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Resource efficiency and resource-policy aspects of the electro-mobility system - Results

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www.oeko.de

Selected results

- **This presentation outlines some of the results, together with conclusions and recommendations for action.**

- **The detailed results, including the underlying data, are contained in the comprehensive report.**

- **The report is available at** www.resourcefever.org and www.oeko.de

Agenda

- Introduction (background to the study)
- Prioritising the elements
- Market scenarios
- Components of e-mobility and their resource needs
- Outcomes of the scenarios
- Environmental aspects
- Recycling
- Growth of overall demand / other sectors in terms of critical metals
- Conclusions and recommendations for action

OPTUM resources

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Title:

- **Resource efficiency and resource-policy aspects of the electro-mobility system***

Objectives:

- **Analysis of the resource aspects of the electro-mobility system (excluding batteries)**, taking account of recycling options and outlook**

- **Identification of important new technological developments that impact on resource requirements**

- **Early identification of possible bottlenecks or critical points in terms of resource policy, and development of corresponding strategies**

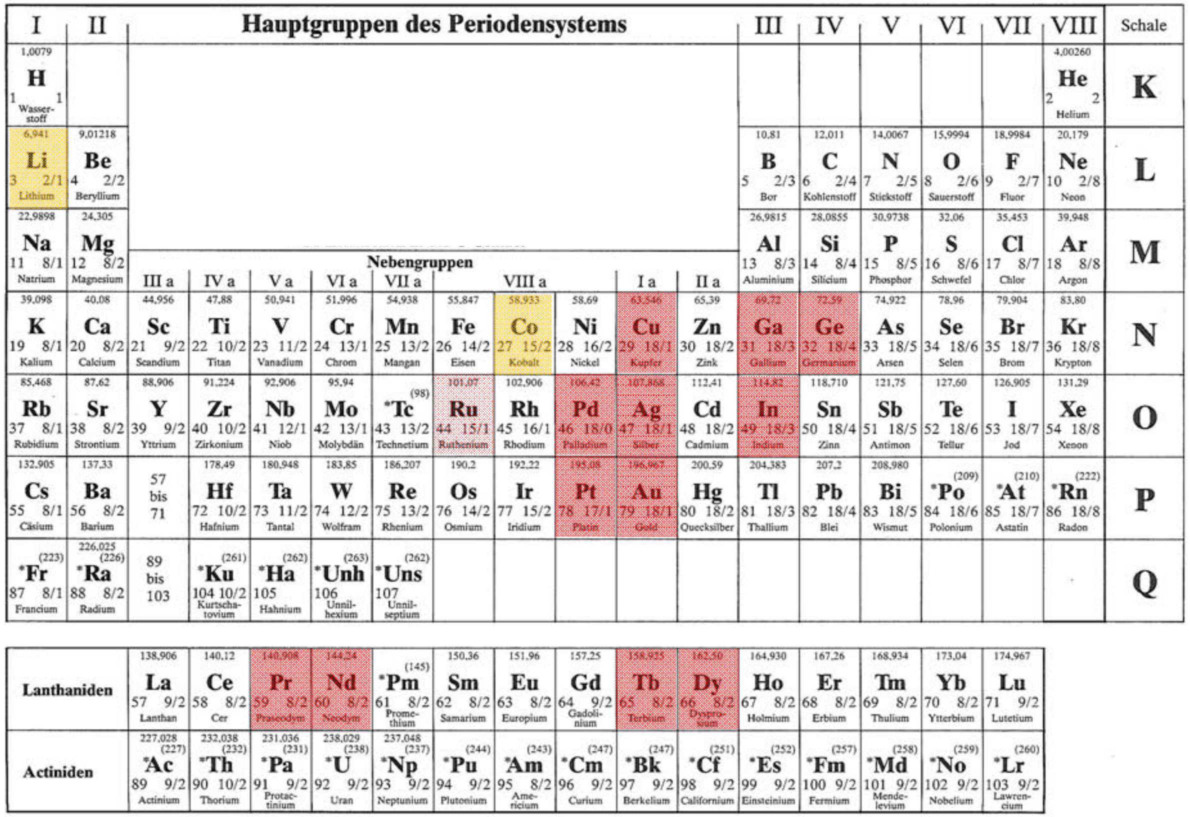
* Covers all the specific components of electric vehicles including charging stations

** Batteries in electric vehicles are analysed in detail in the LiBRi and LithoRec projects

Priority elements

The 15 priority elements of electromobility*:

- **silver**
- **gold**
- **copper**
- **dysprosium**
- **neodymium**
- **praseodymium**
- **terbium**
- **gallium**
- **germanium**
- **indium**
- **palladium**
- **platinum**
- **(ruthenium)**
- **(lithium)**
- **(cobalt)**



* Lithium and cobalt are not considered further in the project since scenarios for these metals are being prepared in the LithoRec project

Ruthenium was downgraded in the course of the project because no significant contribution was identified

Priority elements

- The priority elements were agreed with experts at the first Expert Workshop held in Berlin in September 2010.

- Prioritisation decisions were based on the need for the material in electric vehicles but also on competing uses: e.g.

  - The **rare earths** (neodymium, praseodymium, dysprosium, terbium) are needed in particular for permanent magnets (electric motors in e-vehicles). There are also competing applications – such as wind turbines – that are growing very rapidly.

  - **Indium** is used in electric vehicles in the power electronics. The very rapid growth in competing applications such as PV systems and the potentials in terms of primary resources (minor metal) place indium clearly in the group of critical metals (e.g. the EU's 14 critical metals).

Selection of the market scenarios

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- Five studies were considered:
  - IEA 2009
  - McKinsey & Co., 2010
  - **McKinsey & Co., 2009**
  - The Boston Consulting Group, 2009
  - Fraunhofer ISI, 2009

→ **Selection of the McKinsey & Co. study of 2009 because it meets the following criteria:**

- Describes the market share of different types of electric motor for the years 2020 & 2030.
- Depicts the broadest possible range of possible developments.
- Is internally consistent and can be compared with the alternative scenarios.

Three global scenarios (McKinsey 2009)

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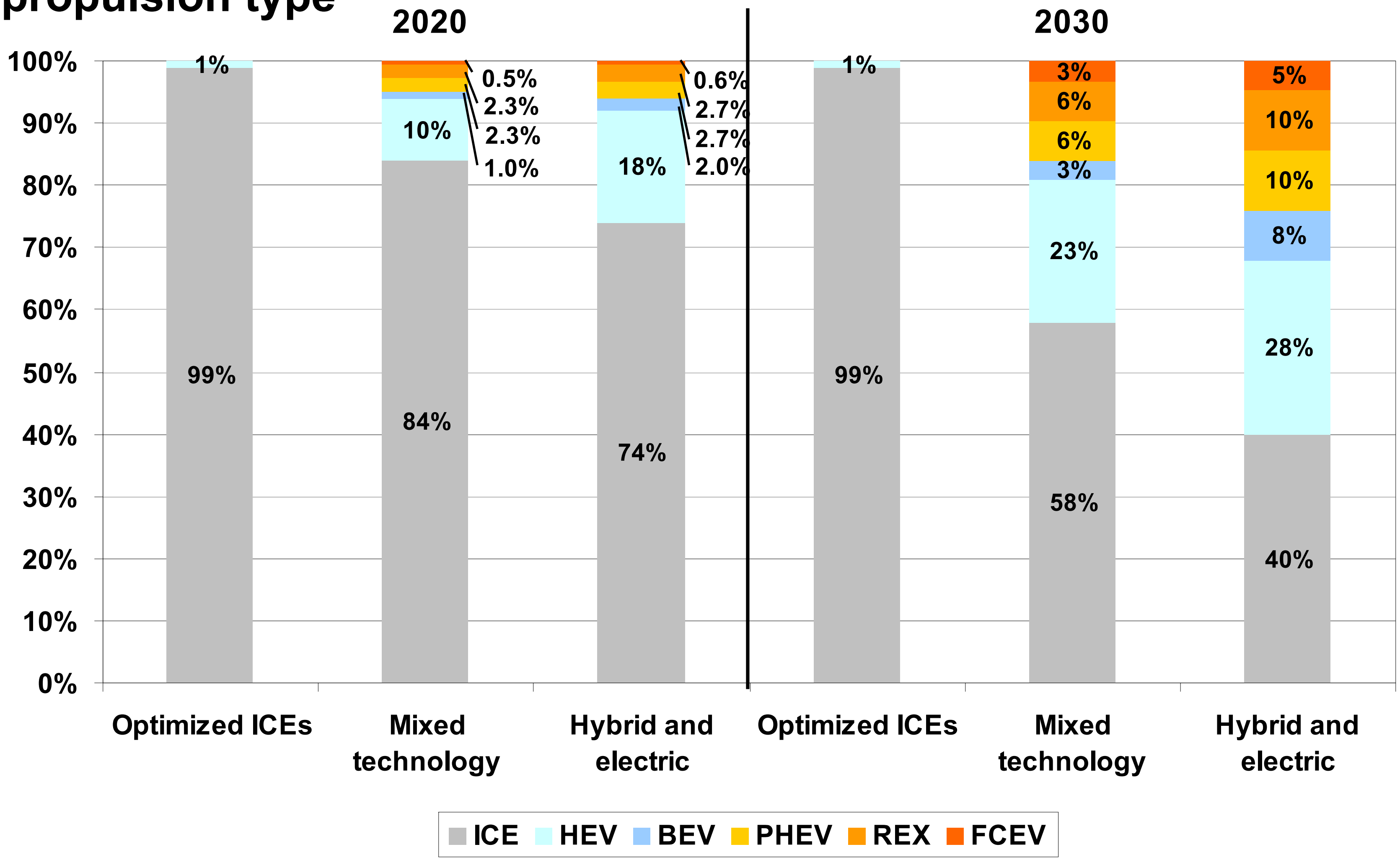
Structure of new passenger vehicle registrations categorised by propulsion type



Three global scenarios (McKinsey 2009)

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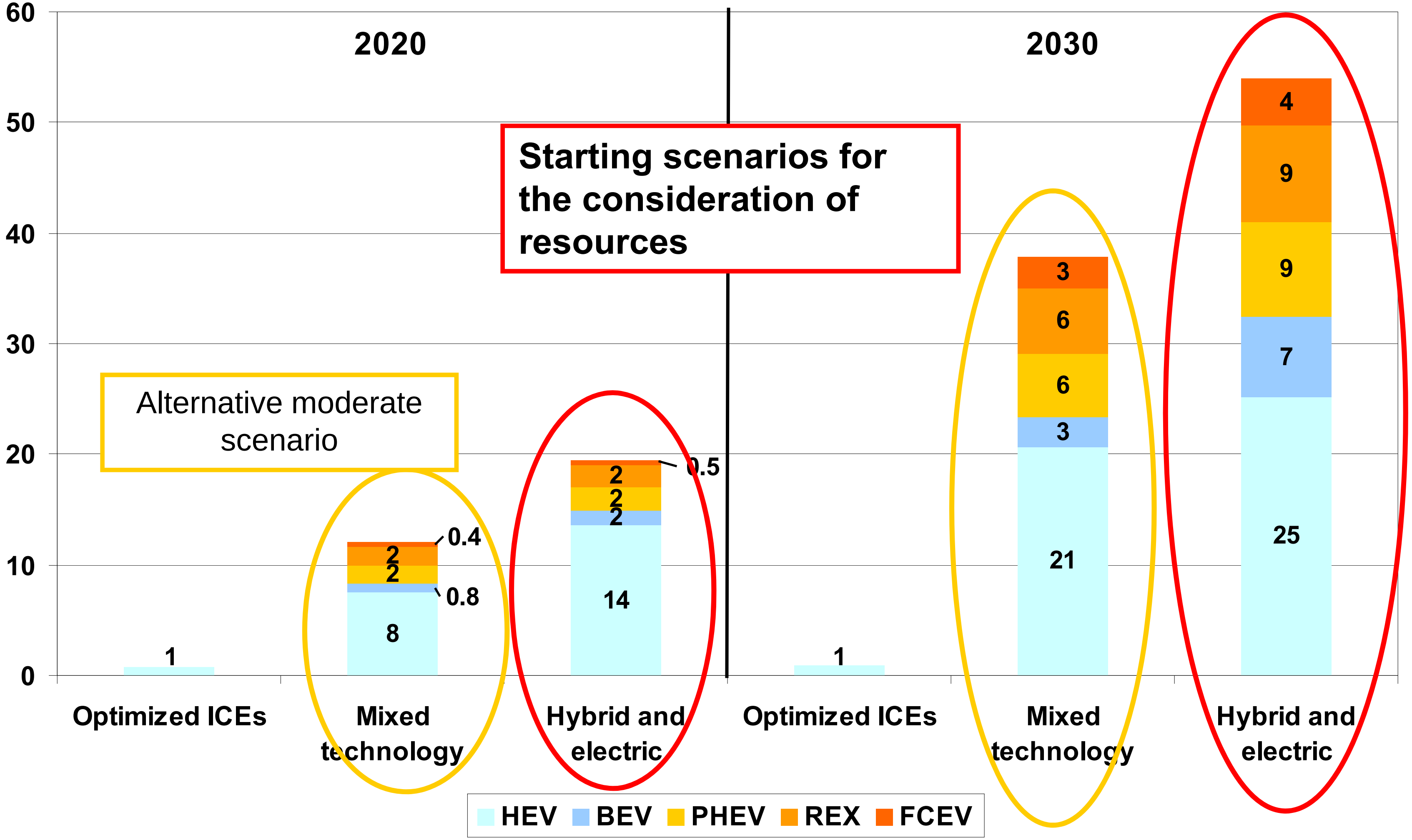
Annual registrations of new passenger vehicles with (partially) electric motor [in million vehicles]



