AMERICAN RESOURCES POLICY NETWORK

ARPN Report

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THROUGH THE GATEWAY:
A Look at how Gateway Metals and their Co-Products Underpin Modern Technology

based on a series of blog posts published by the American Resources Policy Network
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Photo credit: APWorks
Light Rider
World's first 3D printed prototype
for an electric motorcycle.
Made from Scalmalloy®
See page 28 ff

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PREFACE

Friends of ARPN will know that much of our work is grounded in a conviction that the Technology Age is driven by a revolution in materials science – a rapidly accelerating effort that is unlocking the potential of scores of metals and minerals long known but seldom utilized in our tools and technologies.

This revolution is at once familiar and fundamentally different: Familiar, in the sense that historians have long marked the epochs of human development by our species' mastery of tools defined by the materials they employ. The Stone Age, Bronze Age, Iron Age: We are used to these shorthands for earlier stages of human progress. But at the same time, our provisionally-named Technology Age is fundamentally different, in that it draws not on a handful or less of metals and minerals, but on scores of elements long known as the "minor metals." The smart phone in our pockets contains as many as 70 elements on the Periodic Table; the human body carrying the phone is made up of perhaps 30 elements.

This report attempts to provide snapshots from this revolution, but more than that, to note the new realities of the Technology Age. First and foremost is the relationship of these metals and minerals to one another – our schema of Gateway Metals, which as the word implies are the practical access-point to the metals and minerals we call Co-Products (an upgrade, given their rising importance, from the term "by-product").

As a result, the list of Critical Materials has never been longer. And as much as we support learning more about the world-shaping qualities of Rhenium, Scandium, Indium and their fellow Co-Products, it's time to accord some strange new respect to industrial metals like Aluminum, Copper, Nickel, Tin and Zinc which far from being eclipsed by these upstart elements, emerge as the indispensable gateways to metals and minerals whose properties are defining the 21st Century.

The authors are pleased to note that this wonky point about metals and their relationships is now breaking into broader view in the public policy and national security spheres. In the U.S., the new focus on Critical Minerals – what they are, what they do, where they come from – is a welcome development, and one ARPN will continue to champion and engage on.

This report comes at a time of ferment for critical minerals policy. In the context of current efforts to formulate a comprehensive national mineral resource strategy, ARPN Principal Daniel McGroarty made two submissions to the Department of Interior's request for public comments on the draft critical minerals list Secretary of the Interior Ryan Zinke released earlier this year pursuant to Executive Order 13817. Part I of this report features these two submissions.

The discussion of Gateway Metals and their Co-Products in Part II of this report is based on a series of blog posts we first published in 2016. Accordingly, many of the numbers used in this report were taken from USGS's 2016 Mineral Commodity Summaries. While some of the numbers have since changed, the overall premise has not. In some respects, the current public discussion has moved towards the points ARPN has been making for more than two years.

So many of today's hotly debated policy discussions – how to revive manufacturing capacity, how to re-shore jobs and the GDP they generate, how to ensure the continued development of advanced weapons platforms that deter aggression and defend vital national interests – are literally grounded in reliable resource and raw materials access, and Gateway Metals and their Co-Products must be part of any meaningful conversation on how to secure it. The new Wealth of Nations, and the well-being of the billions of people on this planet, depend upon it.

PART I – TOWARDS A COMPREHENSIVE MINERAL RESOURCE STRATEGY: WHY GATEWAY METALS SHOULD BE CONSIDERED CRITICAL MINERALS

Presidential Executive Order (EO) 13817 "on a Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals, was issued on December 20, 2017. Pursuant to the EO, the Department of Interior, in coordination with the Department of Defense, was tasked with compiling a list of Critical Minerals within 60 days. The DOI List was published on February 16, 2018, with a public comment period running through March 19, 2018.

ARPN's Daniel McGroarty filed two sets of comments, the first identifying a group of "gateway" metals critical for defense applications but absent from the DOI List, and the second articulating the gateway/co-product relationships between metals and minerals on the DOI List. The articulation exercise revealed four metals and minerals absent from the DOI List which are gateways to minerals that are on the List.

The DOI list as published on February 16, 2018, includes the following 35 minerals:

- 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

Daniel McGroarty: Public Comment DOI-2018-0001-0126 posted on March 6, 2018 concerning Secretary Zinke's Draft Critical Minerals list

I want to commend the Department of Interior for its work to establish a unified Critical Minerals List (the "DOI List"), and to open the list for comment. Any list is a moment-in-time exercise, based on many factors, not least of which are technology development and industrial demand, which without question contribute to our evolving understanding of what is and is not a critical mineral or metal.

I have testified on critical minerals before various House and Senate committees, I serve on the advisory boards of several U.S. companies developing critical minerals and metals projects, both mining and reclamation/recycling, and I am founder of the American Resource Policy Network, a virtual think-tank that educates and informs on resource dependencies and their impacts.

<u>I offer here four additional metals, in rank order, that I believe merit inclusion on the DOI List, largely from a national security perspective.</u>

From a national security perspective, the single best unclassified source for metals and minerals dependency assessments remains the **Reconfiguration of the National Defense Stockpile Report to Congress (2009)** and its appendices, which offer a rare view into defense scenarios which may be adversely impacted by lack of timely access to critical metals and minerals. While these studies are nearly a decade old, most of the weapons platforms dependent on critical metals/minerals remain in service today, and in many instances, U.S. foreign supply dependencies have only grown more acute.

Many of the DOI List metals/minerals figure repeatedly in the Reconfiguration Report. Detailed here are several additional metals and minerals that are not on the DOI List, and should be added, based on relevant defense criteria.

Cause of Significant Weapons System Delay. Appendix C of the Reconfiguration Report, Table 1, lists a declassified study, based on classified scenarios, that indicates that lack of access to various metals and minerals has "already caused some kind of significant weapon system production delay for DoD."

Of the 21 metals/minerals found to have caused a significant delay, 16 are on the Department of Interior List; 5 are not:

Copper
Molybdenum
Zinc
Nickel
Cadmium

Shortfall Scenarios. Appendix C of the Report, Table 1, lists a declassified study, based on classified scenarios, that assesses the likelihood of a shortfall of various metals and minerals during 1) a National Security Emergency, and 2) a Peacetime Supply Disruption scenario.

Of the 25 metals/minerals found to be in shortfall during a National Security Emergency or Peacetime Supply Disruption, 17 are on the DOI List, while 8 are not:

Copper
Zinc
Quartz
Lead
Mercury
Nickel
Silicon carbide
Silver

Defense Use by Volume. Appendix B of the Report, Table ES-1, lists DoD defense materials, usage by volume. 6 of the Top 10 materials in the table are included on the DOI List; 4 are not:

Copper
Lead
Zinc
Nickel

Three metals are present in each of these snapshots: Copper, Zinc and Nickel, while Lead appears twice.

The first three are also the primary "gateway" to co-product metals/minerals not typically mined in their own right.1 Copper is the practical access point to at least 4 minerals on the DOI List (Cobalt, Rhenium, Tellurium and potentially the Rare Earths [100% dependency]). Zinc is the gateway to DOI Listed minerals Indium, Gallium (100% dependencies) and Germanium, while Nickel is gateway to Cobalt and the Platinum Group Metals. Lead is gateway to Antimony, Bismuth and Tellurium.

Gateway/Co-Product issues have a significant impact on the DOI List.

To cite just one example, such is the dependence of cobalt, for instance, on copper and nickel mining, according to a February 2018 report by the Columbia (University) Center on Sustainable Investment:

> "…The survival of a cobalt project therefore largely depends on nickel and copper prices. If the prices of these two metals are unfavorable, then it is highly unlikely that a mining project will undergo development, regardless of how high cobalt prices are."

[1] For more information about the inter-dependence between Gateway Metals and Co-Products refer to http://americanresources.org/reports-analysis/american-resources-policy-network-fall-quarterly-report/

Recommended Expansion of the DOI List:

For these reasons, I recommend that the DOI Critical Minerals List be expanded to include, in this rank order:

1. **Copper**
2. **Zinc**
3. **Nickel**
4. **Lead**

Daniel McGroarty: Public Comment DOI-2018-0001-0303 posted on March 14, 2018

Primary Minerals, Gateways & Co-Products – Articulated Chart of DOI's 35 Critical Minerals

***Supplementing Public Comment DOI-2018-0001-0126 posted on March 6, 2018

The DOI Critical Minerals List (released Feb. 16, 2018) contains 35 minerals/metals. What the alphabetized list does not convey are the relationships of the various metals/minerals – most importantly, the fact that, as a practical matter, many of the metals/minerals are not mined in their own right, but obtained as "co-products" of primary metal mining.

The attached chart articulates the 35 metals and minerals into Primary and/or "Gateway" Minerals and Co-Product minerals, indicating which Primaries are typically "gateways" to DOI Listed co-products.

Two additional categories are depicted:

- "Hybrids" (metals/minerals that, depending on the deposit, are primary mining products or co-products of other metals/minerals)
- "Recovered" (3 of the 35 DOI Listed minerals, that are neither mined nor co-products of primary mining, but recovered by individualized processes)

Working back from the Listed Co-Products to their "gateway" metals/minerals indicates that there are 4 "gateway" metals/minerals that are not on the DOI List:

Copper, Gold, Nickel and Zinc (see comment below)

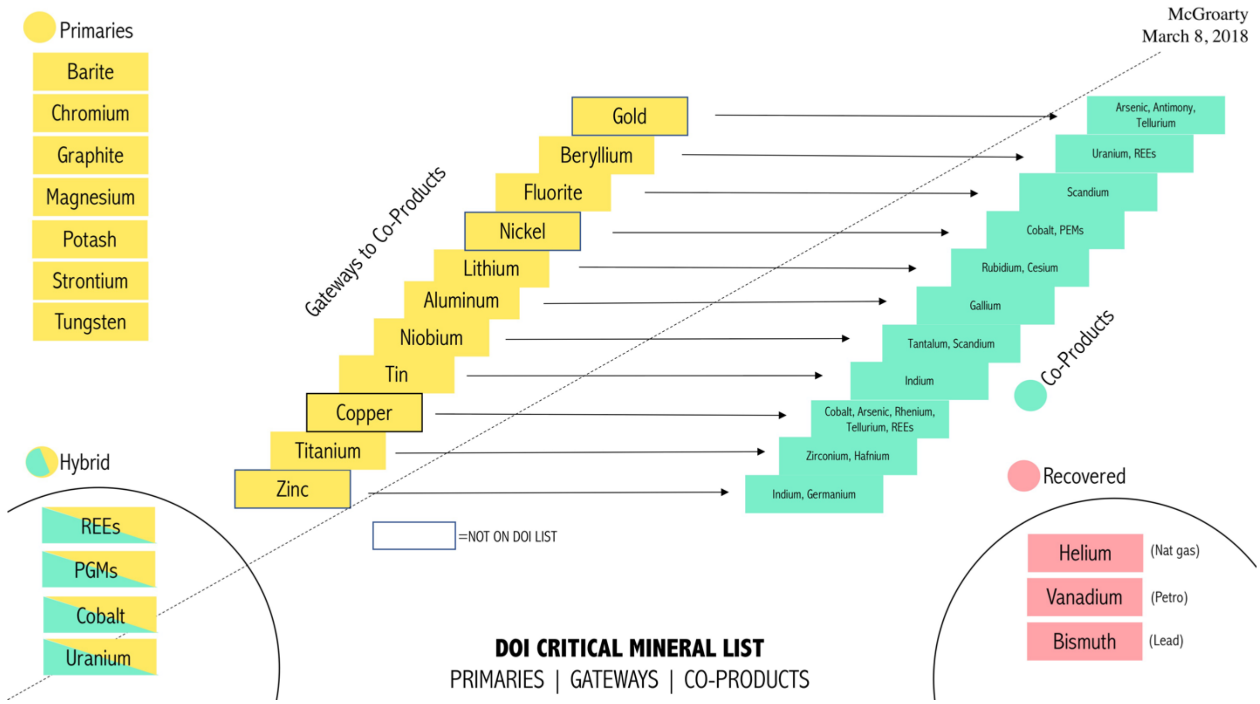
I offer to the DOI review team several observations based on the chart:

Encouraging Co-Product Production is Key to Meeting Strategic/Critical Mineral Needs.

