Life Cycle Assessment

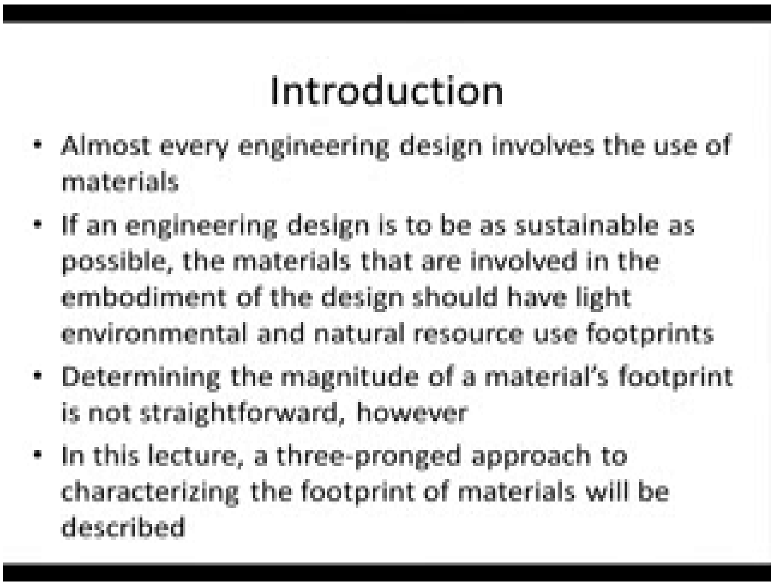
Prof. Brajesh Kumar Dubey
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture – 29
Green Sustainable Materials

Welcome back. So, in the last module, we were looking at say if you have a different chemicals spill, what are the different properties which kind of dictates where the chemical will be. So, those who are essence again those if you remember from this lifecycle impact assessment and all, we were using those information to make those impact assessment. So, now we will move towards little bit in this particular module will do little bit something I would say all though we have talked about, but we may not have dealt in this particular topic in great detail. So, far we have been talking about that we how to measure the sustainability parameter, so that is life cycle analysis is used as a sustainability parameter.

Now we will look at how what are when we say something is a green and sustainable material what does that means, so once the different parameters that we use and then we can come up with something, which is the material which is more greener. Greener means environmental friendly, so that is what we will try to do in this particular module.

(Refer Slide Time: 01:37)



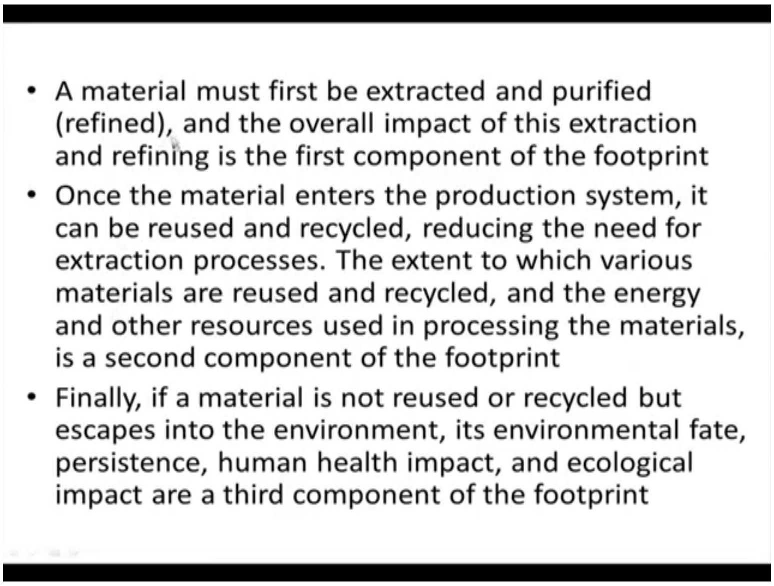
Introduction

- Almost every engineering design involves the use of materials
- If an engineering design is to be as sustainable as possible, the materials that are involved in the embodiment of the design should have light environmental and natural resource use footprints
- Determining the magnitude of a material's footprint is not straightforward, however
- In this lecture, a three-pronged approach to characterizing the footprint of materials will be described

So, let us get it started. So, when we as an engineer, we have to use material. We have whenever we design something the material is needed. And whatever like a material that we use, if it has lower environmental footprint and how will know whether it is lower environmental footprint we have all we already know how to do LCA we have already covered that over last four-five weeks. So, if it has a lower environmental footprint and that of course, will have when I say lower environmental footprint, when it is lower natural resource is used footprint as well and that kind of goes into this concept of circular economy and all that. So, if to make this engineering design sustainable, we should use material, which is as lower environmental footprint as well as of course, natural lower natural resource. So, let use less of that.

