Rare Earth Elements Podcast - Davin Bagdonas

[00:00:00] **Bridget Scanlon:** I'm pleased to welcome Davin Bagdonas to the podcast. Davin is a senior research professional at the Center for Economic Geology Research at the University of Wyoming. And his research focuses a lot recently on **rare earth elements**, and particularly in **coal** and other materials. And we first started collaborating a few years ago through a Department of Energy core CM Project Carbon, or Rare Earth Critical Mineral Project.

Thank you so much Davin for taking part in the podcast.

[00:00:31] **Davin Bagdonas:** Thank you, Bridget, for having me. It's a pleasure to continue collaborating with you this time on a podcast.

[00:00:37] **Bridget Scanlon:** So Davin, Wyoming has been in the news a lot recently about the **Brook Mine** and the rare earth element potential in that mine. And I think Secretary Wright was talking to the media about the potential for rare earth element production. I saw an older article from the Wall Street Journal talking about **2 million coal mine that might hold a 37 billion treasure**. So, maybe you can tell us a little bit about the Brook mine and what the resources look like.

[00:01:06] **Davin Bagdonas:** Yeah, I can say some things. I haven't directly partnered with the Brook operation, but a lot of the preliminary work that went into that site was done by a colleague at NETL. It was one of the sites that helped us develop new methods for assessing critical minerals, rare earth elements especially in coal sediment systems.

So it was one of the **test sites,** some of the core realizing that in fact some of these critical mineral occurrences in coal sediment systems are, now a recognizable or describable **ore body** of sorts. So it was a critical piece of the puzzle there. Having worked across **Powder River Basin of Wyoming**, where the Brook mine is, looking at a number of sites there, it is an interesting basin. And it is a, I would say, a **unique coal** in terms of not only the critical minerals occurrence with rare earth elements but where they **occur in the coal** and some of the **major oxides**, things like **calcium** that seem to be anomalous there too. So it's somewhat of a unique geologic system.

[00:02:09] **Bridget Scanlon:** Right. And I was just looking at different reports about it and seeing they mentioned maybe about **1.5 million tons of rare earths** with about **500 parts per million total rare earths** on an ash basis. And also seeing **65%** of the **critical mineral oxides**, ranging from 300 to 400 parts per million.

So that's, pretty large resource considering that we use about **8,000 tons of rare earth oxides annually**. And I guess some of the reports were talking about **China** having **restrictions** on **exports.** We are so dependent on China for rare earths. And then they imposed restrictions in April of **seven different rare earth elements i**ncluding some that are used for **permanent magnets**, dysprosium, terbium, and also very important ones like scandium and yttrium And I think I also saw mention of other elements in addition to the rare earths, gallium and germanium, and having quite sizable fractions of those. Any thoughts on the range of rare earth elements?

[00:03:14] **Davin Bagdonas:** I think it's important to not only talk about the range, but the occurrence of the individual species or the ratio of the rare earths in not only the Brook Mine, but other powder river basin mines that we've researched to date over the past several years. When you look at the occurrence of rare earth elements in these coal systems in the Powder river basin, it's noticeable that the **middle to heavy rare earths** are fairly enriched.

If we use a traditional metric of looking at critical rare earth, those are mostly middle to heavy rare earths compared to the lights, you're looking around **35%** 36% on average to numbers all the way up into **60, 70%.** Comparing that to a traditional rare earth mine like **mountain pass**, those traditional deposits tend to be heavily enriched in **light rare earths**. We often call those excess rare earth because they're lower value. They're producing such high numbers in traditional rare earth ore bodies that, although you're paying to extract them through the whole process, you're paying to produce things of low value.

So it's, a net loss or at least dinging your overhead over the operation. In the **coals**, like the **Brooks** and the others in the **PRB**, those lighter elements, those lighter rare earth are less concentrated. Things like **germanium, gallium all add antimony** to the argument here co-occur. That's not always the case in coals. But if we start to consider not just rare earth, but other critical minerals it becomes a very interesting deposit. And again, not just the brook, but all across the Powder River basin. Again, it's a, appears to be a fairly unique coal system in terms of critical minerals occurrence.

