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Rare Earths - a Bottleneck for future Wind Turbine Technologies?

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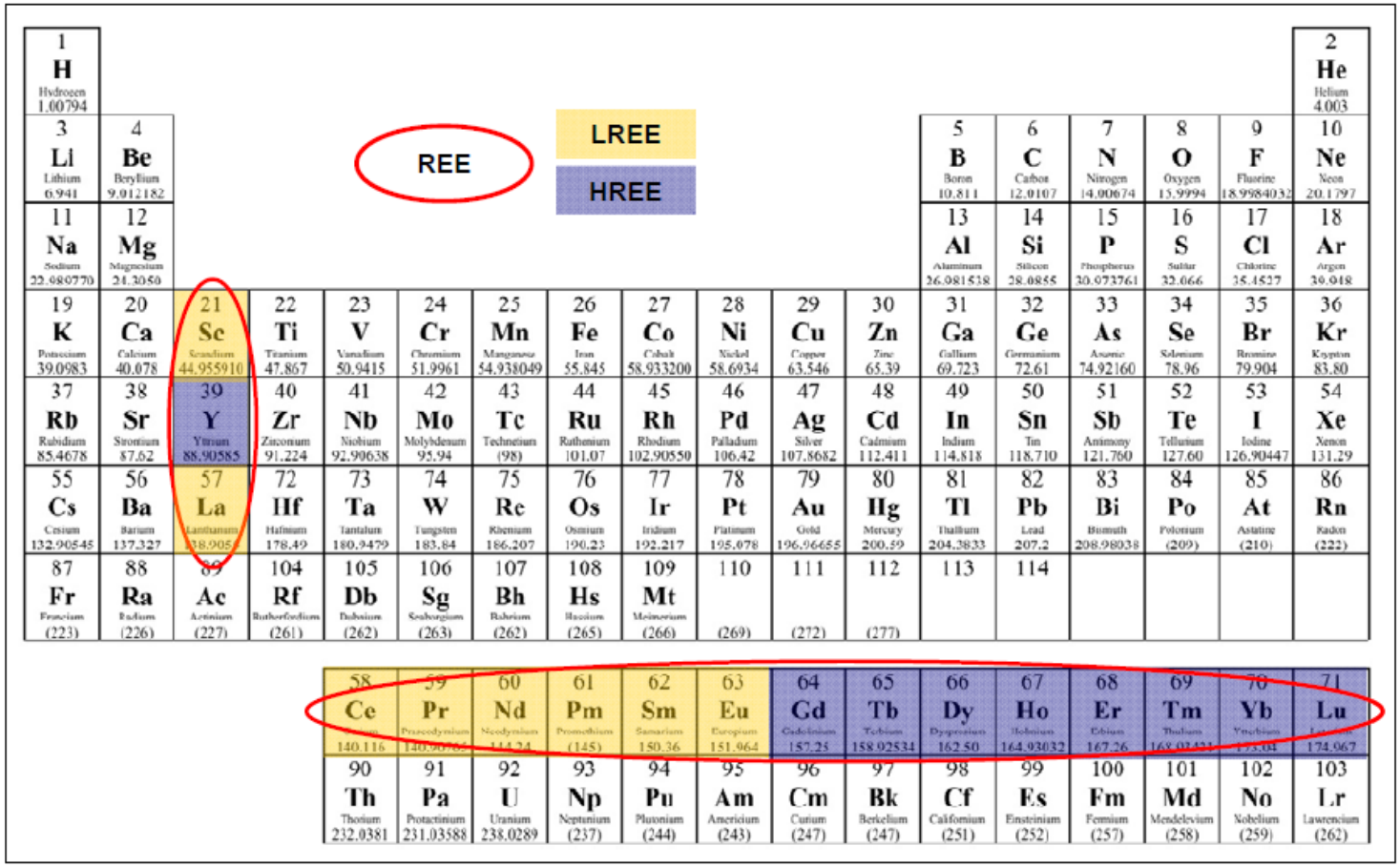
WIND TURBINE
SUPPLY CHAIN & LOGISTICS

Berlin, 29th August 2011

Rare Earth Elements



LREE: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), and scandium (Sc)

HREE: yttrium (Y), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) as HREE

Global production and reserves

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- **Global production in 2010: 134 000 t**
- **Reserves according to USGS: 110 000 000 t (factor 820)**

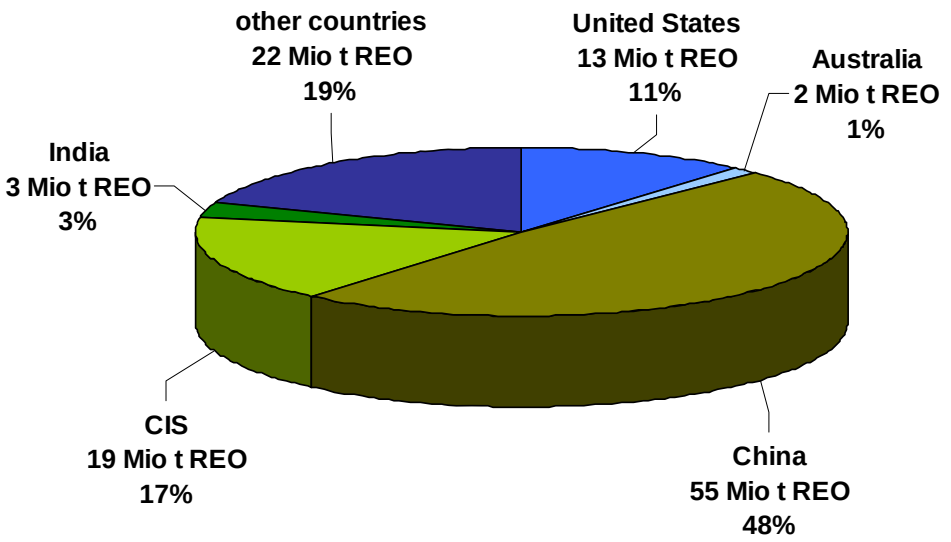
  (reserve which can be economically extracted)

Word Mine production in 2010
(USGS 2011)

Country	t REO	Share
China	130 000	97,3%
Brazil	550	0,4%
India	2 700	2,0%
Malaysia	350	0,3%
World Total*	**133 600**	**100,0%**

