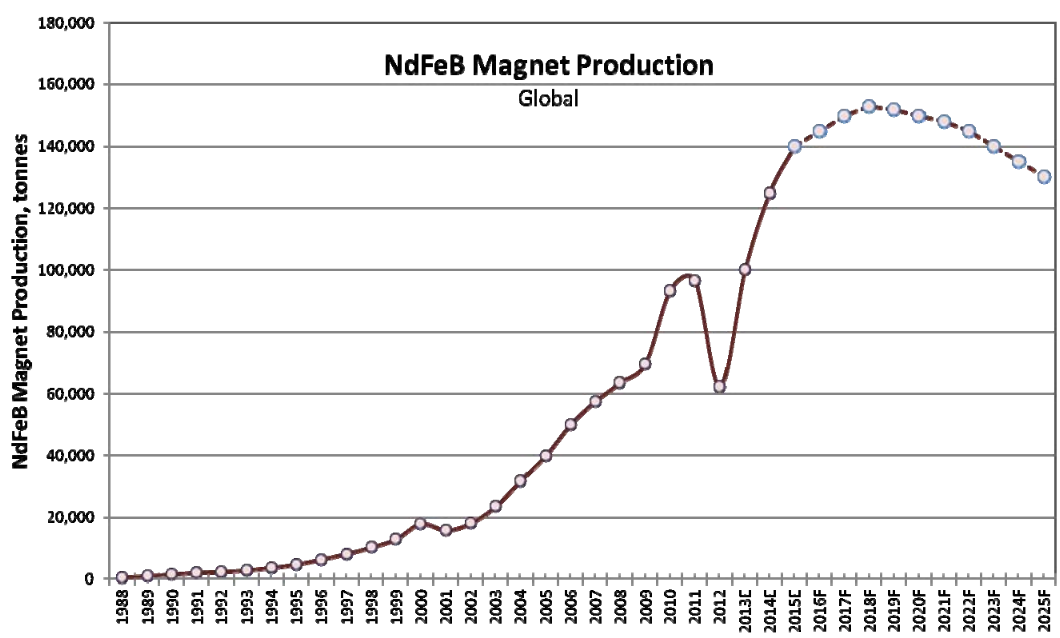
- Both the blue and the purple lines indicate published (public) figures for REO production in China.
- Since the USGS obtains its information from sources in China, it is reasonable for the two lines to be very similar. In fact they only diverge subsequent to 2006, but remain of similar shape and direction.
- The generalized Weng Model, shown here as the red chart line, is a widely used quantitative model for "exhaustible resource" forecasting.
- It shows a period of rapid growth, a peaking, and finally a decline.
- As suggested here, we are approaching a peak.
- Timing of the model is affected by discovery of new resources.
- Shape of the curve is affected by commodity pricing, acceptance in the market and numerous other factors including government intervention through such mechanisms as quotas, taxation or financial incentives.
- Therefore, the red line here is indicative, but in no way absolute.
- But do these curves accurately represent the availability of REO?

NdFeB magnet production



Sources: Multiple including Wang et al; Benecki, Clagett and Trout; JL Mag; MMPA; Yang Luo; other industry sources.