[00:04:58] **Bridget Scanlon:** Right. And the work that you did with Scott Montrose at **NETL** on the Brook, using the Brook data as an example, you guys developed a **conceptual model** of how the rare earths might become **concentrated** at the **margins of the coal seams**. And coming up from **beneath**.

Could you describe that a little bit, Davin?

[00:05:19] **Davin Bagdonas:** Yeah, and Scott's a valued colleague. We've brainstormed a lot over the years in the coal science part of this. I will caution, neither of us is a coal scientist. So this has been an interesting process. Backgrounds in igneous systems, igneous geology. But I think knowing that's where traditional ore bodies occur, generally for rare earths, taking that knowledge into coal systems was a big step.

So the **methodology** we had kind of developed and work on, the **Brook Mine** was one of those sites. Scott has much more experience there than I do. I was working at other coal mines using similar methods, developing similar methods. We were starting to see the same thing on the **boundaries of these coal seams.**

So the very **top** and the very **bottom**, we are starting to see significant concentrations of the rare earth elements. So we've loosely coined that **a bounding enrichment**. Previous authors had referred to it as the **near coal boundary**. So it's, not a completely new finding, but it's new in terms of defining an ore body now in a coal sediment system, which hadn't been done before.

So those bounding enrichments are certainly where the **geochemical** activity is taking place. The sortation of the rare earth elements, the **concentration** of metals, the big activity seems to be right on the edge of the coal seam.

[00:06:35] **Bridget Scanlon:** Right. And the **Powder River Basin** is a really famous coal production area in the US I think accounts for about **40% of US coal production**. And then you export it all over the US to different power plants. And the coal from the Powder River Basin is known for having **low ash content**. You mentioned earlier **5%** or so or less. And so when people present the rare earth concentrations on an **ash basis**, then on a **coal basis,** then they might be much lower, if the ash fraction is so low. So I guess if we had a hundred parts per million rare earth elements, total rare earth elements, and we had 10% ash, so if you present that, if the a hundred per parts per million is on an ash basis, then that would be 10 parts per million on a whole rock basis. And I guess it also depends how they **extract** the rare earths. I mean, if you burn coal. And like you've done a lot of work on coal ash. The coal ash is left behind. Then the **rare earths concentrate** in that, so then it seems appropriate then to talk about it on an ash basis.

[00:07:43] **Davin Bagdonas:** And those are really important points for all of us working in critical minerals and coal space. Unfortunately, not everyone presents data as an **ash basis or a coal basis** number. Sometimes it's hard to determine what that overall concentration is that they're presenting, but you're right, the example of a 100 ppm ash number for a 10% ash is actually a 10 ppm geologic material.

So if we're comparing the **coal to a granite** or any other lithology, apples to apples, we would want to take our numbers and put them in a **coal basis** value set. But the reason we ash the material, there's a couple reasons. One, the methods for assessing trace elements in coal. If you have like a powder river basin coal, where 5% of that coal is the mineral content, 95% is carbon and oxygen in those things in the coal molecule. You can't directly analyze that through **ICP methods**, modern state-of-the-art methods. So we have to **ash** it first, that's a **USGS standard procedure,** and we end up with this leftover mineral content in the ash, which we analyze through ICP. It also provides us a pathway to better compare directly the mineral content itself.

So if we're comparing where the rare earths occur in the mineral content of a coal, we can take that number and compare it to a traditional **ore body** where again, the rare earths are occurring within **mineral phases**. And it's also directly comparable to **power station waste** where through the thermal production process, you're creating an ash but it's a cautionary tale. When we present data for these coals and some concentrations we see in the **PRB** are **4,000, 5,000 ppm total rare earths**, you have to also in that spreadsheet have an **ash percent** for each of those samples so we can back calculate. Extraction does matter.

There are a lot of things we can do with coal and the coal molecule. Where if we have a 5% ash coal, 95% still is usable. So **co-production**, we may be able to produce a carbon based material, generate a waste stream, and then that concentration, that 5% mineral content becomes your extractable waste stream for the rare earth.

So it has meaning, but we have to be careful in how we talk about it and how we report it.

