VIRTUAL WORKSHOP

Mineral Criticality and the Energy Transition

TUESDAY, 2 JUNE 2020 • 10:30 EST / 16:30 CEST

AGENDA

Mineral Criticality and the Energy Transition

10:30 – 11:15	Key-note welcoming addresses
11:15 – 12:00	Panel 1: Governance
12:00 – 12:45	Panel 2: Stewardship
12:45 – 13:00	Wrap-up and closing remarks

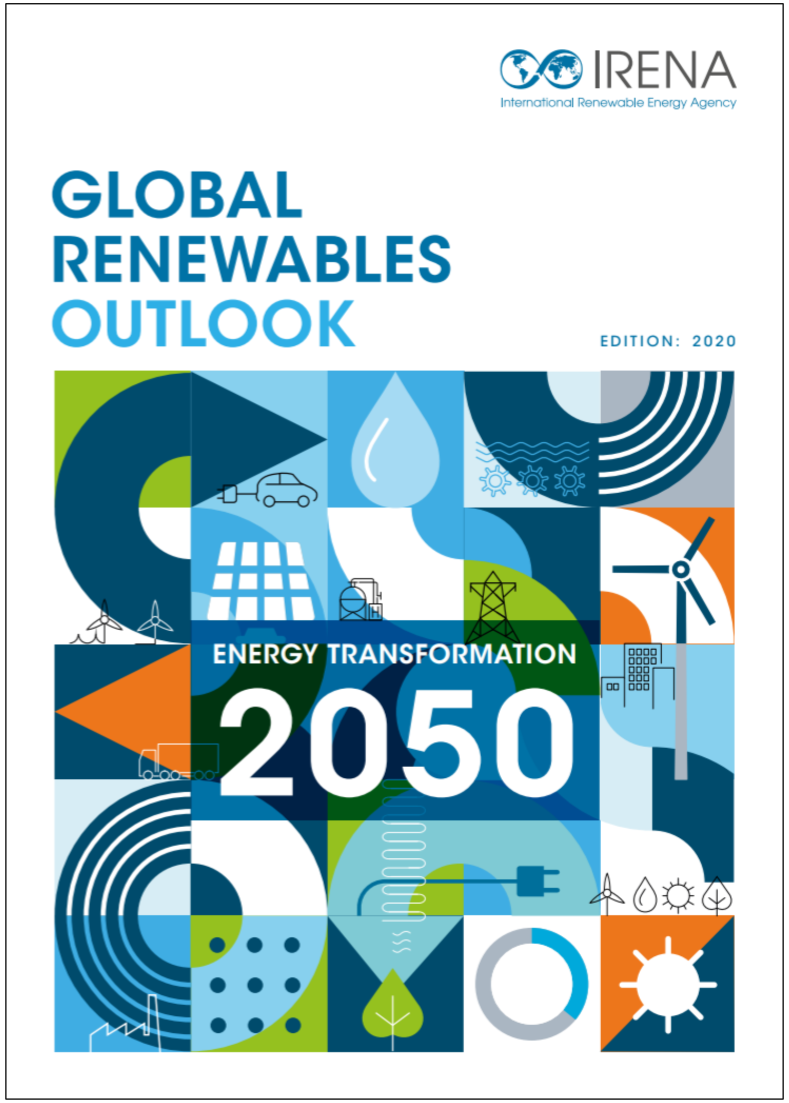
1

Key-note welcoming addresses

Mr Frank Fannon
United States Assistant
Secretary of State
for Energy Resources

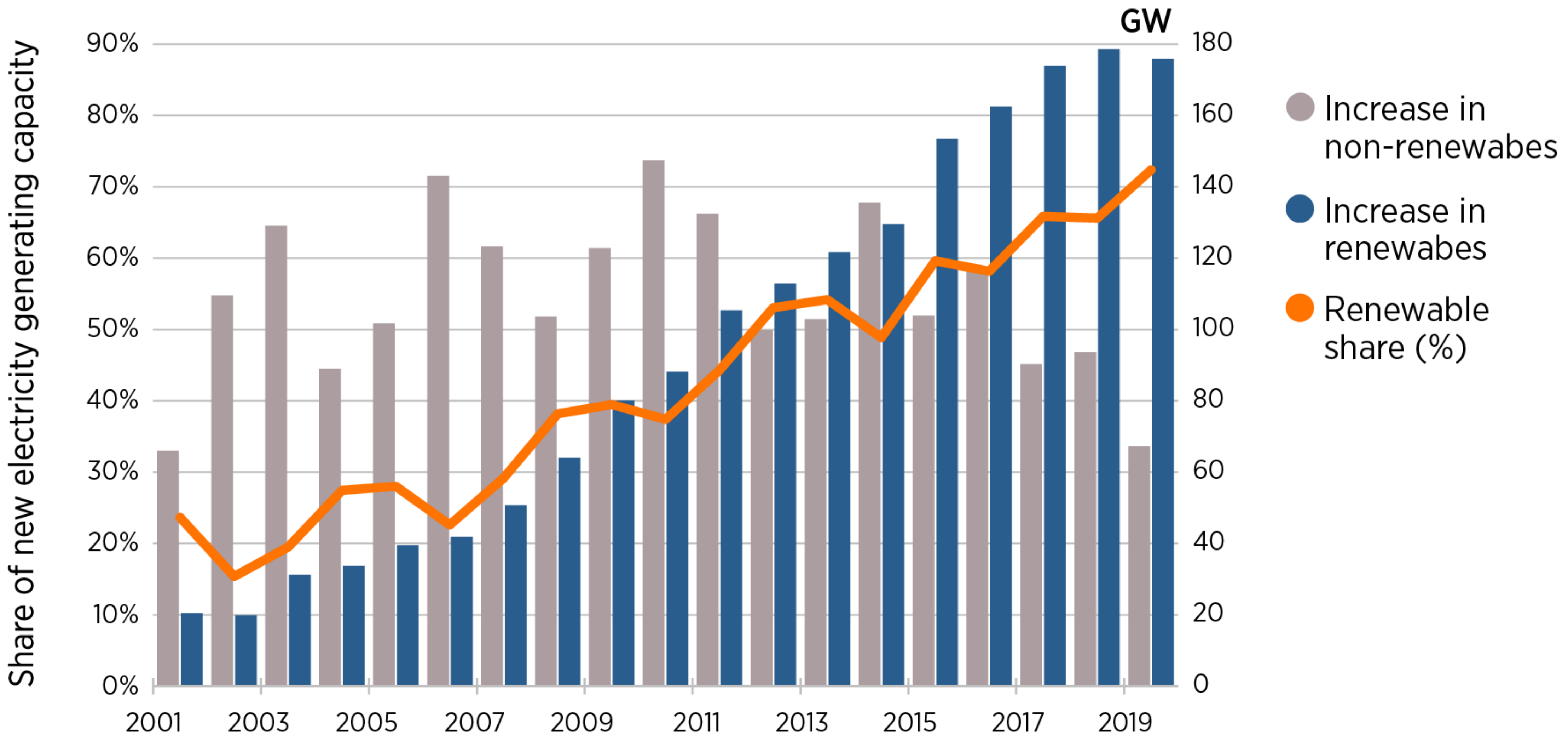
Mr Francesco La Camera
Director-General
The International Renewable
Energy Agency

Global Renewables Outlook: Energy transformation 2050



- The Global Renewables Outlook charts a path to create a sustainable future energy system.

The global energy transition is underway



Renewables now account for one third of global power capacity today

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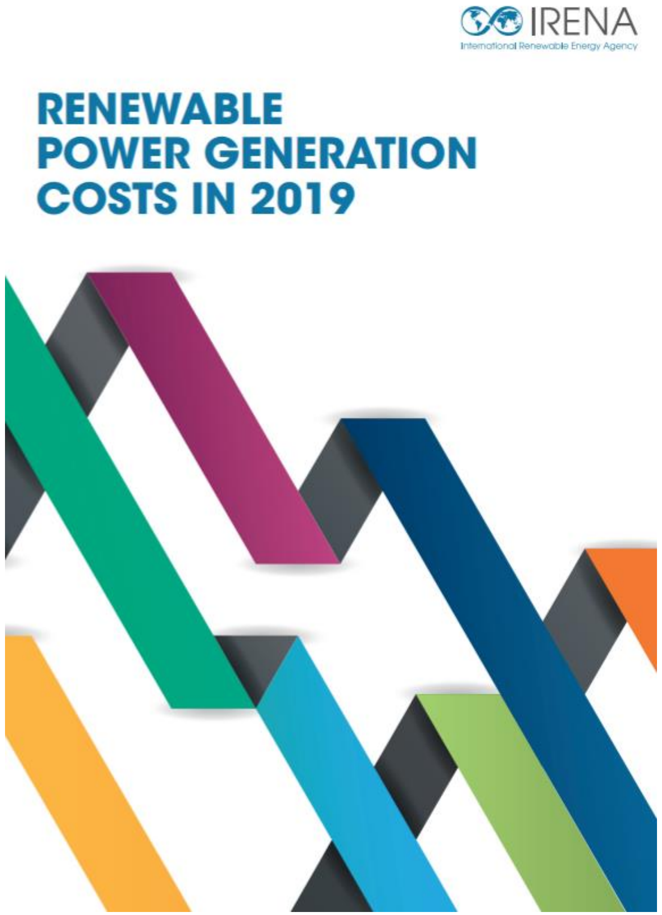
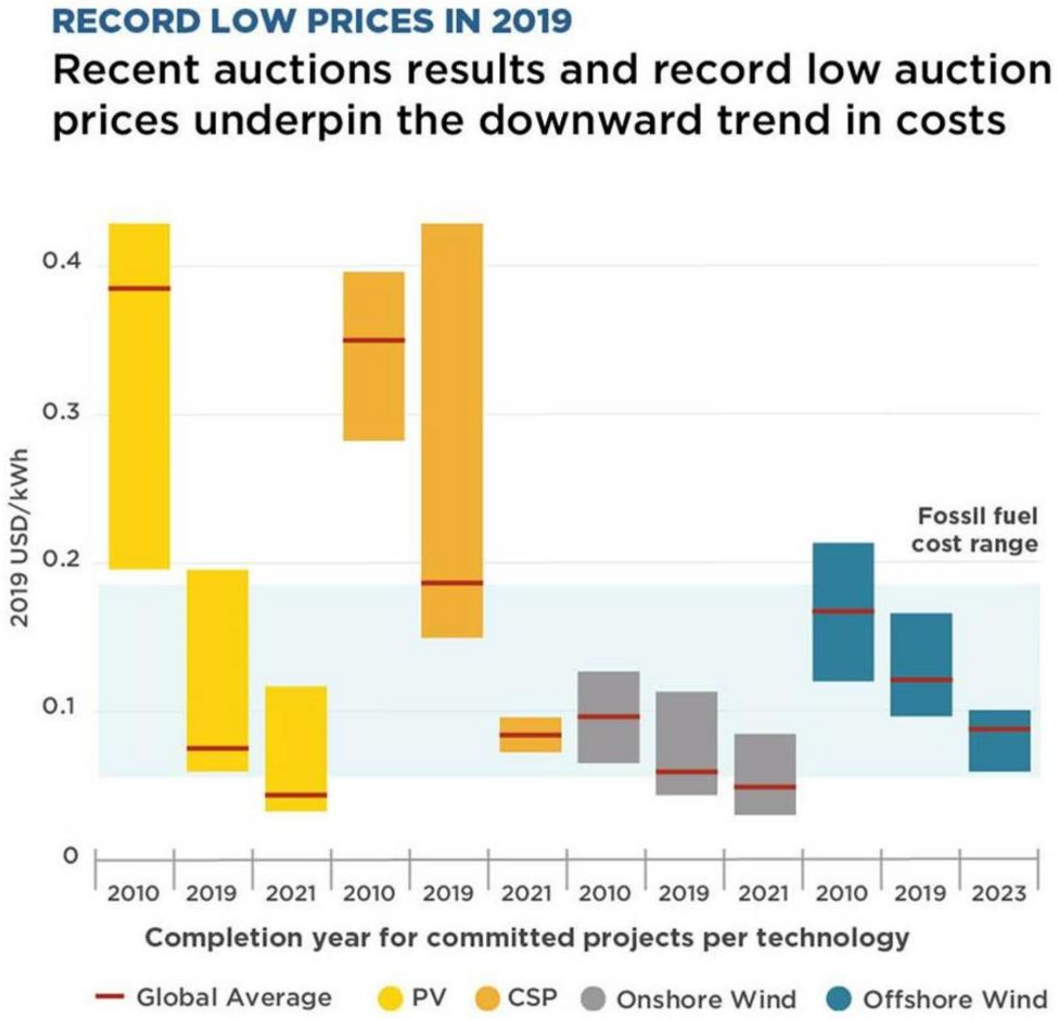
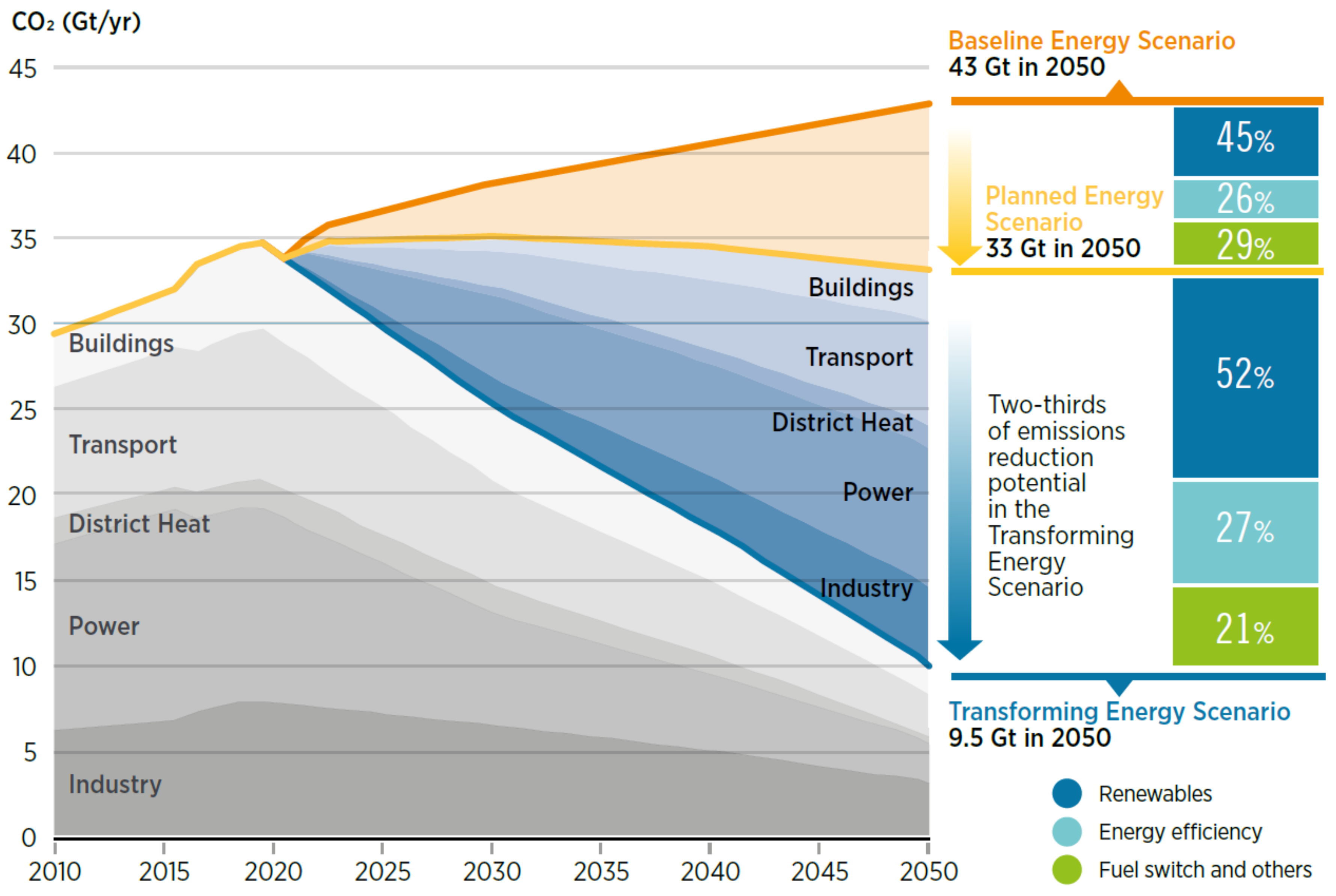
Driving change: the strong business case of renewables



