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Resources for Carbon Neutrality: What Are They, Are They Available, and Where Will They Come From?

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What does carbon neutrality mean? What does it require? Is it possible? Here, I will contextualize carbon neutrality through the lens of the metal resources required to transition from a global energy infrastructure dependent on coal, natural gas, and oil, to one entirely reliant on a combination of photovoltaic solar, wind turbines and battery storage. Manufacturing and deploying those renewable energy resources requires dozens of metals, including copper, lithium, nickel, tellurium, cobalt, indium, tin, chromium, and many others. What types of mineral deposits do those metals come from? What are the geologic constraints on their availability? What are the economic constraints on their availability? What are the environmental permitting constraints on the timeframe for production and delivery to market? What are the political constraints on their availability? Analysis of the current mining supply of most metals critical for renewable energy, and the anticipated production from permitted mines at various stages of development, indicate that the supply of most critical metals cannot meet the demand to achieve the climate neutrality goals established by most countries. For example, the supply/demand ratio through the year 2030 for all the following metals is less than one: manganese, chromium, zinc, silver, silicon, molybdenum, rare earth elements (REEs), platinum group metals (PGEs), copper, lithium, nickel, vanadium, cobalt, and graphite. Such data demonstrate significant supply challenges for the transition to a carbon neutral infrastructure within the timeframe the Intergovernmental Panel on Climate Change (IPCC) indicates is necessary to avert average global temperature increasing by more than two degrees Celsius. Further, it takes an average of sixteen years to go from discovery to production. These supply-side facts have major implications for the transition to a post-carbon world and must be addressed by a mindset change and bold leadership at all scales that supports mineral exploration.