US DOL (US Department of Labor) (2019), *Findings on the Worst Forms of Child Labor: Democratic Republic of the Congo*, https://www.dol.gov/agencies/ilab/resources/reports/child-labor/congo-democratic-republic-drc

Vale (2020), *Sustainability Report 2019*, http://www.vale.com/EN/investors/information-market/annual-reports/sustainability-reports/Sustainability%20Reports/Relatorio_sustentabilidade_vale_2019_alta_en.pdf

Vulcan Energy (2020), Zero Carbon Lithium®, https://v-er.com/wp-content/uploads/2020/11/2020AGMPresentation.pdf

Watson, K. (2020), 'Vale ended our lives': Broken Brumadinho a year after dam collapse, BBC, https://www.bbc.com/news/world-latin-america-51220373

WEF (World Economic Forum) (2020), *Making Mining Safe and Fair: Artisanal Cobalt Extraction in the Democratic Republic of the Congo*, http://www3.weforum.org/docs/WEF_Making_Mining_Safe_2020.pdf

World Mine Tailings (2020), *World Mine Tailings Failures – From 2015, State of Worldmine Tailings 2020* (web page), https://worldminetailingsfailures.org/

WRI (World Resources Institute) (2021), *Aqueduct Country Rankings* (database), https://www.wri.org/applications/aqueduct/country-rankings/, (accessed 30 April 2021).

Acknowledgements

This report was prepared by the *World Energy Outlook* (WEO) team in the Directorate of Sustainability, Technology and Outlooks (STO), in co-operation with other directorates of the International Energy Agency (IEA). Tae-Yoon Kim co-ordinated the work and was the lead author, and he designed and directed the report together with Tim Gould, Head of Division for Energy Supply and Investment Outlooks.

The other principal authors and contributors from across the agency were: Simon Bennett (hydrogen, historical episodes), Francois Briens (renewables), Amrita Dasgupta (battery chemistry and recycling, solar PV), Pablo Gonzalez (solar PV, wind), Alexandre Gouy (modelling), George Kamiya (lead on demand), Milosz Karpinski (lead on security policies), Jeremy Lagelee (international co-ordination), Lilly Lee (battery recycling), Laura Maiolo (renewables, nuclear), K.C. Michaels (lead on environmental and social issues), Toru Muta (lead on supply), Lia Newman (pricing), Tomás de Oliveira Bredariol (environment), Leonardo Paoli (batteries), Sebastian Papapanagiotou (electricity networks) and Rebecca Schulz (renewables, recycling). Marie Fournier-S'Niehotta and Eleni Tsoukala provided essential support. The report relied on the scenario modelling and analysis of the entire WEO team.

The report benefited greatly from contributions from other experts within the IEA: Heymi Bahar, Piotr Bojek, Alan Choi, Elizabeth Connelly, Yuanyuan Gong, Vanessa Koh, Peter Levi, Sakeena Moeen, Susan Nakanwagi, Apostolos Petropoulos, Ryszard Pospiech, Alan Searl, Jacob Teter, Kartik Veerakumar and Brent Wanner. Justin French-Brooks carried editorial responsibility. Therese Walsh was the copy-editor.

Mechthild Wörsdörfer (Director for STO), Pascal Laffont (Chief Legal Counsel) and Aad van Bohemen (Head of Energy Policy and Security Division) provided support and guidance throughout the project.

Valuable comments and feedback were provided by senior management and numerous other colleagues within the IEA, in particular Keisuke Sadamori, Laura Cozzi, Alessandro Blasi, Paolo Frankl, Peter Fraser, Rebecca Gaghen, Timur Gül, Tom Howes, Sara Moarif, Cyril Cassisa, Xiushan Chen, Marine Gorner, Insa Handschuch and Luca Lo Re.

Thanks also to Jad Mouawad, Head of the Communications and Digital Office (CDO), and to CDO colleagues Tanya Dyhin, Merve Erdil, Grace Gordon, Jethro Mullen, Rob Stone, Jon Custer, Christopher Gully, Julie Puech, Mariam Aliabadi, Astrid Dumond, Isabelle Nonain-Semelin, Clara Vallois, Gregory Viscusi and Therese Walsh.

Emissions data for different nickel production pathways was provided by courtesy of Natural Resources Canada (NRCan). Emissions data for copper and nickel was provided by courtesy of Skarn Associates. Mining waste data was provided by courtesy of Professor Gavin M.