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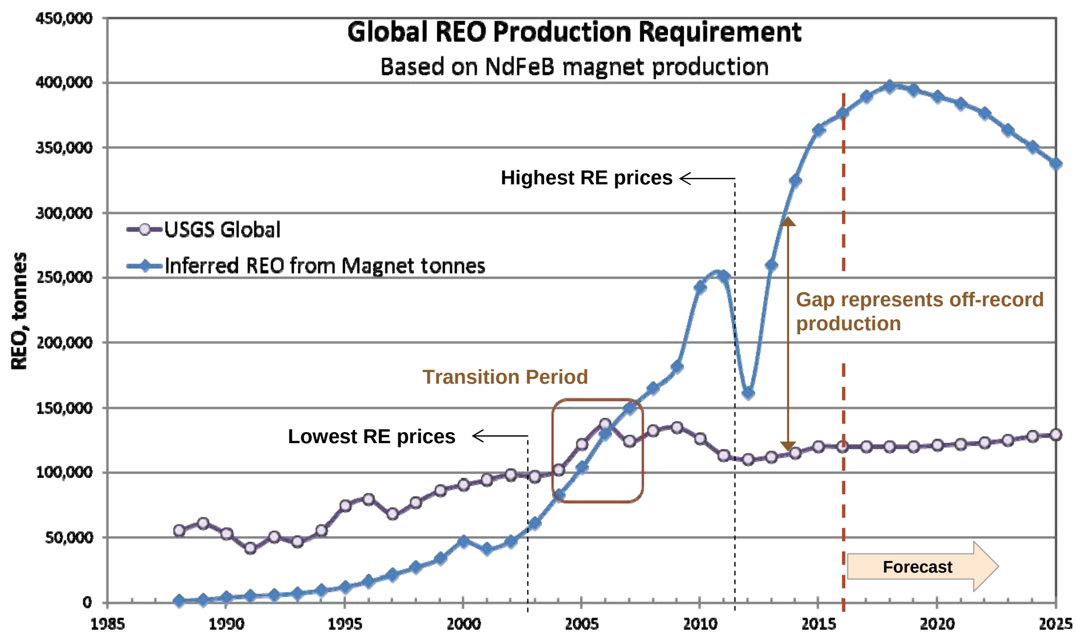
- The line in this chart is best estimate of Neo magnet production based on many sources and over many years.
- The dashed line is my estimate of Neo magnet production based on shifts in the market - and is subject to adjustment.
- For example, more rapid development of the economy of India will increase and prolong the peak.
- Increased availability of rare earth magnet elements will shift the peak upwards.
- Etc.
- Now let’s see what this indicates for required REO to make all these magnets…

REO Production inferred from NdFeB Magnet Production



Sources: USGS; published sources within China; Kingsnorth; Charalampides and Vatalis; Wang et al; others

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Chart explained:

•The purple line indicates published quantities of REO production (left scale).

•The blue line indicates the amount of REO required to produce the magnet quantities shown on the previous chart.

