Production Status and Forecast
for the Availability of Rare Earth Materials (and Cobalt)

Steve Constantinides
Magnetics & Materials LLC

Agenda

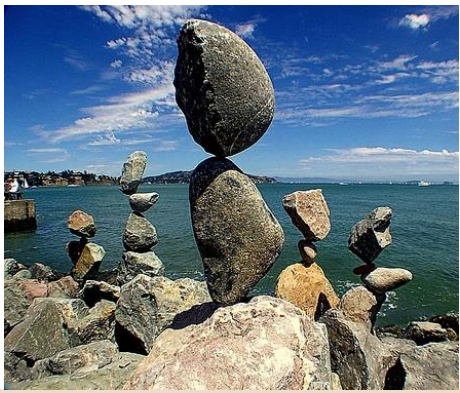
What's the big deal with magnets?

Materials

Supply

Consumption

Summary comments



Balancing Supply and Demand

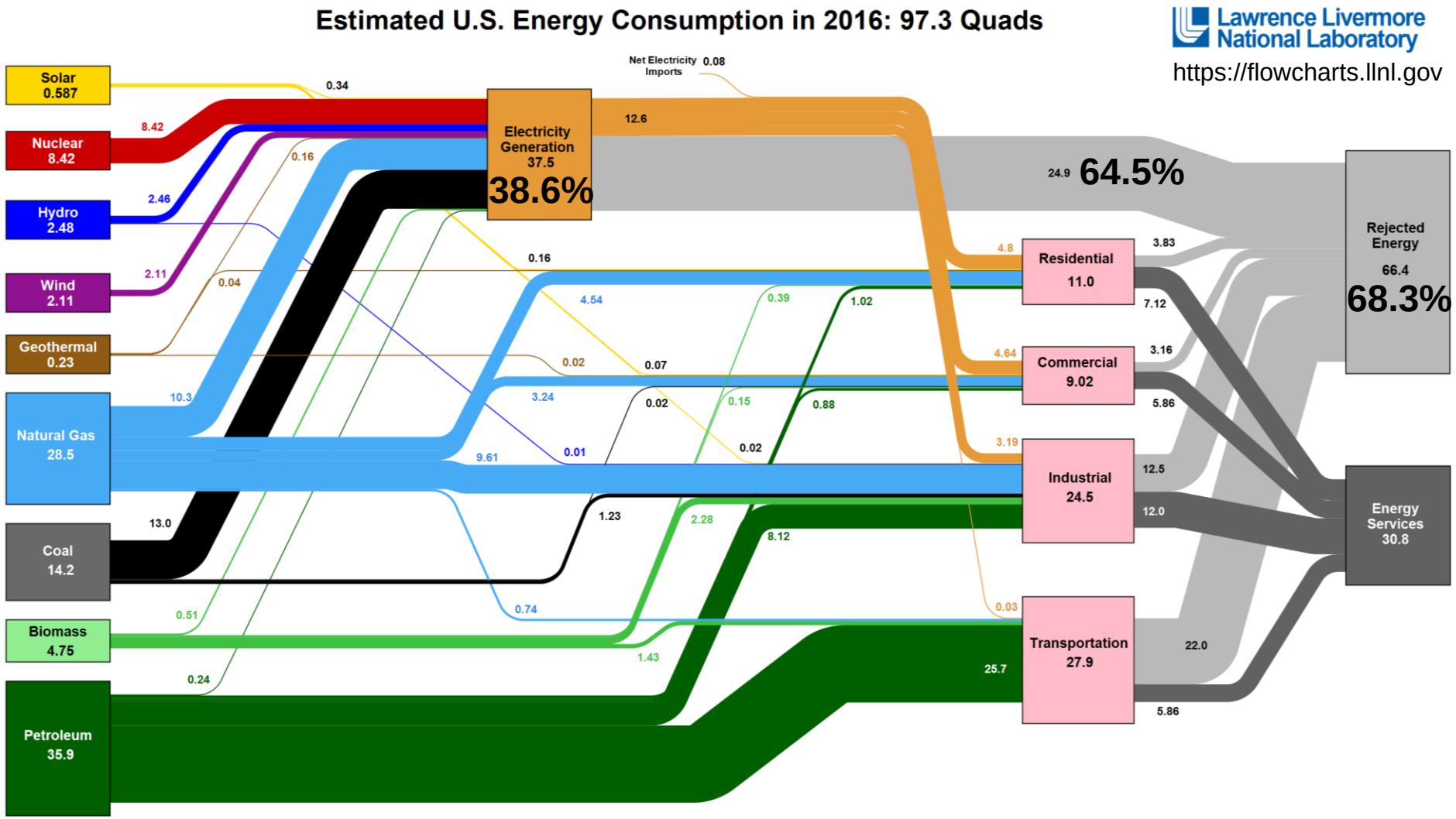
Why are magnetic materials so important?

What do magnetic materials do?

They facilitate the…

- **Conversion of mechanical into electrical energy**
  Both soft and permanent magnetic materials
- **Transmission of electrical energy**
  Primarily soft magnetic materials
- **Conversion of electrical into mechanical energy**
  Both soft and permanent magnetic materials

Energy Production and Consumption (USA)



1 Quad = 10^{15} BTU = 1.055 x 10^{18} J

Why are permanent magnets so important?

- Rare Earth magnets are an enabling material
  - Efficiency
  - Miniaturization
- Electric motors consume between 40 and 50% of produced electrical power
  - Per EIA and global estimates
  - Permanent magnet motors are inherently more efficient
- The effort to convert from ICEs to EVs will increase electrical power consumption
  - Charging stations likely to require an expansion to the electric grid
- Permanent magnet motors are more efficient than induction motors
  - Variable speed permanent magnet motors are much more efficient
  - Induction motors are optimized for a single rpm

Agenda

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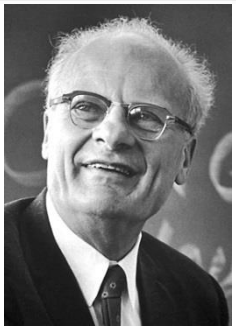
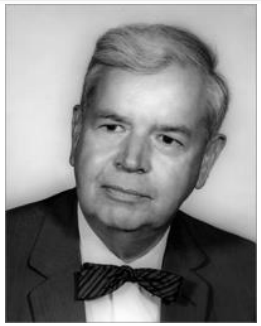
Naturally Occurring Ferromagnetism

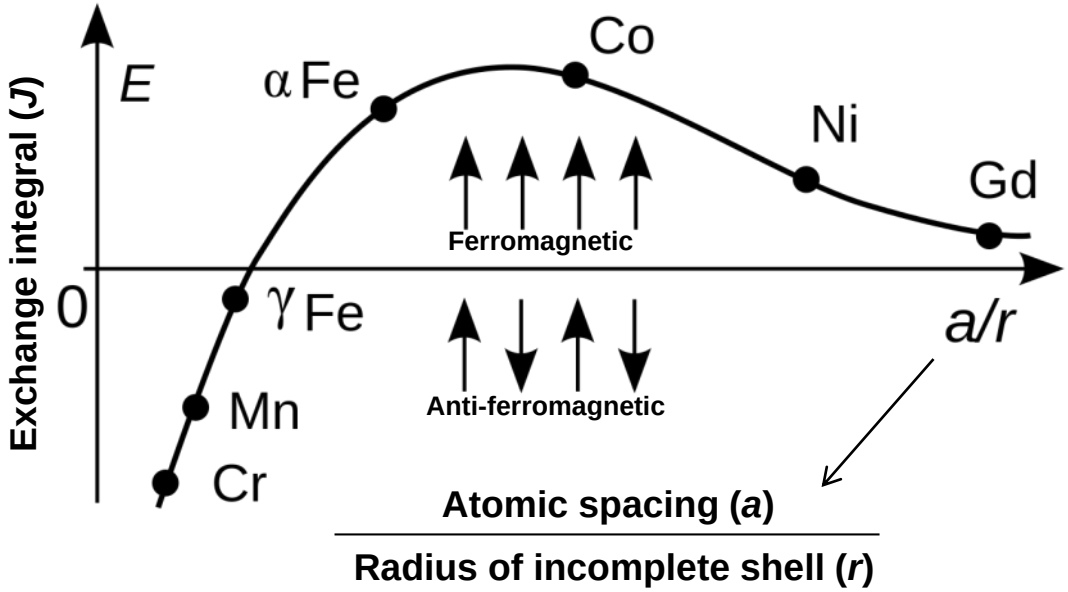


Hans Bethe



John C. Slater

Bethe-Slater Curve

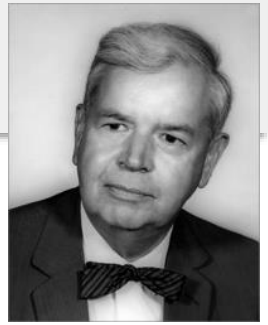


Exchange Interaction

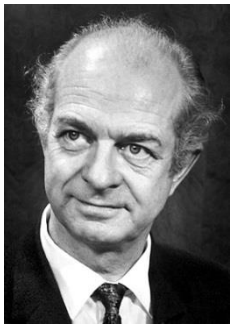
Heisenberg: quantum theory explanation for ferromagnetism

In physics, the **exchange interaction** is a quantum mechanical effect which increases or decreases the expectation value of the energy or distance between two or more identical particles when their wave functions overlap.

