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Global Mining and Materials Research Oral History Project

Alex King and the Critical Materials Institute: Challenges and Opportunities

Interviews conducted by
Paul Burnett
in 2014

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Alex King

Alex King has been the Director of the Critical Materials Institute at the Ames Laboratory since 2013, where he oversees innovation in the processing and recycling of rare-earth minerals, the development of substitute materials for these elements, and economic analysis of their global supply. He was previously the Director of the Ames Laboratory (U.S. Department of Energy), head of the School of Materials Engineering at Purdue University, and professor of materials science at SUNY Stony Brook.

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June 1, 2013 King steps down as director of Ames to run the Critical Minerals Institute — the 2011 DOE three-part Critical Minerals Strategy: source diversification, search for alternative materials, and efficient use and recycling — fourth aspect: basic research — bringing in Colorado School of Mines economist Rod Eggert — more on source diversification, improving extraction technology — reclaiming critical materials during fertilizer production — looking for new uses for relatively abundant rare earths — more on substitution — attempts to find a replacement for europium in lighting technology — rapidly-improving magnet technology — magnets in wind turbines — focus on efficient use of critical materials in magnet manufacture — recycling industrial magnets, challenges of removing magnets — creating financial incentives to recycle items containing critical materials

Cross-cutting research — the Critical Minerals Institute as a consortium of national labs, universities, corporations — the CMI culture, sense of importance of the work, fostering innovation — project planning — nondisclosure agreements — intellectual property considerations — balancing protection of intellectual property while ensuring the necessary flow of information — meeting to foster international cooperation in critical materials issues — tracking flow of critical materials production — improving recycling and efficient use — impacts of various critical materials policy acts — economic analysis and forecasting critical materials need — directorship of the CMI, learning curve

Global Mining and Materials Research Project

For over twenty years, the Regional Oral History Office (ROHO) produced in-depth oral histories of members of the mining community, under a project called "Western Mining in the Twentieth Century," which was overseen by Eleanor and Langan Swent, Douglas Fuerstenau and others. http://bancroft.berkeley.edu/ROHO/projects/mining/index.html The 104 interviews in the project covered the history of mining in the American Southwest, Mexico, South America, and Australia from the 1940s until the 1990s.

ROHO has recently changed its name to the Oral History Center of the Bancroft Library, and with that change we proudly announce a new project entitled “Global Mining and Materials Research,” which will focus on key transitions in technology, policy, and geopolitics that have brought mining to its current state worldwide.

Much has changed in mining industries in the years since the Western Mining project was in full production, including the increased globalization of mining operations, the decreasing concentration of mineable minerals in ore, increasingly complicated regulatory environments, new systems of environmental remediation, new technology for exploration, extraction, and processing, and new stories of political conflict and resolution. In addition to collecting interviews about mining engineering, metallurgy, and administration, we also hope to explore the history of information technology and data analysis with respect to mining, as well as the legal, regulatory, and policy history of the industries.

This interview was funded with support from the American Institute of Mining Engineers, Metallurgists, and Petroleum Engineers (AIME), the Society for Mining, Metallurgy, and Exploration (SME), the Association for Iron & Steel Technology (AIST), the Minerals, Metals, & Materials Society (TMS), and the Society of Petroleum Engineers (SPE). We are also collaborating with the IEEE to host these oral histories on the Engineering and Technology History Website, located here: http://ethw.org/Oral-History:List_of_all_Oral_Histories. Thanks also to former Western Mining Project Lead Eleanor Swent, Dr. Douglas Fuerstenau, and Noel Kirschenbaum for their advice and support while the Global Mining Project was being established. Finally, we are most grateful to Alex King for taking time out of a busy schedule to speak to us about the evolution of the mining industry over the past forty years.

Paul Burnett, Berkeley, CA, 2015

Interview #1 October 13, 2014
[Audio File 1]

01-00:00:00
Burnett: This is Paul Burnett interviewing Dr. Alex King for the mining project of the business series. We're at the Lawrence Convention Center in Pittsburgh, Pennsylvania at the Materials Science and Technology Conference. And it's October 13, 2014 and this is tape one. Dr. King, welcome.

01-00:00:28
King: Thank you.

01-00:00:30
Burnett: I attended your talk this morning. You gave one of the talks at the plenary session of this conference and it is on a topic that is very current, and in some sense it's urgent. Can you tell us a little bit about what some have called "the rare earths crisis?"

01-00:00:54
King: Yeah. I think "crisis" is a term that is widely used. We kind of try and avoid a little bit. But what happened in about 2010 is that the world was getting 97 percent of its rare earths from one place and that place was China. China announced that it was going to impose restrictions on exports of the rare earths. And there was a degree of concern, not to say panic, about that. So the prices started to rise. Governments started to ask questions of their technical advisors and concern rose to a high level. What happened in mid-2010 and early 2011 is prices for the rare earths spiked at levels of about 25 times their value prior to the first inklings of a crisis. They've subsided back since then but what came out of all of that was a recognition in a lot of places around the world, including the US government, that we need to be worried about materials for which we have no clear substitutes and for which we only have a single source, no matter where that source may be. So these materials are now called critical materials, and one of the outcomes of all this was the creation of the Critical Materials Institute, which I now have the job of directing.

01-00:02:50
Burnett: Right, right. It comes as perhaps a bit of a surprise that it was such a surprise. [laughter]

01-00:03:00
King: Yeah, unsurprising surprises are the hardest ones of all to deal with actually. But yeah.

01-00:03:10
Burnett: Well, just, were there Department of Defense departments or officials who were in charge of maintaining an understanding of global supplies, of critical elements?

01-00:03:23
King: Yeah, there is. There's what's called the Defense Logistics Agency which has the responsibility for making sure that the military in the US, or military of the US, probably, more correctly, has all of whatever it needs from food to boots to clothing, fuel, but fundamentally the materials to make things from. And every year the Defense Logistical Agency is required to make a report to Congress, reporting to Congress where they have concerns about supplies of any substance, material, whatever, for the coming twelve months. And usually the Defense Logistical Agency has reported that we have sufficient materials available to us for the next twelve months and that's all they really report. So it's a very narrow statement. When the Department of Energy started looking into critical materials, they started looking not at what we need for the next twelve months but what we expect will be the demand for materials five years and fifteen years out from the present, the present then being 2010, 2011. So they were projecting quite far into the future and projections that far into the future are not necessarily very reliable. But when they started making projections it became clear that there are more materials out there for which there are very few suppliers and for which we can project increased demand and where we have no clear-cut substitutes at the present time.

So they started compiling not so much a list but actually a diagram which I showed in the talk this morning where they plot the sort of essentialness of an element, if you like. How hard would it be to do without this element on the vertical axis and the question of how hard is it to get this element on the horizontal axis. It turns out that how hard it is to get an element is almost directly related to the number of sources. If there's only one you consider that to be very much at risk. If there's two sources it's still pretty highly at risk. Like iron, for instance, you have sources of iron ore all the way around the world. We don't think that's a high risk. So the risk axis is determined almost exclusively by number of sources. The need axis is determined pretty much by how special that material is for its particular purpose. So the rare earths show up as having a very high risk for supply disruption and also high essentiality, if you like that term, for a number of different clean-energy technologies. And, of course, the technologies the military are interested in are a bit different than the ones that the Department of Energy is interested in, although there's a fair amount of overlap, too.

01-00:07:06
Burnett: I imagine, I imagine. And I understand that in 2013 the Department of Defense announced a procurement of a stockpile of critical materials effectively.

01-00:07:20
King: Right. Yeah, they named a few different materials that they deemed sufficiently at risk that they wanted to take some actual action to assure the supply for the next twelve months. And among those was dysprosium, one of the rare-earth elements that happens also to be on our list. So there's some convergence of interest in that particular material. Yeah.

01-00:07:48
Burnett: And perhaps we should clarify, too, because the critical materials as they're defined under your mandate are not exactly the same as the thing named "rare earth element."

01-00:07:59
King: Right. Yeah. This is sometimes a little confusing. On almost everybody's list of critical materials today are several of the rare earth elements and people sort of refer generically to rare earth elements as being critical materials. They're not. Not all of the rare earths are critical materials. Not all of the critical materials are rare earths. But at the top of every list of critical materials that I have seen are several of the rare earths. So they're kind of the poster children for critical materials.

01-00:06:40
Burnett: Right. And I also have read that the term rare earth was coined back in the nineteenth century to define this group of elements that were at the time thought to be very rare but they're in fact not for the most part. But the question is extraction and separation. That's the key.

01-00:09:03
King: That's right. So I sometimes give a talk where I say they're neither rare nor are they earth. Aside from that the name's perfect. The better name is actually the lanthanides. It's technically accurate and correct. But yeah. The abundance of the rare earths, which is what fraction of all of the atoms in the crust of the earth are this particular element, that's broadly speaking what we mean by abundance. The abundance of the rare earths declines as you go from left to right across the periodic table. So from lanthanum and cerium, which are the lightest of the rare earths. There's as many atoms of those as there are things like nickel or copper. So not very rare at all. When you get across to the other end of the lanthanide series and you're looking at lutetium, which is among the heavy rare earths, then you're talking about stuff which is actually quite rare. The reason why they were called rare earths though is because they were initially very, very hard to separate from each other chemically. They have a peculiar sort of electron structure which effectively means they have nearly identical atomic radius at least from one to the next, going across the periodic table and they have nearly identical electronegativity, which means that the two things that a chemist can use to separate them do not work very well. The size of the atoms are the same. Their affinity for electrons or their affinity, therefore, for oxygen and hydrogen is basically the same. And so it was very, very hard to get them separated. And because it was so hard to get them separated nobody had very much of any of them. So, yeah, they were rare in the sense that nobody had any. But they're plentiful relatively speaking. They're not very concentrated anywhere. So if you talk about nickel or copper, which have comparable abundance to some of the rare earths, those are available in high concentrations. The rare earths you don't find such high concentrations anywhere.

01-00:11:38
Burnett: And you said that they were initially difficult to separate. Has there been progress in the last thirty or so years in this domain?

01-00:11:48
King: Well, in the last forty or fifty years, yes. We learned how to separate the rare earths shortly after the Second World War. We learned how to do it on an industrial scale after the end of the Second World War. And it's a tedious process. It's not trivial but it's well understood. We know how to do it. People have been doing it for a long, long time. But it's chemically fairly obnoxious.

01-00:12:28
Burnett: And energy intensive?

01-00:12:31
King: Yeah, it can be. So there are several stages, right. When you mine ore you basically dig rocks out of the ground and then you crush rocks and then you separate the powders into the stuff you want and the stuff you don't want, and that's as energy intensive as any other mining operation for a metal. It gets to be energy intensive when you dissolve the ore into acid, which is the first stage. Then you've got a mixed solution of all the rare earths more or less in oxide or ionic form. That's the point at which we separate rare earths from each other and that's done by a series of solvent extraction steps and it can take about 400 steps. Four hundred stages of—

01-00:13:26
Burnett: Four hundred stages.