[00:10:08] **Bridget Scanlon:** And you are right. I mean, when I was talking to **Nolan Theaker** about the coals in the **Williston Basin**, so it seemed like they're planning on extracting the rare earths directly from the coal because the rare earths are associated with the organic phase in the coal there. And so, presenting the numbers on a whole rock basis or a coal basis seems appropriate there.

And it just depends how they will **extract the rare earths** from the **Powder River basin**. And if they're at the **margins of the cold seam**, how much of other mineral material. Are they associated with the **organics** or are they associated with the mineral fraction?

I mean, do you think these are like the **lignite** or do you think this is different. This is **sub-bituminous coal** so the rare earths are associated with the mineral phase. Is that correct?

[00:10:53] **Davin Bagdonas:** It's a really good question and I'll take one step back. When we look at these resources, and this is a really important note you made me think of, it's not just **concentration**. It's the volume of **accessible critical mineral**, in this case, rare earths and the **extractability**. What phase, what mineral phase are they in?

The **North Dakota** example is a good one. These are **bound organically**, for the most part, to a **lignite**. Therefore, they're very **easily extracted.** It's a feasibly **economic** process.

So in the **Powder River Basin**, our coals are not that great. If you want to burn it for power station use, they're fantastic, but they're **not a high grade coal**, they're a sub bituminous c and we do see coals, I would describe as lignite.

So we think we've done some preliminary testing. We think the rare earth are bound in a **multi-phase group** in those boundaries. So certainly **organic** contribution. There are some low temperature **authigenic phosphatic minerals**. And then there are probably some, so **clays** and other related things.

So the rare earths are not existing in refractory minerals for the most part, at least in the majority of PRB materials we see. So in theory, **extractability** should be fairly easy. Some preliminary tests with weak acids have shown mobilization directly from the coal. The **School of Energy Resources,** where I'm located, also has processes they're working on upscaling to demonstration where we manipulate the **carbon and oxygen**, the coal molecules themselves for other things, **building** materials, carbon materials.

And then we have the leftover for rare earth extraction. So some of those processes to liberate the carbon actually benefit the rare earth extraction. So in terms of concentration, not that great, but **volume and extractability** are pretty positive.

[00:12:53] **Bridget Scanlon:** And you also mentioned having other critical minerals like **gallium and germanium** and others. And I know **Department of Defense** is very interested, I think, in **gallium** and **scandium**. And so having those also is a real plus. And so you have also worked on the **Green River**

and Wind River basins those coals as part of the Department of Energy, Carbon Ore, Rare Earth, Critical Mineral Project. (CORE-CM Project)

Maybe you can describe those resources, Davin.

[00:13:25] **Davin Bagdonas:** Yeah, that's a great comparison. I was the principal investigator for the **Green River Basin Wind River Basin CORE-CM phase one**. That was one of two projects we had at the University of Wyoming. It provided a great contrast to Powder River Basin coals, PRB coals being a **terrestrial** closed basin system.

The **Green River** Basin coals are a **marine** system very different coals. They completely **lack calcium.** They're a little bit higher grade, **bituminous** coals for the most part. They're **older**. A lot have undergone a significant events in the life of the coal through **Laramide orogenic events** in the basin building. There's **faults**. A lot of the coal seams are separated with large non coal sediment packages. So **sandstones**, shales things that can or cannot contribute to fluids, water minerals elements traversing the system and being deposited.

There were a lot of lessons learned. Some of the grids we did to sample **Green River Basin** coals that we took from Powder River Basin didn't really work at first. We weren't finding interesting occurrences of rare earth elements. And I'm glad you brought up **Germanium and Gallium**. One of the lessons learned the Critical Minerals list does change and emphasis on different elements is frustratingly quick sometimes. So we weren't actually looking for germanium and gallium in a lot of samples early on or **lithium** or other things like that. Luckily, we were able to re-sample a lot of locations in Green River Basin and we started to notice these elements, critical minerals occur in the **near coal boundary**, the boundary enrichment, but rather than in the coal itself, like the PRB. We see them in the **non coal sediment**. So **carb shale clay rich** portions immediately adjacent to the coal.

So presumably the coal is still serving as a bit of a **filter** and eh pH boundary, but we're seeing the activity for the mineral host more so in the **clays** than the coals themselves. there's probably some differences there in coal grade. Overall chemistry host ability. There's a lot of factors there.

