European Institute of Innovation & Technology

EIT HEI Initiative

Innovation Capacity Building for Higher Education

Funded by the European Union

Sustainable mining and the digital mine role in the digital age

Dr.-Ing. Dipl.-Wirt.Ing. Stefan Möllerherm

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Technische Hochschule Georg Agricola

RAW MATERIALS APPLICATION

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Group of minerals

Technische Hochschule Georg Agricola

- **Fossil fuels** (coal, lignite, oil, natural gas, uranium, shale gas, tar sands)
- **Ferrous metals** (iron)
- **Base metals** (copper, lead, zinc, tin)
- **Alloys** (chromite, cobalt, manganese, molybdenum, nickel, niobium, titan, vanadium, rhenium)
- **Light metals** (bauxite, magnesium)
- **Precious metals** (gold, silver)
- **Platinum Group Minerals** (platinum, palladium, rhodium, ruthenium, osmium and iridium)
- **Industrial minerals** (potash, rock salt, phosphate, barite, fluorite)
- **Construction materials** (sand, gravel, limestone, gypsum)
- **Heavy minerals** (Wolframite)

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Group of minerals

Technische Hochschule Georg Agricola

- **Fossil fuels** (Coal, lignite, oil, natural gas, uranium, shale gas, tar sands)
- **Ferrous metals** (iron)
- **Base metals** (copper, lead, zinc, tin,
- **Alloys** (chromite, cobalt, manganese, molybdenum, nickel, niobium, titan, tantalum, vanadium, rhenium)
- **Light metals** (Bauxite, magnesium)
- **Precious metals** (gold, silver)
- **Platinum Group Minerals** (platinum, palladium, rhodium, ruthenium, osmium and iridium)
- **Industrial minerals** (potash or potassium, rock salt (NaCl), phosphate, barite, fluorite)
- **Construction materials** (sand, gravel, limestone, gypsum)
- **Heavy minerals** (Wolframite)

eit European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Group of minerals

Technische Hochschule Georg Agricola

- **Mica**
- **Kaolin or china clay**
- **Antimony or stibium**
- **Perlite**
- **Disthene-Group** (Disthene, Andalusite, Sillimanite)
- **Beryllium**
- **Zircon**

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Technology minerals

Technische Hochschule Georg Agricola

- **Germanium**
- **Gallium**
- **Indium**
- **Lithium**
- **Rare Earth Elements REE**
  - *Light Rare Earth Elements*: Lanthanum, Cerium, Praseodymium, Neodymium, Samarium, Europium
  - *Heavy Rare Earth Elements*: Gadolinium, Dysprosium, Terbium, Yttrium, Erbium
- **Scandium**

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Technische Hochschule Georg Agricola

EXAMPLES OF APPLICATIONS

Energy supply, Industry 4.0, Smartphones

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

ELEMENTS OF A SMARTPHONE

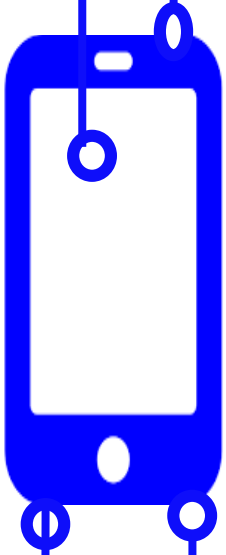
Technische Hochschule Georg Agricola

SCREEN

Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.

The glass used on the majority of smartphones in an aluminosilicate glass, composed of a mix of alumina (Al_2O_3) and silica (SiO_2). This glass also contains potassium ions, which help to strengthen it.

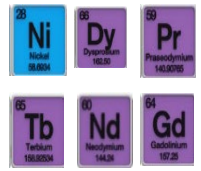
A variety of Rare Earth Element compounds are used in small quantities to produce the colors in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.



ELECTRONICS

Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which micro electrical components are fashioned. Tantalum is the major component of micro-capacitors.

Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium in the vibration unit.



Pure silicon is used to manufacture the chip in the phone. It is oxidized to produce non-conducting regions, then other elements are added in other to allow the chip to conduct electricity.

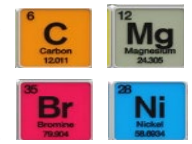
Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

BATTERY

The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in the place of cobalt. The battery's casing in made of aluminum

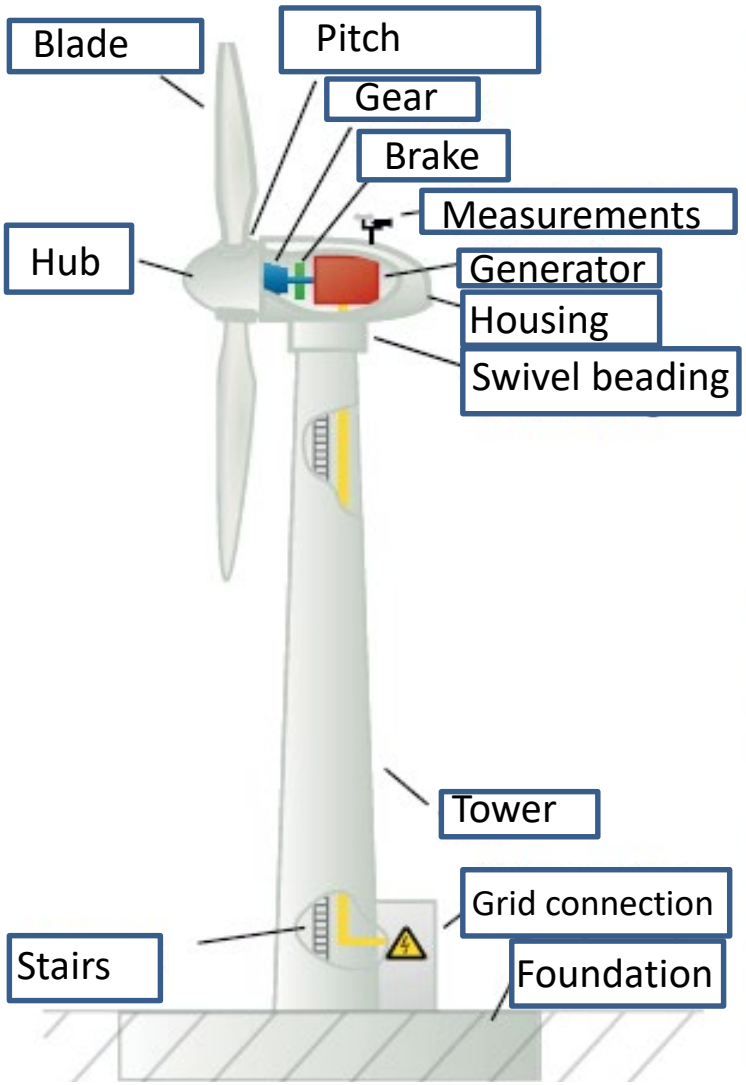
CASING

Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.



Wind mill

Technische Hochschule Georg Agricola

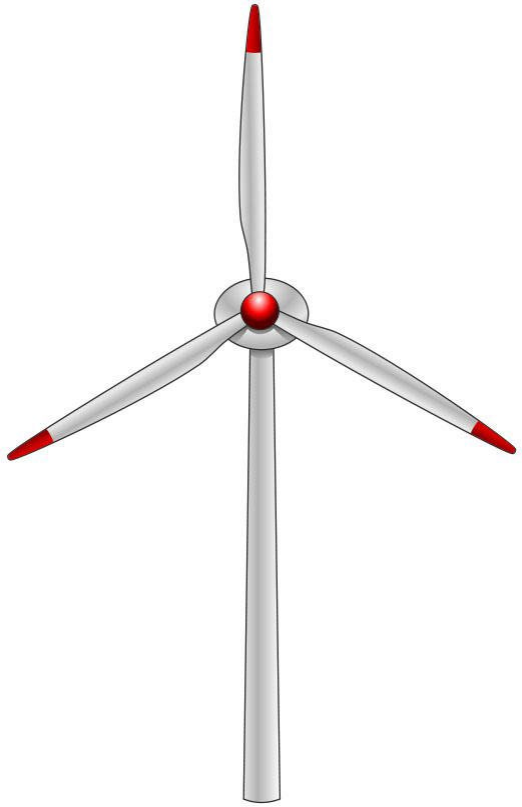


Materials for the construction of a wind mill

Technische Hochschule Georg Agricola

	Typical per cent per weight
Concrete	60 – 65%
Steel	30 – 35%
Composite material	2 – 3%
E-components	< 1%
Copper	< 1%
Aluminium	< 1%
PVC	< 1%
Lubricants	< 1%

Source: DERA 2016



European Institute of Innovation & Technology
Funded by the European Union
HEI4S3RM

Raw materials in wind mills

Technische Hochschule Georg Agricola

Raw material	Wind mill with gear, on shore wo foundation	2 MW off shore wind mill	Wind mill with gear, off shore with foundation	On shore wind mill
Steel/iron	115	148	340	364
Copper	2	2,75		4,6
Aluminium	2	0,42	2	2,6
Concrete		1050		671
Gravel		150		

Material consumption in t/MW

Source: DERA 2016

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Comparison of wind power generator

Technische Hochschule Georg Agricola

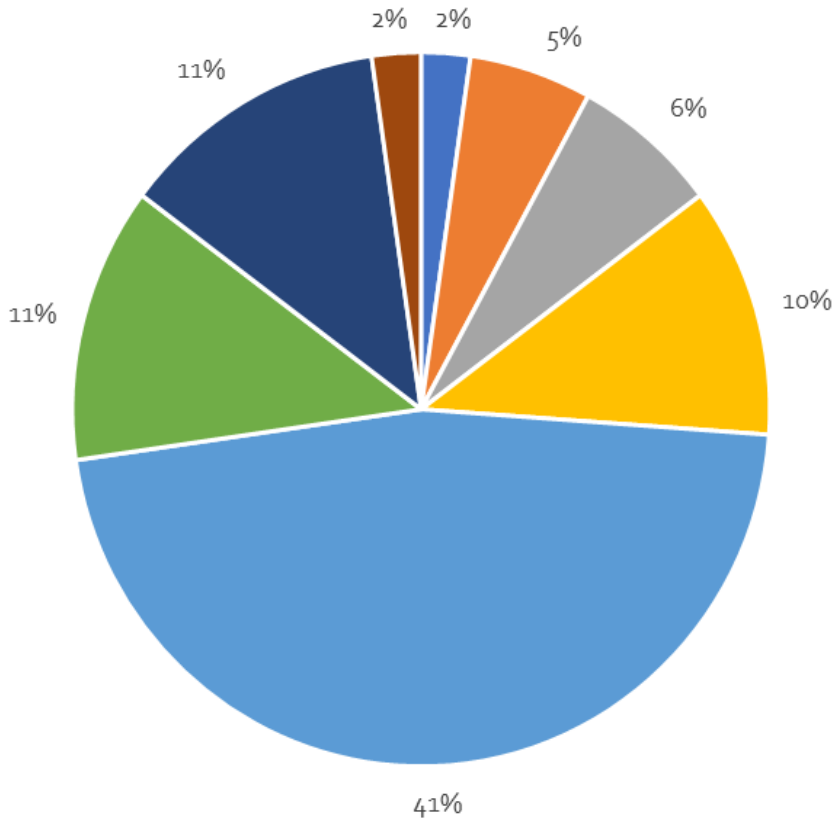
Type	Copper	Permanent magnets	HTS
Rated power	8 MW	8MW	8 MW
Revolution speed	11,5 rpm	11,5 rpm	11,5 rpm
Efficiency	93%	95%	98%
Size			
Diameter	11 m	7	3,8 m
Length	2,8	2,6 m	2,3 m
Raw materials			
Copper	80 t	15,5 t	8 t
Electric steel	330 t	150 t	70 t
REE	0 t	2 t (Nd, Dy)	0,02 t (Y, La, Ce, Gd)

