Permanent Magnets: the Demand for Rare Earths

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Summary

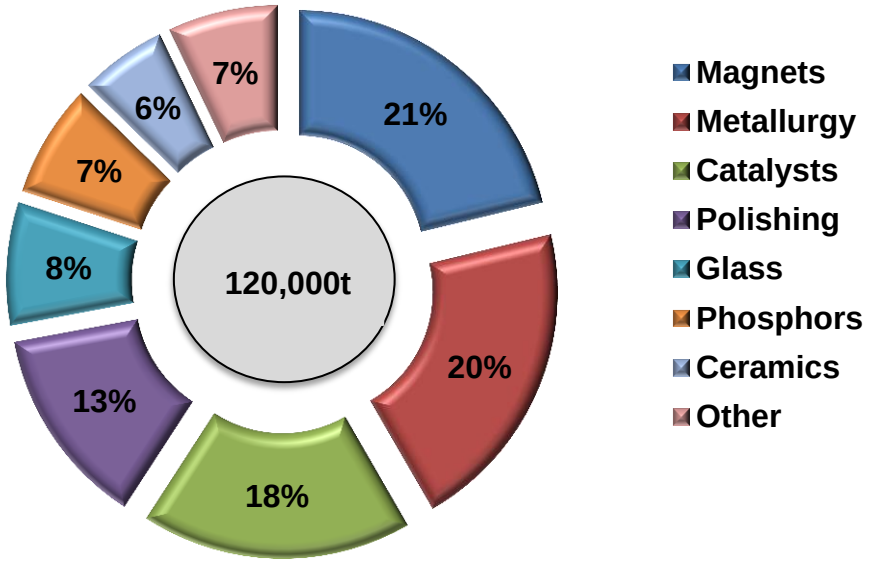
- Overview of the rare earths market
- Permanent magnets – current market trends
- Future demand for permanent magnets
- Consumption of rare earths in permanent magnets

Overview of the rare earths market

Global demand for rare earths by end-use in 2012

- World ‘official’ production of REO ~110,000t in 2012, 85-90% in China
- World demand ~120,000t in 2012, 65-70% in China

World: Demand for rare earths by end-use, 2012 (%)



Source: Roskill estimates

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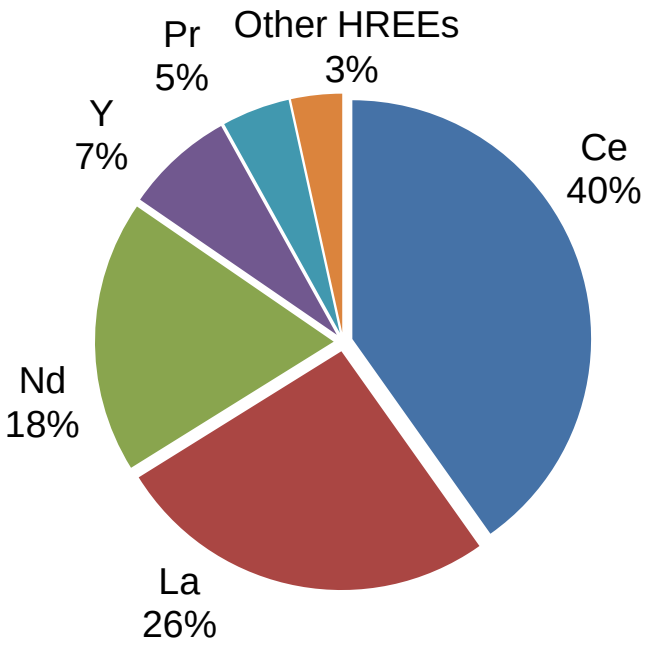
Demand for rare earths by element in 2012

Other HREEs
magnets, lasers, phosphors, glass, metallurgy, other

Pr
magnets, phosphors, ceramics, metallurgy, polishing, other

Y
phosphors, ceramics, other



Ce
polishing, metallurgy, catalysts, glass, phosphors, ceramics, other

La
metallurgy, catalysts, glass, phosphors, ceramics, polishing, other

Nd
magnets, ceramics, metallurgy, glass, catalysts, phosphors, other

Source: Roskill estimates

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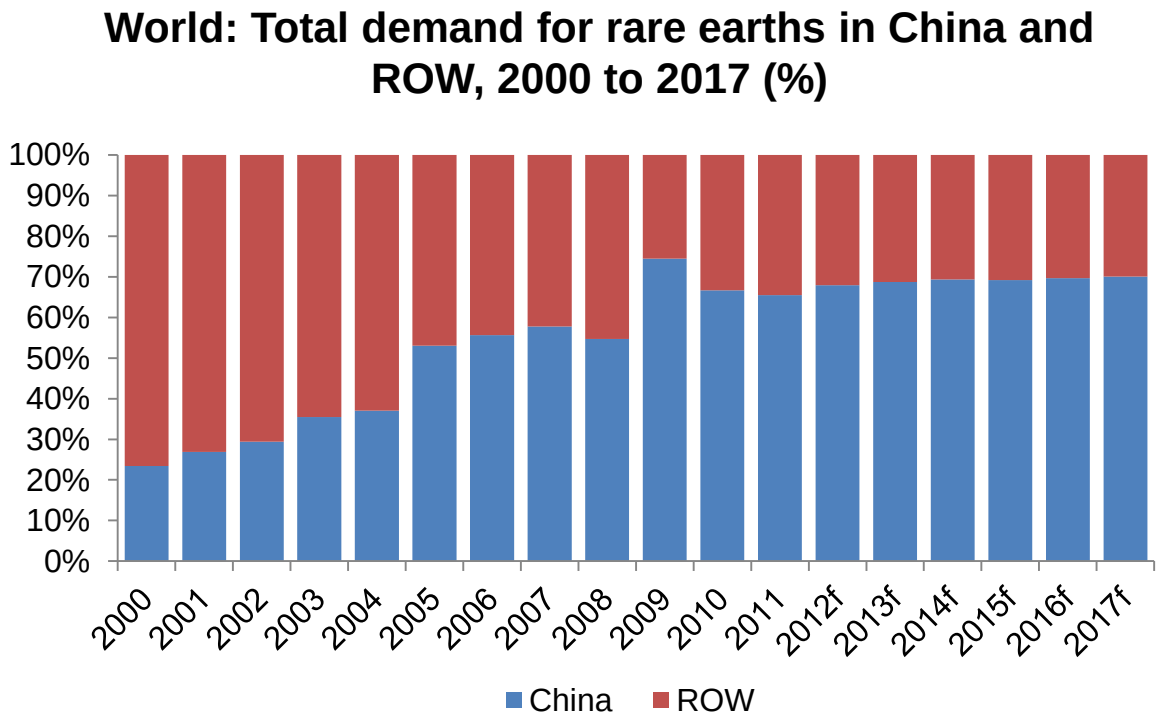
China continues to dominate global demand



- China is leading demand - 70% in 2012
- Demand is increasing from higher value applications
- Chinese demand to exceed 70% by 2019-20

Source: Roskill estimates

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Permanent magnets – current market trends