*** without 20 000 t REO illegal mining**

Rare earth reserves by countries (USGS 2011)



Reserves of HREE and LREE

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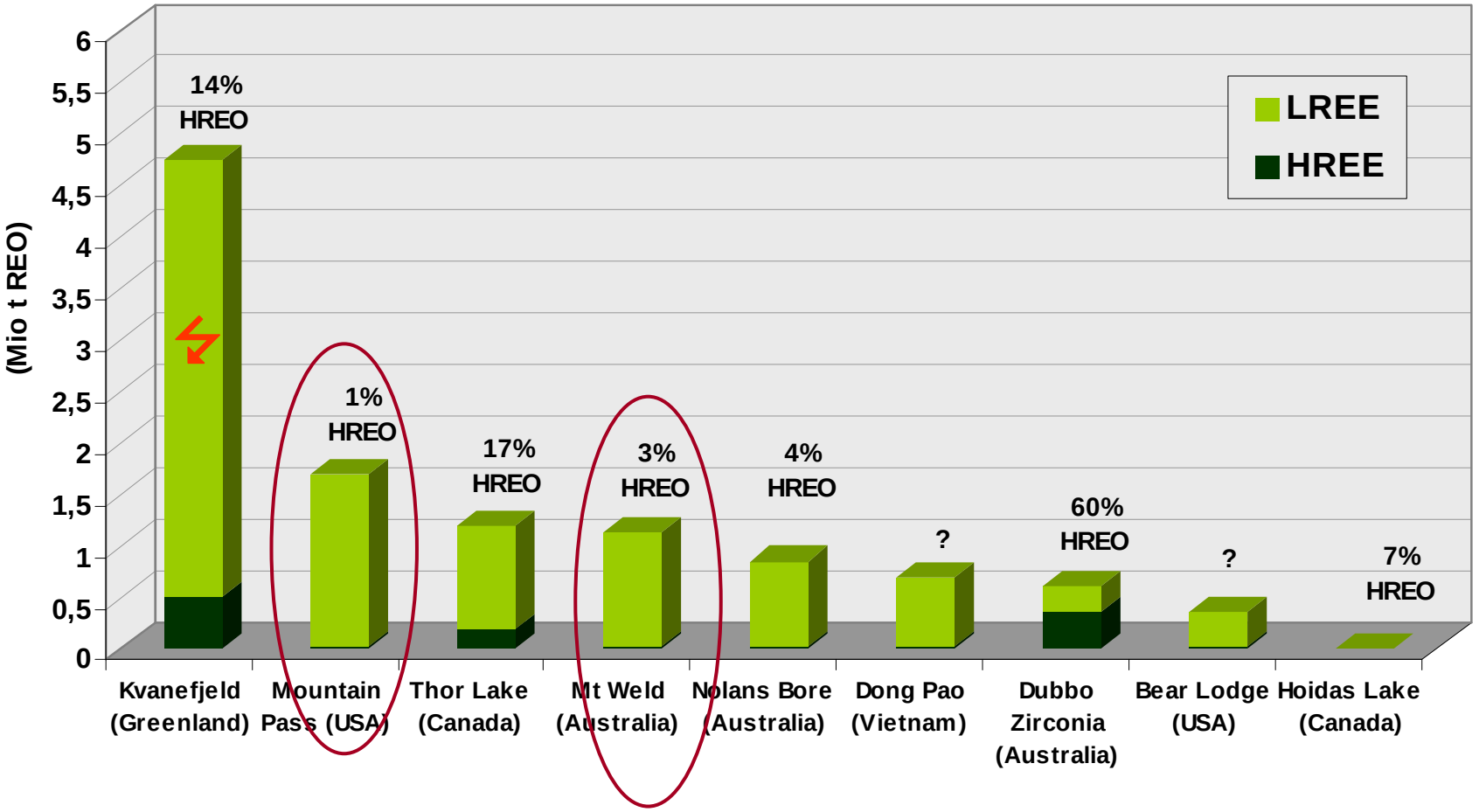
(according to the JORC-code)



Risks of REE-Mining without Environmental Protection Systems

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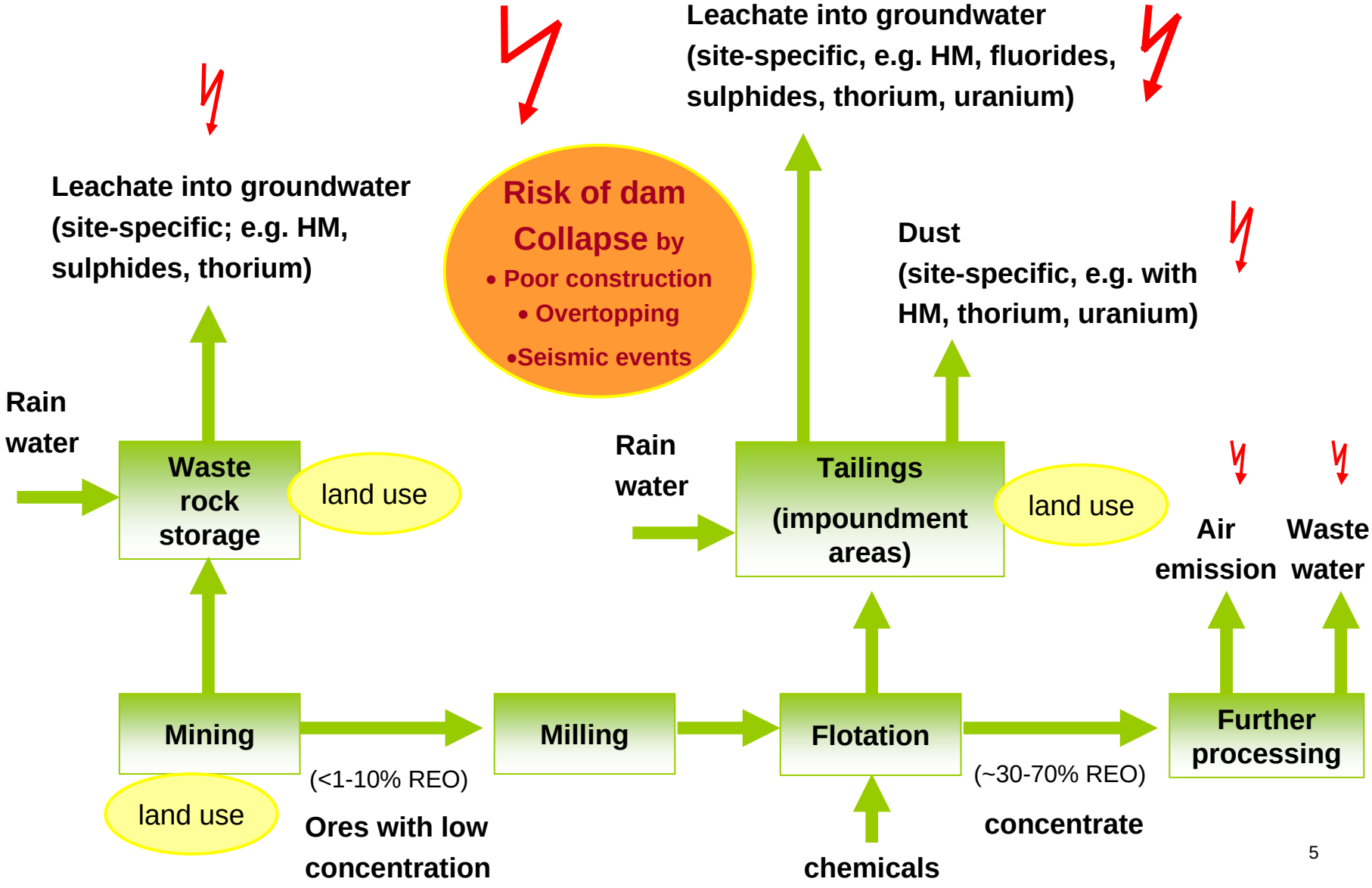

