CRITICAL MATERIALS WORKSHOP SUMMARY

A day-long workshop on *Critical Materials Flow in an Age of Constraint: Exploring Challenges and Solutions Across Materials* was held on May 25, 2011 at the Woodrow Wilson International Center for Scholars in Washington, DC. Hosted by the U.S. Department of Energy's Office of Intelligence, Science and Technology and the Woodrow Wilson Center's Science and Technology Innovation Program, the workshop brought together materials experts from around the country to assess the prospects for shortages in critical materials and for extending their availability and developing substitutes.

OPENING REMARKS

In opening the workshop, **David Rejeski**, Director of the Technology and Innovation Program, stressed the importance of the issues being considered at the workshop for shaping a sustainable future. The possibility of a peaking and decline of Phosphorus production later in the century, for example, has huge implications for a global agricultural system highly dependent on artificial fertilizers made with phosphorus. Elements like neodymium and lithium are critical for the production of everything from wind turbines and electric vehicles to computers and cell phones. He challenged participants to dig below the surface to examine the geopolitical, environmental, social and economic issues related to critical resources.

Irving Mintzer, Chief Strategist for the Potomac Energy Fund, recalled the famous "Simon-Ehrlich Wager" in 1980. Julian Simon had Paul Ehrlich choose any five commodity metals. Simon bet that their prices would decrease over the decade ahead. Ehrlich bet they would increase. Ehrlich decisively lost the bet: every one of the metals he selected was less expensive by 1990. Despite forecasts of resource abundance winning so far, fear abounds today in the press and public about possible resource scarcities, hording by unfriendly nations, and negative impacts diminishing supplies of materials could have on technologies. Whether resource abundance or scarcity will dominate is not just a matter of geology; it depends on many other factors such as the role of policy and trade in supply and technical progress in recycling and developing substitutes. Our dependence on a wide range of resources is epitomized by General Electric, which uses 70 of the first 83 elements in its products.

HELIUM

DR. JOSEPH GLAZER – Crisis Management: USG Response to the ^{3}He Shortage

Helium was chosen an opening case study because it provides an example of a successful, multi-faceted response to a potential critical resource shortage.

^{3}He is used in many areas, from oil and gas exploration and medical imaging to cryogenics, reactor safeguards technology and portal monitors for national security applications. Russia and the US have been the major suppliers; however Russia stopped exporting in 2009. The US was selling ^{3}HE for $100 pee liter because it was priced by added cost, and the price was too low for other suppliers to compete. We were coming into a crisis situation where demand was increasing rapidly while supplies were diminishing, and no one had a clear picture of how much was left because NNSA produces isotopes and DOE sells them and there was a communications breakdown between them.

An aggressive strategy has been put in place to deal with the potential scarcity. The first part of the strategy is to decrease demand. Short and long term user needs were assessed and many users have recalculated their needs and come back with alternative strategies that have brought demand down by **orders of magnitude**. Approximately 30 research projects are underway across the US government aimed at developing alternative technologies, and the government has sponsored two Test Campaigns to test promising developments and encourage industry. Substantial progress is being made: GE, for example, has commercialized a boron lined technology for portal monitors that works as well as monitors using ^{3}HE. International cooperation to reduce demand is an important part of the strategy. Major international neutron scattering facilities are collaborating on the development of neutron detectors that do not rely on ^{3}HE and the US is working with the IAEA to promote alternatives to ^{3}HE detectors in safeguards applications.

The second part of the strategy is to increase supply. The US government initiated a vigorous international campaign to inform other nations about emerging shortages, and several countries that have potential ^{3}HE resources are now considering partnering with the US or developing their own internal capabilities for extracting naturally occurring ^{3}HE from natural gas or capturing it as a byproduct in commercial heavy-water nuclear reactors. Until recently, the ready and inexpensive supply of ^{3}HE from the US nuclear weapons program meant that these alternative sources were uneconomic, but policy changes and the current shortage have changed that, and market dynamics are acting to increase production.

The third element is recycling. The National Nuclear Security Administration Emergency Responder community has committed to providing up to 15% of their own demand through recycling, and the National Institute of Health has received a proposal to recover 91% of ^{3}HE from medical imaging.

As a result of these efforts, demand has decreased sharply, supply is increasing, and the market is being allowed to drive use, substitutions, and recycling.

