Energy-Materials Nexus for a Sustainable Low Carbon System

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Current and Future Challenges to Energy Security

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Table of content

OUTLINE OF THE PRESENTATION

1 – Introduction

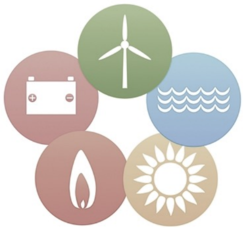
- ✓ Successful implementation of the Paris Agreement and of the 2030 Agenda for Sustainable Development requires the **decarbonisation of the existing infrastructure systems**.

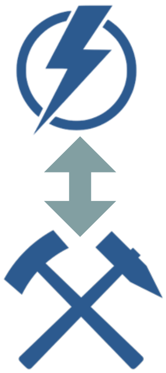
- ✓ Low carbon technologies tend to have **high capital intensity** and require large amounts of **materials**, including common and rare metals. The low carbon system is more material intensive than the traditional fossil-fuel based system.

- ✓ Potential **disruption in material supply** could slow down the transition to a a low carbon system, and, by extension, threaten energy security.

- ✓ **Energy production and material production** are inseparable issues that need to be addressed together in one comprehensive framework.

- ✓ The changing material requirements represent **challenges for industries, policymakers & researchers**. The debates on resource constraints result in growing research in the fields of **resource criticality** and **energy-materials nexus**.