Mining in China

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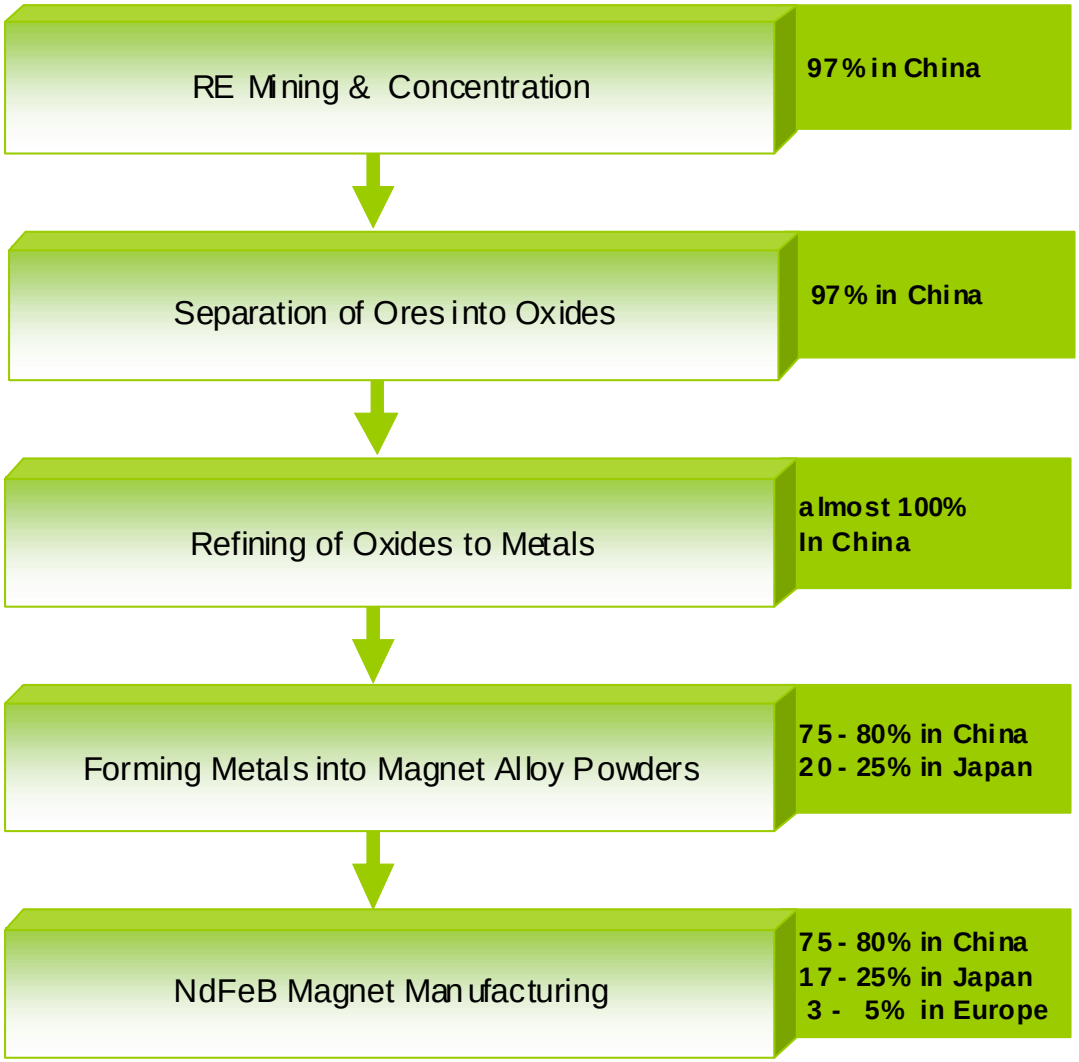
- **Batou Obo Mine – the largest Rare Earth Mine**
  - Main product: iron; side product: LREE
  - environmental burden: radioactive dusts, lung cancer, groundwater contamination
- **Ion adsorption deposits in Southern China**
  - High contents of HREE
  - In-situ leaching, hydro-geologically not controllable

Numerous small illegal mines

  - Estimation of around of 20 000 t REO which were illegally mined and exported
  - Probably, most of these mines have no environmental technologies at all.
- **Plans of the Chinese government**
  - Closing of small illegal mines. Concentration and consolidation of REE economy
  - Installation of environmental technologies for mining and processing

Global Nd magnet production



World NdFeB-magnet (Nd magnet) production: at least 60 000 t magnet material in 2010