PHOSPHORUS

JAMES ELSER - Phosphorus As A Critical Material

From a sustainability perspective there are two key aspects to the phosphorus issue. On the one hand, overuse of P is a a serious environmental problem because phosphorus is a pollutant that causes eutrophication and dead zones in water, like the dead zone in the Gulf of Mexico. On the other hand, phosphorus is potentially running out. Several recent analyses have suggested that global production could peak and begin to decline later in this century. 90% of phosphorus is used to make fertilizer for agriculture, which means that the global agricultural system is unsustainable and will fail to end hunger unless radically redesigned. Food security is a national security issue. As the price of phosphorus increases, food prices increase, and while this is a manageable problem in wealthier countries, it is a crisis in poor countries where people already spend over 50% of their income on food. Increasing food prices can cause unrest and protests and destabilize governments as we saw in 2008 when the price of phosphorus spiked. The high prices dropped after 2008 but spot prices of phosphate rock are climbing again.

There is considerable uncertainty about the global supply of phosphorus. Domestic production from mines in Florida is in decline and the U.S. is now a net importer for both domestic scarcity and economic reasons. Morocco and China have the largest supply, followed by South Africa, Jordan and the U.S. These five nations control 85% of the supply, which means they potentially have considerably more leverage over phosphorus prices than OPEC has over oil prices. China, which uses 36% of global fertilizer production, has already applied a 110% peak season export tax on fertilizer (starting in December 2010). The market has been nationalized by Morocco – is Morocco the next Dubai? Different estimates of when global phosphorus production could peak range to as soon as 2040. A new (2010) forecast adjustment by the IFDC estimates the "run out time" at approximately 300 to 400 years, but this is based on <u>current</u> production and use levels, and it is not known if all of this is truly producible at anything near today's costs and prices.

The future demand for phosphorus is also difficult to estimate. Currently 23 million metric tons are used for agriculture every year. Several factors will act to increase phosphorus demand. The biggest factor is the growth of the world population. Estimates indicate that to acieve global food security in 2050 food production will need to <u>double</u>. Growing affluence is another major factor because it leads to more meat eating, which in turn requires more intensive crop production. And the growing bioenergy industry could be important. Already, in 2009, 10% of the phosphate used in the U.S. was used for corn grown for ethanol. There are also growing non-agricultural uses. For example, the lithium-iron-phosphate batteries in an electric care contain 60 kg of phosphorus. A major limiting factor, however, is that many developed world soils are saturated with phosphorus. Because it has been over-applied in some regions, including China, its use can probably be scaled back while achieving equal or better yields.

High uncertainty about reserves, production and demand makes it difficult to predict how much phosphorus will be needed in the future and what the price will be in the future. We need better assessments, better analyses of the phosphate system, and better planning for various geopolitical scenarios. Despite the uncertainties, we know we need to close a number of institutional gaps and develop new technologies and strategies. Right now there is huge waste in nearly every aspect of the phosphorus cycle, from mining, and over-use in agriculture, to food spoilage waste treatment. “This is no way to run a biogeochemical cycle.”

In particular, animal waste phosphorus needs to be controlled. But in today’s agricultural system livestock aren’t near crops in many cases. We need to change the system in a way that gets manure to where it can be used and makes the manure more useful as fertilizer and for energy recovery. We may need to develop vertical integration within the livestock industry. It may even be possible to develop GMOs for more phosphorus-efficient livestock.

In Elser’s view, there is not an imminent supply shortage, and it should be relatively easy to prevent a shortage from occurring during the next 100 years. However, shortages could still come from political issues, and price increases could lead to serious social disruptions from food price spikes.

DR. IRVING MINTZER – Lithium: Challenges and Opportunities

Lithium’s current markets are for small scale (not vehicle scale) batteries (29%), additives for glass and ceramics (20%), greases and lubricants (13%) and for a variety of smaller applications such as air treatment, polymers, pharma, aluminum and construction. About 60% of applications are in Asia. Future market growth will be driven mainly by vehicle batteries.

China is currently the world’s largest supplier (34%) and the rest is provided by three companies: SQM, Chemetall and FMC. The resource base is quite large. South America’s continental brines are almost half of worldwide reserves, and the U.S. has significant reserves in the form of pegmatites, hectorites and geothermal brines.

A continuing lithium oversupply is likely between now and 2020. As a result, of 60+ lithium development projects currently in play, few will survive. If demand escalates more rapidly than expected due to rapid growth in electric vehicles, the resource is available to meet it. Nonetheless, non-economic considerations could lead to strategic surprises.