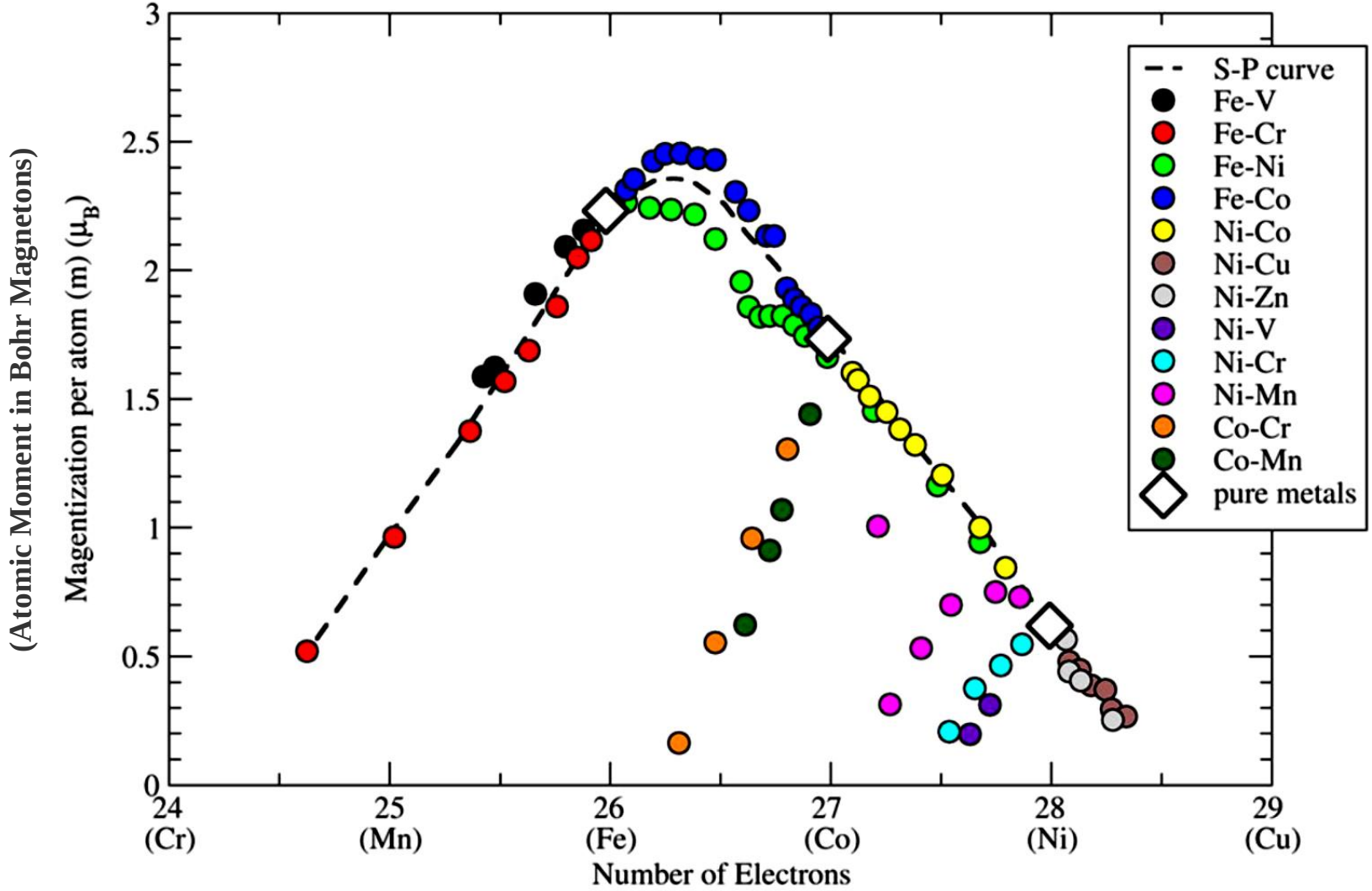
Slater-Pauling Curve



John C. Slater



Linus Pauling



R.M. Bozorth, Ferromagnetism, IEEE, 1993, p.438-441

Color-edited by Dr. Bill McCallum

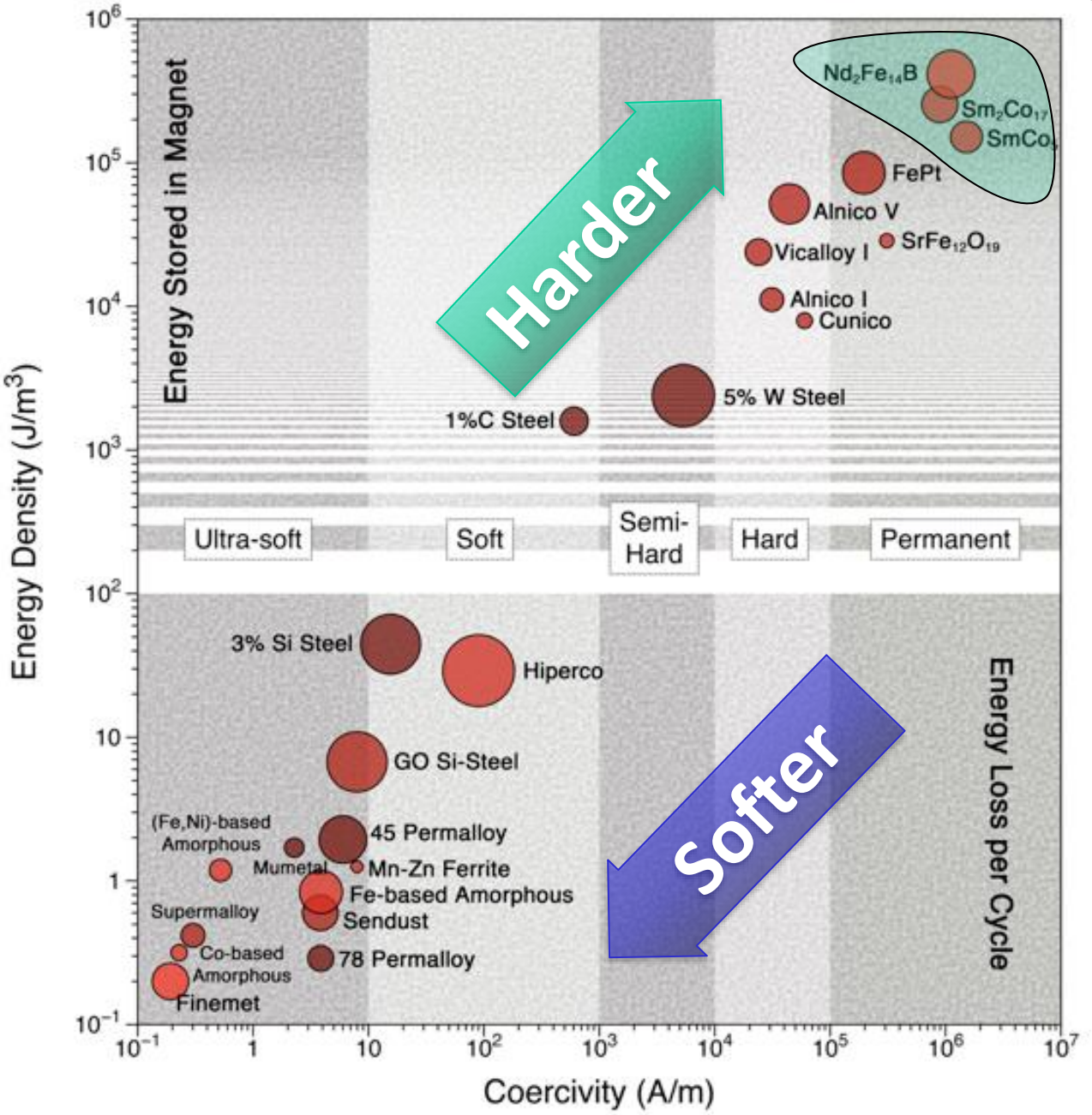
Elements in Existing Magnetic Materials

	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**	(La)	(Co)							Oxygen dilutes; Ba rarely used
SmCo	Co	Sm	(Gd)	**Fe**	Cu	Zr					Sm is underutilized; excess supply
Neodymium-iron-boron	**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**								Interstitial nitrogen; unstable >450 °C
Other											
MnBi	**Mn**	**Bi**									Never commercialized
MnAl(C)	**Mn**	**Al**					Cu	**C**			Not successfully commercialized

Spectrum of magnetic materials

M. A. Willard, "Stronger, Lighter, and More Energy Efficient: Challenges of Magnetic Material Development for Vehicle Electrification" Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2012 Symposium, National Academies Press: Washington, DC (2013) pp. 57-63.

The circle size is proportional to the size of the material's magnetization.



Rare Earth Magnets

4%

- **$SmCo_5$**
  - Sintered (powder metallurgy)
- **Sm_2Co_{17}** – actually $Sm_2(CoFeCuZr)_{17}$
  - Sintered (powder metallurgy)

95%

- **Neo** (neodymium iron boron)
  - Powder for bonded magnets: compression, extruded, injection molded
  - Sintered (powder metallurgy)
  - Hot rolled (no longer made): Cu-modified composition; Seiko-Epson
  - Die-upset / forged, fully dense: Magnequench MQ-3 process (original and modified); Daido Electronics

1%

- **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

Percent by weight of commercially produced rare earth magnets

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	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) MS Schramburg Magneti Ljubljana (not licensed) Vacuumschmelze (Neorem)

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

Global Sales of Permanent Magnets

	2010 Actual					2016 Estimate				
	tons	%	$million	%	$/kg	tons	%	$million	%	$/kg
NdFeB	80,900	12.3%	6,850	65.2%	84.67	105,000	13.1%	7,250	52.7%	69.05
SmCo	2,310	0.4%	270	2.6%	116.88	3,864	0.5%	345	2.5%	89.29
Ferrite	567,000	86.4%	2,950	28.1%	5.20	685,000	85.5%	5,625	40.9%	8.21
Alnico	5,555	0.8%	375	3.6%	67.51	5,950	0.7%	375	2.7%	63.03
Other	540	0.1%	65	0.6%	120.37	1,450	0.2%	170	1.2%	117.24
Totals	**656,305**	100.0%	**10,510**	100.0%	**16.01**	**801,264**	100.0%	**13,765**	100.0%	**17.18**

Data updated as of 2/1/17.