Development of Prices I
- “cheap” rare earth elements

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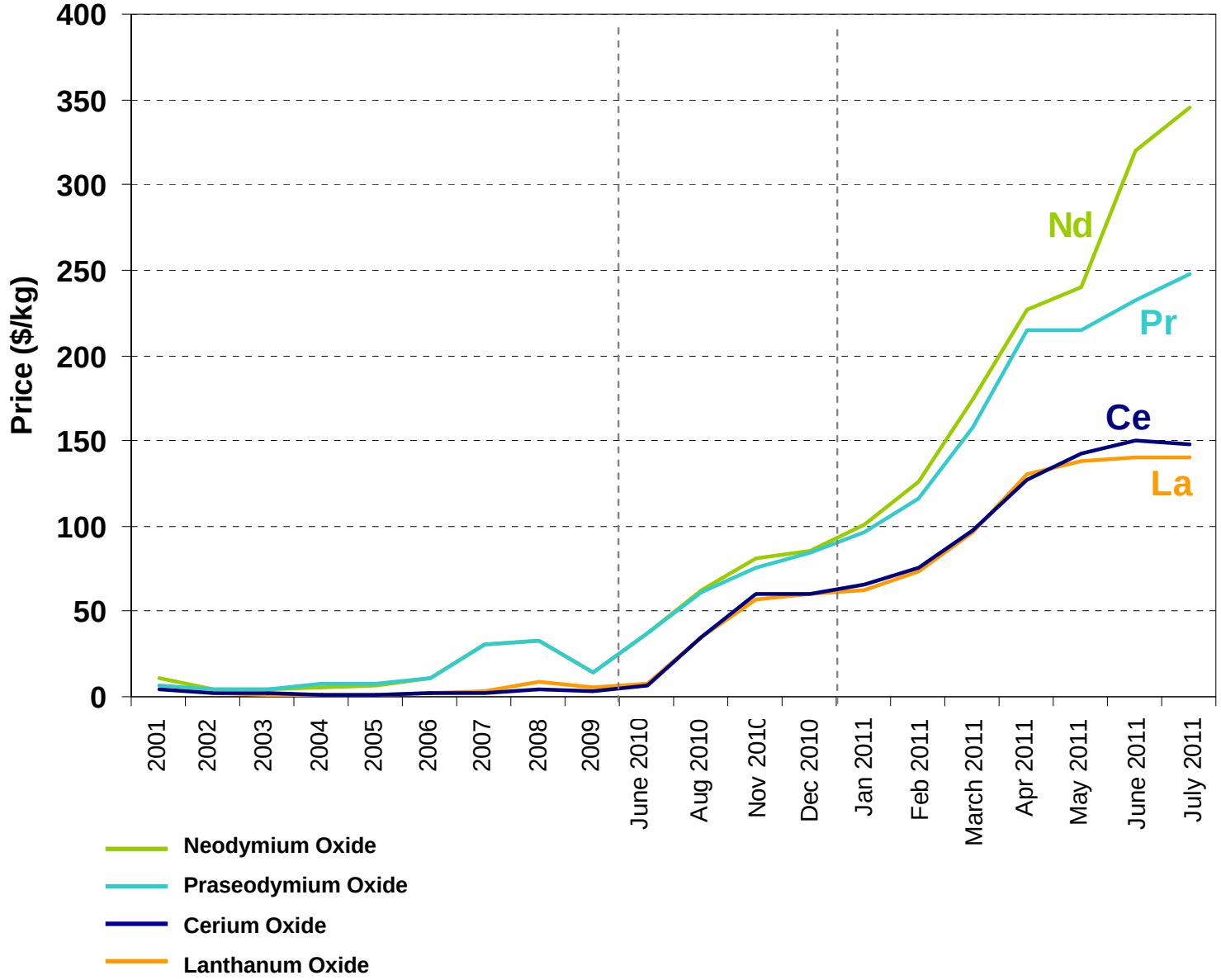

Development of Prices II
- “expensive” rare earth elements

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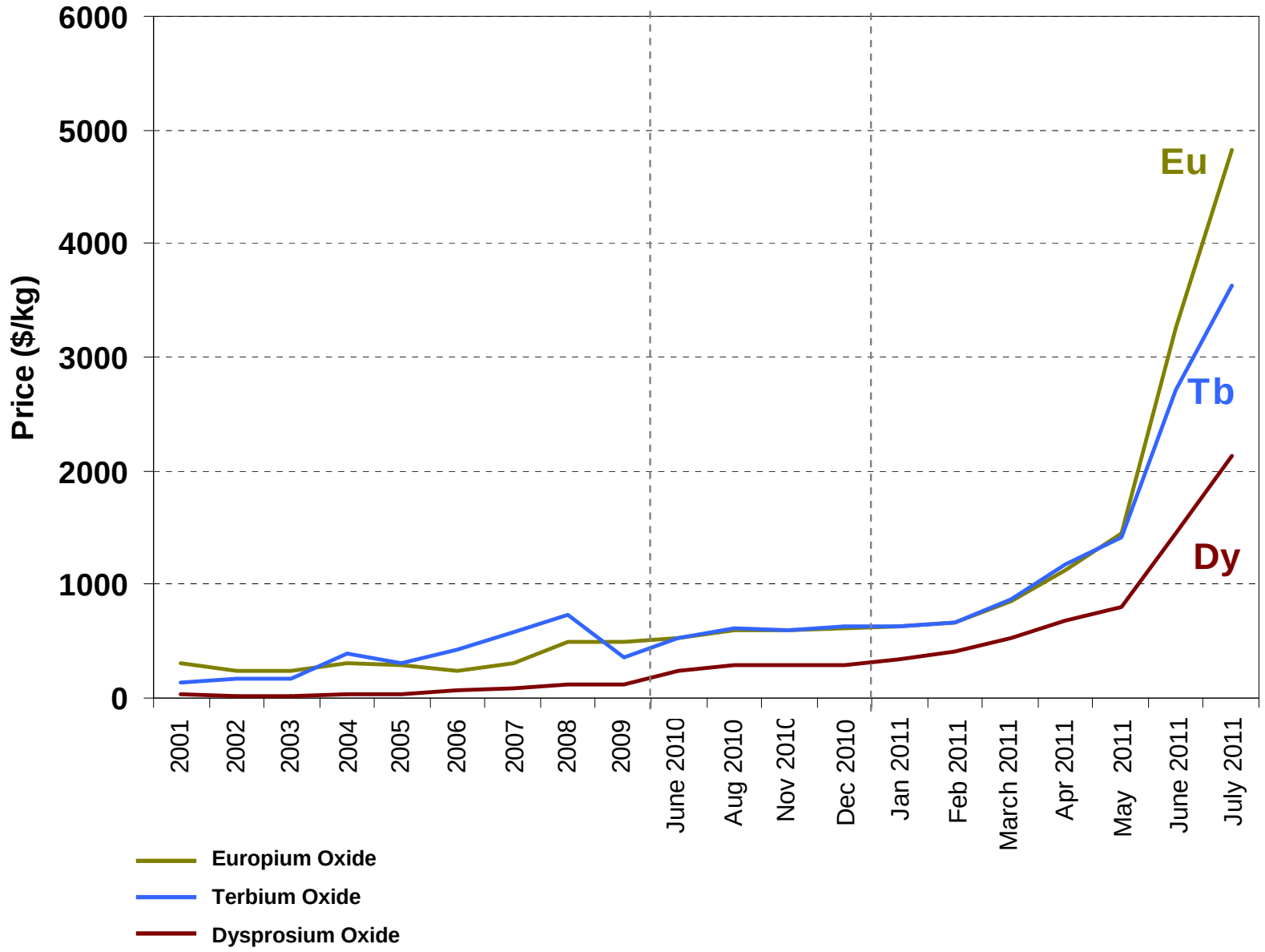