01-00:13:27
King: —of solvent extraction. So you're basically mixing organic and inorganic phases together, shaking them up, then hoping that the rare earth you want dissolves preferentially in one or the other. It turns out they do under well-controlled circumstances but it's not very preferential. So you get a little bit of enrichment in one phase, a little bit of depletion in the other. So then you do it over again and again and again until you get enough enrichment that you can separate. So that takes a lot of time, a lot of chemicals, a lot of acids, a lot of volatile organic compounds. So a lot of opportunities for pollution. Then once you've got them separated you've still got rare earth oxides and converting oxides into metal is very energy intensive indeed. It's usually done electrolytically, meaning large amounts of electric current passing through baths of electrolyte and trying to plate out the material you want on one or another electrode.

01-00:14:44
Burnett: And so it is a difficult process. It's understood. It's a difficult process but it's quite energy intensive and, as you said, tedious from a mechanical or a chemical engineering perspective. But there's also an element of toxicity that is perhaps germane to the question of its production in the United States, for example. Could you talk a little bit about that?

01-00:15:11
King: Yeah. So the rare earths themselves are not considered highly toxic, with the exception of promethium, which doesn't exist in nature anyway. It's radioactive. But the others are not considered toxic. In fact, you can ingest quite large amounts of them and not have to worry about it, not that I recommend that. But what is toxic is the acids that are used and they're usually dissolved in sulfuric or hydrochloric acid at fairly high strengths and you don't want to be around those. And in the separations plant you always have large amounts of organic compounds, typically paraffin, frankly, kerosene, which is also not highly toxic. But there's a lot of it. It evaporates. But the biggest risk, frankly, is fire. These things are done in not very modern facilities and where there's a lot of kerosene around—people don't modernize the plant because it tends to burn down before they can get to that point.

01-00:16:38
Burnett: Really? [laughter]

01-00:16:40
King: Yeah.

01-00:16:44
Burnett: That's scary. So getting back to this question of the sort of geostrategic imbalance, if you will, and the fact that by the late 2000s the Chinese had cornered about 97 percent of the rare earths market. And back in the 1980s the United States produced a significant proportion of this, something like sixty or seventy percent.

01-00:17:16
King: Yeah. And, in fact, the seventies and eighties are referred to in rare-earth terms as the "Mountain Pass era" because there was a mine at Mountain Pass in California that actually produced the vast majority of the world's supply of rare earths, as much as was needed in those days. That plant closed down in I think 2002 and reopened in 2011 in the midst of the crisis, although the company, Molycorp, which owns and runs the mine, actually started work on reopening it before the rare earth crisis was in anybody's viewfinder. So they were working on it. They knew that there was a challenge because of all of the resources coming from China. But what happened in 2002, frankly, is the mine became unprofitable. And it became unprofitable for a number of reasons. There were challenges with meeting the environmental regulations. There was not, as far as I know, any particular regulation where somebody said, "You have to stop mining," but it was just the ongoing cost of meeting all the regulations was an added business expense. And Chinese production was ramping up and Chinese prices were going down. And Molycorp at that time could not mine rare earth and sell rare earths for the same price as the Chinese were and still make a profit. So they closed the mine and soon after that China basically owned the rare-earth world.

01-00:19:20
Burnett: Well, and it also seems that Molycorp or its predecessors, the Molybdenum Corporation, I don't know if that's exactly the same company, owned by the same people?

01-00:19:29
King: Yeah. So the name Molycorp has persisted through many owners. So at one point it was owned by Unocal, it was owned by Chevron and then a group of former Molycorp Chevron employees actually bought out the resource from Chevron and set out about trying to reopen the mine. When it closed I think it was under Chevron's ownership. This group of managers bought it from the company and then set it on the track to being reopened.

01-00:20:09
Burnett: And they had had some heat, I suppose, because there had been some pipeline or liner ruptures in the nineties, I think, that—

01-00:20:17
King: Yeah, there had been some acid spills, which is not a good thing to happen no matter where you are. It turns out it's in the desert between Las Vegas and Los Angles. It's a fairly barren spot but it's actually a very critical environment for a number of creatures, including the desert tortoise, which is endangered. You don't want to go around spilling acid in the desert tortoise environment. And one of the things they have done in reopening the mine is to work very, very hard on control of all of the chemicals used and in particular recycling all the water that's used in the mine.

01-00:21:07
Burnett: Right. And obviously the permitting went through with the EPA and they're fine with what has taken place?

01-00:21:13
King: Yeah. So the EPA and the California Environmental Protection Agency. And Molycorp is very careful to explain that that permitting process is tough and fair and they were happy to go through it.

01-00:21:37
Burnett: And so this is going to eventually ramp up to the point where it can produce—I think the statistic was like a quarter of the needed supply? Is that an ideal?

01-00:21:52
King: Yeah. So Project Phoenix, which is the name of this idea to bring back the mine, comes in two phases. One would get it up to around nineteen or twenty thousand tons of rare-earth oxide per year and the second phase would add almost as much again. So they'd be producing about 40,000 tons, thirty-six to forty thousand tons per year if both phases come online. They have commissioned phase one. It has been struggling to get up to the 19,000 tons a year but they announced actually in a press release that I saw just this morning that the final roadblock—they had a bottleneck in one part of the process that was really holding things up and they have added to their capacity in that part

of the plant and claim that they can now hit the 19,000 tons per year rate of production consistently and reliably. And they've hit it once or twice up to now but they're now confident they can hit it reliably. The question now is the price of rare earths has fallen back down and with all the glitches out of the system can they operate the plant at a low enough cost to stay alive.

01-00:23:35
Burnett: Is there any conversation with the federal government or the Department of Defense about an infant industry argument, about protecting rare earths until such time as the kinks are worked out and they can stand on their own two feet in the market?

01-00:23:52
King: Not as far as I'm aware. But there's an awful lot of stuff goes on behind the scenes.

01-00:23:58
Burnett: Well, they've committed $130 million to purchasing this stockpile. I suppose that's a start. And I imagine they're probably not going to purchase that from the Chinese.

01-00:24:09
King: I think they'll purchase it from wherever they can get it. Yeah.

01-00:23:12
Burnett: Right. Okay. And please tell me if I'm getting way beyond your area of expertise. There are several proximate causes for the—and I'm not going to use the word crisis—tensions surrounding the rare earth market imbalances in China and one story is about some geopolitical intrigue which I'll ask you to explain.

01-00:24:53
King: Sure.

01-00:24:53
Burnett: And then the other is about the Chinese themselves trying to reign in some of their domestic industries. So could you explain those two stories?

01-00:25:05
King: Yeah. There's a lot of things that are said and there are a lot of things that have happened and not everything that is said is the whole story or the complete truth. Not everything that's happened is reported completely accurately. So with that as background, when the premier of China was Deng Xiaoping, he is on record as having said that, "While the Middle East has oil, China has rare earths." And that was taken as a comment to indicate that they would use rare earths to exert political influence the same way that oil is used to exert political influence. The comment went without very much discussion for a while but people remembered it when the Senkaku fishing boat incident occurred back in 2010 where the Japanese Navy arrested a Chinese trawler for fishing in disputed territorial waters. This is not an uncommon event in the

East China Sea, but on this particular occasion, which was some months after the prices of rare earths had started to rise and some months after China had announced export restrictions. When the trawler captain was in custody in Japan, China announced that they would withhold any export of rare earths to Japan until such time as the trawler captain was released. And this was a serious threat because Japan is one of the biggest users of rare earth in its manufacturing industry. The rare earths are particularly used in making magnets. Magnets are used in making electronics. They’re also used in making hybrid cars and I think that Japan is determined that it will not lose its dominance in the hybrid vehicle area. So this was a very serious threat. It was a clear signal to the world that China was willing to use its ownership of rare earths to get what it wants diplomatically. Diplomatically may not be quite the right word in this case.

In the background of all that, when China started to restrict exports of rare earths, it was part of a pattern of behavior where they initially restricted the export of rare earth ore in favor of exporting refined metal, so, moving up the value chain a little bit. Then from exporting rare earth metal, they wanted to go to exporting finished magnets or finished metal alloys of whatever kind. And from there you could see the trajectory was, okay, now we’ve got you only seeing magnets. We want to export not magnets but—

01-00:28:50
Burnett: Finished?

01-00:28:54
King: —devices containing magnets and motors or generators or disc drives or whatever else. And then you can see how it goes on from there so that China becomes the manufacturer of everything that contains rare earths, not just the provider of rare earths. So there was some concern about losing downstream manufacturing after we lose access to the rare earths. And then at some point during all this, when the West was complaining about China’s export restrictions, China started telling us that the reason for the export restrictions is that we’re reducing production so that we can clean up some of the environmental issues with the rare earth mines. And the evidence is that they have been working on that. Whether that was the primary cause, however, opinions differ.

01-00:29:56
Burnett: But you do agree it seems that part of the story is that the Chinese corporations are essentially integrating vertically? They’re reaching back and they’re taking over different parts of the process from extraction to processing all the way to finished goods.

01-00:30:19
King: Right. I think taking over is maybe a slightly pejorative term. Let’s look at what else is happening in China. The growth in the world’s middle class, which I alluded to earlier in my talk, is driven right now almost exclusively by

China and its massive economic development. So the Chinese poverty, poorer classes in China, are vanishing as China becomes a more middle-class nation, becomes a manufacturing nation, provider to the rest of the world. What happens then, of course, is that all of those Chinese citizens who have more to their life than just tilling fields or planting rice want more goods and they want telephones and they start with electrically assisted bicycles and very quickly move to motor scooters and mopeds and quickly from there on to cars. So China wants to provide goods for its own people as well as providing for the rest of the world. And it's an interesting question whether they can actually produce enough rare earths or a number of other materials just to meet domestic demand as it booms. So it's not necessarily true that China really wants to eliminate manufacturing in the rest of the world but they want to be able to manufacture for their own population. And there may not be enough of some materials to meet the needs of China's growth and the rest of the world's continuing demand.

01-00:32:16
Burnett: There can be an element of xenophobia in this, right? There's a lot of China bashing in so many different domains and that's probably, as you've seen, it's just part of the story.

01-00:32:33
King: Right. I want you to be very careful about China bashing. Not everything is exactly as people portray it. China has its own needs. Any sovereign nation will strive to meet its own needs. That doesn't necessarily excuse all of the behavior but you have to understand why China is coming from, the incredible rate of economic growth that's going on there, which frankly could be a benefit to the rest of the world, too.

01-00:33:08
Burnett: Right, right. There were and perhaps are some political elements of this, of course.

01-00:33:19
King: Of course.

