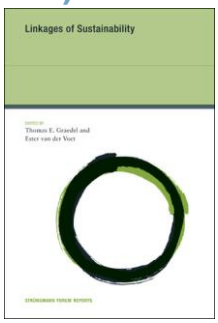
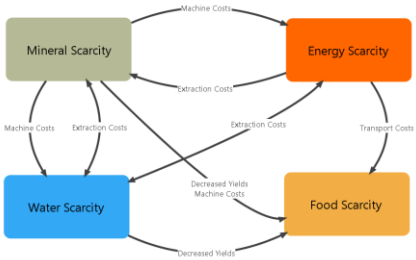
MATERIAL CONSTRAINTS FOR OUR FUTURE ENERGY SUPPLY

- Material needs for future (energy) technologies
  - Material-energy nexus
  - Impact of renewable energy technologies
- Worry about supply of Critical Raw Materials
  - Background of limited growth capacity
  - Supply chain issues
  - Criticality assessments
    - In Europe, US
    - In The Netherlands
- Mitigation?
  - Circular Economy?
  - Substitution?
- Conclusions and next steps

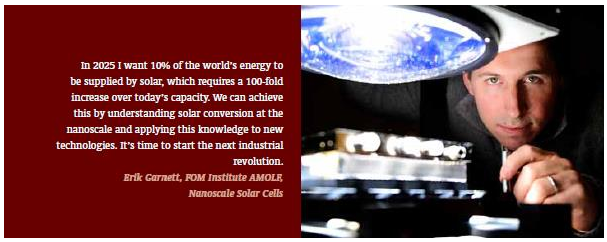
"LINKAGES OF SUSTAINABILITY" (2010)



- Intense linkages:
  - in 2050 up to 40% energy required for metals extraction
  - Metals required for energy transition
  - Material production leads to CO2 emissions
  - Renewable energy leads to less CO2 emission for material production
- Focus of this session:
  - Energy Materials Nexus



Vision paper 2025, ed Robbert Dijkgraaf and many others



In the future, scalability of energy solutions and the use of abundant elements in designing high performance materials will be key (p.18)

Examples are new steels operating at extreme conditions that increase conversion efficiency, alternatives for lithium, alternatives for the magnetic materials with critical rare earth elements currently used in engines and turbines.

Regarding resources, techniques will be developed for recovery/recycling of critical raw materials (p.21)

DE SITUATIE IN 2010 ....

SCENARIOS FOR FUTURE ENERGY TECHNOLOGIES AND MATERIAL CONSEQUENCES

Bron: Scientific American, November 2009

- 'scenario':
  - 3 Mton Nd required
    - If wind turbine with permanent magnets
  - Current production 20 kton Nd
  - 150 years !

replace ALL fossil fuels by 2030 using:

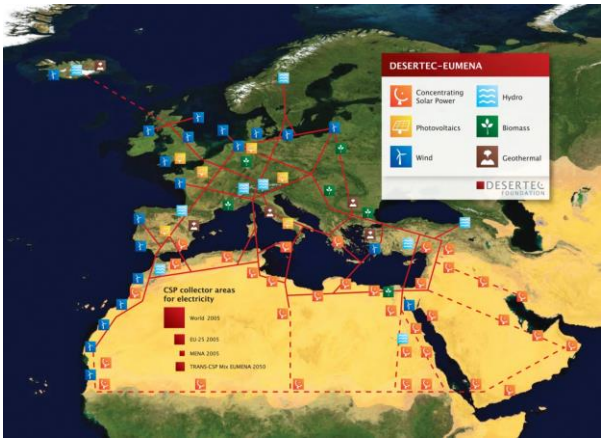
- 490,000 1MW tidal turbines
- 5,350 100MW geothermal plants
- 900 1,300MW hydroelectric plants
- 3,800,000 5MW wind turbines
- 720,000 0.75MW wave converters
- 1,700,000,000 0.003MW rooftop photovoltaic systems
- 49,000 300MW concentrated solar power plants
- 40,000 300MW photovoltaic power plants

6

SCENARIOS FOR FUTURE ENERGY TECHNOLOGIES AND MATERIAL CONSEQUENCES

- 'scenario':
  - 65% primary energy from solar in Sahara
    - Transport through HVDC
    - 1500 km
  - Copper demand: 60 x current mine production

(Rene Kleijn et al, Renewable and sustainable energy reviews, 2010)