Interestingly, a lot of the time the rare earths are not the most interesting in Green River Basin. We found c**obalt, nickel, chromium, lithium** things like that. **Iron** in iron rich phases, and then in the clay species as well. So a little bit different animal there. It took us a lot of time to figure that one out actually.

[00:15:54] **Bridget Scanlon:** And what sort of levels of total rare earths were you finding in the samples there in the Green River or Wind River basins.

[00:16:02] **Davin Bagdonas:** That's a great question. We did see **600 all the way up to 1800 ppm** total rare earths. Those were in **higher ash materials** a lot of the time. So if we're looking at a clay, that may be a 60% ash number, which is quite different than Powder River Basin. And then some just don't have an ash number.

Some were just true clay samples, especially where we found some **lithium**. There were pyritic horizons. So we have iron and sulfide species that had quite a bit of **nickel**, for example. So a pretty different system and different concentrations, but also a different ash percentage.

Another reason to attach that ash percent to our data.

[00:16:42] **Bridget Scanlon:** And you mentioned earlier in the **brook** mine that you may have **40% to 60% heavy rare earth elements**. What was it like in these other basins, the Green River or Wind River?

[00:16:54] **Davin Bagdonas:** For rare earth elements we had a, what I would call a more traditional ratio, we were **richer on the lights**. That being said some of the testing our friends at Colorado School of Mines had done on the **pyrite rich coals**, did find good extraction of **neodymium**. I want to say **dysprosium** and then they had **nickel and cobalt** come out of those pyrites as well.

So they weren't the best in terms of ratio for heavies, for like Department of Defense use. But in terms of some of the energy rare earths and some of the co-produced other metals of interest, it was a good result.

[00:17:31] **Bridget Scanlon:** And reading the paper that you co-authored with Scott Montrose and the Brook mine being one of the examples. And in the recent literature, they're saying **1.5 million tons of rare earth**. So they have a geologic model then to estimate and to interpolate and extrapolate from the samples and stuff.

And you mentioned in the **Green River and Wind River** that it's an older coal and there's a lot of faulting and others, so it would probably be much more difficult to estimate the rare element **reserves** there, even though there's more interest in other things, but just because it's geologically more complex.

Can you describe little bit the geologic model that they used at the **Brook Mine** or the methodology that they used to develop the reserve estimates.

[00:18:19] **Davin Bagdonas:** Yeah. I don't actually know the exact step-by-step methodology they adopted, but it is a **greenfield**, or was a greenfield site, meaning it hadn't been previously explored for rare earth elements as an ore body. So typically you'll go in, begin to recognize, through selective sampling, locations of interest.

And as you get **geochemical** data back, you start to gain an understanding of extent and occurrence. Which coal seams are more interesting. And develop, essentially apply a **grid**. So, the methods we utilize, you start to pull **coal core** and incrementally sample the core first in a larger grid both in depth and across the mine site and then in more refined intervals.

And that really provides you a robust data set to start and model extent of an ore body. So at that site you'd have **rare earth elements, germanium, gallium, scandium,** some of the other things of interest, and you'd start to associate those on a specific location. In terms of taking those numbers and generating **economic forecast,** that's a, quite honestly a big and brave step.

That requires a significant amount of data. You need, both an **average** and a **modal distribution** of those elements of interest, within a fairly well constrained grid across your mine sites. So I was not party to that at the Brooks site, but to achieve an economic number, you have to produce a lot of samples.

I know they did produce a lot of samples. That's really the hurdle we face in a lot of locations with these coal-based resources. **Green River Basin**, for example, we hadn't done much work there until Core-CM started, so we only have **three or four years** of understanding there. It's very **preliminary**.

We do have locations in **Powder River Basin**. We've worked for a decade there including Core CM where we're beginning to approach sample density and statistical relevance in the dataset to make those predictions **economically**. But it's a big step honestly.

[00:20:26] **Bridget Scanlon:** Right. And we had done very little in the Gulf Coast also, I mean, we were probably more like your Green River Wind River project. We just started with the Department of Energy Core CM program, and so we have limited data whereas, I guess you guys at the Powder River Basin and then Nolan Theaker and others, and North Dakota have a much longer track record and a lot more data to develop an understanding of the distribution of rare earth and other critical minerals.