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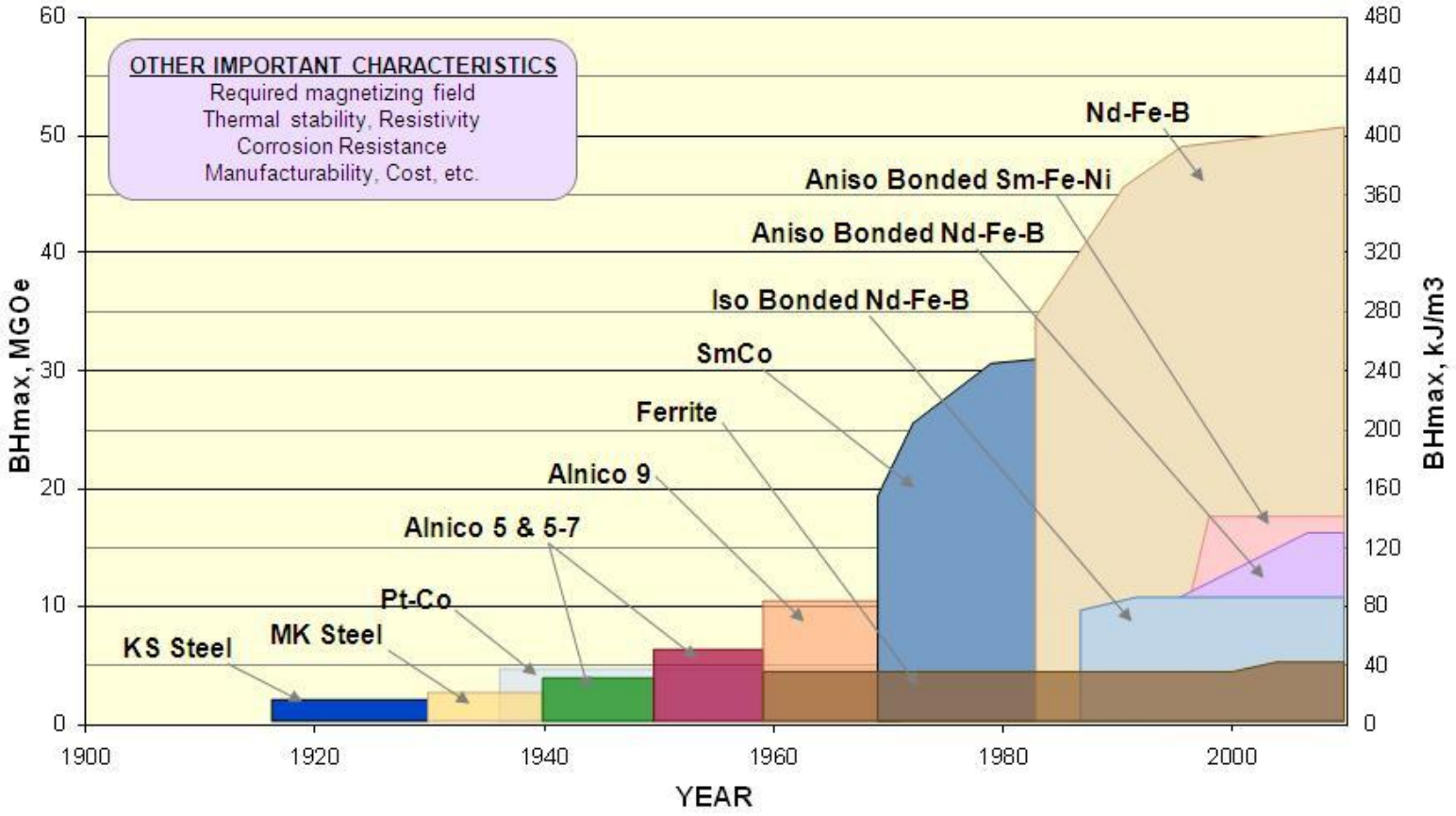
What are rare earth magnets

- **NdFeB** (neodymium iron boron, aka ‘neo’ magnets)
  - Powder for bonded magnets: compression, extruded, injection molded
  - Sintered (powder metallurgy)
  - Hot rolled (no longer made): modified composition; Seiko-Epson
  - Die-upset / forged, fully dense: Magnequench MQ-3 process (original and modified); Daido Electronics
- **SmCo**
  - Sintered (powder metallurgy)
- **SmFeN**
  - Powder metallurgy process resulting in a fine powder suitable for bonded magnets
  - Unstable above ~450 C – no known method for achieving a fully dense magnet