Source: Destertec foundation

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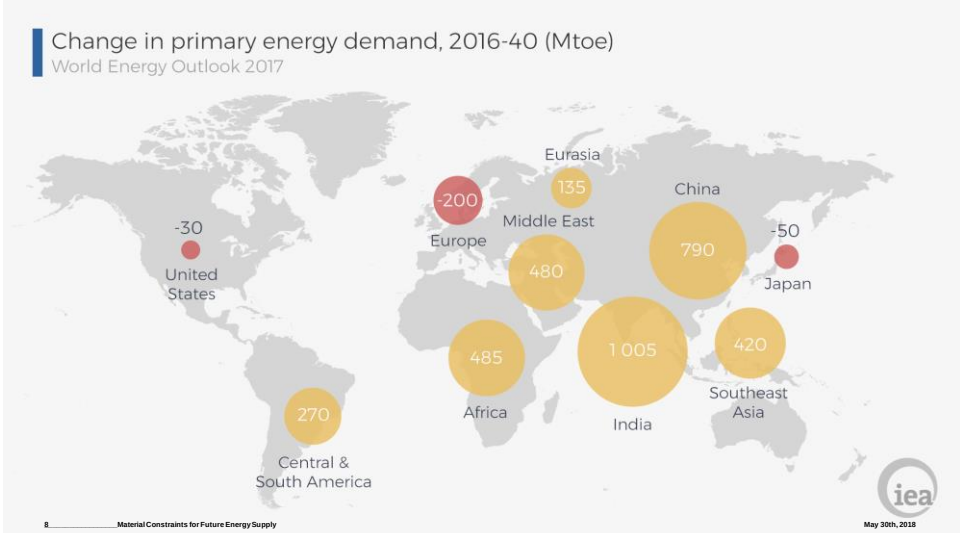
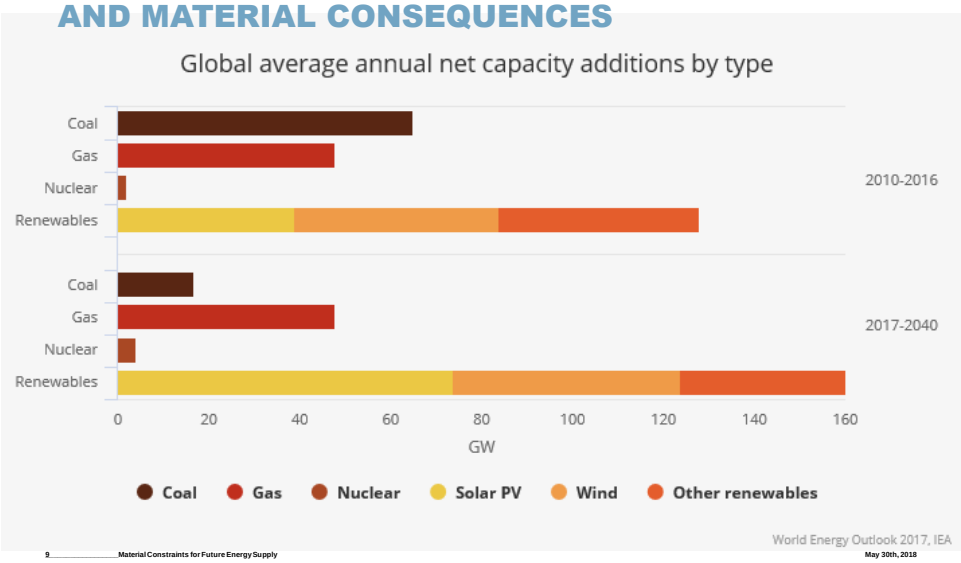
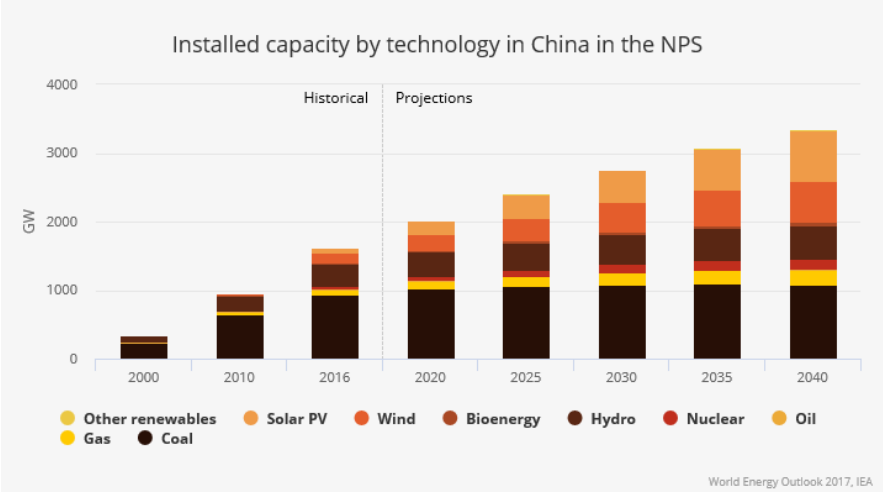
SCENARIOS FOR FUTURE ENERGY TECHNOLOGIES AND MATERIAL CONSEQUENCES



SCENARIOS FOR FUTURE ENERGY TECHNOLOGIES AND MATERIAL CONSEQUENCES



SCENARIOS FOR FUTURE ENERGY TECHNOLOGIES AND MATERIAL CONSEQUENCES



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SCENARIOS FOR FUTURE ENERGY TECHNOLOGIES AND MATERIAL CONSEQUENCES

Metal mining constraints on the electric mobility horizon

Developed in collaboration with

MineSpans By McKinsey

McKinsey Basic Materials Institute

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EV adoption likely to be challenged by cobalt and class 1 nickel availability

Our analysis shows that the market for cobalt will remain tight. The question to be answered is whether a radical shift toward less cobalt-intensive batteries is sufficient to avoid a shortage constraining EV adoption.