As is shown, 13 of the 35 DOI Listed minerals are Co-Products – more than 1/3 of the entire List – essentially only accessible via primary mining of other metals/minerals.

Important Metals/Minerals are Missing from the DOI List.
A depiction of Gateway/Co-Product relationships shows that 4 metals/minerals missing from the DOI List -- Copper, Gold, Nickel, Zinc – access 7 unique minerals that are deemed Critical.

Copper is Gateway to Critical Co-Products.
Of the Gateway metals/minerals, Copper is the most "versatile" – with 5 potential Co-products on the List.



PART II - Through The Gateway:
A Look at how Gateway Metals and their Co-Products Underpin Modern Technology

Pizza, the Age of Rare Metals and Co-Products

> *"If you don't have yeast, you don't have pizza."*

What may seem like a random – albeit logical – conclusion has more to do with critical minerals than you may think. David Abraham, director of the Technology, Rare and Electronic Materials Center, used the yeast/pizza analogy to exemplify the importance of rare metals, which are produced and used in very small amounts, but are indispensable components of certain high-tech goods. As he put it in an interview with the Carnegie Council's Policy Innovations, you only need very little yeast, but without it, you won't have a decent pizza – and *"(i)f you don't have neodymium, then you don't have a speaker for your phone."*

What is important to note, is that many of these rare or tech metals are not mined as stand-alone metals. Says Abraham:

> *"When I was growing up, when I would think about metals, I would think someone was going out West in the 1840s and they were digging and they were trying to find gold, and they would find these little nuggets in the ground. But tellurium and selenium and many other rare metals are not mined for themselves; they are often a byproduct of producing a larger metal, like zinc or copper. And that is an important thing to understand."*

American Resources followers may remember the concept of *"byproduct"* metals in the context of our *"Gateway Metals and the Foundations of American Technology"* report. In our 2012 study, we focused on a group of five such "gateway" metals, which are not only critical to manufacturing in their own right, but *"unlock"* tech metals increasingly indispensable to innovation and development.

Because of the growing significance of these metals and minerals, we are taking a deeper look at the five gateway metals we covered in the 2012 report – aluminum, copper, nickel, tin and zinc, as well as the tech metals they unlock. In doing so, we are zeroing in on some of the cutting edge uses for these tech metals, as well as supply and other issues surrounding them.

If Orange Is the New Black, Then "Co-product" is the New "By-Product"

The five gateway metals we examined as part of our 2012 report – Aluminum, Copper, Nickel, Tin and Zinc - as well as the tech metals they *"unlock,"* have increasingly found their way into many high-tech applications and have become indispensable staples of 21st Century innovation. While their application has dramatically changed, we are still using what has become an outdated label. In keeping with the metals theme – we believe the time has come to scrap the "*by-product"* metal label, and refer to these building blocks of our high-tech future as *"co-products."*

Merriam-Webster defines the term *"by-product"* as

> *1 : something produced in a usually industrial or biological process in addition to the principal product*
>
> *2 : a secondary and sometimes unexpected or unintended result.*

While the first definition certainly applies to the above-referenced tech metals, it's the *"accidental"* connotation of the second definition that continues to stick, and to a certain degree diminishes the importance of these key materials.

The term *"co-product"* better captures the critical nature of metals and minerals like Tellurium, which fuels the bright future of solar energy, or Indium, without which our touchscreens would not function.

So, in other words, – if Orange is the New Black, in the metals world, *"co-product"* is the new *"by-product."*

Through the Gateway: Gateway Metals and the Metals they Unlock Underpin Modern Technology

Are you reading this report on a smart phone, a laptop or tablet? Will you scroll down using your finger to swipe the screen? Safe to say you don't give much thought to how these functions work — even though they're often less than a decade old. That's the wonder of technology — or rather, the reason that, given the pace of technological change, we typically don't wonder much about the inner-workings of how our gadgets do what they do.

But as ARPN followers know, it's not magic. Our advances grow out of the revolution in materials science that is powering the technology age.

In an article in The New Scientist, James Mitchell Crow observed:

> *"We rarely stop to think of the advances in materials that underlie our material advances. Yet almost all our personal gadgets and technological innovations have something in common: they rely on some extremely unfamiliar materials from the nether reaches of the periodic table. Even if you have never heard of the likes of hafnium, erbium or tantalum, chances are there is some not too far from where you are sitting."*

The article may be a few years old, but Crow's premise is as relevant today as it was then:

> "*From indium touchscreens to hafnium-equipped moonships, the nether regions of the periodic table underpin modern technology – but supplies are getting scarce."*

Take Tellurium, for example. One of the least common elements on Earth, according to the USGS, it is essential to photovoltaic solar cells. The challenge, however, is that despite its importance, Tellurium is not mined in its own right – it is largely a by- or (as we will explain later), more appropriately, a co-product of refining Copper and, to a lesser extent, Lead and Gold.

A similar scenario unfolds for many other tech metals critical to innovation today.

As we have argued in our 2012 report *"Through the Gateway: Gateway Metals and the Foundations of American Technology,"* many of them are *"unlocked"* by five *"gateway metals"* – Aluminum, Copper, Nickel, Tin and Zinc.

Copper ore refining yields access to Molybdenum, Rhenium, Selenium, Tellurium, along with small amounts of REEs. Zinc ore is a gateway to Indium, Germanium and Cadmium. Aluminum processing unlocks Gallium and Vanadium. Tin also provides access to Indium and Vanadium, while Nickel is a gateway to Cobalt, Palladium, Rhodium and Scandium.

When cross-referenced with the 2012 ARPN Risk Pyramid — which graphically weighted and segmented the 46 minerals and metals most cited in a series of reports on the national security applications of strategic materials — and we surveyed and analyzed our degrees of mineral resource dependence, we get the following picture:

The five gateway metals we focused on – Aluminum, Copper, Nickel, Tin and Zinc—may only represent only 10% of the Risk Pyramid, but, when counting all Rare Earths individually, they unlock 25 of the remaining 41 metals, accounting, all told, for 60% of the whole Risk Pyramid.

In light of these staggering numbers and the increasing importance of said tech metals to our daily lives and future innovation, we are taking a closer look at the individual gateway metals and their co-product metals.

COPPER

Copper – Far More Than Your "Old School" Industrial Metal

In the past few years, "*old school*" Copper – long acknowledged as an indispensable building block of the industrial age — has been undergoing turbulent times on the global commodity market stage. While some have since recovered, hard rock commodity prices went down significantly over the past five years, and Copper was no exception.

In the long run, we can reasonably expect the self-corrective nature of the market associated with commodities cycles to work -

> *"Growth rates slow, supply exceeds demand, prices fall, producers idle their mines, postpone new projects and abandon exploration. Then, the economy works through the surplus production, demand returns, supply tightens – prices rise – and so does the incentive for investment in new exploration and development."*

In fact, some analysts in 2016 predicted a looming global copper shortage as a cooling investment environment means fewer projects will come online.

Market trends notwithstanding – Copper remains critical for a number of reasons, as our very own Daniel McGroarty outlined:

> *"**National security.** Copper is the second most widely used metal by weight in U.S. defense systems. According to a DoD study, lack of timely copper supply has already led to a significant weapons system delay. An MIT study found that the "risk of copper disruption is significantly greater than for the other major metals… and is at or near a historical high."*
>
> ***Alternative energy.*** *A single industrial wind turbine requires more than three tons of copper. Next generation solar power looks to CIGS-based photovoltaic cells – where the C stands for copper and the S for selenium, 95 percent of which is derived from copper mining. Electric vehicles require 25 percent more copper than gas-fed cars – more than a mile worth of copper wire per EV."*

As the field of materials science advances, new applications for Copper will undoubtably continue to be discovered and add to the metal's relevance.

However, Copper's status as a gateway metal must not be overlooked.

> *"**Versatility.** Copper is often extracted in conjunction with other critical metals, like rhenium, which is used in jet fighter turbines and to formulate lead-free gas. Three-quarters of global Rhenium supply comes from the copper smelting process. And copper yields 95 percent of the world's tellurium – like selenium, key to solar power cells."*

In addition to Rhenium, Copper processing also yields access to Molybdenum, Selenium and Tellurium, as well as (in small trace amounts) Rare Earths.

While we will first explore some of Copper's uses and applications, as well as take a look at supply and demand for this gateway metal, we will begin zeroing in on its co-products – which are important tech metals in their own right.

Copper – Gateway to Renewable Energy

Whatever your views on global climate change – there is no denying that we find ourselves in the midst of a green energy transition. As David Sandalow, former under secretary of energy and assistant secretary for policy and international affairs at the U.S. Department of Energy (DoE), noted in the New York Times, *"[s]olar power is booming. Globally and in the United States, installations grew at least 28 percent last year."*

At the same time, cost reductions courtesy of technological advances have afforded the United States global leadership status in wind energy production.

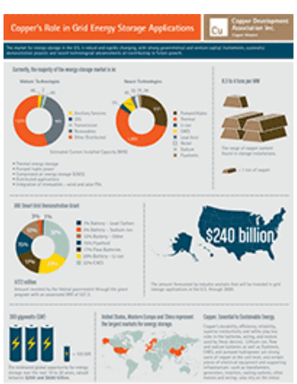
Renewable energy may not be the first thing that comes to mind when you think of Copper, but it's an undeniable fact that its properties – superior thermal and electrical conductivity as well as durability and efficiency — have turned this traditional mainstay industrial metal into an indispensable building block for green energy projects.