Types of permanent magnet



Source: Arnold Magnetic Technologies

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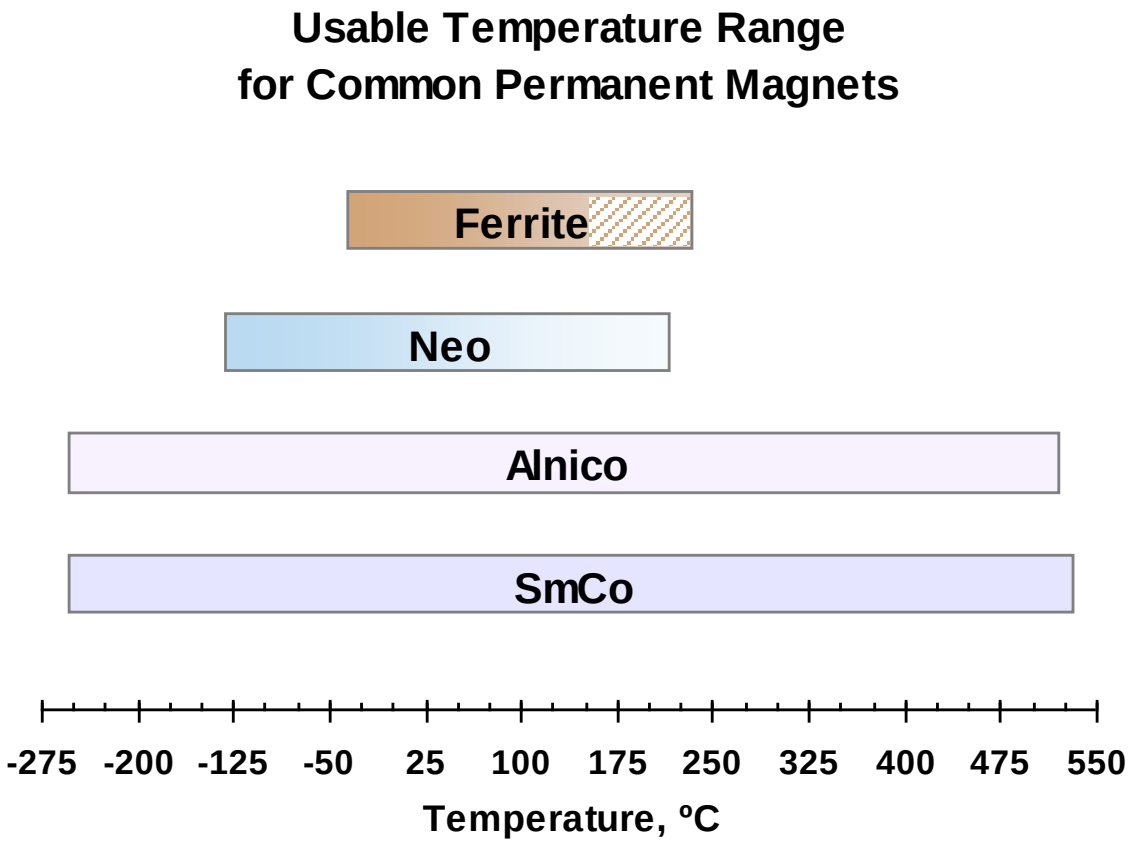
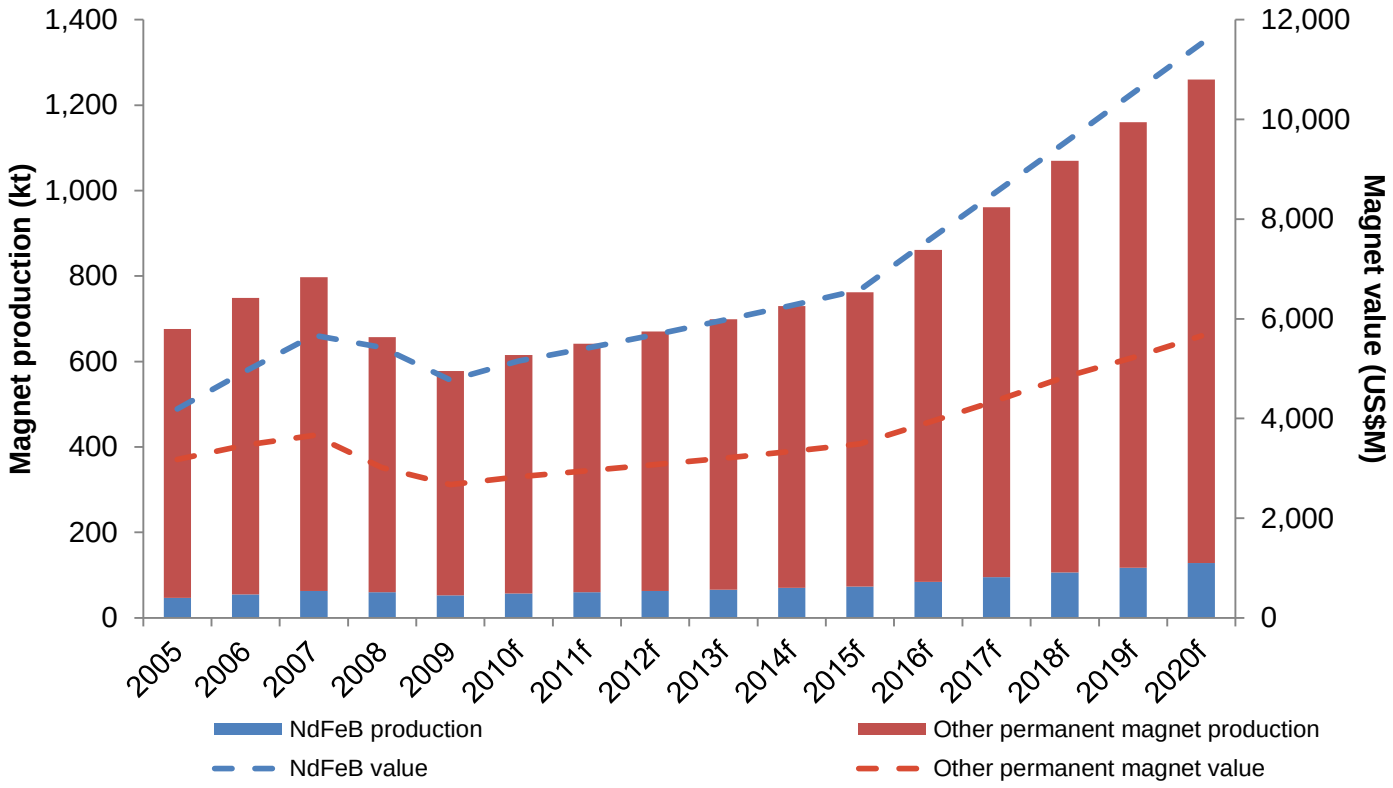
Different magnets for different needs



Source: Arnold Magnetic Technologies

Over the next 8 years demand for NdFeB magnets is forecast to grow by around 9%pa – accelerated growth after 2016