DR. ALBERT “KIP” DAVIS – Lithium

The traditional view is that there is plenty of lithium, because the reserve base is large, and there should be no supply constrains on the supply of batteries for electric vehicles or other potential uses. The alternative view is that there are a number of uncertainties. For example, the development of all liquid batteries for grid storage could use large amounts of lithium. Demand for the lithium-7 isotope for use in nuclear reactor coolants will grow as China increases its nuclear power supply. And environmental and social constraints may limit production.

In the short- and mid-term, the largest uncertainty is about the impacts of oversupply. The seemingly unstoppable supply growth will cause such huge overcapacity that the stability of the industry will be threatened. Existing lithium chemical producers have the capacity to meet nearly all market requirements by expanding capacity. The additional pipeline projects and expansions currently underway could increase production to double what the industry needs. Lithium carbonate prices fell precipitously in 2010 and will remain depressed. Low prices and fierce competition through at least 2020 is bad news for the new lithium project promoters.

In the longer term, there are uncertainties about how much of the resource base can actually be developed. Bolivia provides a case study on these uncertainties. It has the largest lithium resource base, but the per capita supply of fresh water in the country is declining and there is uncertainty whether enough fresh water will be available to exploit it all. Bolivia's Salar de Uyuni basin holds the largest concentration of lithium in the world, but it has a sensitive ecosystem heavily dependent on water resources. Many of Bolivia's deposits are lower quality, less concentrated than others, and contaminated with magnesium, which may limit exploitation. The press and public are sympathetic to the plight of the tribes whose lifestyle would be disrupted by lithium mining, which could deter investment.

There are fundamental strategic questions that need further study before we can assess the future of lithium with confidence. Besides vehicle batteries, what new demands for lithium will arise in the future? Given problems with water and the quality of its reserves, how much will Bolivia actually be able to develop those reserves? What are the "real," exploitable lithium reserves of the world? What technology will be needed to exploit them? What role will recycling and resuse play in the lithium supply chain?

NEODYMIUM

JACK LIFTON – Supply Projection Scenarios for Neodymium

TMR (Technology Metal Research) has developed scenarios of Neodymium supply and demand with an upper and lower demand projection and four supply projections based on both the annual increase in China's production rate and the pace of the roll out of new non-Chinese production. Currently 99.99% of Dy_2O_3 is produced in China, but the Chinese have announced that they do not plan to produce more than they can use, so non-Chinese production is beginning to ramp up. The scenarios suggest that short term shortages could extend out to 2016 if demand is high, Chinese production does not increase, and there are delays in the roll out of non-Chinese production.

KARL GSCHNEIDNER, JR. – Neodymium: Supply, Demand, Substitution and Recycling

The current demand for Neodymium is ~ 23 kton, and supply is tight – a slight shortage. The primary uses are for permanent magnets for electric motors (largest), computer hard drives (second largest), wind turbines, ceramics and glass, and lasers. Wind turbines are emerging as the new rapidly growing market: 50% growth per year is expected through 2015. This means that Kingsnorth's (2010) projection of 40 kton total demand in 2015 is too low by ~ 15 kton. Figuring in Molycorp's and Lynas' combined production, there is still a ~ 9-11 kton shortfall. Considering the potential use of Nd+Pr in permanent magnets, the shortfall is still about 8 kton.
There are three aspects of the rare earth/neodymium crisis. The first is the mining and production of mixed rare earth oxides (REO), the separation of individual rare earths, and metal preparation. Despite inevitable near-term shortages, there is light at the end of the tunnel. Molycorp started mining in January of this year at its Mountain Pass, CA mine and annual REO production is scheduled to increase from 5.2 ktons in 2011 to 20 in 2012 and 40 in 2013. Lynas' Mountain Weld mine in Australia also opened this year and its output is expected to grow from 2 ktons in 2011 to 22 ktons in 2013-14. Aside from increasing production, work is needed on substitution and replacement (difficult, but not impossible), recovering and recycling permanent magnets from computer hard drives, cell phones, etc., and redesigning products so it is easy and cost-effective to remove rare earth magnets from products at the end-of-life.