Demand-Supply Balance 2014

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Company	IMCOA/Kingsnorth	LYNAS
Source	Kingsnorth 2010, figures in ( ) from IMCOA, cited in Oakdene Hollins 2010	Lynas 2010a
	t REO	t REO
Lanthanum	-3 000 bis + 7 000	-13.700
Cerium	+15 000 bis + 25 000	7 500
Terbium	-100 bis + 100	-290
Dysprosium	-500 bis + 100	-1.100
Yttrium	-5 000 bis +3 000	-1.200
Praseodymium	(2 100)	-7 000
Neodymium	(-1 900)	-14 200
Samarium	(2 610)	2 300
Europium	(10)	-110
Gadolinium	(700)	900
Erbium	(60)	n.d.
Ho-Tm-Yb-Lu	(1 100)	n.d.

Applications of Rare Earths

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- Energy efficient lighting
- LED
- LCD
- Plasma display
- Laser

Ce La Eu Tb Y Gd

Phosphors, Luminescence

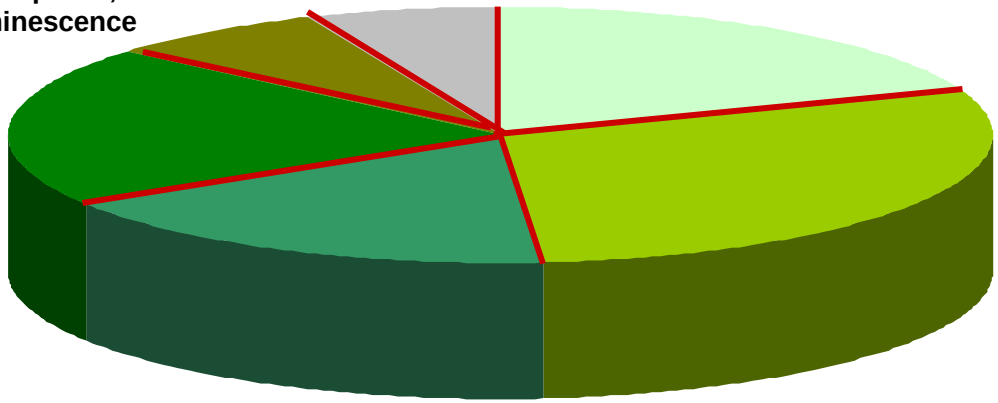
- Water treatment
- Pigments
- Fertiliser
- Nuclear technology
- Defense

Others

- Automotive catalysts
- Catalysts in refining and chemical processing
- Diesel additive

Ce La Pr Nd Y

Catalysts



REE with relevance for Nd-magnets

Magnets

Nd Pr Sm La Tb Dy

- Motors and generators
  - Wind turbines
  - Electric vehicles
  - Hybrid vehicles
- Hard Discs
- MRI
- Speakers
- Magnetic cooling

Metal alloys / batteries

La Ce Pr Nd Sm Sc

- Alloys for steel and iron casting
- Super alloys
- Flint ignition fevices
- NiMH-battery
- Fuel cell
- H_2-storage
- Light weight construction

Glass, Polishing, Ceramics

Ce La Y Pr Nd

- Polishing compounds
- Colouring and decolouring agent in glass
- Stabilizer in ceramics
- Ceramic capacitors
- UV adsorption

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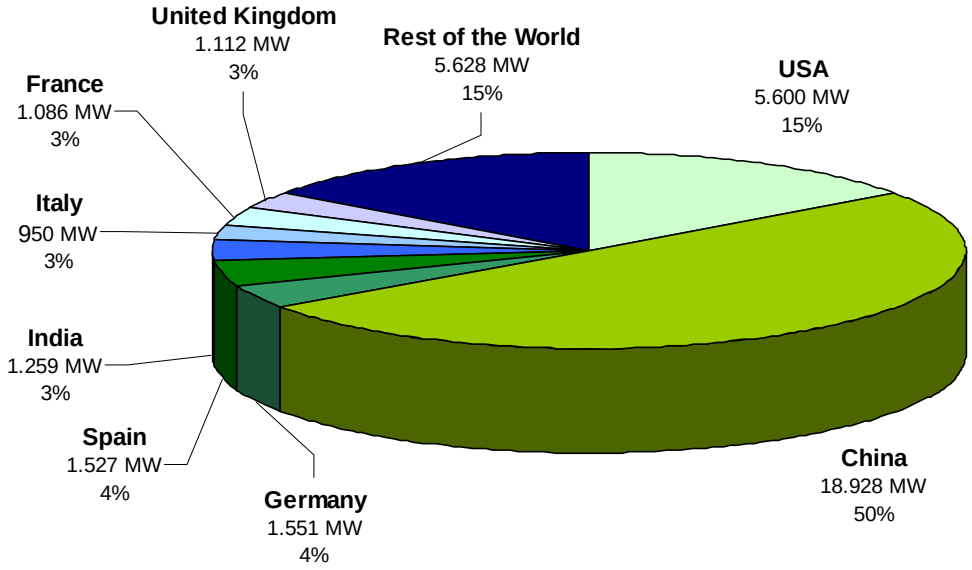
Wind turbines