Source: DERA 2016

HTS = High Temperature Supra conductor

Use of NdFeB magnets in different sectors (2012)

Technische Hochschule Georg Agricola



NdFeB=Neodymium Iron Boron

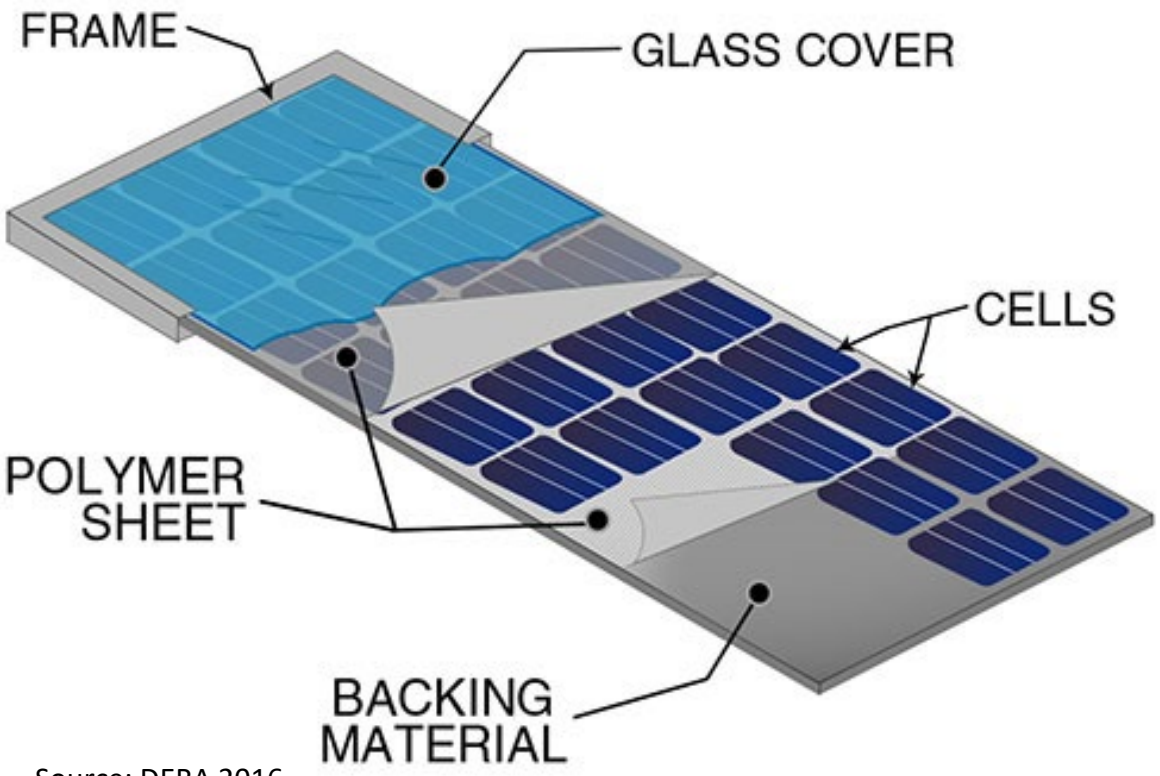
European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Solar module

Technische Hochschule Georg Agricola



Source: DERA 2016

Conventional, traditional or wafer-based cells made of crystalline silicon

"Thin film solar cells"
- Cadmium Telluride (CdTe) cells
- Copper Indium Gallium Selenide (CIGS) cells

Amorphous silicon or amorphous silicon-germanium solar cells

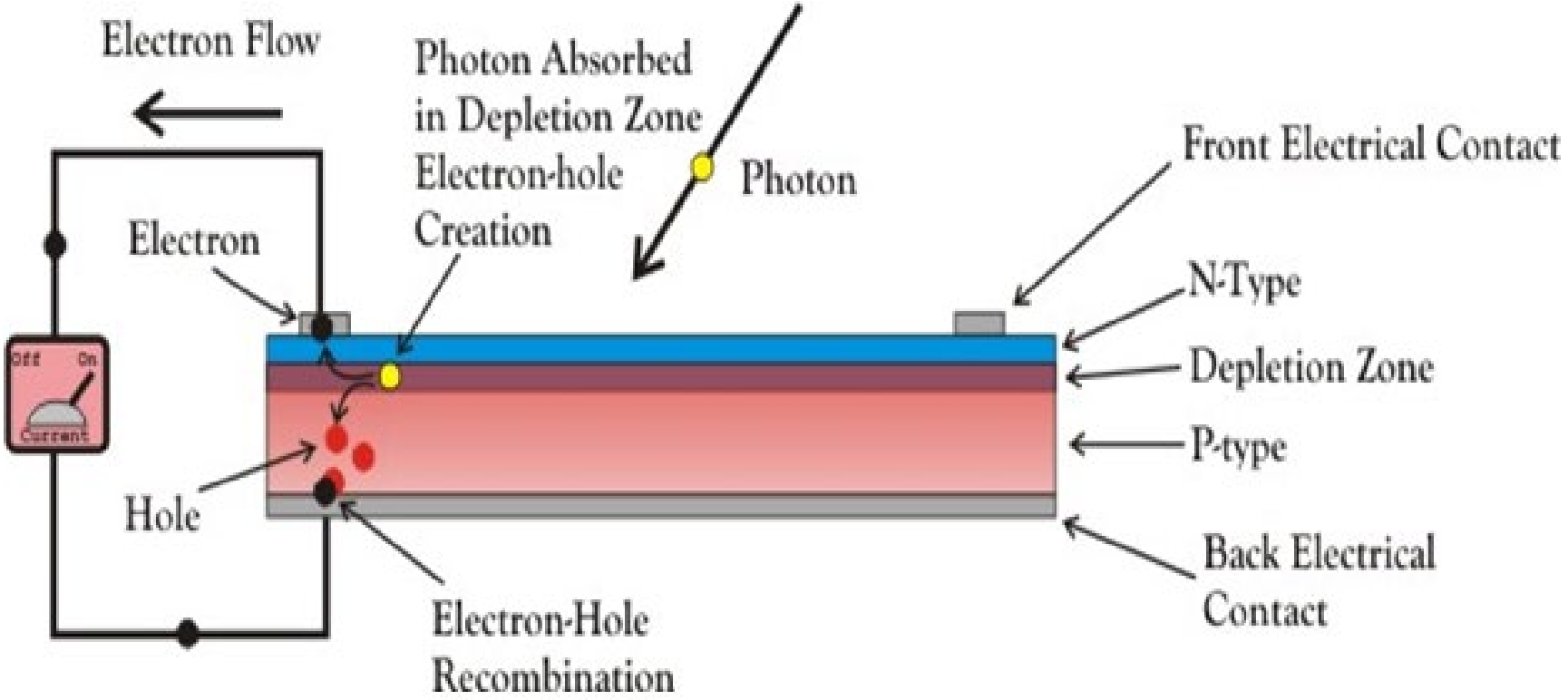
eit | European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Function of a solar module

Technische Hochschule Georg Agricola

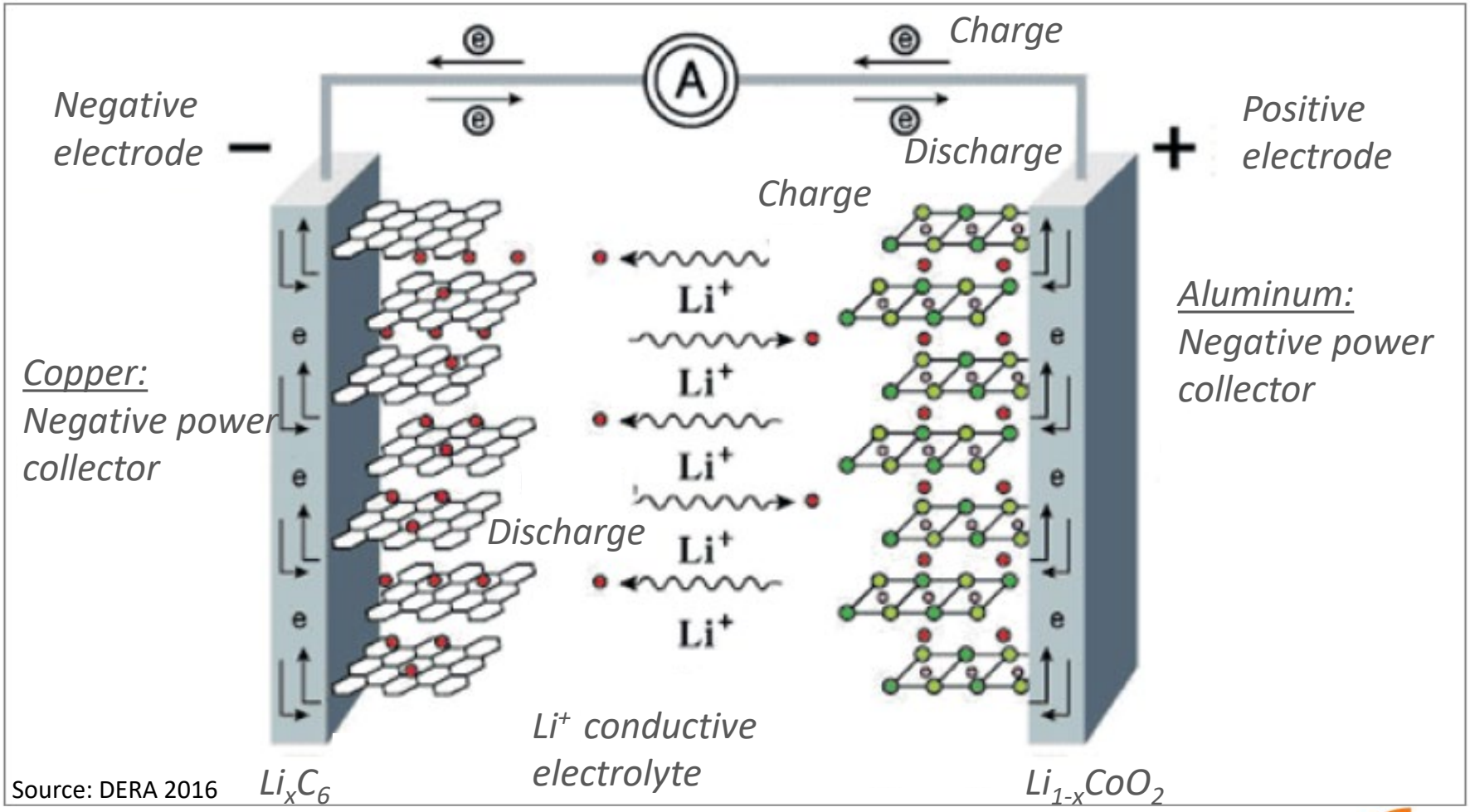


Source: DERA 2016

European Institute of Innovation & Technology
Funded by the European Union
HEI4S3 RM