World: Permanent magnet production and value by type, 2005 to 2020



Source: Benecki, Clagett & Trout, Permanent Magnets 2010-2020

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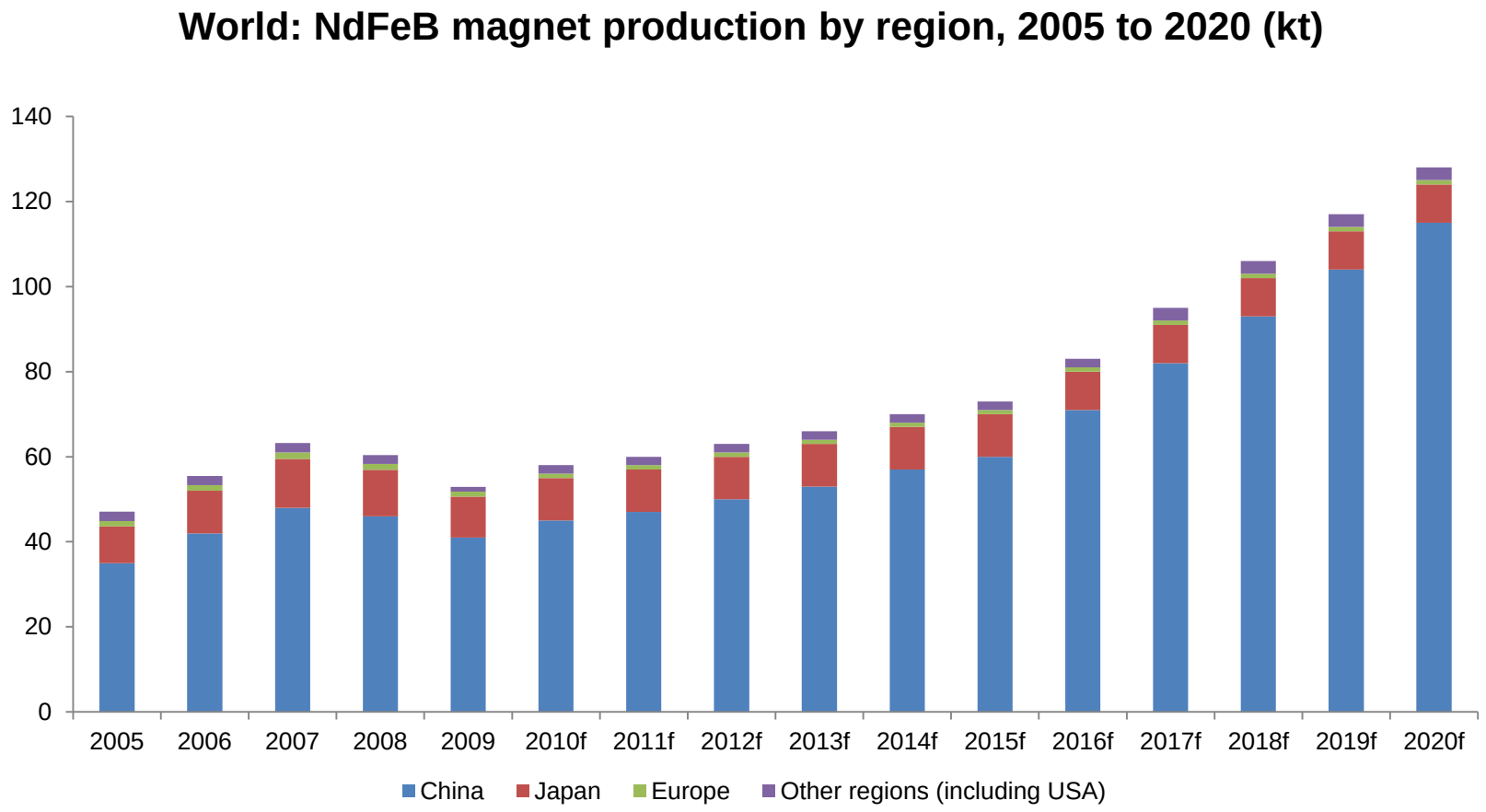
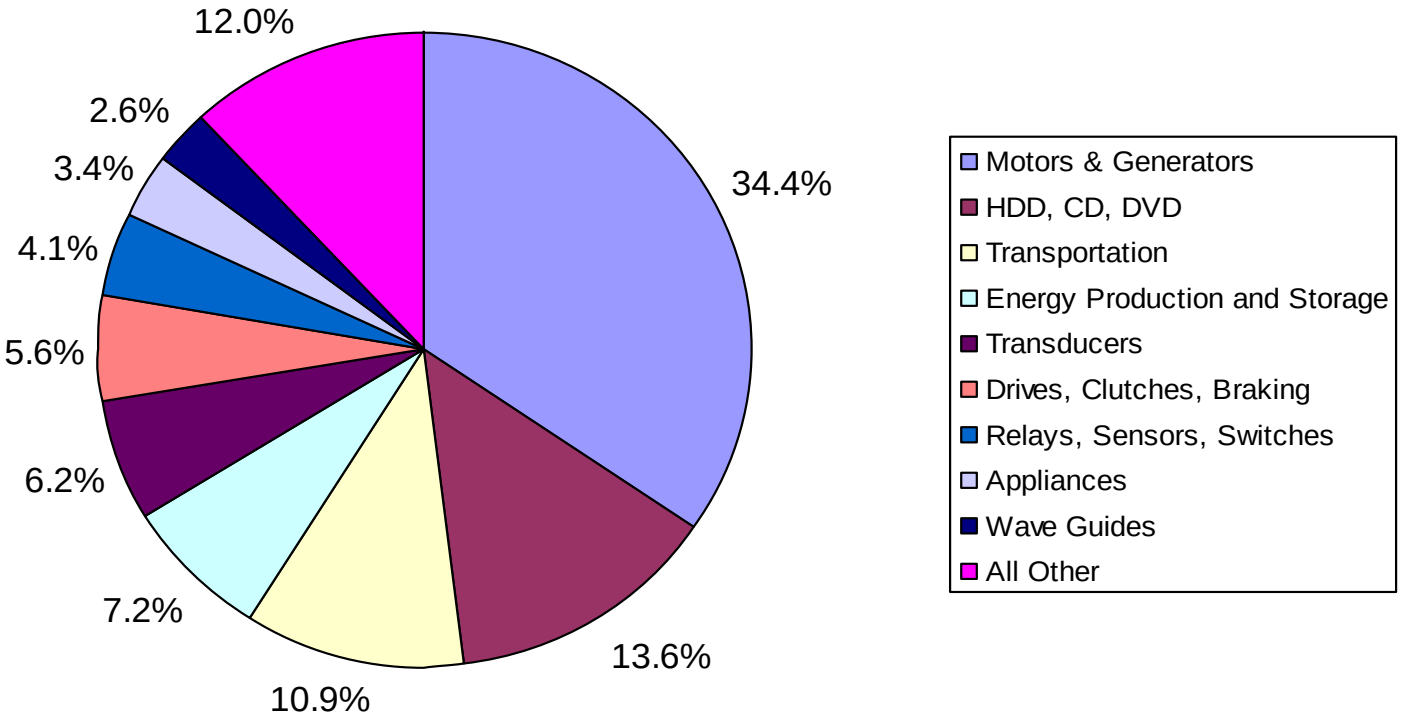
China will maintain its position as the leading supplier of NdFeB magnets



Source: Benecki, Clagett & Trout, Permanent Magnets 2010-2020

Applcations for RE permanent magnets

Rare Earth Magnets by Application, 2012 year-end forecast



Source: Arnold estimates

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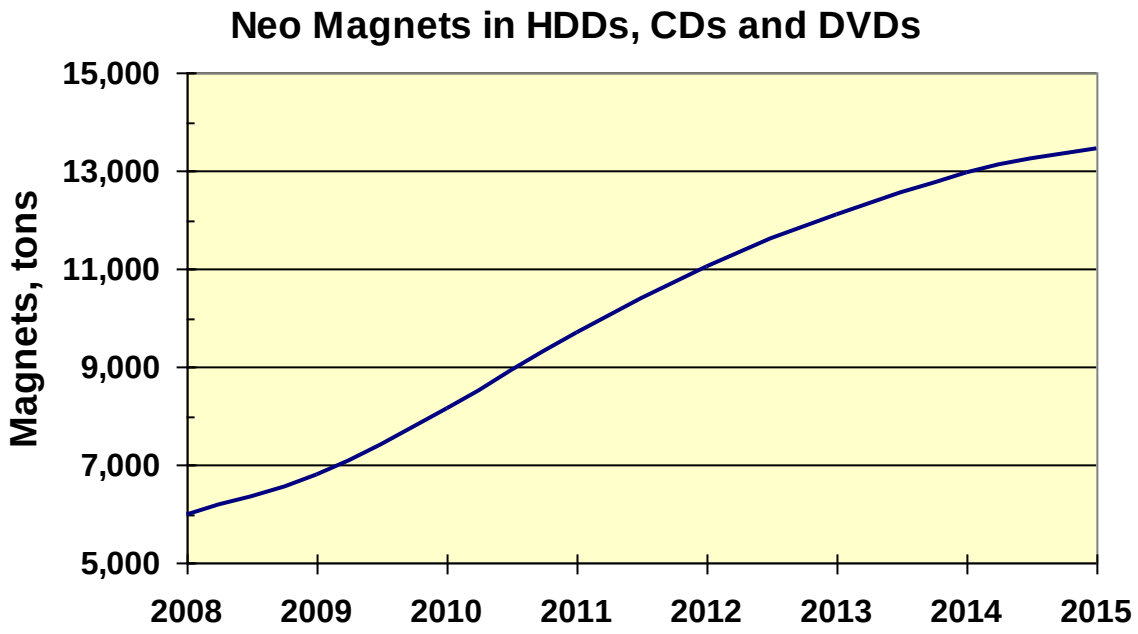
Future demand for permanent magnets

Traditional markets: Consumer electronics

- Important driver for permanent magnet demand over the last 25 years
- Shipments of HDDs alone were an estimated 660 million units in 2011 (~9,000t NdFeB)
- Future growth at lower rate reliant on such issues as
  - ✓ Replacement in mature markets
  - ✓ Expansion of cloud computing
  - ✓ Long-term substitution with new technologies such as SSD (solid state drives).

