Oregon Trail: Labor and housing as essential links in the critical materials supply chain

Introduction:

The critical materials supply chain (CMSC) forms the backbone of modern technology and energy transitions, yet it faces unprecedented strain. Essential materials such as cobalt, lithium, and rare earth elements are in short supply, driven by skyrocketing demand for microelectronics, batteries, and renewable energy systems. Meeting this demand requires addressing profound challenges, including the environmental and ethical issues of resource extraction, such as child labor in cobalt mining in the Democratic Republic of Congo and lithium's water-intensive processing. Further complicating the CMSC are geopolitical dependencies, with China controlling a significant share of rare earth production. Labor shortages, demographic shifts, inadequate housing, and inflationary pressures exacerbate these challenges, creating critical bottlenecks in material extraction, processing, and logistics. Despite these obstacles, opportunities abound. Recent discoveries of asteroid resources in Southeast Missouri and lithium in Northwest Arkansas offer new domestic sources.

Though semiconductor fabrication plants and graphical processing unit data centers may have captured the public's techno-imagination, perhaps the far older, simpler pickaxes and shovels analogy might fit. If green energy and AI get valor and prestige, surely miners and homebuilders deserve their share. This paper examines labor and housing as indispensable yet underexplored links in strengthening the CMSC, emphasizing how targeted interventions could enhance resilience and equity. Focused on contexts in Missouri and surrounding regions, with analogies drawn from Oregon, North Dakota, and Pennsylvania, the analysis incorporates mini case studies highlighting labor market shifts, housing shortages, and public policy solutions. These examples

are framed to guide a diverse audience, including academics, policymakers, industry leaders, and the public, toward actionable insights. Through a combination of vignettes and comparative analysis, the paper outlines systemic labor and housing gaps while exploring public policy pathways to align CMSC needs with sustainable development goals. By confronting these challenges head-on, this work seeks to illuminate a path toward a more robust and equitable supply chain.

In short supply:

Large-scale grid storage appears to finally be making a case for installation, with vanadium flow batteries as a current darling (Plumer and Popovich 2024; Rivero and Wright 2024). But for the foreseeable future the green energy transition begins with cobalt for rechargeable batteries; each iPhone consuming a half ounce of cobalt, each Tesla consuming 50 pounds. No other material approaches the energy density of cobalt. Keeping pace with recent green energy planning leads to a global demand forecast for cobalt doubling in three years (Zeihan 2022, 297).

Nearly two decades of public policy efforts have substantially increased the battery electric vehicle (BEV) demand forecast in the U.S. Lead-acid batteries are a prime success story of regional recycling of critical materials, with studies finding companies recover as much as 99% of materials, with 80% recycled content on new products. Research has shown that 97% of lead-acid automotive batteries sold in North America are eventually recycled (Sheffi 2023, 121).

Unfortunately, the lithium common in BEVs is at the opposite end of the energy density spectrum from cobalt; each Tesla vehicle requiring 140 pounds of lithium. Worse yet, the production and refining of lithium and manufacturing of batteries itself is extremely energy intensive (Zeihan 2022, 299-300). Studies have found each ton of lithium extraction requires over

500 cubic meters of freshwater; Bolivia's San Cristobal Mine for example using 50,000 liters per day in lithium extraction (Evans 2021; Vera 2023).

Rare earth elements (dysprosium, europium, lanthanum, neodymium, promethium, yttrium, and others) are necessary for fabrication and operation of nearly all of our modern technologies, both consumer electronics and green energy related (Zeihan 2022, 308-310). And of further concern these rare earth elements as inputs into our modern manufacturing systems will increasingly be piracy targets (Zeihan 2022, 152). With the growing potential that the U.S. will retreat from globalization and post-World War II policing of international waterways, we will need to re-establish domestic or Western Hemisphere sources for 100% of our CMSC.