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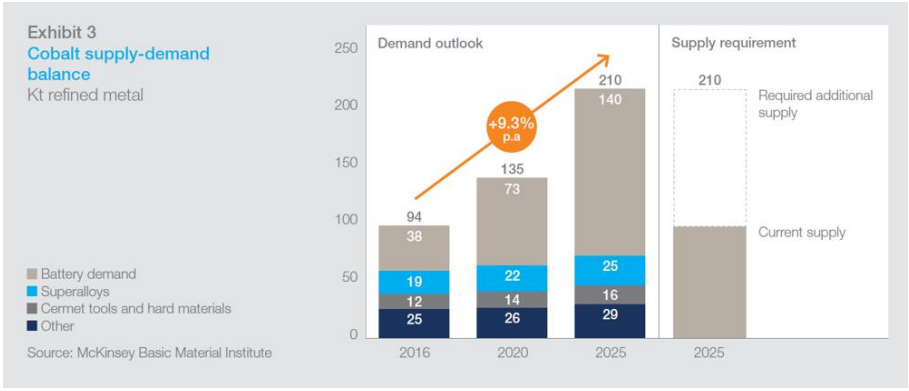
SCENARIOS FOR FUTURE ENERGY TECHNOLOGIES AND MATERIAL CONSEQUENCES



STRONG DEMAND GROWTH FOR HIGH-TECH-MATERIALS

(SOURCE: FRAUNHOFER ISI - DERA, 2016)

RENEWABLE ENERGY

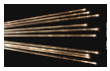
- Rare earths

- Lithium
- Cobalt

- Gallium
- Indium
- Tin

ICT

- Tantalum
- Gallium



- Germanium

- Silver
- Copper

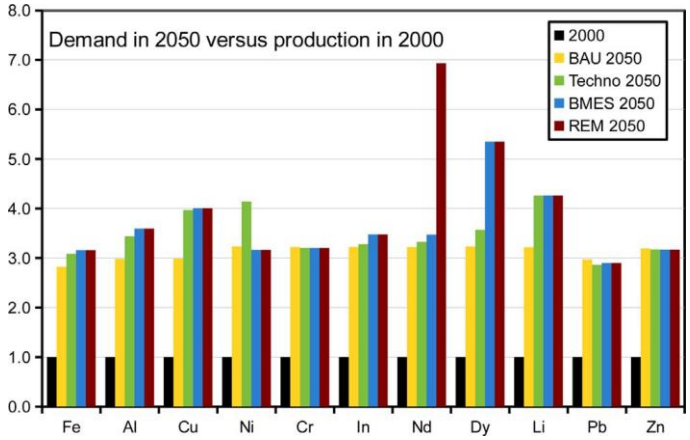
STRONG DEMAND GROWTH FOR HIGH-TECH-MATERIALS

(SOURCE: FRAUNHOFER ISI - DERA, 2016)

metaal	applicatie	vraag 2035 voor applicatie t.o.v. TOTALE supply 2013
Lithium	batteries	3.9
Rare earths	Magnets, e-cars, energy	1.7 – 3.1
Rhenium	Super alloys	2.5
Tantalum	Micro-capacitor	1.6
Scandium	Fuel cells	1.4
Cobalt	batteries	0.9
Germanium	Fibre optics	0.8
Silver, copper	RFID	0.3

METAL SUPPLY CONSTRAINTS FOR A LOW-CARBON ECONOMY?

- Arjan de Koning et al. (Leiden, 2018)



JRC EUROPEAN COMMISSION — The importance of some rare metals

- Rare metals are essential parts of energy technologies
  - 3 MW wind turbine - 2 t magnet - 600 kg Nd
  - 350 GW of additional wind power in EU = 210 kt Nd = 10 kt/y Nd
- … as well as in other important applications (incl. consumer and defence electronics)
  - 1 hybrid motor – 1 kg Nd
  - 100 million vehicles by 2030 in EU = 100 kt Nd = 5 kt/y Nd
- Resources of some rare and noble metals are limited and often concentrated in a small number of countries
  - Nd annual production: 20 kt

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RISK ANALYSIS ON ENERGY TECHNOLOGIES – JRC-2011

- High risk: Dy – Nd – Te – Ga – In
- Medium risk: Nb – V – Sn – Se

Figure 2: Metals Demand of SET-Plan in 2030 as % of 2010 World Supply

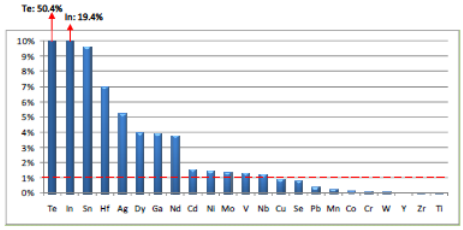


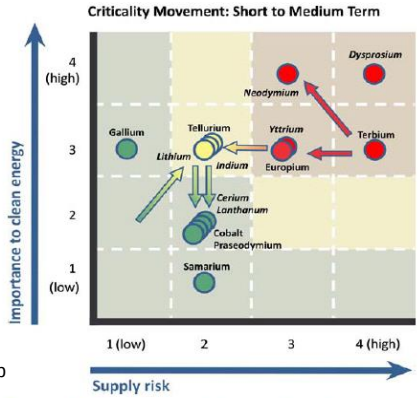
Table 28: Summary of Bottleneck Analysis