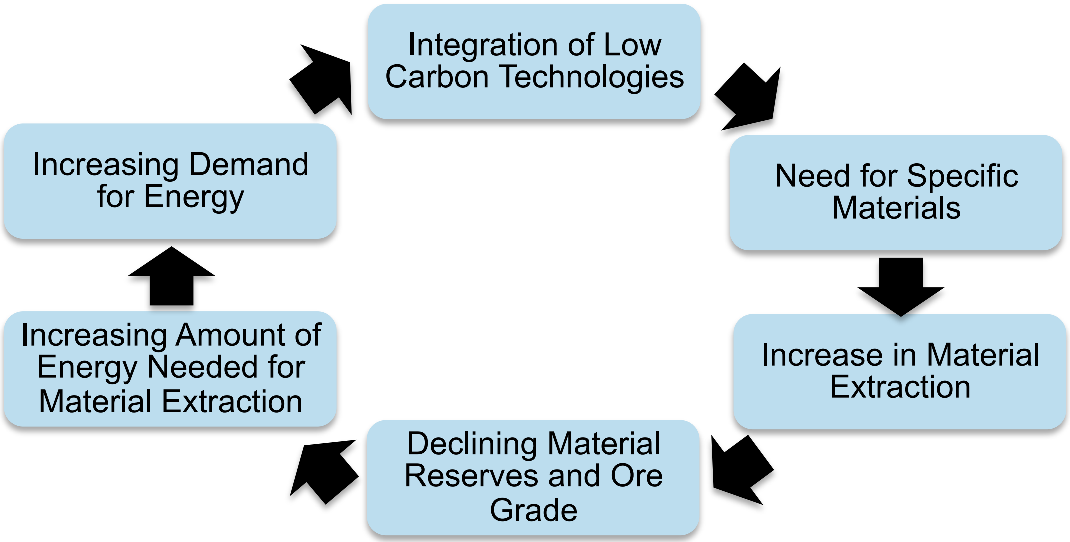


2 – The Energy-Materials Nexus

Energy production requires materials ↔ Material production requires energy

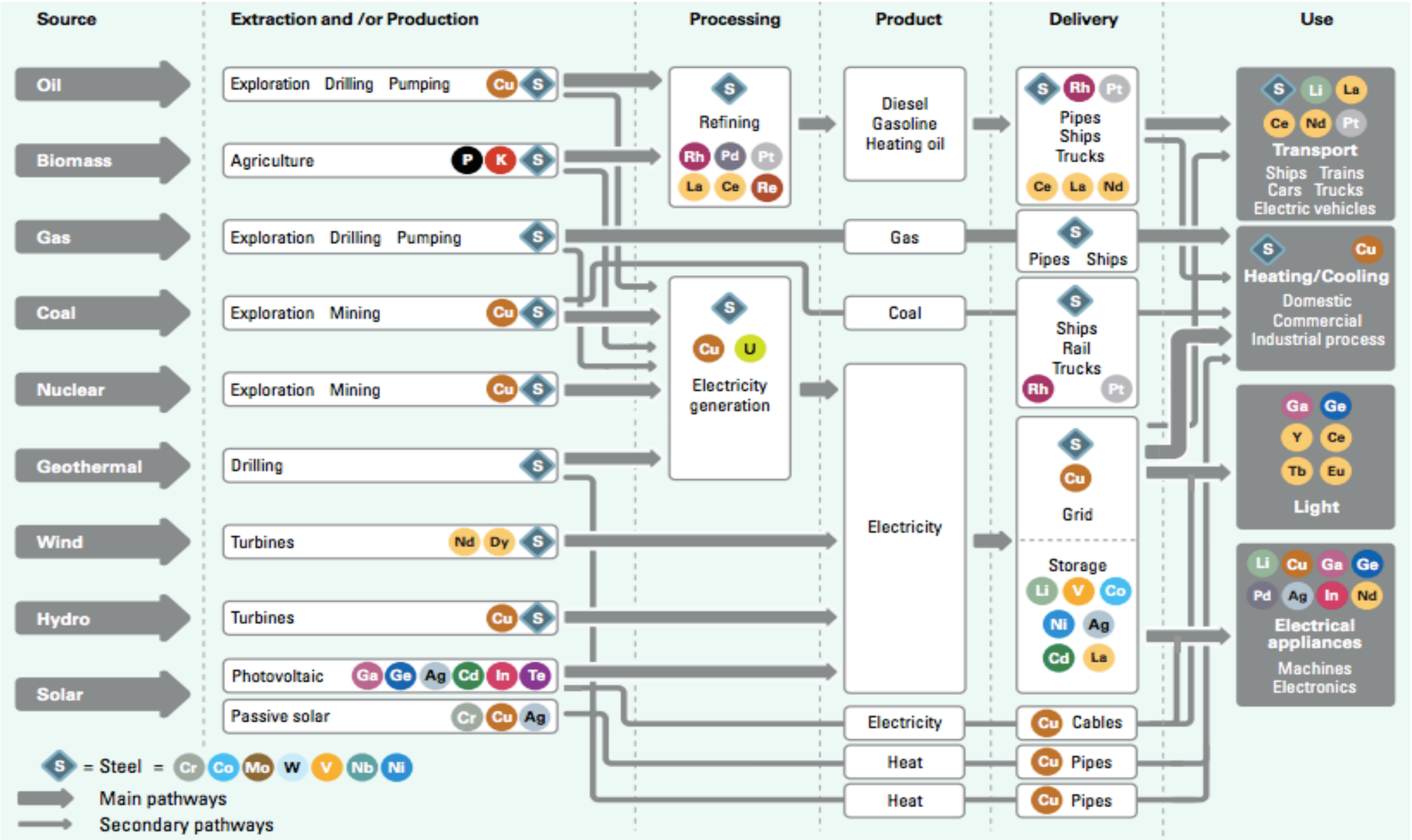
→ The energy and material sectors are strongly interrelated.

E.g. Potential vicious cycle:
The extraction of some materials requires an increasing amount of energy due to a combination of declining ore grade and rising material demand partly due to the development of energy technologies. (Fizaine and Court, 2015)



2 – The Energy-Materials Nexus

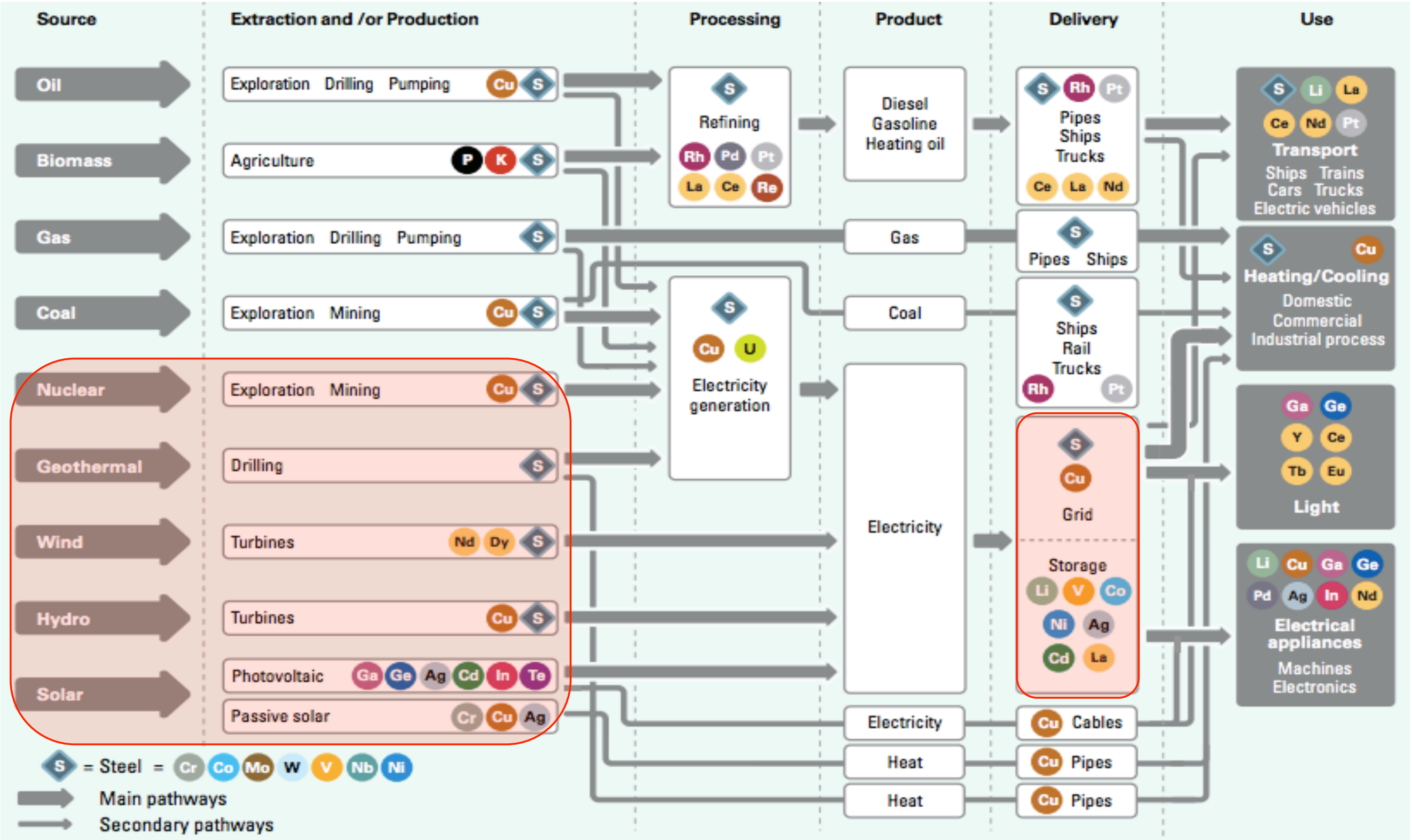
Materials used for Energy Supply Pathways