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

Agenda

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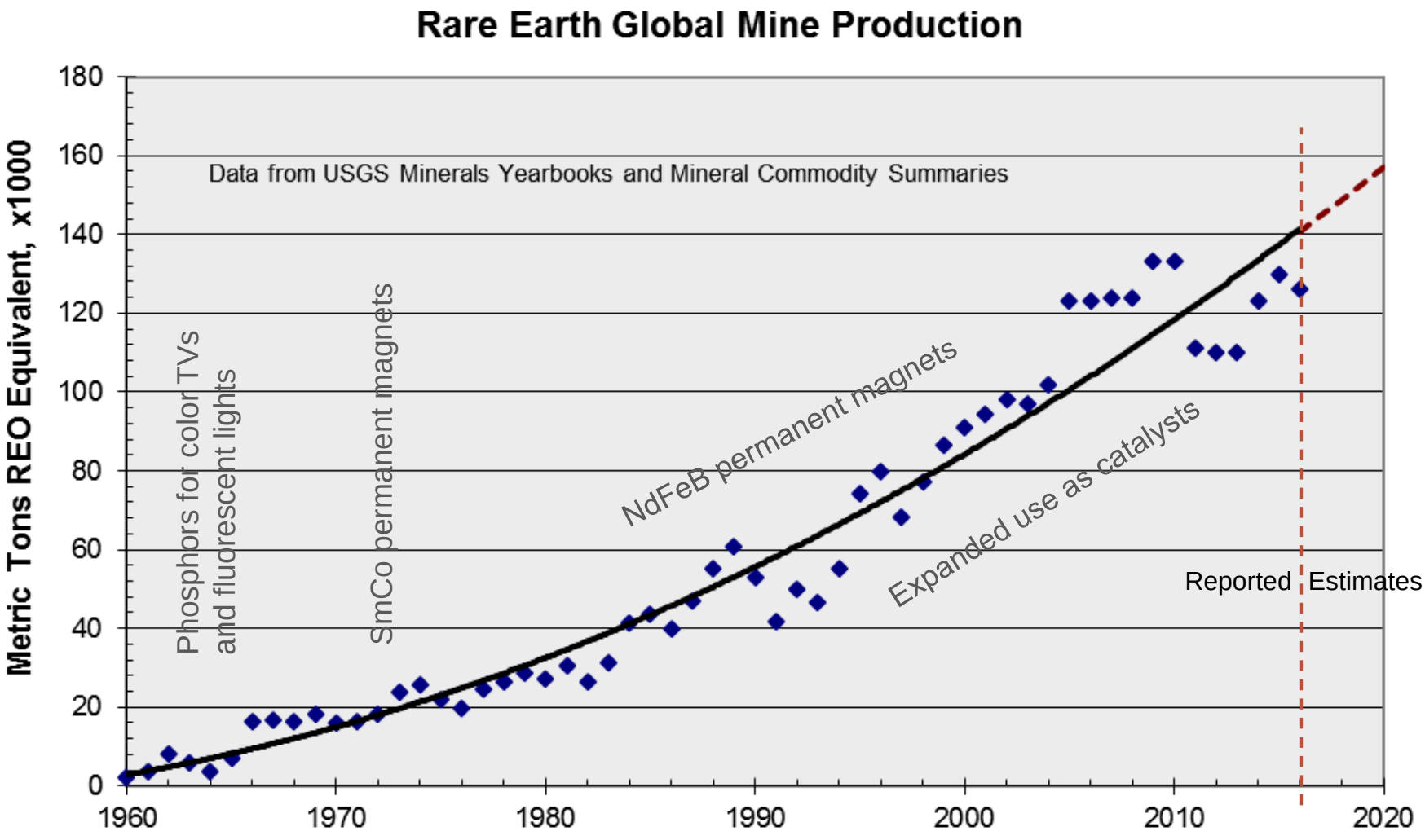
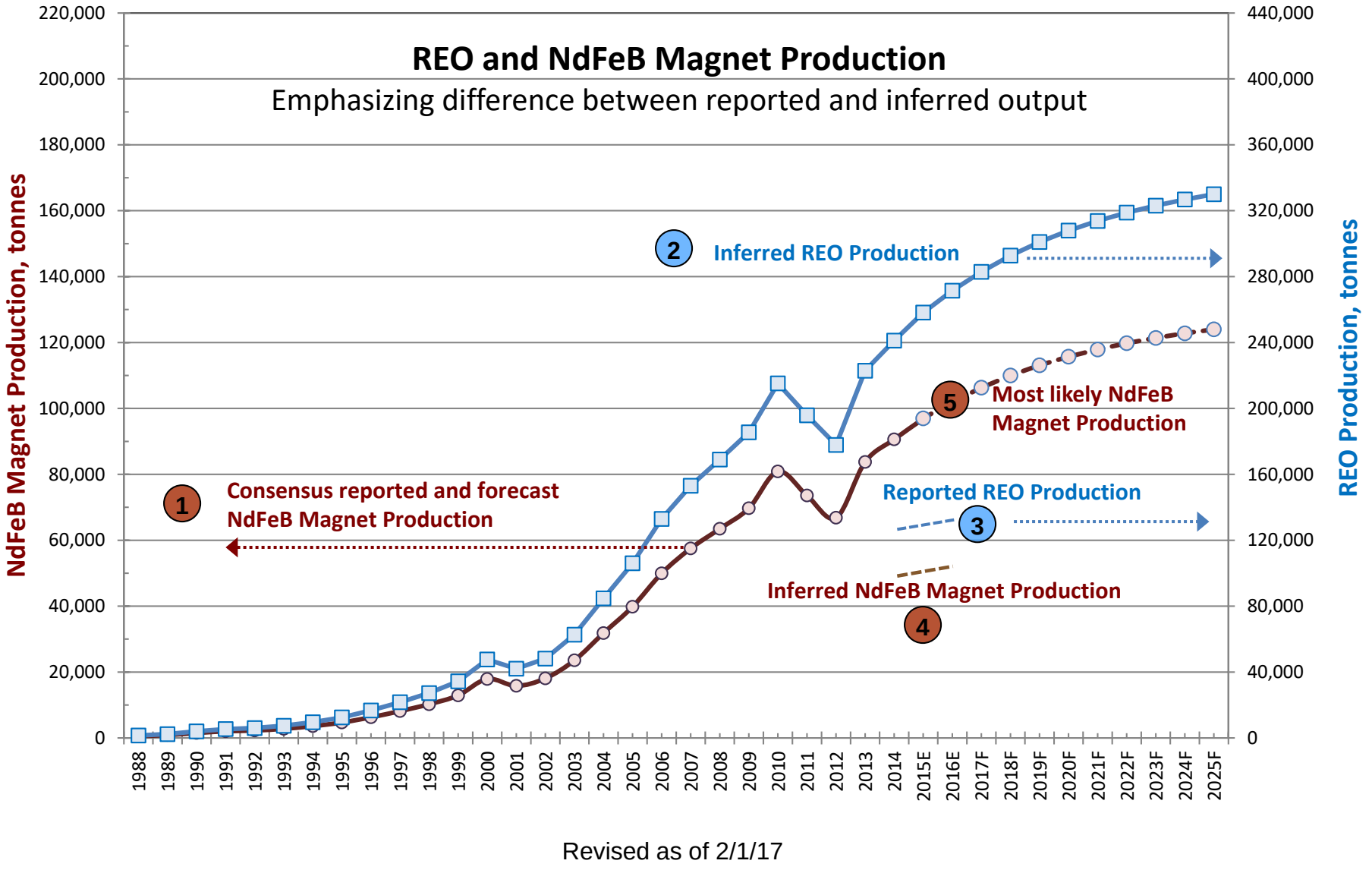
Balancing Supply and Demand

Rare Earth Oxide Production, USGS Data



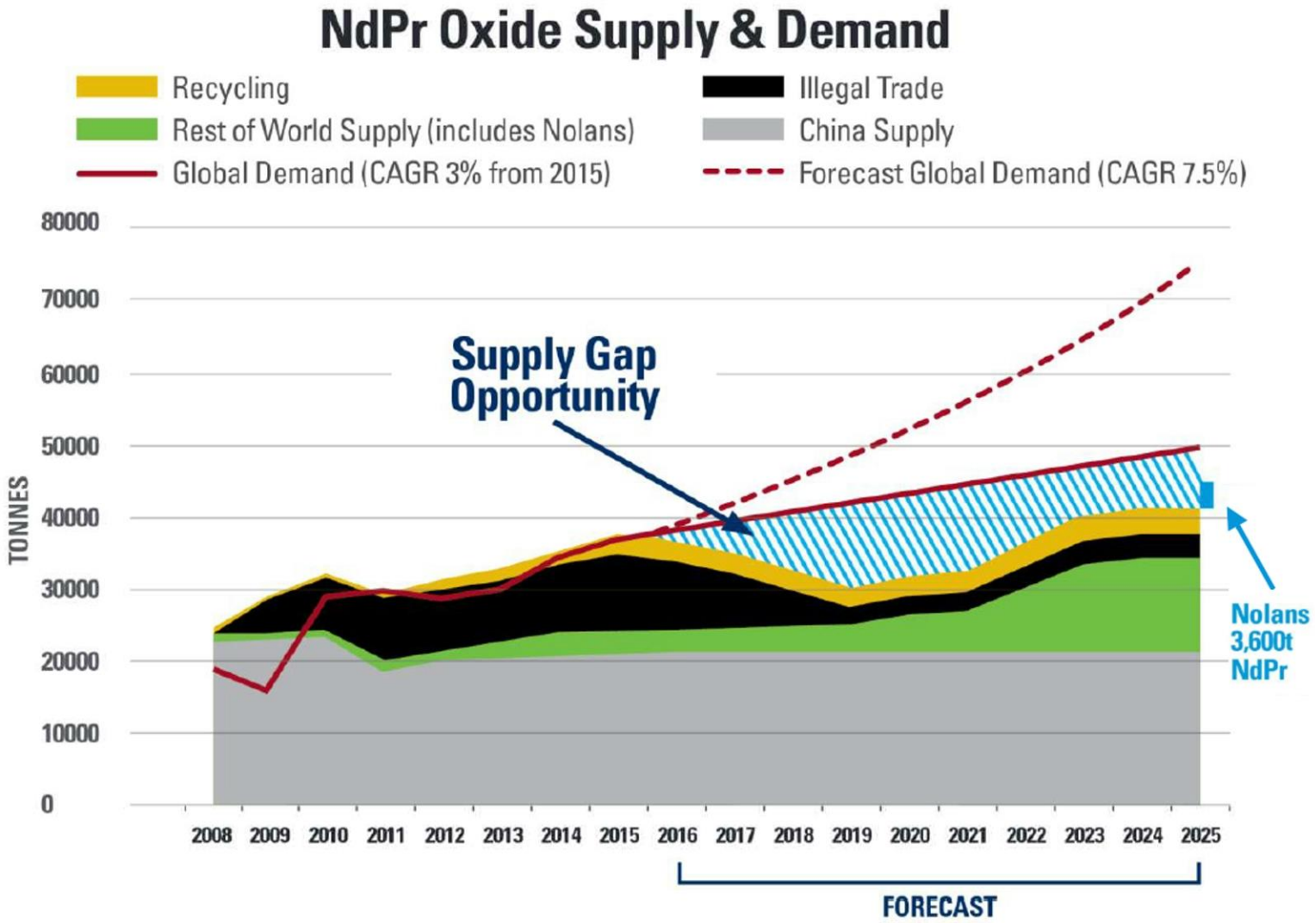
Data through 2016: Mineral Commodity Summaries, USGS

REO and NdFeB Magnet Production



Revised as of 2/1/17

Illegal Trade in Rare Earths



5th Korea-Northern Territory Business Roundtable; High-Value Magnet-Feed NdPr Rare Earths from Nolans, a new opportunity for Korea, July 2017

China Production of REO

- China Aluminum Corporation
- China Minmetals Corporation
- Ganzhou Rare Earth Group Co. Ltd.
- Guangdong Rare Earth Industrial Group Co. Ltd.
- Inner Mongolia Baotou Steel Union Co. Ltd.
- Xiamen Tungsten Co. Ltd.

Production quota, 2017: 105,000 tonnes REO

CHALCO 中国铝业
Aluminum Corporation of China Limited

China Northern Rare Earth (Group) High-Tech Co., Ltd.

XTC
Xiamen Tungsten Co.,Ltd

MINMETALS
China Minmetals Corporation

Guangdong Rare Earth Industrial Group Co. Ltd.

江西铜业集团公司 JIANGXI COPPER CORPORATION
江西钨业控股集团有限公司 JIANGXI TUNGSTEN HOLDING GROUP CO., LTD.
赣州稀土集团有限公司 GANZHOU RARE EARTH GROUP CO., LTD.
China Southern Rare Earth Group

Lynas Production of REO

- Production of rare earth oxides (REO) in FY17: 16,003 tonnes
  - Ready for sale production of neodymium-praseodymium (NdPr) was 5,223 tonnes in FY17 compared to 3,896 tonnes in FY16.
- Record total sales revenue in FY17: $257.0 million
  - After sales commission
  - Compared with $191.0 million in FY16
- Mining campaigns
  - Second campaign commenced January 2017; completed May 2017
  - Approximately 240,000 tonnes of ore at 17.8% REO was mined, sufficient for approximately 1 year's production at current rates.
  - Third campaign planned for fall 2017
- Improved global market conditions
  - In second half of the 2017 financial year have continued into the early part of FY18 and are expected to continue
- Lynas has now been operating safely for 5 years

Lynas Production of REO

- Malawi operations
  - Since fiscal year 2012, no further capital investment has been made on the Kangankunde Rare Earths ("KGK") resource development in Malawi
  - Project remains on hold
- Ready-for-Sale tonnage

	FY14	FY15	FY16	FY17
Ready for sale production volume total (REOt)	3,965	8,799	12,631	16,003
Ready for sale production volume NdPr (REOt)	946	2,258	3,896	5,223

Lynas – CondiSoil®

- CondiSoil® is a byproduct of mining and beneficiation
  - Renders irrelevant the need for a permanent disposal facility
  - Confirmed by the Atomic Energy Licensing Board and Nuclear Malaysia as “non-radioactive”
- Market –ready
  - Registration of CondiSoil® with the Department of Environment (DoE) and the Department of Agriculture
  - Approval is expected very soon
- CondiSoil® can improve farming yield
  - Has been tested on padi, corn, kenaf and palm oil crops

Mountain Pass Rare Earth Mine - Update

Magnequench Update: Neo Performance Materials - September 26, 2017
In 2016, Oaktree Capital Group LLC, as Molycorp's biggest secured creditor, took over a collection of Molycorp's most valuable assets and brought them out of bankruptcy under the name Neo Performance Materials (NPM).