01-00:33:22
Burnett: But there is a larger and perhaps anterior question of supply chain management and a question of who is at the helm when we're thinking of developed nations that are market oriented. The great anecdote that you mentioned in your plenary session is that material scientists for the last thirty years have been trained to just deal with them as a question of chemistry and have not really been taught about where elements come from. So with that in mind can we talk a little bit about the response to develop the Critical Materials Institute and the mandate? To do that, could you give us a bit of the history of the Ames Laboratory? Because it wasn't a foregone conclusion that it would go to Ames.

01-00:34:24
King: Yeah, that’s right.

01-00:34:25
Burnett: Can you talk about the Ames Laboratory and your role in it so we’ll get a bit of Dr. King in this story, as well.

01-00:34:33
King: Okay, sure. So the roots of the Ames Lab were laid down as part of the Manhattan Project. There was a chemist working at what was then the Iowa State College in Ames, Iowa, named Frank Spedding and Spedding was a great separations chemist and was asked by Enrico Fermi to help the Manhattan Project with the separation of uranium. The story goes that he was specifically asked to come to Chicago and work in Fermi’s lab doing the separation and his response, somewhat paraphrased, I think, was, “Well, I’d be happy to work on separating uranium for you but I don’t want to leave Ames, Iowa,” which in his view was the greatest place on earth to live. And it really is a great place to live. But the short story is that a lab was set up on the campus of the Iowa State College in a wooden building and in that building they separated two thousand tons of uranium, unenriched uranium metal, which was all of it shipped in used whiskey casks to Fermi’s lab in Chicago. So that was the beginning.

At the end of the Second World War, after the success of the Manhattan Project and so on, the then Atomic Energy Commission decided that it had built this great resource through the Manhattan Project and it needed to do something with it. They came up with this idea of national labs. So the Ames Lab was established as a national lab in 1946 or ’47. I’m not sure I have the date right [1947]. But the lab was set up then. Frank Spedding was the founding director of the lab. The lab started to work on separating rare earths. That’s the very first step in how we got to where we are. So from that day forth we’ve really had a center of expertise and excellence in rare earth science. We separated the rare earths. We have the purest rare earths on the planet in one of the labs in one of their buildings and if anybody wants to do research on rare earths they either come to the Ames Lab to do it or they buy our material to do it in their own lab. So when a crisis emerged around rare earths there was an assumption that the Ames Lab would be part of the response.

01-00:37:36
Burnett: Were there other contenders? Are there other centers of excellence in the world for research in rare earths?

01-00:37:41
King: We are told that there’s a lot of research on rare earths going on in China but we don’t see very much of it. I think it’s more engineering level, mining, separations kinds of things. But as far as expertise in the rare earths, yeah, there are other places that do research on rare earths and with rare earths but

none that are quite so focused on rare earths themselves as the Ames Lab is. The lab in 2009/2010, when this was all starting up, had an annual budget of about thirty million dollars and at least one-third of that was going into research on or with rare earths. So it's unusual to have one-third of an entire national lab focused on anything quite that exclusively.

01-00:38:38
Burnett: And the Ames Lab also had a general broader mandate. A lot of the national labs did from the seventies on. Can you talk a little bit about that, as well.

01-00:38:48
King: Right. If you ask people at DOE headquarters about the Ames Lab, "Oh, yeah, materials lab. They invent materials." That indeed is what we do at the Ames Lab. We've invented a number of materials. You actually carry at least one of them around in your pocket. We invented the alternative to lead-tin solder, a lead-free solder that is used in all electronics today.

01-00:39:21
Burnett: Can you talk a little bit now about how Dr. King fits into this story? Your background, your area of expertise, the kind of career that you've had that led to leading the lab, the Materials Institute.

01-00:39:39
King: Yeah. So I had no background in rare earths before I came to the lab. People traditionally regard me as an electron microscopist, occasional modeler of materials. I've studied interfaces, grain boundaries, all sorts of things, at the kind of level of abstraction that is characterized by the textbooks that I badmouthed in my lecture this morning. So I had earned my doctorate at Oxford University. Almost immediately on completion of that came to the States as a post-doc at MIT. Got a faculty job at Stony Brook: State University of New York. Eighteen years there, including a small stint as an administrator, which turns out to have been kind of important in my career because that set me up for becoming the head of the School of Materials Engineering at Purdue University, which happened in 1999. I stayed there eight and a half years. Around 2008 I moved to the Ames Lab as the director of the lab and they were in a search for a new director and somehow identified me as a likely candidate. I interviewed, very ill-prepared, but they apparently forgave me for that. And I became the director of the lab. And then the rare-earth crisis started to show up maybe two or three years after I had arrived as the director of the lab and I corralled the team to help write the Ames Lab response to the crisis. And that response eventually became a proposal which involves not just the Ames Lab but three other national labs, seven universities, seven corporate partners, and we wrote the proposal in response to the funding opportunity announcement for critical materials that the DOE put out.

01-00:42:07
Burnett: Right. Can you talk about how the shortages were first reported or how the information circulated to you and the lab? How did you first find out about that?

01-00:42:26
King: Yeah. I actually first found out about it in the registration lobby of this very meeting [Materials Science & Technology Conference] about, I think, four years ago, in this very conference center. I was waiting for somebody who was supposed to meet me at some particular moment. And there were all these flyers out on tables in the lobby. I picked one up randomly and was reading it and it was some obscure report from some investment house that said, “China’s restricting rare earth exports and maybe people should watch this.” I said, “Well, I’m the director of the lab that knows more about rare earths than anyplace else on earth. Maybe we’d better watch this.” And, well, things then started happening at a fairly rapid pace. The first thing that happened was the House Space, Science, and Technology committee held a hearing on what was happening with rare earths when the price had literally doubled and they asked one of our scientists, Karl A. Gschneidner, who is very well-known in this field, incredibly eminent, probably knows more about rare earths than anybody has ever in the past or ever will in the future. But he was asked to testify and he dutifully came to Washington, sat in front of the whole committee, gave a statement and answered questions. And they sent him away. Well, they asked him one question in the meeting which was, “Well, Dr. Gschneidner, what do you think we should do about this?” And we prepared him for that. “Well, you’ve got to tell them that they need a research institute on rare earths,” which they do. We weren’t pushing or anything. But then they came back with another question that he wasn’t prepared for. And when you’re not prepared for a question they allow you to take it as a question for the record or QFR, meaning take that one home, think about it, and send us a response within seven days. And the question for the record was how much money should we fund this research center at. And so Karl and I discussed that. We didn’t have a particular budget in mind so we picked a number and said, “Well, twenty million dollars? That sound good?” And that was the number we submitted to the committee. A while later a line in the federal budget appeared to fund a Hub. Because Hubs were this new funding mechanism that Steven Chu was promoting, the secretary of energy, and they were around the value of twenty million dollars a year. So there was a line in the federal budget for a critical materials hub and it actually was five years funding for $120 million, or a bit over what we had suggested. But in between those we were pretty certain that there was going to be some kind of a program funded so we started building our team and getting ready for it.

01-00:46:06
Burnett: Right, right. It was not simply the doubling in price that led to the House committee.

01-00:46:16
King: No. I think it was more the concern that—maybe today it's rare earths; maybe tomorrow it will be something else. But there are all these things that our military uses. In fact, the military uses almost every element on the periodic table. The sense in the part of Congress, "We do not want to be caught without access to stuff we need." In open conversation it's about US manufacturing and that's a very important part of our security, having a healthy economy. But underlying the thoughts of some, I'm quite certain, is this question of "is our military in good enough shape?"

01-00:47:09
Burnett: When supplies are cut off, what do you do?

01-00:47:13
King: Right. You don't want to go to war with any particular country where you have to get many of your supplies from that country. It's not a good place to be.

01-00:47:22
Burnett: It's interesting because I remember *Harper's Magazine* about twenty years ago had a spread. It was almost like a centerfold. And the centerfold was an imagine of an M1/A1 Abrams tank and it had little bubbles around it for all the different materials that are not actually available in the United States and have to be sourced elsewhere. It's all the electronic components, assemblies, and so on. So there's been a buzz about, if not minerals, then strategic assemblies or strategic components of military parts. Is this, in a sense, the first real response that you've seen or is this part of a trajectory that has been evolving for a while?

01-00:48:12
King: Yeah, I have to say we're not directly involved with the military response in any tangible fashion. I occasionally meet with and talk with some of the people from the Defense Logistics Agency. So they know what we're doing. I know some of what they're doing. That's the nature of the business. I also meet and talk with people in the defense labs. We are by far the biggest effort on anything to do with the rare earths or actually critical materials in general. A lot of what we do involves international collaboration. So there's a trilateral working group on critical materials that involves the US, Japan, and the European Union, and all of the discussions in that group are at the unclassified level, so they're all about commercial manufacturing; they are not about manufacturing for defense needs. So we talk always in the open about commercial things. Is there such a thing about dual-use technology? Oh, you bet. So some of the things we do are almost certainly of interest to the military. I'm sure that one day there'll be a call about something or other that we've done and they'll say, "Is anybody making that?" And if we say, "Yeah, sure," then they'll say, "Who, where can I buy it?" And if we say no there might be other questions.

01-00:49:59
Burnett: Right. Right, right, right. And that's part of the process.

01-00:50:03
King: Yeah.

01-00:50:06
Burnett: From the press, Karl Gschneidner was framed as – he sounded the alarm. That's what happened in the press. He sounded the alarm of this crisis. So in a sense the Ames Lab got embroiled in part of the media excitement, let's say, around this. Is that something that you had to manage and be careful of? It sounds like, by the way you answer the questions here, that you're very adept at that.

01-00:50:39
King: We have to be quite careful about interactions with the media. You do not want to be in a position where by saying something unguarded or something that could be misinterpreted, you create another crisis or a run on any particular material. I always preface my comments, "I don't make predictions about the market, I don't comment on the viability of companies. I don't give tax advice. I don't give medical advice." Yeah, I'm just a scientist. All I do is worry about the science. But in fact everything I do is impacted by the geopolitics. I try not to over-interpret things I see. There's a very lively industry in commenting on what's going on in the rare-earth marketplace. People will sell you very costly subscriptions to information services to tell you things. I have various news alerts and I see people commenting about this and that. And some of it, well, not quite right and some of it, well, speculation or that's wishful thinking. And you have to sift through it all. But I try not to contribute to any of that. And, besides, there's an absolute rule that I don't talk to the press unless DOE knows ahead of time. And they carefully instruct me on what I may or may not say in any particular circumstance. And rightly so. They're there to help make sure that I don't precipitate a new crisis with a slip of the tongue.

01-00:52:34
Burnett: Especially with as much attention. It must be quite—

01-00:52:40
King: Yeah. It's very easy to be considered an expert. It's very easy to be misinterpreted as an expert, too.

