Renewable energy – mineral nexus: Resource availability

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• IEA World Energy outlook 2018
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  • Solar, Wind, Hydro, Gas
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  • Seeking new resource
• Summary
Diversity of elements consumption
Materials use (2060)

Materials use increase

- **2011**: 79Gt
- **2060**: 167Gt

- Materials: 2011 - 8Gt, 2060 - 20Gt
- Fossil fuels: 2011 - 14Gt, 2060 - 24Gt
- Biomass: 2011 - 20Gt, 2060 - 37Gt
- Non-metallic minerals: 2011 - 37Gt, 2060 - 86Gt

- **2017**: 49%
- Metals: 10%
- Fossil fuels: 17%
- Biomass: 24%

32% Share of sand, gravel and crushed rock in total materials use

Construction materials use stabilises in China after 2025

- 2011: 18Gt
- 2025: 24Gt
- 2060: 23Gt

Global Material Resources Outlook to 2060 (OECD)
Cumulative demand and existing reserves by 2050
Motivation of this study

• Energy issue
  • Energy demand increase
  • Climate security
  • Energy security

• Sustainable energy system
  • Renewable energy
  • Energy efficiency

• Do we have enough minerals to support the system?
Energy scenario by 2040

- **Affordability**: The costs of solar PV and wind continue to fall, but oil prices climbed above $80/barrel in 2018 for the first time in four years; and hard-earned reforms to fossil fuel consumption subsidies are under threat in some countries.

- **Reliability**: Risks to oil and gas supply remain, as Venezuela’s downward spiral shows. One-in-eight of the world’s population has no access to electricity and new challenges are coming into focus in the power sector, from system flexibility to cyber security.

- **Sustainability**: After three flat years, global energy-related carbon dioxide (CO2) emissions rose by 1.6% in 2017 and the early data suggest continued growth in 2018, far from a trajectory consistent with climate goals. **Energy-related air pollution continues to result in millions of premature deaths each year.**
Energy demand in future

Change in primary energy demand, 2016-40 (Mtoe)
World Energy Outlook 2017

-30
United States

-200
Europe

135
Middle East

485
Africa

480
Eurasia

790
China

1,005
India

420
Southeast Asia

-50
Japan

270
Central & South America
New Policy Scenario: WEO2018

Change in total primary energy demand, 2017-2040

Low-carbon

- Nuclear
- Renewables

Gas

- Other
- Power
- Industry

Oil

- Petrochemicals
- Passenger cars
- Other

Coal

- Other
- Power

Left-hand: Advanced economies
Right-hand: Developing countries
Sustainable development Scenario: WEO2018
Power capacity (NPS)

Installed power capacity in the NPS

Power generation in the NPS

add to 2040 (2017) GW

Gas 1035 (1690)
Solar PV 2170 (384)
Wind 1180 (532)
Hydro 570 (1270)
Limiting processes in photovoltaic materials.

Albert Polman et al. Science 2016;352:aad4424

Published by AAAS
Materials requirements NPS

**add to 2040**
Gas 1035; Solar PV 2170; Wind 1180; Hydro 570 [GW]

Steel 32Mt, Concrete 101MT
Al 211kt

Si 14Mt, Cu 1.4Mt, Ag 217kt

Steel 31Mt, Concrete 109MT
Cu 717kt, Al 724kt

Steel 342kt, Concrete 57MT
Cu 30kt

Ag reserve: 400kt
Reducing Ag use or shift to Cu

*Estimated Silver use per Watt*

Gram Ag / Watt

Year

Our estimation

Courtesy: Technic Inc
EV by 2040

Electric car fleet, 2016-2040
World Energy Outlook 2017

Million cars

2016 2025 2040

- Other countries
- United States
- India
- European Union
- China
Abundancy of resource in Li-Battery

## Metal use per EV

<table>
<thead>
<tr>
<th>Metal</th>
<th>Weight (g)</th>
<th>Metal</th>
<th>Weight (g)</th>
<th>Metal</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1,149,180</td>
<td>Ni</td>
<td>3,330</td>
<td>Ta</td>
<td>0.003</td>
</tr>
<tr>
<td>Al</td>
<td>95,115</td>
<td>Sb</td>
<td>45</td>
<td>Nd</td>
<td>500</td>
</tr>
<tr>
<td>Cu</td>
<td>35,750</td>
<td>Nb</td>
<td>10</td>
<td>Dy</td>
<td>80</td>
</tr>
<tr>
<td>Pb</td>
<td>7,500</td>
<td>Mo</td>
<td>770</td>
<td>B</td>
<td>20.6</td>
</tr>
<tr>
<td>Zn</td>
<td>1,546</td>
<td>Ti</td>
<td>223</td>
<td>Zr</td>
<td>0.5</td>
</tr>
<tr>
<td>Mn</td>
<td>3,203</td>
<td>Co</td>
<td>19,886</td>
<td>Li</td>
<td>2,805</td>
</tr>
<tr>
<td>Cr</td>
<td>5,742</td>
<td>W</td>
<td>708</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Resource limitation in current technology
Reducing Co consumption