Metal	Market Factors		Political Factors		Overall risk
	Likelihood of rapid demand growth	Limitations to expanding production capacity	Concentration of supply	Political risk	
Dysprosium	High	High	High	High	High
Neodymium	High	Medium	High	High	
Tellurium	High	High	Low	Medium	
Gallium	High	Medium	Medium	Medium	
Indium	Medium	High	Medium	Medium	
Niobium	High	Low	High	Medium	Medium
Vanadium	High	Low	Medium	High	
[illegible]	Low	Medium	Medium	High	
[illegible]lenium	Medium	Medium	Medium	Low	
[illegible]ver	Low	Medium	Low	High	Low
[illegible]ybdenum	Medium	Low	Medium	Medium	
[illegible]nium	Low	Medium	Medium	Low	
[illegible]ckel	Medium	Low	Low	Medium	
[illegible]dmium	Low	Low	Low	Medium	

- Combined EU/US risk list for renewable energy:
- High risk: Dy – Nd
- High/medium: Te – Ga – In – Y – Eu - Tb
- Medium risk: Nb – V – Sn – Se - Li

RISK ANALYSIS DEPARTMENT OF ENERGY US

- High risk: Dy – Nd – Tb – Y - Eu
- Medium risk: Te – In – Li

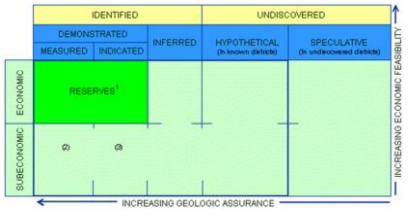


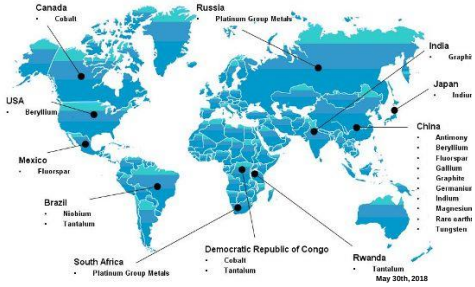
- Combined EU/US risk list for renewable energy:
- High risk: Dy – Nd
- High/medium: Te – Ga – In – Y – Eu - Tb
- Medium risk: Nb – V – Sn – Se - Li

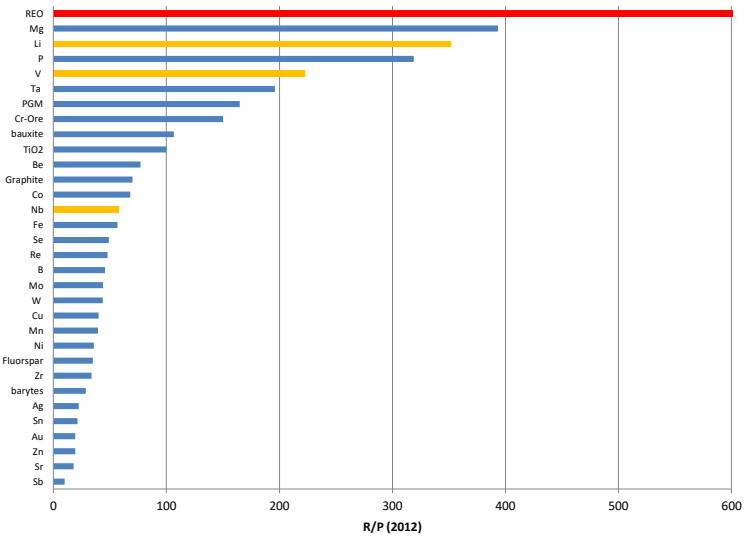
Figure 8-3. Comparison of short- and medium-term criticality

CAUSES FOR REDUCING SECURITY OF SUPPLY

- Increasing demand
  - Especially for hi-tech materials
- Geology
  - Reserves harder to find
  - Reducing quality of reserves
    - That require more water and energy
- Many critical materials are by-products
- Geopolitical monopolies

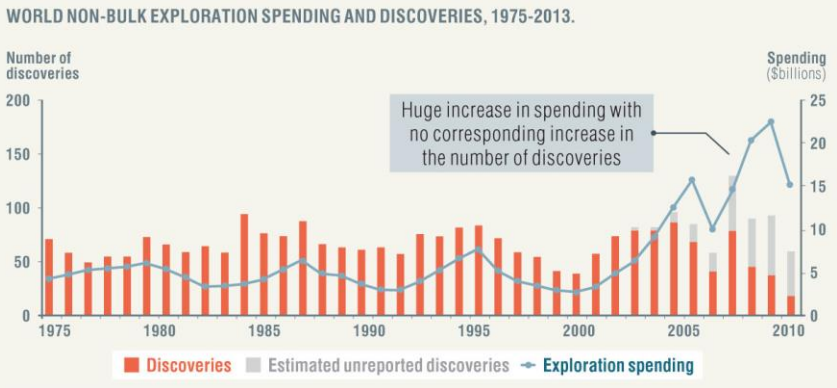






DISCOVERY RATE OF MAJOR MINERAL DEPOSITS

Figure 1. Until recently, discovery rates moved in line with exploration expenditures.

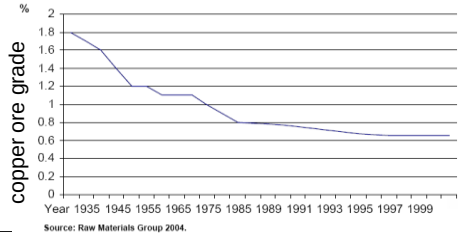


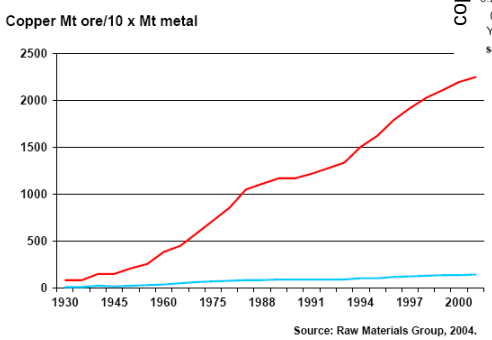
Source: MinEx Consulting.
Note: In constant 2013 dollars. Based on moderate, major and giant discoveries. Excludes satellite deposits in existing camps.