So Davin, I first became aware of your work with the **coal ash** and since, the Powder River Basin supplies about **40% of US coal** and exports it to many other regions. So, Powder River Basin coal ash is all over the US. So there's a lot of interest in understanding what is the potential for extracting rare earths from coal ash deposits.

So can you describe your work with **the coal ash** then in the **Powder River Basin**?

[00:21:28] **Davin Bagdonas:** Yeah, I can do that and provide a quick summary of how I got here. It's actually what first landed me a job here at **School of Energy Resources.** So I completed graduate school. I studied a **granite**. Again, where some of the traditional rare earth elements occurrences are, I studied **uranium** provenance minerals.

That expertise led me to a job here where they were beginning to survey **power station waste** for **rare earth elements.** So this is 10 years ago. I actually had very little expectation to find anything interesting, but it was a great opportunity to apply my skills and we did. We began to survey power station waste across the state of Wyoming.

So **Green River Basin and Powder River Basin** in two different coal systems, provided great contrast. And sure enough, a very interesting result occurred. We noticed vast differences in the chemistry and in some locations in the Powder River Basin. Some nuance differences in the rare earth element concentrations that suggested the **coal systems** themselves need to be looked at.

So we expanded that work with assistance from **National Energy Technology Lab**. We really provided some assistance to them in starting to expand this look at coal. But it really does tie back to that original glance at the power station waste. And to this day, we've continued to survey those materials, tie them back to the **feedstock coals**.

And now in support of National Energy Technology Lab, there is a **pilot facility** that was being stood up in the **Powder River Basin** to utilize those waste streams from power stations locally.

[00:23:01] **Bridget Scanlon:** Right. And as I recall from one of your papers in renewable and sustainable energy resources, the **coal ash**, the average concentration may be around **300 parts per million** in the coal ash. So one aspect of course is the **concentration**. And so the average concentration in continental crust is about **180 parts per million**. But then the other aspect that you mentioned is how readily **extractable** are the rare earths. How easy is it to extract the rare earths? And so you are finding then from working with the coal ash is that the extractability was pretty high.

Can you talk about that a little bit?

[00:23:40] **Davin Bagdonas:** Yes, absolutely. And that was something early on we realized here at School of Energy Resources. And at the same time, luckily some very smart people were realizing this at National Energy Technology Lab and elsewhere. There are other references, but **calcic materials** are famous in the geologic record for **readily weathering**. And we began to see while we were surveying older landfills of ash of the calcic Powder River Basin materials, that it seemed like some of the rare earth elements were **mobilizing** or more readily weathered in those materials when we were comparing to landfill materials in Green River Basin.

Green River materials lack calcium and they are **silica and aluminum** rich. So the silica aluminum bond in nature is traditionally very difficult. They are very happy together. It's very expensive to break that bond. In the Powder River Basin, the **calcium** content is high enough that it's really mimicking natural systems, high calcium systems, in nature where things weather more readily. So that was kind of a first guess. Colleagues at National Energy Technology Lab noticed this in 2019. Dr. **Menling Stuckman and Chris Lopano** wrote a paper. We went to that same conference and kind of looked at each other like, hey, we have a similar idea here.

Realizing that, because of the **calcium**, the glass that makes the fly ash is much more susceptible to chemical weathering, or in this case, **acid extraction**. I'm sure there's other chemicals you could use, but it's much easier to extract from.

So there is a paper we all reference, **Taggart et al.** He had done some preliminary testing on a variety of fly ashes nationwide, and he had found the same thing, that although the concentration is lower in Powder River Basin fly ash, the extractability percent is higher because of that calcic nature. So that was a happy coincidence as well.

[00:25:43] **Bridget Scanlon:** Right, right. And so in that Taggart paper, he had ash samples from the **Appalachian coals** and from the **Illinois coals,** and then also the **Powder River Basin**. And so the concentrations, total rare earths, maybe about **500, 550 parts per million in the Appalachian** and **four 80** or something from **Illinois**, and then **300** and something from **Powder River.**

But the **extractability**, the **Appalachian** material is more **silicic** material, and so more difficult to extract. Maybe 3**0% extractability relative to 70% extractability from Powder River** in that paper. And so you mentioned that you've been working some more on these and you have the extractability to be even higher.