The second aspect of the crisis is further down the supply chain to the production of magnets, batteries, phosphors and catalysts and the manufacture of products such as electric motors, cell phones, monitors and fluorescent lamps. Here the issue is are we going to send the REOs we mine back to Southeast Asia, India and China for the manufacture of intermediate products and consumer products or are we going to do the manufacturing ourselves? To create businesses and jobs here, we need loan guarantees (e.g., H.R. 618 and 1388); companies need to fully automate; and companies need to vertically integrate or form alliances to cover the complete supply chain, from mining to products.

The third aspect of the crisis is the lack of intellectual infrastructure to train scientists, engineers, technicians and technical business managers. We need more people in key fields including chemistry and chemical engineering, materials science, physics and electrical engineering, and research funding from NSF, DOE, DOD and NIST. A key step is to create a university-based National Research Center for Rare Earths and Energy with links to industry and national laboratories and subsidiary branches at other universities.

CRITICAL MATERIALS OVERVIEW

DIANA BAUER – DOE's Critical Materials Strategy

Rare earth metals are not rare, they are found in many countries including the U.S., but over 95% of the rare earth supply currently comes from China due to low labor costs. They are critical for important energy applications such as wind generators and electric vehicle motors, Li-ion and NiMH vehicle batteries, thin film PV cells, and fluorescent lighting. Clean energy's share of total material use is currently small, but could grow significantly with increased deployment. For example, in 2010 16% of dysprosium demand was for clean energy, but by 2025 clean energy could account for as much as 62% of dysprosium use. Only 1% of the lithium used today is for clean energy application, but by 2025 that figure could go up to 50%.

In assessing the different rare earths, DOE used a measure, criticality, based on a methodology developed by the National Academy of Sciences. The measure combines two factors: importance to the clean energy economy and risk of supply disruption. Criticality was estimated for two time frames: short-term (0-5 years) and medium-term (5-15 years).

In the short term, the highest criticality rare earths are Dysprosium, Neodymium, Terbium and Yttrium. Near critical elements are Cerium, Lanthanum and Tellurium. In the medium-term the highest criticality elements are Dysprosium, Neodymium, Terbium, Europium and Yttrium. Near critical elements are Indium, Lithium and Tellurium.

Policy options for addressing the risks include R&D, information gathering, permitting for domestic production, providing financial assistance for domestic production and processing, building stockpiles, recycling, education and diplomacy. Some of these are within DOE's core competence, other's are not. DOE's current programs include a wide range research efforts related to these options, including basic research at the Ames Laboratory, EERE programs on alternatives to permanent magnets and motors and the ARPA-E program on nanocomposite permanent magnets with high energy product and less rare earths.

Five main conclusions emerged from this analysis:

1. Some of the materials studied are at significant risk of supply disruptions. Five rare earth metals (dysprosium, neodymium, terbium, europium and yttrium) as well as indium were assessed as most critical.

2. Clean energy's share of material use is currently small but could grow significantly with increased deployment.

3. Critical materials are often a small fraction of the total cost of clean energy technologies. As a result, demand does not respond quickly when prices increase.

4. Data on these is not well developed. More information is required.

5. Sound policies and strategic investments can reduce risks, especially in the medium- and long-term.

CONGRESSIONAL PERSPECTIVE

MARCIUS EXTAVOUR – for Senator Bingham

Senator Bingham is Chairman of the Senate Energy and Natural Resources Committee. His view is that the whole supply chain of critical materials needs to be considered in policy making. Ideas being discussed on the Hill include stockpiling, workforce training, extraction permitting, loan guarantees for processing, geological assessment, and supply chain collaboration internationally.

COLIN HAYES – for Senator Murkowski

Senator Murkowski's proposed bill focuses on the mining/supply side and applies to more than just rare earths. It asks the USGS to develop a methodology for determining which minerals are critical and to develop a list of critical elements. It provides funding to USGS to mine, dig and use all relevant and available technology to do a thorough resource assessment. It creates a working group on permitting to consolidate the permitting process on critical materials. And it authorizes R&D on developing substitutions and on recycling materials.

MODELS FOR MAKING PRODUCTION PROJECTIONS

ERIC SANDER – The Multi-Cycle Generalized Verhulst Model for Making Production Projections for Nonrenewable Resources

Hubbert Models have frequently been used to predict the growth, peaking and decline in the production of oil and other resources. Hubbert models are "symmetric" in the sense that they produce Bell curves where the rate and timing of decline are a mirror image of the growth curve in the extraction of the resource. However "asymmetric" models provide a much better fit with historical data, and the asymmetry is usually in one direction: the rate of decline is slower than the rate of growth. In 67 of 74 oil producing regions studied, the median rate of increase is 7.8% per year, while the median rate of decline is some 5% less at 2.6%. These data suggest that it is probable that future regions will have more gentle decline rates than rates of increase.