Energy storage

Technische Hochschule Georg Agricola



Source: DERA 2016

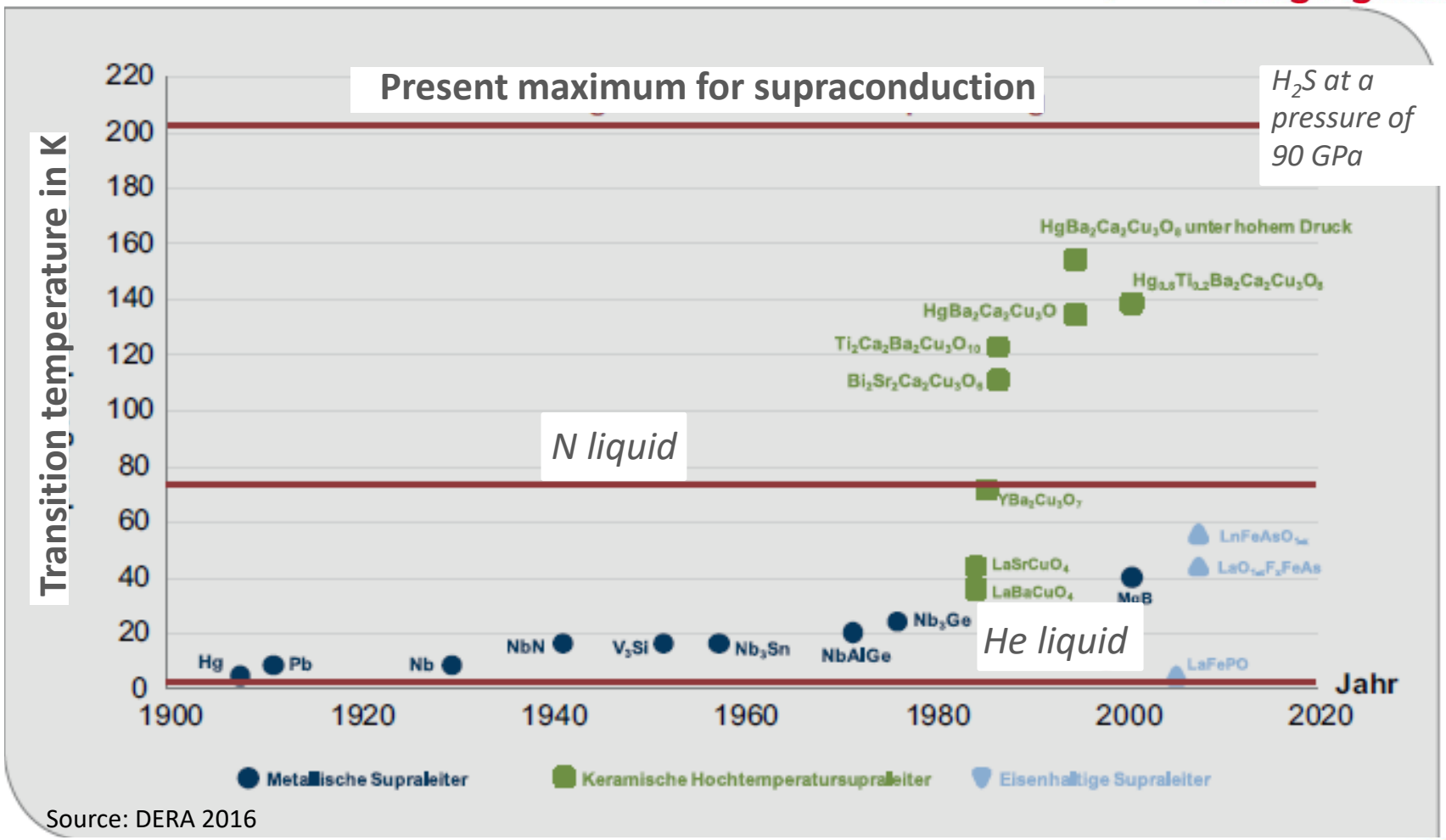
European Institute of Innovation & Technology

Funded by the European Union

HEI4S3RM

Superconductor

Technische Hochschule Georg Agricola



Source: DERA 2016

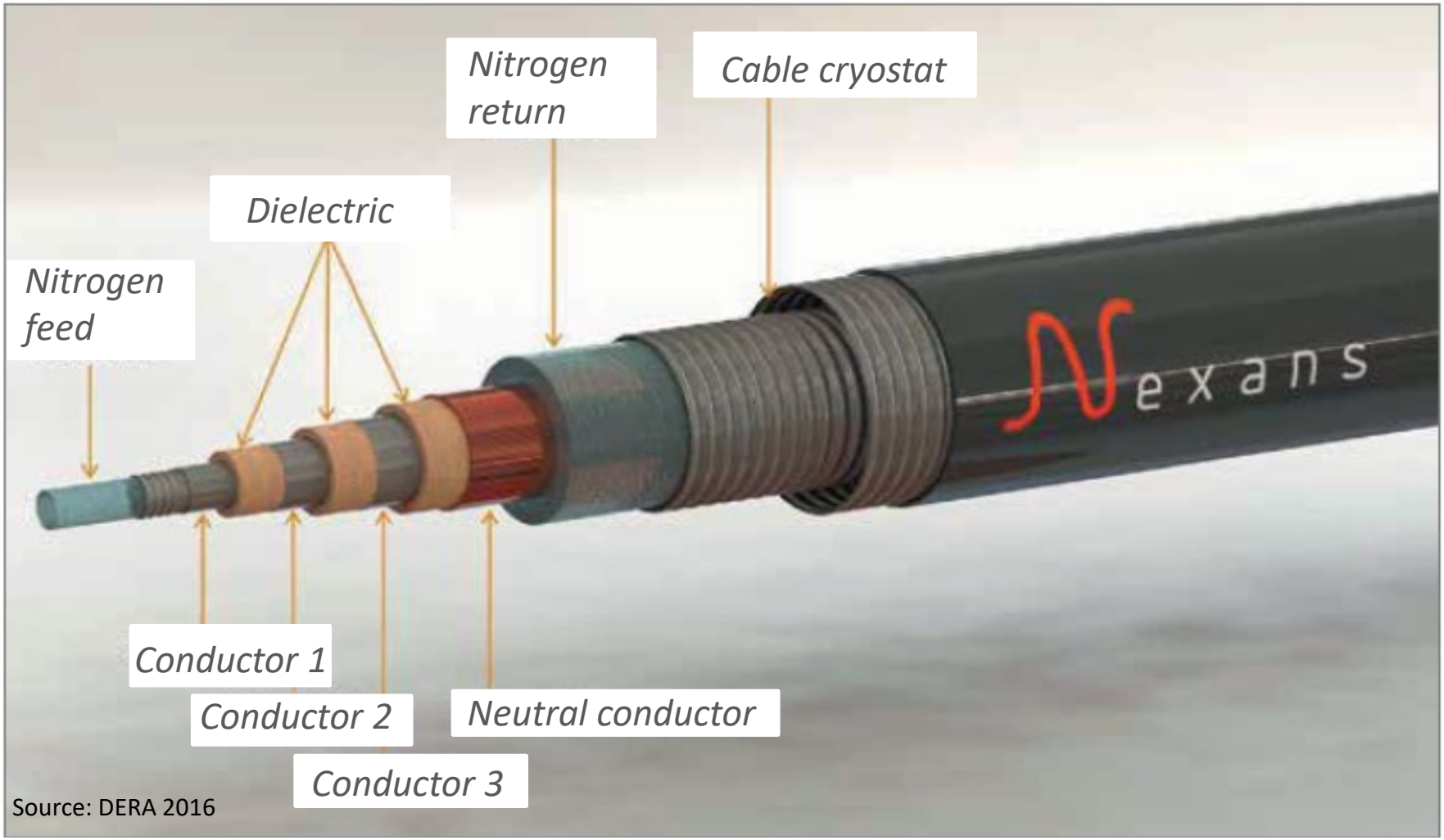
European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Composition of a HTS