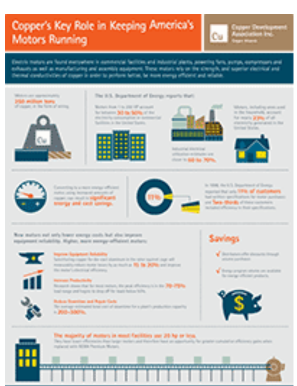
Wind turbines, CIGS-based photovoltaic cells, and electric vehicles all require significant amounts of copper. As one market analyst phrased it in 2015:

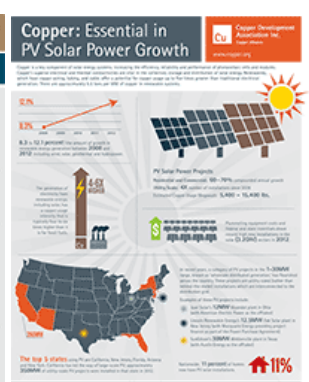
> *"Each megawatt of wind power capacity, for instance, uses an average of 3.6 tonnes of copper. Electric trolleys, buses and subway cars use about 2,300 pounds of copper apiece. Where we'll see the most significant growth, though, is in the production of hybrid and electric cars, which use two to three times more copper than internal combustion engines."*

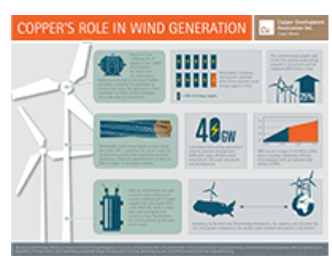
These electric vehicles require 25 percent more copper than gas-fueled cars, and Tesla Motors's Model 3, pre-sales for which have reached the $10 billion mark, is estimated to consume 65 kg of copper per car alone.

The Copper Development Alliance has put together some great graphics visualizing how the red metal is greening our energy future:









And this only paints a partial picture.

Copper's role as a gateway metal — providing us with access to tech metals like Selenium or Tellurium, as well as (potentially) Rare Earths — only underscores Copper's relevance to Renewable Energy, and reinforces its status as a critical mineral.

The Copper Gap That Needn't Be

Like many of its hard-rock commodity peers, Copper saw its price decline sharply over the past five years. Price levels have since gone up again.

Ups and downs notwithstanding, Copper fundamentals remain strong, particularly as Copper, which as we have pointed out, is far more than an *"old school"* industrial mainstay metal and in fact may well be dubbed the *"Gateway to Renewable Energy."*

It is important to note that the current global copper oversupply does not translate into a Copper surplus in the United States – according to the 2016 USGS Mineral Commodities Summaries, we still import 36% of the Copper we consume.

That wasn't always the case. As ARPN's Dan McGroarty has pointed out:

> *"American policymakers once treated copper as a strategic metal. It was held in the National Defense Stockpile during the Cold War. When the Soviet Union imploded two decades ago, the U.S. produced 93 percent of the copper we consumed. Copper was sold out of the stockpile – which today stands at zero. In the past 20 years, copper imports have increased five-fold, to 35 percent.*
>
> *In other words, we've gone from a situation of near self-sufficiency to a shortfall of more than 600,000 tons per year – demand that must be met by imports."*

A similar scenario has unfolded for many other metals and minerals, and in many cases, needlessly so, as the United States has significant known mineral resources with an estimated net worth of $6.2 trillion beneath our own soil. With estimated reserves of 33 million metric tons of Copper, the United States is well positioned to close the Copper Gap – a move that would be beneficial on several levels:

> *"Indeed, American miners could help the U.S. become a copper exporter – just as American farmers feed the world. American alternative energy manufacturers, seeking to build wind turbines and solar panels, would enjoy sources of selenium and tellurium here in the U.S."*

However, a number of policy hurdles – among them chiefly a rigid and outdated permitting process for domestic mining projects – stand in the way of such a development.

In the long term, we can expect commodity prices to pick up again. While we wait for the long term to arrive, the prudent course of action would be to tackle these policy obstacles head on.

Tellurium – A Rare Metal With Abundant Demand

Even less abundant than Rare Earths, most Tellurium used today is recovered as a co-product of mining and refining Copper and other base-metal-rich ore bodies.

Initially, Tellurium was primarily used as an additive to steel, copper and lead alloys, a process in which it helps improve machine efficiency. Here, USGS specifically cites thermoelectric cooling applications and highlights Tellurium's capabilities to improve ductility and tensile strength, as well as sulfuric acid corrosion prevention.

With the advent of the green technology revolution — and its ability to form a compound exhibiting enhanced electrical conductivity when alloyed with elements such as Cadmium — demand for Tellurium as a critical component for efficient, thin-film photovoltaic cells producing electricity from sunlight has soared.

Today, these Cadmium-telluride solar cells represent the major end use for Tellurium in the United States – a fact that is unlikely to change any time soon, as solar power is booming, and recent lab results had CdTe technology break efficiency records when it comes to converting energy in sunlight into electricity.

Meanwhile, for the foreseeable future, experts expect co-product supply via the Copper refinement process to remain the dominant source of Tellurium supply, with secondary production from recycled CdTe having the potential to contribute *"a sizeable share of total production."*

Selenium – More Than Just a Dietary Supplement

Chances are, you've heard of Selenium. As a trace element, it is an essential mineral found in small amounts in the body, with antioxidant properties. It is also a much-used suite of tools to automate web browsers across many platforms — which is why weeding out our news alerts for stories relevant to ARPN followers can be time-consuming.

However, more relevant from our vantage point are this rare mineral's other uses. According to USGS, Selenium, which is known to have semiconducting properties, is used in glass manufacturing to decolorize the green tint caused by iron impurities, and — increasingly important to new applications — to reduce solar heat transmission. In catalysts, it enhances selective oxidation, in plating solutions, it improves appearance and durability, and in gun bluing, it improves appearance and provides corrosion resistance. It is further used in rubber-compounding chemicals, in the electrolytic production of manganese, and in copper, lead, and steel alloys to improve machinability.

Perhaps its most important use today is its application in solar technology. Like Tellurium, Selenium plays a critical role in the performance of thin-film photovoltaic cells. While Tellurium is used in combination with Cadmium for CdTe technology, Selenium is alloyed with Copper, Indium and Gallium, creating a material commonly referred to as CIGS.

Both CdTe and CIGS technologies were the new kids on the block during the first solar boom, though Selenium's photoconductive properties were already discovered by British scientist Willoughby Smith in 1873. Companies engaged in both technologies have since vied for front-runner status in the solar world by attempting to improve the respective material's efficiencies. While CIGS seemed to have a leg up up until recently, new test results for CdTe are promising. The bottom line, however: both materials, and with that Tellurium and Selenium, are in high demand.

What holds true for most tech metals and minerals, applies here too: substitution may occur, but technological advances in materials sciences will likely continue to fuel demand. Selenium may have been replaced by organic photoreceptors in some plain paper copiers, but new nano-technological applications, for example in electronics, are already being tested by researchers.

As is the case with Tellurium, most Selenium used in the United States is derived from residues produced during the refining process of Copper, so the supply of Selenium is of course directly affected by the supply of Copper.

Rhenium – Rare and Sexy?

It has helped make airline travel affordable. It helps keep us safe. And it may just be sexier than Salma Hayek – at least in the eyes of one observer.

We're talking about Rhenium, yet another metal brought to us largely courtesy of Copper refinement. A silvery white, metallic element, Rhenium, according to USGS, has *"an extremely high melting point (3,180 degrees Celsius), and a heat-stable crystalline structure, making it exceptionally resistant to heat and wear."* Thanks to these properties, it has been an indispensable component for superalloys used in turbine blades for jet aircraft engines. As the BBC put it,

> *"[t]he ability of superalloys to operate at such extreme temperatures is what makes your holiday to the Algarve or Florida affordable."*

At an average abundance of less than one part per billion in the continental crust, Rhenium, like its fellow Copper Co-Product is also an extremely rare metal. Global production is pegged at a total of a mere 46 metric tons, with more than 80 percent of that amount going into superalloys.
Its rare metal status is one of the key reasons why recycling rates for Rhenium are increasing. While in the past, scrapped blades used to be sold and recycled in the stainless steel industry, today most of the rare metals contained in the superalloys used in turbine blades are recovered for reuse in manufacturing.

End users have also worked hard on substitution. As the Economist reported a few years ago,

> *"General Electric, one of the world's biggest makers of jet engines, has spent years developing nickel-based superalloys to replace rhenium. But the best GE's boffins could manage was to reduce the amount of metal required, not eliminate it altogether. Moreover, few manufacturers possess the resources to achieve even such limited progress."*

The United States currently imports 79 percent of the Rhenium we use. Because the recovery process is complicated and requires special facilities, we are unlikely to fully meet our demand with domestic resources. However, a strong demand for Rhenium is likely here to stay. That, coupled with the fact that we have proven Rhenium reserves in the U.S. (the development of one of which has been projected to generate more than 20 tons of Rhenium per year as a Copper Co-Product, thus significantly reducing our reliance on foreign imports), should suffice to get policy makers' attention — regardless of their stance on Salma Hayek.

Molybdenum – "The Most Important Element You Have Never Heard Of?"

A writer for Gizmodo has dubbed it the *"most important element you have never heard of."* Writes Esther Inglis-Arkell:

> *"Molybdenum, with its 42 protons and 54 neutrons, sits right in the middle of the periodic table being completely ignored. It's not useless. (…) It just doesn't have that indefinable sexiness about it."*

Inglis-Arkell explains Molybdenum's biochemical relevance:

Taken up by plants from the soil, molybdenum *"forms a crucial part of a little enzyme called sulfite oxidase. The enzyme breaks down incoming sulfites and turns them into useful food. Take away molybdenum, and the enzyme, and things get nasty. The lowest-level problem you can look forward to is a severe allergic reaction. Continued molybdenum deprivation causes uric acid to build up in the blood, which brings on horribly inflamed and painful joints. At it worst, molybdenum deficiency takes out the nervous system."*

Definitely not good.

But there's more to it. Like Rhenium, Molybdenum is essential for creating high-performance alloys used in jet turbines and other defense systems. It is also a critical component of alloyed materials used in water distribution systems, food handling and chemical processing equipment, automotive parts, gas transmission pipes, and heavy construction.

As USGS has noted,

> *"Without molybdenum as an alloying metal, the superstrength steel used in heavy construction (such as in skyscrapers and bridges) would be more costly; in some instances, the increased weight of alternative materials with equivalent strengths would render construction unmanageable or even impossible."*

The question of whether or not it is *"the most important element you've never heard of,"* aside – Molybdenum's importance cannot be dismissed. Luckily, the United States is in a good spot with regards to availability to meet domestic needs.

In fact, as Molybdenum, unlike its previously discussed Copper co-product peers, is actually a metal of which we are a net exporter, industry continues to seek to develop materials that could benefit from its hardening, strengthening and anti-corrosive properties. The advent of additive manufacturing, also known as 3D printing, is just one example here.

While we are fortunate to have an abundance of Molybdenum beneath our own soil, one should note that while there is some primary Molybdenum production, including at two mines in the United States, most of the Molybdenum we use is produced as a Copper co-product. Thus, we should keep Molybdenum on our supply and demand radar, particularly as advances in materials science may increase demand. As USGS points out:

> *"Short- to medium-term changes in copper prices can influence the availability of molybdenum. For example, copper mining activity may drop suddenly in response to reduced metal prices, which in turn reduces the total amount of molybdenum that is produced. Although primary molybdenum mines can fill this market gap between byproduct production and overall demand, they have a limited ability to increase their production rate to meet spikes in demand."*

We Have the Reserves, So Why Aren't We A Copper Net Exporter?