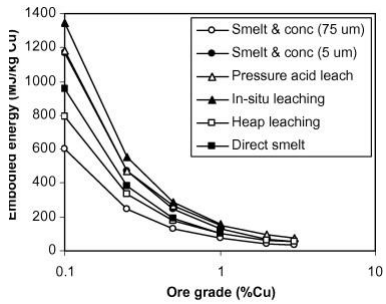
DECREASING QUALITY OF RESERVES: LOWER ORE GRADES AND LESS FAVOURABLE LOCATIONS

The production of 1 ton of copper is associated with 250 tonnes of solid waste

(Monash University, 2007)







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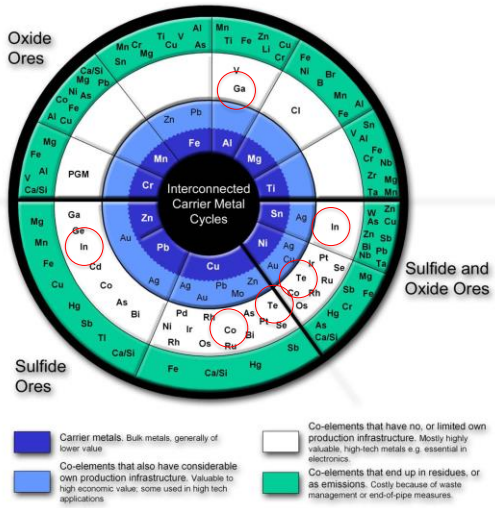
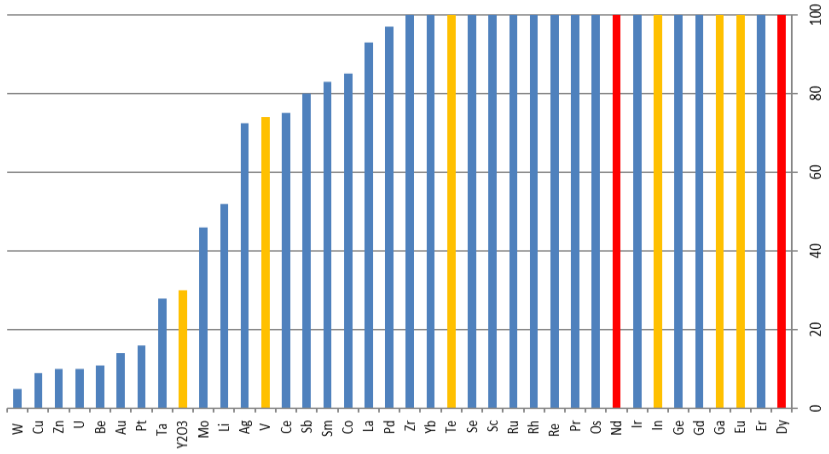
MANY CRITICAL MATERIALS ARE BY-PRODUCTS