So, when we try to do this material footprint it is not very straight forward one part is of course, looking at the LCA part of it. And then we also we have to look at in terms of their abundance. If you remember in that LCA exercise what we are talking about the resource acquisition, mining and all that, so when we talk about the mining it depends on how much of the material is really available with mother earth, then only we will be able to mind. So, we will talk about those kind of stuff which is goes there we will look at some of this three-pronged approach. To look at the footprint of materials in this video as well as the next video, so those two videos will go over this green sustainable material part.

(Refer Slide Time: 03:01)



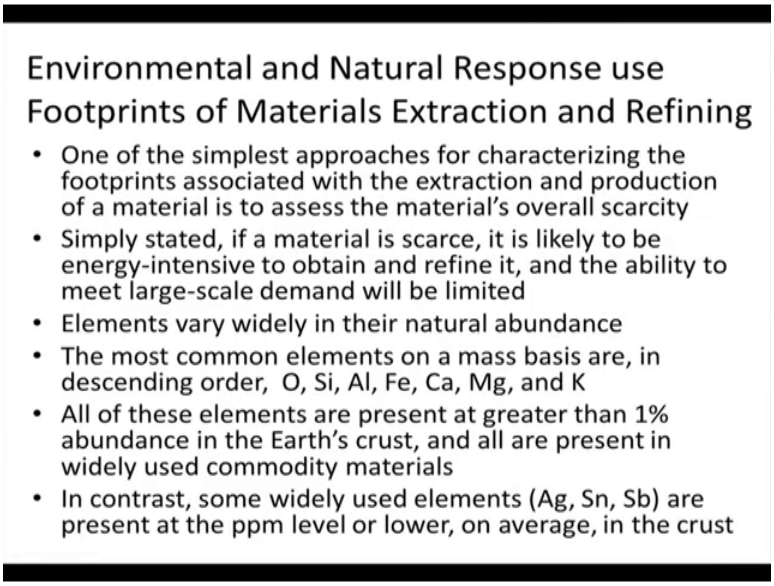
- A material must first be extracted and purified (refined), and the overall impact of this extraction and refining is the first component of the footprint
- Once the material enters the production system, it can be reused and recycled, reducing the need for extraction processes. The extent to which various materials are reused and recycled, and the energy and other resources used in processing the materials, is a second component of the footprint
- Finally, if a material is not reused or recycled but escapes into the environment, its environmental fate, persistence, human health impact, and ecological impact are a third component of the footprint

So, again some of this slides are too boring in terms of too much of a text do not try to read line by line as you are watching this video, but this is again as I said this is for you reading material. This is just for your reading material, and you can read it later on when I give you the PDF of this. So but the bottom line is a material has to be extracted and purified which we talked about that any and we our mining friends do that for us. And that is our first component of the footprint. When we talk about this environmental footprint that is starts from its resource acquisition phase where are the material has to be mined, and it has to be extracted, so that is the first phase.

Then the material will enter the production system. Once it enters the production system it will that can be used, it can be reused, it can be recycled, and then lot of energy and then other resources will be involved, so that is a second component of the footprint. Then later on when it is the product is disposed then we need to look at its environmental fate persistence human health impact which kind of part of it we talked about in the previous module how to look at that that is the third component of the footprint. So, this is the three point strategy.

So, something could be very bad in the mining phase something could be very bad in the mining phase, but they are ok in the second and third phase. So, we have to look at the whole totality. So, what has been happening so far whenever we do this environmental impact kind of environmental impact studies, we do not look at this three parts together, we look them in separate in just by them serves. And later on we realize that it do does very well in this particular area, but does very bad in terms of its mining activity because it has long environmental footprint over there.