NPM is now a private company with corporate offices in Toronto, Ontario, Canada, Greenwood Village, Colorado and Beijing, China. NPM is organized along three business segments: Neo Chemicals and Oxides, Neo Magnequench and Neo Rare Metals. Magnequench has been in business since the 1980's and has a wide range of products under its patent portfolio, which covers rapidly solidified NdFeB-based powders and magnets produced with those powders.

NPM is reportedly now weighing an initial public offering or an outright sale, according to people familiar with the matter. The company hasn't determined which avenue it will pursue, but some expect them to file for an IPO in October, 2017.

Source: Bloomberg Technology

Mountain Pass Rare Earth Mine - Update

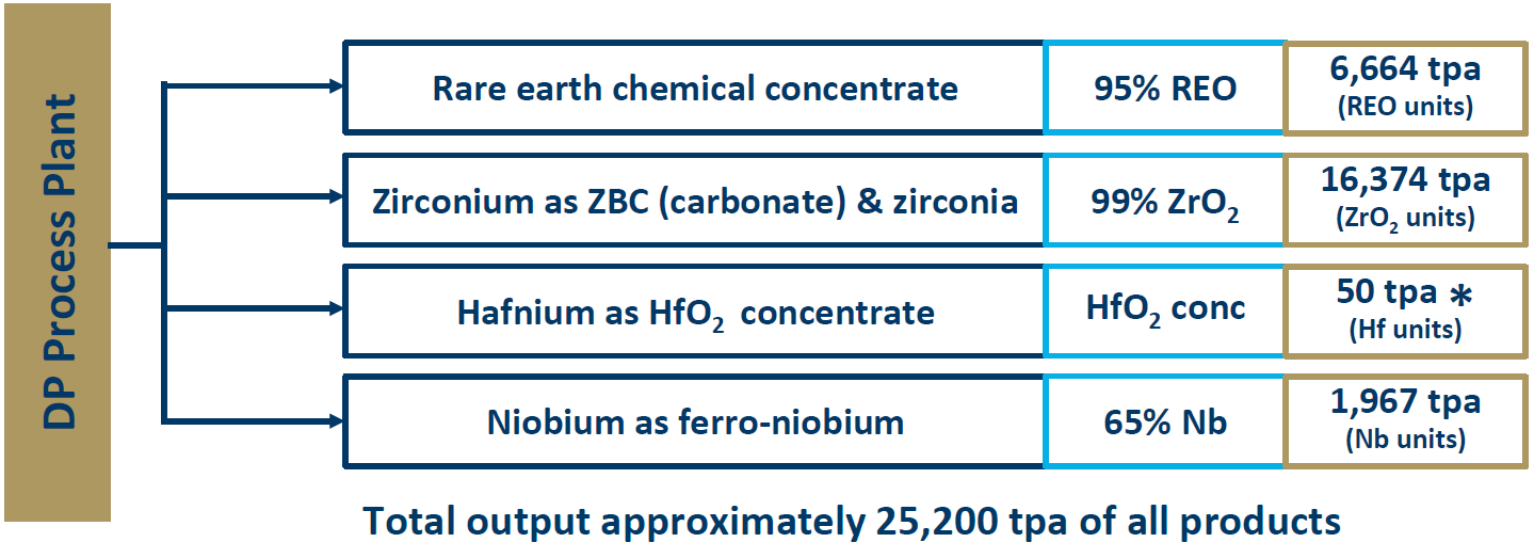
- Potential new owner: MP Mine Operations LLC (MPMO)
  - Chinese-led consortium including rare earths miner Shenghe Resources
  - Bankruptcy auction winning bid of $20.5 million
- Prior to the auction, Oaktree (an investor in Molycorp) filed a lawsuit against JHL and QVT over the mineral rights – status unknown
- As of now, nothing has been reported from the US Government Committee on Foreign Investment

Further information is available on a continuing basis in *The Magnet Industry Newsletter* published bi-monthly and available by subscription from Walter T. Benecki LLC: www.waltbenecki.com/newsletter.html

Alkane Resources Ltd.

- Two projects
  - Tomingley Gold Operations Pty Ltd (TGO)
  - Australian Strategic Materials Ltd (ASM)
    - Dubbo Project
- Dubbo Zirconia Project (DZP)
  - Zirconium, Hafnium, Niobium
  - Rare Earths

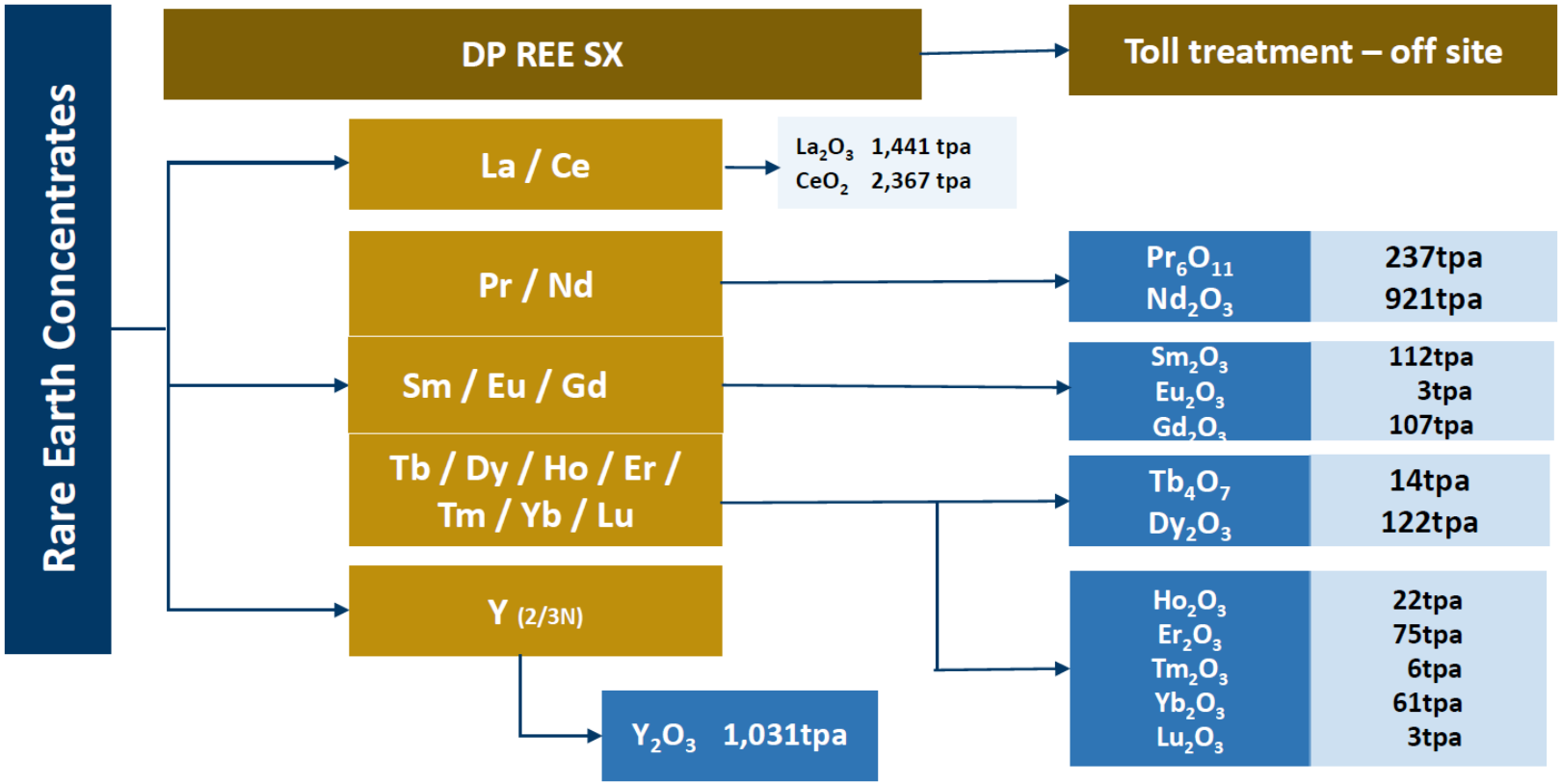
Alkane Resources Ltd. - DZP



Tonnage based upon recoveries developed from mass balances of the demonstration pilot plant.
∗ Start up output. 200tpa potential depending upon market demand

Resource lifespan: greater than 80 years
Capital cost is estimated to be approximately US$1B
Financing options have been initiated with the assistance of Sumitomo Mitsui Banking Corporation.
Production is anticipated in 2019 pending completion of funding arrangements.

Alkane Resources Ltd. - DZP

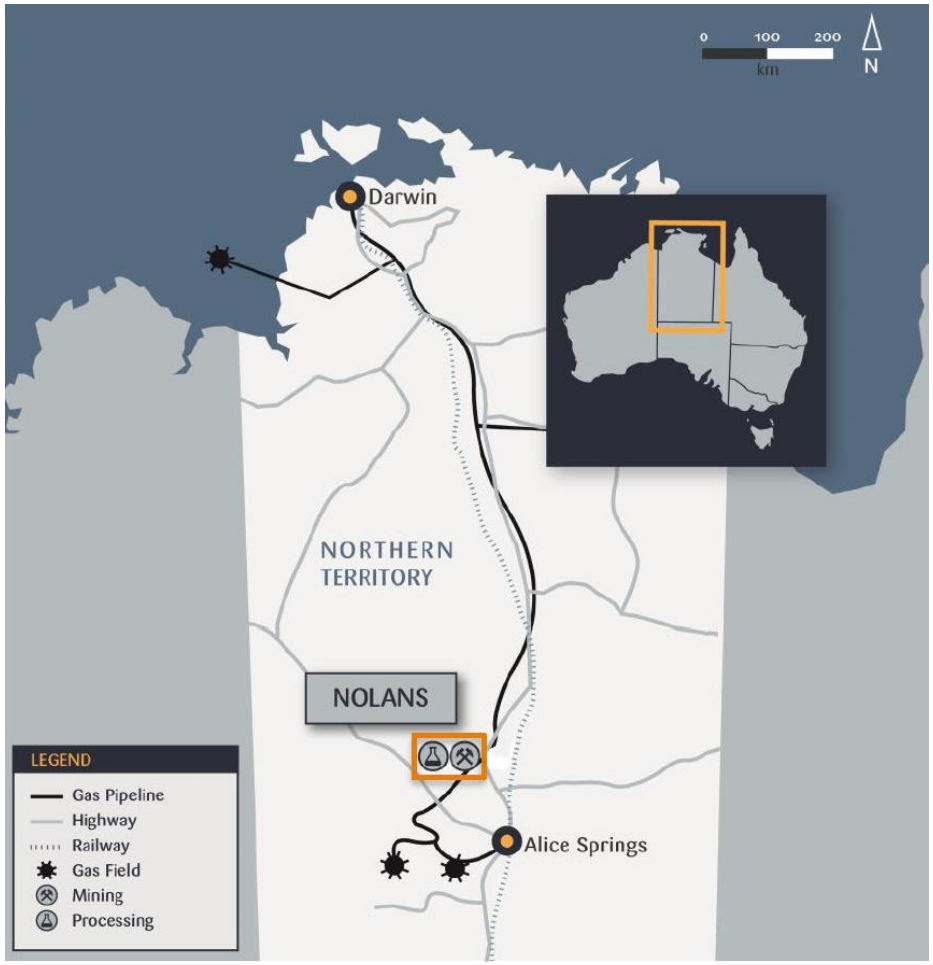


Tonnage based upon recoveries developed from mass balances of the demonstration pilot plant & preliminary solvent extraction stages on site at the DP.