Summary
Components – material requirements 2010

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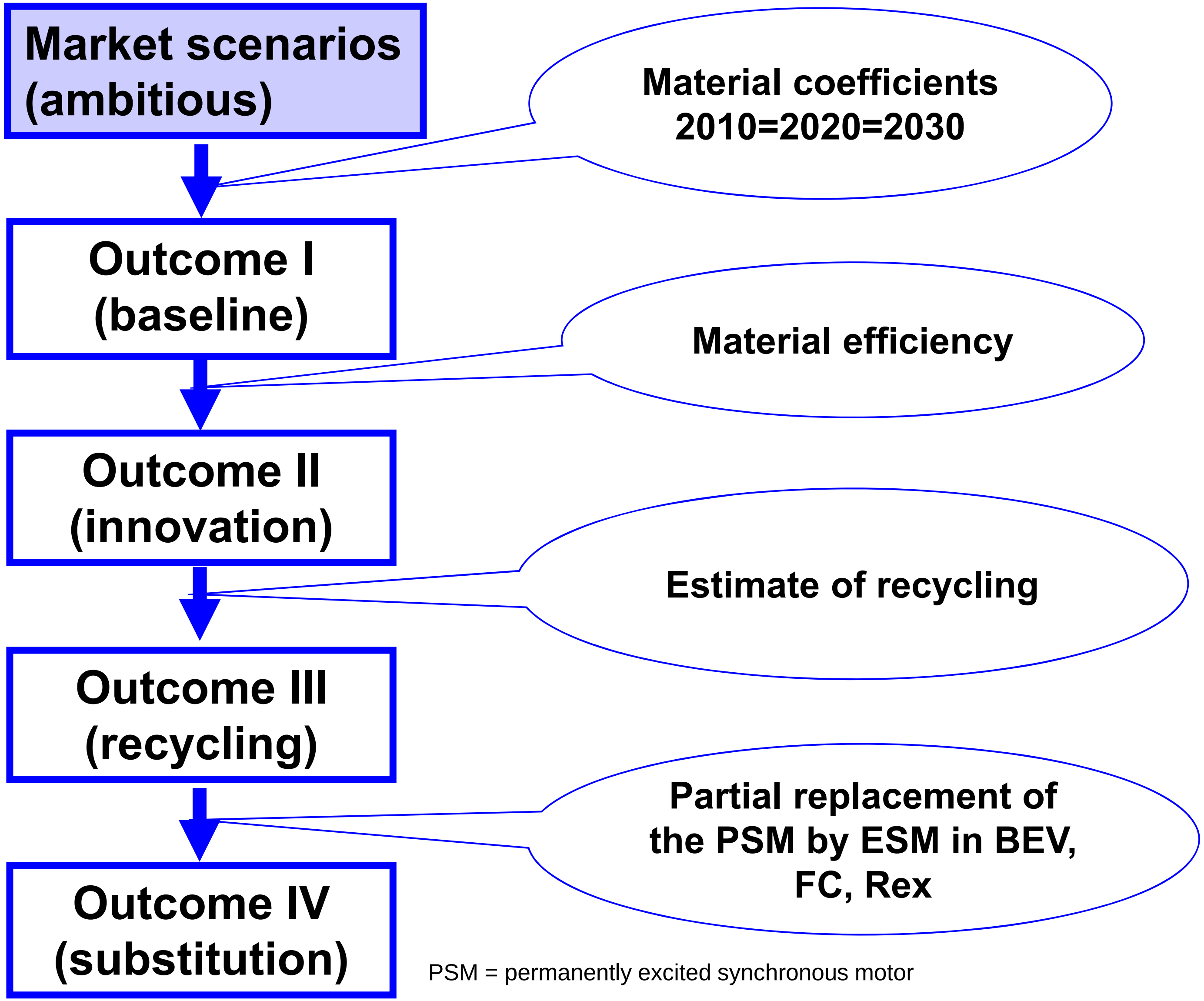
Blank ≙ Material not used
● ≙ Amount per vehicle in the mg range
● ≙ Amount per vehicle in the g range
● ≙ Amount per vehicle in the kg range

Hatched – conventional powertrain

	Gold	Silver	Copper	Gallium	Indium	Germanium	Platinum	Palladium	Ruthenium	Neodymium	Praseodymium	Dysprosium	Terbium
Electric motor			kg	mg						g	g	g	g
Power electronics	mg	g	kg	mg	mg	mg		mg					
Battery / cables			kg										
Fuel cell components (FC system module, -stack, H2 tank)			kg	mg			g			g	g	g	g
Standard in-car cabling		g (hatched)	kg (hatched)										
Charging station / pillar incl. charging cable		mg	kg	mg	mg	mg							
Other electric applications (steering, brakes, electronics)			kg (hatched)										
ICE applications (catalytic converter, combustion engine, alternator)			kg (hatched)				g (hatched)	g (hatched)					

The scenarios



PSM = permanently excited synchronous motor

ESM = externally excited synchronous motor

BEV = battery electric vehicle

FC = fuel cell

Rex = range extender

The baseline scenario

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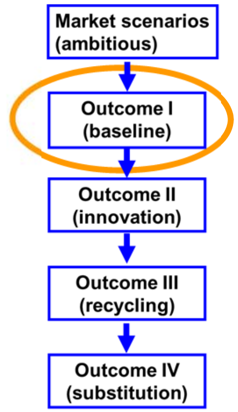
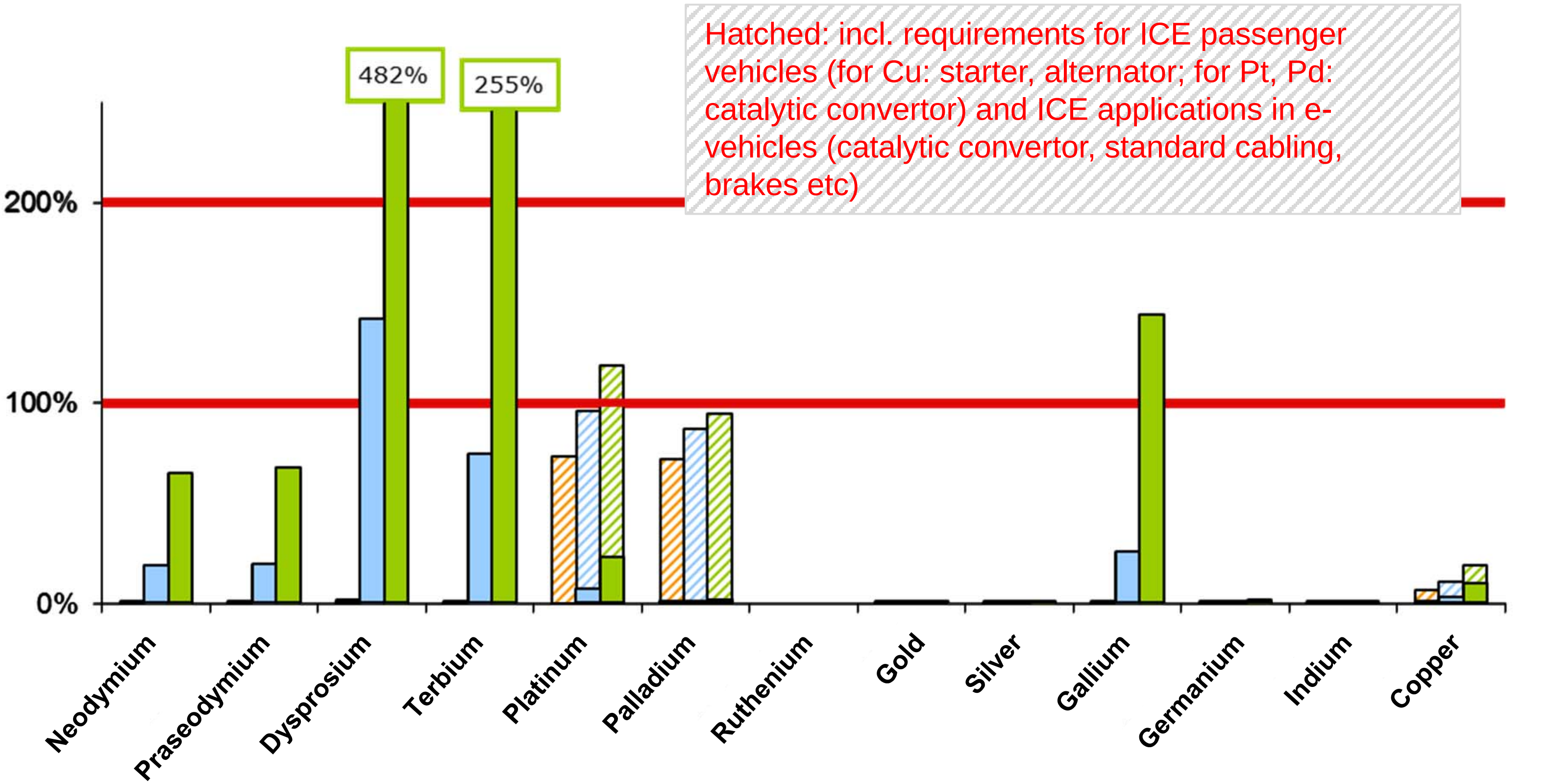
Primary resource requirement for electric passenger vehicles worldwide / total primary production in 2010 (in %)





Baseline scenario for hybrid and electric:
ambitious market penetration
Material coefficients 2010 = 2020 = 2030 (except for platinum)

PKW = passenger vehicles

The innovation scenario

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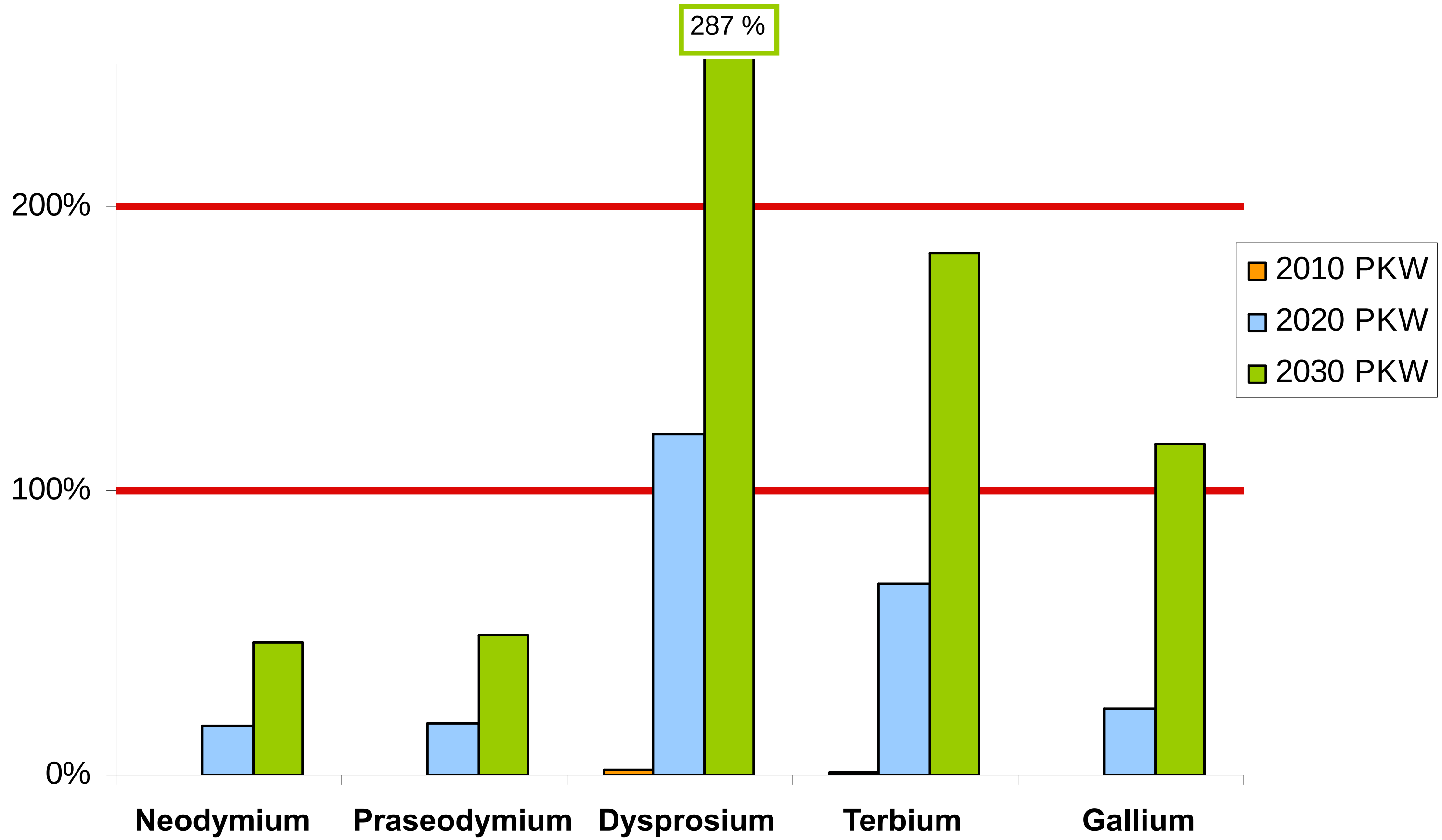
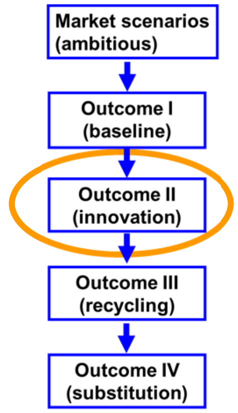
Primary resource requirement for electric passenger vehicles worldwide / total primary production in 2010 (in %)