01-00:52:49
Burnett: Right. Well, perhaps we should change the tape and talk more about the science—

[Audio File 2]

02-00:00:0
Burnett: This is Paul Burnett interviewing Dr. Alex King for the mining project of the business series and this is tape two and it is October 13, 2014. So we last left

off talking about the establishment of—well, your tenure as director of the Ames Lab from 2008 to 2013 and then January 1, 2013 you became director of—something like that—in the very beginning of 2013.

02-00:00:45
King: It was actually June 1st.

02-00:00:47
Burnett: June 1st. Okay.

02-00:00:48
King: So the award was announced very early in January of 2013 and it took about five months to negotiate all the terms. So when you get the phone call what you hear is, "Well, congratulations. You've won the competition. You've been awarded this $120 million." There's a sharp intake of breath as the reality sinks in and you think, "Oh, dear. Now we have to do it." But the next day you get a letter which says, "Congratulations. You have been awarded the right to negotiate for—" and so then there's a period of negotiation. But, yeah, six months later, June 1st, we formally kicked off and I stepped down from being the director of the Ames Lab to devote my attention full-time to starting up and running the Critical Materials Institute.

02-00:01:44
Burnett: And you had already begun thinking about it to some degree?

02-00:01:48
King: At that point we had spent a little over two years from starting to build the team and put the structure in place which, of course, was part of the proposal. And when the competition ended in late November of 2012 we sort of went into this stage of hibernation. We were just waiting for the outcome. After the announcement on—I think it was January 6th, we went into pretty high gear putting into place the staff, the number of necessary pieces. But we hit the ground running on June 1st.

02-00:02:31
Burnett: Right, right. And you mentioned that there was a DOE report in 2011?

02-00:02:39
King: That's right. The Critical Materials Strategy.

02-00:03:40
Burnett: Right. And I imagine the Ames Lab was involved in that.

02-00:02:45
King: Actually not nearly as much as we would have liked to have been. But it turns out that's a good thing because by not being part of it we had some plausible deniability. It didn't look as though we designed the whole thing. And the folks at DOE headquarters did a good job. They wrote a strategy. I might have changed a few dots and commas here and there through the document but the broad strokes of the strategy are very good. So the DOE suggested a strategy

in three pillars, the three pillars being: Source diversification. That is, if you can't get enough from the one place that supplies anything, find more places to get it from. The second pillar, which is almost counter to the first, is to find alternative materials. If you can't get enough of material A, find material B that does the same thing. And the third pillar of the strategy was just make do with what you have by being more careful about how you use it, meaning waste less during manufacturing, recycle what you waste, and recover at the end of life and recycle end-of-life products. So those are the three main pillars of the strategy. Not being entirely dumb, we wrote our proposal to mirror what DOE had always said it wanted to do. So we have a structure of research programs within CMI. Focus area one is called Source Diversification. Focus area number two is called Materials Substitution. Focus area number three deals with renewables—

02-00:04:56
Burnett: Efficiency.

02-00:04:57
King: —efficiency recycling, all those things. But we added a fourth focus area which has the task of serving the other three focus areas with basic science: knowledge that is needed for the more technical aspects of the first three. So regard focus area one, two and three as being highly technical, highly linked to industry, building things that industry wants, but focus area four is linked in the same way to focus areas one, two, and three, providing the underlying science, thermodynamic data, phase diagrams. Also environmental science to go with the things we're working on. So whenever we come up with a new process we check carefully to see if it produces any environmental toxins. There's another part in focus area four which is something I particularly like and I'm proud that we included and that is an economic analysis component where we are looking at supply chains, we're looking at models for predicting what materials may become critical in the future. We're looking at how we can better understand the existing supply chains, how we can collect data more efficiently to know where materials are being used and so on and so forth and how we can look at life-cycle analysis within all of that.

02-00:06:38
Burnett: And I'm assuming that the Ames Laboratory did not have a high number of economists?

02-00:06:47
King: I think you could say that we had zero and you wouldn't get any dispute on that. So in part of building the team for this we found that the Colorado School of Mines has, as you'd expect in a school of mines, they had a very good mining program but they also had a very good mineral economics program headed up by Rod Eggert. As we developed our research projects and we built our proposal, one of the tests that we put everything up against was, does this make economic sense? Is there a demand for it in industry? If we succeed with it will it have a significant impact on the total availability of rare

earths or is this a project that will solve a problem that has microgram impact in a kiloton kind of market. So the economic analysis and economic thought processes almost—I wouldn't claim that I've become a great economic analyst out of this but I've learned an awful lot from talking to the economists about ways to think about how much impact you're really having. So in the end Rod became the deputy director of the Critical Materials Institute. So I'm the director because, I suppose, people think that I have a lot of administrative and leadership experience. There is no such thing as enough administrative and leadership experience for these things. But I have a certain amount of technical experience in totally unrelated areas and Rod brings in the economics. And Karl Gschneidner serves as the chief scientific officer for the whole operation.

02-00:08:55
Burnett: Wow.

02-00:08:55
King: It's a really good team. I am really proud of the team actually.

02-00:09:00
Burnett: Yeah. And you got put onto the Colorado School of Mines—was it the suggestion of someone that—

02-00:09:07
King: No. It was one of these things where there were various efforts to put together reports on critical materials and the American Physical Society and the Materials Research Society both have public affairs programs and they joined forces and they said, "Well, let's do a report on critical materials." And actually, Rod Eggert was one of the members of that study, as was I, and as was Karl Gschneidner. And I think it was walking along 15th Street in Washington, DC one night between a committee meeting and trying to find dinner. We sort of persuaded each other that, yeah, if we joined forces, Colorado School of Mines and Ames Lab, would be pretty much unbeatable as the proposal was being developed.

02-00:10:02
Burnett: It sounds like it.

02-00:10:04
King: And then we had to convince the rest of the world, of course. [laughter]

02-00:10:07
Burnett: Right. Well, mineral economics at Colorado School of Mines is highly specialized and their analysis of doing all of the cost-accounting for exploration and how to take an operation that takes fifteen years before it's profitable, that's a very particular kind of economic knowledge and one would think that would be extremely germane to the kind of stuff that you're doing.

02-00:10:31
King: Right, exactly.

02-00:10:32
Burnett: Absolutely. So perhaps we could take each domain one at a time and talk about how you set it up and what kind of surprises have come along the way because I imagine there are some.

02-00:10:54
King: Yeah. One or two.

02-00:10:56
Burnett: And how things stand now in each of those domains. So starting with Source Diversification. Can you talk a little bit about that?

02-00:11:02
King: Yeah. And that one's perhaps the most complicated and difficult to explain. So the basic approach there has been we're not allowed to use our funds to support any single mine, miner, corporation, whatever. We're supposed to be developing technologies that enable any miner to operate and by virtue of developing technologies that make it more economical to operate a mine ,or some other way of getting these materials, then we make it possible for those people to get enough financing on their own. The whole idea is just generate technologies, let the market use them as they see fit. We have a few very specific areas of research. One is, I mentioned earlier, this problem of separating rare earths, where you have to have 400 mixer-settler stages to separate just the ones you want from a rare-earth mine. And anything that can be done to improve the separations process is really important. But it pays off big because if you increase the enrichment ratio—so I told you you have rare earths dissolved in acid, you mix it up with some organic and you hope some of the rare earths dissolve in the organic. If you can change the enrichment ratio by a small amount then the number of stages of enrichment that you need to reach a certain concentration goes down exponentially. It's not linear. So if you double the enrichment factor then you get a factor of ten improvement in the number of stages you need.

02-00:13:07
Burnett: Wow.

02-00:13:08
King: So, yeah, it's significant. So we've been working pretty hard on trying to find new chemical bonding agents that improve separation ratios. And we have some extremely promising results. We have in one case demonstrated a factor of two improvement in enrichment factor in the traditional mixer-settler type of enrichment. So that if that works across the board that means you go from 400 mixer-settler stages to forty. That means that the capital investment to build a separations plant goes down by a factor of ten. That should help a lot of miners.

02-00:13:54
Burnett: That's not an incremental change.

02-00:13:57
King: We think that's fairly revolutionary, yes. So that addresses traditional mining. Another one that we're looking at that actually uses the same underlying basic science is the question of froth flotation which is this really basic—

02-00:14:16
Burnett: And old, right?

02-00:14:17
King: —and old technology. Yeah. You grind up rock, you throw it in a vat of water and you blow bubbles through it and you hope the bubbles stick to either the valuable rock or the non-valuable. One floats to the top and the other sinks to the bottom. Well, it turns out that in rare-earth mines the efficiency of that process is only about 65 percent. So that means you collect 65 percent of the bastnasite ore that contains rare earths and the remaining 35 percent ends up in the tailings heap. Well, if you can improve on that 65 percent to, say, 75 percent, we're not even thinking about going to a hundred. But if you can get to 75 percent that means you've improved the yield of the mine by a sixth. That's huge. So it'd be another major step forward. What it amounts to is you have to find chemical bonding agents that stick to the bastnasite ore that you want to collect and also stick to air bubbles. And it's designing chemical ligands – bonding agents – that do those things. So those are two approaches to traditional mining.

We're also looking at non-traditional sources. So in the chemical fertilizer business, which is the largest-tonnage material producer of anything on this planet. They produce nine hundred million tons of fertilizer every year. Just throw it on the ground. Well, it's not just throw it on the ground, but that's basically what happens. But in that nine hundred million tons there exists as much rare earth as is currently produced from rare-earth mining. But it just flows through the process and it is included with the fertilizer at very low concentration. We are looking at ways to intervene in the fertilizer production process and extract rare earths, return the process flow to the fertilizer manufacturers at the same rate and temperature and acidity as we got it from them. And they can go ahead and make fertilizer but we've just sucked the rare earths out of the stuff—

02-00:16:51
Burnett: That's brilliant.

02-00:16:52
King: —before they get to it. And that's showing some promise. The other thing that we're doing in this area is kind of not intuitive. And that is that we are looking for new uses for some of the rare earths. The reason for this is that when you mine for rare earths you get all of the rare earths from cerium to lutetium in varying quantities. Mostly you get the light rare earths because nature produces light elements more than it produces heavy elements.

02-00:17:32
Burnett: Is that because they're so similar chemically?

02-00:17:34
King: Yeah. So it's exactly the same thing as, we find it hard to separate the rare earths; well, so does nature so it puts them all in the same place. So it's not that we're dumb that it's hard for us to separate rare earths. Nature can't do it either. So there they all are. And when you start separating them you get lots and lots of cerium and lots and lots of lanthanum and, in fact, more than 50 percent of a mine's production might be cerium and certainly, cerium plus lanthanum might be more than 50 percent. Then you get down to the neodymium, which is stuff you can really sell. But what we're doing is looking for new uses for cerium in particular, which is overproduced. We refer to materials that you have too much of or that you really want to get rid of as anacritical. They're not shortage materials but if you could get rid of them that would be really good, especially if you could sell them. So we're looking at a number of ways of using up cerium in other areas. There are some things that you can do with cerium in terms of alloying of other metals. It's used in some glass to absorb ultraviolent light. It's used as an abrasive. It has great potential, currently unrealized, as a catalyst in the production of polymers. So we're looking at a lot of those to see if we can find new uses for cerium. Because that adds to the value of a mine and that means the mine is therefore economically more viable. So not necessarily the most intuitive thing, but we're looking at the anacritical aspects of critical materials, too, in that. So that's focus area one.