Mudd at the Royal Melbourne Institute of Technology University. Professor Raphael J. Heffron at the University of Dundee provided valuable assistance on the economic benefits of mining. Louis Maréchal and Benjamin Katz of the Organisation for Economic Co-operation and Development (OECD) provided helpful input and suggestions on responsible sourcing and supply chains. Antonio Vaya Soler and Luminita Grancea of the Nuclear Energy Agency (NEA) provided helpful input on mineral intensities for nuclear.

The work could not have been achieved without the support and co-operation provided by many government bodies, organisations and companies worldwide, notably: Department of Industry, Science, Energy and Resources, Australia; Ministry of Economy, Trade and Industry, Japan; and Ministry of Economic Affairs and Climate Policy, Netherlands. Activities within the IEA Clean Energy Technologies Programme provided valuable support to this report. Thanks go to the experts from the IEA Technology Collaboration Programmes (TCPs) for their support to review material intensity assumptions, particularly to Marina Holgado, Darina Blagoeva, Franz Lehner and Xin Pang from the Hydrogen TCP, Stefan Nowak and Garvin Heath from the PVPS TCP and Ignacio Marti and John McCann from the Wind TCP.

Many experts from outside of the IEA provided input and reviewed preliminary drafts of the report. Their comments and suggestions were of great value. They include:

Shabbir Ahmed	Argonne National Laboratory
Patricia Alves-Dias	European Commission Joint Research Centre (EC JRC)
Harmeet Bawa	Hitachi ABB Power Grids
Morgan Bazilian	Payne Institute for Public Policy, Colorado School of Mines
Carlos Felipe Blanco	University of Leiden
Antoine Boubault	Bureau de Recherches Géologiques et Minières (BRGM)
Camille Boulianne	Natural Resources Canada
Jorge Cantallopts Araya	The Chilean Copper Commission (COCHILCO)
Samuel Carrara	European Commission Joint Research Centre (EC JRC)
Ryan Castilloux	Adamas Intelligence
Alec Crawford	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF)
Aidan Cronin	Siemens-Gamesa
Shobhan Dhir	University of Oxford
Alison Fleming	Department of Industry, Science, Energy and Resources, Australia
Michelle M. Foss	Baker Institute, Rice University

Mitsunori Fukuda	Japan Oil, Gas and Metals National Corporation (JOGMEC)
Hiroyuki Fukui	Toyota
Francesca Gostinelli	Enel
Luminita Grancea	NEA
Emmanuel Hache	IFP Energies Nouvelles
Georgina Hallett	London Metal Exchange
Mark D. Hansen	Siemens-Gamesa
Sara Hastings-Simon	Payne Institute for Public Policy, Colorado School of Mines
Raphael Heffron	Dundee University
Chris Heron	Eurometaux
Daniel Hill	Natural Resources Canada
Noé van Hulst	Special Advisor Hydrogen
Hiroyuki Kaneko	Nissan
Benjamin Katz	OECD
Nobuyuki Kikuchi	Ministry of Foreign Affairs, Japan
Jihyun Kim	Samsung SDI
Tae Heon Kim	Korea Energy Economics Institute (KEEI)
Yu-Tack Kim	Korea Battery Industry Association
Kazuaki Kobayashi	Ministry of Economy, Trade and Industry, Japan
Anna Krutikov	Glencore
Francisco Laveron	Iberdrola
Yolanda Lechón	Ciemat
Dan M. Levy	Credit Suisse
Johannes Lohmeyer	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
Luca Maiotti	OECD
Louis Maréchal	OECD
Rémi Mayet	European Commission
Adam McCarthy	Cobalt Institute
Luca Meini	Enel
Dennis O. Mesina	Department of Energy, United States
Matteo Minervini	Eni
Mark Mistry	Nickel Institute
Susana Moreira	World Bank
Anders Nordelöf	Chalmers
Louise Pearce	Environmental Resources Management (ERM)
Mark Pituch	Department of State, United States

Greg Radford	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF)
Marco Raugei	Oxford Brookes University
Carolina Salvaterra	Department for Business, Energy and Industrial Strategy, United Kingdom
Gondia Sokhna Seck	IFP Energies Nouvelles
Tristan Stanley	BHP
Nikos Tsafos	Center for Strategic and International Studies (CSIS), United States
Antonio Vaya Soler	NEA
Antonin Vergez	Ministry for an Ecological Transition, France
Takuma Watari	National Institute of Environmental Studies, Japan
Peter Wood	Shell

IEA Publications

International Energy Agency

Website: www.iea.org

Contact information: www.iea.org/about/contact

Typeset in France by IEA - May 2021

Cover design: IEA - Image Copyright - ShutterStock