[00:26:29] **Davin Bagdonas:** Right, and so that's, important. Those, first tests, it was the same method for each flash, which is a great place to start. You have control. You had around 30% extraction in those silicic, high silicic materials. **Powder River Basin** again, where we have **calcium**, the initial result was around **70%.** In some of the testing to scale up where we're considering how to deal with calcium, it's reactivity with different assets, we're achieving over **80, over 90%**.

And some of the really, really well conducted tests I'm aware of are, over **98%**. So I think it's a lesson for not just the process that has been developed for Powder River Basin, but any extractive process, it's always step by step and you begin to tweak that extraction to the material's specific elemental needs.

So that was, it was a few years to get there, but it is very promising now. It's a good high percentage for the extraction of total rare earths despite it being a relatively low concentration in terms of feedstock.

[00:27:35] **Bridget Scanlon:** And part of the reason, it took me a while to grasp this, the part of the reason it's a, low concentration is that the **rare earths** are at the **margins** of the coal seam when you've got the whole coal that you've burned. But if you were really trying to target for rare earths, if you focused on the **margins**, you might get a much higher concentration eventually.

And so, yeah, that's extremely interesting. But, one of the things, talking to **Nolan Theaker in North Dakota,** they limit their extraction. The bench scale projects suggested maybe 70% extractability or even higher. But because of **uranium** in the coal, they don't want to create a waste stream that is hazardous.

And so they're probably limited to about **50% extraction** to avoid having an overly concentrated waste stream with the radioactive materials like uranium and thorium. Does that factor into your work?

[00:28:31] **Davin Bagdonas:** Yes. And this is very much worth talking about. The **co-production** that can benefit an extraction process can also be very **detrimental**. And uranium, the radionuclides, are expensive to get rid of. A lot of regulation and policy permitting considerations there. In the Powder River basin, **uranium and thorium** concentrations are anonymously very low.

That was also a surprise. Some of the **Green River basin** materials have uranium and thorium in **higher** concentration, but in the Powder River basin we just don't see them in high concentration. And the reason that's strange, Wyoming is also host to the **largest uranium production** in the United States.

So we have the largest coal mines in the Powder River basin, and we also have a large amount of uranium. And they're independent of each other in terms of behaviors, element behaviors in the basin. And that's part of what we're working on as geologists, trying to understand why these coals are so high in some metals and not in uranium thorium. And as a prospecting tool, which sites have the lowest concentrations of uranium and thorium so that we can target those for critical minerals production and not have that burden, not have that excess burden on the process.

[00:29:47] **Bridget Scanlon:** One thing that I really liked about your rare earth elements in coal ash paper was the **techno economic analysis** that you did with it and highlighting the importance of these co products and emphasizing that it is essential to have co products. I mean, I think I was reading the other day, maybe, **Powder River Basin coal** sells for maybe **$15 a ton**, I'm not sure. But then when you export it to other places in the US, that price can go up to **$30 a ton** because of the cost of transporting the coal to the other regions. But can you describe a little bit the techno economic analysis that you did on the coal ash?

[00:30:28] **Davin Bagdonas:** I can, and let me first say, I won't take credit for that chapter of the paper. Those are valued colleagues at Center for Business Economic Analysis, who are much, much better at making those calculations. But the two hurdles are recognized and that paper is, I would say, dated a few years now.

Hopefully we can all work together and come up with a new version of this. But one of the hurdles was **technology**. Technology hadn't advanced far enough along to make calculations on **commercialization for extraction** from rare earth. We're getting closer there. And the other was exactly that, **transportation costs**.

So if we are able to co associate **extraction** facilities close to where these waste streams are produced, we have significant economic advantage. That being said, there is this idea, all these trains leave Wyoming full of coal and they come back empty. They're servicing a fleet of power stations nationwide that are producing fly ash.

And there is some consideration of what does that look like in terms of economic forecasting to bring those materials back to a central facility for processing? But initially I think those findings of co-association are probably more relevant today until a lot more work is done.