Problematic sources:

Critical materials mined in the Democratic Republic of Congo have been labelled "conflict minerals," not unlike "blood diamonds," due to the coercion, terror, and violence used on labor (Sheffi 2023, 114). When Intel attempted to map their supply chains and establish provenance of their critical materials, they discovered they needed visibility all the way back to the smelters of raw ores, six or seven tiers upstream (Sheffi 2023, 115). More than half of the cobalt we rely on for rechargeable batteries is sourced in the Democratic Republic of Congo, where Chinese dealers frequently buy illegally mined cobalt from individual "artisanal miners" (Zeihan 2022, 297-299).

Lithium batteries are the second or third most expensive component in smart phones and 75% of the cost in BEVs (Zeihan 2022, 272-273). Lithium is recognized as a potential bottleneck in battery supply chains (Magill 2024b) leading to plans for a new U.S. lithium refinery in Oklahoma (Magill 2024a). Water usage in mining and ore processing operations, both due to

consumption of critical resource and residual contamination, is of concern (Sheffi 2023, 118-119). Sodium-ion batteries have been suggested as a sustainable alternative to lithium-ion, with U.S. gigafactory construction for sodium-ion batteries announced in 2024 (Raza 2024).

China's rapidly escalating military presence in the South China Sea is well known (Nakashima and Karklis 2024). But also of great concern, China owns eight of fourteen of the largest cobalt mines and refines nearly all cobalt ore mined globally. Fortunately for the U.S., Canada is the second-place cobalt refiner, providing a North American source with processing expertise (Zeihan 2022, 297-299). As of 2021 China produces and processes approximately 90% of rare earth elements globally. Interestingly, while China has taken the environmental and political risks and subsidized the production of rare earth elements, the higher value-added work following ore processing is most often done by others (Zeihan 2022, 309-310). Regardless, basic access to some of these critical materials is clearly at risk, with China announcing bans on export of some rare earth elements to the U.S. (Pierson et al 2024).

Key challenges:

In the U.S., sufficient labor to re-shore these activities is frequently lacking. Falling family sizes are compounding retirement of Baby Boomers. Significant societal shifts in education, types of work, and gender roles have contributed to reduced family sizes. As women gain education, they improve their career options, increase their workplace participation, and delay marriage, and as they gain access to birth control, they delay starting families. Together, these societal developments manifest a decline in population growth (Wigger, 2026). "The collapse in birth rates that began

across the developed world in the 1960s and across the developing world in the 1990s now has decades of steam behind it" (Zeihan 2022, 55-61).

Providing the U.S. with significant competitive advantage, our population is relatively stable, and people want to come here, as evidenced by strong immigration. "A central factor in every growth story that accompanies industrialization is that much of the economic growth comes from a swelling population. What most people miss is that there's another step in the industrialization-cum-urbanization process: lower mortality increases the population rates . . . but only for a few decades. Eventually gains in longevity max out, leaving a country a greater population, but with few children. Yesterday's few children leads to today's few young workers leads to tomorrow's few mature workers. And now, at long last, tomorrow has arrived" (Zeihan 2022, 56). Prior to World War II the U.S. population was under 135 million; in the two decades following war's end the U.S. Baby Boom added over 70 million births (Aki 2023; Wigger, 2026).

We can draw valuable lessons from the recent past about the impact of sudden surges in resource extraction on housing markets, and how a relative scarcity of housing at the right price points throttles economies. Following each of the last century's world wars, major waves of migration from Appalachia to Midwest manufacturers have been documented by researchers. Millions of people traveled the "hillbilly highway" between, seeking more lucrative job prospects and a middle-class lifestyle (Vance 2016, 27-28). The industrial revolution is a story of coalminers and farmers becoming factory workers.