(Refer Slide Time: 04:52)



Environmental and Natural Response use Footprints of Materials Extraction and Refining

- One of the simplest approaches for characterizing the footprints associated with the extraction and production of a material is to assess the material's overall scarcity
- Simply stated, if a material is scarce, it is likely to be energy-intensive to obtain and refine it, and the ability to meet large-scale demand will be limited
- Elements vary widely in their natural abundance
- The most common elements on a mass basis are, in descending order, O, Si, Al, Fe, Ca, Mg, and K
- All of these elements are present at greater than 1% abundance in the Earth's crust, and all are present in widely used commodity materials
- In contrast, some widely used elements (Ag, Sn, Sb) are present at the ppm level or lower, on average, in the crust

So, one of the simplest approach in terms of doing that, so we will look at the three part that environmental footprint of the material extraction. So, one of the simplest thing for that to do it is we have to find out whether the material is a scarce. When we say scarce means the material is not available too much, the natural abundance of this material is very less. So, some of the elements are available in a large scale. So, for example, we have oxygen, silica, aluminum, iron, calcium, magnesium, potassium they are available all these elements are present at greater than 1 percent abundance. So, they are they are over there.

But some of these widely used element for example, silver, tin, antimony they up they are available in a very low concentration and that kinds of tells us even you can use your common kind of common sense, it take. When you look at the price of certain of these heavy metal the pricy of the when you something is very very pricy; that means, their abundance is very, very low. So, gold for example, silver is you see silver is much less price much less costly than gold. So, gold is costlier because gold's abundance is much less than silver. So, it is the abundance part. So, in terms of the material extraction or refining some of, so there are environmental footprint associated with that. So, we have to look at that part in terms of its impact. So, there are different elements which has different kind of like a abundance part is present over there and as you can see that this particular table, the mass abundance has been provided to you.

(Refer Slide Time: 06:23)

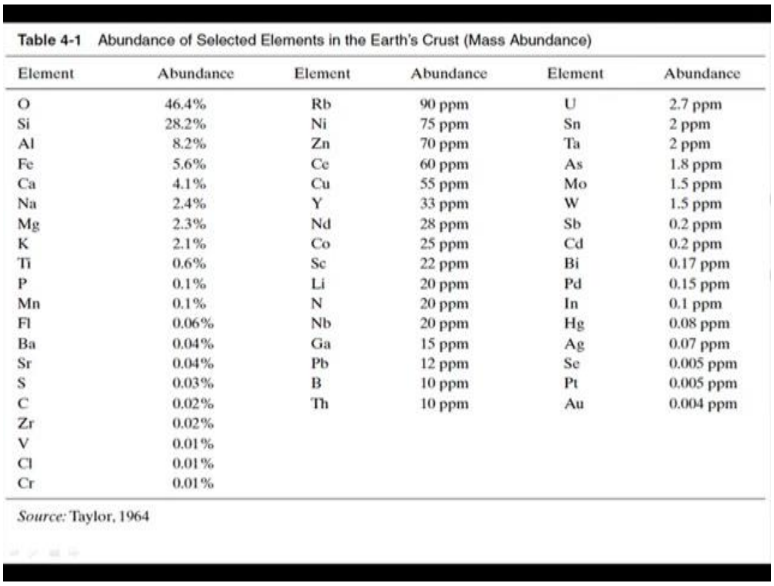


Table 4-1 Abundance of Selected Elements in the Earth's Crust (Mass Abundance)

Element	Abundance	Element	Abundance	Element	Abundance
O	46.4%	Rb	90 ppm	U	2.7 ppm
Si	28.2%	Ni	75 ppm	Sn	2 ppm
Al	8.2%	Zn	70 ppm	Ta	2 ppm
Fe	5.6%	Ce	60 ppm	As	1.8 ppm
Ca	4.1%	Cu	55 ppm	Mo	1.5 ppm
Na	2.4%	Y	33 ppm	W	1.5 ppm
Mg	2.3%	Nd	28 ppm	Sb	0.2 ppm
K	2.1%	Co	25 ppm	Cd	0.2 ppm
Ti	0.6%	Sc	22 ppm	Bi	0.17 ppm
P	0.1%	Li	20 ppm	Pd	0.15 ppm
Mn	0.1%	N	20 ppm	In	0.1 ppm
Fl	0.06%	Nb	20 ppm	Hg	0.08 ppm
Ba	0.04%	Ga	15 ppm	Ag	0.07 ppm
Sr	0.04%	Pb	12 ppm	Se	0.005 ppm
S	0.03%	B	10 ppm	Pt	0.005 ppm
C	0.02%	Th	10 ppm	Au	0.004 ppm
Zr	0.02%				
V	0.01%				
Cl	0.01%				
Cr	0.01%				