02-00:19:42
Burnett: Because I think I misunderstood—oh, okay, sorry. The secondary is substitution. So you're going to talk about that. Okay.

02-00:19:53
King: Right. Substitution. So focus area two. Focus area one is, okay, let's find more places to get rare earth and focus area two, which is sort of in a sense completely at war with focus area one, although they're really good friends. There's no open hostilities. But focus area two is intended to completely relieve the world of the need to mine rare earths. So on one hand we're trying to make mining for rare earths cheaper and more efficient; on the other hand we're trying to make it go away completely. We just develop solutions and let the marketplace decide. But focus area two is looking specifically at the use of rare earths in two particular technologies. One is magnets and the other is lighting. I would say that I am convinced that we will have success in one of those. The one that we will have success in is lighting. Fluorescent tubes, when they're turned off they look white and that's because there is a white powder coated on the inside of the glass. What that white powder does is it converts ultraviolent light, which is produced inside the tube, into visible light which you can see and which lights us up even here today. The phosphor is made of some fairly complex oxide compounds which include europium, which produces red light, and terbium, which produces green light. And blue

comes along almost free for the ride. But with red, green, and blue you get what's called a tri-band phosphor and the lights that we're sitting under today actually produce red, green, and blue light in a carefully balanced mixture that is either a warm white or a cool white light. But the terbium and the europium, being heavy rare earths, are among the rarest of the rare earths. So the hunt is on for a phosphor that can produce red and green without using europium and terbium. And this is a big challenge. It was a major, major breakthrough in the 1960s when the red light production from europium was discovered and the first generation of color TVs, which had terrible color rendition, gave way to the second—what lasted throughout all cathode ray tubes until they went away and were replaced by flat panels. They all contained europium.

02-00:22:59
Burnett: And that's what Mountain Pass was for for the most part?

02-00:23:02
King: Originally, yeah.

02-00:23:04
Burnett: Coating on the inside?

02-00:23:05
King: Well, depending on who you talk to, yeah, it was for europium for TV tubes or it was for something called mischmetal, which is a mixture of praseodymium and neodymium which was used in lighter flints because people used to smoke more in those days. So a lot of its production went into lighter flint. But we are investigating a number of substitute materials for europium and terbium in phosphor applications, particularly for fluorescent lights, and we are getting very close to solutions for that. And we have an industrial partner. GE makes fluorescent lights. They're working very hard with us to test all of the solutions that we come up with. The only thing that can stop us is if LEDs take over from fluorescents before we get the job done.

02-00:24:08
Burnett: Well, so far fluorescents have it in terms of being a bit more appealing as a light source. No?

02-00:24:13
King: That's arguable right now. LEDs over the last year or so have improved radically in the color rendition, in the light production. I have some LED lamps in my kitchen that frankly are a little bit dull. But the ones you can buy today are much better. And the prices have dropped precipitously. So people will still make fluorescent tubes to replace the ones that are currently installed. New installations I think are going to shift over to LEDs. Originally when we started this we asked the lighting manufacturers when they thought that—because it was clear it was going to happen. We asked when they thought it would happen. They said, and this was just a year and a half ago, they said, "That'll be fifteen years at least." And I checked back in with them a few months ago. Said, "Well, could be next year." So one of the things you have

to deal with is change. Technological change happens really fast and it happens in a series of tipping points. It's not a smooth progression, okay. So we have to be agile like that. But I think we're coming close to some phosphors that will really work.

On magnets things are a little bit more difficult. The neodymium iron boron magnet is really a tough act to beat. But, interestingly, it was invented in response to the cobalt crisis of 1978. The best magnets in the world in 1978 were samarium-cobalt and everybody was worried about samarium because it's a rare-earth metal. But, in fact, it was cobalt that went into short supply because of political instability in Zaire. In response to that, in two labs independently, one in Japan, one at General Motors, General Motors research lab, people looked at samarium-cobalt and they said, "Well, samarium's a rare earth. Cobalt is a magnetic transition metal. Why don't we look at other mixtures of rare earths and transition metals and see if they perform." So they, among other things, looked at iron and neodymium, which turned out to be a winning combination. Then somebody added boron and there are various legends about whether that was by accident or that it was deliberate to try and make the stuff more processable. But the boron addition was the icing on the cake. So a formula of 2:14:1, two atoms of neodymium, fourteen atoms of iron, one atom of boron, is the strongest magnet that you can get per unit weight in the world today. And it's very tough to follow because what it does, it's really an iron magnet.

02-00:27:19
Burnett: That's been doped—

02-00:27:20
King: Most of the atoms in it are iron but the neodymium has this bizarre effect that nobody really understands yet, but it makes all of the magnetic moments of all the iron atoms line up and it's like the iron is really, really well-behaved when there's neodymium there. It's like mom and dad are in town. Shape up. Clean up your bedroom. But all the iron atoms are perfectly aligned. So you've got the best iron magnet you can possibly get. And there's not much you can do to get beyond that. But there's one thing that's really important. The behavior of the neodymium iron magnet declines as temperature goes up and it declines quite badly, actually. So people add dysprosium to it, which is another rare earth, heavy rare earth. It's about ten times the price of neodymium. And the dysprosium is put in and that helps the magnet to retain its strength as temperature rises. Magnets in power types of operations, so where you're converting power to electricity or electricity to power. So big motors or big generators, they get hot. The mechanical engineers try and constrain the temperature increase. In fact, they're limited to about 200 degrees Celsius. Not by anything very special. That's where the insulation melts on the wires. So okay. Two hundred Celsius is what they design to. And dysprosium is put into neodymium iron boron to get its performance acceptable at 200 Celsius. Dysprosium's very, very expensive. If you've got enough neodymium you

may not have enough dysprosium. So one of the things we're working on is reducing the amount of dysprosium that's needed in a magnet. And there's a lot of very clever approaches to that. So that's one of our areas of interest. And that involves a lot of very basic physics, actually. So that's partly by our fourth focus area.

We have one kind of, I'd say, the Hail Mary project in a sense. We are actually looking at trying to develop an alternative material, completely different material and it's going back to samarium-cobalt, which is still widely used. But trying to make the samarium-cobalt [magnet] perform at the level that neodymium-iron-boron performs. And you can do that by using an idea called a spring magnet where you actually have to mix very fine layers of very fine-scaled mixtures of a hard ferromagnet with a soft ferromagnet. It turns out that this has a particular ability to enhance the magnetic field of the hard magnet. The trouble with it is that it has to be done at the level of a few layers of atoms. So you need samarium-cobalt and a soft magnet phase layered one on top of the other in very, very fine scale. And getting it to that very fine scale is what's challenging. So we've been successful in making nanometer scale samarium-cobalt. We've been successful in coating it. Now we've got to be successful in joining it, sintering it together into a magnet.

02-00:31:19
Burnett: Wow. So scaling up is the next phase?

02-00:31:22
King: Yeah. Anything you do in nanotechnology—it's easy to make nano stuff. It's not so easy to make it at tonnage scales, which is what you really need.

02-00:31:35
Burnett: Right, right. So you're looking at finding different combinations of elements that can be used to make magnets that are as strong or even stronger perhaps as the elements that are favored right now?

02-00:31:50
King: Right.

02-00:31:51
Burnett: And when people say neodymium magnets they're basically talking about iron magnets that have a tiny bit of neodymium and bor—

02-00:31:59
King: Yeah. It's not that tiny. If you count the atoms, the neodymium atoms, they're definitely a minority. But neodymium's a fairly heavy atom so weight wise, I forget, I haven't done the math for a while, but the neodymium's about 30 percent of the mass of the magnet. So, yeah.

02-00:32:19
Burnett: Okay. Oh, right. Okay. Fair enough. I read that the neodymium, in some of the large wind turbines, the neodymium magnet assembly weighs a ton. Literally a ton.

02-00:32:28
King: Yeah, yeah. That's right. So the rule of thumb is five hundred kilograms of magnet per megawatt of power. So today's wind turbines, land-based wind turbines, are about two to two and a half megawatts. So about a ton of magnet if you used a magnet. The problem is that because that is so much neodymium, that most manufacturers don't do that. They would prefer to put in a lower powered magnet and increase the voltage by just increasing the speed of rotation by using a gearbox. Gearboxes unfortunately are prone to failure.

02-00:33:19
Burnett: Right. You showed us a slide in your presentation of a gearbox exploding, catching fire.

02-00:33:25
King: Yeah, right.

02-00:33:28
Burnett: And this is a failure. Like 33,000 wind turbines in the United States and only 233 have big neodymium magnets in them.

02-00:33:35
King: Yeah, right.

02-00:33:36
Burnett: So obviously if you can get the cost down the applications can increase and you can get wide adoption of new emerging technologies that are fuel efficient and can give us a different kind of energy mix. There are all these downstream consequences for these kinds of substitutions that you're talking about.

02-00:33:56
King: Right. And the next wave of wind energy is going to be larger wind turbines. So Siemens has announced a six-megawatt wind turbine and it's going to be offshore. So you really, really want a high reliability wind turbine when you go offshore. You do not want to be going out there in a boat or helicopter and you do not want to be having to lift a three-ton magnet up to the top of a three hundred meter tower in a gale because it just—

02-00:34:33
Burnett: Right. And the gale would tend to accompany the areas where wind turbines are used.

02-00:34:40
King: You put wind turbines where the wind blows. It's one of those catches that you just can't work around unfortunately. Yeah.

02-00:34:49
Burnett: Exactly, exactly. So there are substitutions in magnets, there are substitutions in lighting and there was a decision because those are the two most economically and environmentally promising areas or were there other areas that were on the table at some point?

02-00:35:08
King: It’s because they are for the respective materials. For magnets, neodymium and dysprosium magnets are the biggest single use of that material. So that’s the place where you can have, economically speaking, the biggest impact. For europium and terbium lighting is by far the biggest use of those materials. There are other uses but why would you start to develop a recipe for breadcrumbs if you were making loaves.

02-00:35:45
Burnett: Right, right. Of course.

02-00:35:49
Burnett: And so the third area, in very broad categories, is efficiency of production and efficiency of supply. So also recycling, as well. Can you talk about the efforts? These are trickier areas I understand.