Innovation scenario:
ambitious market penetration of hybrid and electric minus innovation potentials/material efficiency

PKW = passenger vehicles

The recycling scenario

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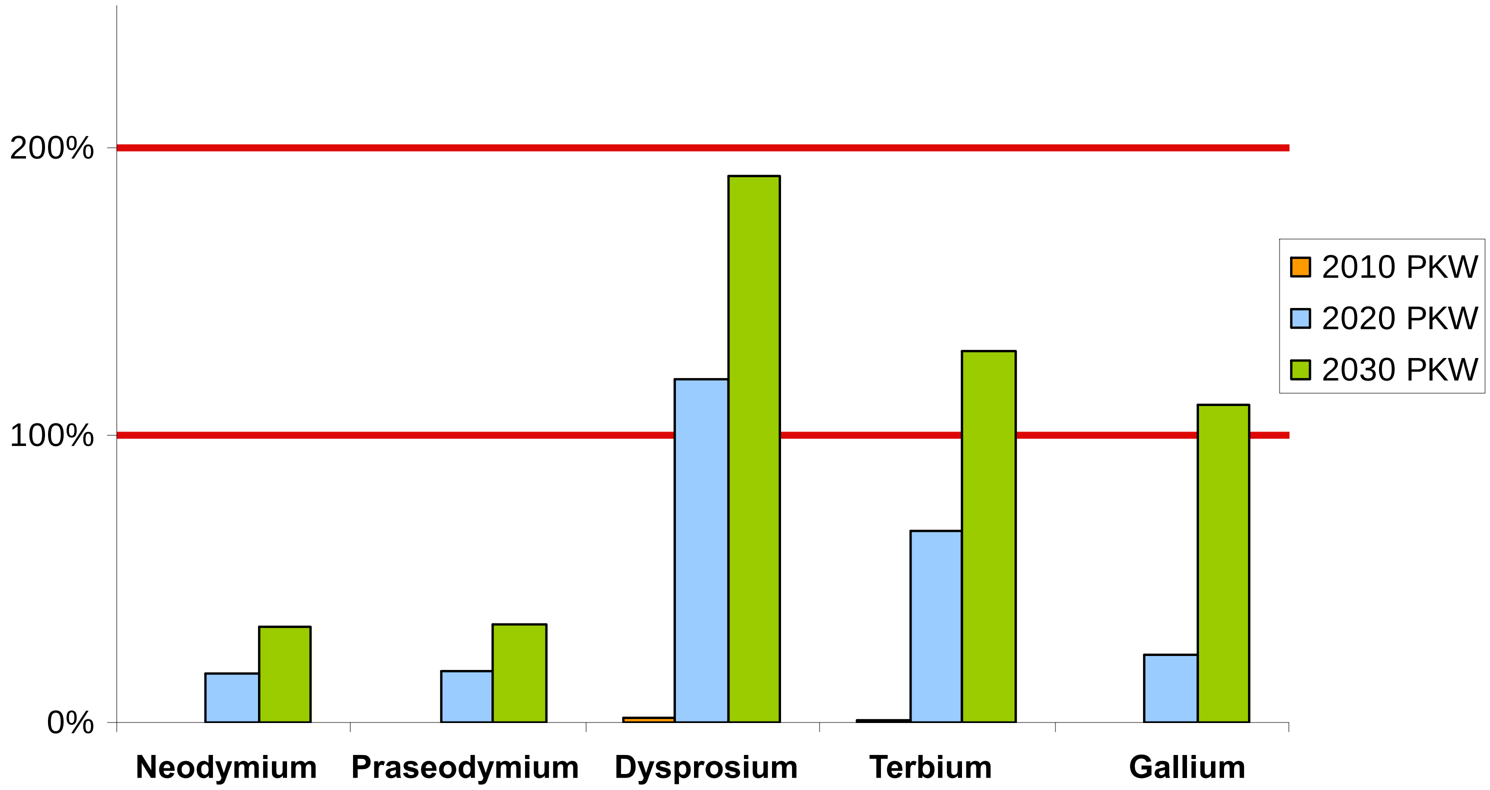
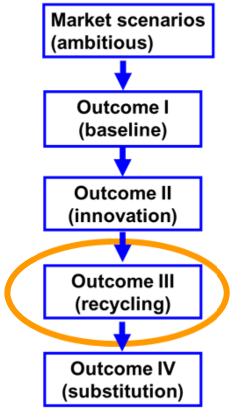
Primary resource requirement for electric passenger vehicles worldwide / total primary production in 2010 (in %)

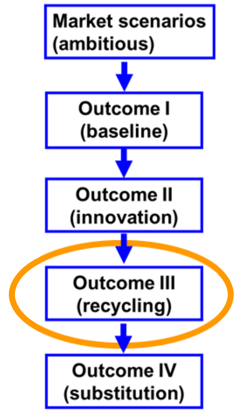




Recycling scenario:
ambitious market penetration of hybrid and electric
minus innovation potentials
minus recycling

PKW = passenger vehicles

Recycling rates*



	2010	2020	2030
rare earths (Dy, Tb, Nd, Pr)	0%	60%	80%
Pt, Pd	55%	70%	80%
Ag, Au	2%	15%	40%
Cu	50%	75%	80%
Ga	0%	10%	25%
In, Ge	0%	5%	15%

* Recovery rates from the automobile system

The substitution scenario

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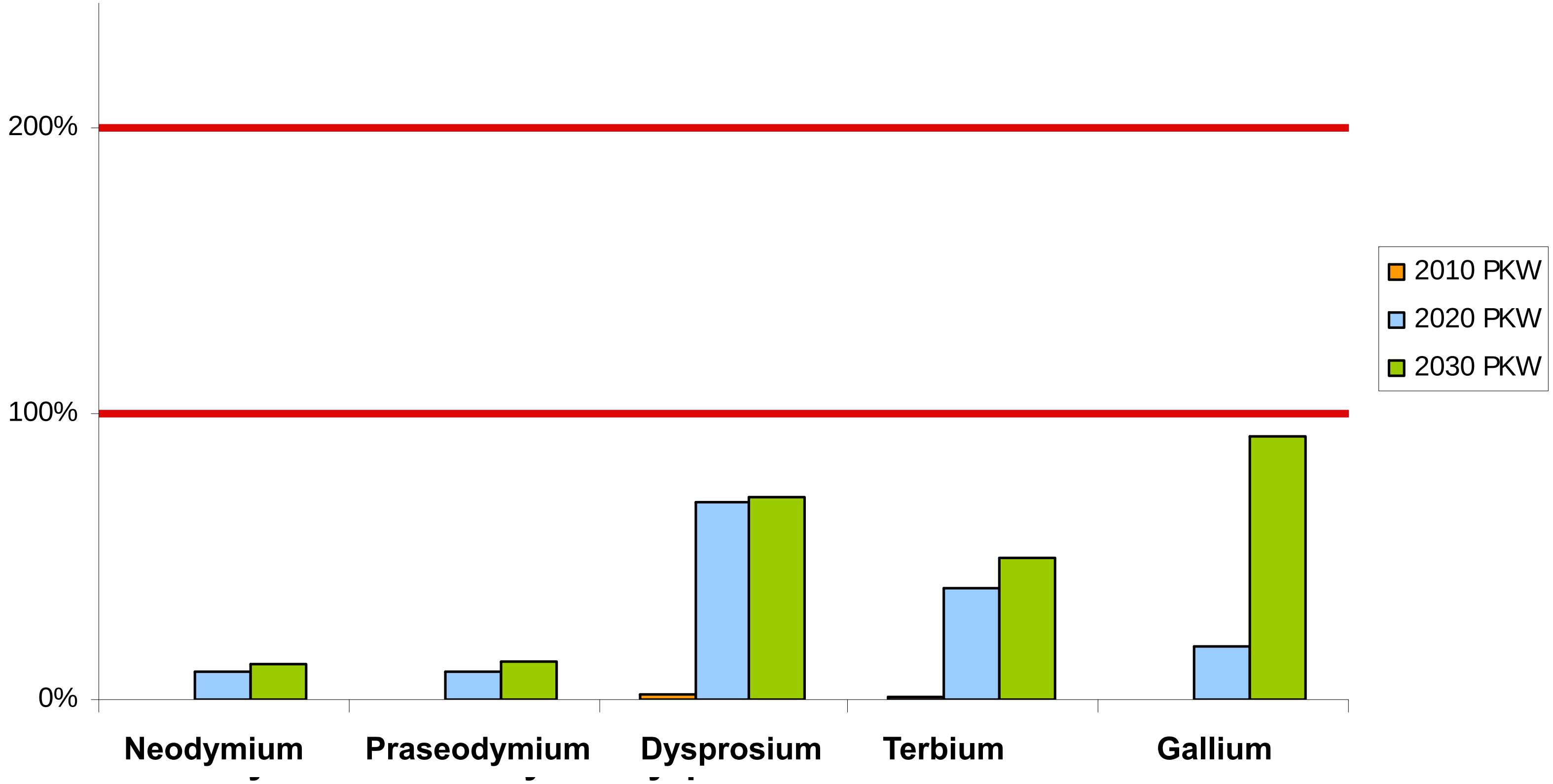
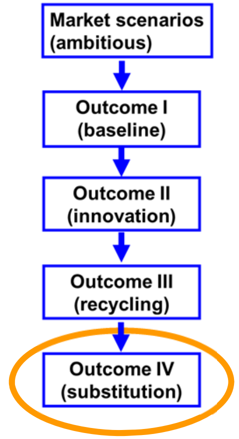
Primary resource requirement for electric passenger vehicles worldwide / total primary production in 2010 (in %)





Substitution scenario:
material requirements for ambitious market penetration of hybrid and electric
minus innovation potentials
minus recycling
minus substitution of electric engine for BEV, FC, Rex (33% of e-vehicles in 2030)

