SUPPLY OF RAW MATERIALS AND FUTURE ENERGY SECURITY

- Background
  - Worry about supply
  - Impact on renewable energy technologies
- Criticality assessments
  - In Europe
  - In The Netherlands
- Conclusions and next steps
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).
"THE LIMITS TO GROWTH"

- Appeared 1972
- 30 year update 2005

Basics:
- Physically limited world
- Overshoot
- Exponential growth
- Complex interferences
- Multidisciplinary approach
“LINKAGES OF SUSTAINABILITY” (2010)

- Sustainability of use of:
  - Land
  - Water
  - Energy
  - Mineral resources (metals)

- Intense linkages: in 2050:
  - Up to 40% energy required for metals extraction

- Focus of this session:
  - Rare earth metals and
  - Critical metals in general

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)
DISCOVERY RATE OF MAJOR MINERAL DEPOSITS

low expectations of yet to be discovered deposits

FREE MARKET?

- Minerals are unevenly distributed
- May become a strategic resource
- With geopolitical consequences

Quelle: Naumov 2008, basierend auf Daten von USGS (verschiedene Jahrgänge)
METALS 2030: DEMAND V PRODUCTION
(SOURCE: INSTITUTE FOR FUTURES STUDIES AND TECHNOLOGY ASSESSMENT (IZT) / FRAUNHOFER ISI, 2009)

Gallium (used in LEDs, solar cells, IC’s): 6 x

Indium (transparent electrodes in LCD, mobile phones and solar cells): 3 x

Neodymium (lasers, electrical power): 3 x

Germanium (fibre glass and IR optics): 2 x

Scandium (fuel cells): 2 x

China has 70% of Indium and 97% of Neodymium reserves. Mid-African countries have monopoly of Cobalt (wear-resistant alloys) and Tantalum (capacitors).
**RESOURCE SCARCITY INTERFERES WITH ENERGY TRANSITION**

Bron: Scientific American, November 2009

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

- 3 Mton Nd required
- Current annual production: 18 kTon
RESOURCE SCARCITY INTERFERES WITH ENERGY TRANSITION

If 65% of primary energy comes from solar energy in the Sahara
- Transport through HVDC
- Over 1500 km
- Required Cu: 60 times current mine production

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

Source:
Desertec foundation

RISK ANALYSIS DEPARTMENT OF ENERGY US

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

Figure 8-3. Comparison of short- and medium-term criticality
RISK ANALYSIS ON ENERGY TECHNOLOGIES – JRC-2011

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

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

EU CRITICAL MATERIALS ASSESSMENTS
- 1st assessment 2010 – revision 2014
- 2nd revision now underway: to be published 2017
  - Deloitte – BGS – BRGM - TNO
CRITICAL MATERIALS FOR THE DUTCH ECONOMY

- 64 materials studied – report published December 2015
- Based on link between raw materials/intermediates/final products – industrial sector

<table>
<thead>
<tr>
<th>Aluminium</th>
<th>Bauxite</th>
<th>Graphite</th>
<th>Rhenium</th>
<th>Dysprosium*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>Iron ore/iron</td>
<td>Silicon</td>
<td>Strontium</td>
<td>Samarium*</td>
</tr>
<tr>
<td>Barites</td>
<td>Nickel</td>
<td>Silicon</td>
<td>Strontium</td>
<td>Samarium*</td>
</tr>
<tr>
<td>Bentonite</td>
<td>Industrial sand (silica)</td>
<td>Tantalum</td>
<td>Tantalum</td>
<td>Tantalum*</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Limestone</td>
<td>Talc</td>
<td>Talc</td>
<td>Talc</td>
</tr>
<tr>
<td>Beryl/rubber</td>
<td>Clay (Kaolin)</td>
<td>Tantalum</td>
<td>Tantalum</td>
<td>Tantalum*</td>
</tr>
<tr>
<td>Chromite</td>
<td>Coal</td>
<td>Lanthane</td>
<td>Tantalum</td>
<td>Tantalum*</td>
</tr>
<tr>
<td>Coke</td>
<td>Copper</td>
<td>Sn</td>
<td>Cerium*</td>
<td></td>
</tr>
<tr>
<td>Diatomite</td>
<td>Oilax</td>
<td>Titanium dioxide/Titanium</td>
<td>Lanthane *</td>
<td></td>
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<tr>
<td>Feldspar</td>
<td>Magnesia/magnesium</td>
<td>Uranium</td>
<td>Ytterbium*</td>
<td></td>
</tr>
<tr>
<td>Fluorspar</td>
<td>Magnesium</td>
<td>Uranium</td>
<td>Ytterbium*</td>
<td></td>
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<tr>
<td>Phosphorus</td>
<td>Molybdenum</td>
<td>Tungsten</td>
<td>Scandium*</td>
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</tr>
<tr>
<td>Quartz</td>
<td>Nickel</td>
<td>Silver</td>
<td>Platinum*</td>
<td></td>
</tr>
<tr>
<td>Germanium</td>
<td>Uranium</td>
<td>Zinc</td>
<td>Palladium*</td>
<td></td>
</tr>
<tr>
<td>Gypsum</td>
<td>Perlite</td>
<td>Zircon</td>
<td>Indium*</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>Ruthenium</td>
<td>Cerium*</td>
<td>Rhodium*</td>
<td></td>
</tr>
</tbody>
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HOW ARE RAW MATERIALS ENTERING THE DUTCH ECONOMY?
IMPORT OF RAW MATERIALS THROUGH FINAL PRODUCTS