Information from Alkane Resources website and linked presentations. Figures on this and prior slide from June 2017.

Arafura Resources Ltd. - Nolans

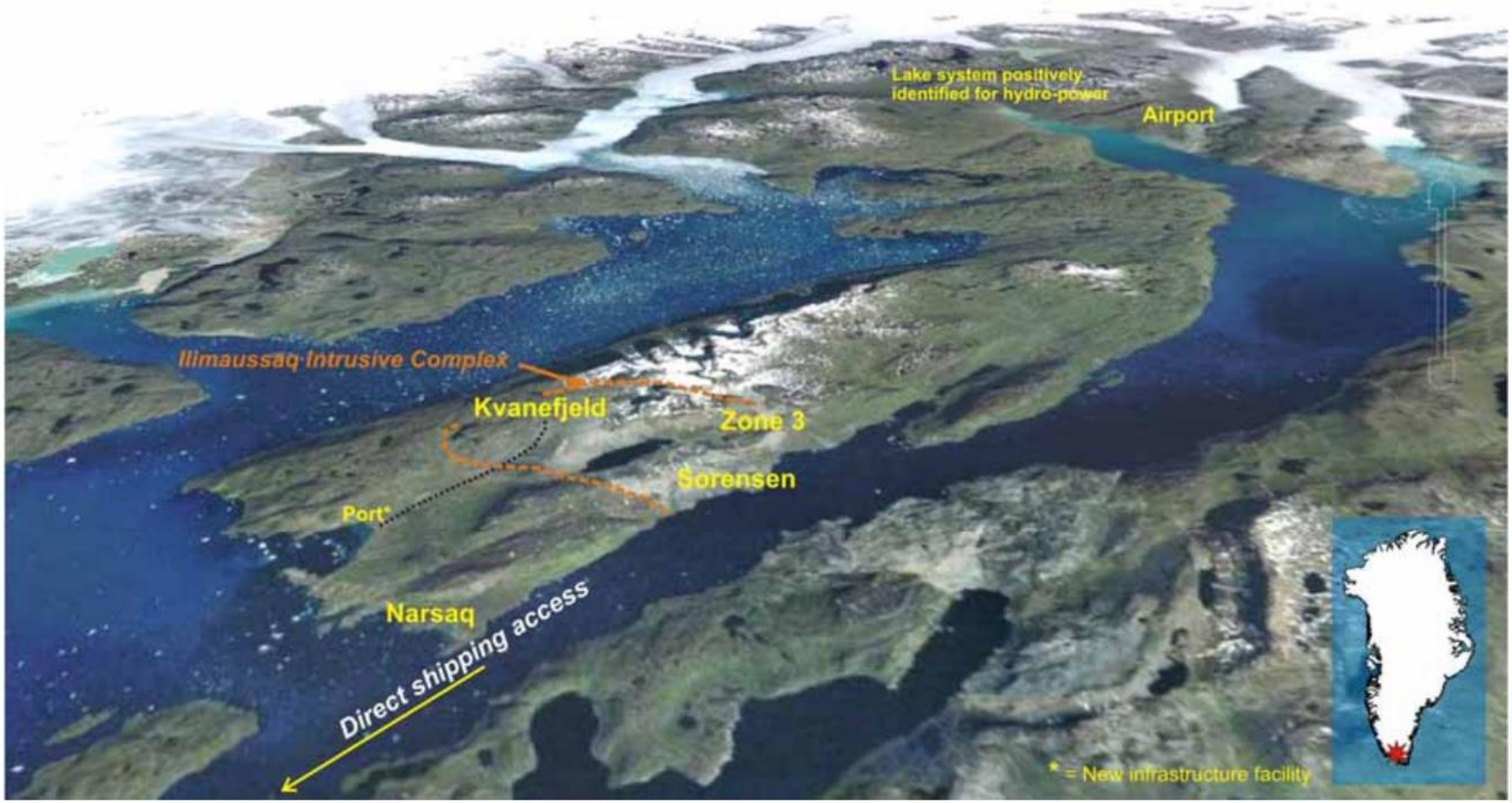
- Capex: US$680m
- 14,000 tpa TREO
- 23 year life
- Offshore separation at OCI Co. Ltd. (South Korea) add'l capex: US$85m



Greenland Minerals and Energy Ltd. - Kvanefjeld Project

- Globally unique, and significant multi element project
- Rare earth elements, uranium, zinc, fluorspar
  - Potential for further by-products
- Located in accessible southern Greenland, close to infrastructure
- Advanced project status– permitting underway, regulatory framework established
- Industrial project partner– Shenghe Resources Holding– 12.4%shareholder
- Brings downstream rare earth processing, international customer base

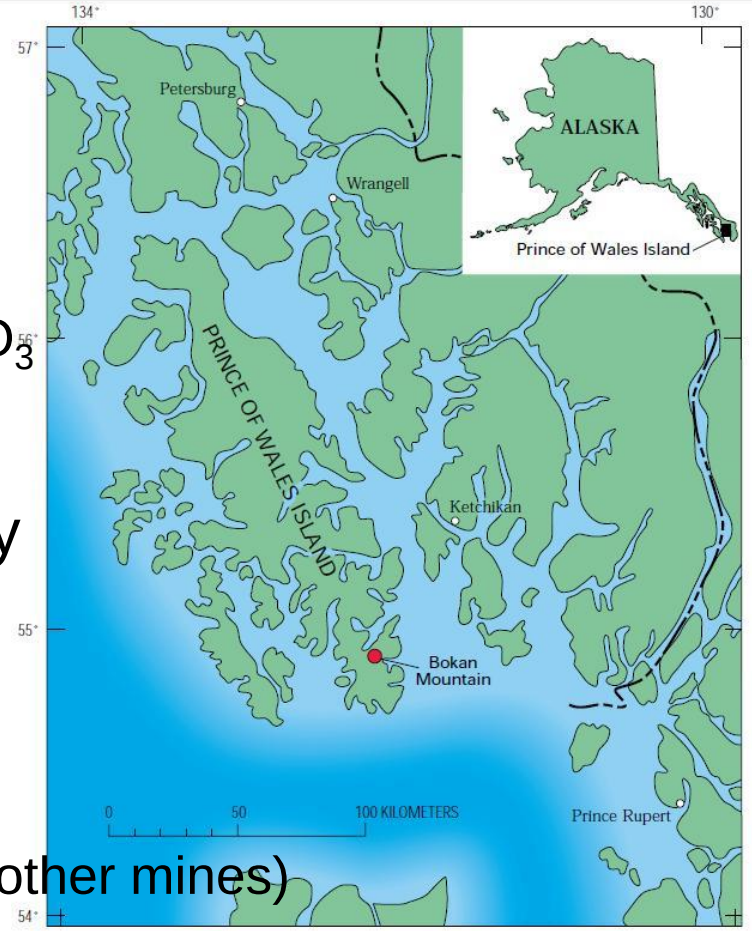
Greenland Minerals and Energy Ltd. - Kvanefjeld project



>1 billion tonnes defined (JORC 2012), <15% of prospective area evaluated

Ucore Rare Metals

- Bokan Mountain
  - 11 year mine life
  - 2250 tpa TREO
    - Includes 95 tpa Dy_2O_3 and 515 tpa Y_2O_3
- SuperLig® Process
  - Molecular Recognition Technology
  - Developed by IBC Advanced Technologies, Inc.
  - Ucore applying MRT to
    - Rare earth ore processing (Bokan + other mines)
    - Coal ash metals reclamation
    - Metals separation from oil sand tailings
    - Market scrap recycling



Recycling of REE-Containing Products

- Collection challenge
  - Require strategies for efficient collection of EOL products
    - Lease versus purchase
    - Deposit – return
  - Transportation to recycling centers
- Processing challenge
  - Diversity of products likely to require a diversity of processes
  - Variation in contained REEs
  - Highly variable content percentage from fractional percentages of products to major portions
    - Trace amount of bulk product: phosphors, LEDs fluorescent lamps, and high performance alloys, catalysts
    - Major fraction: magnets in motors/generators, loudspeakers
- Recovery of REEs from waste streams (Fe, coal, oil)
- Design for Recycling

Recycling of Magnets: Example

- Clean “hard” scrap (magnets)
  - Directly re-introduced into the magnet manufacturing process
  - Crushed powder can be chemically modified and used in bonded magnets
- Reacted fines (magnets) and melt dross (alloys)
  - Require reduction back to the metal
    - Molecular Recognition Technology (Ucore)
    - Penn State method using a new organic compound (H3TriNOx) for binding rare earth cations
    - Rare Earth Salts chemical process
    - Conventional processing

Organizations Engaged in Recycling Efforts

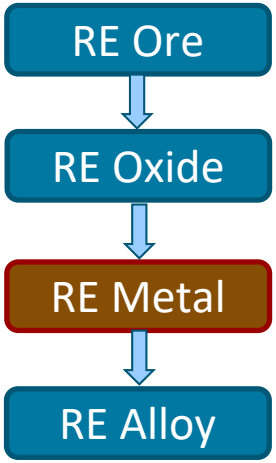
Google search returns 1.5 million hits – literally too many to list... three examples shown here

- CMI (Critical Materials Institute)
  - Mines (Colorado School of Mines)
- CR3 (Mines, Worcester Polytechnic, others)
- Rare Earth Salts & Medallion Resources
- Urban Mining Co.

Excellent overview of recycling of rare earths

"Recycling of rare earths: a critical review"; Binnemans et al.; May 2013
Downloaded from:
http://www.kuleuven.rare3.eu/wp-content/plugins/rare/images/papers/JCLEPRO_Binnemans_REE_Recycling_May2013.pdf

Raw Material Sourcing – Comparing REEs & Cobalt



China, Australia/Malaysia (Lynas)
India, Kazakhstan, Vietnam, etc.