Case studies have found employers report persistent shortage of workforce housing for those earning 80-120% of average median income (AMI), earning too much to qualify for affordable housing subsidies, yet not enough to afford market-rate housing. Nationwide,

dependent upon source, we find shortfalls of between three and five million units of housing of all types; growing areas naturally have less available housing stock for the workforce required to drive the U.S. economy (Garcia et al 2024; Patel et al 2024). As housing becomes less affordable due to supply constraints, urban and rural centers alike eventually see talent leave in search of more affordability, leading to a paucity of young workers. Follow-on impacts include extended commute times, added childcare costs, decreased employee retention, and increased recruitment and staffing costs (SEDCOR 2024; Wildfire 2024). Upon receiving a $30 million U.S. Department of Defense grant "to develop and commercialize new battery technologies and manufacturing processes," researchers at the University of Texas at Dallas listed "(d)eveloping the workforce needed for energy storage system development and manufacturing" as one of four main goals (Horner 2023).

When the Marcellus Shale natural gas boom hit rural Pennsylvania, the population of most resource extraction regions of the state had been in decline for years. The Rust Belt, which powered the U.S. through WW II and the decades to follow, comes by its name honestly. The result of this recent new economic growth then had little impact on the housing market, other than declining vacancy rates in existing units (Monnat et al 2017). The resource was distributed broadly across a relatively highly populated state with sufficient vacancy. Necessary housing stock was mostly already existent, waiting for residents to occupy. In contrast, when a similar natural gas rush occurred in the Bakken Shale fields of North Dakota, there was far less latent housing supply with which to meet the sudden demand (Gershenson et al 2023). The result was "rural gentrification" – the rapid acceleration of housing prices, displacing residents and disrupting local economies. The region lacked ability to rapidly meet the housing needs of the commodity boom.

Other industry sectors hold lessons for the CMSC. Tourism economies in rural places often have the same rapid growth and land constraints associated with resource extraction and refining economies, as they are in hard-to-reach places, often mountainous and with greater environmental sensitivities. Tourism economies continually find their workforces squeezed by an influx of capital consuming all available labor, leaving the economy to sputter for lack of workers. The new Federal CHIPS investment is another example about to descend on tens of economies across the US. Billions of dollars will be poured into reshoring supply chains necessary for domestic semiconductor manufacture, but there are scant real plans for the housing booms that will accompany the construction and operation of these massive operations. Without rapid deployment of housing, the success of the CMSC reshoring initiative will be throttled.

Globalization of retail marketing and supply chains have stalled during the pandemic. Unlimited, expansionary financial spending can certainly drive inflation in the prices of real stuff. And as the U.S. is arguably seeing, that competition for real resources risks hyper-inflation in supply chains and for citizen consumers. While automation will increasingly mitigate shortages, the ratio of job openings to job seekers averaged two to one in March 2022. For example, we continue to experience a global shortage of truck drivers, with a driver turn-over rate in the U.S. of 91%, which of course further fuels inflation (Sheffi 2023, 60-61). Contemporary headlines disclose hiring challenges and worker shortages; employee retention is harder today than ever. The spatial, temporal, and skills mismatches; people with the right skills and experience are not available in the right place, at the right time for organizations to recruit and hire. And of course, the wage inflation; cost of labor is up, significantly, and still increasing (Barnett 2022; Wildfire 2023).

Additional opportunities:

Contemporary supply chain disruptions have been incredibly disruptive to commerce and life. The COVID-19 lockdowns, followed by Russia's invasion of Ukraine, drove bottlenecks in supply that have simultaneously fueled inflation and recession (Sheffi 2023, 127; Wigger 2024, 442). Pre-Covid, supply chains were severely lacking in both geo-diversity in sourcing and data transparency. The extended supply chains from Asia all involved painful bottlenecks at each point of transfer, warehouses, ports, ships, rail, terminals, trucks (Abundis 2024; Altus 2024). Concern in lack of geo-diversity is from too much concentration in one place. In strategic assessment of supply chains, redundancy is sorely lacking. As economies continue to develop, low-cost offshore sources are increasingly consuming their own productive output; the U.S. should expect to more and more return to doing the same domestically. Each organization will be stronger, more resilient, with lower risk, when there is sourcing or production in each hemisphere, on each continent even. Increasing geo-diversity in supply chains to mitigate risk is imperative.