It has become abundantly clear that Copper is a critical mineral, not just as a stand-alone traditional mainstay metal, but also as a gateway to the (mostly) rare tech metals it unlocks.

In spite of the fact that, as we've pointed out, the United States is home to vast mineral riches, including Copper, we are still relying on foreign imports to meet our domestic industries' Copper demand. With our own reserves and at mining projects ready to come online, the U.S. would not only be able to become self-sufficient with regards to meeting Copper needs, but could even position itself to be a Copper net exporter. A similar scenario is feasible for a number of other critical metals and minerals, where we could, at a minimum, significantly reduce foreign import dependencies by harnessing our domestic mineral potential.

Standing in the way of such a development, however, is a combination of decreased exploration spending and an increase in the time it takes for domestic mineral resource extraction projects to come online courtesy of a rigid and outdated permitting process.

At present, it takes roughly seven to ten years to get a mining project permitted in the United States. Without compromising environmental standards, that very process is wrapped up in one to two years in Australia, and three to five years in Canada.

With that said, there may be some light at the end of the tunnel.

In 2016, we pointed to these developments:

> *In a rare show of bipartisanship, the United States Senate has passed legislation that may represent a first step at addressing the United States' over-reliance on foreign mineral resources. For the first time in years, a set of provisions aimed at improving our near worst-in-the-world permitting process included in Sen. Lisa Murkowski's (R-AK) energy bill, which is co-sponsored by Sen. Maria Cantwell (D-WA), may actually stand a chance of making it to*

the President's desk. However, only weeks before the summer recess, the path towards reconciling Senate and House versions of the legislation has yet to be cleared.

At the executive branch level, efforts are also underway.

Several initiatives, such as the Defense Logistic Agency's work to overhaul the defense stockpile to appropriately address today's critical mineral needs, the White House's Materials Genome Initiative, and the Critical Materials Institute operating under the auspices of the Department of Energy come to mind.

However, much more must be done.

Legislative efforts since then have unfortunately faltered, though a new push for Representative Amodei's National Strategic and Critical Minerals Production is currently underway.

At the executive branch levels, we have seen a flurry of encouraging activity since late December of 2017, which included an Executive Order *"on a Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals"* and the subsequent release of a draft list of 35 minerals deemed critical to U.S. national security.

As ARPN's Dan McGroarty told Congress earlier in 2016:

"*I don't think there's another nation in the world that can match American ingenuity. We can pioneer the ideas behind wind and solar and so much else – but where will the materials that make these new energy sources real – where will they come from?*

How we answer that question will determine to a large extent whether the U.S. can regain its manufacturing might… Whether America will lead the alternative energy revolution… And whether the U.S. will have the metals and minerals we need to provide the modern military technology we depend on."

** While the Copper refinement process on occasion also yields access to some Rare Earth Elements (REEs), these quantities are very limited. As ARPN readers will find plenty of REE coverage on our blog, REEs will not receive separate treatment as part of this series.*

Aluminum – Versatile and Timely

After showcasing our first Gateway Metal, Copper, and its co-products, it's time to move on to our next Gateway Metal.

Chances are, it's a staple in your kitchen. It is being featured as a part of a massive art installation currently hosted by London's historic Kew Gardens. And it is a hot-button trade issue

We're talking about Aluminum.

The second most abundant metallic element in the Earth's crust, according to USGS, aluminum has only been commercially produced for a little over a hundred years, but has since become a widely used mainstay industrial metal – for good reason.

Weighing about one-third as much as Steel and Copper, Aluminum is highly malleable with low density and a low melting point, has great conductivity and corrosion-resistance, and can be engineered to be extremely strong — with certain aluminum alloys being as strong if not stronger than certain types of steel.

Some of the more traditional applications for Aluminum include usage in transportation, packaging, and construction, as well as consumer appliances and machinery. More recently, however, the metal's versatility has made it a driver in our society's move towards more energy efficiency. As is the case with Copper, we can reasonably expect further advances in materials science to yield new, innovative uses for Aluminum and Aluminum-based alloys.

Meanwhile, Aluminum is also a Gateway Metal, with the mining and mineral processing of Bauxite ore for Aluminum yielding access to the tech metals Gallium and Vanadium.

We will first explore some of Aluminum's uses and applications, before taking a look at the metal's supply and demand picture. ARPN followers will quickly notice distinct differences from policy issues we have typically highlighted for other minerals and metals. Yet, these issues are no less critical, interesting, and extremely timely.

Aluminum – Building Block of our Sustainable Future

Probably one of the most important buzzwords of our time is *"Sustainability."* When thinking of the term, mining and industrial metals are probably not the first things that come to mind, but they are in fact integral components of our society's move towards a greener, more sustainable energy future. We have already outlined how Copper serves as a gateway to renewable energy, but the same rationale applies to Aluminum.

Because of its light weight, many car companies have turned to aluminum to be able to comply with government standards and meet consumer demands for increased fuel efficiency and reduced tailpipe emissions. The Automotive Science Group recently concluded that the Ford F-150's Aluminum design was key to said truck's *"elevated performance, which not only reduces environmental burdens associated with raw material mining and processing, but with reduced vehicle weight, less power is required to physically move the vehicle."*

Particularly for heavy vehicles like pick-ups and SUVs, aluminum tends to be the material of choice, with analysts assuming that

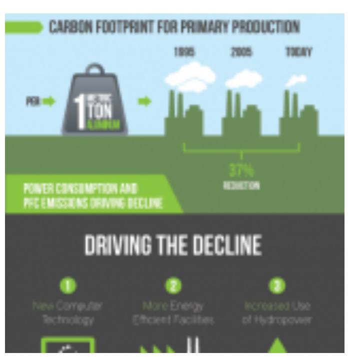
> *"aluminum's share of the average automotive materials mix in the world is likely to reach 15-16% by 2025, up from approximately 9% in 2015, while the average aluminum content in cars in Europe and North America is expected to increase to 19-20% of the car's curb weight, up from 10-11% in 2015."*

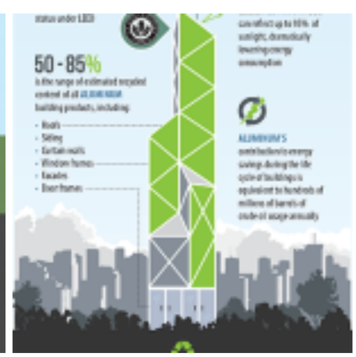
The use of Aluminum-air batteries, which consume aluminum as fuel and are able to power electric vehicles for up to 1,000 miles, further contributes to increased fuel efficiency and emission reductions.

In the building and construction industry, Aluminum was initially used for decorative purposes and structural strength and durability, but has since been recognized as one of the most sustainable materials available. It is 100% recyclable without loss of properties, and, properly coated, can reflect up to 95 percent of solar energy, thus reducing the need for cooling technologies significantly. As such, builders turn to aluminum to receive the coveted Leadership in Energy & Environmental Design (LEED) green building certification.

Meanwhile, the Aluminum industry itself has significantly reduced its carbon footprint. According to the Aluminum Association, since the early 1990s, greenhouse gas emissions from primary production were cut by 37 percent, while those derived from secondary production were slashed by more than 50 percent.

The Aluminum Association has put together a great set of infographics on the subject. The International Aluminum Institute also hosts a campaign with many examples underscoring Aluminum's role in the building, and transportation sectors worldwide.





Last but not least, we should also acknowledge that Aluminum's status as a Gateway Metal to the tech metals Gallium and Vanadium, both of which are critical to renewable energy in their own right, further underscores the metal's contribution to our sustainable energy future.

Aluminum Alloys – Versatility On Steroids

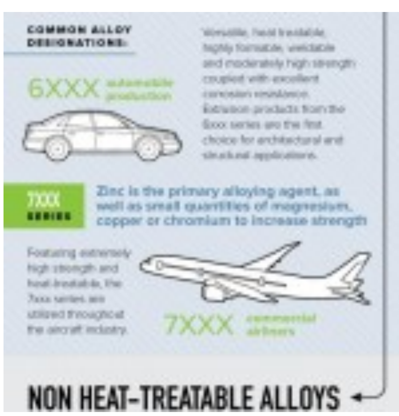
Recently, researchers developed a material "*that's as strong and light as titanium, another expensive material, but at just a tenth of the cost.*" They were able to achieve this feat by tweaking Aluminum's alloying properties at the nano level.

Aluminum's properties as a stand-alone metal already make it one of the most versatile materials in engineering and construction, and as engineering database Total Materia notes, *"a mere recital of its characteristics is impressive."* It is lightweight, but extremely durable, has a high resistance to corrosion, boasts good electric and thermal conductivity, and reflects both heat and light. It is highly malleable, and can be treated with many different surface finishes.

Add to that its alloying capabilities, which were first harnessed around 1911, and Aluminum's versatility soars to new heights. The addition of other metals and minerals, including fellow Gateway Metals Copper and Zinc, but also Iron, Silicon, Magnesium or Manganese, to pure aluminum further enhanced its properties. Multiple alloys make up America's *"favorite beverage container,"* the aluminum can, but that's just the tip of the proverbial iceberg – aluminum alloys are used in a wide range of industries today.

Because of the wide range of alloying options, and with international designations becoming a mess with some countries merely assigning numbers in the order of their development, the uniform International Alloy Designation System (IADS), a designation system previously developed by the Aluminum Association of the United States, became the international standard for Aluminum alloy designation in the 1970s. Based on this system, Aluminum alloys are assigned a four-digit number of which the first digit represents a general series or class, characterized by its main alloying elements.

Some of the main categories of Aluminum alloys are *"Commercially Pure Aluminum," "Heat-Treatable Alloys,"* and *"Non-Heat Treatable Alloys,"* but new alloy compositions continue to be developed. According to the Aluminum Association, which has put together a great series of infographics on Aluminum alloys, the number of registered active compositions has grown to more than 530 from the 75 initially registered at the time of the classification system's initial inception in 1954.



The development of a Titanium-like iron-aluminum alloy, which ultimately could be used in *"everything from bicycles to airplanes"* only underscores that Aluminum is more than tin foil and beverage cans. As materials sciences advance, we can expect the number of registered alloys to continue to grow, and we will be able to reap the benefits.

Aluminum – Fueling the Renaissance of American Manufacturing

Aluminum is not only one of the most sustainable materials these days, it is also keeps making headlines. Invoking challenges associated with China's trade policy, in 2016 then-President Obama issued a call at what was dubbed the "Three Amigos Summit" for the U.S., Canada and Mexico to work together to *"ensure a level playing field for the steel and aluminum industries here in North America."*

Today, the discussion revolves around tariffs.