China (Japan, France, Vietnam, other minor)

China, Japan, Eutectix (USA), LCM (UK), others;
magnet producer "in-house" processing

Country	Estimated Number of Facilities	Estimated TREO Production Capacity (tonnes)	Current Rare Earth Products Yielded	Estimated Capacity Utilization (%)
China	59+	320,000	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%
World	**71+**	**389,600**		**36%**

83%

RARE EARTH MARKET OUTLOOK: SUPPLY, DEMAND, AND PRICING FROM 2014 - 2020
Adamas Intelligence: Critical Metals and Minerals Research - October 1, 2014

Raw Material Sourcing – Comparing REEs & Cobalt

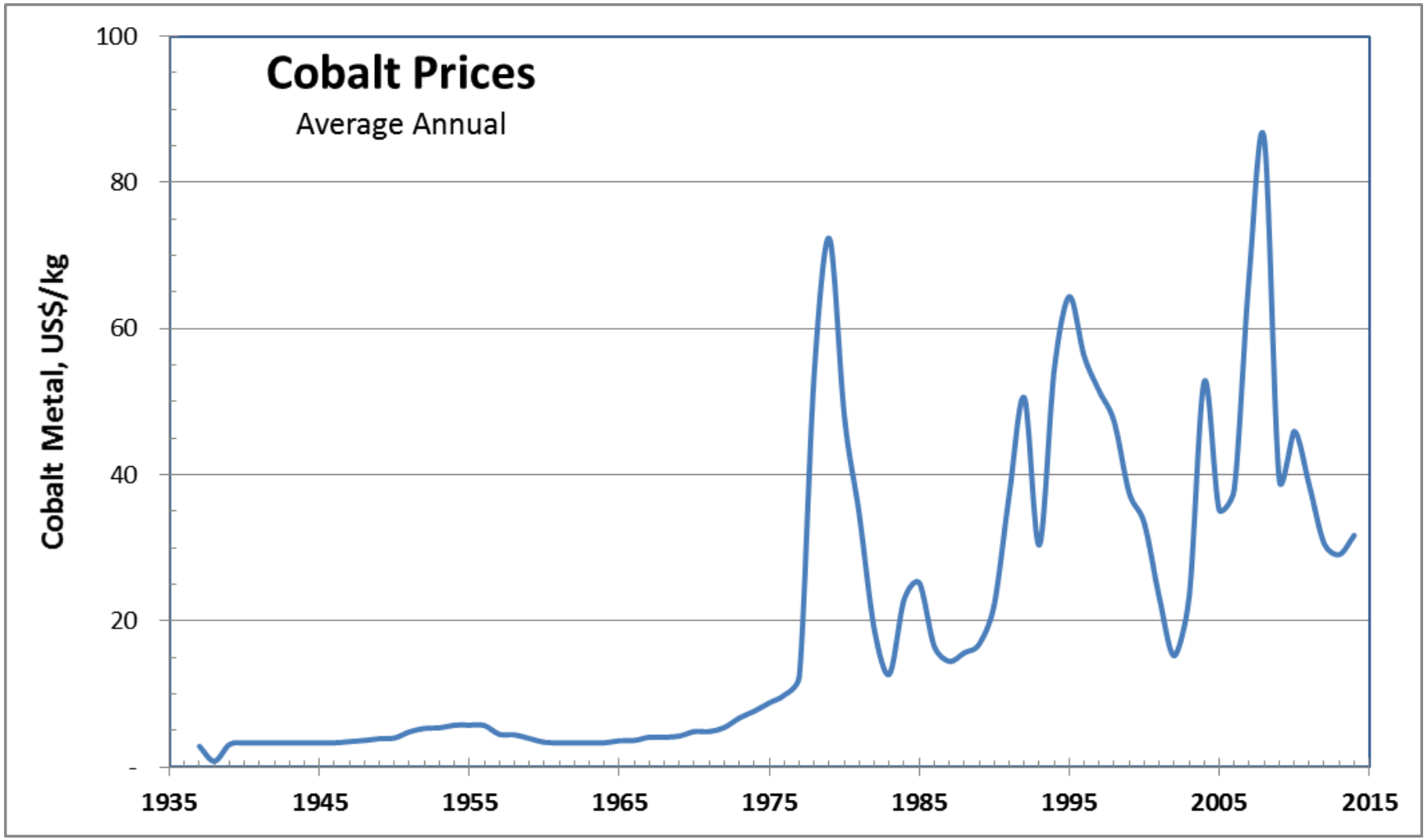
Year 2015 Production				
Country	Mine		Refinery	
	Tonnes (Co-contained)		Tonnes (Co content)	
Australia	6,000	4.8%	5,150	5.3%
Belgium	-	-	6,306	6.5%
Botswana	316	0.3%	-	-
Brazil	3,800	3.0%	1,300	1.3%
Canada	6,904	5.5%	4,072	4.2%
China	7,700	6.1%	**48,700**	**50.0%**
Congo (Kinshasa)	**63,000**	**50.1%**	3,141	3.2%
Cuba	4,300	3.4%	-	-
Finland	440	0.4%	9,615	9.9%
France	-	-	133	0.1%
India	-	-	150	0.2%
Indonesia	1,300	1.0%	-	-
Japan	-	-	4,259	4.4%
Madagascar	3,700	2.9%	3,464	3.6%
Morocco	2,600	2.1%	1,722	1.8%
New Caledonia	3,680	2.9%	-	-
Norway	-	-	3,100	3.2%
Papua New Guinea	2,505	2.0%	-	-
Philippines	4,300	3.4%	-	-
Russia	6,200	4.9%	2,040	2.1%
South Africa	3,000	2.4%	1,300	1.3%
United States	760	0.6%	-	-
Vietnam	277	0.2%	-	-
Zambia	4,600	3.7%	2,997	3.1%
Zimbabwe	360	0.3%	-	-
Totals (rounded)	**125,700**		**97,400**	

China: 50.0% of refinery output

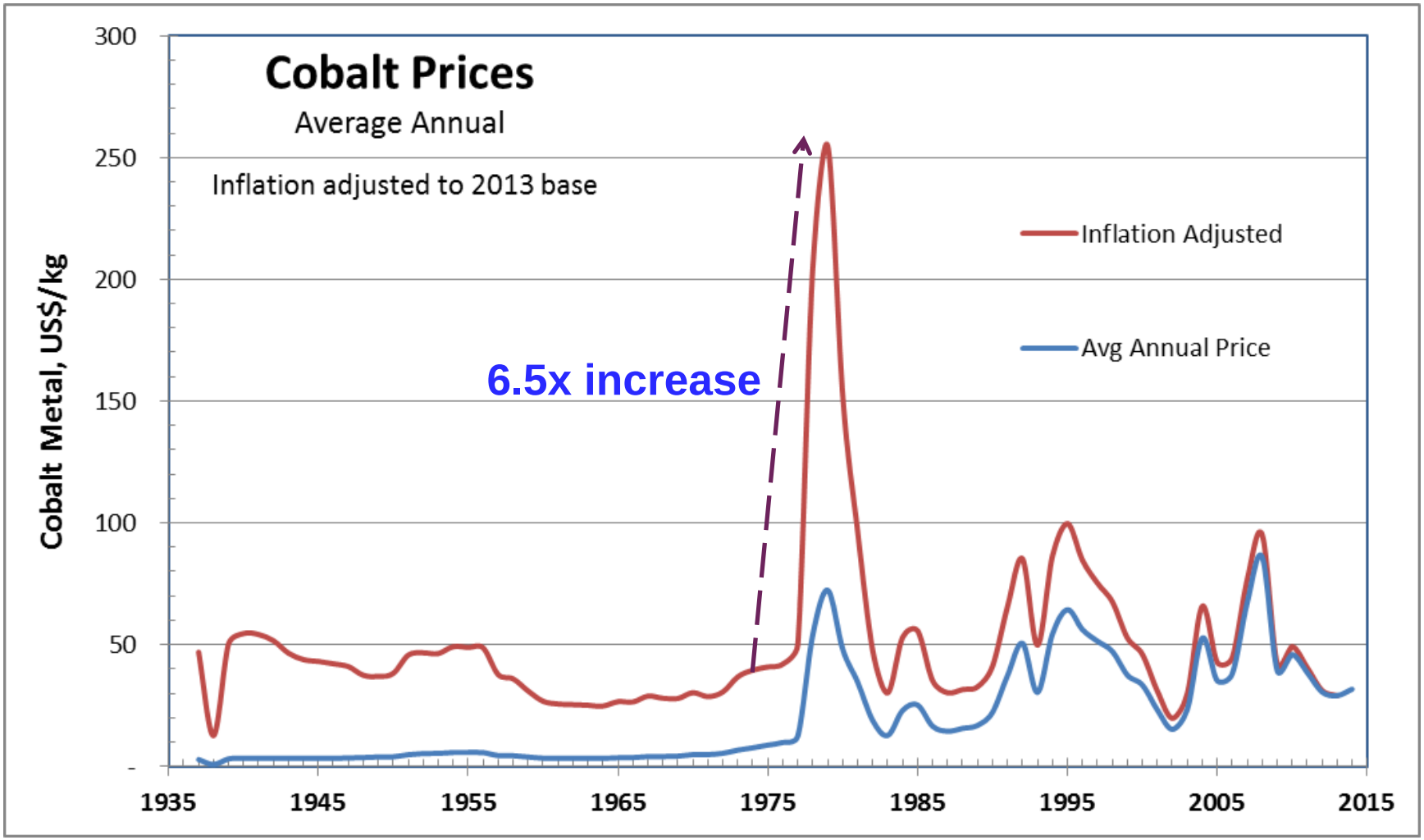
Congo: 50.1% of mine output

Data from USGS Mineral Commodity Summaries

Material Prices - Cobalt



Material Prices - Cobalt, Inflation Adjusted



Agenda

What's the big deal?

Materials

Supply

Consumption

Summary comments

Balancing Supply and Demand

Populations and Markets, by Region

Region	Population 2017	Yearly Change	Forecast 2030	World Share
Asia	**4,504,428,373**	0.94%	**5,039,637,399**	66.7%
Africa	**1,256,268,025**	2.55%	**1,699,457,399**	22.5%
Europe	**742,073,853**	0.08%	**749,229,191**	9.9%
Latin America and the Caribbean	**645,593,253**	1.02%	**729,201,164**	9.7%
North America	**361,207,811**	0.73%	**394,151,461**	5.2%
Oceania	**40,690,786**	1.43%	**48,249,541**	0.6%
World	**7,550,262,101**		**8,659,926,155**	

http://www.worldometers.info/world-population/population-by-country/

Where are Rare Earths Used?