• Alternative technology

<table>
<thead>
<tr>
<th>Anode</th>
<th>Cathode</th>
<th>Note</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li_{1+x}(Fe_{0.3}Mn_{0.7})_{1-x}O_2</td>
<td>Graphite</td>
<td>FM-G</td>
<td>AIST</td>
</tr>
<tr>
<td>Li_{1+x}(Fe_{0.3}Mn_{0.5}Ti_{0.2})O_2</td>
<td>Graphite</td>
<td>FMT-G</td>
<td>AIST</td>
</tr>
<tr>
<td>LiFePO_4</td>
<td>Graphite</td>
<td>LFP-G</td>
<td>X. Lou</td>
</tr>
<tr>
<td>LiMn_2O_4</td>
<td>Li_4Ti_5O_12</td>
<td>LMO-LTO</td>
<td>L. Belharouak</td>
</tr>
</tbody>
</table>
Resource limitation in developing technology

The graph shows the number of vehicles (in $10^8$) for various elements over the year 2040. The elements are Fe, Al, Cu, Pb, Zn, Mn, Cr, Ni, Sb, Nb, Mo, Ti, Co, W, Ta, Li, Nd, Dy, B, Zr, Pt. Each element is represented by a bar graph with different colors indicating different technologies or categories (FM-G, FMT-G, LFP-G, LMO-LTO).
Honda develops Nd permanent magnet motor without heavy rare-earth metals (Dy, Tb)

August 11, 2016

The Japanese automaker has freed its hybrids of the need for heavy rare earth elements. Working with Daido Steel, the automaker has developed the first magnet suitable for automotive drive applications that doesn’t require materials like dysprosium or terbium to improve its heat resistance.

Instead, the neodymium-iron magnets are manufactured using a new hot deformation method to create a fine crystal grain structure that can handle high temperatures without the additives. Honda designed an all-new motor to accommodate them.

The sourcing of heavy rare earth elements has been an issue for the automotive and electronics industries in recent years as China has a near monopoly on their production and has often been accused of restricting their supply for economic and political ends. Neodymium is classified as a light rare earth, but is more widely available.

Honda will introduce the new motor this year in a hybrid version of an Asian-market minivan called, somewhat appropriately, the Freed and plans to quickly expand its use to other hybrid models. However, the technology is not yet ready to withstand the higher temperatures generated when used in a pure-electric car.

Full article here: http://www.autonews.com/article/20160712/OEM01/160719972/honda-develops-hybrid-motor-without-key-rare-earth-metals

For sustainable society

Recycling system
Recycling rate in the world

**Recycling Rates around the world**

*Most developing countries do not have a formal waste disposal system in place, but in many places there is a strong informal recycling sector. Waste pickers retrieve reusable materials from landfills and resell them to make a living, which benefits the environment and provides the poor with a source of income. In fact, the global recycling industry employs the largest amount of people in the world apart from the agriculture sector.*

- **Highest Recycling Rate**: Germany → 65%
- **Biggest Producer of Waste**: United States → 624,700 tons per day
- **Biggest Producer of E-waste**: Norway → 28 kilograms per capita per year

**Countries with Recycling Rates**
- **Canada**: 24%
- **United Kingdom**: 43%
- **Germany**: 65%
- **Austria**: 58%
- **Slovenia**: 58%
- **South Korea**: 59%
- **Japan**: 20%
- **Australia**: 41%
- **United States**: 35%
- **France**: 38%
- **Italy**: 41%
- **Israel**: 19%
- **Mexico**: 5%
Recycling on renewable energy

• Materials use
  • Recyclable materials – metals: Fe, Al, Cu
  • Materials/Energy recycling – plastics: PE, PP, PS
  • Energy recovering – organics: food
  • Reusable materials – oxides: soil, cement
  • Natural cycling – CO₂, H₂O

• Difficulties in recycling
  • Additives: Dy in magnet, P, B in Si, Mo in steel
PV recycling

Materials recycling

An employee works at Veolia’s solar panel recycling plant in Rousset, France, June 25, 2018.
REUTERS/Jean-Paul Pelissier

Wafer recycling

Jeongeun Shin, Solar Energy Materials and Solar Cells, Volume 162, 2017, Pages 1-6,
New resources in ocean

Main Distribution of Marine Mineral Resources

- Polymetallic Sulphides
- Polymetallic Nodules
- Ferromanganese Crusts
Ratio of oceanic contents to land reserves

Economical feasibility taken from seawater
Summary

• Renewable energy, especially solar PV will be installed in a large scale near future
• Mineral demands also increase
• Some critical elements, Ag, Co, Dy are identified
• New technology will solve the major issues
• Promoting recycling is a key for the sustainable society
• Utilizing new reserves in ocean will be feasible
Thank you for your kind attention

Acknowledgement
To Ms. I. Mori, a part of this study was conducted as her Master’s degree.