[00:31:46] **Bridget Scanlon:** And what percentage of the ash is **fly ash** and what percentage is **bottom ash**? I know most of your work focused on the fly ash because it's finer grained, maybe more uniform. Can you talk about that a little bit?

[00:31:58] **Davin Bagdonas:** Well it's generally an **80 20 cutoff. So majority is fly ash**. The bottom ash is heavier. It does tend to have greater concentrations of rare earth and critical minerals. The slag, the glass. But it is a lesser percentage of the material. That being said, there are some upfront processes being considered to preliminarily crush it or provide us with a more accessible surface area of the material.

We did a lot of studies on that and found it's **growing minerals.** It looks like an igneous system. They're very cool thin sections. As a geologist to look at, we see pyrites and things growing, **feldspars**. So it's a living geologic material we're making. But because of that, it does require, or would require some upfront processing to make it viable.

[00:32:46] **Bridget Scanlon:** Right and you mentioned, and also the folks in North Dakota emphasized the importance of **co-products.** So I mean, I hear about bricks, roof tiles, humic acid for soil amendments, activated carbon, graphite, graphene, all of these different potential products. So I think you have a separate group that's working on that.

Is that correct?

[00:33:10] **Davin Bagdonas:** We do, we have a center here at **School of Energy Resources** focused on carbon utilization, manipulation. That's a lot of engineers over there. Very smart people. One thing we have with Powder River Basin is very high volumes of **coal**. As you stated earlier, we're supplying 40 to, 46% of the US coal stock comes from Powder River Basin.

So the solutions there we seek for co-production, include a lot of high volume carbon materials. There are **soil amendments, building materials**, a lot of high volume carbon materials. Sometimes, often those solutions are considered low value. But we are exploring **high value, high volume carbon** uses for those materials.

In contrast, some of the coals in **Green River Basin** are apparently much better suited. They have much **higher carbon contents** than Powder River Basin, so they're much better suited for advanced carbon materials. Those lower volume, much higher value carbon chain. So we're looking at co-production both locations.

It is an important consideration. I know that the folks up in **North Dakota** are looking at **humic acid,** as you said, and other co-productions. It really is the economic hurdle using the entire material. And the more you can diversify that, I think the better off many of these projects will be.

[00:34:29] **Bridget Scanlon:** Right. And the Department of Energy Program, the **CORE-CM program**, started off focusing almost exclusively on **coal carbon** or coal material and **coal ash** and turning.

Turning waste into resources, which is very valuable. But then they expanded the program halfway through and said we could look at other materials.

And so, you have been looking at some other materials and maybe phase two gets off the ground. We'll have more opportunity to look at these other materials. Can you describe some of these other potential materials in Wyoming?

[00:35:05] **Davin Bagdonas:** Yes. And I agree with you, maybe, hopefully soon, we get CORE CM phase two off the ground for all of us. So **Wyoming** produces, we are a production state and extraction production state. We have **Trona** in abundance. The world's largest producer of Trona. So we've done, at least in CORE-CM, phase one, started to look at sediments co associated with Trona.

Trying to apply some of the methods from coal and those materials. We have **heavy mineral sands**. We have **phosphates**, phosphatic rocks, are the example geologists think of for rare earth occurrences. So we have facilities here that produce **fertilizer** from those rocks. So we're interested in those waste streams.

Again, we are the largest producer for **uranium** in the country. So co-association of other critical minerals with uranium is interesting. We are trying to forward several projects there. We have **mine tailings**. Hard rock deposits for traditional things, **gold, copper**. So we're looking at those materials.

Zeolites, a colleague of mine, **Bob Gregory** did an extensive survey of zeolites in Wyoming a few years ago, and we're utilizing that knowledge to look at co-association of a wide variety of critical minerals there. Waste streams, for all those industries are being considered. **Produced waters**, as you're very familiar with.

So not just the primary geologic material, but waste streams of those industrial processes are being considered as well.