- **Neodymium magnets in generators (about 9% of new installations in 2010)**

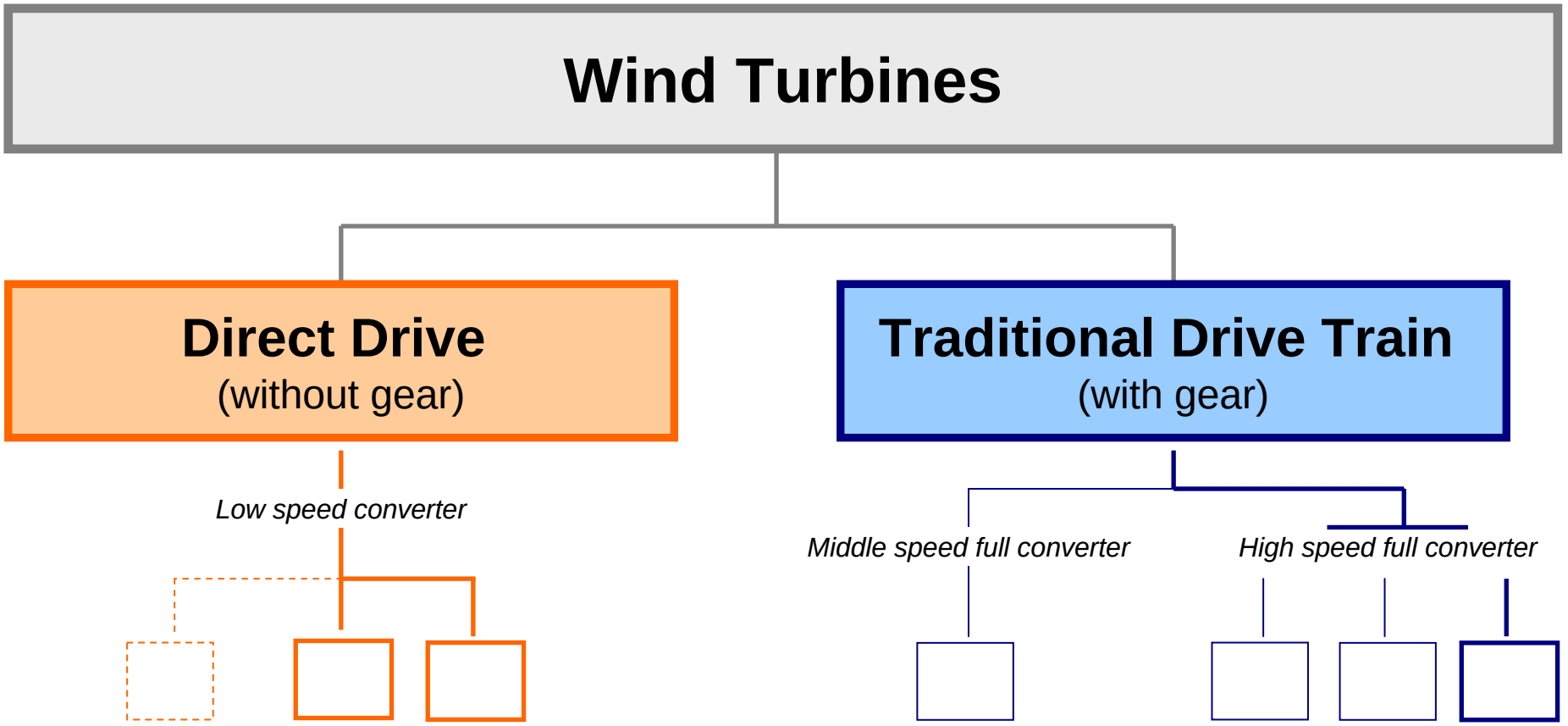
Global new installations 2010 (37 642 MW, +24%):