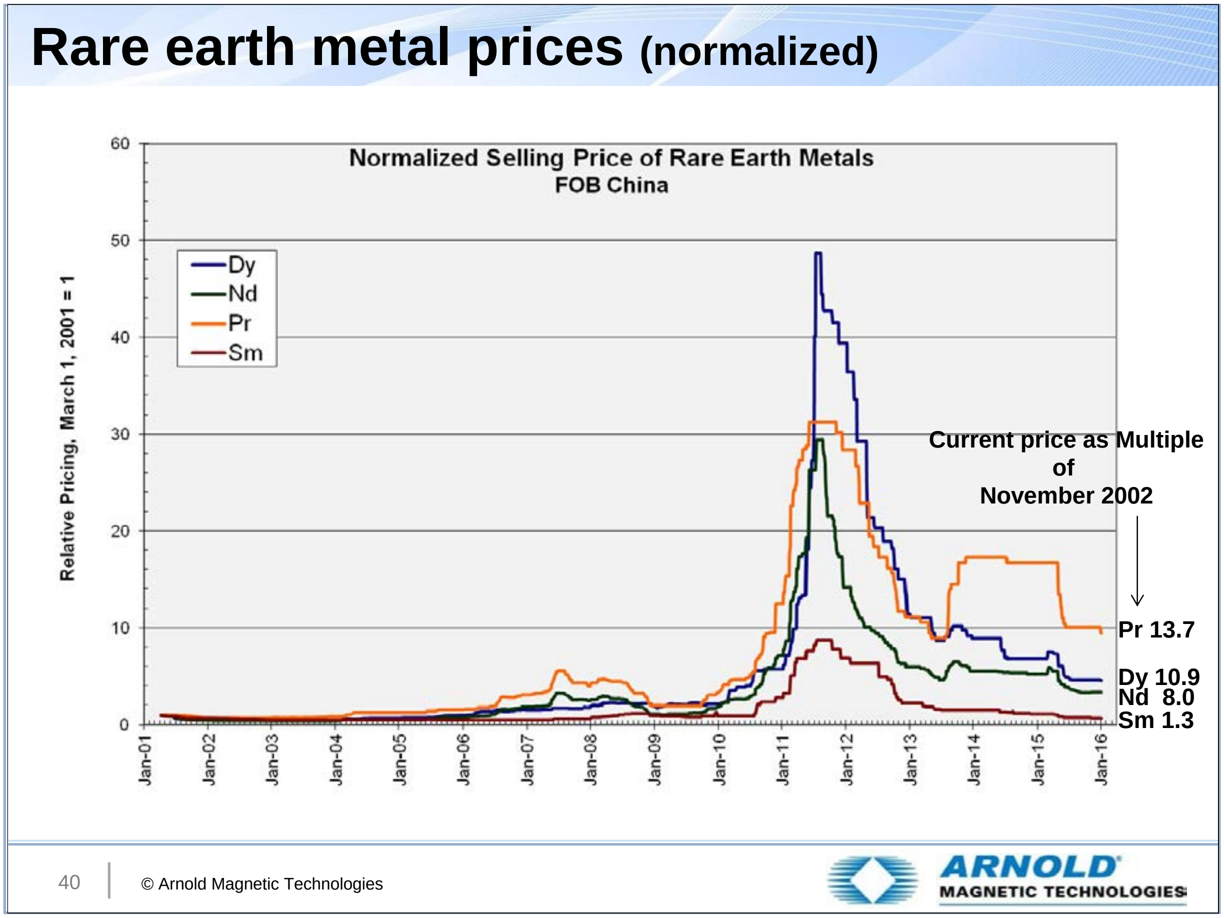
•The sharp drop (blue line) in 2012 was due to rapid and dramatic market contraction due to very high material prices in 2011.

•The market has since rebounded, less so in the West, but greatly so within China - (exports from China of REOs and metals are up only modestly since 2011).

•What we see is a huge gap between published REO output and REO required to produce known magnet quantities.

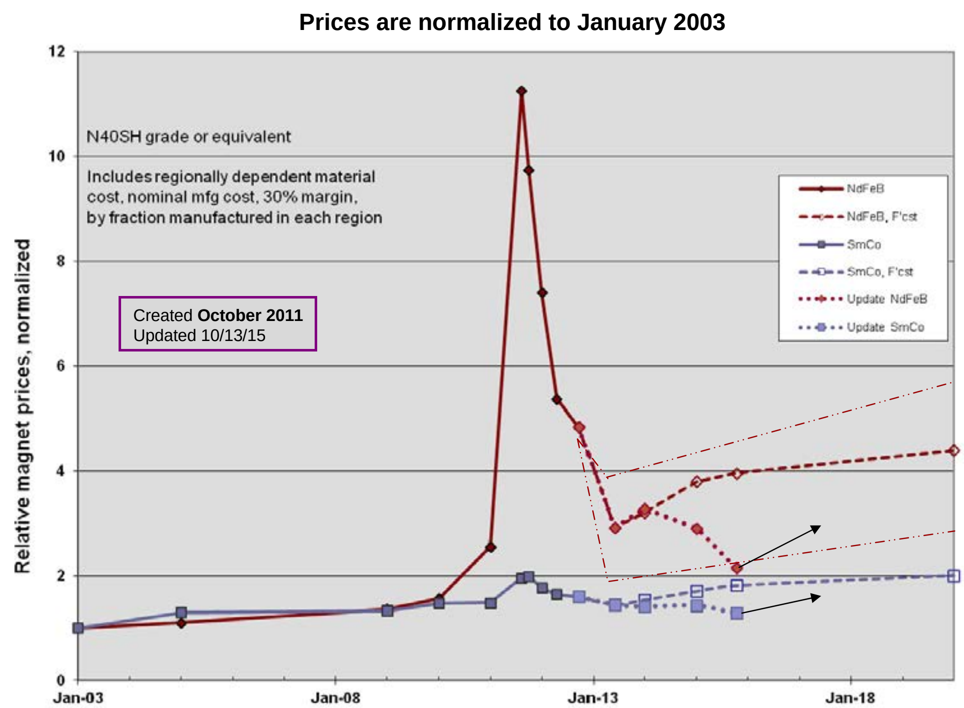
•The excess (black market) REO also explains, at least in part, why rare earth prices are continuing to remain low – even drop.