Source: BP, 2012

2 – The Energy-Materials Nexus

Materials used for Energy Supply Pathways



Source: BP, 2012

2 – The Energy-Materials Nexus

The demand for materials is changing and overall rising.

ENVIRONMENT

- Environmental Awareness
- Sustainable Development
- GHG Emissions Mitigation

INNOVATION

Sectors with highest technological innovation:
ICT, energy, biotech, pharma

GROWTH

- Growing Population
- Rising Standards of Living
- Global Economic Growth

Decarbonisation Efforts for Low Carbon System: Integration of Low Carbon Technologies

Global Increase in Energy Demand

Global Increase in Production & Consumption In All Sectors

Demand for Materials in the Energy Sector

Demand for Materials in other Sectors (Building, ICT, Agriculture…)

INCREASING DEMAND FOR MATERIALS

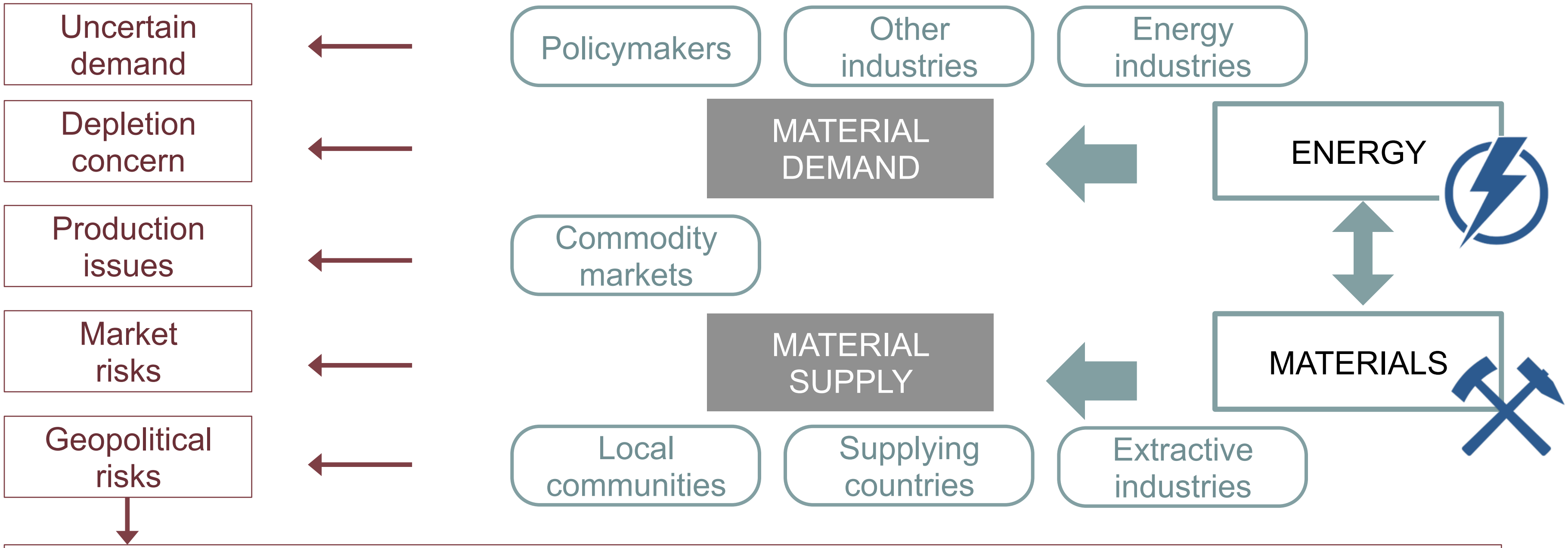
3 – Research Approach

- **OBJECTIVE:** Identify the issues related to the energy-material nexus and the risks for energy security and sustainable development
- **APPROACH:**
  - Reviewed expert elicitation process involving literature from diverse disciplines
  - Preliminary scanning of published evidence on relationships between energy systems, materials and SDGs
- **CONTRIBUTION:** This work contributes to the literature by:
  - Organizing and analyzing recent studies on the energy-materials nexus
  - Highlighting the implications of the findings on the SDGs and for further research and action
- **OVERVIEW OF REVIEWED LITERATURE:**

Type	Organization or journal name	Methodologies
Reports from governmental or research institutes	World Bank, European Commission, Joint Research Centre, ICMM, Stockholm Environment Institute, UKERC, WEF, WWF, etc.	• Material criticality assessments • Scenarios analyses • Stakeholders engagement methods • Literature Reviews • Indicator-based analyses • Top-down / Bottom-up analyses • Material flow analyses • Life-cycle assessments • Forecasting methods • Technology-specific analyses
Journal articles	Applied Energy, Ecological Economics, Energy, Energy Policy, Energy Procedia, Environmental Science & Technology, Journal of Cleaner Production, Renewable Energy, Renewable & Sustainable Energy Reviews, Resources, Conservation & Recycling, etc.	

4 – Challenges of the Energy-Materials Nexus

Risks or issues associated with the material requirements for the low carbon system can be related to different levels of the supply chain and different stakeholders.

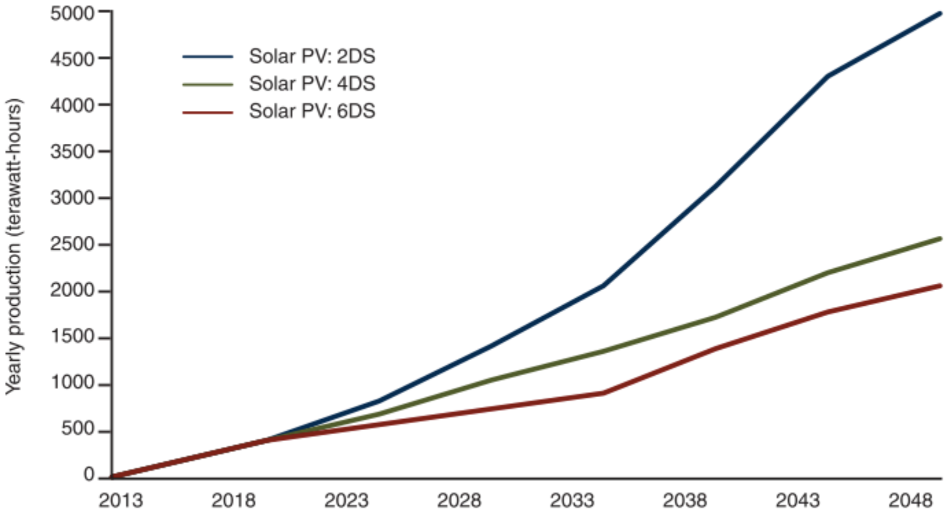


Risk to slow down the low carbon transition, to threaten energy supply security & to prevent the achievement of the 2030 Agenda for Sustainable Development

4 – Challenges of the Energy-Materials Nexus

Future material demand is expected to grow but complex to predict.
Drivers of material demand growth are multiple (technology, policies, other sectors, etc.)

- Uncertain demand
- Depletion concern
- Production issues
- Market risks
- Geopolitical risks



Example: Solar PV (World Bank, 2017)

Global PV power production in 2016 was ± 328 TWh, and is projected to rapidly increase in all IEA scenarios. But IEA data do not specify the mix of solar technologies that might be used in the future.

Demand of materials used for solar PV will not only depend on solar penetration, but also on the market penetration of different solar technologies:

- **Crystalline silicon** need Aluminium, Iron, Lead, Nickel and Silver
- **CIGS** need Gallium, Selenium, Indium, Copper and Lead
- **CdTe** need Cadmium, Copper, Lead, Tellurium

4 – Challenges of the Energy-Materials Nexus

The risk of material supply shortages could occur as a result of resource depletion.
But physical depletion may not be the primary determinant of a material's availability (Pior et al., 2012).