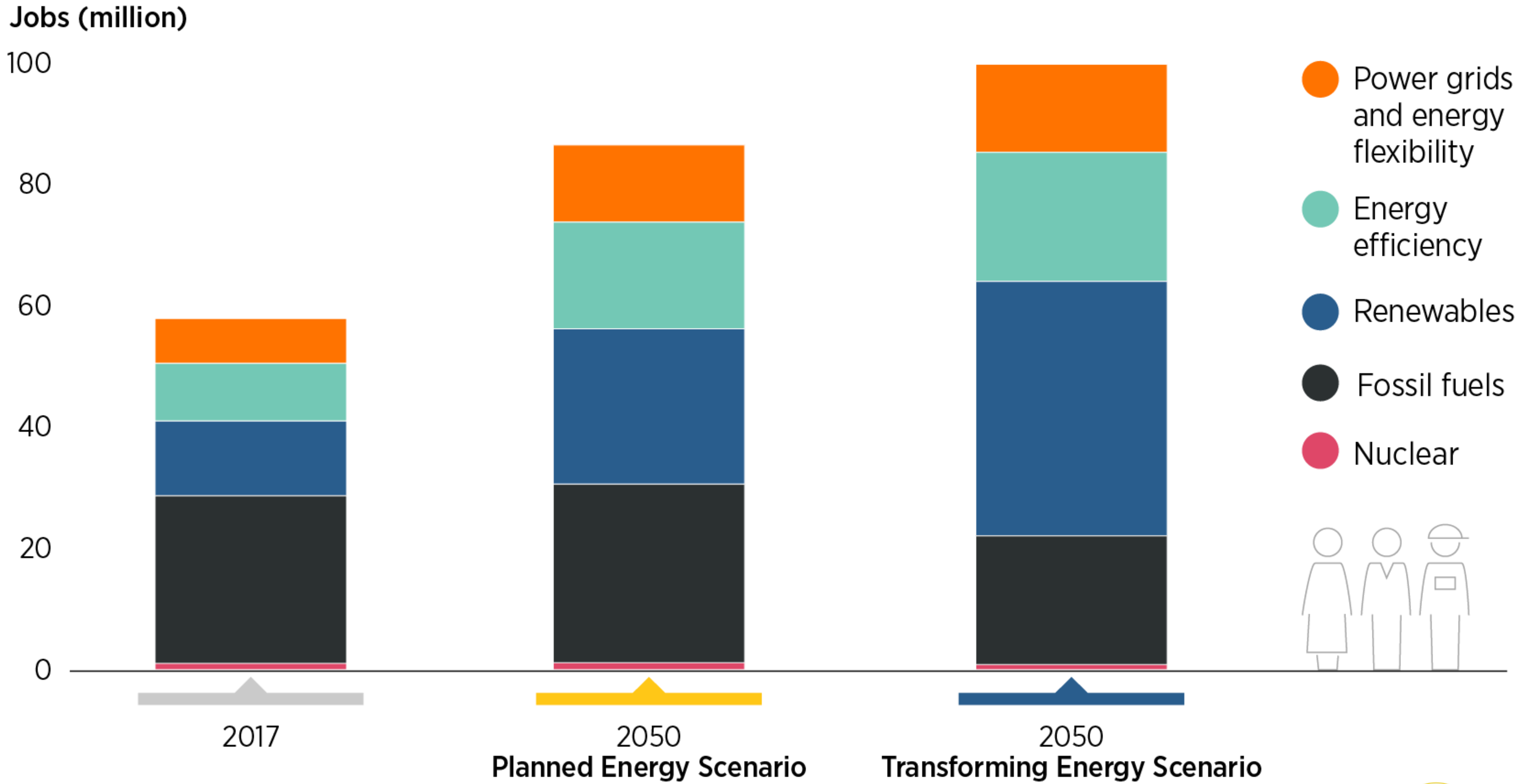


Renewable power generation has become increasingly competitive with, or in many situations less costly than, fossil-based or nuclear power

The bulk of emission reductions potential: renewables and efficiency

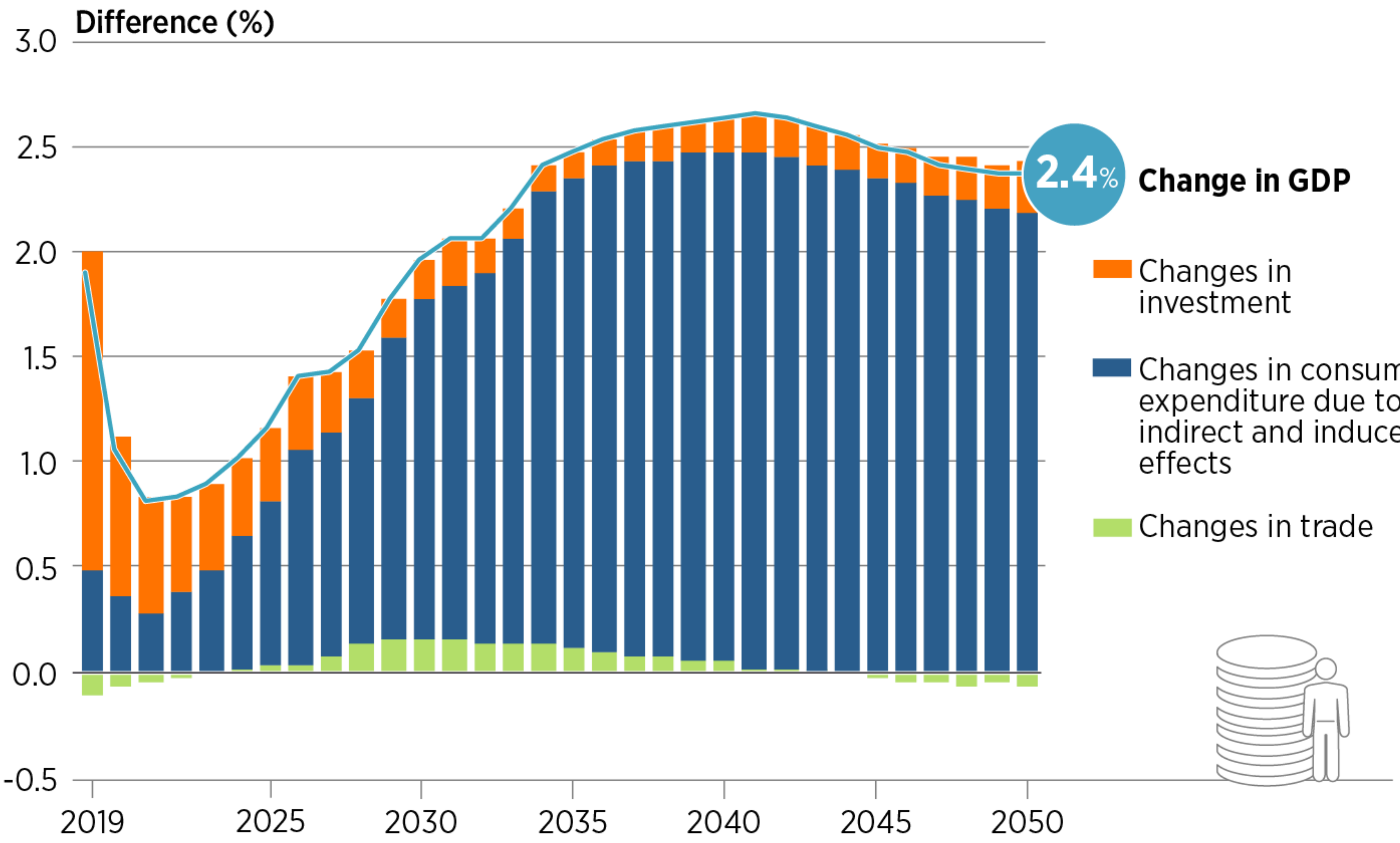


The energy transition will create jobs



Renewables jobs would increase to 42 million globally by 2050, 4 times more than today

The energy transition will also stimulate economic growth



Global economy would grow, amounting GDP gains from now till 2050 to USD 98 trillion