Technische Hochschule



Source: DERA 2016

Global production and forecast for HTS

Technische Hochschule Georg Agricola

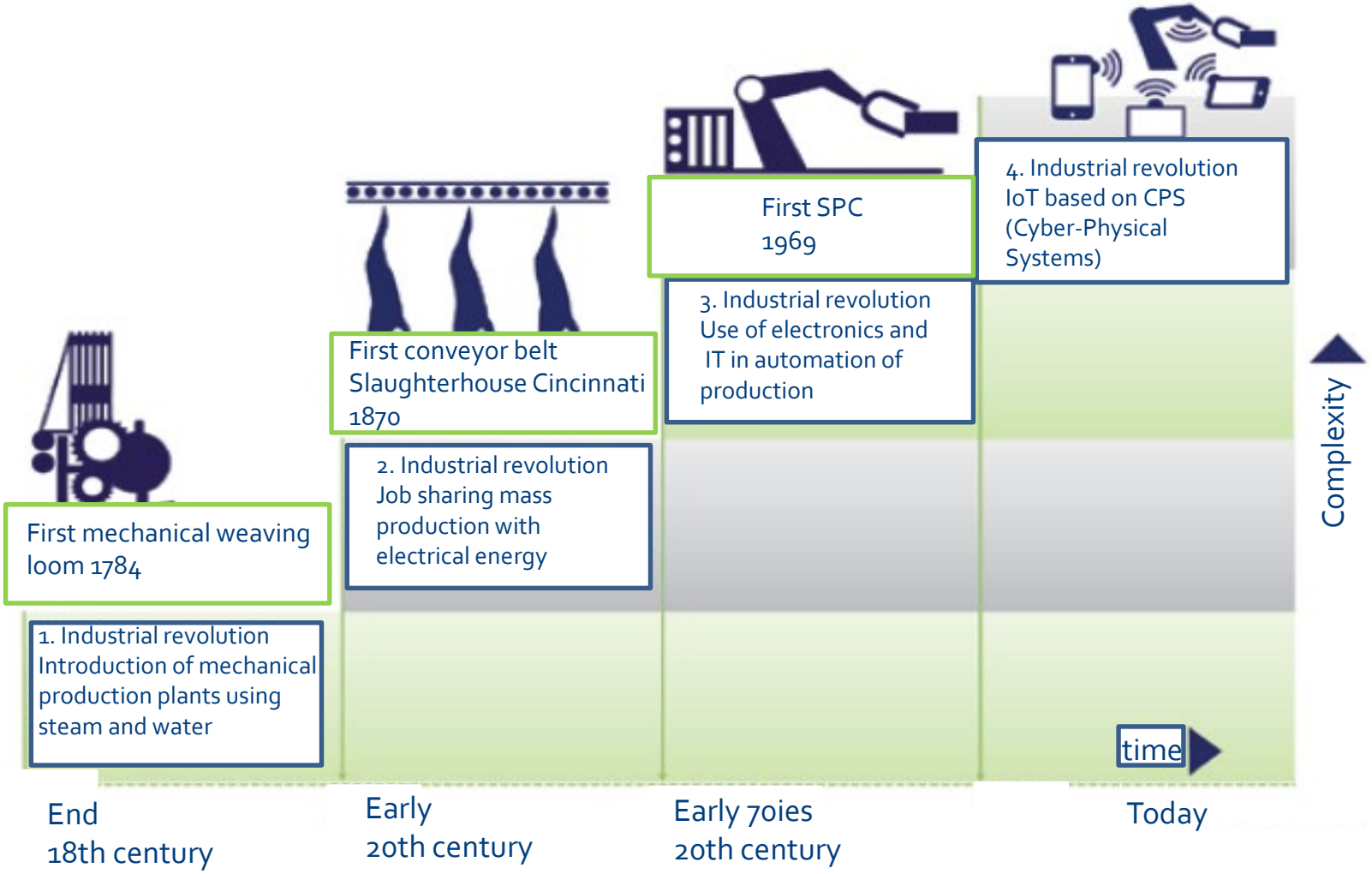
Demand for HTS in engines, generators, transformers and cables

Raw material	Production 2013 (t)	Demand 2013 (t)	Forecast 2035 (t)
Silver	26.241 (Mine)	6	720
Bismuth	17.850 (Proc.)	1	125
Calcium	1.500.000	0,2	24
Ytterbium	5.500	0,0	0,4
Strontium	330.000	0,5	53
Barium	5.431.156	0,0	1,4
Cobalt	129.763 (Mine)	0,0	6,2
Chrome	13.422.102 (Mine)	0,2	40
Molybdenum	270.739 (Mine)	0,2	40
Nickel	2.601.745 (Mine)	0,9	142
Wolfram	82.000 (Mine)	0,1	10
Copper	18.365.341 (Mine)	1,7	260

Source: DERA 2016

Industry 4.0 and IoT

Technische Hochschule Georg Agricola



Materials in temperature detectors

Technische Hochschule Georg Agricola

Type of detector	Material
Temperature measurement	
Pyroelectric detector	$LiTaO_3$ $Pb_3Ge_3O_{11}$ as detector material
Non-contact temperature measurement	Photodiode: Germanium, Silicon, InGaAs
Resistance thermometer	Hot conductor: metal oxides of Mn, Ni, Co, Cu, Fe, Ti Cold conductor: Pt100, $Pb(Zi,Ti)O_3$, $BaTiO_3$
Thermal elements	NiCr or Ni
Semi-conductor temperature sensor	Silicon, Germanium
Bi-metallic switch	Zinc, steel, brass

Source: DERA 2016

European Institute of Innovation & Technology
Funded by the European Union
HEI4S3 RM

Materials in flow and pressure detectors

Technische Hochschule Georg Agricola

Type of detector	Material
Flow measurement	
Ultrasonic sensor	Piezo-electric ceramics, modified lead-zirconat-titanat, and for low-voltage actors: Lead-manganese-niobat
Coriolis mass flow meter	Stainless steel, titanium, tantal
Thermal flow meter	Heated fine metal wire (e.g. platinum, wolfram or its alloys)
Pressure measurement	
Piezo-resistive pressure sensor	Silicon
Piezo-electric pressure sensor	Lead-zirconat-titanat
Hall-generator	Silicon, magnet

Source: DERA 2016

eit European Institute of Innovation & Technology

Funded by the European Union

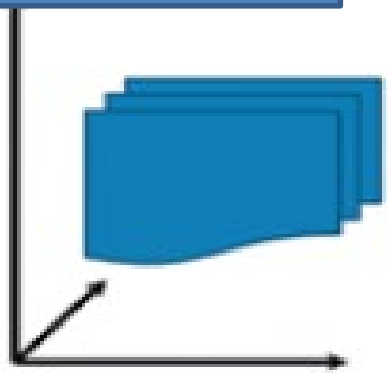
HEI4S3 RM

Additive manufacturing

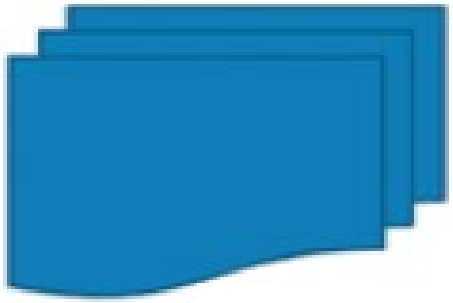
Technische Hochschule Georg Agricola

I Data preparation

II Data processing



III Manufacturing process



IV Finishing

Methods of additive manufacturing

Technische Hochschule Georg Agricola

Method	Principle	Raw material	Activation energy	Market
VAT Photopoly-merisation	Hardening of liquid photopolymer	Plastics, ceramics (liquid, pasty)	UV radiation of laser or lamp	prototyping
Powder Bed Fusion (PBF)	Selective melting of a powder bed	Metal, plastics, ceramic (powder)	Heat radiation of laser or radiator	Prototyping direct part
Direct Energy Deposition (DED)	Targeted melting on the job	Metal powder	Heat radiation of laser or radiator	Direct part repair
Material extrusion	Pointwise charge of melted material	Plastics	Heat radiation in nozzle or pressure head	prototyping
Binder jetting (3D-Printing)	Selective gluing by pointwise binder charge	Metal, plastics ceramics (powder)	No (liquid binding agent)	Prototyping, cast, direct part

Source: DERA 2016

Jet engine

Technische Hochschule Georg Agricola

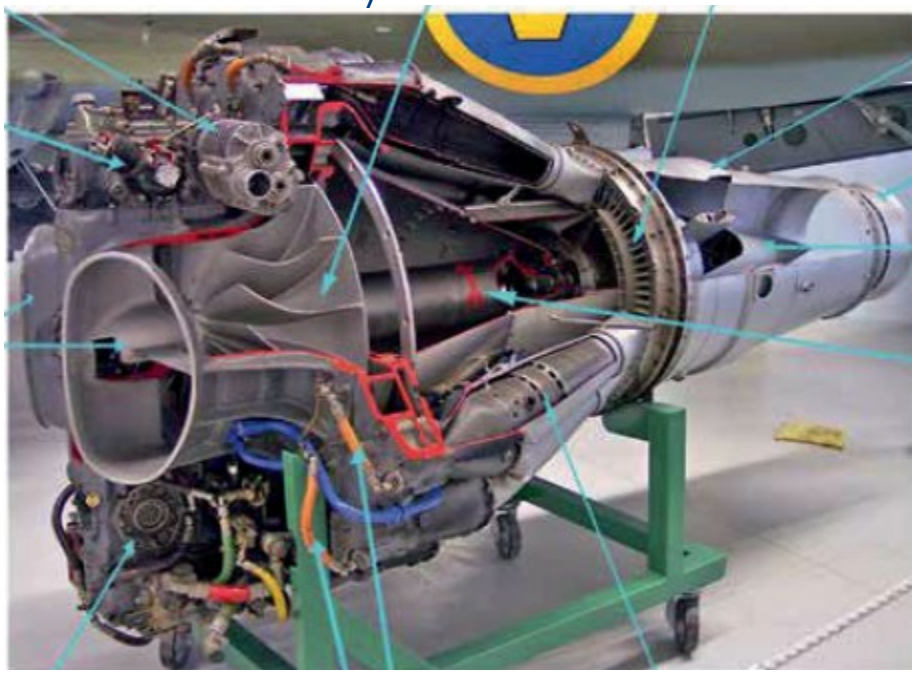
Compressor for the pressure cabin

Centrifugal compressor driven by the turbine

Stator of the turbine

Flange around the jet pipe suppling the cabin with warm air

Compressor for the pneumatic system



Jet pipe

Conus of the turbine

Jet engine air inlet

Main drive shaft combining turbine and compressor

Flange for the starter engine (not mounted)