- Uncertain demand
- **Depletion concern**
- Production issues
- Market risks
- Geopolitical risks

✓ **Future material availability**
Studies compared future cumulative demands with reserves or resources.

✓ **Resources ≠ Reserves**
Reserves are resources that are "geologically evaluated AND can be economically, legally and immediately extracted" (WWF, 2014).

✓ **Quality depletion ≠ Quantity depletion**
Decreasing quality of a material implies degradation of ore grade.

✓ **Uncertainty** on the estimation of resources and reserves, of the speed of degradation of average ore grade, etc.

Example: Indium used in thin film solar cells (NREL, 2015)

- Indium **reserves** are estimates 15.000 tons.
- Indium **resources** are estimated at 50.000 tons.
- Yearly **primary production** could rise from 770t in 2013 to ± 1300t by 2030.

→ No concern in the short or medium term,
BUT concern in the long term

4 – Challenges of the Energy-Materials Nexus

Issues associated with material production include slow reaction of capacities, indirect production costs, external costs and other material specific issues.

- Uncertain demand
- Depletion concern
- **Production issues**
- Market risks
- Geopolitical risks

✓ **Reaction of production capacities**

Production capacities tend to react slowly to changes in demand.
Long time lapse between material deposit discovery and start of exploitation

✓ **Indirect costs (e.g. Energy costs)**

Energy consumption in the metal sector increased faster than the rest of the economy: + 400% in the metal sector, while + 200% in the global economy between 1973 and 2011 (Fizaine and Court, 2015).

✓ **External costs**

Negative externalities can not only damage the environment and local communities, but also generate social reactions, resulting in closure of mines or delays in projects.

✓ **Material-specific issues**

E.g. Companion metals

Example: Indium (used in thin film solar technology) is currently produced almost solely as a byproduct of zinc smelting and refining.

4 – Challenges of the Energy-Materials Nexus

Today's commodity markets can present structural weaknesses.

- Uncertain demand
- Depletion concern
- Production issues
- **Market risks**
- Geopolitical risks

✓ **Commodity market imbalances:**

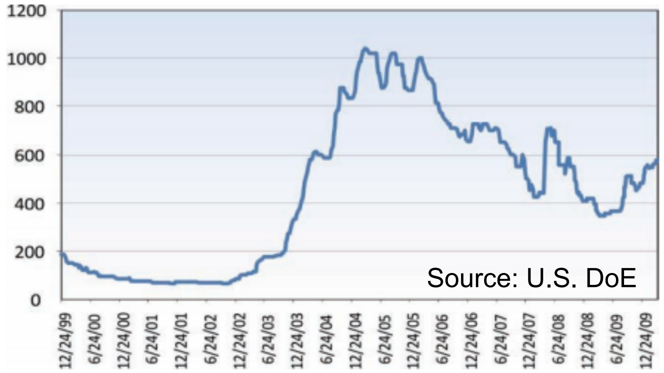
- When demand drops, prices drop, supplies build up and marginal projects become less attractive (Deloitte, 2014)
- Commodity markets are influenced by social, technological, economic, environmental and geopolitical drivers (WWF, 2014).

✓ **Commodity prices:**

- Price volatility: High fluctuations over time and across materials
- Price rises: Negative impact on market development of low carbon technology

Example: Solar PV (NREL, 2015)
Future Indium prices could be volatile or rise due to high extraction costs and high demand.
→ This could constrain the deployment of thin film technologies (CIGS).

Indium prices in $/kg



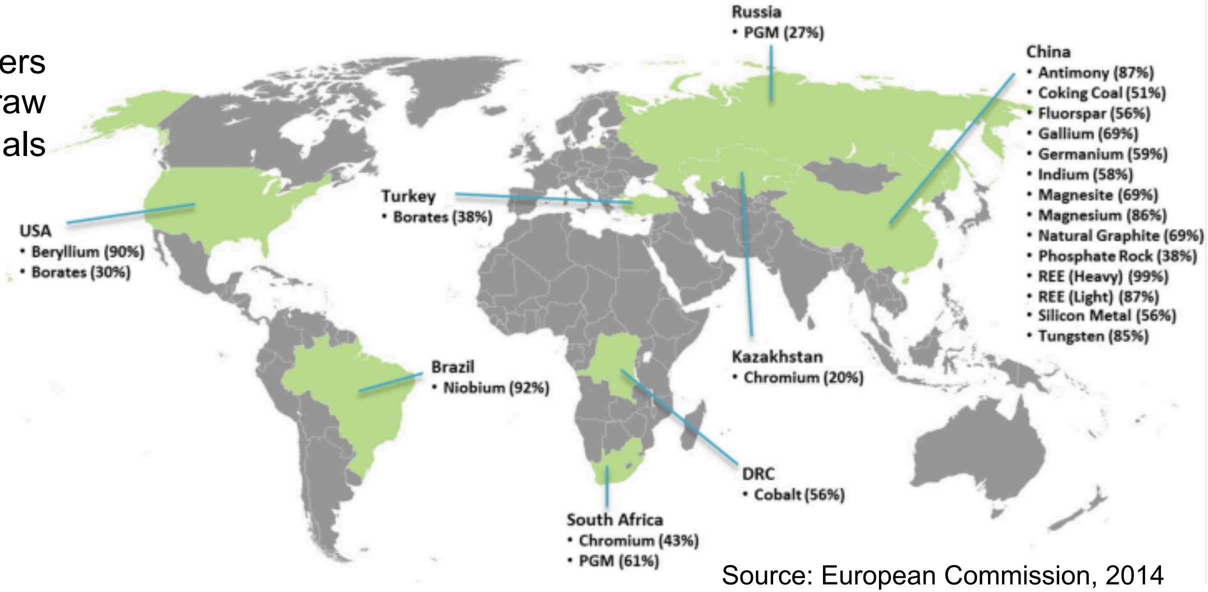
4 – Challenges of the Energy-Materials Nexus