Application	Rare Earths	Advantages
Batteries (NiMH)	La, Ce, Pr, Nd	High energy density energy storage vehicle electric batteries for EV and hybrid vehicles
Catalysts Automotive	Ce, La, Nd	Catalyzes complete combustion in exhaust gases to meet stricter emissions standards
Catalysts Hydrocarbon Cracking	La, Ce, Pr, Nd	Petroleum production: hydrocarbon cracking for normal grades and improved yields from heavy oils and tars
Catalysts Synthetic Rubber	Nd	Nd-catalized styrene-butadene for "easy rolling" tires
Ceramics	Y	Stabilization and strengthening
Fiber Optics	Er, Y, Tb, Eu	Reduction of signal loss during transmission
Glass Additives	Ce, La, Nd	"Decolorizes" glass, changes refractive indices, reduces transmission of selected frequencies (UV), prevents CRT "washout"
Magnetic disc data storage	Gd, Tb	Improved areal density of magnetic disc films
Magneto-strictive alloys	Tb, Dy	Greatly enhanced sensitivity with rare earths
Magnets	Ce, Nd, Pr, Dy, Tb, Sm, Gd, Y	Motors, generators, EV and hybrid vehicle drives, consumer electronic controls, hard disks, CD-ROM's, speakers, cordless power tools, MRI's, etc.
Metal Alloy Modifiers	Ce, Er	Aluminum structure refinement; high temperature creep resistance, better impact strength, improved iron ductility
Phosphors	Eu, Y, Tb, La, Ce	CFL's (compact fluorescent lamps), TV's and CRT monitors, LED's, LCD's, portable electronics
Plating & Galvanizing	Ce, La	Ce enhances plating, La improves zinc galvanizing
Polishing Powders	Ce, La	Oxides used as polishing agents for TV's, LCD's mirrors, telescope lenses, silicon chips
Refrigeration	Gd, La	Magneto caloric effect

Rare Earth Oxide Consumption by Application

Source:
The Rare Earths Industry in 2016, "Thriving but threatened by illegal production in China"; Prof. Dudley J. Kingsnorth

2015

Table 3: Estimated Global Rare Earths Demand in 2015E (t REO +/- 15%)

APPLICATION	CHINA	JAPAN	USA	OTHERS	TOTAL	SHARE %
Catalysts	13,000	4,000	9,000	2,000	28,000	19%
Glass	6,000	1,000	750	750	8,500	6%
Polishing	14,500	2,500	2,000	1,000	20,000	14%
Metal Alloys	19,500	3,500	1,500	1,000	25,500	17%
Magnets	35,500	7,000	1,500	1,000	45,000	31%
Phosphors	4,500	500	250	250	5,500	4%
Ceramics	3,000	500	1,500	500	5,500	4%
Other	4,000	1,000	2,500	500	8,000	5%
Total	**100,000**	**20,000**	**19,000**	**7,000**	**146,000**	100%
Share %	68%	14%	13%	5%	100%	

2020

Table 8: Estimated Global Rare Earths Demand in 2020E (t REO +/- 25%)

APPLICATION	CHINA	JAPAN	USA	OTHERS	TOTAL	SHARE %
Catalysts	16,000	5,000	9,500	2,500	33,000	17%
Glass	8,500	2,000	1,000	1,000	12,500	6%
Polishing	17,500	3,500	2,500	1,500	25,000	13%
Metal Alloys	28,000	5,000	3,000	2,000	38,000	19%
Magnets	50,000	9,000	4,000	2,000	65,000	33%
Phosphors	4,500	500	250	250	5,500	3%
Ceramics	4,000	1,500	750	750	7,000	4%
Other	7,500	2,000	3,000	1,500	14,000	7%
Total	**136,000**	**28,500**	**24,000**	**11,500**	**200,000**	100%
Market Share	68%	14%	12%	6%	100%	

Major and Developing Uses of Neo Magnets

- **HDD** (Global): mature data storage products
  - Magnet total weight consumed in 2015 is estimated = **7,600 tonnes** declining thereafter
- **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 = **4,000** rising to **18,000 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 could require ~275 tonnes of neo magnets
  - Global 2015 consumption = **8,500 tonnes** rising to **10,500 tpa** in 2020
- **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 68 million per year globally in 2020
  - Annual neo magnet usage in 2015 = **9,400** rising to **13,100 tpa** by 2020
- **Air Conditioning** (primarily southeast Asia and India)
  - In rapid growth phase
  - Use permanent magnet reluctance type motors to achieve ~20% efficiency gains
  - Neo usage in 2014= **>4,000 tonnes**

- **Acoustic transducers and miniature applications**
  - More than 6.8 billion cell phones currently connected use speakers and vibrator motors
  - Speakers in transportation – more than 280 million speakers per year
  - Speakers, ear buds, headphones Neo usage in 2015 = **>4,500 tpa**

2015: 6.8 billion cell phones were connected

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.	Chevy Volt
BEV	**Battery Electric Vehicle BEV)** Powered exclusively by electricity from its on-board battery charged by plugging into the grid.	Leaf; Tesla Model S; Chevy Bolt
FCEV	**Fuel Cell (Electric) Vehicle (FCEV)** Converts the chemical energy from a fuel, such as hydrogen, into electricity.	Honda FCX Clarity; Hyundai Tuscon

Sales in the USA

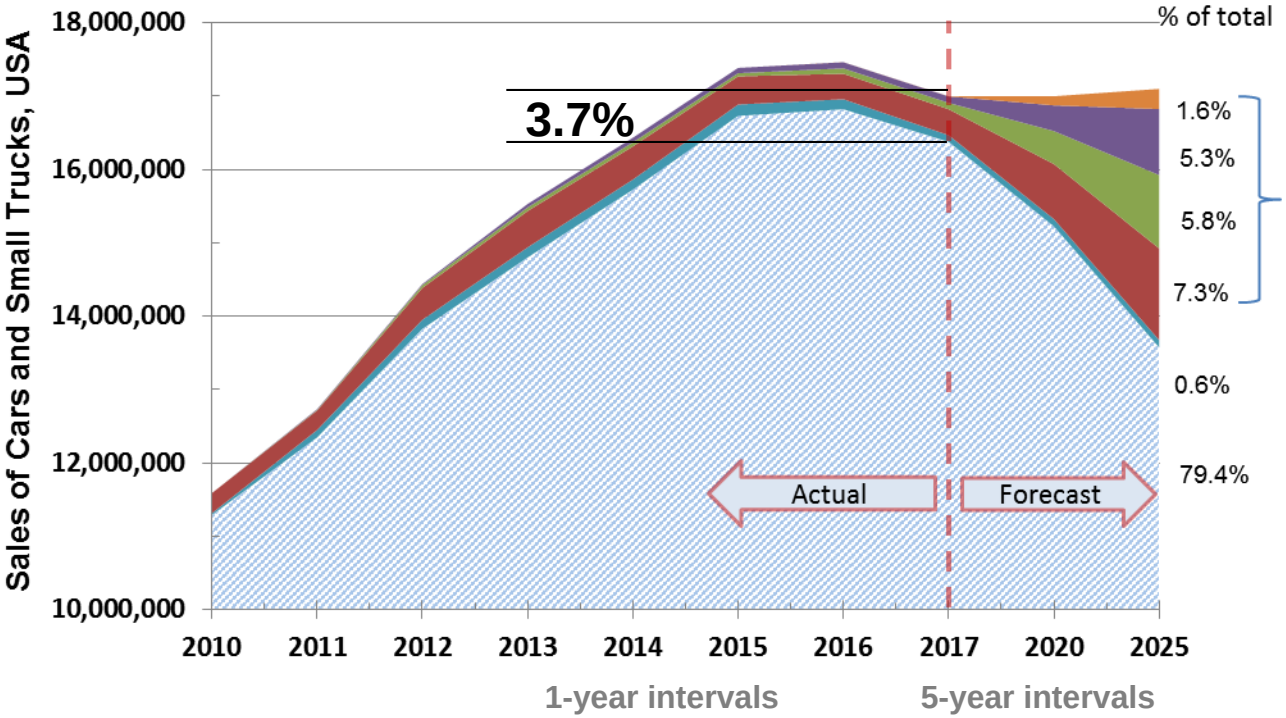
2017 Data annual sales based on sales through July

Manufacturer	Hybrid	PHEV	BEV	CNG	FCEV	Diesel	Total	Total%
Accura	1,812	-	-	-	-	-	1,812	0.29%
Audi	-	4,008	-	-	-	139	4,147	0.67%
BMW	-	10,740	6,159	-	-	4,330	21,229	3.41%
GM	4,807	21,483	16,418	-	-	13,179	55,887	8.97%
Fiat - Chrysler	-	2,558	3,638	-	-	1,515	7,711	1.24%
Ford	73,269	18,830	2,067	-	-	42,072	136,238	21.88%
Honda	23,398	-	58	-	645	-	24,101	3.87%
Hyundai	22,358	2,700	343	-	36	-	25,437	4.08%
Infiniti	1,797	-	-	-	-	-	1,797	0.29%
Jaguar	-	-	-	-	-	5,230	5,230	0.84%
Jeep	-	-	-	-	-	1,243	1,243	0.20%
Kia	29,434	891	1,682	-	-	-	32,007	5.14%
Land Rover	-	-	-	-	-	6,046	6,046	0.97%
Lexus	22,990	-	-	-	-	-	22,990	3.69%
Mercedes	5	2,109	682	-	-	139	2,935	0.47%
Mini Cooper	-	146	-	-	-	-	146	0.02%
Mitsubishi	-	-	10	-	-	-	10	0.00%
Nissan	667	-	14,625	-	-	-	15,292	2.46%
Porsche	-	1,966	-	-	-	-	1,966	0.32%
Smart	-	-	98	-	-	-	98	0.02%
Subaru	69	-	-	-	-	-	69	0.01%
Tesla	-	-	39,651	-	-	-	39,651	6.37%
Toyota	173,841	19,435	-	-	1,354	-	194,630	31.25%
Volkswagen	106	-	3,763	-	-	16,574	20,443	3.28%
Volvo	-	1,682	-	-	-	-	1,682	0.27%
TOTAL	**354,553**	**86,548**	**89,194**	**0**	**2,035**	**90,467**	**622,797**	**100.00%**
% of alt. fuel	**56.93%**	**13.90%**	**14.32%**	**0.00%**	**0.33%**	**14.53%**	**100.00%**	
2017 → % of total Mkt	**2.11%**	**0.51%**	**0.53%**	**0.00%**	**0.01%**	**0.54%**	**3.70%**	
2016 → % of total Mkt	**1.99%**	**0.42%**	**0.48%**	**0.00%**	**0.01%**	**0.79%**	**3.68%**	

Data source: www.hybridcars.com

Steve's Forecast - USA Market, Sep 2017


Photo Courtesy of Drayson Racing



These technologies use electric traction drive motors

- FCEV
- BEV
- EREV, PHEV
- HEV
- Diesel
- Conventional Gas

Magnet Requirements for EVs

Year	Total Market, millions		% EV (inc. hybrid)		No. EV (inc. hybrid)		Magnets Req'd, tons	
	USA	Global	USA	Global	USA	Global	USA	Global
2015	17.4	88.0	2.9%	3.5%	0.5	3.1	631	3,850
2020	17.2	103.0	9.7%	14.0%	1.7	14.4	2,086	18,025
2025	17.1	113.0	20.1%	35.0%	3.4	39.6	4,296	49,438
2030	17.0	119.0	30.0%	50.0%	5.1	59.5	6,375	74,375
2040	17.0	125.0	50.0%	80.0%	8.5	100.0	10,625	125,000

Vehicle quantities shown in millions

Average kg NdFeB magnets per traction drive system = 1.25

Extreme case in 2040:

All cars are EV = 125,000,000 vehicles

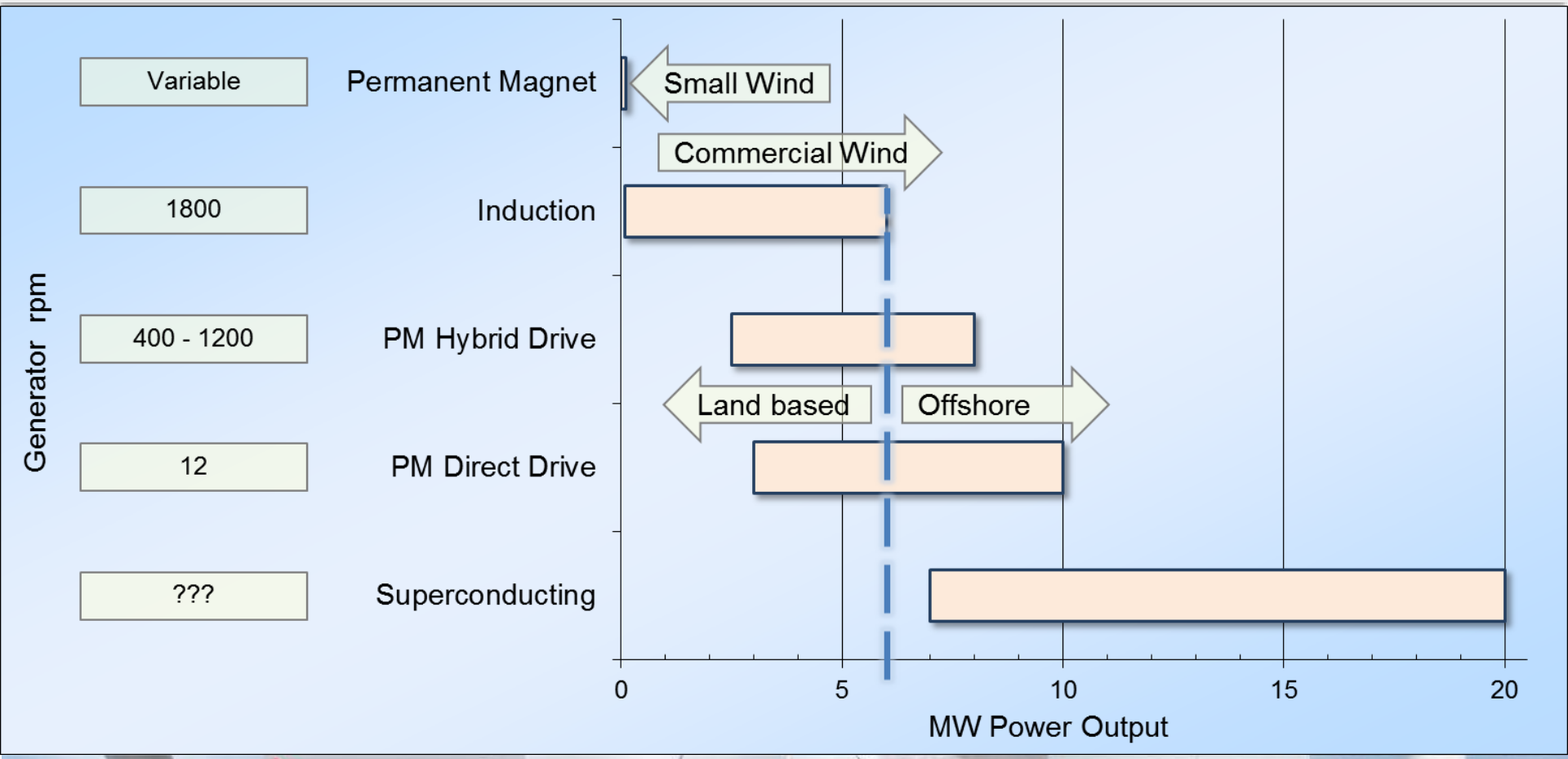
1.25 kg per vehicle traction drive = 156,250,000 kg = 156,250 tons of magnets

156,250 tons of NdFeB magnets requires 416,000 tons of REO

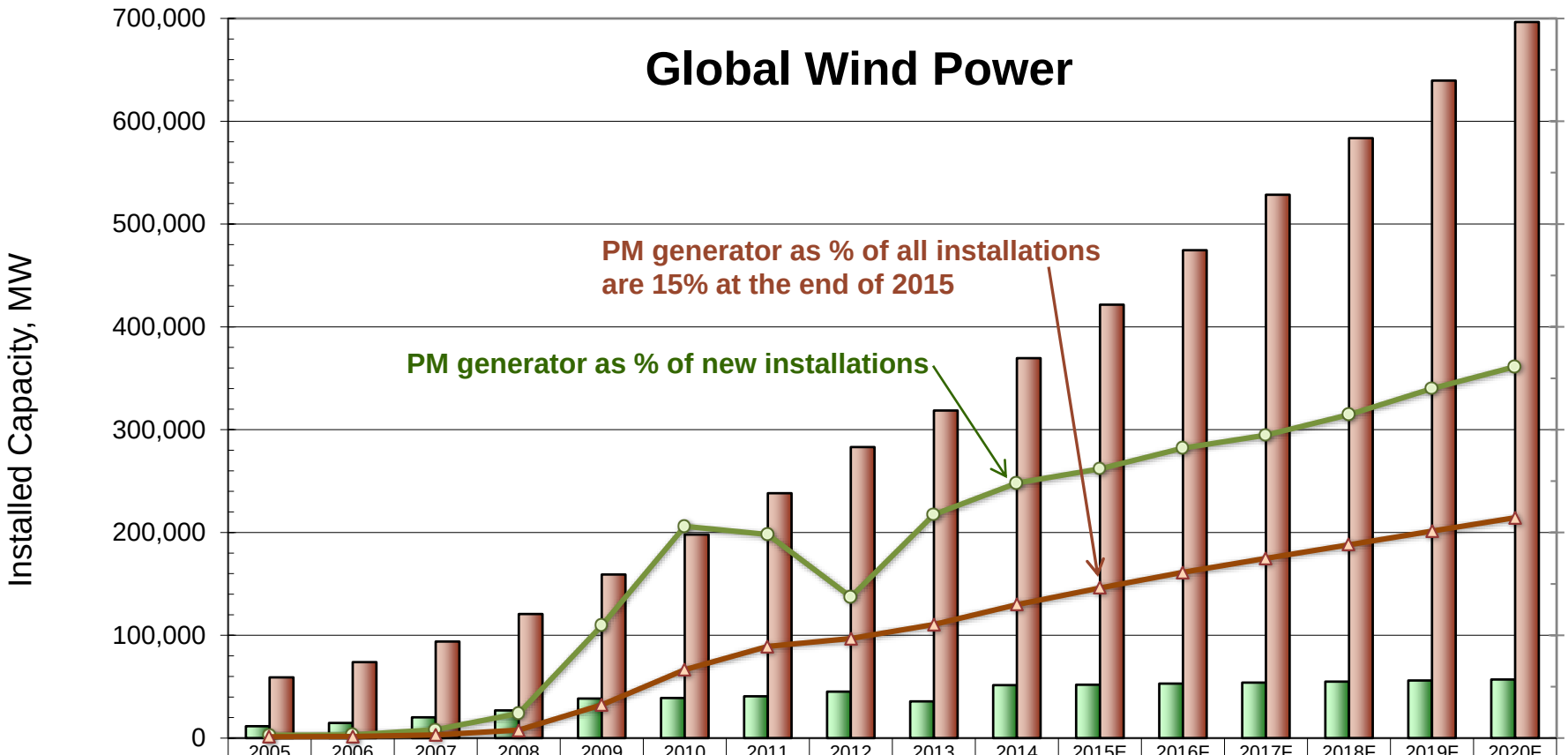
REO production * 37.8% = NdFeB magnet output
NdFeB magnets / 37.8% = REO required

Data are estimates, not forecasts

Wind Power - Types and Locations



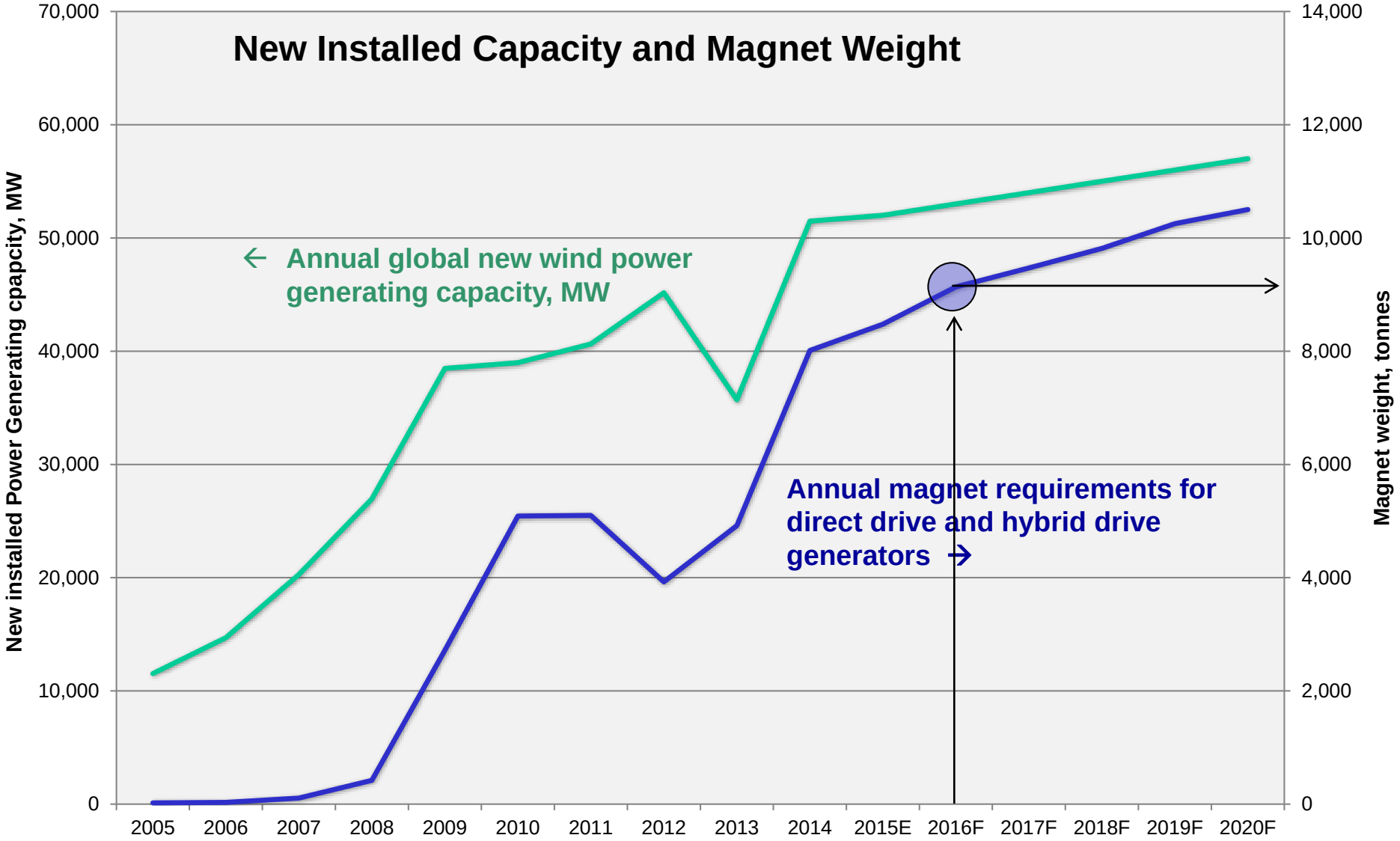
Global Wind Power Generation: Total and PM



	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

Direct and Hybrid Drive Generator: Magnet Requirements



Agenda

What's the big deal?

Materials

Supply

Consumption

Summary comments

Balancing Supply and Demand

Summary

- Soft and permanent magnets are essential to modern life
- The strongest permanent magnets incorporate rare earth elements
- Rare earth permanent magnets are increasingly important for electrical efficiency
- Supply and demand is too easily out of synch and requires long periods to bring back into balance
- Without additional sources of REEs coming on-stream in 2-5 years, it is likely there will be shortages and price spikes such as in 2011