The moderate scenario

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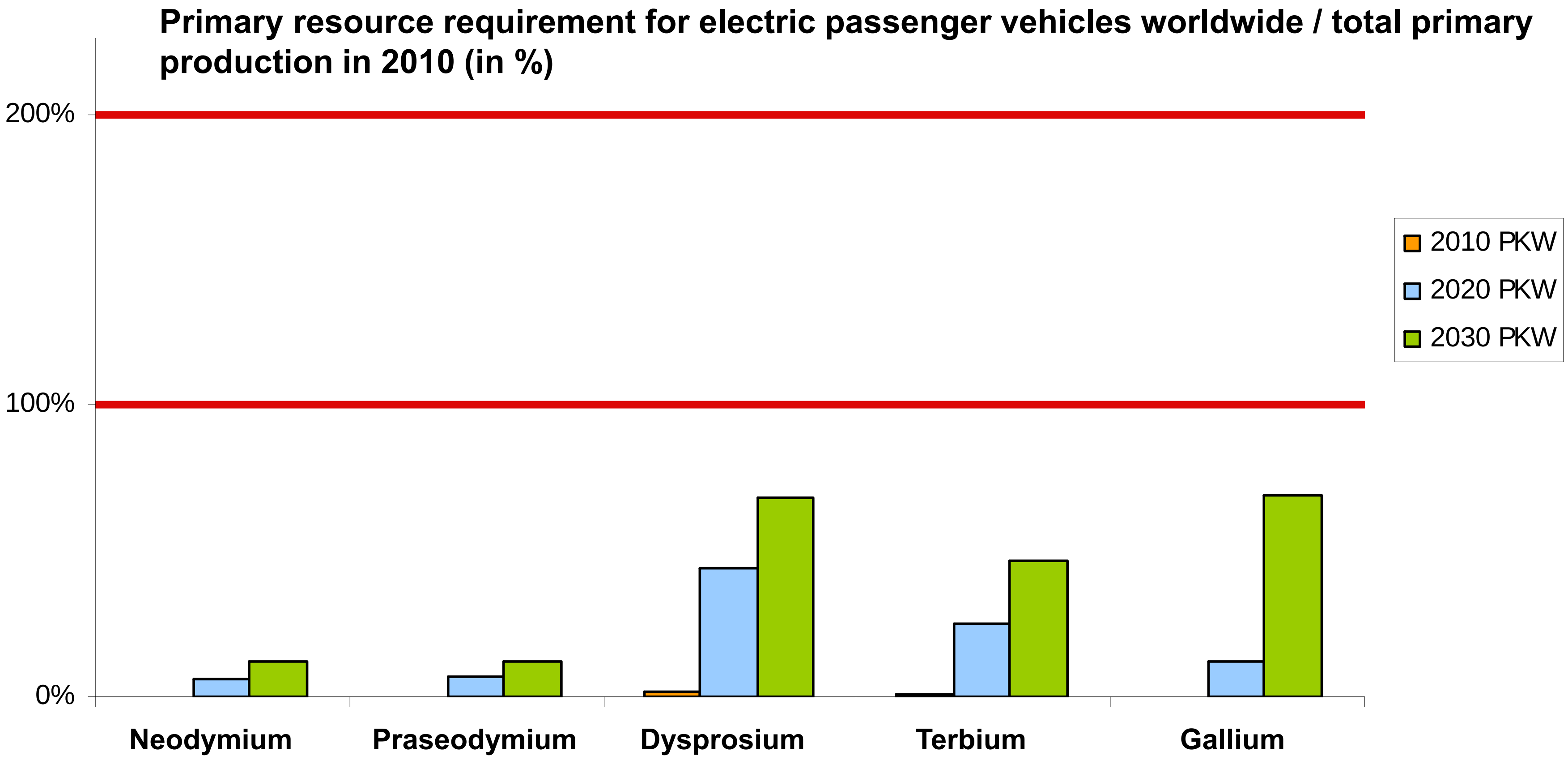

moderate market penetration of mixed technology
minus innovation potentials
minus recycling
minus substitution of electric engines
replacement of amb. by moderate market scenario

PKW = passenger vehicles

Gallium profile 1/2

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Reserves: **28 billion tonnes of bauxite**
250 million tonnes of zinc ore

Primary production 2010: **106 tonnes Ga**
(211 million tonnes bauxite production)
(12 million tonnes zinc production)

→ **Stat. reach:**
133 years (bauxite)
21 years (zinc)

Major metal: **no → always minor metal**

Natural ores: **Bauxite** (50 ppm Ga); of which 50% in solution in the Bayer process – 80% of this can be extracted
Zinc (up to 0.01% Ga)

Demand growth (in % per year) by 2020*: **Ga: approx.16%** (derived from EU study 2010)
Zinc growth 2-3.5% (source: BGR 2007)
Alu: 1 – 2.3% (source: BGR 2007)

2020 – 2030*: **Ga: approx. 14%** (derived from EU study 2010)
Zinc growth 2-3.5% (source: BGR 2007)
Alu: 1 – 2.3% (source: BGR 2007)

Ga potential from current bauxite production is far from being fully utilised

***Base year 2010**

Gallium profile 2/2

EOL recycling rate 2010: < 1%

Assessment of gallium recycling

Post-consumer recycling at present only rudimentary (Umicore).

Gallium recycling from production processes is better established.

Future recycling potentials for gallium 2020 / 2030:

Currently unpredictable. Most applications are dissipative in nature; there will be a sharp increase in quantities used in future.

Nd, Dy, Tb, Pr profile 1/5

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Reserves:	**approx. 24 million tonnes**
Primary production 2010:	**approx. 35,355 tonnes Nd, Dy*, Tb*, Pr oxides**

* **Dy: 1.980 t** (Source BGR 2011)
* **Tb: 375 t** (Source BGR 2011)

Stat. reach: 679 years

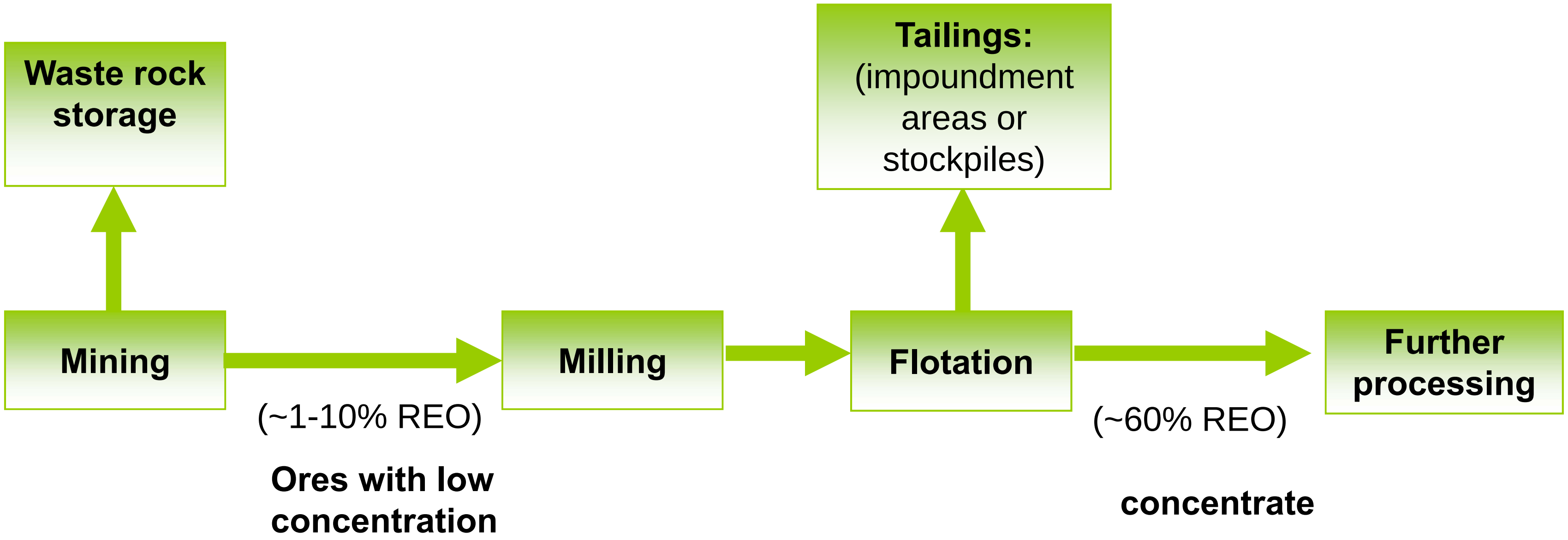
Major metal:	**associated with other REOs**
Natural ores:	**bastnaesite, xenotime, monazite, ion adsorption/deposit**

Demand growth (in % per year)

to 2020*:	**approx. 10% (average estimate)**
2020 – 2030*:	**approx. 10% (average estimate)**

*Base year 2010

Extraction of rare earths 2/5



Environmental risks in the extraction of rare earths 3/5

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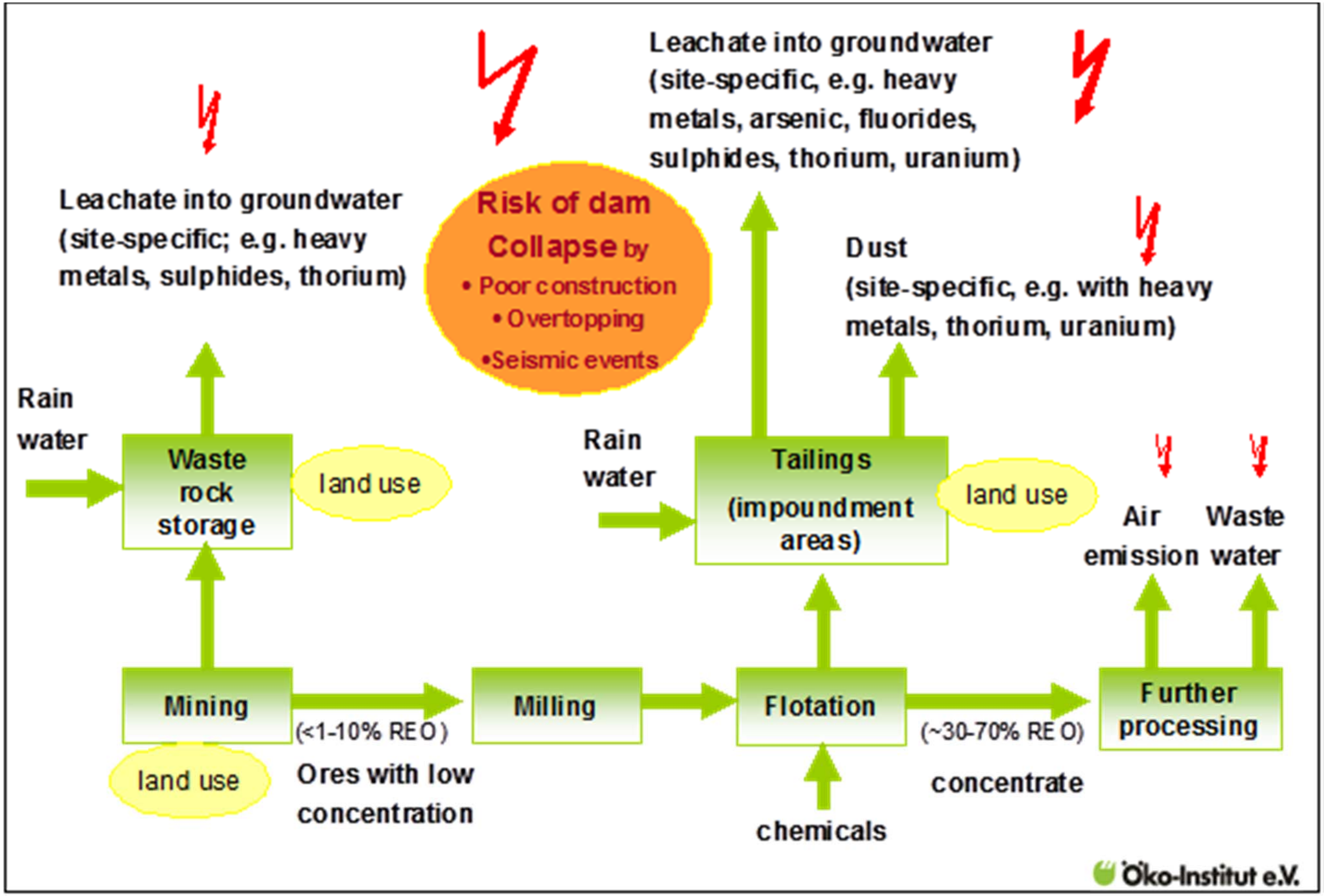

Environmental risks in the extraction of REs – Summary 4/5

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- **Primary extraction of rare earths is usually associated with radioactive pollution**
- **Residues remain mainly in the form of tailings, which are stored in large basins: heavy metal pollution etc.**
- **In-situ leaching poses major risks to groundwater**
- **Separation and refining of rare earths and their compounds requires large quantities of chemicals and energy**
- **As a result of the huge problems in China, the government has adopted extensive plans to optimise and consolidate operations (closure of small mines) over the next 5 years**