Concerns on geopolitical risks arise due to the control of an increasing share of material supply by a decreasing number of countries and companies.

- Uncertain demand
- Depletion concern
- Production issues
- Market risks
- **Geopolitical risks**

✓ Tendency of the formation of monopolies and oligopolies (E.g. China)
✓ Risks of political instability in supplying countries (E.g. Conflict minerals)
✓ Import dependence of some countries (E.g. Europe)

→ Major producers of EU critical raw materials



Source: European Commission, 2014

4 – Challenges of the Energy-Materials Nexus

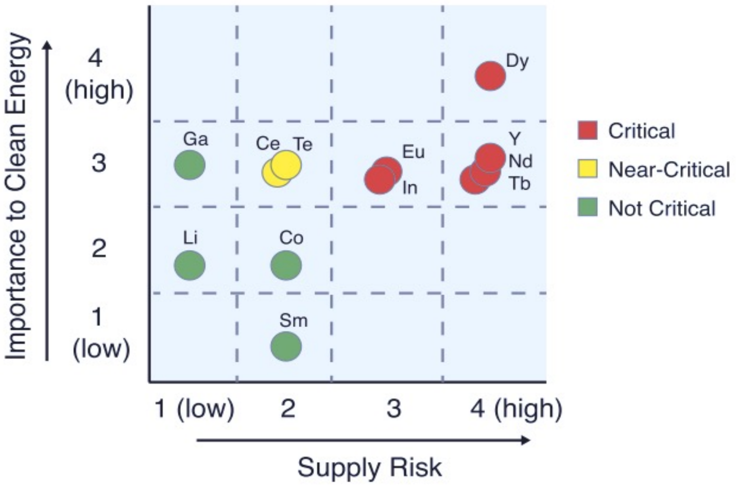
What make materials critical?

Consensus on guidelines for determining criticality - The material:
- Appears essential for the performance of the system
- But is subject to uncertainty or risk for its supply

Material criticality is a subjective concept that has evolved throughout history.
Recent literature uses a variety of criteria and methodologies to determine criticality.

Example of a **criticality matrix**
(Resnick Institute, 2011; US DOE, 2010)

The criteria used are:
- **Importance to clean energy**: Energy demand and substitution limitations
- **Supply risk**: Production vs demand, competing technology demand, political, regulatory and social factors, co-dependence on other markets



5 – The Energy-Materials Nexus and the SDGs

Issues & risks threatening material supply for a low carbon system can impact all SDGs directly or indirectly.

6 – Further Research, Development and Action

Technical R&D	• Material efficiency and energy efficiency • Material recycling from waste and end-of-life products • Material substitution
Externalities	• Research on environmental impact of any new technology • Evaluation of social consequences (local communities, conflict…) • Life-cycle assessments
Data Quality	• Data on material composition of technologies • Reporting by companies (e.g. indirect costs of material extraction) • Estimates of geological resources and economic reserves
Transversality	• Need for multidisciplinary & comprehensive research • Need to perform cross-sectorial analyses • Need to consider longer time scales and adopt dynamic approaches
Stakeholders	• Industrial stakeholders: Material industry & energy industry, industrial symbiosis • Governments & policymakers: Need for an international resource policy • Other stakeholders: Investors, local communities, consumers…

7 – Conclusion

- ✓ The development of a low carbon system is changing the requirements for materials.
- ✓ The main risks related to material supply can be due to resource depletion, grade decline, energy & environmental costs of material production, unpredictable demand & policy impacts, geopolitical issues, price volatility and market imbalances.
- ✓ Material supply shortages could slow down the low carbon transition, threaten energy security and prevent the achievement of the 2030 Agenda for Sustainable Development.
- ✓ Among the 5 SDG dimensions "people, planet, prosperity, peace and partnership”:
  - “**Planet**” & “**Prosperity**”: Most direct synergies with the energy-materials nexus can be found with the environmental and economic dimensions.
  - “**People**” & “**Peace**”: Links to the those dimensions exist, but more indirectly.
  - “**Partnership**”: Collaboration is not only a goal, but also a essential means to achieve all SDGs.