Source: Taylor, 1964

So, if you start from the bottom of the table which is over here, which this is a three like a as we go into the like a bottom part of the table, gold, platinum, silver, mercury, indium, palladium, bismuth, cadmium, antimony, molybdenum, arsenic, these are available at a very low concentration. Gold 0.004 ppm as opposed to if you go to iron for example, iron we had 5.6 percent of iron. So, in that case that is why gold is so expensive because there are so less gold is available with mother earth. Had it been some other element which is available at lower concentration probably that would have been more expensive than gold. So, there are there will be things which are, so based on their abundance that what you see.

So, something which is low at low concentration already once we have mining it, mining, mining, mining and at some point of time we will run out of that. So, today if we have to if your mining set 100 kg to get 1 kg of for certain elements, tomorrow you may have to mine 1000 kg to get 1 kg of that element, just because it is the of the proportion is going down in the earth’s crust because they are they are rarely available. So, that is for many of these are also called rare earth metals.

(Refer Slide Time: 07:59)

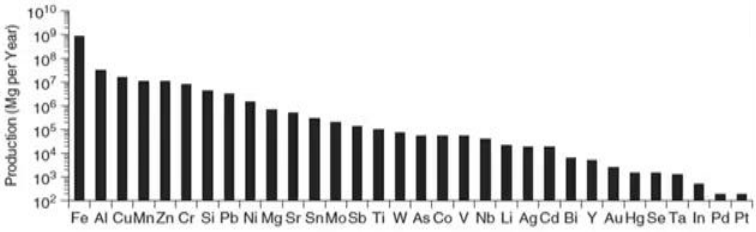
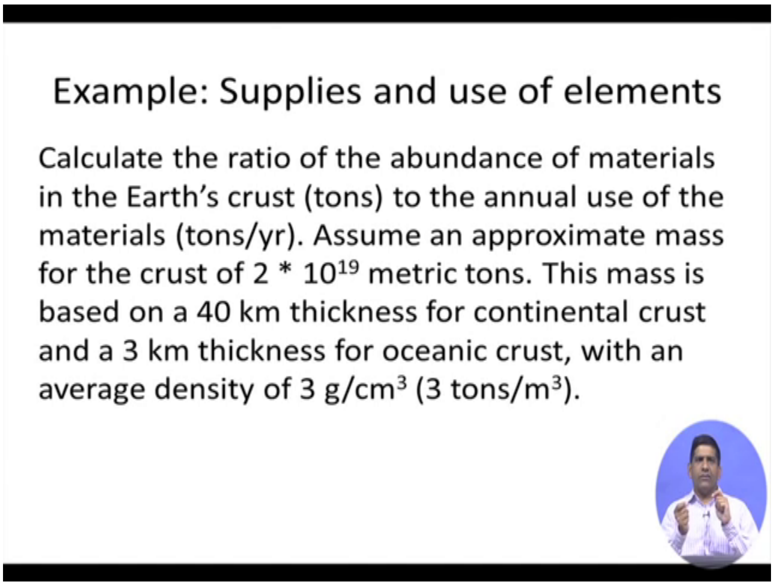


Figure 4-1 Annual production of elements for use in commerce (Reprinted with permission from Gerst and Graedel, 2008. Copyright 2008 American Chemical Society)

So, similarly as you can if you look at the previous table and this graph, you will see a correlation that more the abundance of course, more or more are those metals that we are using iron, aluminum, copper, manganese we use them a lot because they are available in lot as well. But that is not a always the case, but in general you see the annual production right for use in commerce this, so that is in general more the abundant we use more of those element, gold is used less, silver is used more as we can probably see over there then arsenic is over there. So, there was waste on their abundance you see different elements present over there.