HDD sales from iSuppliCorp: www.isuppli.com



Source: Arnold estimates

Traditional markets: Standard automotive

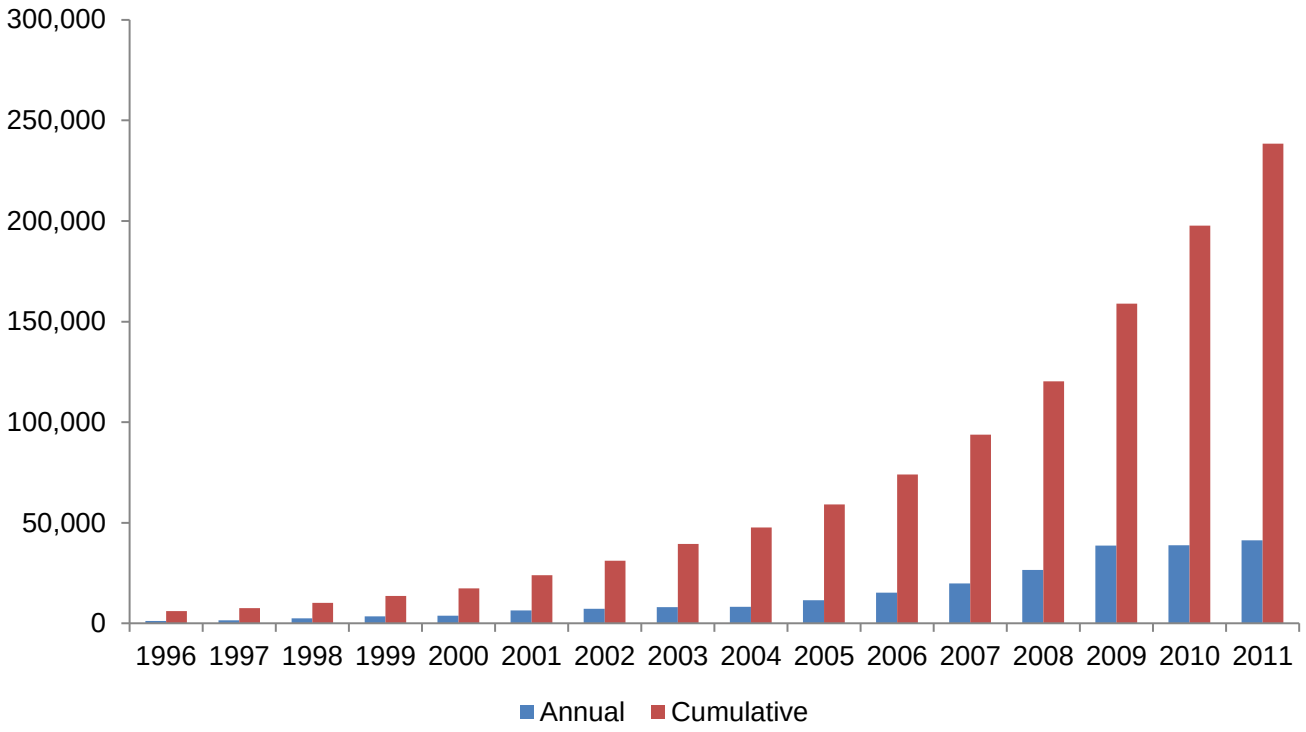
- Engine components, battery components, moving car parts and other integral systems – larger magnets, ferrite and NdFeB
- Interior applications – smaller magnets, typically NdFeB
- Around 40 magnets in motors and actuators, and 20 sensors in a typical car
- Average of 250g NdFeB and 10-20g SmCo
  - Primarily in small motors and sensors
- Car and light vehicle production
  - 80M units 2011 ~ 20,100t NdFeB
  - Forecast 90-95M units by 2015, but increasing intensity of use

Traditional markets: Electric bicycles

- Large and growing market, mainly in Asia
- >16M produced in China in 2008 and >30M in 2011
- Production increasing but so is legislation to discourage use
  - Banned in South China cities of Guangzhou, Dongguan and Shenzhen
  - Vehicles of 20 kg or more and a top speed of 30 km/h will require a motorcycle license to operate

Will future growth come from wind turbines?

Global growth in wind turbine capacity, 1996 to 2011 (MW)



- Global growth in wind turbine capacity of 27%py 2000 to 2011
- Global capacity could reach 450GW by 2020, led by growth in China

Source: Global Wind Energy Council

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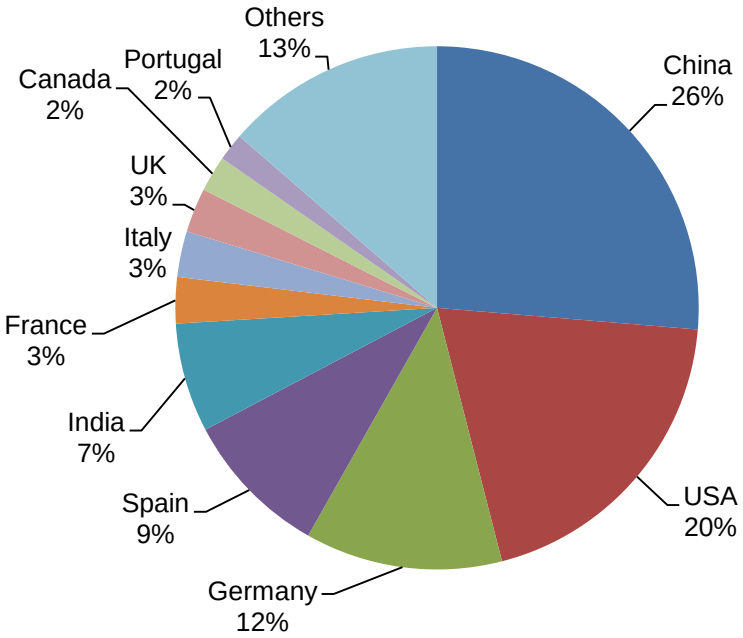
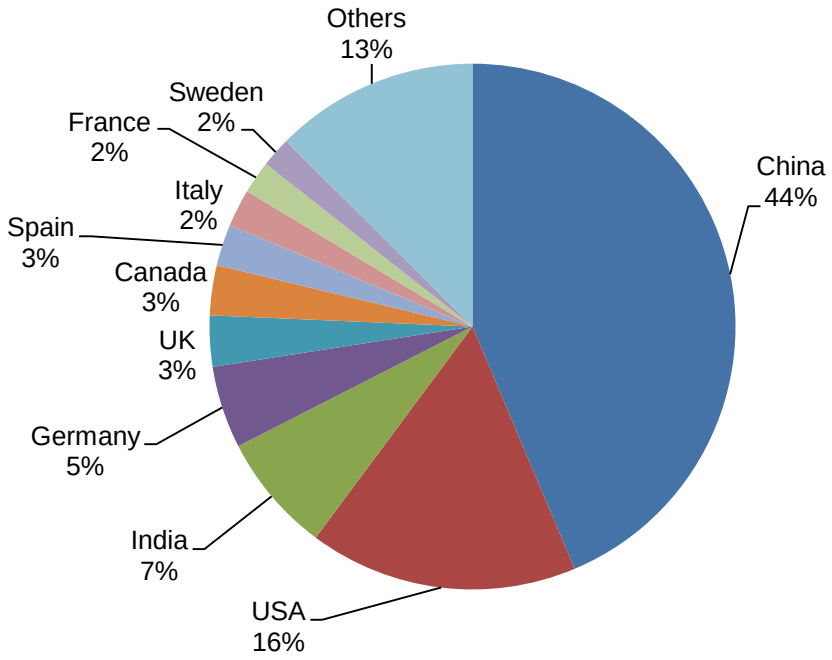
Growth in wind energy dominated by China

Top 10 new installed capacity, Jan-Dec 2011 (%)



Top 10 cumulative capacity, Dec 2011 (%)



Source: Global Wind Energy Council

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Wind turbine generator type and location

Generator Design	Generator rpm (approx.)	Generator Output in MegaWatts (MW) <1 >10
Induction (no Permanent Magnets)	1800	Land-based older technology
Half Speed (200 kg magnets/MW)	800	Land or offshore hybrid drive, simpler gearbox
Direct Drive (600 kg magnets/MW)	12	Mostly offshore
Superconducting (no Permanent Magnets)	??	Land or offshore