02-00:36:06
King: They are very tricky. So what we’re talking about here is the best possible use of available supplies. And that means wasting less through manufacturing efficiency. When you make magnets, and you’re sitting there with the headphones on, you’ve got at least two neodymium-iron-boron magnets up close to your ears driving the loudspeakers. If you’ve got an iPhone you’ve probably got five or seven neodymium magnets in microphones and loudspeakers in the phone. When you make those tiny, tiny magnets what you generally do is you make big magnets and then cut them down into little magnets. And when you cut anything you produce sawdust or what’s called swarf technically. So there can be as much as 50 percent waste in making some of these things. And we’re looking at ways to cut down the waste by either not machining magnets, not cutting them down, but making them at the scale that they are wanted. And that’s not going to happen for the very, very small ones. But we’re looking at additive manufacturing of magnets as a way forward and additive manufacturing, a big hot topic these days. Lots of fun. So looking at additive manufacturing, which has some interesting advantages. Generally you can’t make a strong magnet that way but you can make it in the shape that you want it and that can compensate. So that’s one approach.

02-00:37:55
Burnett: And that would be essentially 3D printing, in the popular parlance? That’s what people are talking about?

02-00:38:01
King: Yeah, exactly.

02-00:38:02
Burnett: And you can make magnets using 3D-printing technologies?

02-00:38:05
King: Yeah. Already demonstrated that that’s possible. In another project we have found that most commercial magnets are not fully optimized. So we’ve taken magnets out of existing devices and we have a little process of our own where we can actually push up the magnet properties so that the magnet gets stronger or better properties of one kind or another. And we’ve shown that this is fairly consistent and we believe that if we can use that technology we can make magnets stronger. And if you can make them stronger then you need only have a smaller magnet. So that’s another efficiency. So these are on the manufacturing side.

On the recycling side we’re looking at what you can do with the sawdust that comes when you do cut magnets. And actually most manufacturers are already recycling that as much as they can. We think there may be a few tricks yet to play out in that. But the big one I think is post-use recycling. And there are lots and lots of challenges there. So we talk about neodymium-iron-boron magnets. They’re actually not just a chunk of neodymium-iron-boron that’s been magnetized. In many cases the magnets that are used in electronics, so the loudspeaker, the microphone, the motor magnets and the hard-disc drive are what’s called laminated magnets. So they make thin sheets of magnet material, layer them up with layers of glue and stick them together. So you’ve got lots of layers of glue in that. And then because neodymium and iron are prone to corrosion you have to protect them from the environment so they’re coated either in paint or in nickel or in a layer of copper and then a layer of nickel.

So if you want to capture that magnet and recycle it you have to find ways to dissolve the magnet material, which is sort of basic. We know how to do that. But you’ve also got to find ways to get around the nickel layer that’s typically on the surface, or the paint and all the glue which can be, depending on the manufacturer, almost anything. So there’s some interesting challenges in how we do that. And we’ve got a number of techniques for dissolving a magnet in whole or just certain components of magnets depending on what the design outcome is. A few techniques in that regard. Those are chemistry. I really annoy my chemist friends: “That’s just chemistry. It’s easy.” Because it’s not. But I love to say it just because you get the reaction.

But the really big challenges are collecting enough of whatever you want, whether it’s small motors from products like hair dryers and hand drills or air conditioning units, small appliances around the home. The biggest single use is hard disc drives in computers. But just collecting enough of those is by far the biggest economic barrier. You have to drive a truck from door to door. If people actually put them out for recycling, which they don’t—driving a truck around the neighborhood to pick up maybe two hard disc drives a day is not economical. And then once you've got them disassembling a hard disc drive is really hard. Have you ever tried to take one apart?

02-00:42:44
Burnett: In a moment of rage.

02-00:42:45
King: Yeah. We've all had that. But actually what we've come up with is sort of therapeutic to some extent. When people first started looking at hard disc drives and getting the magnets out of them, they talk about giving retired people screwdrivers and undoing the whole assembly. And then the Japanese came along with a machine that basically tumbles hard disc drives in what looks like a tumble dryer. Makes an awful lot of noise but it shakes the screws loose and then the case comes apart. And then they came up with this idea that that's a waste of time. What you really want to do is just take a big punch. If you know where the magnet is, it's usually in one of the four corners of the disc drive, you take a punch that's big enough, circular, and just punch it through and you punch out the magnet and then you throw away the rest of the disc drive. And that's kind of therapeutic. And then we said why make a circular cut? Why not just make a straight cut right across the corner? And so actually the way things are moving, simplify the process. So get away from having any machines, specialized. Just take this to a shear. You can actually put this on a foot-operated metal shear, put your hard disc drive on the shear, line it up, and just stamp down with your foot and the corner just falls off. So trying to get these things simplified to the extent possible so that disassembly is no longer as costly as it was. But still, collection of a wide diversity of different devices is really, really hard to do.

02-00:44:35
Burnett: It's true. There's a number of authors who have looked at the kind of disassembly lines in China where you have whole villages that are dedicated to one-by-one removing all the platinum, all of the – and it's extremely labor extensive.

02-00:44:57
King: And they get all the toxins, too.

02-00:44:59
Burnett: Of course. Yeah, yeah. This seems to be an area where the laboratory can contribute a great deal at the point of interaction with the device. But getting the devices there, it's part of a larger cultural and social system that has to be built essentially.

02-00:45:21
King: Right. And a lot of it is sociology in some sense or some level. So I'm just back from Japan where recycling is much more in people's mindsets. They do not fill their trashcans with all their garbage. They separate and recycle and electronics recycling is the accepted behavior in Japan. In the US the attitude is—I guess we call it landfills. What's the problem with those? Landfills are

not the best place to put these things. So one of the things we're doing is instead of trying to collect hard disc drives, going to where the hard disc drives are, which is data centers. What we refer to as the cloud is actually a brick and mortar.

02-00:46:24
Burnett: Yeah. It's a place.

02-00:46:25
King: It's a place and they buy and discard on the order of two or three hundred thousand hard disc drives per year. That solves the collection problem to some extent.

02-00:46:40
Burnett: Right, right. Going to the source.

02-00:46:43
King: What we're still trying to work around is the fact that data centers shred hard disc drives to protect data. And once you shredded it all the pieces of the magnet just stick to whatever metal is around and they're hard to recover. So we have a ways to go on that. But there's one bright spot. There's always a bright spot somewhere out there. We're also looking at recycling lamp phosphor. So we talked about replacing lamp phosphor with other materials. Fluorescent lamps are collected for recycling by law in this country because they contain mercury and we try and keep the mercury out of the environment. There is no financial advantage to recycling the mercury. In fact, the recyclers get paid by effectively a fee levied on the manufacturer or the seller of the lamp, depending on which state it's in. And they go around and collect lamps and extract the mercury from them. We're trying to get to the point where we can piggyback on that process to also collect the lamp phosphor from the inside of the glass and recycle for the europium and terbium and yttrium in there. And that's looking fairly attractive actually, working with some downstream recyclers on that. Again, the problem is still collection. Although it's required by law that you recycle your fluorescent lamps, most people throw them in the garbage. You're supposed to be able to take them back to a hardware store. There's supposed to be a collection box for them. I challenge you to find that in any hardware store in the US.

02-00:48:37
Burnett: I've tried. Yeah. Well, we can go back to this, I suppose. But I know that you have a mandate to do research and you have to be bounded and limited. But let's take for example the case of the data centers and your shear. So you know you have an old industrial device, a machine tool that just does this job with your foot. It could be as simple as making a report saying if you could require this of data centers and offer some kind of tax break to do so, put one of those in there and have somebody do that for their—

02-00:49:20
King: Yeah. That's okay. But in an ideal world we would like to be able to do this in a process that actually generates revenue for all parties involved. So the data center gets a few pennies per hard disc drive. They get assured that the data is being destroyed. But the recyclers can take the material from the hard disc drives, refine it, purify it, do whatever is needed to turn that back into a usable material, and they can make money selling that material. If you can get the economics of the process to that point then you don't need taxes, you don't need subsidies, you don't need legislation. And in the current climate in this country it's hard to get Congress to do anything but name a post office. Waiting for legislation is not really an attractive option. Let's do something that makes it cost effective without waiting for legislation. That's kind of where we're headed with it.

02-00:50:42
Burnett: So the Japanese solution of urban mining is something you'd like to develop in countries such as the United States but in a way that has the proper market incentives for different agents.

02-00:50:54
King: Right. So everybody can see a profit from it instead of seeing it as a cost.

02-00:51:02
Burnett: So that covers the first three that were suggested in the DOE report. Perhaps we'll change the tape and we'll talk about the fourth.

02-00:51:13
King: Okay. Go for it.

[Audio File 3]

03-00:00:30
Burnett: This is Paul Burnett interviewing Dr. Alex King for the mining project of the business series. It's October 13, 2014 and this is tape three. So, Dr. King, we were talking about the different categories of work being conducted at the Critical Materials Institute. And you talked about the first three that were in part proposed by the DOE in a 2011 report. And you and your team added a fourth category, which is in line, more in line with what the Ames Lab has always done, which is basic scientific research. Can you talk about how that fourth dimension helps the other three categories and the kind of work that's being done?

03-00:00:55
King: Yeah. So we refer to it as cross-cutting research. It's a nice catch-all term. I guess everybody uses it. But in our case it's kind of fundamental research on demand. So when one of our technical focus areas, the first three focus areas, is working on something, trying to find a way to extract rare earths from phosphate processing or something, almost always you run into a case where we don't understand how this ion or this ligand works in solution. We don't

have all the details of the thermodynamics of solution, of that phase, how it's affected by other things that are put in the solution. We just really need some basic thermodynamic models or basic thermodynamic data. So we have what we refer to as a thermodynamics team, which is actually a couple of different projects. One is aqueous thermodynamics and another is melt or pure metal alloy thermodynamics. And these guys are really, really good at determining thermodynamic data from computer models and also in terms of confirming those models with well-performed thorough experimental validations. So we have a team that can make measurements, make predictions, and go back and forth and find data very quickly. We can provide phase diagrams where they're not in the ASM handbook, which is the first resource you always turn to. We can check the accuracy of what's in the ASM handbook again by computation using off-the-shelf software like CALPHAD enhanced to deal with things like magnetic phases which behave a little differently. But we also have the capability to do experimental determinations of phase diagrams using what are called combinatoric methods, meaning you make arrays of specimens of different composition which can be done very rapidly in thin-film form. You can make a silicon wafer with composition gradients across it and then test different points on it for different properties. But that doesn't help with magnets so we have developed a tool that allows us to make little—

03-00:03:47
Burnett: Mini-magnets.