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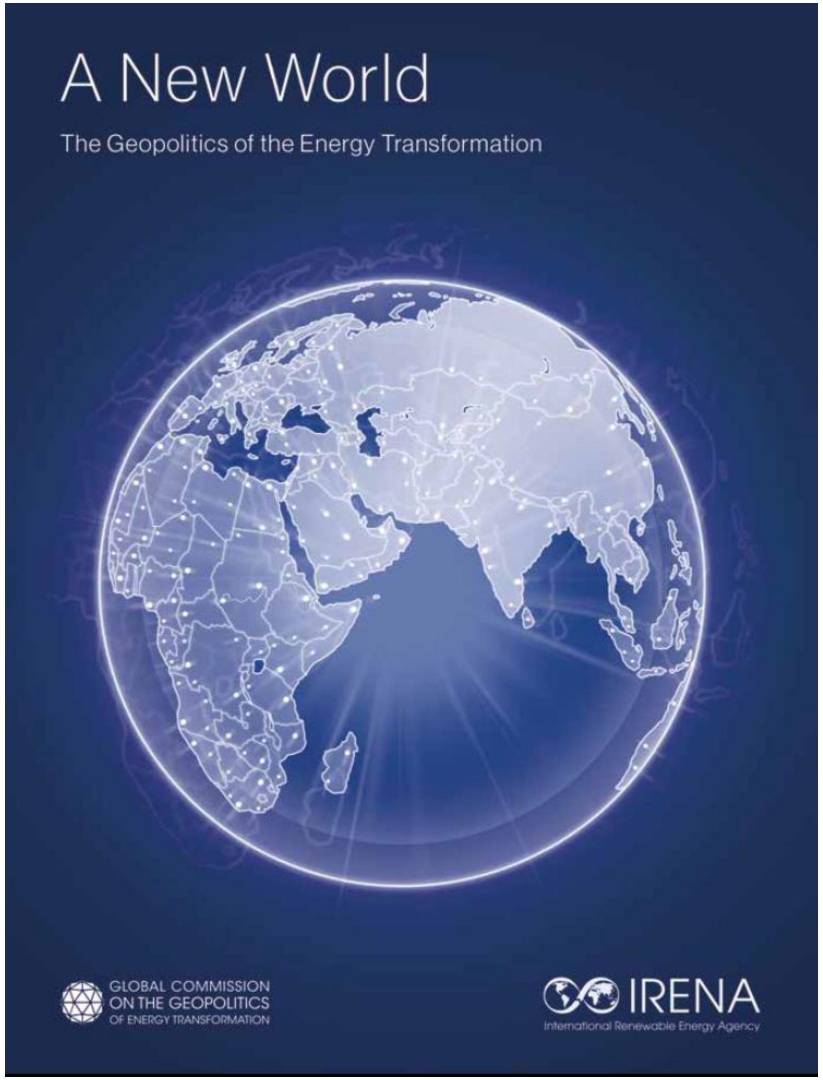
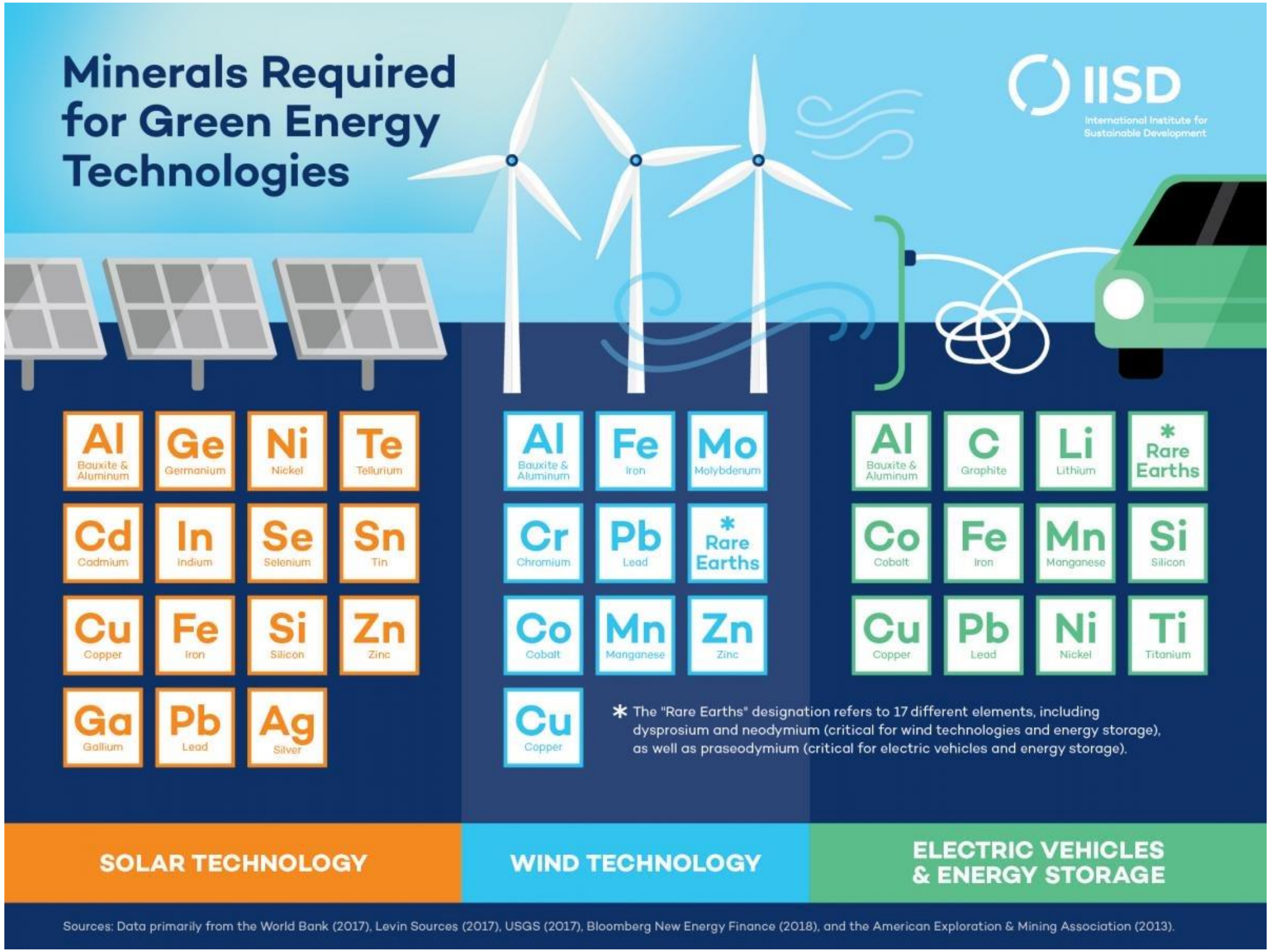
A New World – The Geopolitics of the Energy Transformation



- A 2019 report by the Global Commission on the Geopolitics of Energy Transformation, which analyses the geopolitical implications of the accelerating global shift to renewables.

- IRENA's Collaborative Framework on Geopolitics on Energy Transformation will build on the Commission's work with upcoming events.

Critical minerals in the energy transition



Source: International Institute for Sustainable Development, 2019

Examples:

- **Solar PVs** use silicon, tellurium, gallium and indium
- **Fuel cells** use elements from the platinum group
- **EV batteries and energy storage** use lithium and cobalt
- **Wind turbines and EVs** use dysprosium, terbium, europium, neodymium, and yttrium

IRENA
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Dr Morgan Bazilian
Director of Payne Institute
Professor of Public Policy,
Colorado School of Mines

Critical Minerals

U.S. Department of State and IRENA
June, 2020

Morgan D. Bazilian, Ph.D.

Director, The Payne Institute, and Professor of Public Policy

The Payne Institute for Public Policy

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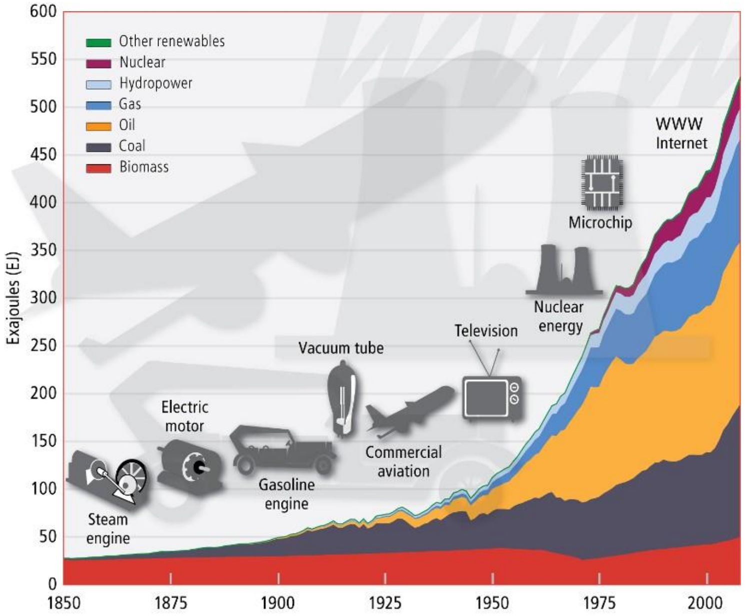
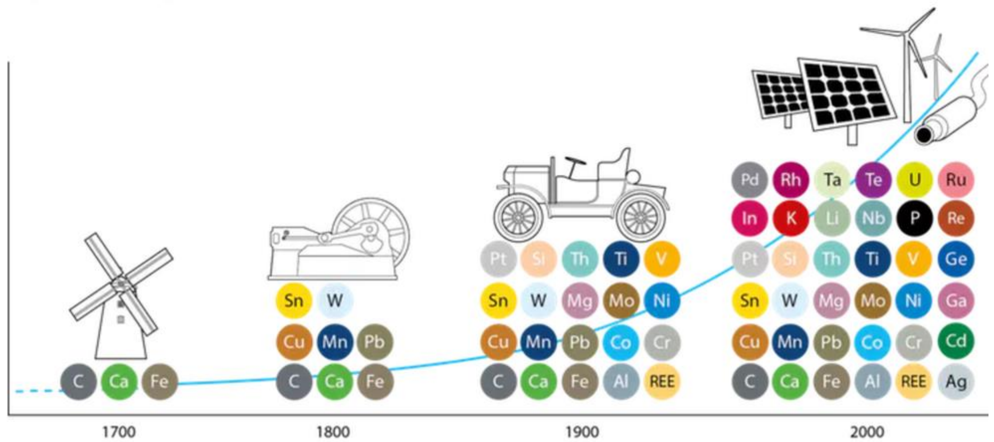
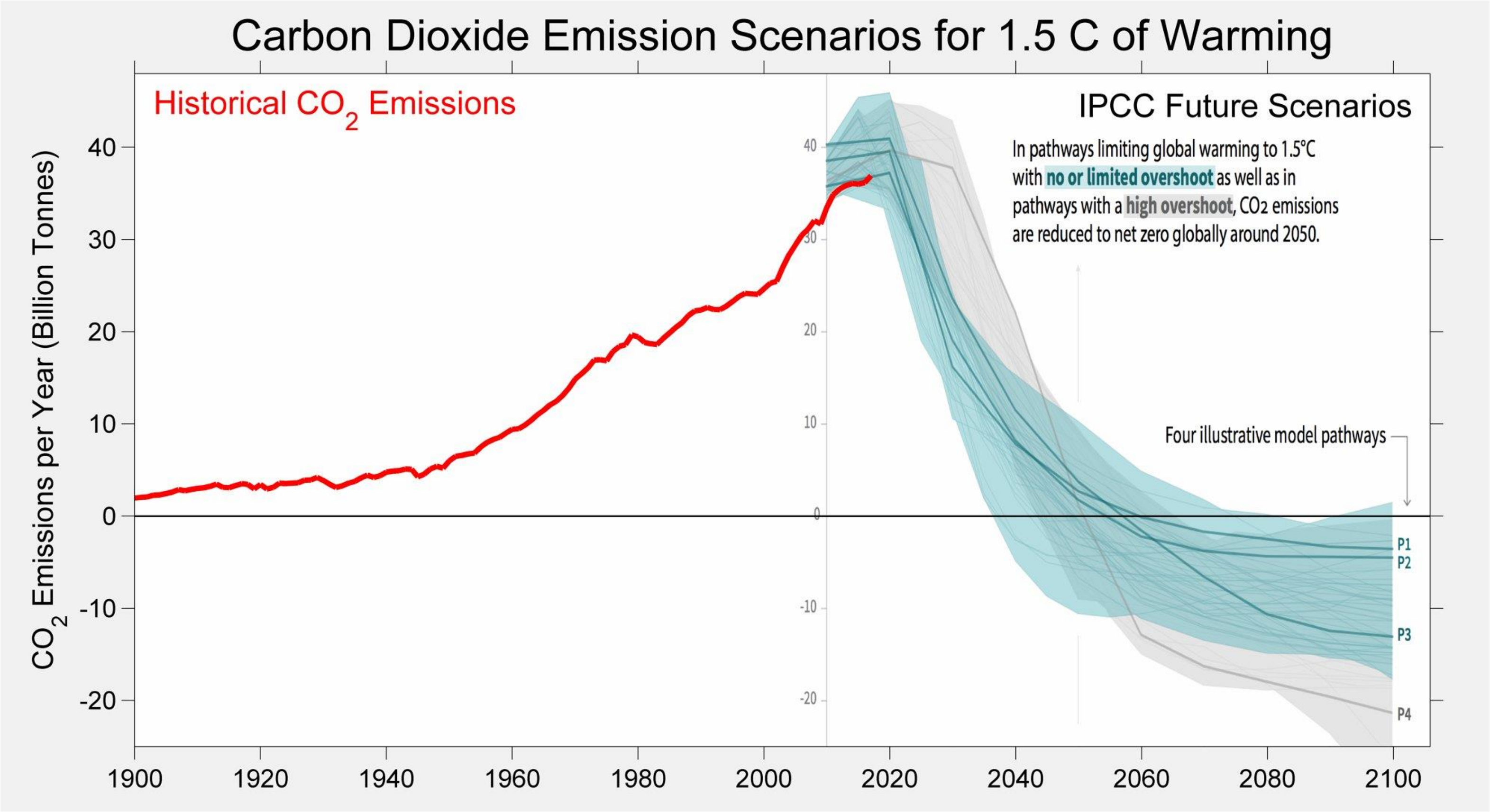
Of non-linear (rising) curves…