Fuel pipes to the fuel nozzles in the combustion chambers

16 combustion chambers surrounding the engine

Source: DERA 2016

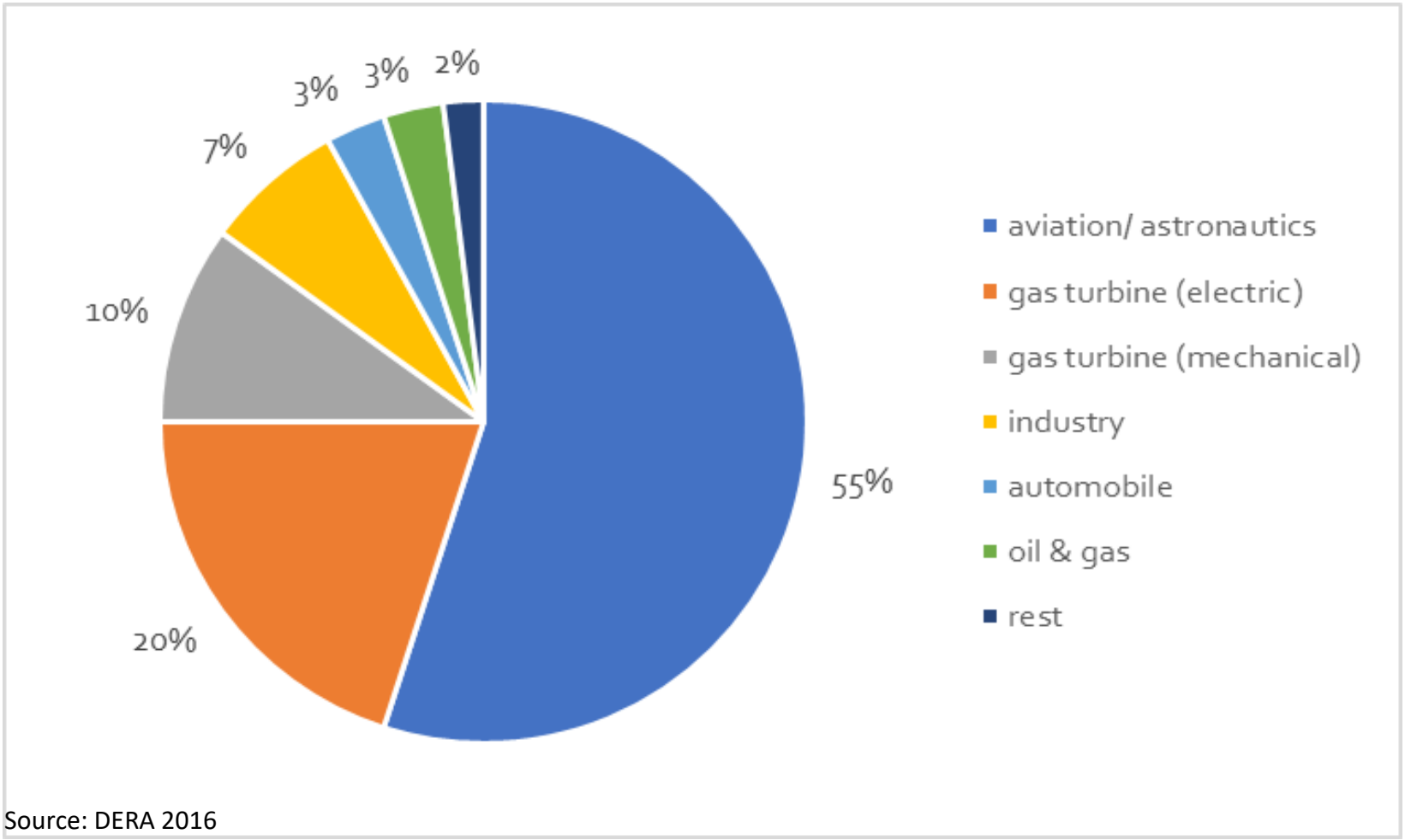
European Institute of Innovation & Technology

Funded by the European Union

HEI4S3 RM

Super alloys usage (2012)

Technische Hochschule Georg Agricola



Source: DERA 2016

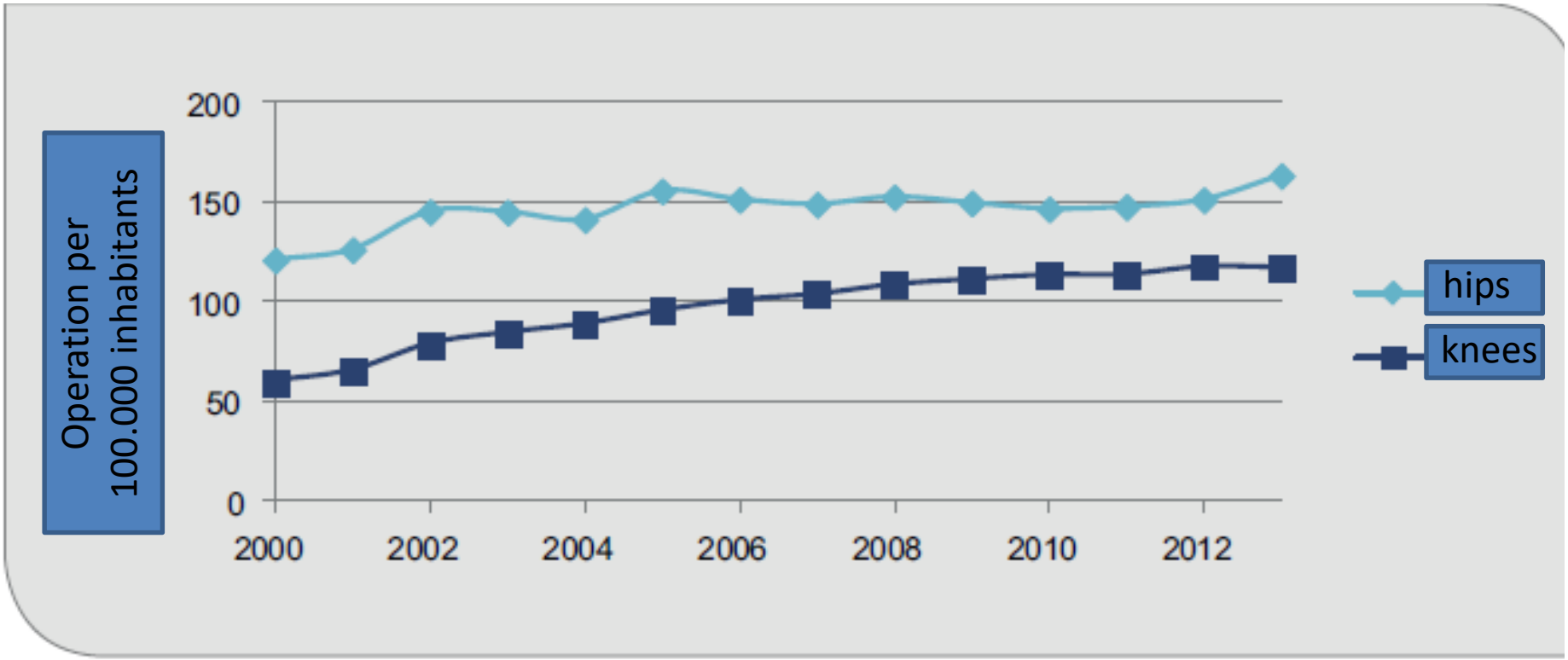
Raw material in medicine

Technische Hochschule Georg Agricola

Metal	Weight/(g)			
	hip prosthesis with Titan shaft	hip prosthesis with CoCrMo shaft	Knee prosthesis with Titan	Knee prosthesis with CoCrMo
Cobalt	140	720		277
Chrome	60	300		125
Molybdenum	15	70		27
Titan	435		280	
total	650	1.090	280	430

Raw materials in medical applications

Technische Hochschule Georg Agricola



Source: DERA 2016

European Institute of Innovation & Technology
Funded by the European Union
HEI4S3 RM

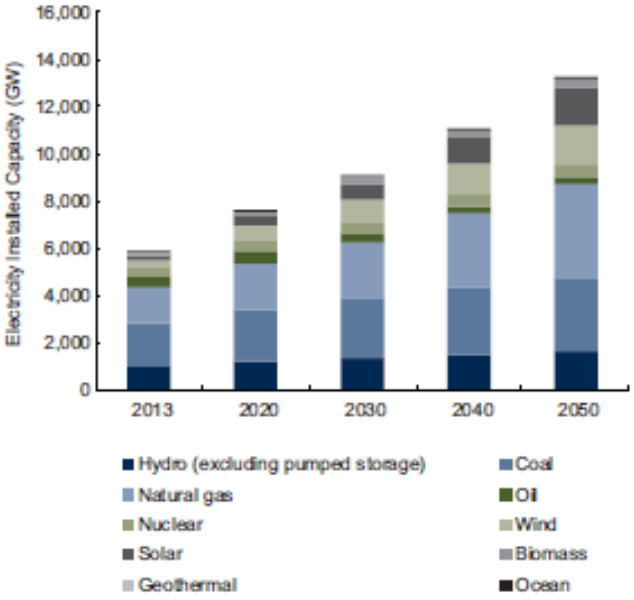
Technische Hochschule Georg Agricola

RAW MATERIALS DEMAND FORESIGHT

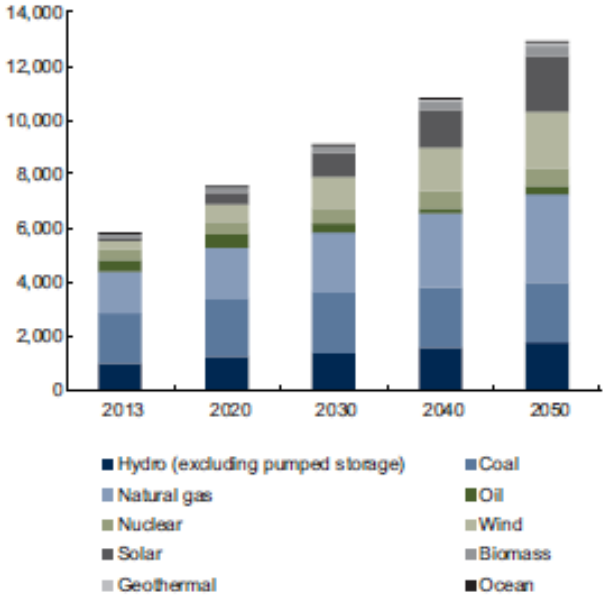
IEA Technology Scenarios for Electricity Installed Capacity