The stakes are high, and with demand on the rise for durable, lightweight and sustainable materials, the Aluminum industry's contribution to the U.S. economy — and with that, to the renaissance of U.S. manufacturing — is significant.

And that significance is measurable. According to an April 2016 study conducted by economic research firm John Dunham & Associates, the U.S. aluminum industry provides 161,000 direct jobs, and accounts for nearly 551,000 additional jobs created through multiplier effects. Expressed in dollar figures, that means the U.S. aluminum industry's direct contribution to the U.S. economy has reached $75 billion. When accounting for induced impacts, that number shoots up to $186 billion — more than one percent of national GDP. The Aluminum Association has a great infographic on this:

While the U.S. is home to significant bauxite deposits, from which aluminum is sourced, we import a significant percentage of the aluminum consumed domestically. Unlike with other metals and minerals, this represents a marked decrease in geopolitical risk, as most of our aluminum imports are sourced from one of our closest trading partners, Canada. In fact, in 2015, Canadian-sourced imports accounted for 65% of crude aluminum, 21% of semimanufactures, 64% of scrap, and 54% of total aluminum imports. The number of total aluminum imports sourced in Canada has since increased to 56%.

In other words, viewed in isolation and from the upstream end of the supply chain at the minesite, the U.S. is increasingly import-dependent for the aluminum it needs. But in the context of an integrated North

American supply chain between the two trading partners, a look at USGS's 2014 Minerals Yearbook reveals that Canada is helping the U.S. close a 3.4 million ton domestic aluminum production shortfall by supplying more than 2.2 million tons of crude ingot and 227,000 tons of semifabricated aluminum.

The geopolitics of resource supply are complex and constantly changing. Trade gives us a more complete picture — but the fundamental fact remains that in our tech-dependent era, manufacturing might is rooted in reliable resource supply.

Of Pokémon and Co-Products – A Look at Gallium

All over the world, people were wandering through the streets staring at their smartphones for some time. Whether you were part of the PokémonGo phenomenon that took the world by storm in 2016, or whether you could only shake your head, you don't only have Nintendo to thank for (or blame). One of the Co-Product Metals we're focusing on plays an important role in allowing you to track down your favorite Pokémon in your neighborhood for hours on end: Gallium.

The *"smart metal"*, as USGS has dubbed Gallium, is one of the Periodic Table's premier social networkers: it forms compounds with various elements. Among those are Gallium Arsenide (GaAs) and Gallium Nitride (GaN), the strong semiconducting properties of which make them key components of the integrated circuits of smartphones and other wireless communication devices.

Today, its use as semiconductor compound is Gallium's major application. CIGS compounds (with CIGS standing for Copper-Indium-Gallium-Selenide) are also used in solar technology with CIGS photovoltaic panels promising to efficiently capturing sun rays. Gallium is also a component in other optoelectronic devices (LEDs, photodetectors) in aerospace applications, consumer goods, industrial equipment and medical equipment.

While it is an Aluminum co-product, Gallium is significantly less abundant in the earth's crust than its main Gateway Metal. Many Bauxite deposits which are mined and processed for Aluminum contain small amounts of Gallium, as do Zinc deposits. However, most of the Gallium we use today is derived from the processing of Bauxite Ore.

In spite of the fact that we are home to significant Aluminum deposits, the United States is 100% reliant on foreign imports to sufficiently supply our domestic manufacturers with the primary Gallium they need. Meanwhile, researchers from Yale University sounded the alarm in 2015 on several metals used in our favorite gadgets – including Gallium – being at risk of running out globally. One of the researchers' comments aptly underscores the broader challenge associated with Co-Product metals:

> *"The metals we've been using for a long time probably won't present much of a challenge, (…) But some metals that have become deployed for technology only in the last 10 or 20 years are available almost entirely as byproducts. (…)*

You can't mine specifically for them; they often exist in small quantities and are used for specialty purposes. And they don't have any decent substitutes."

Even though Gallium is generally considered a scarce resource, it is not so much its overall abundance (or lack thereof) that is problematic here. According to USGS estimates, *"world resources of gallium in bauxite exceed 1 billion kilograms and that a considerable quantity of gallium could also be present in world zinc resources."* However, – and that is probably the bigger issue - *"[m]ost of the gallium in bauxite resources cannot be considered to be available in the short term, however, because much of the bauxite will not be mined for many decades. Also, only a small percentage of the gallium metal contained in bauxite and zinc ores is economically recoverable using current separation methods. Larger amounts of gallium could be recovered from these ores if more efficient and improved extraction and separation methods are developed in the future."*

With demand for electronic gadgetry and advanced technology on the rise, Gallium is definitely a material to watch in its own right. But the case of Gallium also underscores why we should care about the relationship between Gateway Metals and their Co-Products in the grand scheme of things, as changing supply and demand scenarios or even mining and refining processes for one can affect the other.

Vanadium – Next-Gen Uses Drive Co-Product Challenge

Beyond their traditional uses, both Gateway Metals and their Co-Products have become building blocks of our renewable energy future. This held true for Copper and its Co-Products, but it is also equally true for Aluminum and its Co-Products. While Gallium's ability to form compounds with various elements lends itself to its application in smartphones and other wireless devices, as well as solar technology, Vanadium – another material *"unlocked"* by Aluminum – is making an entry.

Traditionally known as an alloying component in various steels, where its strengthening properties come to bear, it has been used in the building and construction industry for a long time. Ferrovanadium alloys have also been used in protective military vehicles while a Titanium-Aluminum-Vanadium alloy is used in jet engines and high-speed aircraft.

More recently, however, the material's use in energy storage technology has been making headlines. With the demand for renewable energy continuing to soar, the energy storage market itself is booming. As Cleantechnica.com explains:

"Since wind and solar energy come and go, energy storage fills a critical gap in terms of availability and reliability. (…) So far, lithium-ion (Li-ion) technology has staked a claim to the gold standard for energy storage in terms of performance relative to cost. (…) However, other energy storage technologies have an eye on the prize as well."

First generation flow battery technology using Vanadium was initially mired by inefficiencies and costliness, but research efforts, in particular by the Department of Energy's Pacific Northwest National Laboratory (PNNL), have since resulted in significant improvements of the technology. A breakthrough came with PNNL's 2011 development of a flow battery design, which added a new electrolyte mix to traditional Vanadium batteries. This led to a 70 percent increase in storage capacity.

The vastly improved third generation technology is now being applied in national grid modernization efforts: In 2016, a new collaboration between industry, the utility EPB of Chattanooga and three U.S. national laboratories using Vanadium flow battery technology was launched in an effort to *"develop metrics for evaluating renewable energy and storage integration and demonstrate the benefits of leading energy storage technology to our nation's grid modernization efforts."*

The bottom line: demand for Vanadium may well increase as technology advances, with new challenges looming large. It's a story with a familiar theme for ARPN followers — the co-product challenge:

According to USGS, Vanadium is at least as plentiful as Nickel and Zinc – at least in terms of its availability in the earth's crust. However, it rarely occurs in deposits that can be economically mined for the element alone. Between 2009 and 2013, some co-product vanadium production occurred domestically (though not from Bauxite mining for Aluminum), but it has since been suspended. As a result, the United States is currently 100% import dependent for its domestic Vanadium needs – in spite of the fact that *"domestic resources and secondary recovery are adequate to supply a large portion of domestic needs."*

Aluminum – From 3D Printing to Co-Product Access, It's Time to Connect the Dots

If you're in the market for a new and unique motorcycle, here's an option for you: Using a state-of-the-art aluminum alloy powder dubbed *"Scalmalloy,"* which has *"almost the specific strength of titanium,"* Airbus subsidiary APWorks would like to introduce you to its "Light Rider." But Light Rider is more than the world's lightest and first 3D-printed motorcycle, and Scalmalloy is more than just another aluminum alloy.

Both represent manifestations of research breakthroughs in materials sciences which are transforming the way we utilize metals and minerals. These transformations are fast-paced — who would have thought commercialized 3D printing would become a reality just a few short years ago? — and we're quick to accept them as the new normal. But while changing the way we *use* metals and minerals comes easy, what is lagging is a change in the way we *think about* metals and minerals, and with that, address them from a policy perspective. Aluminum is a case-in-point.

As we have pointed out over the course of our *"Through the Gateway"* discussion of Aluminum and its co-products, this metal has not only established itself as one of the key building blocks of our sustainable energy future. Its versatile alloying properties have also placed it at the forefront of cutting edge technologies. And it serves as a gateway to its co-product metals Gallium and Vanadium, which are increasing their footprints with new uses in their own right.

Yet, many still largely think of Aluminum only as a mainstay industrial metal — and of Gallium and Vanadium as somewhat obscure materials – without connecting the dots between them.   Connecting the dots, however would be critical, because, as one of the researchers we cited in our Gallium segment, so aptly explained:

> *"(…) some metals that have become deployed for technology only in the last 10 or 20 years are available almost entirely as byproducts. (…) You can't mine specifically for them; they often exist in small quantities and are used for specialty purposes. And they don't have any decent substitutes."*

Another aspect that deserves more attention is the geopolitics of resource supply. The case of Copper underscored the importance of pursuing policies conducive to harnessing our domestic mineral resource potential. The case of Aluminum shows that these policies are best coupled with an emphasis on strong trade relations with our closest allies in the context of an integrated North American supply chain to ensure reliable resource supply.

21st Century innovation is moving at lightning speed. Today a 3D-printed lightweight motorcycle using a new aluminum alloy is big news in a field in which so far, Titanium powders have been getting much of the attention. However, we can reasonably expect that Aluminum's properties will make it a key player in the field of additive metal 3D printing. Research efforts are already underway.

The key to not only being able to keep up but stay ahead of the curve as we race towards our high tech, clean energy future lies in a more comprehensive approach to mineral resource policy. This would help pave the way for more innovative technologies, like the Light Rider, to be developed in the United States.

Tin – More Than Just A Food Preserver

Both Copper and Aluminum not only yield access to several co-product metals, but are important mainstay metals with a plethora of new applications that make them important building blocks of our high-tech, green energy future. For both Copper and Aluminum, the United States has significant known reserves, and their domestic development will continue to play a significant role going forward.

For Tin, another Gateway Metal we covered in our 2013 report, the story line is somewhat different, though no less interesting:

As the BBC noted in a feature story in 2014:

"Tin wouldn't come anywhere near the top of most people's list of the most important elements, yet the history of our species is very closely entwined with this dull grey metal. (…) Tin was the basis of man's first great technological revolution."

Indeed, according to USGS, *"tin is one of the earliest metals known and used."* Its low melting point and the discovery of its hardening effect on copper, and with that the world's first alloy, effectively ushered in the Bronze Age, during which metal weapons and tools replaced stone. In the 19th Century, the metal found a new use revolutionizing the way we conserve food: when iron and steel cans were plated and tin and soldered with a tin alloy, the tin can was born.

While many of today's cans have eliminated tin as a component, the name stuck, and cans and containers still account for more than 22 percent of Tin usage in the United States, followed by chemicals at 20 percent, solder at 18 percent, and alloys at 14 percent.