03-00:03:48
King: —micro-magnets. They're a few millimeters of controlled composition and we'll make maybe a thousand of them on a plate and we can take those to a facility at Stanford Synchrotron Radiation Lab where we can measure the composition, the structure, we can measure the magnetic properties, and we can do all that while we change the temperature up from room temperature to about eleven hundred Celsius. So we can simulate processing and measure phase diagrams as a function of composition and temperature. So anything where we need basic compositional data, thermodynamic data, we have a team that does all of that. Within the same area we have a team that is working on some very fundamental aspects of the electron structures of rare earth elements, particularly in the environment of a magnet or a phosphor. So the thing that characterizes the lanthanides or the rare earths is they have what's called 4f electrons. The 4f shell goes from having no electrons in it to being full as you cross the lanthanide series. The 4f electrons behave weirdly. They are not the outermost shell of electrons. They are one in from the outermost shell. But nobody has really paid much attention to physically modeling on a thorough quantum-mechanical basis how those electrons really behave and particularly how they behave in the presence of atoms surrounding them. So we have a team that works on that. And that helps us to predict magnet properties. And once you can predict magnetic properties you can maybe invent materials that may improve them, things like that. You also need that information for determining how rare earths respond to other

chemicals and that goes into developing separations agents. So there's a lot of basic, very basic science that goes into the work in focus area one, two, and to some extent focus area three.

03-00:06:03
Burnett: And you mentioned outsourcing to the synchrotron at SLAC.

03-00:06:11
King: At Stanford, yeah.

03-00:06:12
Burnett: And synchrotrons and cyclotrons are useful for materials science. Could you talk about cooperation with—because it's not just one-site where this work is done. Can you talk about the kind of structure of the CMI and who does what where?

03-00:06:30
King: Yeah.

03-00:06:31
Burnett: Well, maybe not in too much detail.

03-00:06:32
King: Well, not in too much detail. But, yeah. CMI is a consortium. It's headquartered by the Ames Lab and I directed—my office when I was around there is in Ames, Iowa. But we have a fairly large footprint of research being done at Ames, some being done at Oak Ridge National Lab, Lawrence Livermore National Lab, Idaho National Lab. A good bit being done at Colorado School of Mines, half a dozen other universities. And I hesitate to start listing them because I'll forget one and therefore offend somebody. And seven or so corporations, soon to be a lot more corporations. So it's very spread out and in every focus area, in every project we draw on the strengths, where the strengths really are. Because people are close together we don't try and get everybody to do what they need to do. We say, "Okay, if you really need that quantum-mechanical calculation we have somebody at Ames who can do it or somebody at Livermore who can do it. Which one's the best?" That's the person who will do it. So always pick the best person for the job and make sure you define the job right to start with because otherwise nothing works. So we're spread out. We're diversified in terms of location and expertise. And in some sense that's a strength. And in others it's a great challenge because you can't just walk down the hall to the guy you're collaborating with and say, "Hey, I did this on the back of an envelope. Does it make sense to you?" But we do have fairly sophisticated videoconferencing to link up our sites. And people are beginning to get used to using that instead of email. That's a culture shift frankly.

03-00:08:38
Burnett: Well, time and again people talk about cultures of innovation. The story over and over again is the importance of place to research and to innovation.

Whether it's the famed Chicago School of Economics hanging around the elevator. That's where all of the innovations happened. To other instances where scientists congregated in a certain place. So if you can talk a little bit about that.

03-00:09:04

King: Right. So when Steven Chu was the Secretary of Energy he came up with this idea, the energy innovation hubs, and he said it should be modeled after the Bell Labs in its heyday. And he had worked at Bell Labs so you didn't want to argue with him about that. And the idea was, in one description of it, really well-funded research groups, lots of expertise in different kinds all working in the same place and, in one version of it, eating in the same cafeteria. Apparently Chicago economics department it's the elevator lobby. At Bell Labs it revolves around food. I guess the cafeteria was good. We do not have a cafeteria. We do not often gather together. We do have a phenomenal number of conference calls, video conferences and stuff going on every week. But we still have managed to be very innovative. We will probably by the end of this week announce our twentieth invention disclosure. That's in fifteen months of actual operation.

It's hard to attribute that to any one thing but there are a number of things that have contributed to it. One is that very early on, after about three months, we went—DOE is constantly saying, "Well, what have you done? What have you done? What have you done?" We keep telling them, "Well, we all got to work on time this morning." Minor achievements like that that used to count for something. Well, after three months we said, "Well, we've got three invention disclosures. How's that?" They said, "That's pretty impressive in only three months work." And then after six months we had six. So someone said, "Well, you're going at one a month." And the word went back to our researchers that DOE really liked us having invention disclosures and it went the other way, from DOE apparently reported to Congress in some way, shape, or form that these guys are really producing a lot of invention disclosures. And then the next thing I know I am getting calls from people in the Senate appropriations committee saying, "Tell me something about all these inventions you've made." So positive feedback counts. Let's be absolutely clear about that. When people are told what you're doing is really important, you're on the right track, people respond.

Now, yes, you can produce endless numbers of invention disclosures if you want to. Right. It's very easy. But we're not writing trivial invention disclosures, or at least we're trying not to. The way we're getting a lot of invention disclosures, the big trick we have found, is finding out what our industrial partners really, really want. It's not that hard. The way most researchers think inventions go is, look, I have this great idea. I work on it in the lab, I do a little bit of modeling and theory and try and make some in the lab, make some measurements. If the measurements don't work I go back to the theory, revise that, go around that cycle and eventually I've got something that works. Then I take it to industry and I say, “Hey, look, isn’t this great?” Then they say, “Yeah. Not going to use it but it’s cool.” We worked the other way. We listen to what industry wants and then go backwards and say, “Okay, how would we meet that need.” And if we can’t meet that need, well, what basic science do we need and that goes back to our fourth focus area. But it’s always directed to a specific need.

And what we’ve found is that when we start our projects, we’ve been trying to roadmap them. So, okay, if you want to develop this, whatever this might be, you know you’re going to spend some time doing theoretical modeling, maybe more, maybe less depending on the project. You’re going to have a few candidate materials and at some point you’re going to down-select. So you say, okay, in the roadmap this is a decision point. Critical decision has to be made here. Maybe nothing works and then we cut off that project, it’s gone. But what we’ve found is that knowing when your critical decisions are being made is really, really important because the industry that needs that material is working in sort of another plane and they’re developing a product and they’re making critical decisions about, okay, what material are we going to make this product from and they’re going to make that critical decision at this point in their roadmap. If you’re not ready with your material when they make that decision you might as well sort of be inventing and then throwing it over the wall and seeing what will take. But if you are cognizant of when they will make their decision and if you can present a solution ahead of that decision, then you are in the innovation business. If you’re just inventing stuff and throwing it over the wall, that’s great but that’s what they call the valley of death. And we prefer the roadmap of life. So you kind of follow your roadmap to where there’s a bridge across the valley of death instead of reaching the fence.

Road-mapping our projects is really, really, really important and so part of our economic analysis group is actually devoted to the road-mapping of the research and constantly reviewing the roadmaps. Making sure we’re on the roadmap, maybe making sure we’re not straying off it and making sure that our roadmap matches the industry roadmaps.

03-00:15:34
Burnett: Right. Well, it sounds like it’s not just mapping. It’s also flagging and signaling. So you are communicating with outside partners or is it more industry-wide in the sense that those who stand to benefit from this technology are aware and they’re following you.

03-00:15:56
King: Right. Yeah. So we take it and put wherever we can get it. But we get the most from our existing partners who have all signed a massive non-disclosure agreement with us and are therefore comfortable with sharing information that they might not want to share beyond the group. So the quality of information goes up as you get closer to people. But still, even without that, when we were

writing our proposal I spent lots and lots of time just going and talking to people in industry, saying, “What’s your biggest fear in terms of materials supply chain?” and listening to what they had to say.

At our annual meeting, which took place a few weeks ago, where we actually gather everybody onsite and they can all talk to each other, decide what they’re going to do next hopefully—we had a great meeting. But one of the things I did was laid out what I had observed of the way the group works. And it’s sort of a set of what in industry or in corporate culture they call the “corporate value statement.” I hesitate to use those terms. But it’s things that we have started doing by no design, just by instinct or because of who the group of people is. But the first thing on my list, I think there’s seven or eight value statements or “this is how we work” statements, the first thing is we listen. And if you don’t listen, yeah, you can do great research and it will maybe have a one-in-a-thousand chance of generating an actual product one day, but if you listen to what industry really wants, and if industry listens to what their clients really want, then you have a chance of producing something that’s of value. So all of the twenty or so invention disclosures we have so far are responses to requests that industry has come to us with. They’re not things that we have just gone out there and said, “Hey, isn’t this cool?” They’re all responses. And that’s the biggest single issue.

03-00:18:21
Burnett: And by definition that means that they’re not just idle disclosures where you could just say, “We discovered something,” but it was a discovery that is a response to a need that was identified?

03-00:18:31
King: Yeah. But in some cases it’s close enough to what the industry wants. In some cases they say, “Yeah, I know we said that but times change.” And that’s okay because times do change and you have to be agile. But if there’s any one thing we have discovered from an innovation perspective it’s the value of listening.

03-00:19:01
Burnett: Well, I want to ask one follow-up question with respect to the non-disclosure agreements. Intellectual property. There’s an increasing trend of industry-university partnerships, including public universities, and there’s an office of technology policy for every university and they work out all kinds of materials transfer arrangements. Do you have those kinds of—so if there’s non-disclosure, how does that work when this becomes a product?

03-00:19:33
King: Right. So, yeah, we have a master non-disclosure agreement, an intellectual property management plan, and everybody who comes into the Critical Materials Institute as any kind of a partner has to sign those plans. And it took forever for the lawyers of the first set of partners to agree. Seven industries, four national labs, seven universities, lord knows how many lawyers. Shakespeare had it right when he said, “First, kill all the lawyers.”

03-00:20:08
Burnett: [laughter] We'll edit that one out or attribute it solely to Shakespeare.

03-00:20:11
King: Yeah. [laughter] They're all there to protect the interests of their clients. And the problem is that there's a little bit more bias toward protecting the interests of the clients than promoting the progress of the science. So we've had very long discussions with lawyers. And then in the middle of this, somewhere, some lawyer leaves an office or gets replaced by somebody else and basically you start all over again because every lawyer looks at every contract slightly differently. And there's one company I would dearly love to bring into CMI and their lawyers are absolutely opposed to one clause in our management plan that every other company has signed onto. We're not going to go back and renegotiate it with every other company. So it's kind of reached the point of, "It's take it or leave it, guys. If you really want to be part of this, you can be part of this. If you just want to talk to us on a non-protected basis, we still want to talk to you."

03-00:21:33
Burnett: Right, right. And during that process, what kind of case for science did you make in saying—because in the past sociologists of science have said this is how science works and there's communalism or communism but there has to be a free flow of information for it to work at all. And if you want that level of innovation you have to buy in. Did you make a case for a certain kind of transparency and openness?