Technische Hochschule Georg Agricola

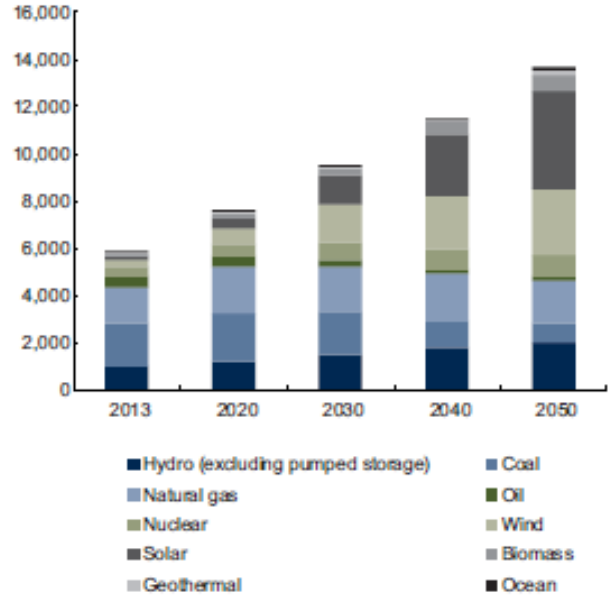
6 degree scenario



4 degree scenario



2 degree scenario

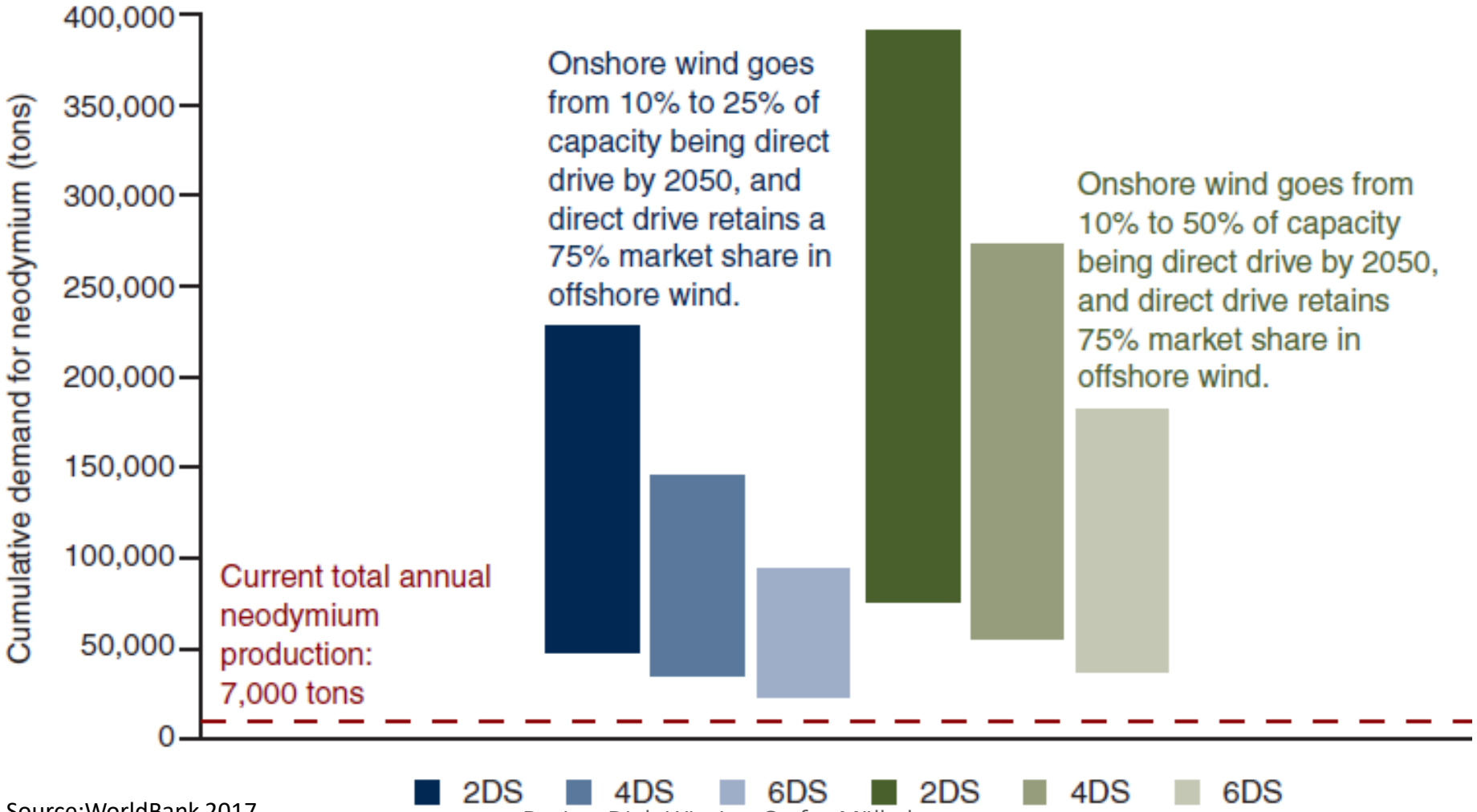


GW = gigawatt

Source: IEA 2016

Future metal demand for wind energy

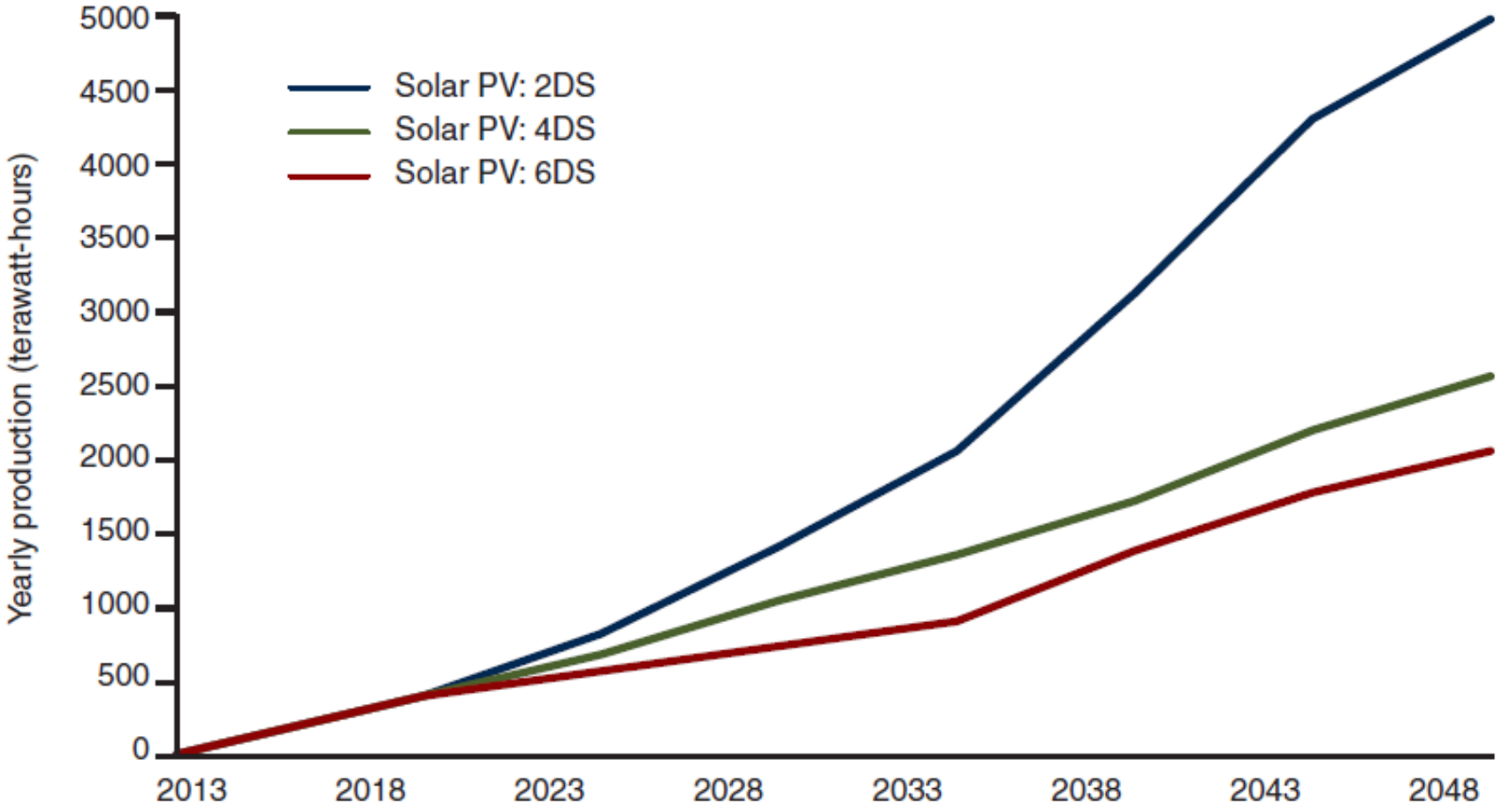
Technische Hochschule Georg Agricola



Source:WorldBank 2017

Solar PV Electricity Production

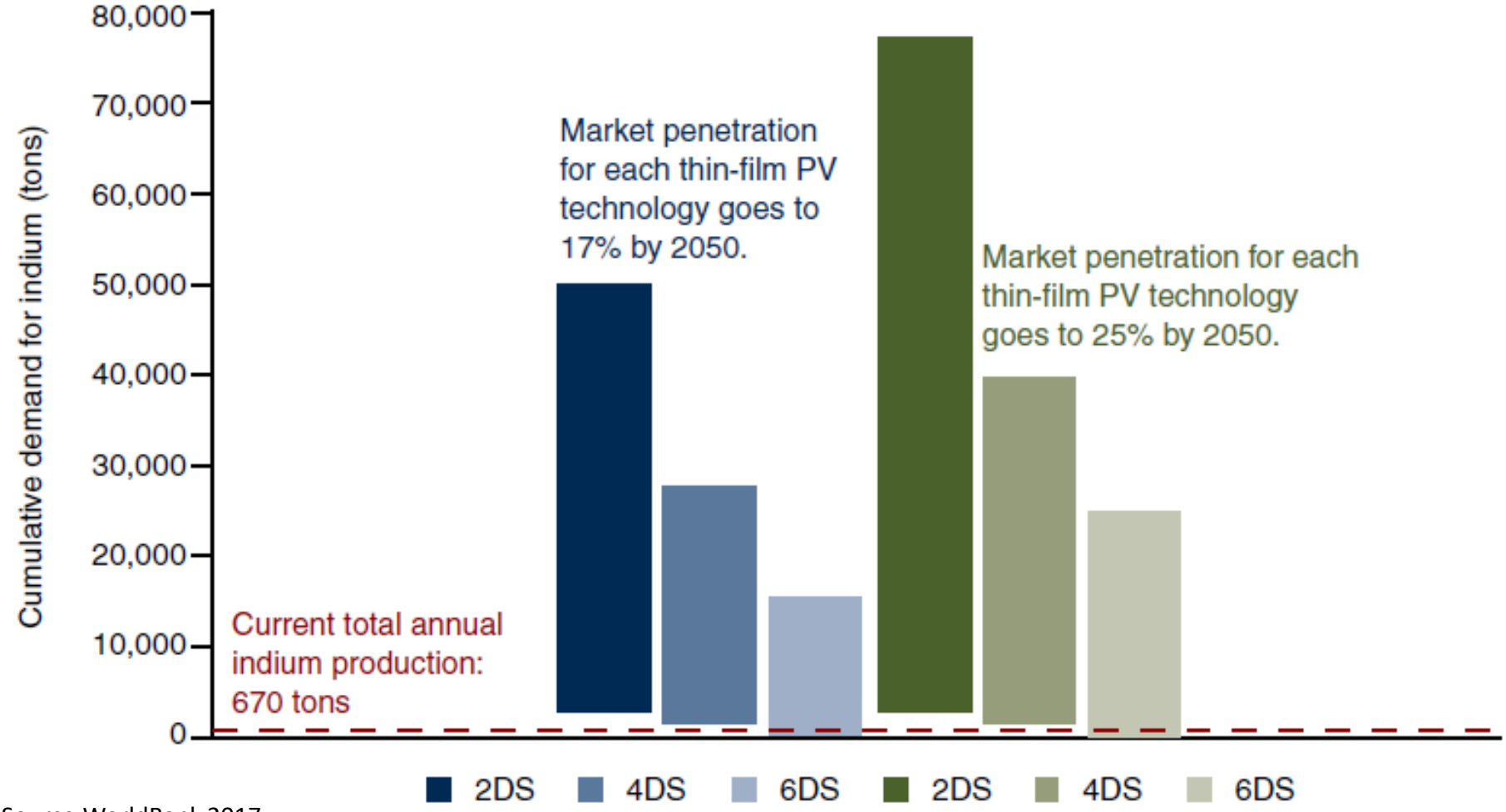
Technische Hochschule Georg Agricola