Tin may not be as hot as the other two Gateway metals in terms of new applications, but its versatility will continue to fuel demand for the metal. Serving as Gateway metals for Scandium and Indium, for both of which there may be growth markets with new actual and potential applications, may further continue to drive demand.

While recycling yields about 30 percent of the Tin consumed domestically, the U.S. has remained import dependent for more than 70 percent for the past few years, with USGS pegging our degree of dependence at 75 percent in its 2016 Mineral Commodity Summaries. For ARPN followers know that we consistently call for policies that help alleviate our reliance on foreign resources – where possible.

However, there has not been any domestic Tin mining or smelting since 1993 and 1989, respectively, and identified resources of Tin in the United States are insignificant when compared with the rest of the world. Our main supplier nations include Bolivia – arguably not one of our stronger trade partners – and Peru.

As we've stated for Aluminum, where Canadian imports help the U.S. close a 3.4 million to domestic aluminum production shortfall, the case of Tin once more underscores the complexity of the geopolitics of resource supply, of which trade is an important facet.

A further layer of complexity was added by a 2016 WTO case by the EU against China, the world's largest tin producer in which the EU alleged that China was once again violating WTO rules with its restrictions on exports of various metals and minerals, including tin. While this development may not have a direct impact on Tin supply in the U.S., it goes to show that resource policy cannot occur in a vacuum, but must take into account the multi-dimensional nature of geopolitics.

Indium – Taking Virtual Reality Mainstream?

Like it or not, the Pokémon Go craze may have given us a glimpse into our future, or more precisely, the future of smartphone technology. And, you guessed it … it's a future that once again involves a rare tech metal that is not mined in its own right, but supply of which originates as a co-product of processing Gateway metals, among them chiefly Zinc and Tin – Indium.

As is the case with any iPhone release, there were a lot of rumors floating around in the weeks leading up to the release of the iPhone 7. Writing for ZDNet, Jason Perlow wondered whether it might be possible *"that the iPhone 7 isn't just a smartphone, but part of an integrated system that is something else entirely?"* The integrated system he alludes to is virtual reality, and he is basing his speculation on the fact that one of the primary manufacturers of the iPhone, FoxConn, has just bought Sharp, which a few years ago developed displays using IGZO (Indium, Gallium, Zinc Oxide) semiconductors – which *"have significant technology benefits (…), would mean increased luminosity, higher reaction speed and increased battery efficiency."*

Coupled with some of the other rumored features, which included twin cameras, a new docking connector and stereo speakers, he said using IGZO displays could well turn the iPhone 7 Pro into *"the brains of a virtual reality/augmented reality headset"* that *"performs as a smartphone by day, but snaps into a head-mounted cradle at night,"* allowing for a *"headset to be able to be used for augmented reality applications, such as a true-AR version of Pokémon Go."* In other words, the use of Indium could help take virtual reality technology to go mainstream.

It is tech metals like Indium that make developments like these possible. New applications like IGZO will likely increase demand for Indium, which is already a sought after tech metal because of its application in CIGS (Copper, Indium, Gallium, Selenide) solar panels, as well as in more conventional things alloys and solders, compounds, and electrical components.

Meanwhile, the U.S. is 100 percent import-dependent for the Indium consumed domestically. Supplier nations include trade partners like Canada, and Belgium, but also China – which, according to the USGS, produces nearly half of the world's Indium — once more underscoring the complex nature of the geopolitics of mineral resource supply.

Scandium: A Co-Product Metal Ready To Take Off

While Indium is becoming a hot tech commodity its fellow Tin co-product Scandium is another metal with huge potential in high-tech applications.

Its electrical and heat resistant properties lend itself to the application in solid oxide fuel cells, and its optical properties can be used for high-intensity lamps. The biggest opportunities for Scandium, however, lie in its usability in the creation of extremely strong heat-tolerant and corrosion resistant aluminum alloys.

As discussed in our Scandium segment, Airbus subsidiary APWorks has developed a 3D-printed light-weight motorcycle, for which the company used *"Scalmalloy"* – a Scandium-Aluminum alloy which features *"almost the specific strength of titanium."* With the rise of 3D printing and in light of Scandium's formidable ability to form super-strength alloys with aluminum, there is a good chance that demand for Scandium will increase in the near future.

And that's the challenge:

According to USGS, world resources are abundant in relation to demand. Scandium is more abundant than lead, mercury and precious metals – but it is rarely concentrated in nature *"because of its lack of affinity for the common ore-forming anion."* As a result, commercially viable deposits of Scandium are in fact rare. Because of this low concentration, Scandium is exclusively produced as a co-product during the processing of various Gateway metals, including Tin. Global production rates range from 10 tons to 15 tons per year – and these figures are on the high end of estimates, others peg primary annual production at only 400 kg per year. In total numbers, that is not much material to work with if new uses proliferate.

Thus, not surprisingly, while according to USGS the United States currently does not produce any Scandium, developers of multi-metallic deposits are studying the inclusion of scandium recovery into their project plans. Australia and Japan are also looking into Scandium co-product development. For now, however, the U.S. (in what is already a familiar challenge) has to rely on the main Scandium producers, which at this point in time include China, Kazakhstan, Russia, and Ukraine – arguably not our strongest trading partners.

With numerous applications, many of them associated with aluminum alloys, having been filed, Scandium is a metal to watch. What is currently holding the metal back is the lack of a reliable supply. Should that change, it may well take off.

As John Kaiser of Kaiser Research put it: *"This obscure metal is going to go ballistic in the next few years."* As friends of ARPN will appreciate, the question is whether U.S. scandium dependency will deepen — or whether U.S. policymakers will understand that resource development policy is key to American innovators' access to another critical metal.

The Geopolitics of Co-Product Supply– Another Look at Scandium

Throughout ARPN's work, we have consistently highlighted the geopolitical dimension of mineral resource policy. Where we source (or fail to source) our metals and minerals is an often forgotten – or ignored – factor, with implications for our domestic manufacturers, and, at times, even for our national security.

Case in point – and in keeping with our focus – Scandium. As we previously pointed out, the main producers for this co-product mineral, which is *"ready to take off,"* as of 2016 were China, Kazakhstan, Russia and Ukraine, none of which is among our strongest trading partners.

Russia has stepped up its Scandium game. As reported by Platts, Russian Aluminum producer Rusal in 2016 announced production of high purity (exceeding 99%) scandium oxide for the first time at its Urals smelter – an announcement following the launch of a pilot project for processing scandium concentrate into scandium oxide from red mud, a byproduct of alumina refining. Target production — 96 kilograms per year; not quite 4 pounds per week — shows why Scandium is arguably the rarest of the rare earths.

The announcement ties into the overall context of Scandium's growing potential, particularly in the context of the aluminum-scandium alloys.

Russian demand for Scandium has soared in recent years due to its use in various defense applications, including the 5th generation fighter, as well as its modernized version, and may well increase as Russia researches Scandium usage in combat equipment.

Meanwhile, while some developers are studying the possibility of including co-product development of scandium into their portfolio, the U.S. at present does not produce any scandium, even though the Defense Logistic Agency in 2013 deemed the material *"critical"* from a national security perspective.

Tin, Co-Products and Shifting Paradigms

While not as flashy as some other metals, Tin's versatility will continue to drive demand. We are familiar with its use in food preservation. Meanwhile, ITRI, the tin industry's UK-based trade association, highlights the *"storage, generation and conservation of energy as key drivers for new applications for the metal over the next 3 to 30 years."* Coupled with its application in soldering paste on circuit boards, demand will likely remain steady or grow.

In a recent report, the organization found that *"[f]rom the analysis, at a global level there is no reason to suggest that remaining tin deposits will be unable to sustain a long term, gradual upward trend in primary tin demand well into the future."* However, *"far more efficient exploration and mining technologies"* would be required.

Factor in our supplier nations – not necessarily the best trading partners – and a recent WTO case against the world's largest Tin producer, China, that may or may not affect global supply – and you have all the makings of a geopolitical resource supply challenge.

Against this background, a 2016 announcement that a Tin mining operation in Cornwall in the UK was being brought back to life after a two-decade-long closure did not come as a surprise. Cornwall was once home to roughly 2,000 tin mines, but as prices fell in light of increased global competition and supply, these mines began shutting down, and have not been reopened until now.

In the U.S., the picture is similar – domestic Tin mining or smelting was abandoned in 1993 and 1989, respectively, and, when accounting for Tin recycling as a source, we were 75 percent import dependent for the metal in 2016.

While the United States' identified Tin resources may be insignificant when compared with the rest of the world, the bottom line is that we must change the way we approach metals and minerals. With advances in technology and materials sciences, old paradigms are out the window.

Copper is no longer just a mainstay metal and conductor of electricity. Aluminum is more than a building material. And Tin is more than just a food container. All of these metals have found new important and versatile applications. But beyond that, they are Gateway Metals yielding access to some of the so-called "minor" metals (in Tin's case Indium and Scandium) that are quickly becoming the quintessential building blocks of our 21st Century high-tech and sustainable energy future and manufacturing renaissance.

Of Diaper Rash Cream, Fertilizer and Battery Technology – A Look at Zinc

If you're a parent of young children, you'll probably appreciate Zinc for its medicinal properties – a good diaper rash cream or sunscreen for the little ones comes with a good dose of Zinc oxide.

Otherwise, you may have come across this metal primarily as an anti-corrosion agent used to prevent metals like steel and iron from rusting, or as an alloying agent, for example in brass, bronze, nickel silver and aluminum solder. Zinc oxides and sulfates are also used in vulcanized rubber, phosphorescent applications, as well as heat sinks in laptops and cell phones.

New and interesting uses may increase demand going forward. One such area is agriculture, with China and India turning to Zinc as an addition to fertilizers to improve crop yields and to ultimately reduce mineral deficiencies in end-consumers.

Another growth market lies in Zinc's applications in battery technology, itself a growing segment in its own right. Here, Zinc's flexibility lends itself to application in wearable battery technology. Zinc batteries' ability to quickly recharge constitutes another big selling point.

Furthermore, one should not forget Zinc's Gateway Metal status – yielding access to metals and minerals as diverse and critical as Cadmium, Indium, Gallium and Germanium.

Domestically, according to USGS, Zinc was mined in five states at 15 mines in 2015. However, in spite of the fact that the United States is home to significant Zinc reserves, our degree of import dependence rose from roughly 71% in 2012 to 82% in 2015.

While our main supplier nations are Canada, Mexico and Peru, recent developments in China, which accounts for roughly 40% of global Zinc production, may affect the supply scenario going forward. As Bloomberg reported recently, Chinese smelters are having trouble securing sufficient raw materials and may have to cut production, and analysts see structural deficits looming.

Zinc's growing importance due to new applications and its Gateway Metal status is only another reason why policy makers would be well advised to look at our domestic manufacturing base's mineral resource supply needs (and the needs of parents trying to prevent diaper rashes and sunburns) comprehensively, and strategically — because more often than not, turning to the vast mineral riches beneath our own soil could help prevent supply shortages and ultimately fuel the renaissance of American manufacturing.

Germanium – Semiconductor of the Future?