Rare earths profile 5/5

EOL recycling rate 2010: < 1%

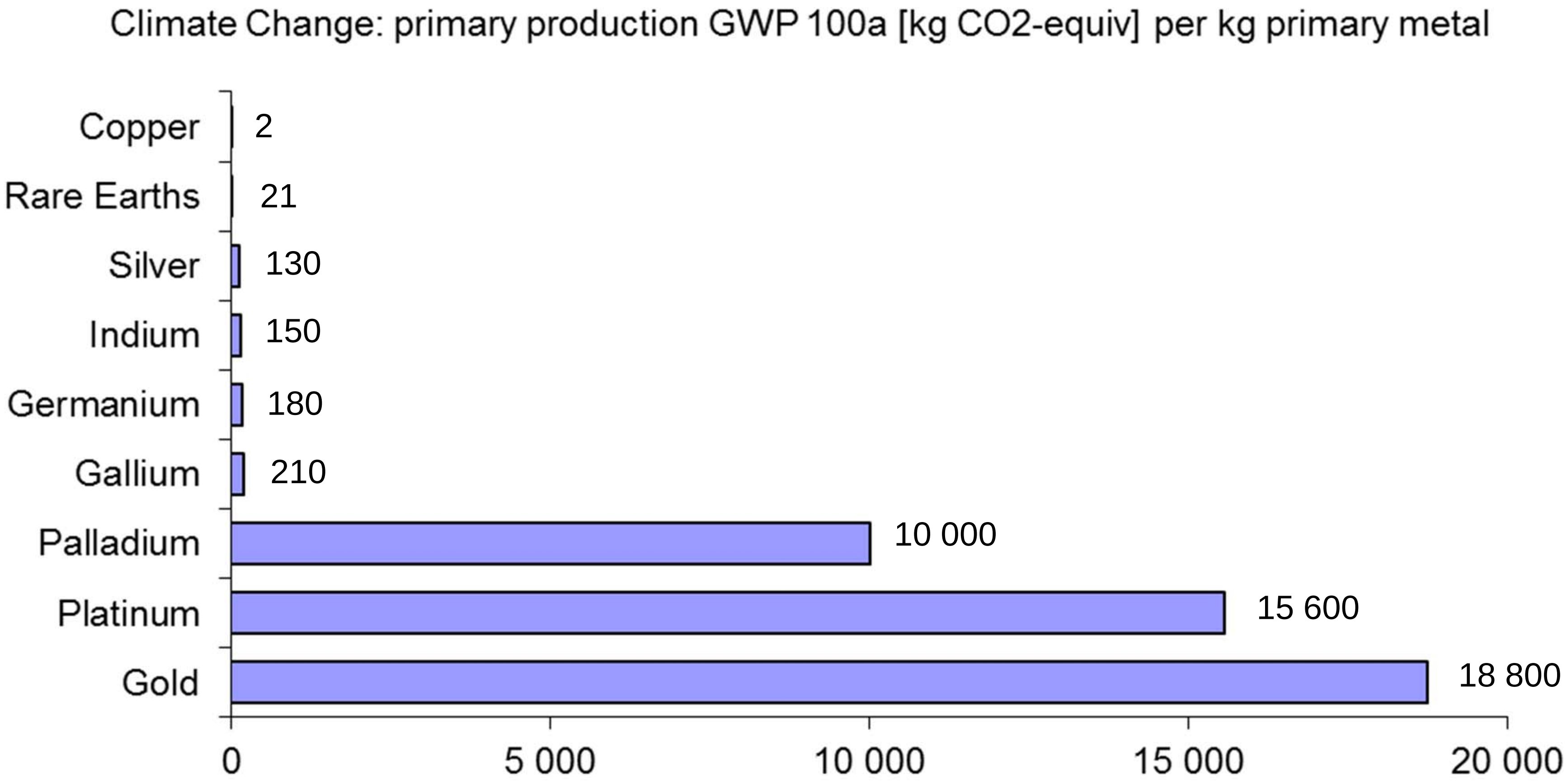
Assessment of rare earth recycling (Nd, Pr, Dy, Tb):

Reports on pre-consumer recycling, mainly in Asia, indicate:
recovery of grinding sludge from magnet manufacture,
recovery of rare earths from nickel-metal hydride batteries (Mischmetal).

Future recycling potentials for rare earths (Nd, Pr, Dy, Tb) 2020 / 2030:

For heavy rare earth oxides the BGR estimates a recycling rate in 2015 of 10% of the supply. On account of rising prices for REs, rapidly rising demand and scarcity of primary supply, increased research & development and initial implementation of recycling schemes can be expected: see Rhodia's announcement of recycling of REs from compact fluorescent lamps.

Environmental impact of primary extraction per kg of extracted metal



Source: ecoinvent 2010

Environmental impact of primary extraction per kg of extracted metal

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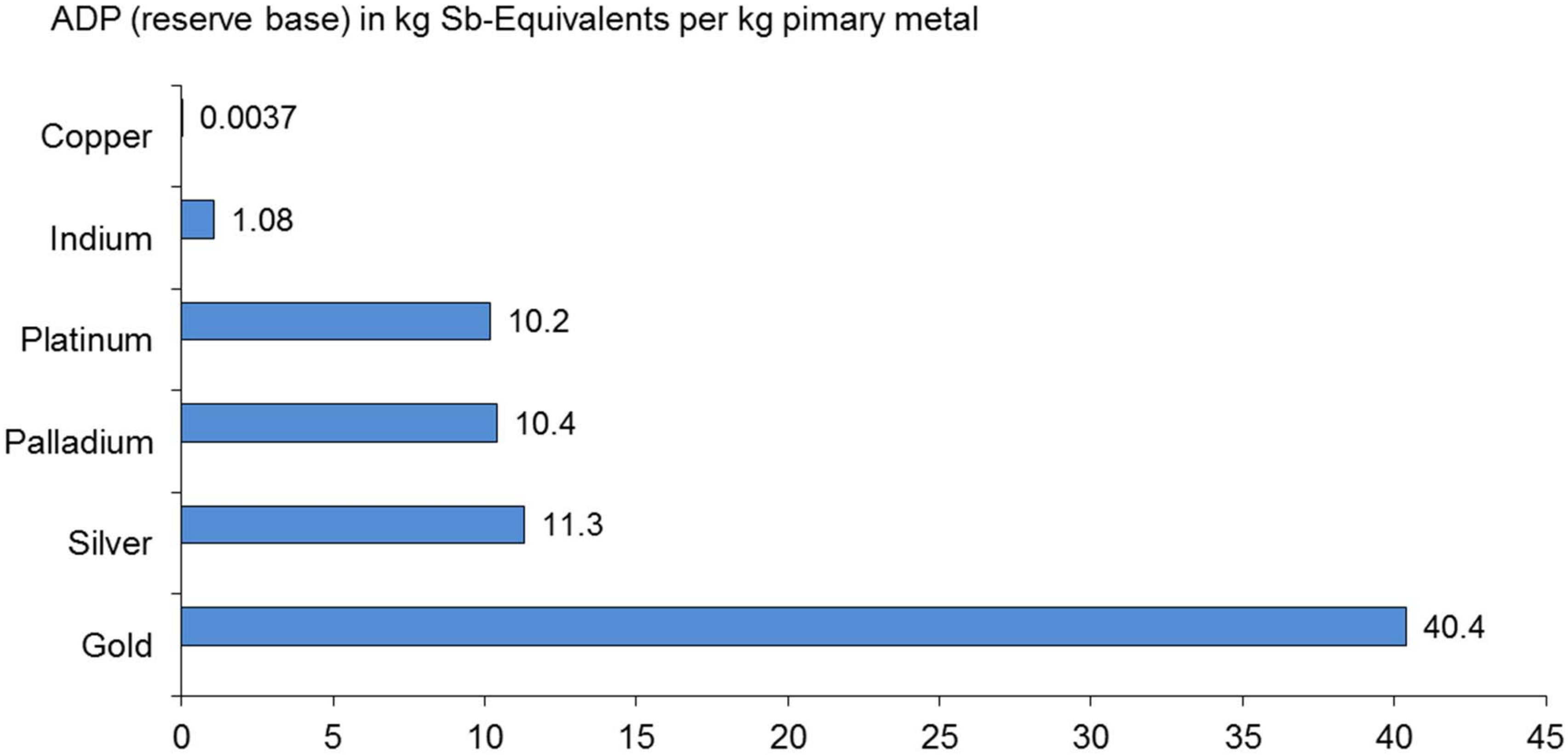

No data available for gallium, germanium, ruthenium, rare earths

Global environmental impact of primary production as a result of demand for electric vehicles*

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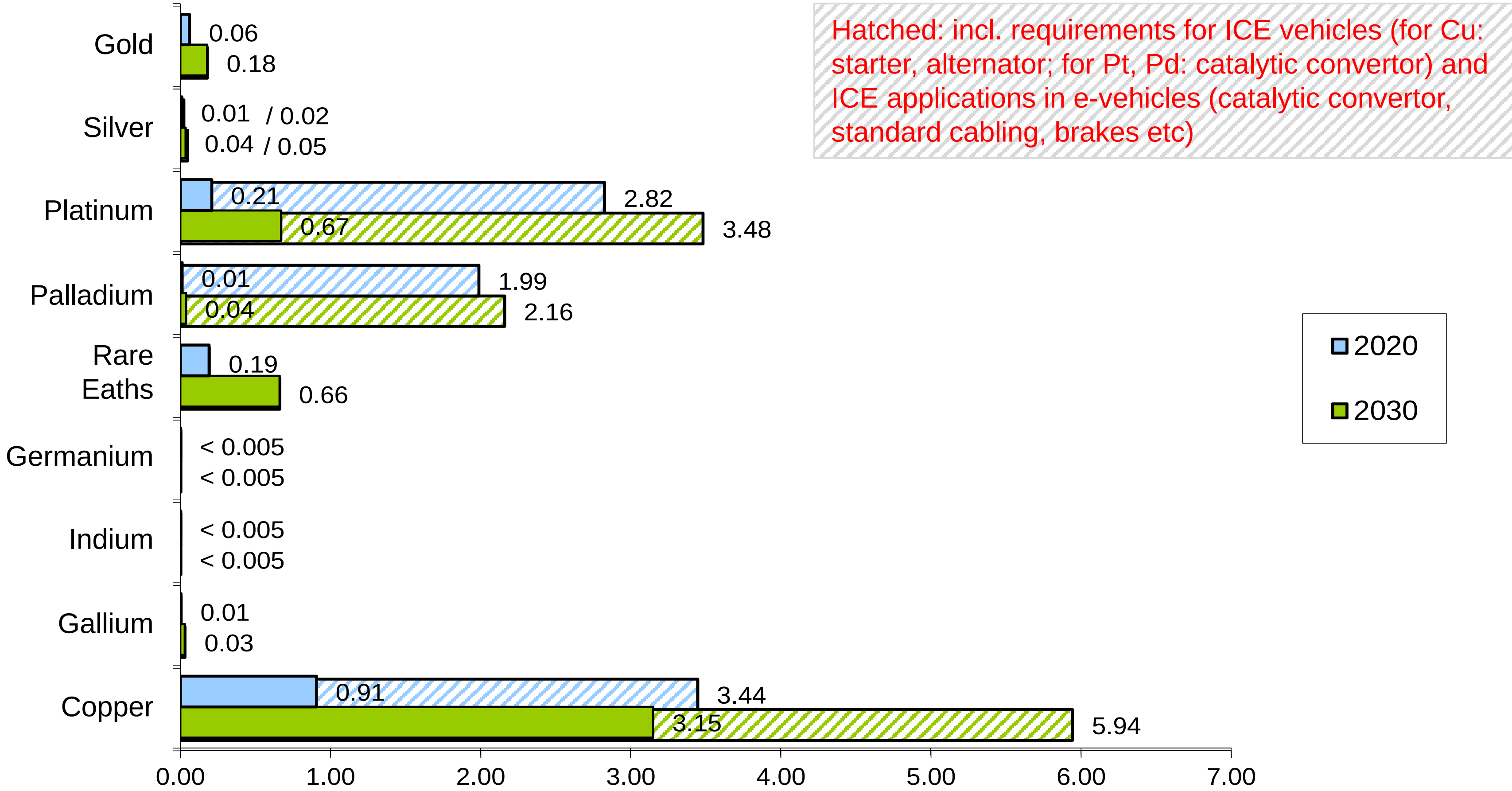
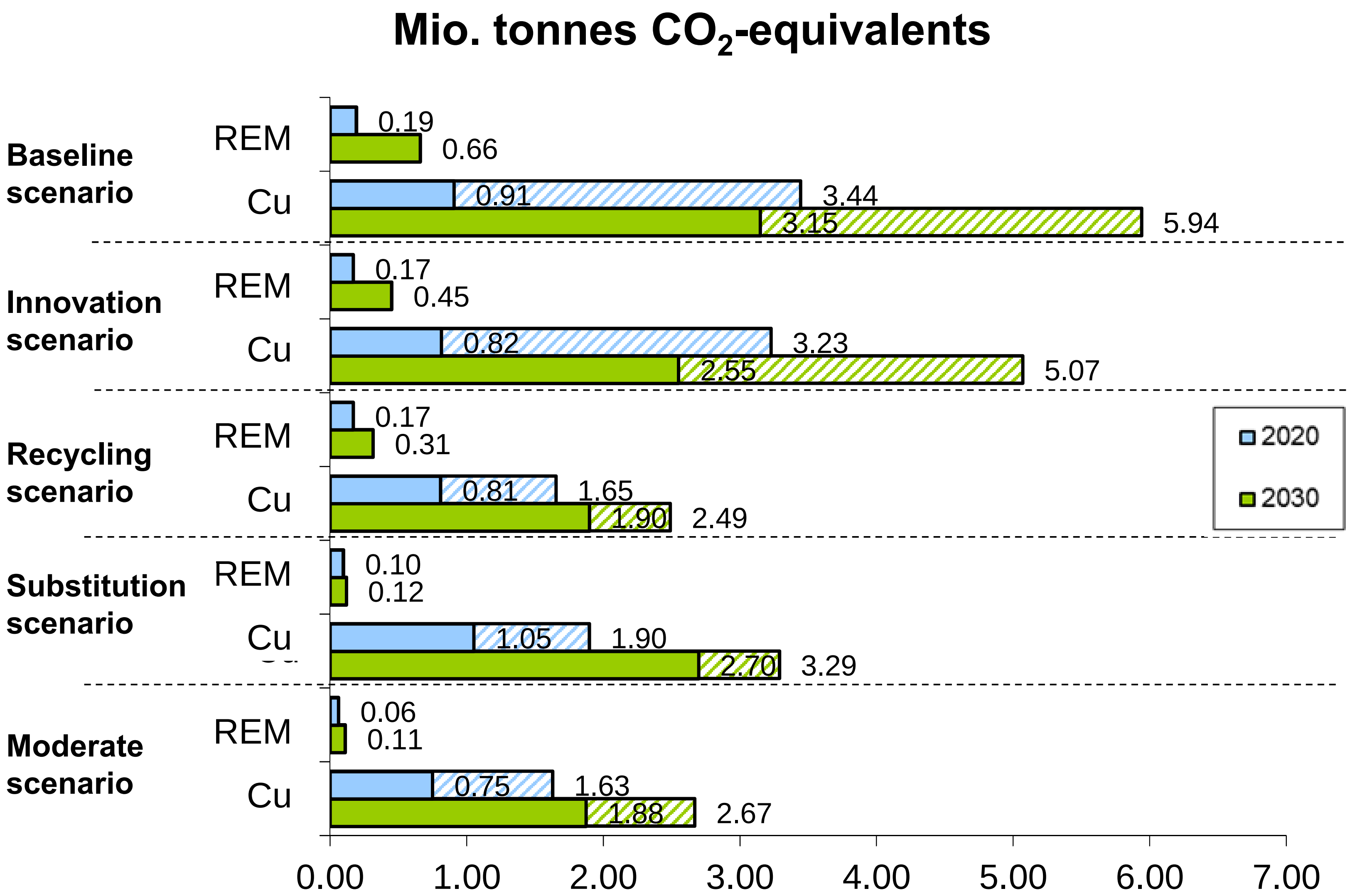
Baseline scenario in million tonnes CO_2-equivalents