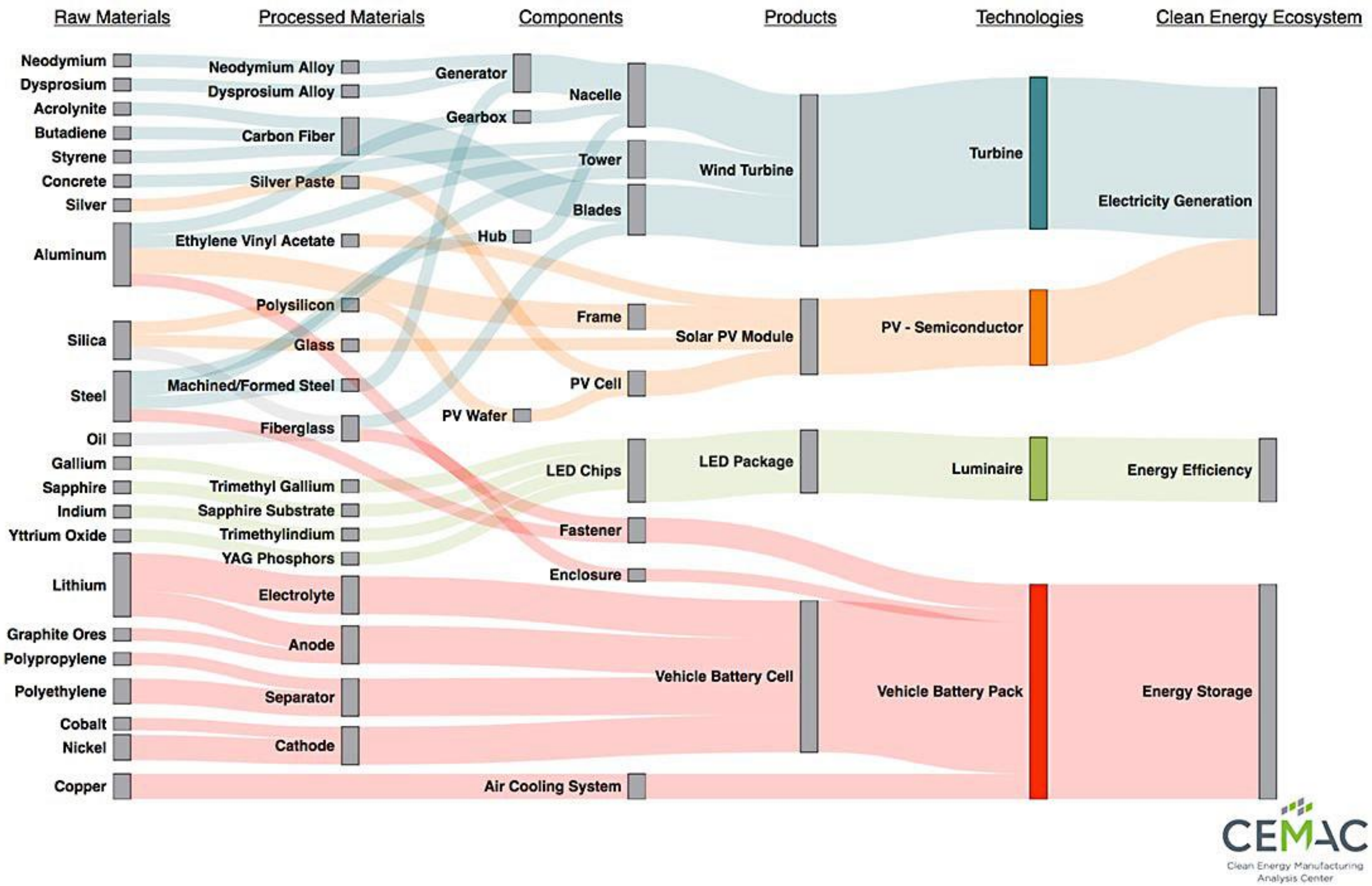
IIASA, Nakicenovi, Zepf, 2014c



….and downward

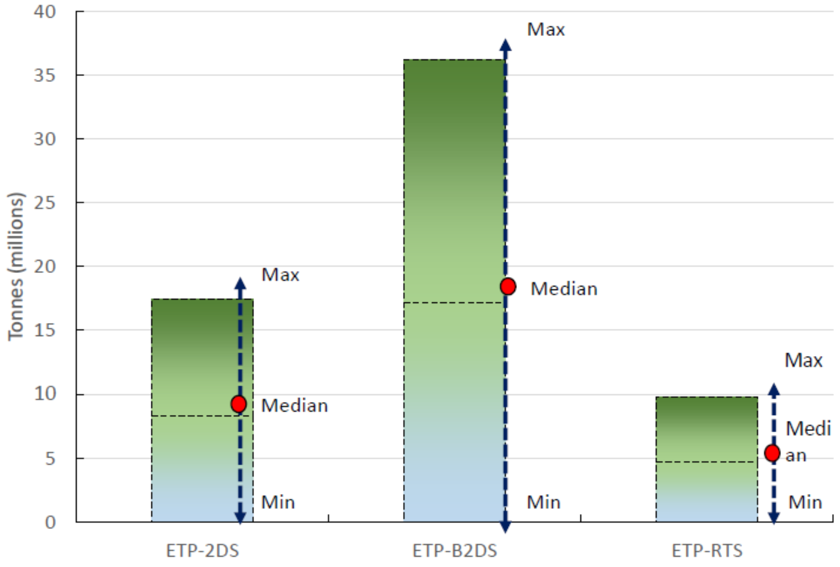


Clean energy technologies and minerals



Changing technologies…difficult to forecast

Total cumulative cobalt demand from energy storage through 2050



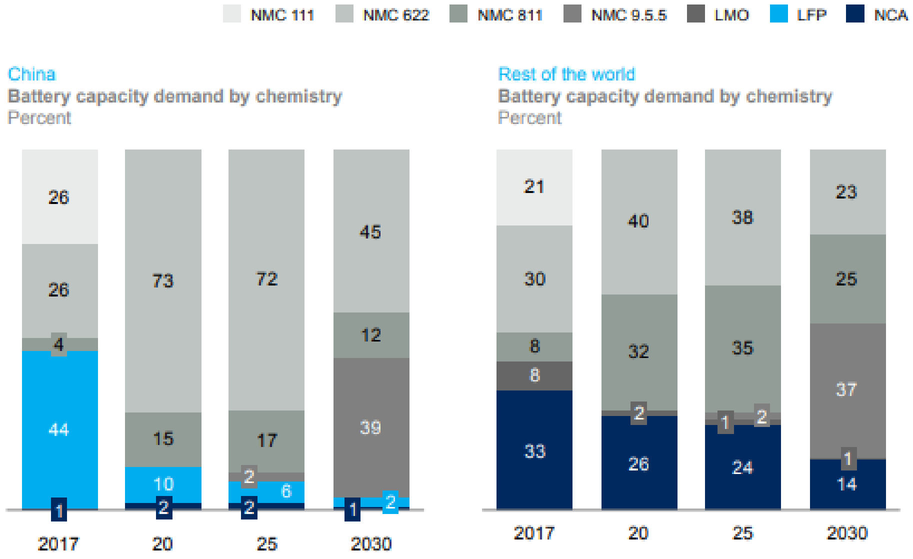
World Bank Analysis (2018)

Max - All Lithium ion batteries are Nickel Manganese Cobalt (NMC 111)

Median - All Lithium ion batteries are Nickel Manganese Cobalt (NMC 622)

Min - All Lithium ion batteries are Lithium Iron Phosphate

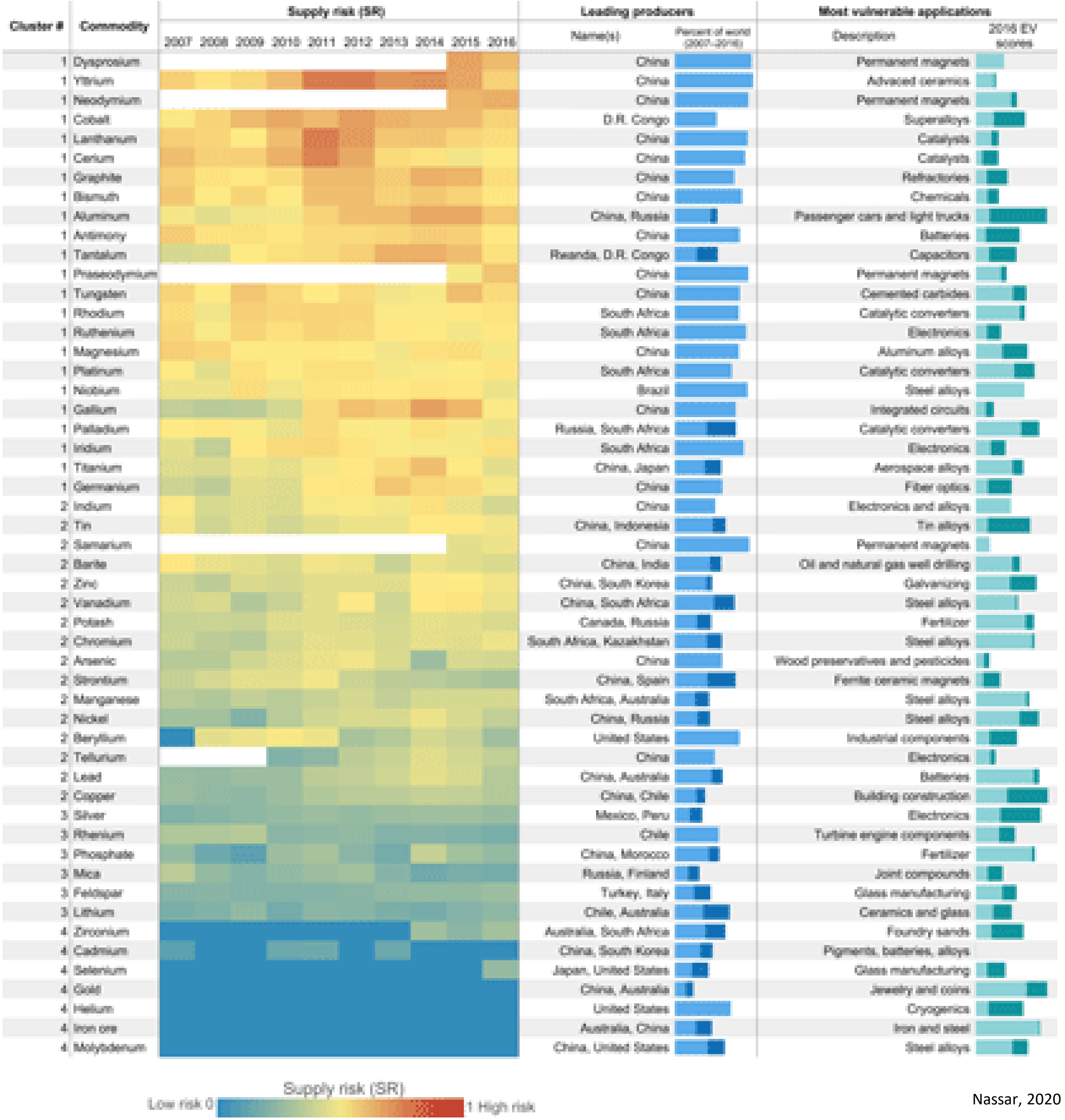
Exhibit 2 Distribution of EV by battery chemistry[1]



1 Other battery demand segments have been excluded

SOURCE: McKinsey Basic Material Institute's battery raw materials demand model

Defining criticality



Nassar, 2020

USA Critical materials

- Aluminum (bauxite), used in almost all sectors of the economy
- Antimony, used in batteries and flame retardants
- Arsenic, used in lumber preservatives, pesticides, and semi-conductors
- Barite, used in cement and petroleum industries
- Beryllium, used as an alloying agent in aerospace and defense industries
- Bismuth, used in medical and atomic research
- Cesium, used in research and development
- Chromium, used primarily in stainless steel and other alloys
- Cobalt, used in rechargeable batteries and superalloys
- Fluorspar, used in the manufacture of aluminum, gasoline, and uranium fuel
- Gallium, used for integrated circuits and optical devices like LEDs
- Germanium, used for fiber optics and night vision applications
- Graphite (natural), used for lubricants, batteries, and fuel cells
- Hafnium, used for nuclear control rods, alloys, and high-temperature ceramics
- Helium, used for MRIs, lifting agent, and research
- Indium, mostly used in LCD screens
- Lithium, used primarily for batteries
- Magnesium, used in furnace linings for manufacturing steel and ceramics
- Manganese, used in steelmaking
- Niobium, used mostly in steel alloys
- Platinum group metals, used for catalytic agents
- Potash, primarily used as a fertilizer
- Rare earth elements group, primarily used in batteries and electronics
- Rhenium, used for lead-free gasoline and superalloys
- Rubidium, used for research and development in electronics
- Scandium, used for alloys and fuel cells
- Strontium, used for pyrotechnics and ceramic magnets
- Tantalum, used in electronic components, mostly capacitors
- Tellurium, used in steelmaking and solar cells
- Tin, used as protective coatings and alloys for steel
- Titanium, overwhelmingly used as a white pigment or metal alloys
- Tungsten, primarily used to make wear-resistant metals
- Uranium, mostly used for nuclear fuel
- Vanadium, primarily used for titanium alloys
- Zirconium, used in the high-temperature ceramics industries

Under the Executive Order, these commodities qualify as "critical minerals" because each has been identified as a non-fuel mineral or mineral material that is essential to the economic and national security of the United States, that has a supply chain vulnerable to disruption, and that serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economy or national security.

NORTH OF 60 MINING NEWS

In-depth News News Nuggets Northern Neighbors Northern Mining History Opinion

Mineral import reliance US Achilles' heel

By Shane Lasley
Mining News

Murkowski calls for Congressional action to curb dependence

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Last updated 2/15/2019 at 6:12am

U.S. Sen. Lisa Murkowski, R-Alaska, called on Congress to pass legislation that will curb the United States' increasing dependence on foreign countries for its growing mineral needs.

In its Mineral Commodity Summaries 2018, the U.S. Geological Survey identified 50 minerals for which the U.S. was reliant on other countries for at least 50 percent of its supply,

Other Countries….