Our first Zinc co-product, Germanium, is a silvery metalloid. According to USGS, *"in nature, it never exists as the native metal in nature"* and *"is rarely found in commercial quantities in the few minerals in which it is an essential component."* That said, the *"most commercially important germanium-bearing ore deposits are zinc or lead-zinc deposits formed at low temperature."*

Discovered in 1886, it was initially considered a *"weakly conducting metal without much use"*, but Germanium has been an important factor in semiconductor technology since the development of the world's first transistor in 1947 – the purified Germanium semiconductor.

Today, its main uses worldwide, according to USGS, are estimated to be fiber optics, infrared optics, polymerization catalysts, electronics and solar applications. There has been some fluctuation in domestic consumption – consumption for fiber optics for space-based uses increased while infrared optics use declined — but that decline was partially offset by growth in commercial and personal markets.

In the semiconducting sector, Germanium was superseded by Silicon as the material of choice, but, according to Purdue University researchers, that may soon change. Silicon's properties limit the ability to make smaller transistors and more compact integrated circuits, making Germanium all the more attractive for future advances in this field.

While there is some domestic Germanium production, most of it comes from *"either the processing of imported Germanium compounds or the recycling of domestic industry-generated scrap,"* while Germanium recovered from Zinc concentrates at two domestic mines is exported for processing. All told, the U.S. is 85% import dependent for its domestic Germanium needs.

Meanwhile, it might be worth taking a look at the British Geological Society's 2015 Risk List – an assessment of *"current supply risk for elements or element groups which are of economic value"* – which assigns Germanium the fourth highest risk score on its *"relative supply risk index."* The main factor here is one that ARPN followers will find familiar: nine of the top ten metals in BGS's risk list count China as the world's primary producer.

Christopher Ecclestone, discussing the issue for InvestorIntel, raises a good point:

> *"The Chinese don't dominate Gallium, Germanium and Antimony because they are the only country that has these metals. It is only because of a conscious policy on the part of the Chinese government and an unconscious acquiescence on the part of West that has allowed this situation to evolve. A goal for 2020 (dare we call it a Five Year Plan) should be to break the Chinese dominance in the top ten metals on this BGS list."*

Once again, the path to co-product access leads *"Through the Gateway"* – in this case, most often Zinc. And in spite of having significant known resources of Zinc, the U.S. is 82% import-dependent on this gateway metal.

A Look at Cadmium

Most of us have heard of Cadmium as a component of NiCd (Nickel-Cadmium) batteries. To date, this also happens to be the most frequent use for the metal, accounting for about 85% of the Cadmium consumed globally in 2015.

A silvery metal with a bluish surface tinge, Cadmium is corrosion-resistant and its oxides are insoluble in water. Nearly all the world's Cadmium is derived as a co-product from Zinc sulfide ore, which is mined in many countries. In the U.S., according to USGS, two companies produced refined Cadmium in 2015 – one by way of co-product recovery, and the other one by way of recycling of secondary cadmium metal from spent NiCd batteries and other scrap.

Over the past few years, there have been a slew of European Union directives classifying Cadmium as a toxic *"hazardous substance"* and prohibiting its use in many consumer products, including NiCD batteries in most power tools and Cadmium-containing quantum dots for light-emitting diodes for displays. However, usage of industrial-sized NiCd batteries in electricity storage from photovoltaic systems could counter some of the decline in Cadmium usage.

The current solar power boom could do the same – and once again underscores our Gateway Metal/Co-product Metal focus: Lab results for Cadmium-Telluride solar cells scored CdTe technology breaking efficiency records when it comes to converting energy in sunlight into electricity. Just like Cadmium, Tellurium is also a co-product metal (though unlike Cadmium, it is not a Zinc co-product, but rather derived mostly in the Copper refinement process). As such, both Cadmium and Tellurium are not mined in their own rights — but they are essential to a key 21st Century technology.

In light of materials science's rapid pace of discoveries of new applications for metals and minerals, other new applications for Cadmium may also be found.

While exact data are withheld, the U.S. is currently considered a net exporter of Cadmium. However, what is instructive here is the fact that the metal is almost exclusively derived as a co-product – so whatever happens to the Gateway Metal Zinc will in some shape or form affect the supply scenario for Cadmium. Or, in other words, the road to Cadmium leads Through the Gateway.

"Fairy Dust" Supply Woes Loom - Indium

Another Zinc co-product we have previously referenced is a metal that touches us — more precisely, we touch it — every day, too many times to count: Indium, which is one of the rarer tech co-product metals.

USGS pegged total global refinery production of Indium at 755 metric tons in 2015. The United States does not produce any Indium – making us 100% import-dependent and Canada – which is our biggest supplier of Indium – accounting for 66 metric tons of our domestic supply.

Aside from being a key component for the construction of CIGS (i.e. Copper, Indium, Gallium, Selenide solar panels) Indium happens to be the *"fairy dust"* that turns a regular computer, tablet or smart phone screen into a touch screen. The majority of newer smart phone and tablet makers have turned to ITO (Indium Tin Oxide) to form the conductive layer, which is *"used to monitor changes in electrical state as you touch and swipe the screen."* AZoMaterials has a great write-up and quick video explaining the technology.

Rumors that new IGZO (Indium, Gallium, Zinc Oxide) semiconductor technology has found its way into the displays of the iPhone 7 turned out to be just that – rumors - but the bottom line is that Indium is one of the tech metals that is growing in importance.

In 2015, the United States consumed 124 metric tons of refined Indium. If Canada were to reduce its output or exports to the United States, we might be forced to turn to China to meet demand even more than before – a daunting proposition.

Meanwhile, there is a serious disconnect with regards to resource policy. Most policy makers – and candidates for political office for that matter – fail to connect the dots – everyone is in favor of strengthening our manufacturing base, but they fail to acknowledge that we need *"stuff"* to make *"stuff."*

Maybe if their touchscreens stopped working all of a sudden they'd get the memo, and would focus on devising a comprehensive mineral resource strategy. Word of a potential Indium shortage may cause our eyes to glaze over — but if we lose touch with our touch-screens, maybe then we'll get a feel for the role co-product metals play in our 21st Century lives.

NICKEL

Nickel – "The Metal that Brought You Cheap Flights"

> *"It made the age of cheap foreign holidays possible, and for years it was what made margarine spreadable. Nickel may not be the flashiest metal but modern life would be very different without it."*

We couldn't have introduced our next Gateway Metal any better than the BBC did in a feature story on Nickel and its uses last year. Nickel's alloying properties have indeed transformed our lives – and without them, our best bet for long-distance travel might still be by train or ship.

As the BBC outlines, the first jet engines made of steel in the 1930s and 1940s did not have sufficient heat and corrosion resistance. With Tungsten too heavy and Copper melting at too low a temperature, Nickel's (with Chromium mixed in) strength, heat and corrosion resistance, low price point and light weight turned out to be the *"Goldilocks recipe."* And, as the BBC writes:

> *"Today, the descendants of these early superalloys still provide most of the back end of turbines – both those used on jet planes, and those used in power generation."*

Other uses, again drawing from Nickel's alloying capabilities, add to Nickel's importance:

> **Monel** – a Nickel-Copper alloy, is stronger than steel, malleable and corrosion resistant, and comes at a significantly lower price point than other alloys, making it a material of choice *"everywhere where corrosion is a concern – from chemists' spatulas to the protective coating on bicycle sprockets."*
>
> **Invar** – a Nickel-Iron alloy is used in precision instruments and clocks because it has the lowest thermal expansion of metals and alloys.
>
> **Nitinol**, a Nickel-Titanium alloy, is considered a *"shape memory alloy"* – a material that *"remembers"* their original shape. The BBC story has a fascinating clip demonstrating Nitinol's memory, the composition of which can be tuned. This lends itself to applications in medicine, for example, where a rolled up Nitinol stent can be inserted into a blood vessel, and allow blood to flow through it once the body's temperature prompts the stent to open itself out. Nitinol is also used in military, robotics and safety applications.

Suffice it to say that Nickel is a material that is here to stay. When factoring in Nickel's Gateway Metal status, yielding access to materials like Cobalt, Palladium, Rhodium and Scandium (which we've discussed a fair amount because of its application in 3D printing technology), its importance only increases.

Meanwhile, USGS has revised its Nickel supply assessment in recent years. While previous year reports showed no domestic reserves for Nickel, reserves as of 2016 were pegged at 160,000 metric tons – and one active new Nickel mine in Michigan produced 26,500 metric tons of concentrates for export to Canadian and overseas smelters. Our net import reliance for Nickel is 37 percent, and new projects in varying stages of development in Minnesota may further reduce our dependence on foreign supplies of Nickel.

This is a promising development, however to ensure a steady and stable supply of mineral resources fueling 21st Century technologies for our domestic industries, policy makers would be well advised to look at Nickel – and all other Gateway Metals and their Co-Products more comprehensively.

Through the Gateway: Cobalt – A Critical Mineral Under Scrutiny

A lustrous, silvery blue, hard ferromagnetic, brittle element, Cobalt's physical properties are similar to Iron and Nickel. It forms various compounds, stable in air and unaffected by water. Main uses include many alloys, including superalloys used in aircraft engine parts and high-speed steels, as well as magnets, and catalysts, to name but a few.

It's Cobalt's use in battery technology, however, that increasingly affords the metal *"critical mineral"* status.

A co-product of Nickel, the relevance to batteries of which we previously discussed, Cobalt is not only indispensable to the technology that powers electric vehicles and, increasingly, every aspect of our lives, from gadgets to household items to industrial applications – its supply is also fraught with challenges.

Says ARPN expert and Benchmark Mineral's Managing Director Simon Moores:

> *"I think cobalt is the most critical of the battery raw materials, (…) I don't think it's necessarily the most important. I think that's actually lithium. But cobalt, really, because 66 per cent comes from the DRC (Democratic Republic of Congo), then you've basically got a very lopsided industry from the supply perspective."*

Indeed, while China is the leading consumer of Cobalt, and supplies 62 percent of global refined Cobalt, most of the world's Cobalt is mined in the DRC. Roughly 93 percent of the Cobalt refined in China originates in the DRC, which, at 3,400,000 metric tons, is also home to the world's largest Cobalt reserves. In the United States, a Nickel-Copper mine in Michigan recently ramped up production of Cobalt-bearing nickel concentrate, but our domestic manufacturers remain import dependent for 75% of the Cobalt they consume.

Meanwhile, scrutiny of mining operations in the DRC is growing. A 2016 Washington Post feature outlines the conditions, which in some cases include child labor, and poor environmental standards.

Not surprisingly, battery makers and makers of consumer electronics and electric vehicles using these batteries, find themselves increasingly pressured to track where their Cobalt comes from, but the supply chain often remains murky. While currently not a conflict mineral under the "Dodd-Frank Act," a 2010 U.S. law requiring American companies to *"attempt to verify that any tin, tungsten, tantalum and gold they use is obtained from mines free of militia control in the Congo region,"* calls to add Cobalt to the metals covered by Dodd-Frank are getting louder.