RESEARCH → SOLUTIONS → DECISIONS → ACTIONS → IMPACTS

Research must find solutions to those issues. It should be both technology-specific and cross-disciplinary.

All stakeholders have a role to play and must collaborate to develop, decide and implement sustainable solutions.

SUSTAINABLE DEVELOPMENT GOALS

THANK YOU!

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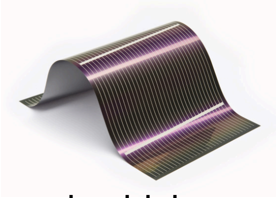
List of Critical Materials

Technology	Component	Material
Wind	Generators	Neodymium
		Dysprosium
Vehicles	Motors	Neodymium
		Dysprosium
	Li-ion Batteries (PHEVs and EVs)	Lithium
		Cobalt
	NiMH Batteries (HEVs)	REEs
		Cobalt
PV Cells	Thin film PV	Tellurium
		Gallium
		Germanium
		Indium
		Selenium
		Silver
	CIGS Thin Films	Indium
		Gallium
	CdTe Thin Films	Tellurium
Lighting	Phosphors	REEs: Yttrium, Cerium, Lanthanum, Europium, Terbium
Fuel cells	Catalysts and Seperators	Platinum & other PGMs
		Yttrium

Indium



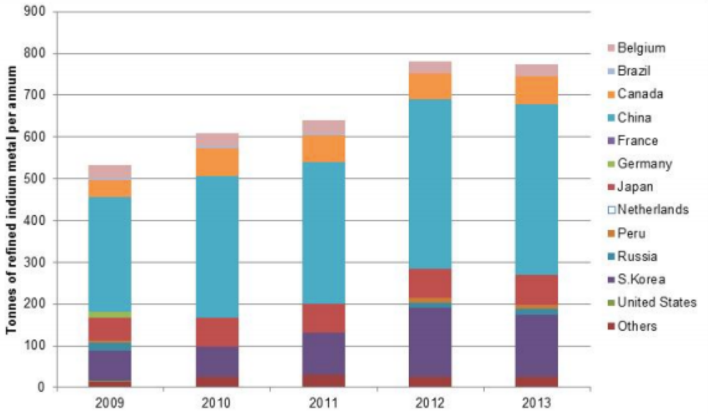
Demand for indium could increase if thin-film materials, specifically CIGS and II-V thin films, become preferred PV materials.

But the indium supply can be fragile:

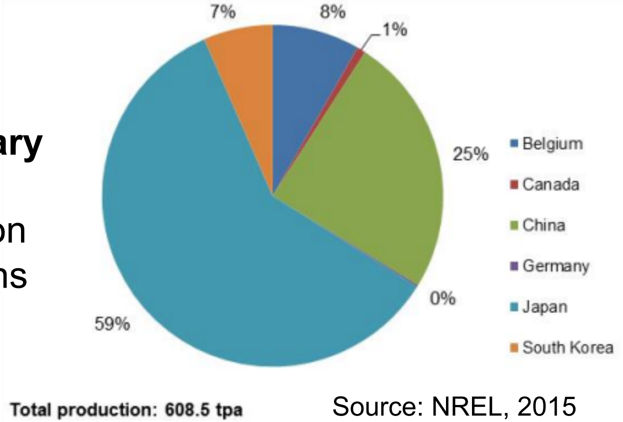
- Markets for metallic forms of indium are small (± 100 tpa). Any new use could alter demand, which could grow faster than production capacity.
- Indium is produced mostly as byproduct of zinc smelting and refining. If future indium demand increases, more costly sources will be needed.
- Indium is one of the scarcer elements in terms of abundance in the Earth's crust.