*** Excluding consideration of the battery**

Current GWP was held constant for 2020 and 2030

Global environmental impact of primary production as a result of demand for electric vehicles *



Cu = copper

REM = rare earth metal

* Excluding consideration of the battery

Current GWP was held constant for 2020 and 2030

Reduction in material consumption attributable to electric vehicles

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Electric mobility (fuel cells and fully electric passenger vehicles) means that the following components and metals contained in conventional vehicles are no longer required:

- engine (copper, aluminium, steel / ferrous materials)
- exhaust (copper, steel / ferrous materials)
- fuel system (steel / ferrous materials)
- catalytic convertor (platinum, palladium)

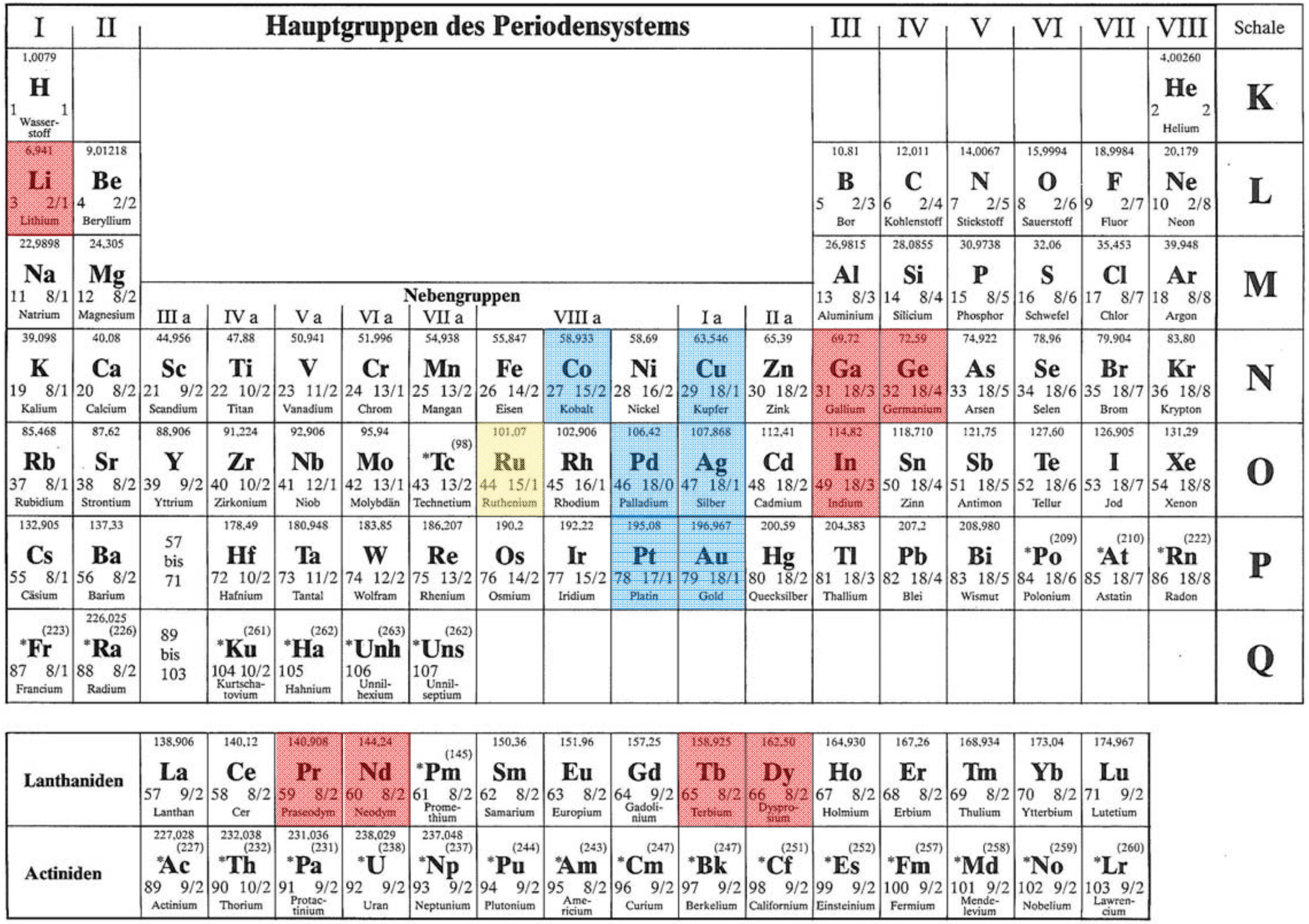
	Copper	Platinum	Palladium	Aluminium	Steel
Saving 2020					
in tonnes of material	ca. 4 500	4	5	ca. 66 700	ca. 250 400
in tonnes of CO_2-equivalents	ca. 8 600	ca. 70 000	ca. 52 700	ca. 826 000	ca. 415 300
Saving 2030					
in tonnes of material	ca. 26 500	26	31	ca. 394 000	ca. 1 479 200
in tonnes of CO_2-equivalents	ca. 51 000	ca. 412 400	ca. 311 400	ca. 4 879 500	ca. 2 453 200

In relation to the baseline scenario for 2020 or 2030

Summary of present recycling situation*

Recycling rates (EOL-RR)* of the relevant elements

*EOL-RR = End-of-life recycling rate (post consumer)



- > 50%
- > 25-50%
- > 10-25%
- 1-10%
- < 1%

Source: Graedel, Buchert et.al UNEP 2011

* Excluding consideration of the battery metals

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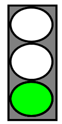
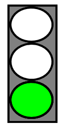
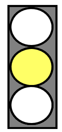
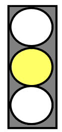
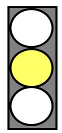
Recyclability of top-priority elements

Element	Recyclability	Assessment
Palladium **Silver** **Platinum** **Gold**	Recycling precious metals presents no metallurgical problem. The most important requirement is appropriate pre-treatment of the products so that the precious metals are actually removed for recycling / refining and are not lost in other compounds as a result of unsuitable processing.	
Copper	Copper is used as a "collector" for precious metals in pyrometallurgical processes and can be recovered by leaching and electrical precipitation.	
Gallium **Germanium**	In low concentrations there are virtually no opportunities for economic recycling; recyclability increases with increasing concentration. In pyro-processes (Hoboken) Ga and Ge are vaporised and pass into the fly ash.	
Indium **Ruthenium**	Losses of In and Ru would be high if these elements were to be introduced right at the start of the recycling process, even in prepared form; better recovery rates are achieved for both if Ru is fed into the pyrometallurgical pre-concentration of precious metals, or if In is fed into the lead process; however, without pre-concentration losses are high.	
Praseodymium **Neodymoim** **Terbium** **Dysprosium**	As trace elements forming part of the mix in complex materials, e.g. in combination with precious metals, rare earth ores usually pass into the slag where they are diluted to such an extent that recycling is not worthwhile. Recyclability is greater if high concentrations of rare earth ores are present in the product (see permanent magnets) or if the slag is enriched (see UHT). Recycling and preparation processes are currently being developed / some solutions are already available.	

Summing up: The environment and recycling 1/3

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The following statements do not cover the largest component – the battery

- **CO_2-equivalents:**
  The copper requirement of electro-mobility plays the largest role, followed by platinum for fuel cells and rare earths for electric motors.
- A similar picture applies to acidifiers, photochemical oxidation, over-fertilisation and cumulated energy requirement.

- **In terms of ADP copper also makes the largest absolute contribution**

- Classical life-cycle assessments do not adequately depict the specific environmental impact potential: in the case of rare earths specific impact factors such as radioactivity etc. have substantial relevance.

- **Recycling:**
  Established systems exist for recycling copper and precious metals – the main issue here is collection of the materials.
  For special metals (rare earths, indium etc.) extensive research and development is needed.

Summing up: The environment and recycling 2/3

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The following statements do not cover the largest component – the battery

- **Good recycling systems have clear environmental benefits** (as experiences with precious metals show).
- A rough calculation of the savings of classical materials for ICE passenger vehicles shows significant raw material savings and corresponding reduction of environmental impacts (steel etc.).
- The findings show where important environmental impacts and benefits arise. They by no means have the same weight as the findings of life-cycle assessments, because
  - A) the battery was completely excluded
  - B) the manufacturing processes of electrical components and specific components of ICE vehicles were not taken into account.

Summing up: The environment and recycling 3/3

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- For future projects there are the challenges of comprehensive inventorising and evaluation of the environmental impacts and benefits of the various components of electric mobility: life-cycle assessment procedures supplemented by additional considerations (see rare earths).
- It is important not to underestimate the level of complexity (different components involving a very wide range of materials, manufacturing processes with a major secrecy element and dynamic developments).
- Calculating future relative environmental impacts (per production unit) for the production of metals etc. is a challenging task since it needs to include the development of environmental standards, electricity generation costs etc. in many different countries.
- Care should therefore be taken to avoid over-hasty conclusions when assessing the environmental impacts and benefits of electric mobility.

Nd requirements of e-mobility in the scenarios and total requirement across all applications