Source:WorldBank 2017

Cumulative Demand for Indium for CIGS Solar PV Technology

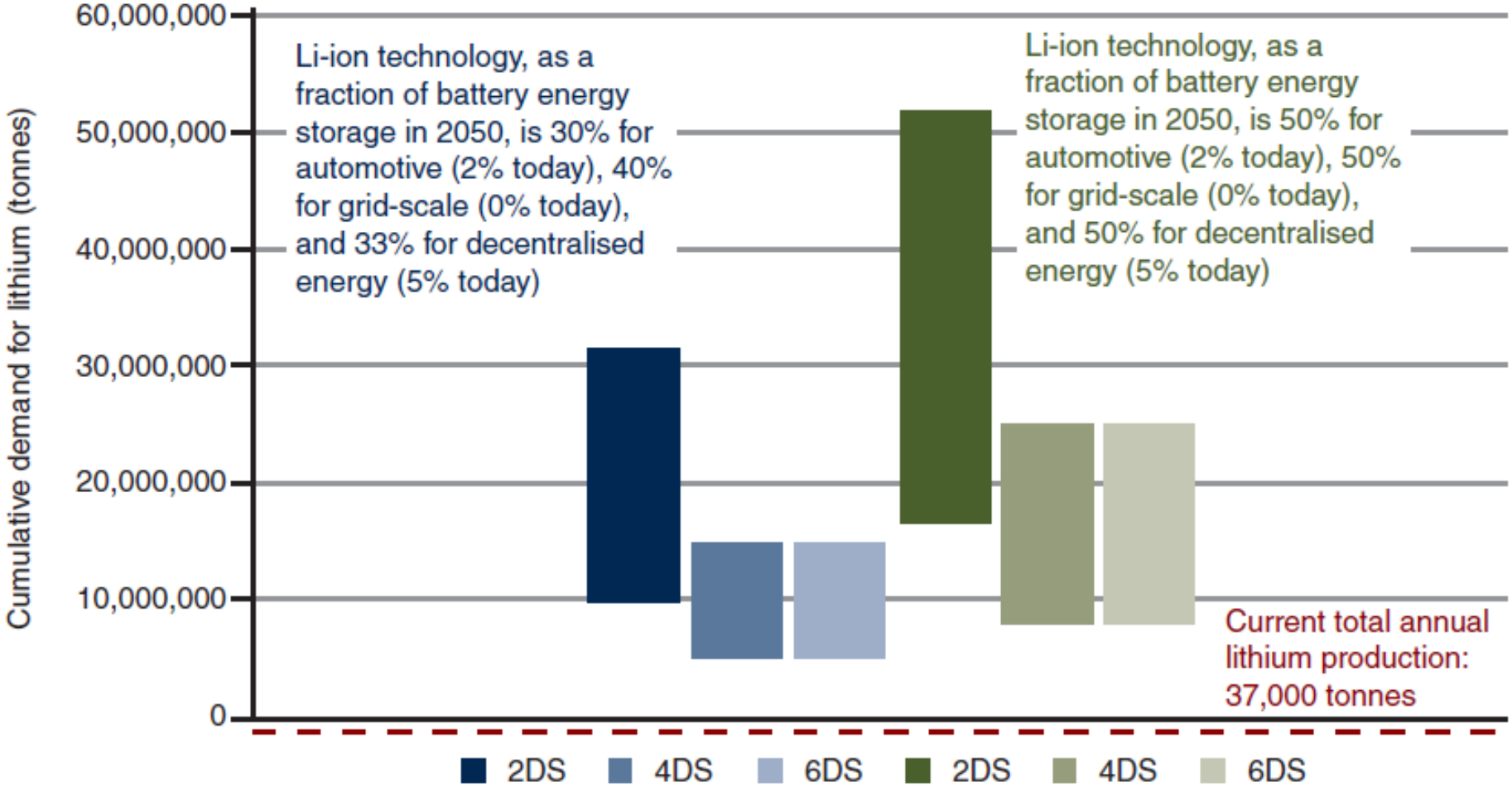
Technische Hochschule Georg Agricola



Source:WorldBank 2017

Demand for Lithium-Ion Battery Technology

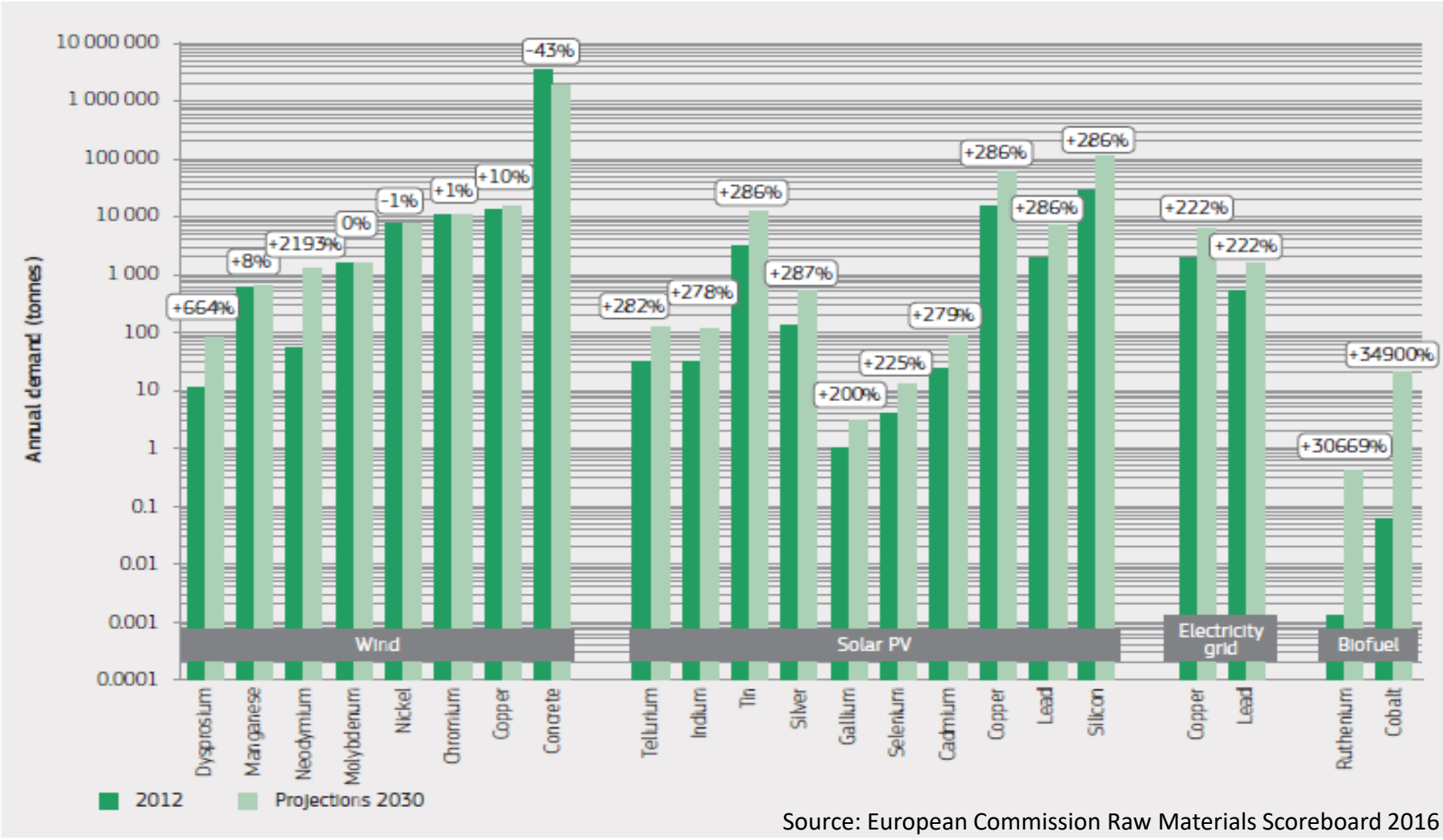
Technische Hochschule Georg Agricola



Source:WorldBank 2017

Current (2012) and projected (2030) annual demand of raw materials used for selected low-carbon energy technologies