CRITICAL MATERIALS FOR THE DUTCH ECONOMY

<table>
<thead>
<tr>
<th>Influence on</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term Security of Supply</td>
<td>Number of years of uninterrupted production (Reserves/Production (R/P))</td>
</tr>
<tr>
<td>(&gt; 10y)</td>
<td>Companiornality (degree to which a raw material is a by-product)</td>
</tr>
<tr>
<td></td>
<td>Concentration of raw material reserves (HHI_res)</td>
</tr>
<tr>
<td>Short-term security of supply</td>
<td>Concentration of raw material extraction (HHI_extraction)</td>
</tr>
<tr>
<td></td>
<td>Stability and quality of governance in source countries represented by WGI</td>
</tr>
<tr>
<td></td>
<td>Existing export restrictions (OECD data)</td>
</tr>
<tr>
<td></td>
<td>End-of-life recycling rate</td>
</tr>
<tr>
<td>Operating profit</td>
<td>Price volatility of raw materials/materials (MAPII)</td>
</tr>
<tr>
<td>Corporate Reputation</td>
<td>Environmental impact of extracting and refining of raw materials</td>
</tr>
<tr>
<td></td>
<td>Performance of source countries in terms of human development (HDI)</td>
</tr>
<tr>
<td></td>
<td>Regulations concerning conflict minerals</td>
</tr>
</tbody>
</table>
CRITICAL MATERIALS FOR THE DUTCH ECONOMY

- Criticality (short term) =
  \[ \text{Criticality} = \text{country concentration} \times (\text{quality of governance-index} + \text{OECD-restrictions}) \times (1 - \% \text{end-of-life recycling rate}) \]

COUNTRY CONCENTRATION

- Countries: China, Chili, Peru, Bolivia, South Africa, Russia, USA, Kazakhstan, India, Brazil, Congo, Mocambique, Zambia, Canada, Australia, Morocco, Indonesia, Filipijnen, Mexico, Mongolia, Korea, Argentina, Turkey, EU, Japan, Rwanda, Uzbekistan.
CHINA’S DOMINANT ROLE

EXPORT RESTRICTIONS (BASED ON OECD DATA)
CRITICAL MATERIALS FOR THE DUTCH ECONOMY

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Agriculture, forestry and fishing
Mining industry
Man. of food products, beverages and tobacco products
Man. of textiles, etc.
Man. of wood and paper products
Man. of coke and refined petroleum products
Man. of chemicals and pharmaceutical products
Man. of rubber and plastic prod.
Man. of other non-metallic mineral products
Man. of basic metals
Man. of metal products, except machinery and equipment
Man. of machinery and equipment n.e.c.
Man. of transport equipment
Man. of furniture and other equipment
Man. of computer, electronic and optical products
Man. of electrical equipment
Man. of transport equipment
CRITICAL MATERIALS FOR THE DUTCH ECONOMY

Criticality (long term) = f (country concentration for reserves + # production years + % companionability)

RESERVES ARE NOT EQUALLY DISTRIBUTED EITHER
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IMPACT PRICE VOLATILITY

Maximum price increase
In last 20 years
**IMPACT PRICE VOLATILITY**

![Impact Price Volatility Chart]

**REPUTATION AND ENVIRONMENTAL FOOTPRINT**

The Guardian:

Rare-earth mining in China comes at a heavy cost for local villages.

![Rare-earth mining image]
REPUTATION AND RESPONSIBLE SOURCING

- Apple has begun publicising which of its suppliers may be sourcing minerals from conflict zones
- …we confirmed that all active, identified tantalum smelters in our supply chain were verified as conflict-free by third party auditors, and we’re pushing our suppliers of tin, tungsten, and gold just as hard to use verified sources. To heighten smelter accountability and help stakeholders follow our progress, we are releasing, for the first time, a list of the smelters and refiners in our supply chain along with their verification status.

CONCLUSIONS AND NEXT STEPS

- Energy transition is strongly related to supply of raw materials
- Raw material supply faces challenges in decades to come
  - Specific attention for some rare earths (Dy – Nd – Eu – Tb – Y), indium, gallium, tellurium
- Vulnerability relates to security of supply, price volatility and reputational damage
- Raw materials implications of large scale implementation of (new) renewable energy technologies should be assessed in early stages
- Search for robust, alternative strategies desirable
  - The Circular Economy
    - Ensure lifetime extension
    - Design for maintenance, repairability
  - Substitution strategies
THE CIRCULAR ECONOMY CONtributes to solving raw material supply issues

CONCLUSIONS AND NEXT STEPS

A fantastic challenge for energy technologies research !!