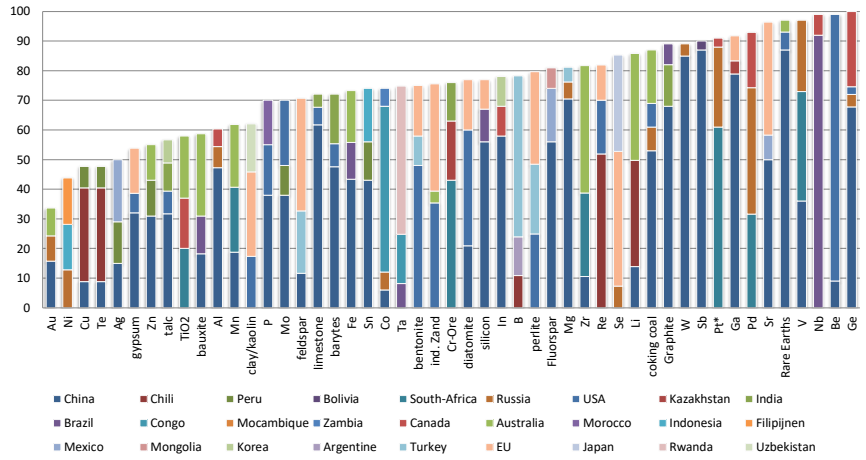
MANY CRITICAL MATERIALS ARE BY-PRODUCTS



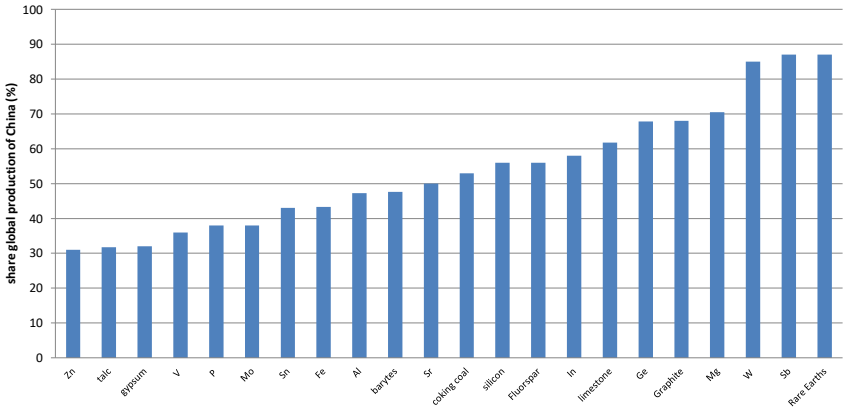
Prijzen stijgen door quota

China houdt zeldzame metalen zelf

COUNTRY CONCENTRATION



CHINA'S DOMINANT ROLE



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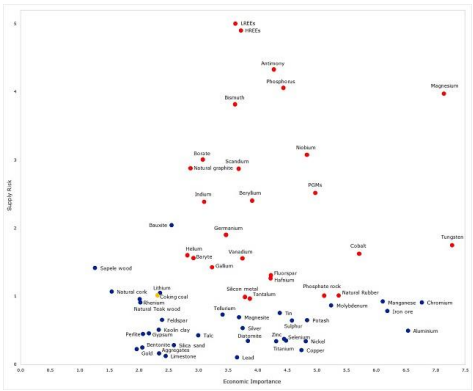
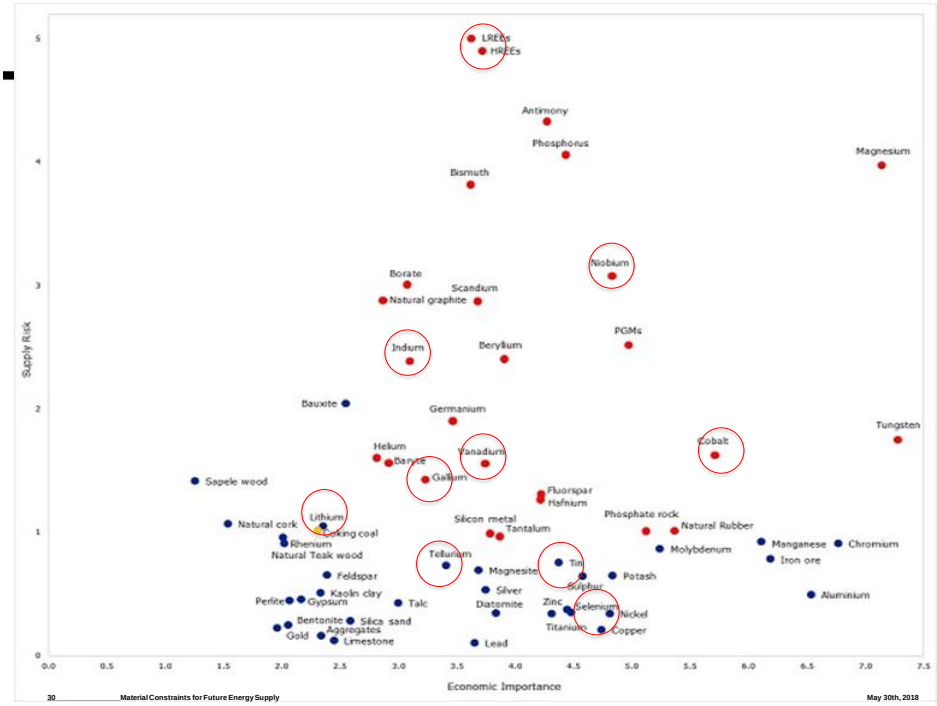
EC MATERIAL CRITICALITY ASSESSMENTS

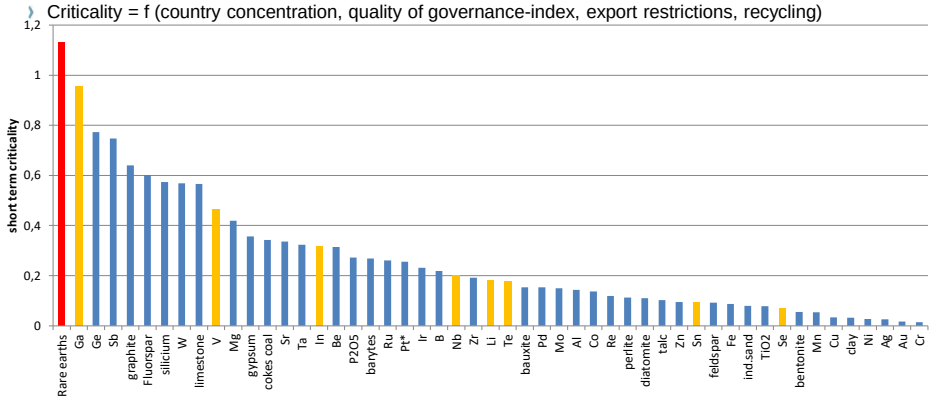
- 1st assessment 2010
- 2e revision 2017 by Deloitte – BGS – BRGM - TNO