Table 1: Table of critical minerals in Australia[4]

	Critical Mineral	U.S. list[5]	E.U. list[6]	Japan list[7]	Australia's Geological Potential[8]	Australia's Economic Demonstrated Resource[9]	Australia's Production	Global Production	Market Value (Global) (US$m)[10]
1	Antimony	✓	✓	✓	Moderate	138 kt	5.5 kt	150 kt	$185.2
2	Beryllium	✓	✓		Moderate	-	-	230 t	$918.6[11]
3	Bismuth	✓	✓		Moderate	-	-	14 kt	$69.2
4	Chromium	✓		✓	High	-	-	31 000 kt	$4,705.3
5	Cobalt	✓	✓	✓	High	1221 kt	5 kt	110 kt	$541.8
6	Gallium	✓	✓	✓	High	-	-	495 t	$918.6[11]
7	Germanium	✓	✓	✓	High	-	-	134 t	$918.6[11]
8	Graphite	✓	✓	✓	Moderate	7140 kt	0	1200 kt	$1,076.1
9	Hafnium	✓	✓		High	756 kt	-	-	$918.6[11]
10	Helium	✓	✓		Moderate	-	4 hm^3	160 hm^3	$591.0
11	Indium	✓	✓	✓	High	-	-	0.72 kt	$918.6[11]
12	Lithium	✓		✓	High	2803 kt	14.4 kt	43 kt	$1,430.6
13	Magnesium	✓	✓	✓	Moderate	-	0	1100 kt	$716.4
14	Manganese	✓		✓	High	231 000 kt	3200 kt	16 000 kt	$5,443.7
15	Niobium	✓		✓	High	216 kt	-	64 kt	$1,709.5[12]
16	Platinum-group elements	✓	✓	✓	High	24.9 t	2.6 t	200 kt	$19,316.6
17	Rare-earth elements	✓	✓	✓	High	3270 kt	14 kt	130 kt	$415.4[13]
18	Rhenium	✓		✓	Moderate	-	-	52 kt	$918.6[11]
19	Scandium	✓	✓		High	-	-	-	-[13]
20	Tantalum	✓	✓	✓	High	55.4 kt	-	1.3 kt	$1,552.9
21	Titanium	✓		✓	High	Ilmenite: 276 500 kt Rutile: 32 900 kt	Ilmenite: 1400 kt Rutile: 300 kt	Ilmenite: 6700 kt Rutile: 750 kt	$1,609.9
22	Tungsten	✓	✓	✓	Moderate	386 kt	0.11 kt	95 kt	$164.0
23	Vanadium	✓	✓	✓	Moderate	3965 kt	0	80 kt	$1,709.5[12]
24	Zirconium	✓		✓	High	52 662 kt	600 kt	1600 kt	$1,003.4

Australian Government, 2019,

- **The United States** lists 35 minerals and commodities as critical to their economic and national security.
- **The European Union** lists 27 raw materials as critical due to risks of supply shortage and their impacts on the economy being higher than those of most of the other raw materials.
- **The Japanese** report that identified the 31 critical minerals

It's the supply chain

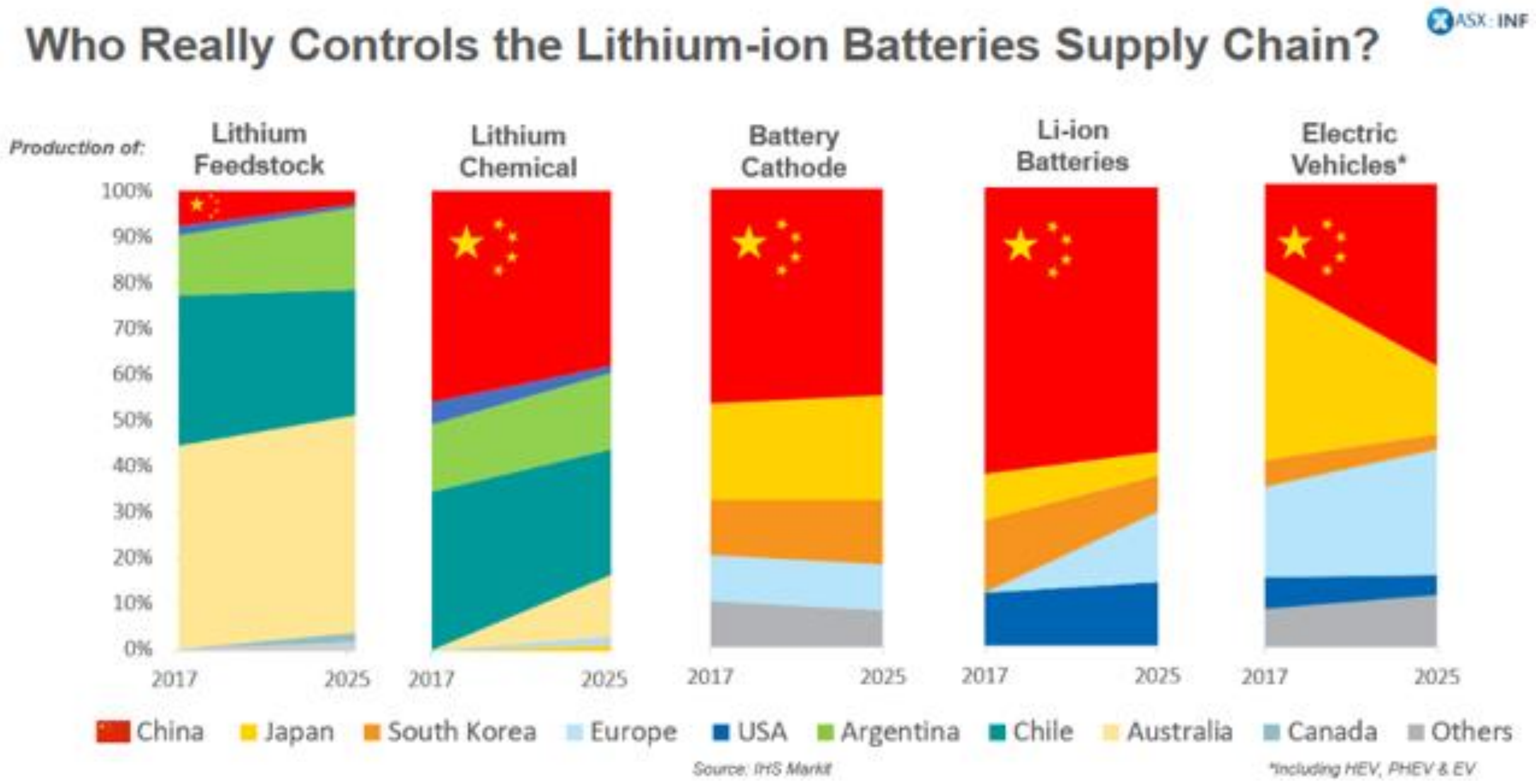
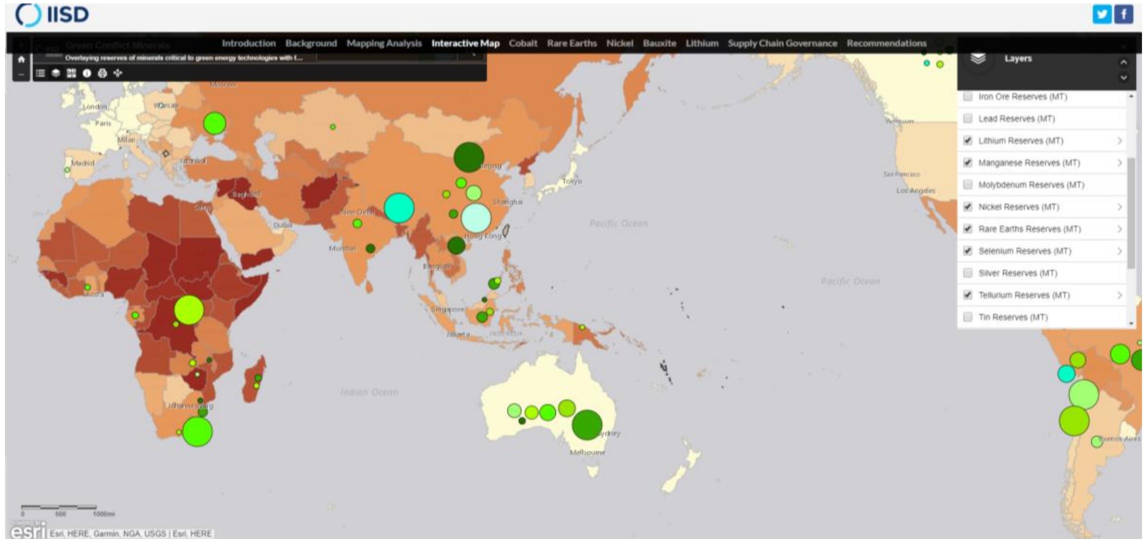


Table 2
Cobalt production and reserves (metric tons) (Drexhage et al., 2017 based on USGS, 2016).

Country	Mine production	Reserves
Congo (Kinshasa)	63,000	3,400,000
Australia	6000	1,100,000
Cuba	4200	500,000
Zambia	2800	270,000
Philippines	4600	250,000
Russia	6300	250,000
Canada	6300	240,000
New Caledonia	3300	200,000
Madagascar	3600	130,000
China	7200	80,000
Brazil	2600	78,000
South Africa	2800	31,000
Other countries	7700	633,000
Total	120,400	7,162,000



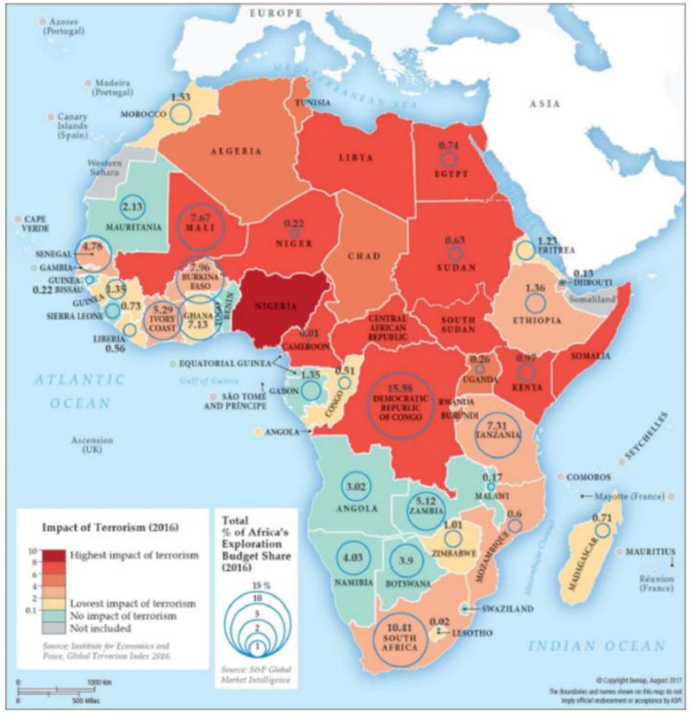
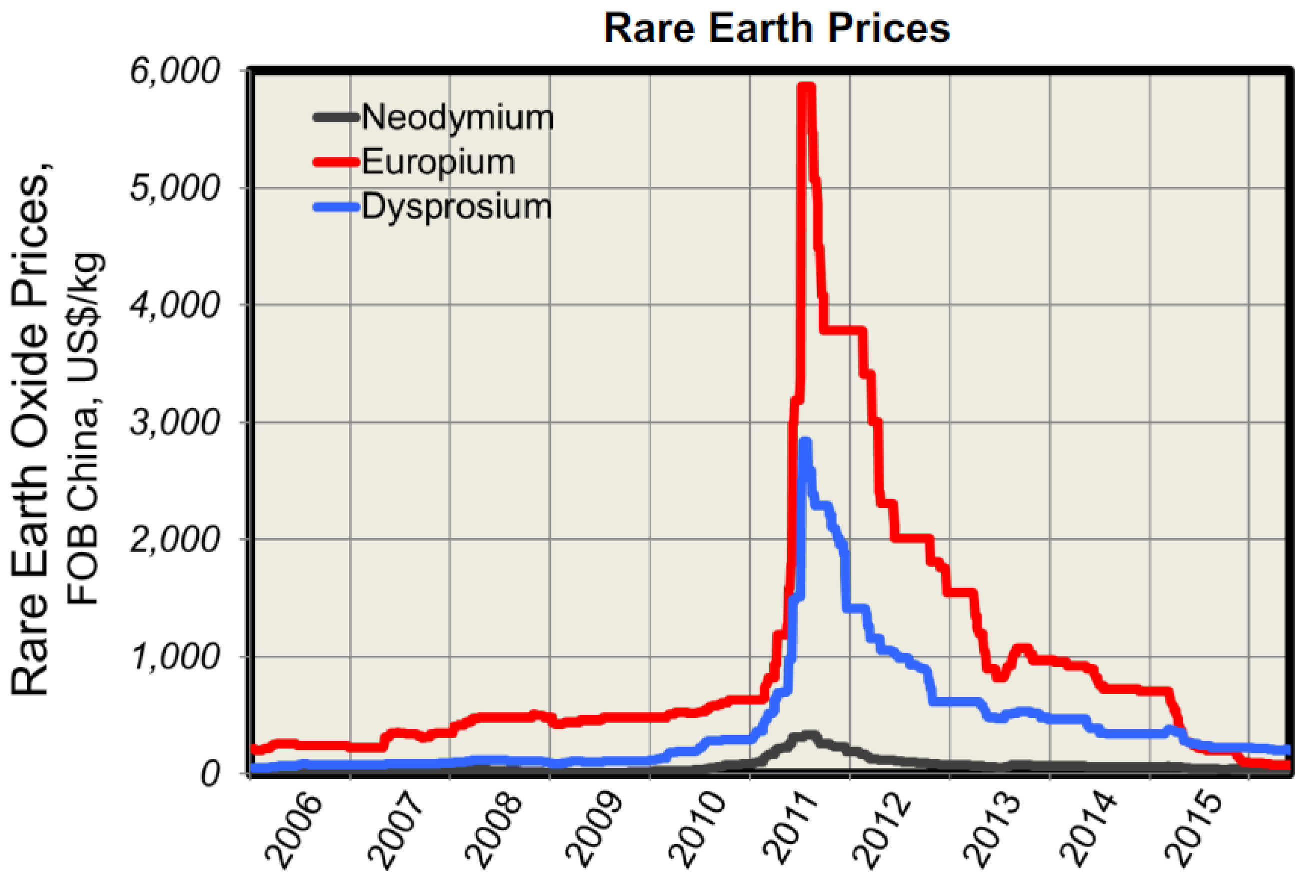
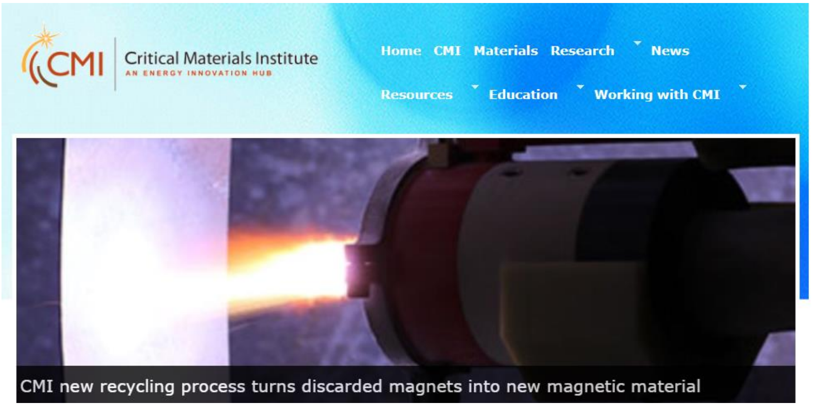