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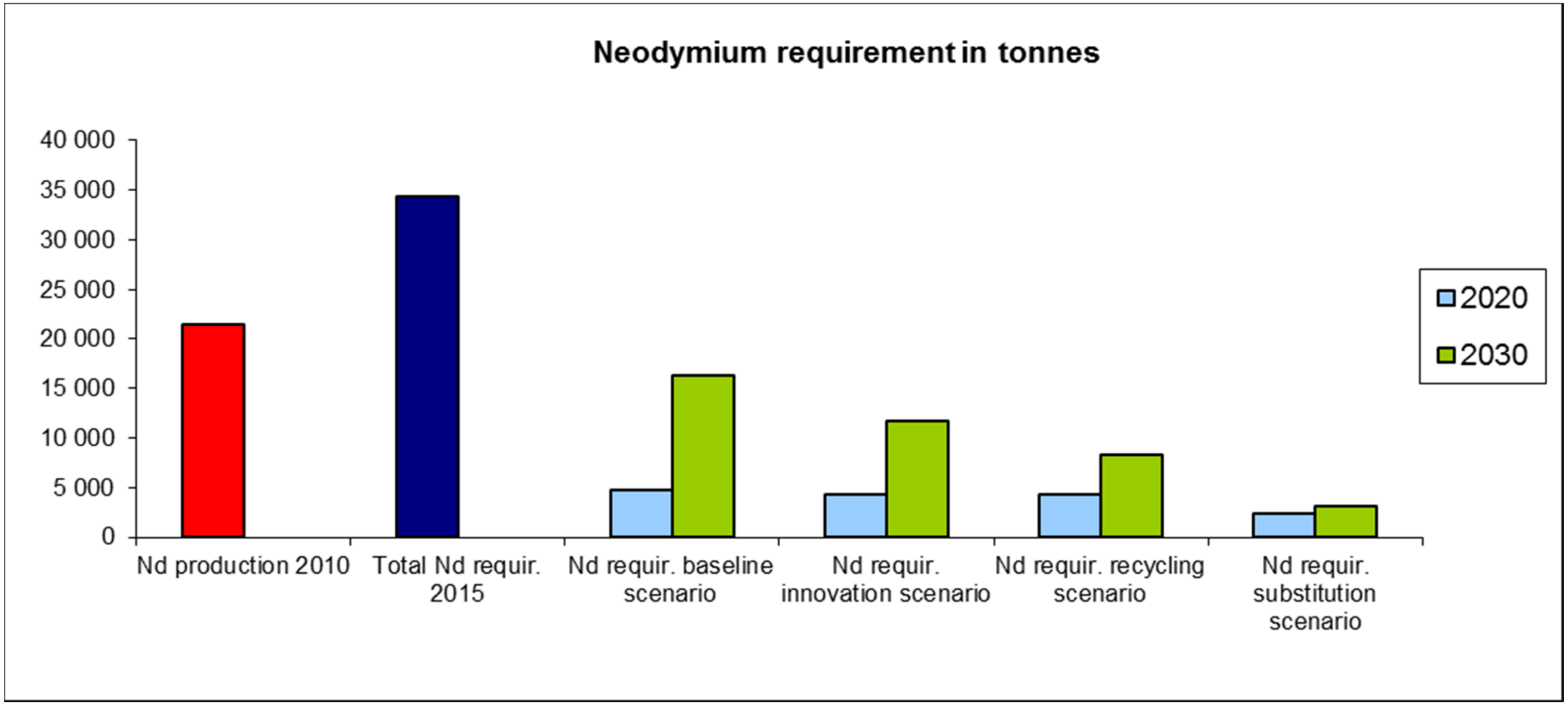
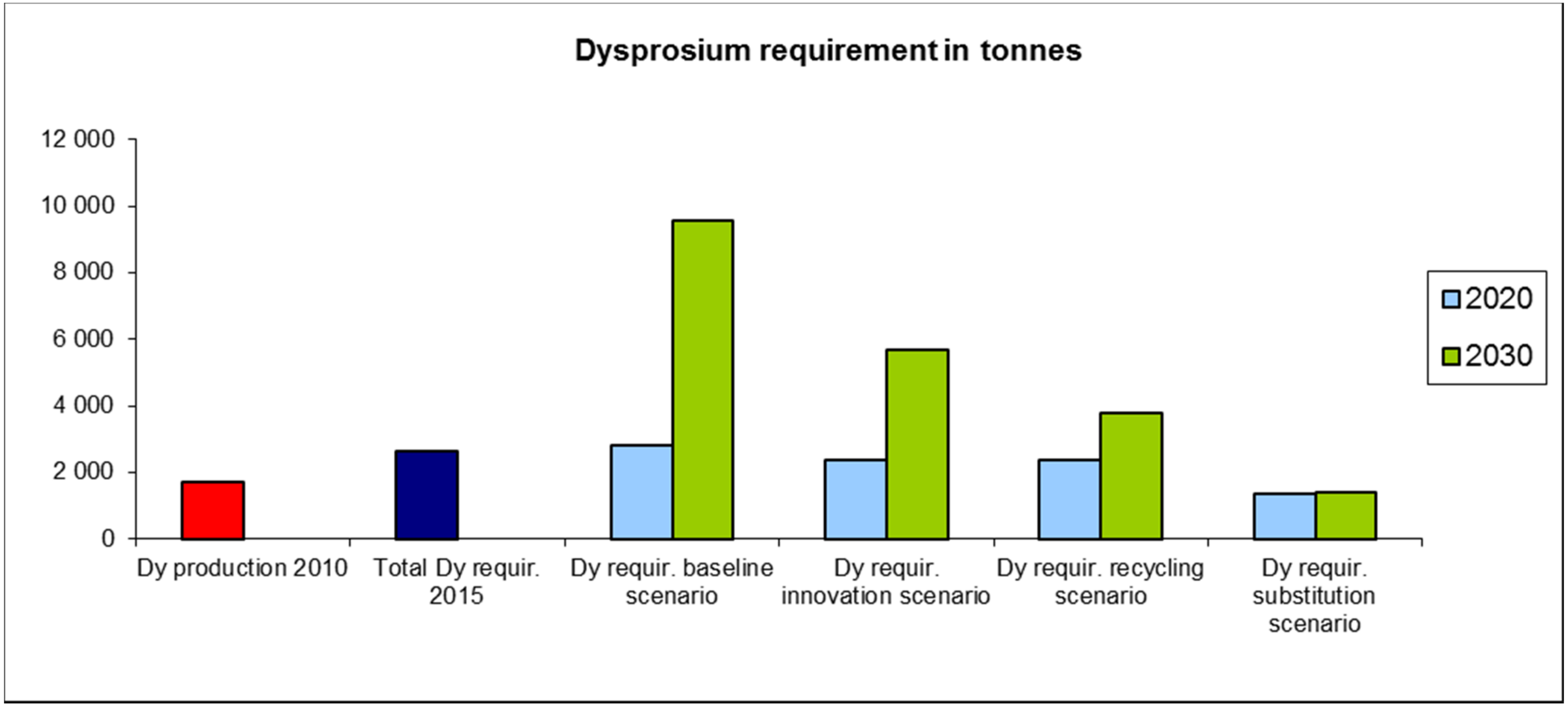


Source: IMCOA 2011 (total Nd requirement 2015), Öko-Institut 2011

Dy requirements of e-mobility in the scenarios and total requirement across all applications



Sources: BGR 2011 (Dy production 2010), IMCOA 2011 (total Dy requirement 2015), Öko-Institut 2011

Tb requirements of e-mobility in the scenarios and total requirement across all applications

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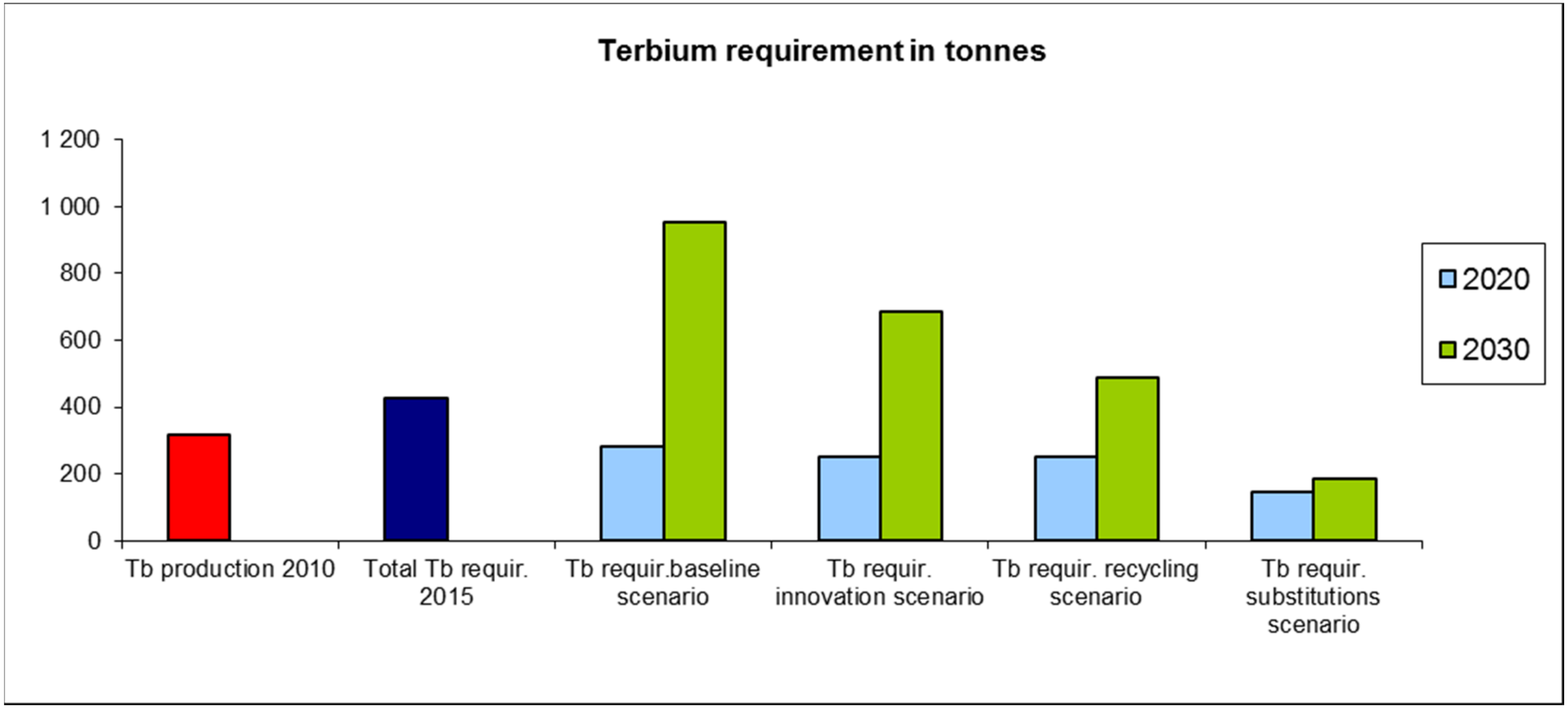

Sources: BGR 2011 (Tb production 2010), IMCOA 2011 (total requirement 2015), Öko-Institut

Ga requirements of e-mobility in the scenarios and total requirement across all applications

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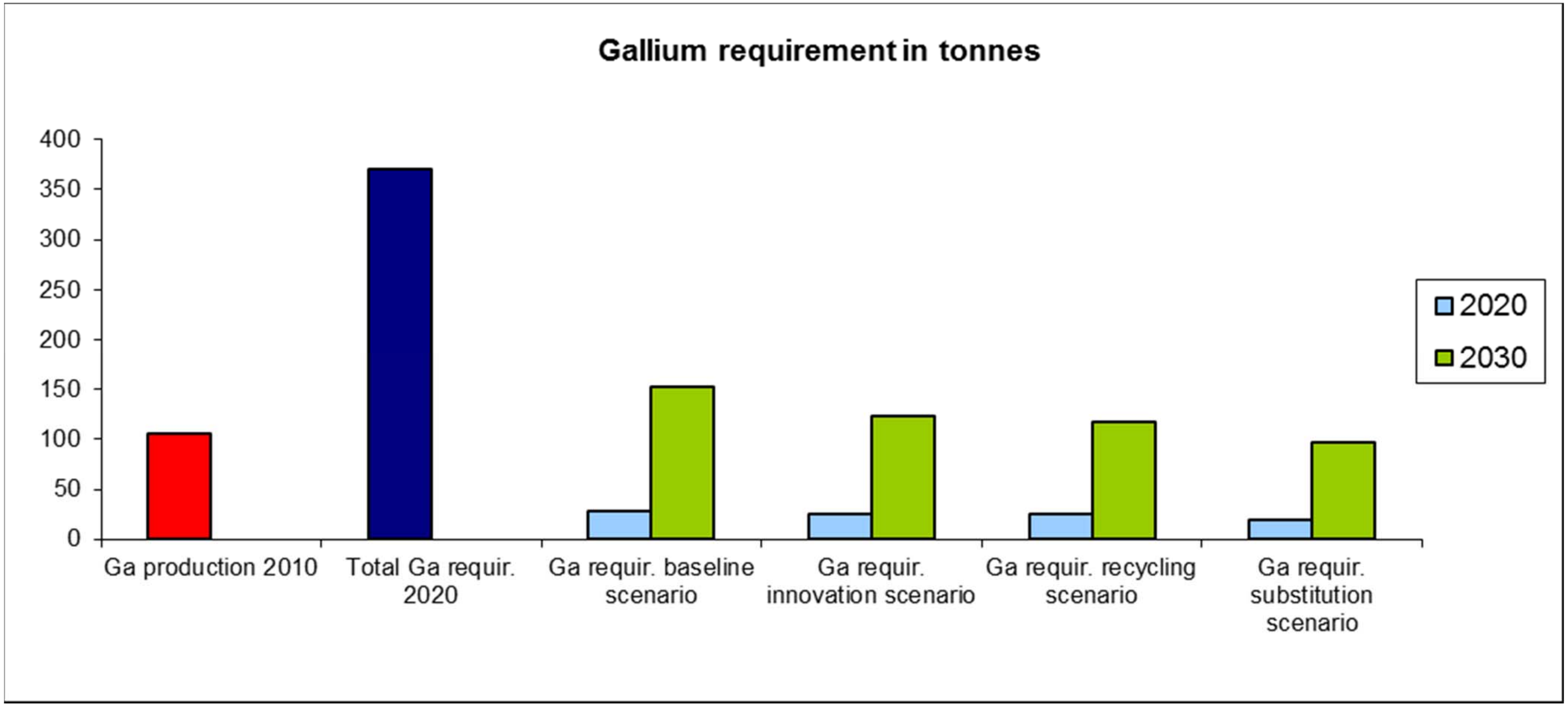


Sources: USGS 2011 (Ga production 2010), EU critical raw materials 2010 (total Ga requirement 2020), Öko-Institut