Indium production in 2013 = 1.380 tons

Primary refined production = 770 tons

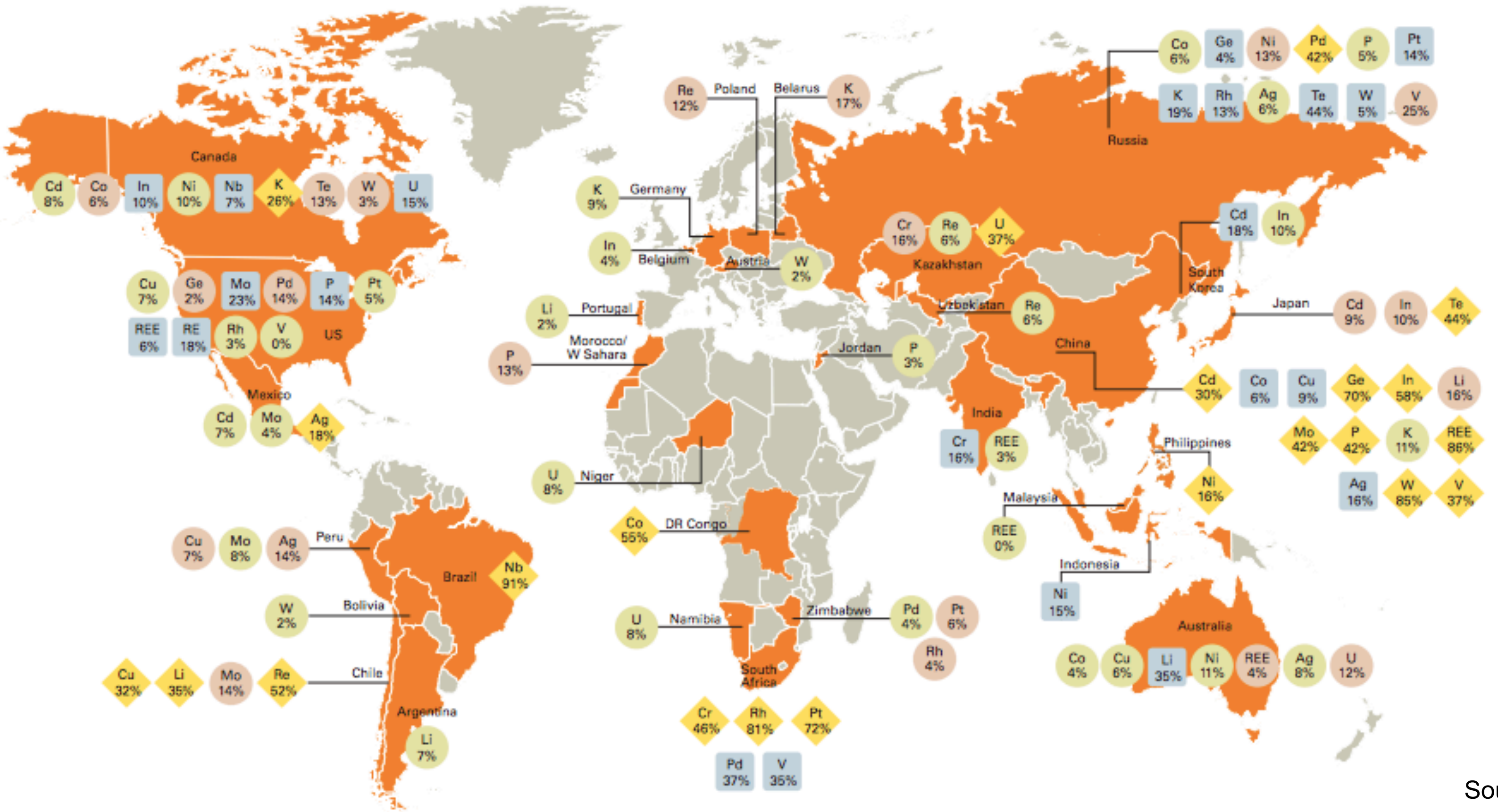


Secondary refined production = 610 tons



Source: NREL, 2015

Top Producing Countries



Source: BP, 2012

Risks by Volatility and Peaks of Resources Market Prices

Risks for national economies and producing companies have risen through an increasing volatility of resources market prices.

The distortion of the market price development is influenced by a lot of factors:

- Demand-supply imbalances
- Politics: weak organizational structures and political unrests
- Externalities: Climate change, loss of biodiversity
- Monopolies, cartels and oligopoly structures & market manipulation
- Time-lagged investments in market supplies
- Rising extraction costs, differences to expected reserves, lack of legal certainty
- Speculation on the resources market are difficult to identify
- Backstop technologies substitution potential
- Technology development like fracking and new reserves
- General uncertainties about existing reserves

Inter-technology and intra-technology choices

Uncertain demand: How material demand will increase depends on both inter- technology choices and intra- technology choices within particular technologies (World Bank, 2018).

Transition towards a low-carbon economy

- → **Radical restructuring of energy supply and transmission systems globally**
- → **Material intensive composition of low carbon technologies**

INCREASE IN METAL DEMAND

INTER TECHNOLOGY CHOICES

INTRA TECHNOLOGY CHOICES

WIND TECHNOLOGIES
- Geared turbine
- Direct drive turbine
- …

SOLAR TECHNOLOGIES
- Crystalline Silicon
- Thin Film
- …

STORAGE TECHNOLOGIES
- Lithium ion
- Lead acid
- …