Companies and countries are investigating deep seabed mining for cobalt and rare earth elements, at great risk to ocean ecology (Shackelford et al 2023). Other contemporaries like Elon Musk and Jeff Bezos have their eyes set on mining the asteroid belt. But in the ancient mountains of Southeast Missouri geologist William Jud is focused on extracting resources deposited when a massive asteroid or comet impacted earth 1.5 billion years ago (Jud 2024, 21-24). Yet such a discovery if proven and operationalized would call forth the labor and housing shortage left when Missouri's last generation of miners traveled their own "hillbilly highway" (Benincasa 2021).

There is some excitement in Northwest Arkansas lately, with increasing talk of extracting $150 billion in lithium deposits in the Smackover Formation, potentially at game-changing scale

(Main 2024). Following the U.S. Geological Survey discovery, Exxon Mobil and others active in the local oil and gas industry have already begun drilling exploratory wells for these new lithium deposits. While the necessary labor in Arkansas might no longer be available, it was perhaps less a geographic migration, and more sectoral shift, with miners becoming truckers, supporting the massive logistics operations of the Wal-Mart ecosystem. Long-term extraction and processing of millions of tons of lithium would surely contribute to wage inflation as firms compete for workers.

Addressing the challenge of increasing affordable workforce housing requires a multifaceted strategy grounded in local leadership and collaboration. Identifying a trusted organizing capacity to lead efforts ensures alignment with community needs, while a deliberate approach to inclusivity fosters diverse stakeholder input. Building strong relationships among city leadership, developers, and financial institutions is critical to creating momentum. A revolving investment fund to subsidize predevelopment costs, managed by a trusted entity with guidance from housing experts, can act as a catalyst, addressing a key financing gap. Predevelopment costs are the riskiest and most challenging to secure, particularly for middle-income housing. Leveraging innovative financing mechanisms, like bonds, alongside newer building materials and methods, can further reduce costs and expedite construction. Collaborations such as this, informed by expertise and exhibiting flexibility, enables scalable solutions, ensuring long-term sustainability and reducing housing costs for middle-income earners while expanding unit availability.

Conclusion:

The modern global economy is deeply dependent on critical materials such as cobalt, lithium, and rare earth elements, which form the backbone of essential technologies ranging from

microelectronics to renewable energy systems. As the demand for these materials surges, fueled by trends in electrification and decarbonization, their availability has become a linchpin in the supply chain. However, this growth is accompanied by significant challenges, particularly in sourcing and processing these materials responsibly. For instance, cobalt mining in the Democratic Republic of Congo often relies on exploitative labor practices, including child labor, while lithium extraction and processing raise environmental concerns such as excessive water consumption and contamination. Compounding these issues is China's stranglehold on the global supply of rare earth elements, underscoring the geopolitical vulnerabilities associated with these critical materials.

Beyond raw material challenges, structural factors such as labor and housing are increasingly recognized as essential links in the critical materials supply chain. Demographic shifts, the need for an upskilled workforce, and disparities in housing availability all influence the industry's ability to scale and adapt. Inflationary pressures further complicate these dynamics, amplifying costs across production and logistics. Yet, amidst these challenges lie untapped opportunities, including advances in battery material recycling and resource discoveries in regions like Southeast Missouri and Northwest Arkansas. These developments, alongside lessons learned from COVID-19 supply chain disruptions, offer avenues to reimagine the supply chain. This research examines how addressing labor and housing shortages can create a more resilient and equitable framework for the critical materials supply chain. We may not "have died of dysentery" on our own "Oregon Trail" but if we do not include workforce development and affordable housing holistically with efforts to reinvigorate our domestic supply chains of critical materials, the outcomes could be similarly existential.

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