Hubbert models with only one full cycle (growth-peak-decline) can be reasonably good in situations where the production trend does not exhibit major fluctuations over time. However most worldwide oil producing countries display more than one production cycle. Production goes up and down as a result of many factors, reflecting the changing state-of-the-art in extraction technology and changes in government regulations, economic conditions, and political decision-making. In these situations, a multi-cycle Hubbert model produces more accurate projections.

To his knowledge, this is the first attempt to apply a multi-cycle model that is also an asymmetric (Verhulst) model to forecasting global production of conventional oil. The model uses estimates of Ultimately Recoverable Resources (URR) from a USGS 2000 petroleum assessment and world production data for conventional oil from DOE's Energy Information Administration and British Petroleum. Using this data, a four cycle generalized Verhulst model projects the year of "peak oil" to arrive sooner than forecast by a four cycle Hubbert model: 2016 using the USGS's mean URR estimate and 2019 using the USGS's optimistic estimate. However the four cycle Verhulst model portrays the production decline as significantly more gradual than the Hubbert model. In terms of society's ability to adjust to declining availability, the rate of decline is arguably a bigger factor than the exact timing of the peak.

He has also applied a two-cycle Verhulst model to Phosphorus. The peak was much further away (~ 2070), so there is no immediate crisis. Nevertheless, the actions needed to prevent shortages over the long run need to get underway in the generation ahead.

He cautions that reality is always more complicated than models. As George Edward Pelham said, "All models are wrong, but some are useful."

CROSSCUTTING DISCUSSION – RECYCLING AND RECOVERY

In an discussion that included all workshop attendees, participants were challenged to think across all the resources that have been discussed and identify the major barriers to recycling and recovery of resources. A wide range of barriers were identified in a brainstorming discussions, and then voting by a show of hands was used to identify the barriers participants saw as most important. The results of the voting are displayed in the box below.

Most Important Barriers to Recycling and Recovery	**Votes**	
Technical		20
Products not engineered to be recycles	12	
Infrastructure limitations	4	
Technology limitations	4	
Cultural		12

Psychological barriers	6	
Consumer motivations	4	
Time horizons (elections, bonuses…)	2	
Economic		8
Price of virgin vs. recycled materials	7	
Financial barriers (financing)	1	
Government		7
Government regulation	4	
Subsidies	2	
Unintended consequences of policies	1	

CROSSCUTTING DISCUSSION – DATA AND RESEARCH NEEDS

In this all-in discussion, participants were asked to consider what we need to know, what data are missing, and what research areas are most important to pursue. The results are displayed below.

Most Important Research Areas	**Votes**
Material flow analysis (USDA + EPA joint effort on phosphorus)	13
Resource evaluation – all critical resources	13
Broader systems analysis – systems flow, city workings, etc.	10
Education – of resource specialists, of public	7
Behavioral science/ influencing public opinion	7
Alternative energy	5
Materials in engineering efficiency	5
Basic research	5
Liquids/oil	1
Recycling	1
Functional design of materials	1
Biofuel + phosphorus (Dept. of Agriculture)	-
Changing from “recycle + reuse” to resource optimization	-
Recapture engineering	-

Workshop Planning Team

Anita Street, Department of Energy
David Rejeski, Woodrow Wilson Center
Todd Kuiken, Woodrow Wilson Center
Bob Olson, Institute for Alternative Futures

Workshop Facilitator

Bob Olson, Institute for Alternative Futures

Workshop Presenters

Diana Bauer, Department of Energy
Albert "Kip" Davis, Department of Energy, Office of Intelligence and Counterintelligence
James Elser, Arizona State University, School of Life Sciences
Marcius Extavour, Senate Committee on Energy and Natural Resources
Joseph Glaser, Department of Energy, National Nuclear Security Administration
Karl Gschneidner, Jr., Iowa State University and DOE Ames Laboratory
Colin Hayes, Senate Committee on Energy and Natural Resources
Jack Lifton, Technology Metals Research
Irving Mintzer, Chief Strategist, Potomac Energy Fund
Eric Sander, Department of Energy