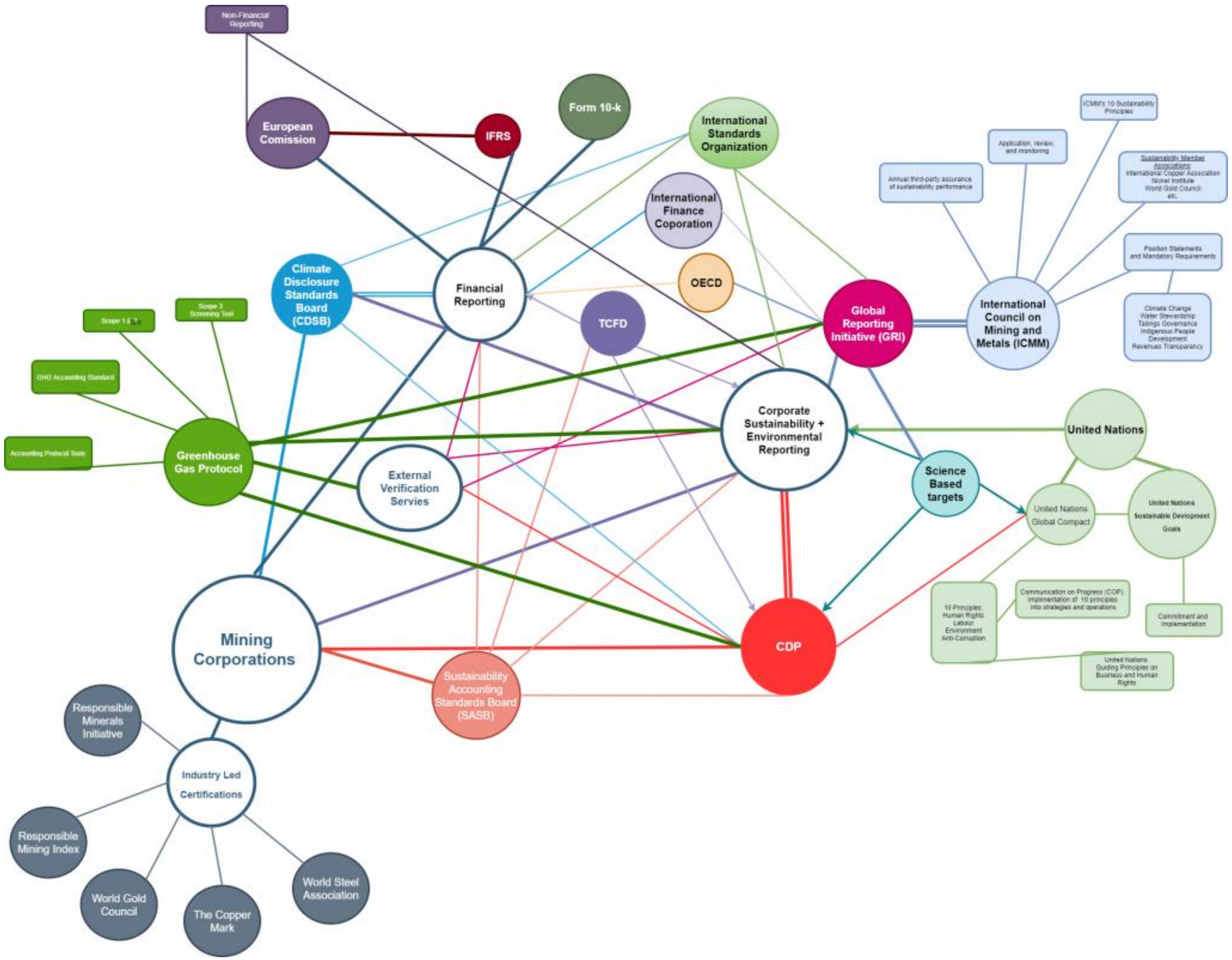
Fig. 3. Mining exploration budget and terrorism impact (Sharland et al., 2017).

Motivation to start CMI





Complex to track



Parting thoughts

- Many analogies between minerals criticality and energy security
  - Social license
  - Security of supply
    - Not just a supply risk!
  - Both public and private elements
  - Importance of developing economies
  - Resource and reserve frameworks

- Need to think across many different supply chains
  - Each supply chain has several uncertainties
  - Each has a very different “market” profile
  - Deeply interconnected, not independent.

- The energy transition looks sure to be mineral and metal-intensive

- Mining investments and development can take decades

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2

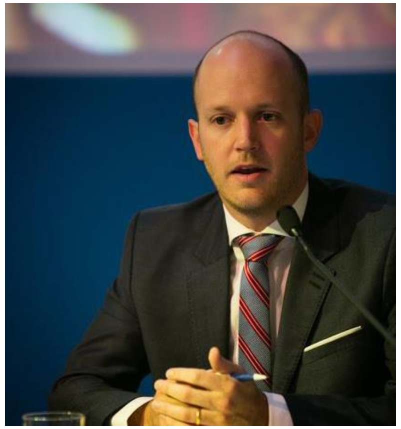
PANEL 1: Governance

Laying the Institutional Framework
to Attract Competitive and Transparent Investment

SPEAKERS

Shawn Tupper
Associate Deputy Minister
Natural Resource Canada

Augusto Cauti
Vice Minister of Mines
Peru



Tyler Gillard
Head of Sector Projects &
Legal Adviser, OECD

MODERATOR

Jenna Schroeder
Global Energy Programs Manager
U.S. Department of State

3

PANEL 2: Stewardship

Supporting the Full Value Chain
from Minerals to Energy Technologies

SPEAKERS

MODERATOR

Christopher Sheldon
Practice Manager
for Extractives,
World Bank

Peter Handley
Head of Energy Intensive
Industries & Raw Materials
DG Grow, European
Commission

Jeffrey Spangenberger
ReCell Center Director
Argonne National
Laboratory

Dr Dolf Gielen,
Director
IRENA's Innovation &
Technology Centre

Christopher Sheldon
Practice Manager for Extractives
World Bank

MINERALS CRITICALITY AND THE ENERGY TRANSITION VIRTUAL WORKSHOP

SUPPORTING THE FULL VALUE CHAIN FROM MINERALS TO ENERGY TECHNOLOGIES

CLIMATE-SMART MINING

New Climate Smart Mining Report:
The Mineral Intensity of the Clean Energy Transition (2020)

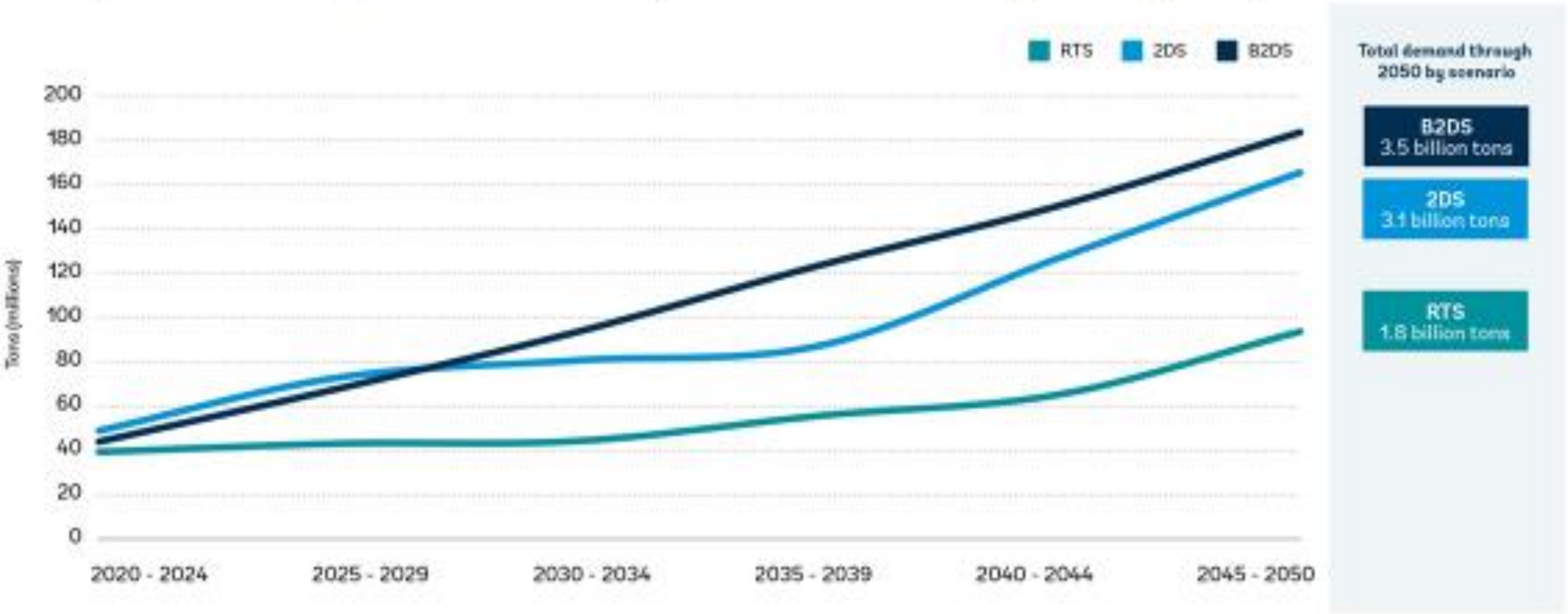
This new report looks at:

- How the **demand risk** for each mineral changes, depending on whether it is used in one technology, or across multiple technologies clean energy technologies
- Deep dive into different low-carbon technologies and how **technological improvements** and **material efficiency** could impact mineral demand
- Potential role of **recycling** and **re-use** in meeting demand under a 2-degree scenario
- **Carbon footprint** of the minerals needed for low-carbon technologies relative to conventional technologies