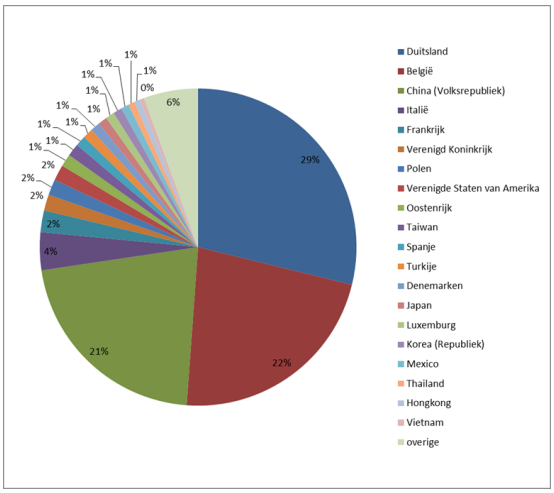


CRITICAL MATERIALS FOR THE DUTCH ECONOMY

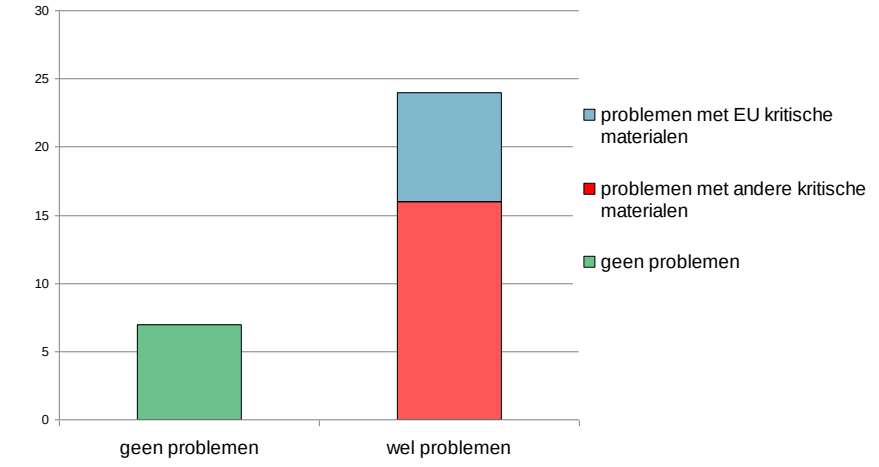
- 64 materials studied by TNO (tasked by Ministry Economic Affairs)– report published december 2015
- Based on link between raw materials/intermediates/final products – industrial sector
- Criticality = f (country concentration, quality of governance-index, export restrictions, recycling)



NOT JUST ABOUT RAW MATERIALS, BUT ABOUT THE WHOLE VALUE CHAIN



FME-INTERVIEWS 2012: DID YOU EXPERIENCE SUPPLY IDSRUPTIONS?



Wat zeggen de ondernemers?

- "China heeft de markt opgekocht, waardoor het materiaal niet meer leverbaar was. Dat is wat de toeleverancier heeft verteld"
- "Single source was de oorzaak van het probleem en het feit dat die ene fabriek beperkte capaciteit had, die de voorraad aan andere sector had verkocht"
- "Met diverse kritische elementen heeft ons bedrijf in het verleden leveringsproblemen (erg lange levertijden) of kostprijsproblemen gehad"

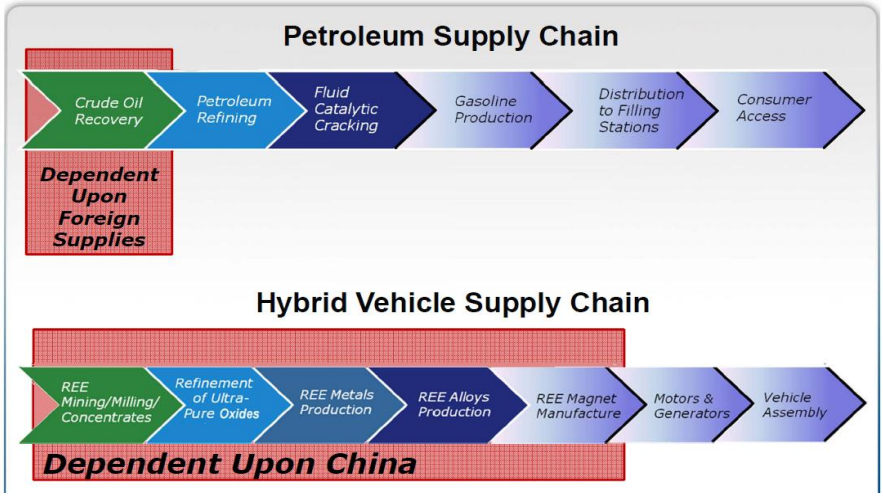
Wat zeggen de ondernemers?

- "We hebben een leverancier gehad die vlak bij Fukushima zat. Door de lek in de reactoren van de kerncentrale gingen de bedrijven dicht na de aardbeving."
- "China heeft de RVS markt opgekocht, met als resultaat dat de levertijden langer werden en dat de prijzen stuk hoger werden"
- "Er was tekort aan staal op de markt, en ons bedrijf is een relatief kleine speler"
- "Het heeft te maken met pre-scribed leveranciers, waar jij een klein spelertje bent."

M2i Materials innovation institute TNO innovation for life TU Delft 35

Molycorp THE RARE EARTHS COMPANY

Trading One Dependence For Another?