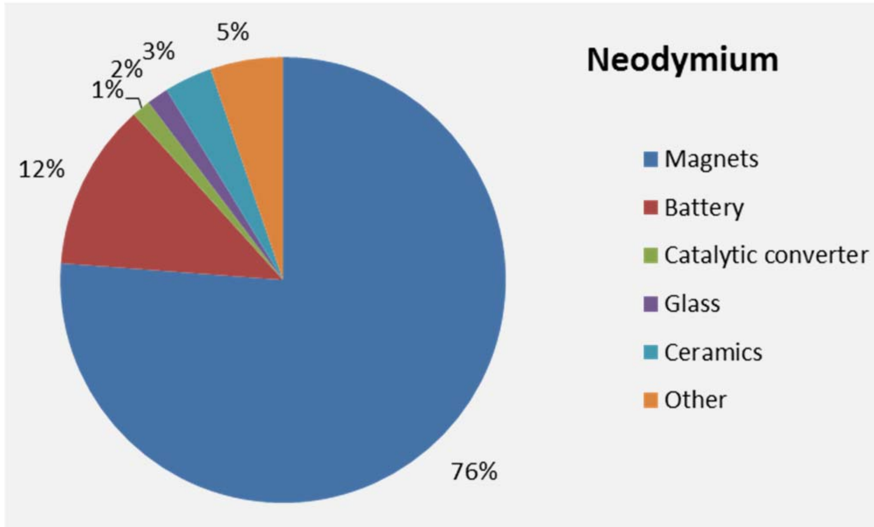
Rare earth applications: current distribution (Nd, Pr, Dy, Tb)

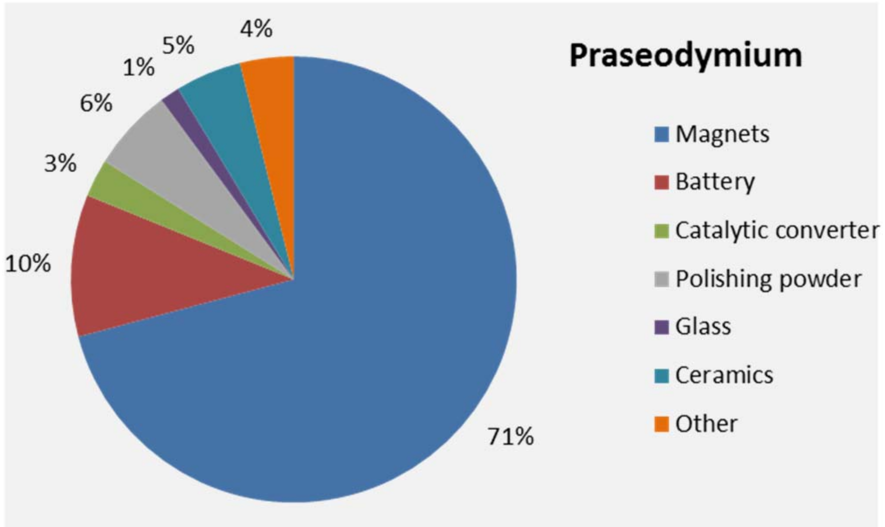
- **Neodymium use:**
  approx. 77% in magnets,
  approx. 12% in batteries,
  and approx. 3% in ceramics, approx. 2% glass, approx. 1% catalytic convertors, approx. 5% other

- **Praseodymium use:**
  approx. 71% in magnets,
  approx. 10% in batteries,
  approx. 6% in polishing powder,
  and approx. 5% in ceramics, 3% catalytic convertors, 1% glass, 4% other

- **Dysprosium use:**
  100% in magnets

- **Terbium use:**
  approx. 11% in magnets,
  approx. 89% in illuminants





Calculation performed by the Öko-Institut

Other rare earth applications: Future distribution

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- Growth rates are rising faster for magnet applications (approx. 12.5% per year to 2014) than for other applications (5-8% per year).
- The proportions of neodymium and praseodymium used for magnet applications will rise to approx. 80% and 74% respectively. These proportions may increase further by 2020 or 2030.
- The future requirement for dysprosium will be determined entirely by magnet applications. In the case of terbium illuminants will continue to dominate until 2014, accounting for 87%; magnet applications for terbium are also becoming slightly more important (approx. 13% in 2014)

As far as we can currently tell, magnet applications will remain the key growth driver for neodymium, praseodymium and dysprosium until 2020 or 2030*

Calculation performed by the Öko-Institut

*** Providing no revolutionary new motors or magnet technologies are introduced.**

Rare earth applications: Various magnet applications

- Within magnet applications, only very small percentages are attributable to electric mobility (passenger vehicles) in 2010:
  - for neodymium and praseodymium the proportion is approx. 0.25% of all magnet applications,
  - for dysprosium it is approx. 1.4%,
  - for terbium it is approx. 5.7%

- New **wind power** technology will account for approx. 2% of neodymium (praseodymium) and approx. 5% of dysprosium.

In 2010 magnet applications continue to be dominated by a wide range of classical applications such as PCs, notebooks, medicine, loudspeakers, electric motors for industry, other industrial applications, and many more.

Calculation performed by the Öko-Institut

Rare earth applications: Various magnet applications

- The findings of the OPTUM resources work package and other Öko-Institut studies of rare earths and wind energy show that both these new technologies are likely to account for a much larger proportion of all neodymium magnet applications than they do now.
- For neodymium and praseodymium the proportion of neodymium magnet applications for which they account could rise to up to 12% by 2020 and to 12-25% by 2030.
- For dysprosium the proportion attributable to electric mobility could rise to 60% by 2020 and to 65-90% by 2030.

By 2020 or 2030 electric mobility will account for a significant proportion of rare earth magnet applications. This is particularly true for dysprosium. Wind power will also require increasing percentages: both applications will be major drivers of future demand.

Calculation performed by the Öko-Institut

Ga requirement by application

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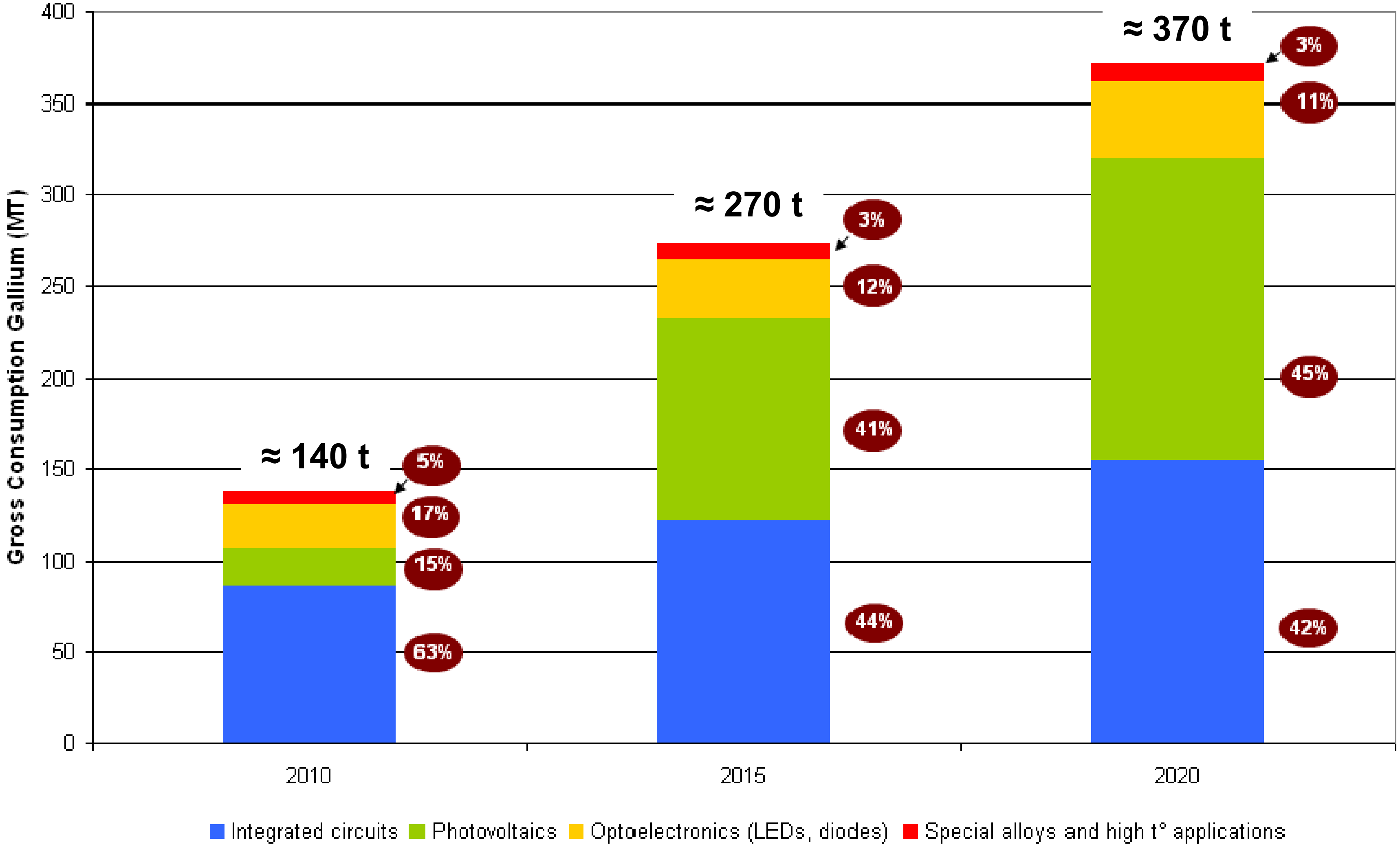

Source: EU critical raw materials 2010

Resource efficiency and resource-policy aspects of the electro-mobility system

- Conclusions and recommendations for action

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Conclusions 1/2

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- Supplies of **rare earths** (esp. Dy, Tb, Nd, Pr) are particularly critical. Recycling will be an important option for reducing scarcity but is not the sole solution for meeting future demands.

- **Gallium** is used in many types of application (e.g. PV, LED). The requirement for it is likely to rise sharply. If demand growth is strong, supply will not become critical in the short term but it will do so in the long term.

- **Indium** does not make a crucial contribution to electric mobility.
BUT: There are many competing areas of application with rapid growth rates. Indium occurs only as a minor metal and must therefore be watched closely.

- **Germanium** does not make a crucial contribution to electric mobility.
BUT: Rapid growth rates could occur in other applications (e.g. fibre optic technology, LEDs) and we lack basic information on germanium (the "phantom" element) and growth in demand for it.

Conclusions 2/2

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- **The precious metals silver, gold, palladium and platinum** also play a part in components for electric mobility: platinum, in particular, is important for fuel-cell vehicles. On the other hand, the development of electric mobility in terms of fully electric vehicles may reduce demand pressure on platinum and palladium by doing away with the need for catalytic convertors.

- **The current critical supply situation of some rare earths** serves as a warning that, despite extensive global geological reserves, shortages can occur – at least temporarily – if geopolitical factors (extraction restricted almost entirely to one country) goes hand in hand with very rapidly rising demand growth. There are lessons to be learnt from this for the future so that appropriate action can be taken promptly and proactively (through timely exploration and development of deposits, diversification of supply, promotion of recycling etc.)

Recommendations for action 1/4

- **In view of the risk of a "bottleneck" in the supply of rare earths, different relief strategies need to be pursued simultaneously**
  - R&D into reduction of REs (esp. Dy) in magnets for e-engines and into RE-free e-engines
    → *Responsible: Government ministries for promotion programmes, OEMs (manufacturers of electric engines, magnet manufacturers) and the scientific community with regard to innovation*
  - Development of recycling technologies for permanent magnets from different applications
    → *Responsible: Government ministries for promotion programmes, the recycling industry, the scientific community*
  - Promotion of environmentally friendly primary production of REs (standards!)
    → *Responsible: German government and EU Commission via international negotiations, companies involved in rare earth mining*

Recommendations for action 2/4

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- **Promotion of more environmentally sound mining of critical metals**
  - There is significant potential to make better use of natural resources by improving extraction rates in the primary production and processing of many metals (e.g. rare earths). For important minor metals such as indium potential also exists in the form of unused residues at mining sites now partly closed.
    → *Responsible: BGR and institutes involved in mining and processing that can prospect for mining residues and promote technical cooperation and knowhow transfer in relation to optimised extraction*

Recommendations for action 3/4

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- **Development of recycling strategies and technologies for the recycling of power electronics from EOL electric vehicles**
  - Recovery of copper, gallium, precious metals etc.
    → Responsible: Government ministries for promotion programmes, the recycling industry and the scientific community

- **General research needs:**
  - Analysis of potential and opportunities available in "conventional" electronics and special magnet applications in future vehicles of all types in terms of precious and special metals incl. rare earths

    → Responsible: Government ministries for promotion programmes and OEMs (manufacturers of auto electronics and magnets)

Recommendations for action 4/4

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- Significant increases are expected in the use of gallium, indium and germanium in other applications: it is at present unclear whether growth rates – and hence supply risks – resulting from technological revolutions such as LED or PV (post Fukushima) are still being underestimated:
  the medium- and long-term effects on e-mobility need to be explored and solution strategies developed.
  → *Responsible: Government ministries for promotion programmes*

Final comments

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- Despite the challenges associated with supplying the specific raw materials needed for electric mobility, it is important not to underestimate the positive environmental effects (e.g. reduced use of classical components and materials) and the other dimensions of sustainability (e.g. new added value and jobs through innovative recycling structures).
- In the discussion it is extremely important not to ignore the significant emission reduction potentials of electric mobility in the use phase, provided that appropriate use is made of green electricity.

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