•What is remarkable is the amount of “off-record” production !



- This chart of RE metal pricing is normalized to March 2001 and is not inflation adjusted.
- Numbers at the right show the multiple of current price to metal prices in November 2002, when they reached their lowest.
- Samarium, which is in excess supply, if inflation adjusted, is lower in cost now than in 2002.
- The others have remained at greater multiples in part due to the higher cost of production as the result of imposition of environmental regulations.

Relative Change in Magnet Prices



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- Excess raw material which is depressing commodity prices permits manufacture and sale of magnets at low prices.
- Reports from China indicate that the supply is stressed due to the low prices and they are unlikely to continue.
- I stand by my earlier forecast of relative magnet pricing, but when the prices will correct is uncertain.
- By some estimates, magnet production is between 30 and 50% of installed capacity.
- So between black market REO and excess magnet manufacturing capacity, it might take some time for the correction to occur.

Sales of Major PM Materials

	2010 Actual				2016 Forecast			
	tons	%	$million	%	tons	%	$million	%
NdFeB	67,300	10.5%	5,700	65.1%	145,000	14.8%	10,365	68.0%
SmCo	2,310	0.4%	270	3.1%	3,864	0.4%	315	2.1%
Ferrite	567,000	88.2%	2,600	29.7%	822,000	84.1%	4,325	28.4%
Alnico	5,555	0.9%	125	1.4%	6,050	0.6%	160	1.1%
Other	540	0.1%	65	0.7%	570	0.1%	68	0.4%
Totals	**642,705**	100.0%	**8,760**	100.0%	**977,484**	100.0%	**15,233**	100.0%

Issues distorting material sales balance include: 1) artificially low RE prices, 2) shift to light-weight technologies in transportation and portable devices, 3) increasing use of PM generators in wind and 4) slowing of major economies (China, Europe).

- Due to the relatively low prices and resulting high volume of Neo output, this table has seen significant shifts over the past year.
- Notably, Neo production is shown here unconstrained resulting in an increase in Neo % by both weight and dollars over the earlier table.
- Since Neo has increased so markedly, ferrite shows a decline on a percentage basis.
- Ferrite also shows this decline on an absolute basis since Neo is so affordable that some motor applications that had converted from Neo back to ferrite have now moved (at least in China) back to Neo.
- Markets and uses for alnico and other permanent magnets are well-established and not likely to experience major change.

Wrapping it up

- Magnet Alternatives
  - The are a limited number of materials and each is a material-of-choice in selected applications
- Constituent materials
  - Elemental material options have been researched for 150+ years
  - A breakthrough is possible but not likely
- Magnet supply chain
  - 80+ percent of permanent magnets are made in China – and consumed in China
  - Supply issues include all the variables shown on the “geopolitical slide”
- Changing markets
  - Use of permanent magnets are being adapted to satisfy new technology requirements as well as a global, growing middle class
- Forecast
  - The off-record production of REOs and magnets is indicative of the difficulty governments have in attempting to control what would otherwise function as a “free market”

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