36 Material Constraints for Future Energy Supply May 30th, 2018

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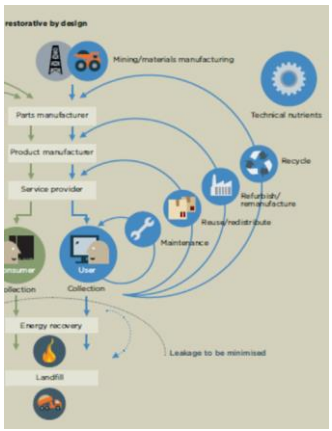
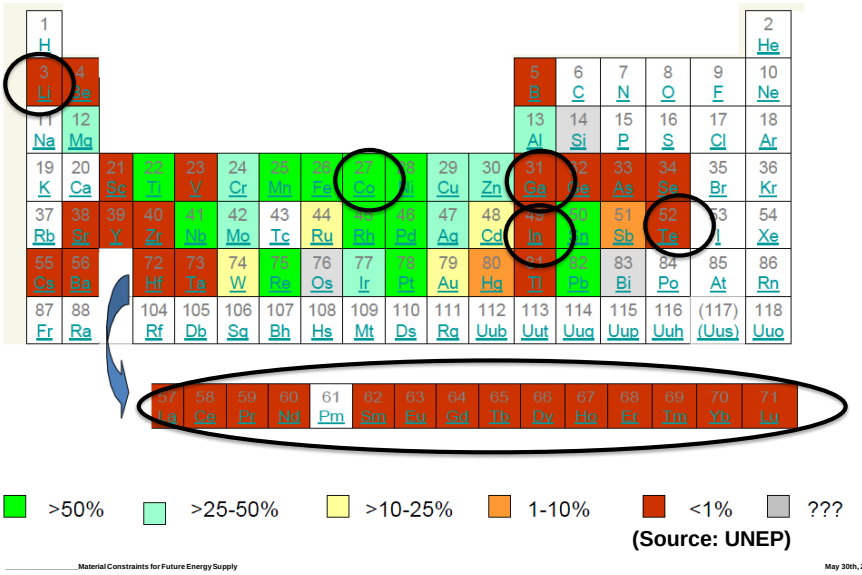
THE CIRCULAR ECONOMY MAY CONTRIBUTE TO SOLVING SUPPLY ISSUES





39

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Global sales, 2009

a) Mobile phones	b) PCs & laptops	a+b) Urban mine
1300 million units/ year	300 Million units/year	Mine production / share
X250 mg Ag ≈ 325 t Ag	X1000 mg Ag ≈ 300 t Ag	Ag: 21,000 t/a ► 3%
X 24 mg Au ≈ 31 t Au	X 220 mg Au ≈ 66 t Au	Au: 2,400 t/a ► 4%
X 9 mg Pd ≈ 12 t Pd	X 80 mg Pd ≈ 24 t Pd	Pd: 220 t/a ► 16%
X 9 g Cu ≈ 12,000 t Cu	X~500 g Cu ≈150,000 t Cu	Cu: 16 Mt/a ► <1%
1300 million Li-Ion batteries	~140 million Li-ion batteries	Co: 75,000 t/a ► 19%
X 3.8 g Co ≈ 4900 t Co	X 65 g Co ≈ 9100 t Co	


Tiny metal content per piece → Significant total demand

Other electronic devices add even more to these figures

40

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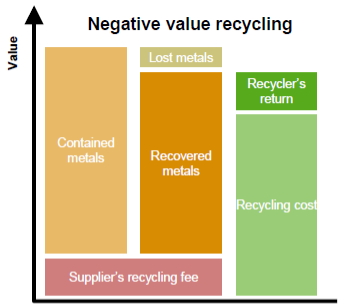
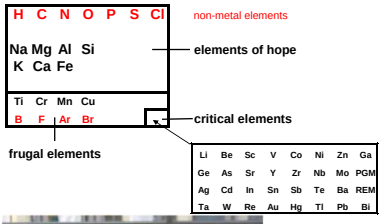


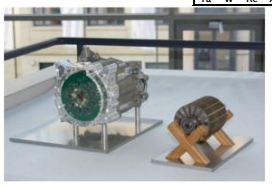
- Rechargeable batteries
- LCD displays
- PhotoVoltaic (end-of-life) modules
- Dispersed Silver in Textiles or RFID's

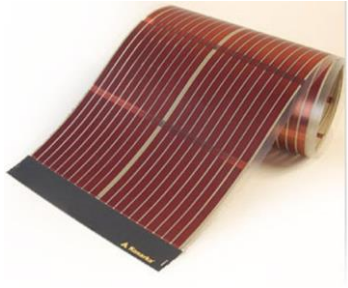
The value of the material is **not sufficient** to cover suppliers return + recyclers return + recycling cost

➲ financing models, government incentives or legislation is needed

SUBSTITUTION AS A STRATEGY







- **A fantastic challenge for energy technologies research !!**

CONCLUSIONS AND NEXT STEPS

- Energy transition is strongly depending on secure supply of raw materials
- Raw material supply faces challenges in decades to come
- Raw materials implications of large scale implementation of (new) renewable energy technologies should be assessed in early stages

- More attention for the complete supply chain for energy technologies

- Search for robust, alternative strategies desirable
  - The Circular Economy
    - Ensure lifetime extension
    - Design for maintenance, repairability
    - Enhanced recycling
  - Substitution strategies

- What are the implications for Dutch policy and Dutch companies?

- CALL FOR A PROGRAM:
  - ENERGY TRANSITION AND MATERIAL REQUIREMENTS IN CIRCULAR PERSPECTIVE