Technische Hochschule Georg Agricola



Source: European Commission Raw Materials Scoreboard 2016

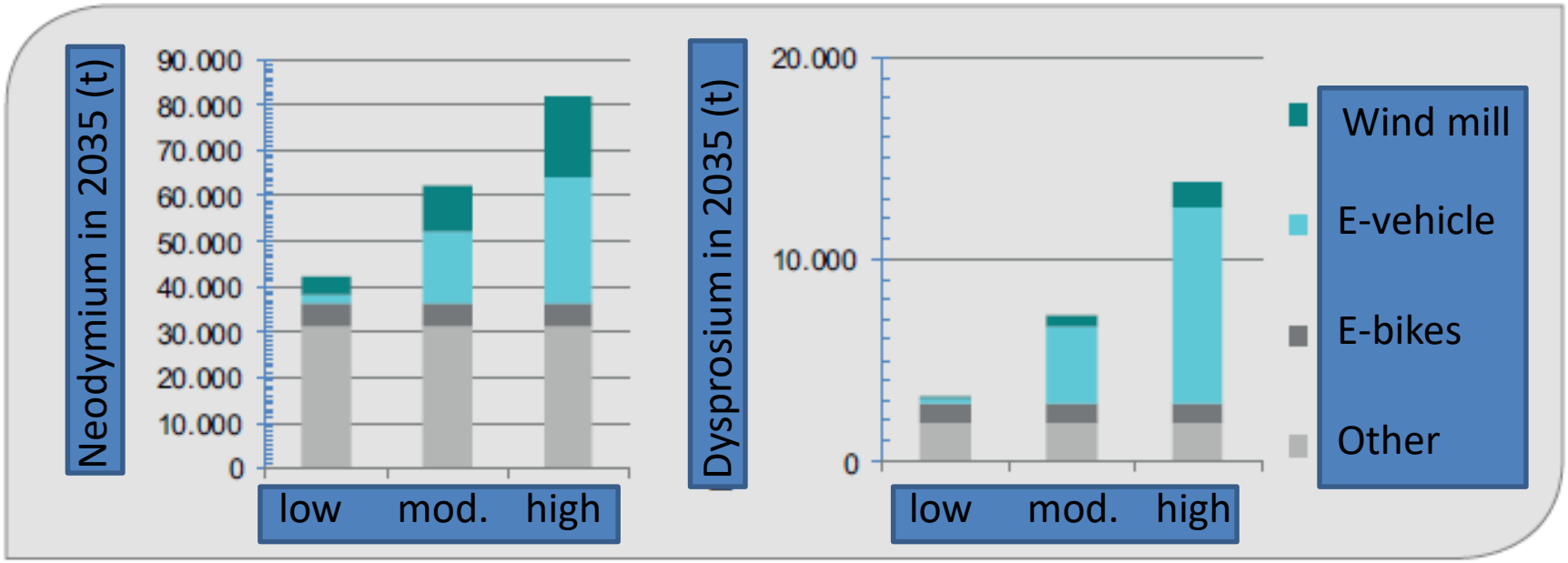
Foresight

Technische Hochschule Georg Agricola

Raw materials	Production 2013	Requirement 2013	Requires preview 2035
Raw steel	1.655.549.570	17.510.000	41.496.660 (23.252.600-55.271.760)
Copper	18.365.341 (M) 21.446.333 (R)	103.000	2444.098 (136.780-325.128)
Aluminum	47.811.880 (R)	103.000	244.098 (136.780-325.128)
Chrome	13.422.102 (M)	48.884	115.849 (64.916-154.306)
Nickel	2.601.745 (M) 1.955.132 (R)	36.313	86.057 (48.222.-114.624)
Molybdenum	270.739 (M)	7.457	17.673 (9.903-23.539)
Manganese	16.900.000	4.975	11.790 (6.606-15.704)
Tin	289.790 (M) 362.996 (R)	8.096	19.186 (10.751-25.555)
Nd, Pr	36.600	To low	10.100 (3.800-17.600)
Dy, Tb	2.330	To low	500 (130-1.170)

Need for REE

Technische Hochschule Georg Agricola



Source: DERA 2016

Worldwide usage of REE in 2012

Technische Hochschule Georg Agricola

Element	Magnet (t REO)	Batteries (t REO)	Metallurgy (t REO)	FCC catalyst (t REO)	Car catalyst (t REO)	Other catalysts (t REO)
Lanthanum		8.185	3.085	13.950	450	
Cerium		1.275	8.490	800	5.965	1.250
Praseodymium	3.800		195			
Neodymium	17.640		480		340	
Samarium	500					
Gadolinium	360		290			
Terbium	70					
Dysprosium	835					
Erbium						
Ytterbium						
Sum	**23.005**	**9.460**	**12.540**	**14.750**	**6.755**	**1.250**

Source: DERA 2016

Demand of REE (light)

Technische Hochschule Georg Agricola

Element	Technology	Demand 2013 (t)	Demand 2035 (t)
Lanthanum	SOFC	10	80
Cerium	SOFC	2	20
Neodymium	Automatic piloting of cars	0	16
Neodymium	Micro-energy harvesting	2,9	1.207
Neodymium	Solid body laser for industrial manufacturing	0,04	0,3
Neodymium/ Praseodymium	High performance permanent magnets	28.900	62.400
Nd/Pr	**Total demand**	**28.903**	**63.624**
Nd/Pr	**Demand / production 2013**	**79%**	**174%**
La	**Total demand**	**10**	**80**
La	**Demand / production 2013**	**0%**	**0%**
Ce	**Total demand**	**2**	**20**
Ce	**Demand / production 2013**	**0%**	**0%**

Demand of REE (heavy)

Technische Hochschule Georg Agricola

Element	Technology	Demand 2013 (t)	Demand 2035 (t)
Ytterbium	Automatic piloting of cars	0	1.004
Ytterbium	SOFC	0,7	5
Ytterbium	Solid body laser for industrial manufacturing	15,1	43,8
Ytterbium	High temperature supra conductor	0	0,9
Dysprosium	Micro-energy harvesting	0,4	162,6
Dysprosium/ Terbium	High performance permanent magnets	2.000	7.200
Y	**Total demand**	**16**	**1.054**
Y	**Demand / production 2013**	**0,3%**	**19%**
Dy/Tb	**Total demand**	**2.000**	**7.363**
Dy/Tb	**Demand / production 2013**	**85%**	**313%**

Source: DERA 2016

Gallium

Technische Hochschule Georg Agricola

Application	2010 (%)
Integrated circuits	41
LED	25
Alloys, batteries, magnets	17
Solar technologies	17
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
White LED	6	19
High performance micro chips	38	86
Thin layer PV	45	25
Total demand	**89**	**130**
Primary production	**25%**	**37%**
Demand for refined production	**45%**	**65%**

Source: DERA 2016

Germanium

Technische Hochschule Georg Agricola

Application	2010 (%)
Infrared optics	30
Glass fibers	20
Polymerisation catalyst	20
Electronics and solar applications	15
Others: (e.g. illuminant, metallurgy, chemotherapy)	15
	100

Source: DERA 2016

Technology	Demand 2013 (t)	Demand 2035 (t)
Glass fibers	56	118
Total demand	**56**	**118**
Demand for refined production	**39%**	**81%**

Indium

Technische Hochschule Georg Agricola

Application	2010 (%)
Flat screens	55
Alloys and brazing solder	10
PV	8
Heat conducting material	6
Batteries	5
Alloys	4
Semi-conductor	3
Others	9

Technology	Demand 2013 (t)	Demand 2035 (t)
Indium-Tin-Oxide (ITO) in display technology	130	274
White LED	0,1	0,3
Thin layer PV	103	87
Total demand	**233**	**361**
Demand for refined production	**29%**	**45%**

Source: DERA 2016

Cobalt

Application	2010 (%)
Batteries	41
Super alloys (Ni, Fe, Co, Cr)	16
Hard metal (carbide, diamante tools)	10
High performance fast cutting steel and other alloys	7
Pigments: glass, enamel, plastics, ceramics, textiles	6
Magnets	5
Catalyst	5
Animal feed, biotechnology, electrolysis,	4
Adhesion means for tires, drying mean for soap and colors	4

Technology	Demand 2013 (t)	Demand 2035 (t)
CCS	1	25
Lithium Ion high performance electricity storages	1.200	110.000
Micro-energy harvesting out of the environment energy	0,5	203
Synthetic fuels	0	2.000
Medical implants	710	1.070
Super alloys	3.100	8.300
High temperature supra conductor	0	12
Total demand	**5.012**	**121.811**
Demand for refined production	**6%**	**142%**

Copper

Technische Hochschule Georg Agricola

Use of copper in the EU

Application	2011 (%)
Electrical infrastructure and equipment	41
Buildings	13
Machines and equipment	13
Automobile	10
Electronics and ICT	7
Traffic (other)	4
Other applications	12
	100

Source: DERA 2016

Technology	Demand 2013	Demand 2035
Electrical traction motor in hybrid, electrical, fuel cell cars	low	5.000.000
RFID Radio Frequency Identification	162	10.800
Micro-electrical capacitor	52	350
Thin layer PV	136	74
CCS	<1	2.338
Inductive transmission of electrical energy	Max 7	1.138
Micro-energy harvesting	43	18.185
Wind mills	103.000	244.098
Medical tomography (Copper and non-ferrous metals)	15.800	53.000
High temperature supra conductor	2	400
Additive manufacturing (3D-printer)	46	9.380
Total demand	**119.049**	**5.339.763**
Demand / mine production 2013	**0,6%**	**29%**
Demand / refinery 2013	**0,6%**	**25%**

Lithium

Technische Hochschule Georg Agricola

Application	2013 (%)
Glass, ceramics	35
Batteries	29
Grease	9
Polymer and pharmaceuticals	5
Air cleaning	5
Aluminum melt	1
Continuous casting	6
Other application	10
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
Alloys for airframe light construction	0	4.650
Lithium Ion high performance electricity storages for cars	607	110.000
Total demand	**607**	**114.650**
Demand/ mine production 2013	**2%**	**385%**

Source: DERA 2016

Platinum

Technische Hochschule Georg Agricola

Application	2013 (%)
Car catalyst	36
Jewelry	35
Investment	10
Chemical catalyst	6
Electronics	3
Medical technology (incl. dental technology	2
Petrochemical industry	2
Glass	1
Other application	5
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
Fuel cell e-vehicles	0	max 93
Synthetic fuels	0	20
Total demand	**0**	**113**
Demand/ mine production 2013	**0%**	**60%**

Source: DERA 2016

Rhenium

Technische Hochschule Georg Agricola

Application	2013 (%)
Aerospace	63
Gas turbines	13
Catalyst	9
Car	5
Tools	2
Oil and gas	2
Other application	5
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
Super alloys	46	120
Total demand	**46**	**120**
Demand/ mine production 2013	**98%**	**250%**

Source: DERA 2016

Scandium

Technische Hochschule Georg Agricola

Application	2013 (%)
Aluminum alloy	85
Illumination	10
Fuel cell	5
Other application	5
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
SOFC	1,1	9
Total demand	**1,1**	**9**
Demand/ mine production 2013	**17%**	**138%**

Source: DERA 2016

Tantalum

Technische Hochschule Georg Agricola

Application	2013 (%)
Capacitors	40
Super alloys	21
Sputter targets for coating processes	12
Rolled Products	11
Carbide containing tools and cutting steel	10
Chemicals	6
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
Micro-electrical capacitors	128	1.070
Super alloys	370	1.000
Total demand	**498**	**2.070**
Demand/ mine production 2013	**38%**	**159%**

Source: DERA 2016

Titan

Technische Hochschule Georg Agricola

Application	2013 (%)
Colors	56
Plastics	27
Paper	9
Carbide, alloys and chemicals	5
Other	3
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
Micro-electrical capacitors	122	800
Micro-energy harvesting	0,3	126
Sea water desalination	8.100	39.000
Medical implants	820	1.240
Total demand	**9.042**	**41.166**
Demand/ mine production 2013	**3,8%**	**17,5%**

Source: DERA 2016

Tin

Technische Hochschule Georg Agricola

Application	2013 (%)
Brazing solder	52
Tin plate	16-17
Chemicals	23
Bronze and cast alloys	5-6
Flat glass production	2
Other	0-2
	100

Technology	Demand 2013 (t)	Demand 2035 (t)
Lead free brazing solder	173.400	133.600
Micro-electrical capacitors	30	210
Micro-energy harvesting	0,2	77,2
Wind mills	8.096	19.186
Total demand	**181.526**	**153.073**
Demand/ mine production 2013	**63%**	**53%**
Demand/ refined production 2013	**50%**	**42%**

Source: DERA 2016

Technische Hochschule Georg Agricola

THANK YOU FOR ATTENTION!

European Institute of Innovation & Technology

Funded by the European Union

HEI4S3RM