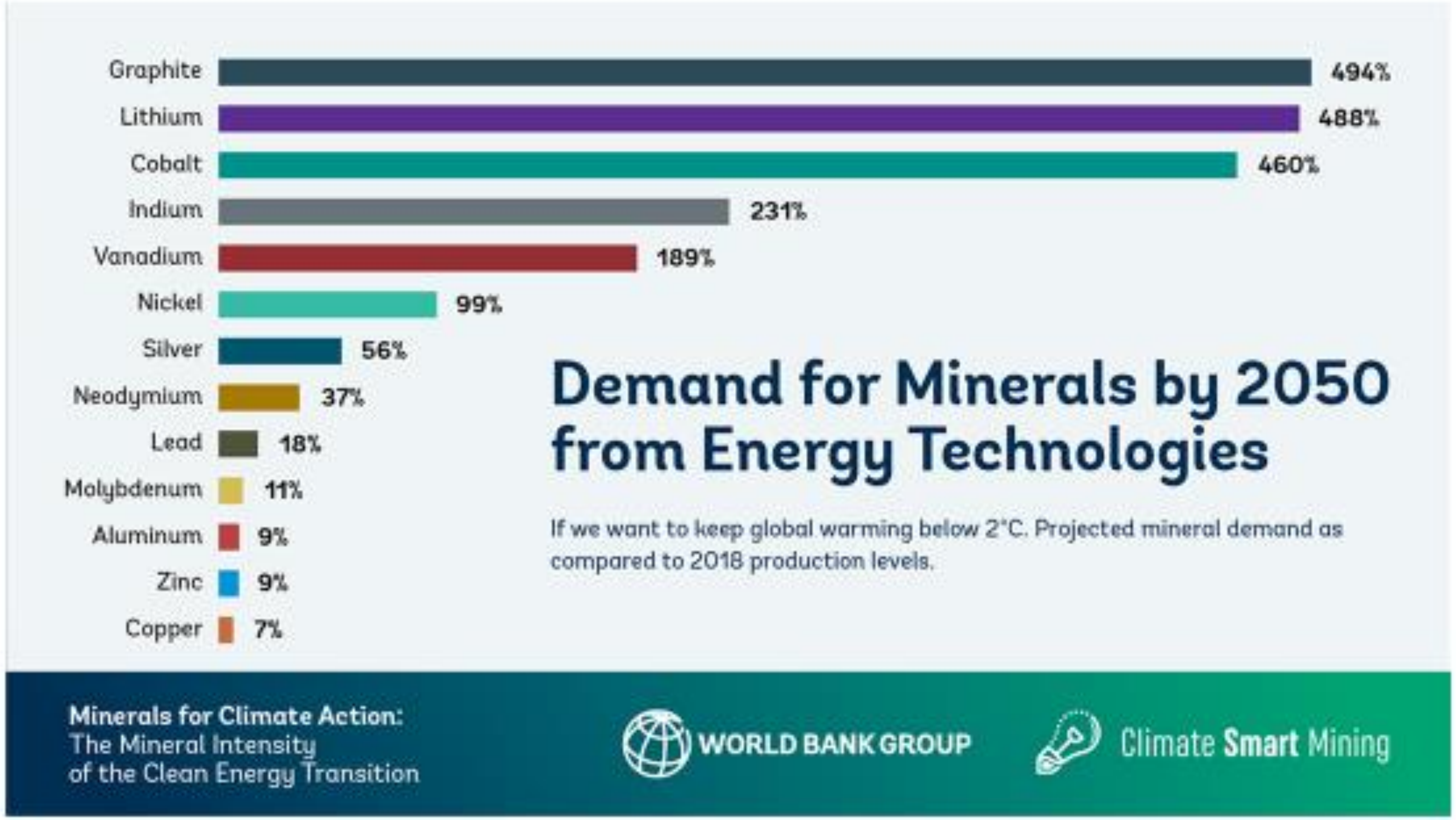
New report findings:
THE MORE AMBITIOUS THE CLIMATE SCENARIO, THE MORE MINERALS NEEDED

More than **3 billion tons** of minerals and metals will be needed by 2050 to achieve a **<2°C scenario**, equivalent to more than a third of all plastic produced between 1950-2015.

Projected Annual Average Demand of Minerals up to 2050 Under the IEA Energy Technology Perspective Scenarios



New findings:
Demand will increase significantly for some minerals to achieve 2DS



202 Report Methodology: Recycling

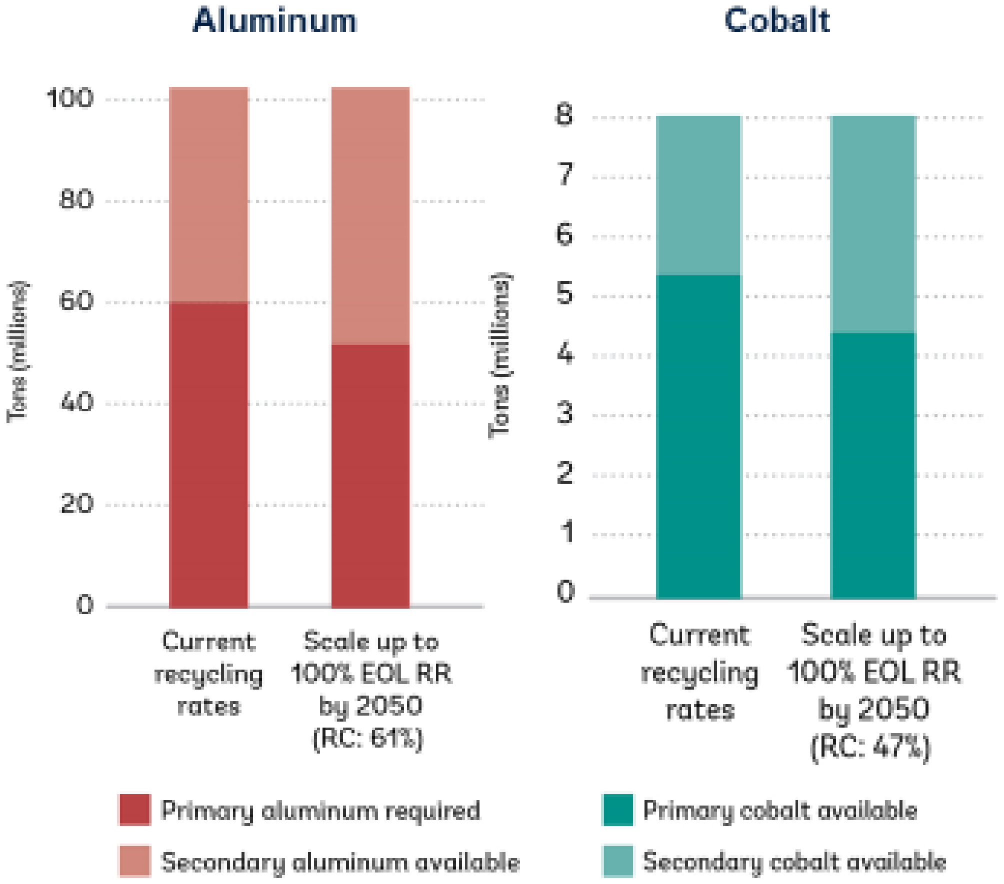
- Estimates of current **end-of-life (EOL)** and **recycled content (RC)** rates drawn from the literature
- Assumed increase of **EOL to 100% by 2050** and ratio of EOL to RC rates remain constant
- **RC rates** used to give estimates of primary and secondary demand

Mineral	End-of-life recycling rates	Recycled content rates
Aluminum	42%–70%	34%–36%
Cobalt	68%	32%
Copper	43%–53%	20%–37%
Lithium	<1%	<1%
Nickel	57%–63%	29%–41%

Source: UNEP 2011.

2020 Reort New findings:
The role of recycling in meeting demand under 2DS

- **Current recycling rates** refer to how many minerals are recycled at the end of a product's life (**EOL RR**)
- **Recycled content** refers to secondary minerals, which is the amount of recycled mineral that is used in new products
- Even if aluminum and copper from current products are recycled at **EOL at 100%**, it still wouldn't be enough to meet mineral demand under a 2DS
- While recycling can play an important role in meeting demand, **primary production** will still be needed



Note: 2DS = 2-degree scenario.

Peter Handley

Head of Energy Intensive Industries &
Raw Materials
DG Grow, European Commission

Minerals Criticality and the Energy Transition

Panel 2 – Stewardship. The EU perspective

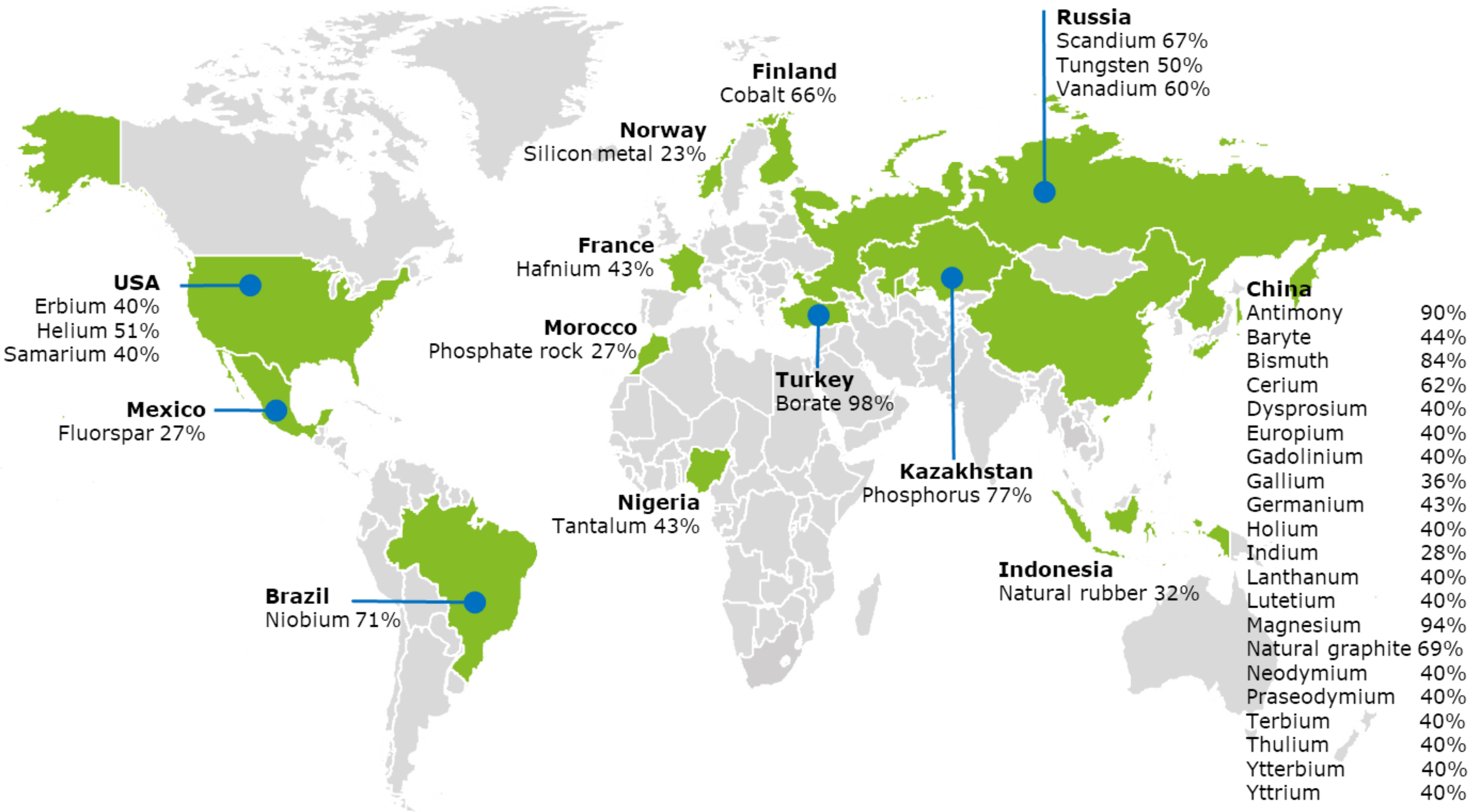
IRENA Workshop, 2 June 2020

Peter Handley

European Commission

Head of Unit „Energy-intensive Industries and Raw Materials“

Critical Raw Materials Suppliers to the EU (2017)



Source: List of Critical Raw Materials for the EU, 2017

International Renewable Energy Agency

Critical Raw Materials for the EU, 2017

Antimony	Baryte	Beryllium
Bismuth	Borate	Cobalt
Coking coal	Fluorspar	Gallium
Germanium	Hafnium	Helium
Indium	Magnesium	Natural graphite
Natural rubber	Niobium	Phosphate rock
Phosphorus	Scandium	Silicon metal
Tantalum	Tungsten	Vanadium
Platinum Group Metals	Heavy Rare Earth Elements	Light Rare Earth Elements