Source: Arnold Magnetic Technologies

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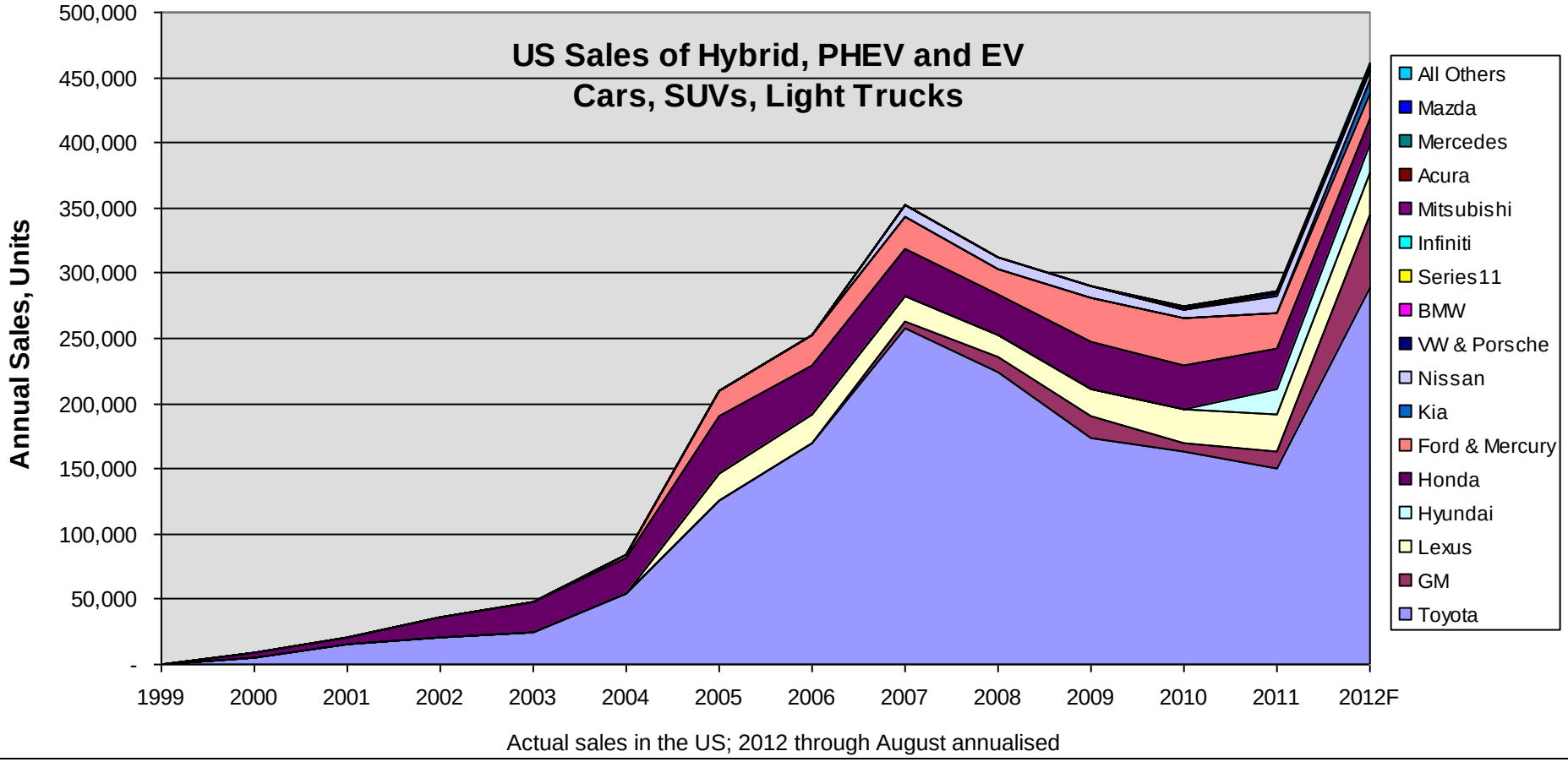
Direct and hybrid drive wind power turbines containing NdFeB

- Very little of the current installed capacity contains rare earths
  - Small and early commercial turbine designs used induction generators
  - Some small turbines converted to permanent magnets to improve efficiency
  - Generation-4 wind power generators designed to use permanent magnets for commercial power production
- Only new design, Generation-4, large-size direct drive or hybrid (half-speed) turbines rely on large quantities of NdFeB magnets
- Direct drives are favored for large offshore turbines.
  - These turbines have a higher production cost due to recent magnet prices but are more efficient and reliable
- Other sources of renewable energy may also utilise permanent magnet generators
  - Examples are tidal and wave power turbines

Direct and hybrid drive wind power turbines containing NdFeB

- The European Joint Research Centre estimates that turbines containing permanent magnet motors will account for 15% of global market share by 2020, increasing to a possible 20% by 2030
- Optimistic forecasts predict direct drives to grow by 50-60% 2012-2013, led by growth in China, followed by slower growth of 10-20% to 2015 once penetration stabilises
- However, companies still offer traditional geared models for smaller turbines and could easily revert to this technology if Nd prices rise to unsustainable levels
- What is the future for direct drives in China?

Will future growth of come from EV/HEVs?



Actual sales in the US; 2012 through August annualised

Source: www.hybridcars.com

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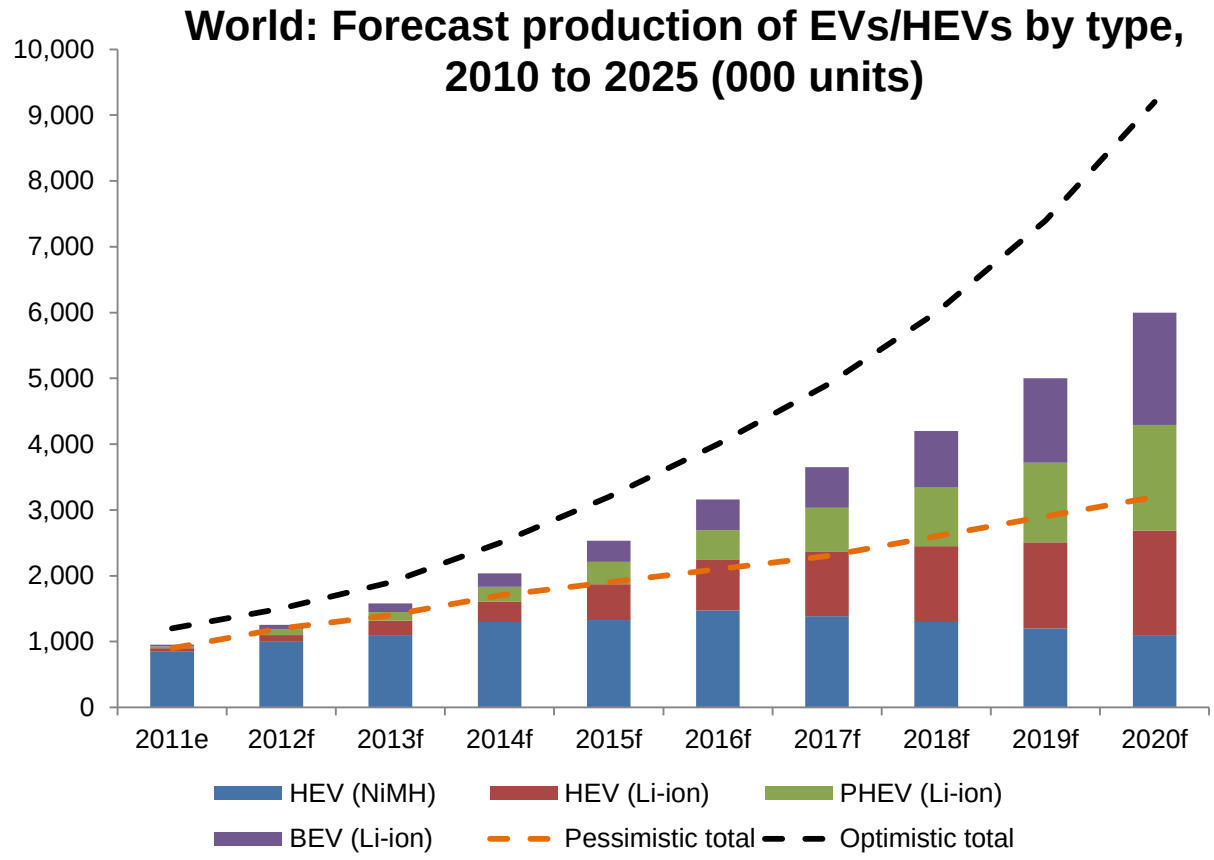
Will future growth come from EVs/HEVs?