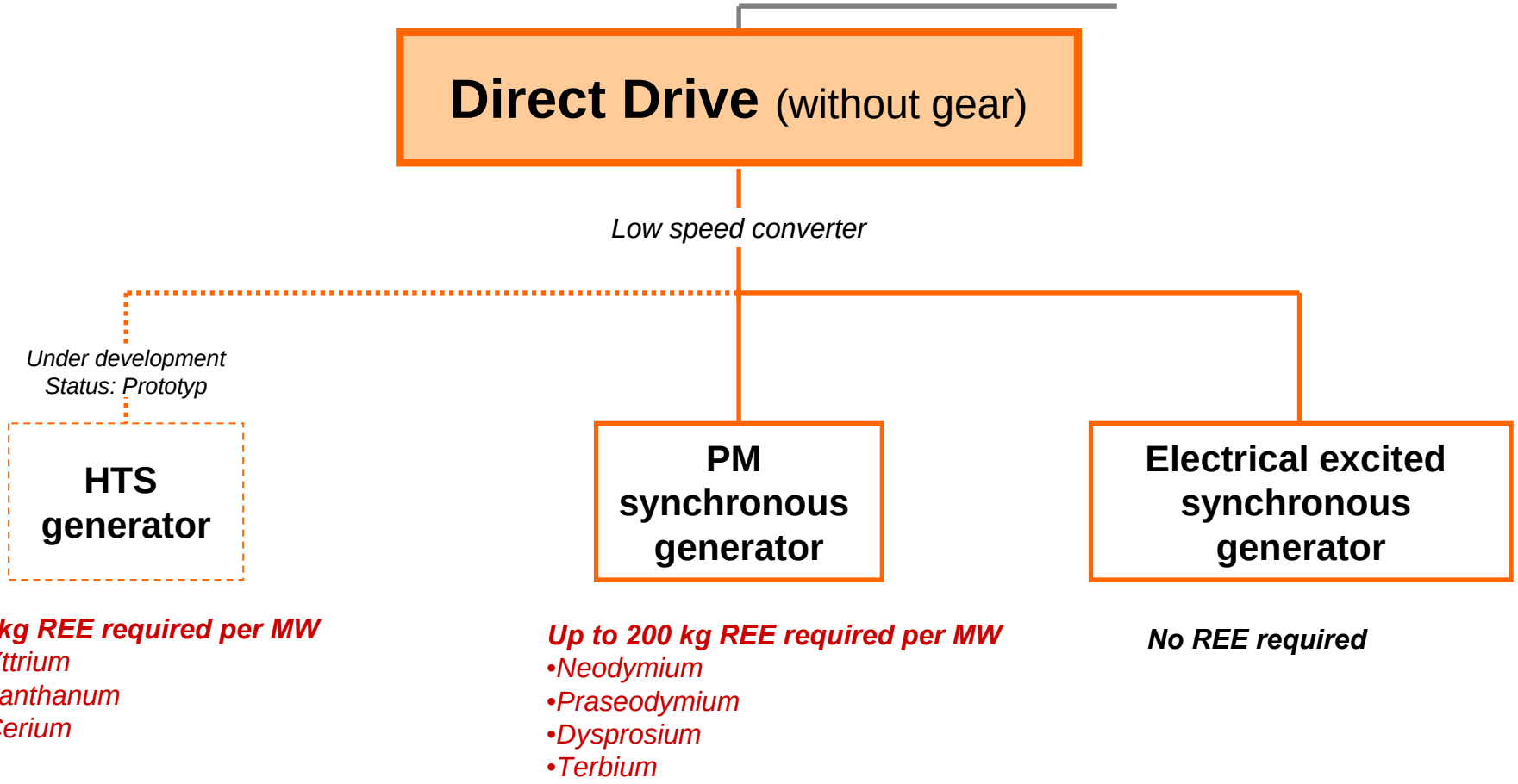
Source: World Wind Energy Report 2010

- **Technologies without magnets (mainly gear drive technology) show still the largest market share, but here R & D on higher reliability (Offshore) is required**

Wind turbines



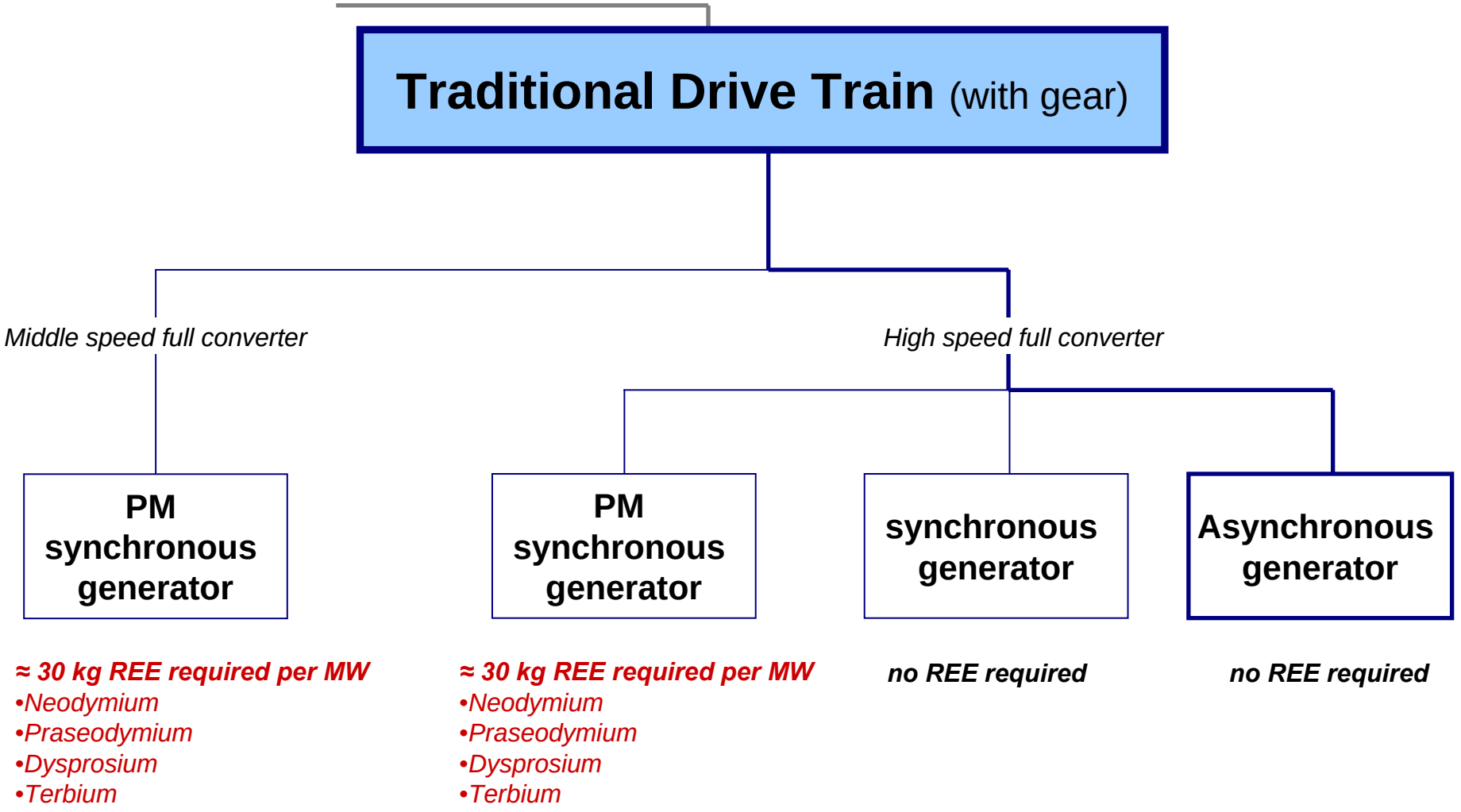
Wind turbines



PM = Permanent magnet

HTS = High temperature superconductor

Wind turbines



PM = Permanent magnet

Wind turbines

- **Weight of magnet material per MW: 500-600kg* (DD)**

  (Source: expert assessment of the project "OPTUM – Optimising the environmental benefit of electric vehicles – An integrated consideration of vehicle use and the electricity sector in Germany")