03-00:22:09
King: We didn't have a hard time making that case. It's sort of out there. Everybody knows that if you want science to proceed there has to be a free flow of information at some stage. The harder part was actually not having free flow of information within the group, it's how do you protect the information once it's in the wild inside the group? We've got 250 researchers fully or partly on payroll and they're also engaged in research on other things and some of them work at the Ames Lab and they report to me but the vast majority report to somebody else in some other institution. How do I discipline that group and prevent them from letting the information that they learned through CMI leak into a partnership they may have with some other project that they're working on outside of CMI? So a lot of the contentious issues were not how do we encourage free flow but how do we put fences around it. How do we set up a hard disc drive that our researchers can access but nobody else can and how do we manage that? So lots of challenges. Yeah.

03-00:23:29
Burnett: Yeah, yeah. And for the seven industry partners so far, it's just information? It's conversations? Or is there investment?

03-00:23:41
King: Some of them are investing significant sums. We're actually paying at least one of them to do some of the research. So GE has a wonderful research

facility in upstate New York and we're paying them to do some research that we need to get done. And the deal is if we use federal funds to pay for that research then the results are all in the public domain. Okay, so GE gets to see where it's headed before everybody else, obviously, but once it's done it's done and it's out there and anybody else can license it.

03-00:24:23
Burnett: Right, right. This is at the national level and these are global companies. But the cooperation and coordination is part of the trilateral Critical Materials Institute. Could you talk about what's happening in those other countries and how the work is coordinated or whether it's coordinated?

03-00:24:52
King: Yeah. Okay. If you think it's hard to build a twenty-five-million-dollar-a-year thing with, what is it, seventeen or eighteen partners and 250 researchers, just try getting two nations to talk to each other. But early on, after the onset of the so-called critical materials crisis, there were some fairly informal meetings at governmental administrative level type of level between Japan, the US, and the European Union saying, "This is a global problem. It affects everybody. What can we do to help?" And there was an informal meeting in California way back that was followed by—it's been basically an annual meeting. Actually, Ames Lab hosted the last one the first week of September. So the first one was in Washington, DC. Second one was in Tokyo, third one was in Brussels, and the fourth one was in Ames, Iowa. So that's an interesting set of locations. But what it actually reflects is that in Washington it was very high-levels of government, not elected officials but administration officials came together and talked about, okay, this is the set of problems that we see in the US and this is the set of problems that the Europeans see and this is the set the Japans see and all listening to each other. When it got to Japan it was a little bit more, okay, where are the overlaps and we're still kind of talking at each other. When we got to Brussels a bit more than a year ago there was a sense of, okay, we see the overlaps. Where can we come together and collaborate? And when we got together in Ames a month ago it was, okay, how do we get these people working together now.

And they're interesting challenges. And then there are observers come in every now and again. So the Canadians and the Australians have been invited. South Africans in one meeting. There's an interesting diversity of needs. Japan is entirely a user nation. They have no resources of rare earths. They get their resources from elsewhere in the world but they are a great manufacturing nation and they use a lot of the world's rare-earth resources in building things that we all love to have. Europe has virtually no rare earth sources. There's a small mine in Russia that feeds a refining plant in Estonia. Maybe some of that goes into Europe. But Europe is also manufacturing intensive but it's a different kind of manufacturing. In Japan they make a lot of things that use magnets. In Europe they make a lot of things that use light sensors and light emitters. The US is interesting because it's both a rare-earth producer and also a manufacturer using rare earths. Australia is a rare earth producer, not much of a manufacturer, frankly. Canada is hoping to be a rare earth producer, less so a manufacturer. So there's always differing interests.

The places where we share mutual concerns are in the tracking of the flow of materials. So what we call materials-flow analysis. Who knows where all the rare earth is coming from, where it's going to, can we tell how much is flowing into a particular nation, how much if flowing out of that nation, are they stockpiling the rest or are they just wasting it? What's going on? So all these are important questions. And because there's no open market for rare earths all trades are basically—I call up a supplier and make an offer and they say, "Nah, you need to give me 10 percent more. Ten percent." But it's all done in the dark, as it were. So it's hard-to-track trading. So there's a lot of effort in that area. In CMI we believe that we have a great deal to learn from the Japanese in terms of recycling technologies so we're working with them to learn more and we're trying to help out because after you recycle you have to separate and we have good separation science. With the EU they have some great downstream recycling capabilities so that probably the post-recycling separation of metals is done better by a couple of European companies than anywhere else, so we're trying to get engaged with them to help us out on that.

In terms of magnets, we are collaborating with the Japanese. So the development of alternative materials, better understanding, better processing of magnets, both the US and Japan are collaborating very closely together. So a lot of bilateral kind of things have come out of this. Very few truly trilateral agenda except the data-collection side of it. So these are the things we're doing.

So it's taken a long time, first establishing there's a political will to collaboration, determining what each other can do, what our strengths and weaknesses are, what we're willing to share with other countries, what we're not willing to share. And it's like building the company collaborations we have already but at the next highest level up. If I collaborate with Japan, how do I know that information isn't going to be diffused to some other places that we don't want it to go?

03-00:31:58
Burnett: Right, right. So one of the things that is now running its way through Congress, if it hasn't already done so, is the Critical Minerals policy act.

03-00:32:12
King: Yeah.

03-00:32:14
Burnett: How does that impact your work or the CMI's work at all, if at all?

03-00:32:20

King: So actually there have been several acts proposed in both the House and the Senate and some of them don't affect me at all. Some of them affect us quite profoundly and there's one in the House right now, which is the one I think you refer to, which actually contains within its language what's called an authorization of the Critical Materials Institute. And this gets into the workings of Washington pretty deeply. So, usually a federal program is authorized by a committee, like in this case the Space, Science, and Technology Committee, but an authorization says this is something that Congress would like to do. It doesn't happen unless there is an appropriation for it. So authorizations say this is what we want to do. Appropriations committee says, yeah, this one we'll do. We'll provide funds for it. The Critical Materials Institute didn't work quite that way. We were appropriated. The funds were given to the Department of Energy to create CMI but it was never authorized. And you don't have to have an authorization to have an appropriation. But if you have an authorization and actually the authorization describes all the things the Critical Materials Institute is supposed to be doing, then those activities appear in the federal budget whether or not the president or the executive branch put them in its budget request. So they get in the debate and the appropriations committee acts on them or not. It depends. But one of the nice things that the authorization does is it lasts beyond the current funding appropriation for CMI. So it gives us a little bit more extension of life, if you like. So that bit I like.

There are other things in the bill that have no impact on me directly. They deal with things like speeding up the approval process for the permitting of a mine, for example, and one of the big challenges with starting up a new mine is the length of time it takes to get permits issued because all the time that you spend doing that—you're a start-up company trying to open a mine—is burning through cash and you can only get so much cash invested and if you burn through it all while you're still trying to get permits then you're never going to open a mine. So speeding up the permitting process consistent with checking that all of the right actions have been taken and the environment's been protected, that the financing hasn't been laundered, all those things are important. But not letting it sit on somebody's desk six months just because it says, "You shall act in six months." Those things are important.

There's other things in there about maintaining a list of critical materials. My only concern with that is that when the government maintains a list it tends to be slow to change. The process needs to be agile. Because as we've seen, materials become critical or not so critical in a very short timeframe. And if the government list says, "These are the critical materials," and that's cast in stone for five years, if we have a crisis in two years, I have to deal with material X or Y and I go to the government and say, "I'm working on XY," and they say, "That's not on the list. You can't do that." That's potentially a problem. I don't think that will happen. I certainly addressed those concerns with the committee and they said, "No, that's not the intention." Your intention is good but the language in the law is what will be interpreted when the people who wrote it are gone away. So you have to be very careful what's written into laws.

03-00:37:02
Burnett: Well, in the fourth category of the work that's done in CMI, the subset of that is the economic analysis. Does that or could that potentially serve as a kind of economic intelligence unit for the development of new material supply chains?

03-00:37:20
King: Yes, absolutely. So one of the things we're trying to do is provide a bit more foresight on what materials are likely to be critical. We don't call it forecasting because nobody can do that. Or if I could I wouldn't be selling it to the government. I'd be selling it where I could make much more money on that. But we get questions from industry every now and again of the flavor of, "Look, we're thinking of introducing a product that contains X amount of element Y. And we think the market for this is so many units per year. What do you think that would do to the material supply chain?" And in some cases it's, "Well, that's hardly a blip on the supply chain for that material." In other cases that will significantly perturb the market in that material, you could cause a disruption in the market. If speculation follows disruption, then prices can go up. So we don't say this will happen but we provide scenario modeling. And I think that that has tremendous value and provides some interesting guidance to companies that come to us with those questions.

03-00:38:44
Burnett: And presumably to the government, as well, to make them aware of what could be happening.

03-00:38:49
King: Yeah, right. Of course.

03-00:38:53
Burnett: So in this interview we've talked about so many different domains, so many different areas of expertise. Can you talk a little bit about the learning curve for Dr. King and what you expected when you started and how things have turned out so far.

03-00:39:17
King: So we are the fifth energy innovation hub that DOE created and this was a great experiment on the part of Steven Chu. I sometimes tell people we are the fifth of four because there are four left now. One other one was dismantled because it wasn't performing as an energy innovation hub. And there were leadership issues that led to the demise of the energy-efficient buildings hub. It's still there at a much reduced level, still trying to invent new ways to make buildings more efficient but it's no longer considered an energy innovation hub. So I spent a lot of time talking with the other hub directors about what's worked for them, what hasn't worked for them. But perhaps the better source of information was the DOE managers of those hubs because it's relatively

easy for me to listen to what those DOE managers say about the other hubs and hear what they really mean. It's very hard for a hub director to hear what his manager says and not see it in a context that kind of fogs or distorts the message. So coming in as the last of the five hubs I could see how messages get distorted between managers and directors. And so one of the things I set out to do is establish a very open line of communication with our DOE managers, and not just the immediate manager who I have, is great—but two, three, four layers up the structure in DOE. And I've had great interactions with those guys. I can pick up the phone and talk to them at any time. They don't hesitate to pick up the phone and tell me what they need from me. But having them trust me to deliver what they want and having me able to trust them and understand what they're trying—because they never quite say exactly what they mean. But being able to interpret what they mean has been very important. Having been a national lab director before I was a hub director – and none of the other hub directors have had that experience – but having been a national lab director first was really an important learning experience. So it got me a long way up that learning curve before we started.

03-00:42:20
Burnett: Well, I want to thank you for your time and I wish you the best of continued success.

03-00:42:27
King: Thanks.

03-00:42:28
Burnett: It sounds like it has been a runaway success so far and—

03-00:42:31
King: Well, we like to portray it that way. So if we can maintain the illusion we're okay.

03-00:42:37
Burnett: Excellent. All right. Thanks very much.

03-00:42:39
King: Yeah, great. Thank you.

[End of Interview]