- Production of EVs/HEVs could reach 3.2-9.2 million by 2020
- In particular, HEV motor systems often rely on NdFeB magnets
- Toyota and others are looking at induction motors in EVs in case the price of Nd becomes unsustainable or supplies are undependable

Source: Roskill estimates

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Consumption of rare earths in permanent magnets

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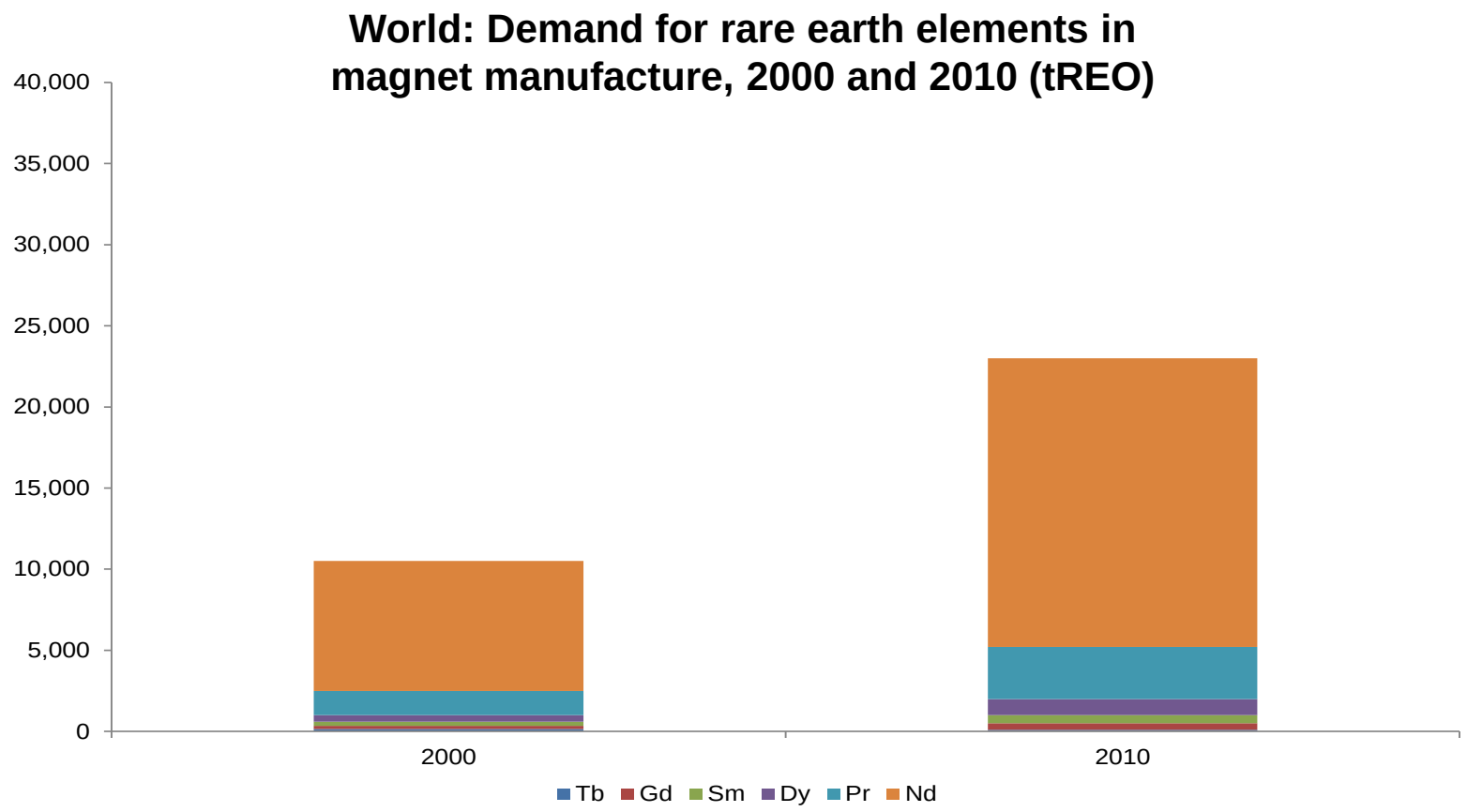
Over the last decade demand for Nd more than doubled – driven by increased use of NdFeB magnets in electronic equipment rather than "green" applications



Source: Roskill estimates

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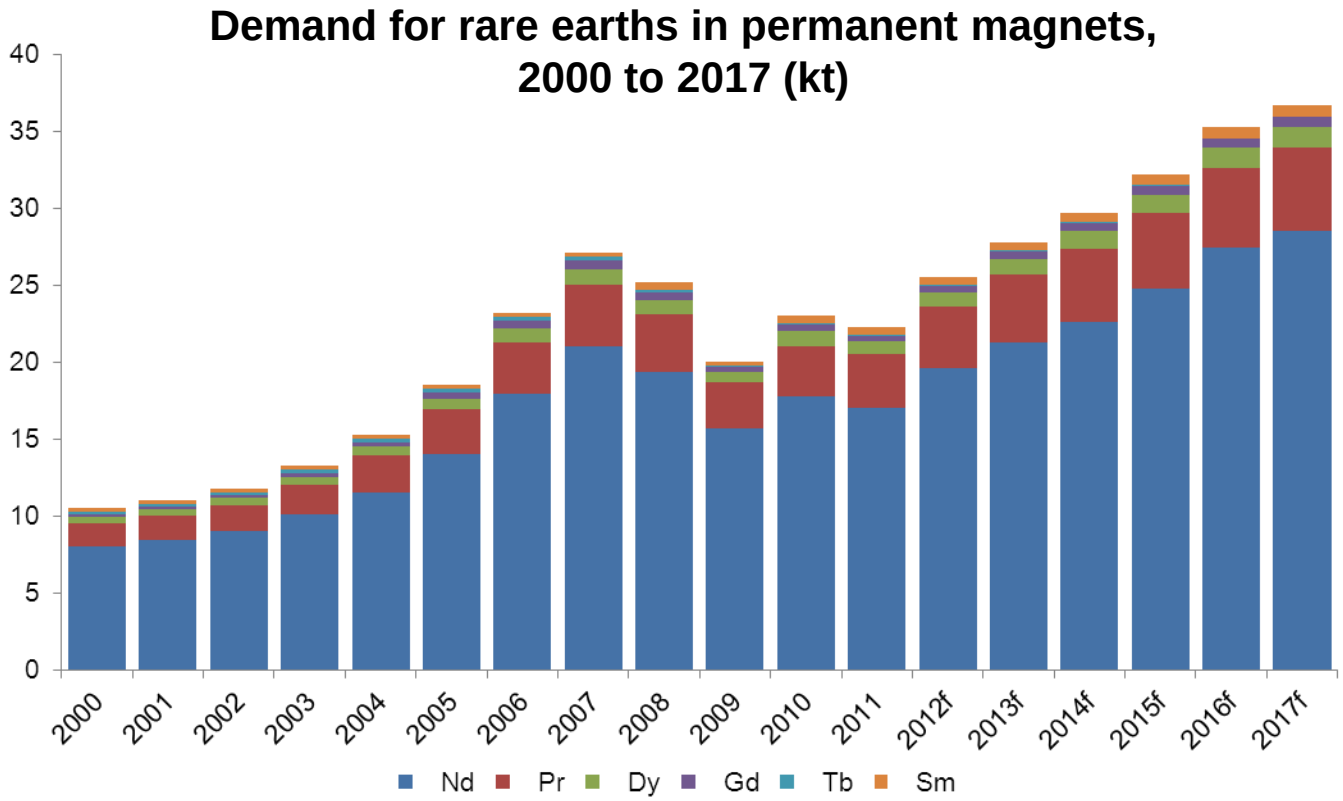
Demand for rare earths in permanent magnets estimated at 25,500t in 2012