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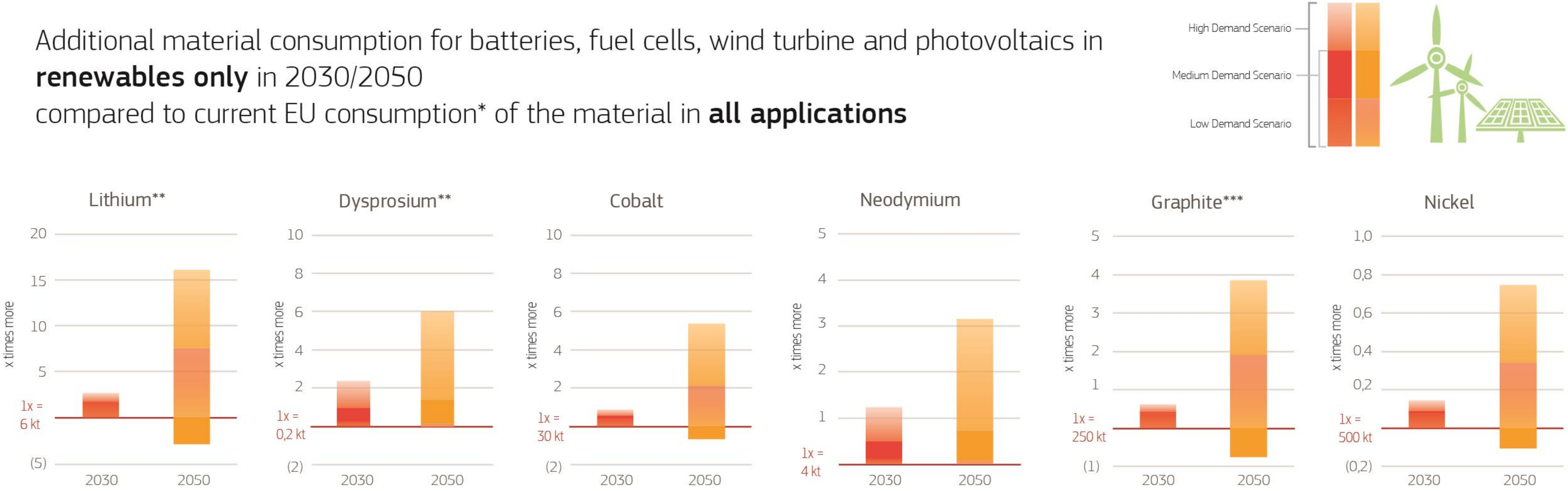
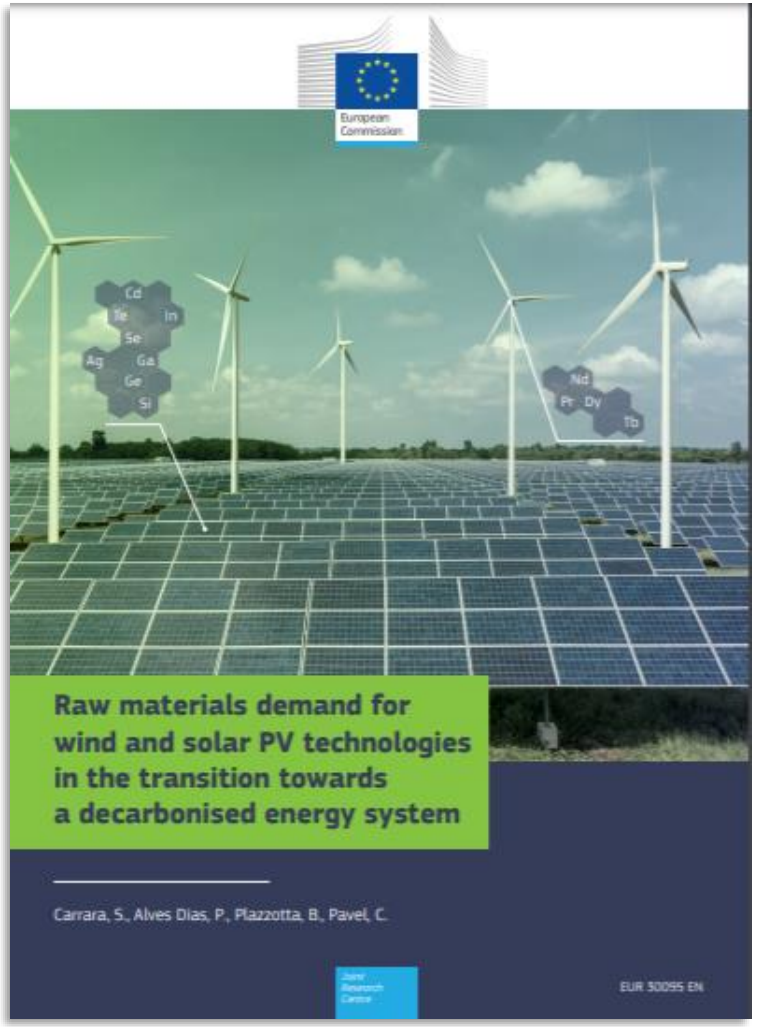
Demand forecast for renewable energy

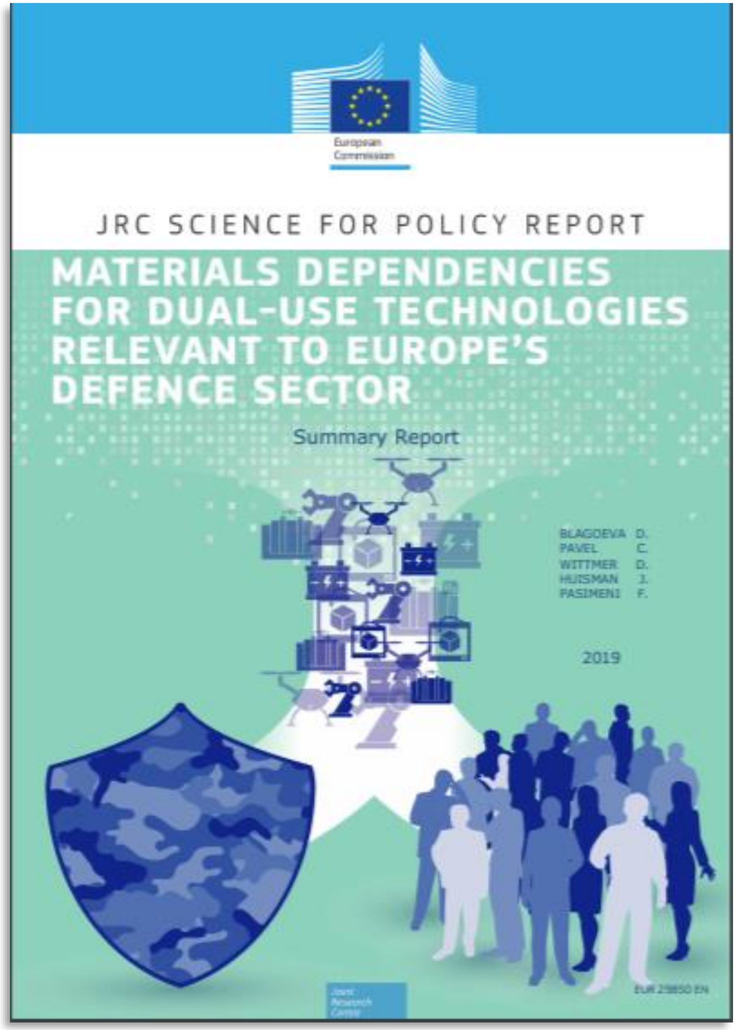
Additional material consumption for batteries, fuel cells, wind turbine and photovoltaics in **renewables only** in 2030/2050
compared to current EU consumption* of the material in **all applications**

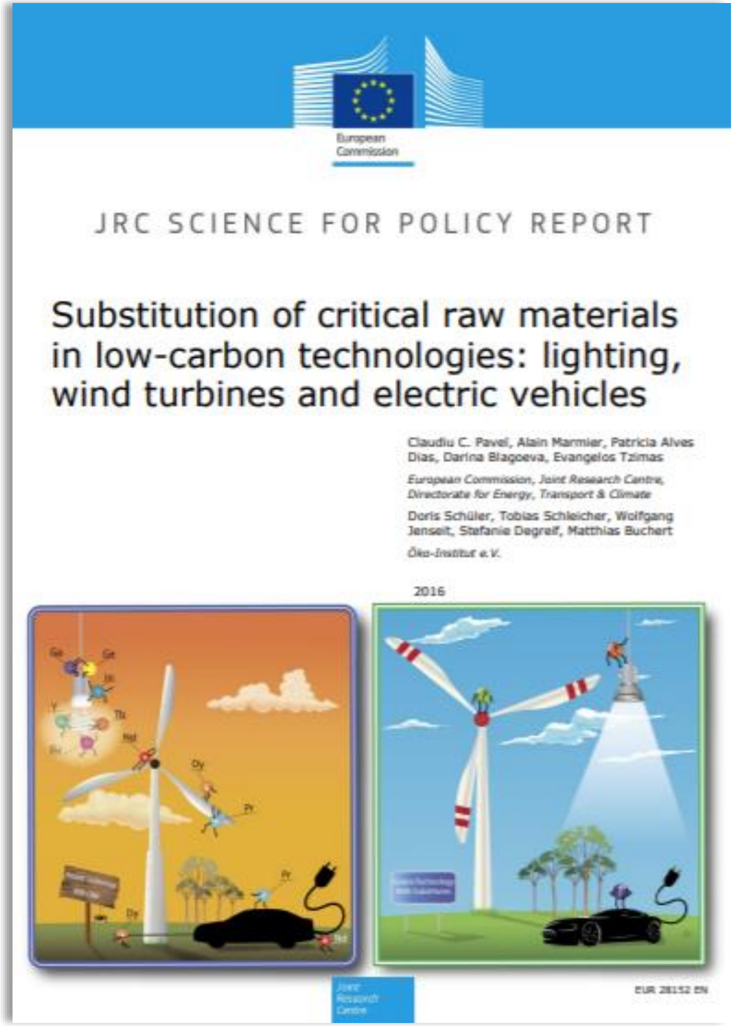


Source: Forthcoming Report on Critical Raw Materials in technologies and sectors

EC Publications





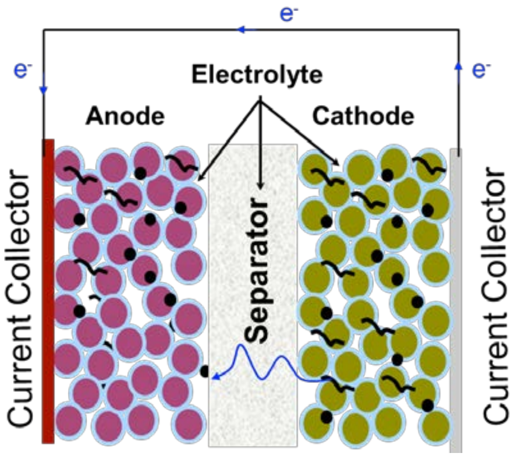


International Renewable Energy Agency

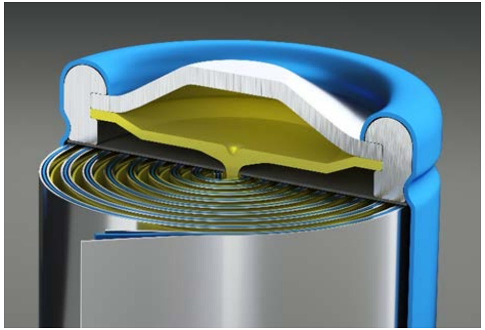
Jeffrey Spangenberger
ReCell Center Director
Argonne National Laboratory

LITHIUM ION BATTERY RECYCLING

- Lithium-ion batteries do not contain lithium metal
- Lithium-ion batteries work by shuttling lithium ions back and forth between the anode and cathode through an electrolyte. There is a separator between the anode and cathode.
- Not all lithium-ion batteries are created equal
  - Different chemistries for different applications
  - Consumer electronics use high cobalt chemistries that are worth money
    - These have very low collection rates and the batteries are typically hard to remove
  - Plug-in electric vehicles use lower cobalt chemistries and they cost money to recycle
    - Collection is not expected to be an issue



Courtesy Argonne National Laboratory



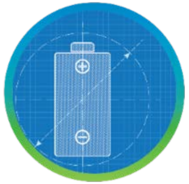
Courtesy Shutterstock ID: 1353094883

The ReCell Center: Advanced Battery Recycling

The center will establish cost-effective, flexible processing techniques to extract as much value as possible from current and future batteries chemistries to make recycling economically viable.

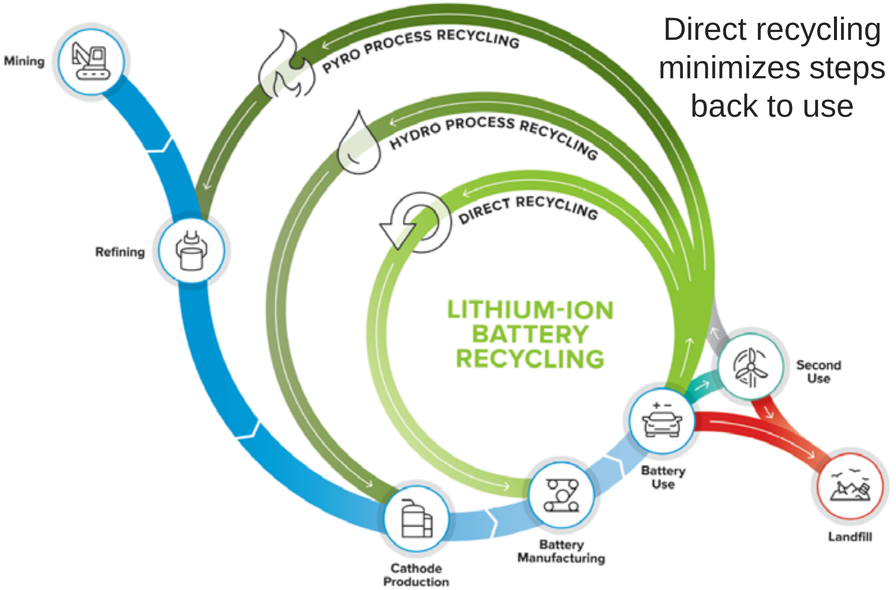
DIRECT CATHODE RECYCLING
- Cathode Separation
- Binder Removal
- Relithiation
- Compositional Change

OTHER MATERIAL RECOVERY
- Electrolyte
- Graphite
- Foil



DESIGN FOR RECYCLING
- Cell Design
- Cell Rejuvenation

MODELING AND ANALYSIS
- Materials Analysis
- Thermal Analysis
- Supply Chain Analysis
- TEA/LCA Modeling



Direct recycling minimizes steps back to use

Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

OAK RIDGE National Laboratory

Michigan Technological University 1885

WPI

UC San Diego

Bringing together battery recycling expertise and bridging the gaps between them to efficiently address the many challenges that face a successful advanced battery recycling infrastructure.

*ReCell is funded by the U.S. Department of Energy's Vehicle Technologies Office

ReCell ADVANCED BATTERY RECYCLING

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WRAP-UP & CLOSING REMARKS

THANK YOU FOR JOINING US!

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