[00:36:25] **Bridget Scanlon:** It always looks pretty bleak at the beginning of a study. You just think, oh my gosh. Like you said earlier, you didn't hold much hope when you started to look at coal ash initially, coming from your igneous background and ore deposits. But its amazing when we get more and more data, how much we learn, and also that it becomes more feasible and we develop approaches maybe you call **coal beneficiation** or, to work with the material and improve and optimize the processing and understand what's controlling where it is occurring. So it blows my mind really. We've come a long way in the past. You guys have been doing it for over a decade, but we've only been doing it for a few years, but we've learned a lot.

[00:37:10] **Davin Bagdonas:** We have. It's exciting and it's also daunting. At one of our annual meetings where we all get together, I think it was presented that, these projects are sort of like a **new Manhattan project**, and then that was quickly dismissed because it's more like, our **moonshot** in a way. Standing up domestic supply chains of critical minerals is a significant task. So there are, as your group and the group here at University of Wyoming in North Dakota, across the country, it's a relief that some of the best minds are working on this. There are a lot of us. These collaborations we have with your group, especially all across the country, are extremely valuable.

Taking lessons learned, successes, failures that each of our groups have experienced through this process. It's hugely beneficial and I think it's going to result in some really fantastic things, a really diverse supply chain. It would be foolish to put all our eggs in one basket in this country with a single source. So this, provides us a pathway that's very diverse. And it's incredible to meet with the engineers, the chemical engineers, the, those advancing the technologies for the extraction and separation. It's pretty amazing what they've done so far.

[00:38:19] **Bridget Scanlon:** And you recently spoke with **Chris Young**, I think at **Element USA** and they're very interested in looking at a variety of feed stocks and trying to get it to the next level. And also working with people that would process the different elements and Nolan Theaker has been talking to rare salts in Nebraska. They will provide the oxides and mixed oxides and then rare salts would separate out some of the different elements and other critical minerals.

So, we not only have to develop the feed stocks, but we also have to advance the processing. That's going to be critical too in the US.

[00:38:57] **Davin Bagdonas:** Yes. And I'm glad you mentioned Elements USA among others. **Public private partnerships,** what we develop with private sector input, is absolutely essential to make this happen. I think that's, I think that's dead on. I lost a thought there, but I was thinking about a, about those broader collaborations that you just touched on.

Each region that, sorry, that's the thought. That each region is going to produce different strengths and different weaknesses. Just the two projects we had at the University of Wyoming, Powder River Basin and Green River Basin, when we conceptualize how to advance technologies in each of those regions? They're very different from each other.

one's going to solve one problem in the supply chain, another will be something completely different. So I think that's important to keep in mind. The upfront side of this too. New ways to just access these materials. It is not just separation, extraction, and those processes.

We traditionally think of a big metal building with pipes doing the work for us, but how we access those materials that are in the ground. We have to advance some things there as well. I know a lot of people are thinking about how to do that.

[00:40:05] **Bridget Scanlon:** Right and understanding in some of your situations in like the Brook mine, that if the rare earths are in near the margins, then maybe the extraction will focus on the margins for that aspect and maybe focus on the coals for **non-thermal purposes** or **activated carbon** or other things.

So we're developing a lot of different products. And then I think you mentioned that as you process them maybe for rare or critical minerals, then they may be **better for other products.** Also what you're left with after that processing, so. And I think Nolan Theaker has seen some of the same things in North Dakota.

The **coal**, after you remove the ash, then it's stronger and better for different purposes.

[00:40:47] **Davin Bagdonas:** Yeah, absolutely. And we have a number of miners we work with who are pretty excited on this. They have not immediately offered, but suggested that they would like to go out and test some of these **new mining techniques.** You know, what does a coal mine look like if it's a **split stream mine**, where you're producing a material for carbon and producing one for critical minerals, and you're also supplying a power station, which is the original purpose of course.

So a lot of the stakeholders are interested as well on how to test some of these ideas.

[00:41:17] **Bridget Scanlon:** All right. Well, thank you so much Davin. I really appreciate your time and I really enjoy collaborating with you. Our guest today is Davin Bagdonas, who is a senior research professional at the University of Wyoming. And if you want to learn more, there will be a script attached to this podcast on the website.

And also highlights and links to papers and reports to provide information on the data. So thanks a lot.

[00:41:43] **Davin Bagdonas:** Thank you Bridget. I look forward to all our future work on this.