- **96% NdFeB**, growth driven by consumer electronics, standard automotive, air conditioning, electric bicycles
- **3% SmCo** for specialist, high temperature applications
- **1% SmFeN** for bonded magnets
- ~78% China
- ~22% Japan, other Asia and Europe

Source: Roskill and Arnold estimates

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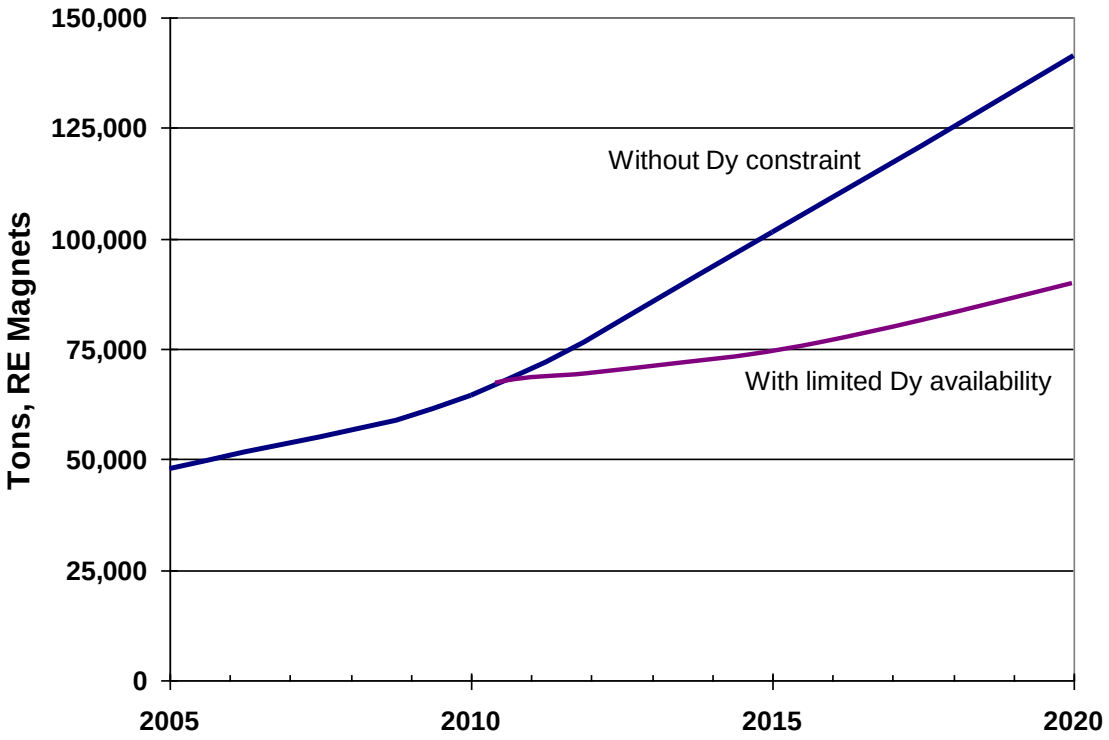
Factors affecting future consumption of Nd, Pr and Dy in magnets

- Demand for REEs in magnets is forecast to grow at 6-8% to 2016 – much of this growth will be related to continuing demand for use in consumer electronic equipment (as well as electric bicycles in China and southeast Asia in general)
- Higher growth rates likely from 2016 if “green technology” applications materialise
- Concerns about high prices and availability could limit the extent to which NdFeB permanent magnet direct drive generators are adopted for wind turbines
- Similarly, auto manufacturers are seeking alternatives to permanent magnet motors in electric vehicles
- Additional sources of rare earths are still to be established; adequate light rare earths (Nd and Pr) are expected to be available
- The key ingredient is the heavy rare earth, Dy (dysprosium), which is required for neo magnets to perform at elevated temperatures - supplies of Dy are expected to remain tight

Factors affecting future consumption of Nd, Pr and Dy in magnets

- Dy is seen as the limiting factor
  - Research is underway in Japan and the USA to identify ways of reducing intensity of use – already cut by half in some magnets
- Technologies in-play or under research include
  - Diffusion of Dy into the neo magnet to reduce the total quantity required
  - Induction and synchronous reluctance traction drive motors (no magnets)
  - Research on nano-structured and exchange-coupled magnet materials with reduced or no rare earth content
  - Lower application temperature to reduce demand for Dy
  - Superconducting generators for wind power
- Recycling (or re-use) is a major thrust area
  - Hitachi, Showa Denko and Mitsubishi Materials are all researching ways of recycling REEs from discarded hard disc drives and other appliances
  - A variety of organisations are seeking to increase recycling such as the Center for Resource, Recovery and Recycling (CR^3, www.wpi.edu/academics/Research/CR3/)

Future consumption of NdFeB



- Consumption of NdFeB magnets constrained by lack of availability of dysprosium
- Between 2010 and 2015: influence of Dy-diffusion technique and device temperature control will permit modest growth
- After 2015: minor additional sources of dysprosium allow the market to expand slowly

Chart based on existing technology regarding use of Neo at elevated temperatures and upon max use requirements of applications

Source: Arnold Magnetic Technologies

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Meeting the demands of the market

- In 2012 there is a discontinuity between the natural occurrence of REEs and the ratio in which they are consumed
- The likely shortages of heavy rare earths (and possibly neodymium) will also occur in China – how will this affect Chinese government policies – could it lead to more restrictions on supply to the ROW?
- Supply of neodymium should ease from 2014/15 onward permitting expanded Neo magnet use in electronics and other lower temperature applications
- It is unlikely that there will be any significant supply of HREEs from the ROW before 2016/17 – companies dependent on a secure supply of dysprosium, terbium and europium rely on the developing dynamics of the REE industry in the south of China

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