- **Weight of REE per MW: 160-200kg* (DD)**

  (Source: expert assessment of the project "OPTUM – Optimising the environmental benefit of electric vehicles – An integrated consideration of vehicle use and the electricity sector in Germany")

- **REE in permanent magnets: Nd, Pr, Dy, Tb**

- **Market share DD technology: about 18%**

- **Market share DD PMSG technology: about 9%**

- **Notice: PM demand for fast running PMSG is about 100kg per MW**

* conservative estimation;
see Oakdene Hollins 2010: 700kg magnet material per MW

DD = Direct Drive

PMSG = Permanent magnet synchronous generator

Announced advantages of Direct Drive technology

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- No gearbox
- Higher efficiency
- Higher reliability
- Reduced maintenance
- Offshore suitable (lighter) / large wind power plants possible

Recent developments

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- Wind energy (installed capacity) continues to grow strongly, especially in China
- Hugh Chinese players develop and boost the PM-technology forward: large growth rates
- Also renowned European and US companies offer large new models of wind power plants based on Nd-magnet-technology
- Development towards larger wind power plants (capacity); Onshore / Offshore

Scenarios for REE demand for Wind power plants

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	Conservative scenario		Ambitious scenario
2010	9%	Market share DD PMG 2010 of new installations	9%
	4 GW/a	GW DD PMG 2010 of new installations	4 GW/a
2015	15%	Market share DD PMG 2015 of new installations	25%
	12 GW/a	GW DD PMG 2015 of new installations	20 GW/a
2020	15%	Market share DD PMG 2020 of new installations	40%
	45 GW/a	GW DD PMG 2020 of new installations	121 GW/a

DD PMG: Direct Drive with permanent magnet generator

Source: own estimation Öko-Institut; in 2020: 302 GW new installation, 1 470 GW accumulated installed capacity

REE demand according the scenarios

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	Conservative scenario		Ambitious scenario
2010	**638 t**	**Sum REE to 2010***	**638 t**
	402 t	thereof Neodymium	402 t
	96 t	thereof Dysprosium	96 t
2015	**2 196 t**	**Sum REE to 2015***	**3 661 t**
	1 382 t	thereof Neodymium	2 304 t
	329 t	thereof Dysprosium	549 t
2020	**8 155 t**	**Sum REE to 2020***	**21 747 t**
	5 132 t	thereof Neodymium	13 687 t
	1 222 t	thereof Dysprosium	3 259 t

Even in the conservative scenario the REE demand rises by 1 278% until 2020 and Dy demand in 2020 is 62% of the global production 2010.

Production of Nd_2O_3 in 2010: *25 000 t (Source: own estimation Öko-Institut)*

Production of Dy_2O_3 in 2010: *1 980 t (Source: BGR 2011, Commodity Top News Nr 36)*

* The rest is mainly Praseodymium and to a less degree Terbium

Wind turbine for the future?

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- New HTS-technology (High Temperature Superconductor) under research and development
- Higher capacity feasible (up to 20 MW)
- Light weight, reliable, compact wind turbine nacelle design
- Prototype phase by Seatitan powered by AMSC
- 2 kg of rare earths per MW are required (Yttrium, Lanthanum, Cerium) *(Source: BINE Informationsdienst)*

Issues of discussion

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- What will be the growth rate for PM-Technology? (market share, total volume)
- What would be the “break even point” in price terms of REE: Which price level would be the “killer” for the PM wind turbines?
- Could the HTS technology be competitive in the future?

Recycling

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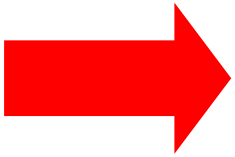
- So far unknown: relatively new
- A future recycling of the large magnets in the sector wind energy seems to be very attractive: development of a recycling infrastructure (dismantling, refining, etc) is necessary.
- End of life recycling rates currently < 1% for REE
- Now research efforts in Nd magnet recycling from other application sectors (consumer electronic, e-vehicles) are started.



Future recycling of Nd-magnets from wind turbines will be a decisive contribution for a positive balance of the entire life cycle

Background information

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- **The expected supply shortages and the current high prices provide for the first time the chance to initiate REE-recycling in Europe.**
- **In the past prices were too low for an economical recycling.**
- **Environmental impacts of the mining played no role in public discussions.**
- **The currently high publicity of this topic revealed the environmental damage caused by Chinese mines.**
- **Build-up of a recycling scheme should start now: it takes a minimum of 3 – 5 years for implementation**

Advantages of Recycling

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- Secondary REE potential arise.
- Lower dependency on foreign material supply.
- Building up of know-how on rare earth processing.
- No radioactive wastes in processing.
- Environmental benefits concerning air emissions. groundwater protection, acidification, eutrophication and climate protection.

Developing a recycling scheme

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Basic research

Identification of stakeholders

European Competence Network on Rare Earth

European Material Flow Analysis

Identification of initial products to be recycled

Development of Pretreatment & Collection Schemes

Installation of Pilot Plants for Recycling / R&D

Promotion of re-use

Financial support

Improvement of legal framework in EU

Implementation of large scale collection and recycling for initial products

Recent news about rare earths

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New publication by the German BGR (Federal Institute for Geosciences and Natural Resources) about heavy rare earth elements:

- **Confirmed the critical situation for many of the heavy rare earth elements**
- **Terbium-Oxide demand in 2010 exceeds supply in 2010 and production forecast 2015**
- **Forecast 2015: production of Yttrium-, Samarium-, Europium-, Terbium-, Dysprosium-Oxide will decrease in China compared to 2010**
- **Additional mines (Dubbo, Pitinga, Others) with small contribution**
- **Estimated 10% recycling contribution in 2015 as optimistic assumption**

→ **ambitious goal for a quite short period**

→ **For the wind industry (and for other sectors) Dysprosium is the most critical REE and the biggest challenge!**

Conclusions

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- **The supply situation for REE remains critical!**
- **Concerning Nd magnets especially Dysprosium supply will be the most important challenge in the future!**
- **Increasing REE demand from other sectors (e-mobility etc.) has to be taken into account!**
- **HTS technology could be an option to reduce REE demand; but today a statement is not possible!**
- **Recycling of Nd magnets will be an important contribution for overall REE supply in the future!**

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Thank you for your attention!

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