Moores argues that this growing *"corporate social responsibility"* (CSR) problem may likely lead to battery makers turning to Cobalt sourced outside the Congo. Should that happen, it would be the equivalent of a two-thirds reduction in supply, at a time when clean-tech cobalt demand alone is set to spike.

While junior miners developing Cobalt-bearing properties see a great opportunity here, policy makers should also take note.

James Nelson, CEO at junior miner Cruz Capital, explains why:

> *"Any problems, geopolitical or otherwise, within the Congo and/or China, will definitely affect the rate at which cobalt is produced."*

The U.S. may not be home to massive Cobalt reserves like some other countries, but Cobalt co-product production may be feasible in a number of states, including Alaska, California, Idaho, Michigan, Minnesota, Missouri, Montana, Oregon and Pennsylvania.

Working towards a policy framework conducive to promoting domestic resource exploration would be a wise proposition for policy makers going forward, if we don't want run the risk of our laptop screens going dark.

Palladium – A Catalyst For Comprehensive Resource Policy?

For some, the first thing that comes to mind when they hear the word Palladium is boots – made popular by the French Legion and the Grunge movement of the 1990s. Others may be more familiar with the element Palladium, a member of the Platinum-Group Metals (PGMs), and as ARPN would argue, of greater interest to us than footwear – which happens to be another Nickel co-product.

A lustrous silver-white metal, it is the least dense of the Platinum-Group Metals, and has the lowest melting point among its peers. It is strongly corrosion resistant at ordinary temperatures, forms many compounds and has a great ability to absorb hydrogen.

Palladium's leading uses (which also apply for its fellow PGMs) are in catalytic converters to decrease harmful automobile emissions – an area where demand is likely to grow in light of tighter environmental standards. It is also used in catalysts in petroleum refining and bulk-chemical production, as well as electronic applications, and jewelry-making.

More recently, a team of Japanese researchers successfully used a permeable Palladium film to transform radioactive waste into the Rare Earth Element Praesodymium. Whether or not this discovery of Palladium's uses will have any impact on demand remains to be seen, but it goes to show the revolution in materials science that is going on — and the potential for new uses to change the supply and demand picture for metals and minerals.

Currently, a U.S. mine in Montana is one of only two mines worldwide producing primary Palladium, while all other Palladium is derived as a co-product of mostly the Platinum and Nickel mining process. The main suppliers of global co-product Palladium are South Africa, Russia, and the United Kingdom, leaving the United States import-dependent for 58 percent of the Palladium required by domestic manufacturers. And our dependency exists in spite of the fact that the U.S. is home to significant PGM reserves.

According to a 2012 USGS study, projects to produce Palladium as a Copper-Nickel Co-product were underway in Minnesota; however, as of yet, these projects have not gone online. Meanwhile, U.S. relations with Russia – one of our lead suppliers – are deteriorating, calling into question the stability of Palladium supply for our domestic manufacturers.

Rhodium – Not Just Another Platinum Group Metal

A rare, silvery white, hard and corrosion-resistant metal, Rhodium is not only one of Palladium's fellow members of the Platinum Group Metals (PGMs); it, too, happens to be a Nickel co-product. And, as is the case with Palladium, one of Rhodium's main uses is in catalytic converters to reduce automobile emissions, as well as in industrial catalysts.

Alloyed with Platinum and Palladium, in the process of which it serves as a hardening agent, Rhodium is also used in furnace windings, and thermo-coupling elements, to name but a few industrial applications. The exceptional hardness of plated Rhodium, which is derived by electroplating or evaporation, further lends itself to the metal's application in optical instruments.

USGS does not track production numbers or net import reliance statistics for Rhodium as a stand-alone metal; however, considering that there is currently only one domestic mining company producing PGMs — and that U.S. import dependence on the two PGMs USGS does track is 90% for Platinum and 58% for Palladium — plus the fact that we import roughly 11,000 kg of Rhodium per year, our import dependence to meet domestic needs is in all likelihood not insignificant.

As is the case with Palladium, new applications for the metal may become game-changers going forward and may drive up demand. One such recent discovery is the unveiling of a chemical process *"using the sun's thermal energy to convert carbon dioxide and water directly into high-energy fuels."*

In what may turn out to be a big step towards the chemical storage of solar energy, researchers at the Switzerland-based Paul Scherrer Institute (PSI) and the ETH Zurich have developed a procedure to do so using a new material combination of Cerium Oxide and Rhodium.

While this potential application is quite interesting, friends of ARPN will note that a compound comprised of two elements for which the U.S. is significantly import-dependent illustrates once again the constraints on the United States' ability to capitalize on advanced materials development.

What we have argued elsewhere, applies for Rhodium, too – the revolution in materials science represents a paradigm shift for traditional supply and demand scenarios for the raw materials that fuel it. It's time for a new comprehensive approach to mineral resource policy that embraces these changes - especially as we move into a potential period of uncertainty on the trade front.

Scandium Embodies Materials Science Revolution

While we worked on our blog series *"Through the Gateway,"* on which this report is largely based, we noticed that one metal has kept popping up in our coverage – Scandium.

A co-product of Tin, we also discussed it in the context of the alloying properties of Gateway Metal Aluminum. It is also a co-product of Nickel.

There is good reason it keeps popping up. For one, while on paper, Scandium resources may in fact be abundant, it is rarely concentrated in nature, making commercially viable deposits extremely rare. Because it is at present largely recovered as a co-product during the processing of various Gateway Metals, including Tin and Nickel, total global production rates are quite low (see our previous post). Scandium may also be present in certain Copper and Rare Earth deposits.

Enter Scandium's high tech applications – perhaps most importantly Scalmalloy, the state-of-the-art lightweight aluminum alloy powder with almost the strength of titanium, which perfectly illustrates the ongoing revolution in materials science.

In light of these and other relevant high-tech applications for Scandium, some expect demand to soar as high as by 800% over the next decade. Unsurprisingly, several mining companies – most recently in Russia and Australia – have thrown their hats into the ring, and are looking to go into the business of primary Scandium recovery. In the U.S., which is currently 100% import dependent to meet our domestic Scandium needs and has to rely on Kazakhstan, and Russia, developers of multi-metallic deposits are also studying the inclusion of scandium recovery into their project plans.

A key challenge – as we have frequently lamented - lies in the fact that resource development cannot happen overnight, especially in a regulatory environment that does not encourage the harnessing of our domestic resource potential.

How the new projects coming online will affect supply and demand remains to be seen, particularly as the materials science revolution continues to yield new research breakthroughs and applications for tech metals. However, the bottom line is – if Scandium is not yet on your radar, it needs to be.
As we previously pointed out:

> *[T]he question is whether U.S. scandium dependency will deepen — or whether U.S. policymakers will understand that resource development policy is key to American innovators' access to another critical metal.*

Nickel – Powering Modern Technology

We have established that the importance of each of the co-products is growing as the revolution in materials science advances. Meanwhile, our import dependence for each of the co-products is significant, and ranges from 58 percent for Palladium to 100 percent for Scandium.

For Nickel, the U.S. domestic supply picture has recently changed, with our import dependence dropping from roughly 50 percent to currently 37 percent with new projects having come online.

Here, too, new uses may increase demand going forward. We already touched on Nickel's alloying capabilities, which underscore its versatility and staying power. However, it is its application in battery technology that may become a game changer for the metal's supply and demand going forward.

In light of across-the-board predictions of higher battery use over the course of the next few years, and in particular in the consumer and electric vehicle segments, analysts see demand for its component metals – including Nickel – soaring.

Gateway Metals not only provide us with access to many co-product metals that underpin modern technology. They are also important building blocks of the 21st Century.

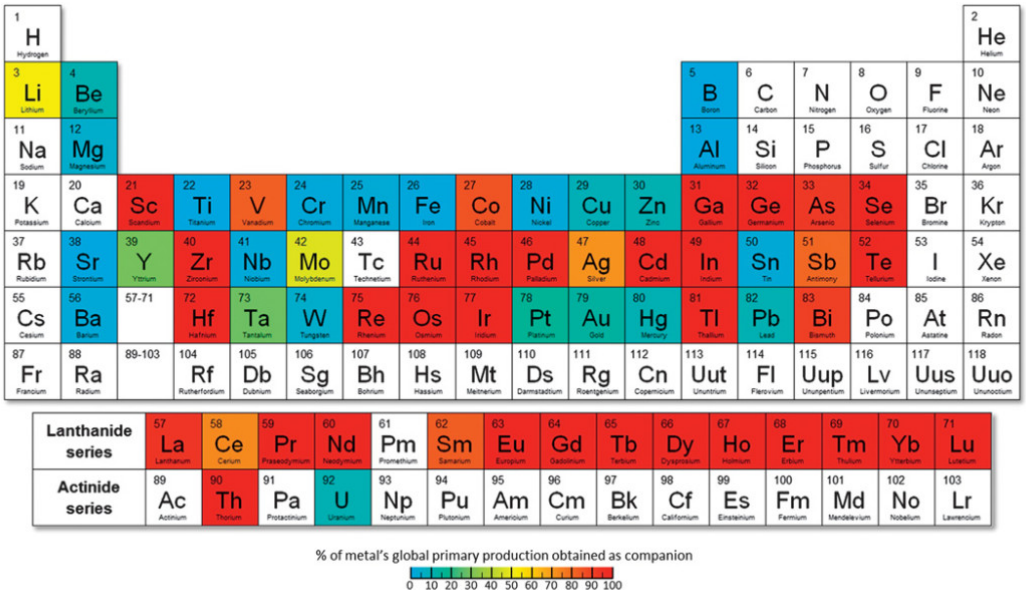
Through the Gateway: A Scholarly Look

In spite of the fact that the five Gateway Metals Aluminum, Copper, Nickel, Tin and Zinc and their Co-Products are growing in significance, stakeholders in academia, policy making and industry have been slow to take note of the correlation between them.

One notable exception is a study by N.T. Nassar, T.E. Graedel, and E.M. Harper, published in Science Advances in April of 2015.

The authors of *"By-product metals are technologically essential but have problematic supply"* cast their net a bit wider using a somewhat more scholarly approach and different terminology to describe *"Gateway Metals"* and *"Co-Products"* – they refer to them as *"Host Metals"* and *"By-Product"* or *"Companion Metals."* Nomenclature aside, their findings and conclusions are similar to the ones we have drawn.

Of particular interest is their depiction of the periodic table of elements showing *"companionality"* based on data for 62 metals and metalloids. Their conclusion: *"61%, or 38 of the 62 metals evaluated, have the majority (that is, >50%) of their global production obtained as a companion."*



The bottom line, according to Nassar, Graedel and Harper, should sound familiar to American Resources followers:

> *"It is undeniable that the widespread use of companion metals has resulted in markedly improved performance in many product sectors. Sustaining those uses may become a challenge going forward because of the dependence of companion metal supplies on the production of host metals. (…)*
>
> *As it now stands, much of modern technology depends on metals whose supplies are uncertain and whose market transactions are largely opaque; in concert, this produces a supply situation that may prove difficult to sustain."*