(Refer Slide Time: 08:43)

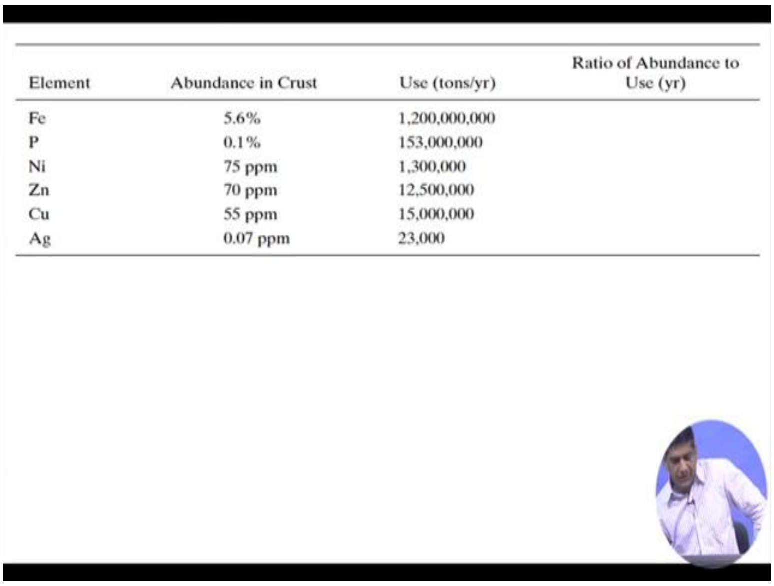


Example: Supplies and use of elements

Calculate the ratio of the abundance of materials in the Earth's crust (tons) to the annual use of the materials (tons/yr). Assume an approximate mass for the crust of $2 * 10^{19}$ metric tons. This mass is based on a 40 km thickness for continental crust and a 3 km thickness for oceanic crust, with an average density of 3 g/cm^3 (3 tons/m^3).

So, what does all these means? So, let us look at an example. So, kind of try to understand what is all these really mean. So, if you look at the abundance of material in the earth's crust, so how much tons of the material that is basically ton of material available with mother earth. And then we try to compare with the annual use of the material like in tons per year how much we are using it up. So, approximately we can take a mass of earth crust is 2 times 10 to the power of 19 metric tons this is the mass based on 40 kilometer thickness of the continental crust and 3 kilometer thickness of the oceanic crust, and with an average density of 3 tons per meter cube. So, if you take the average approximate mass of the crust as 2 times 10 to power of 9 metric ton based on the previous two this table data and this graph data, if you try to do for some of these elements and for some of these elements.

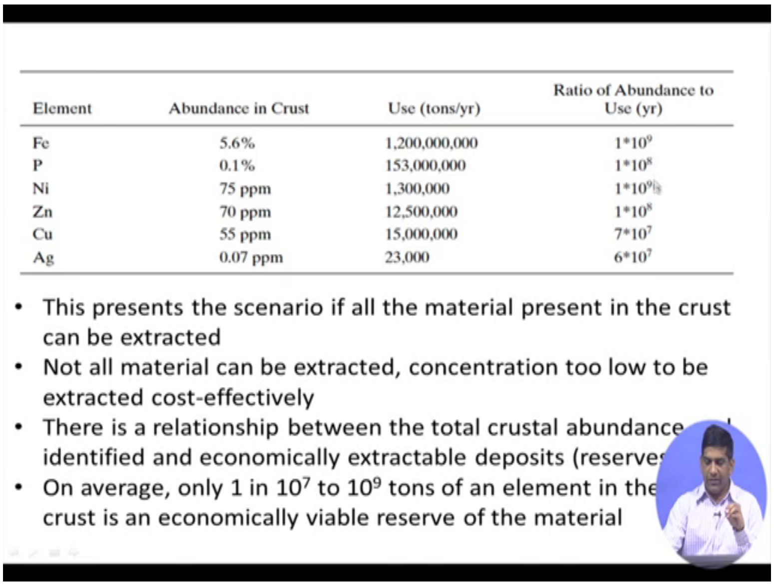
(Refer Slide Time: 09:36)



Element	Abundance in Crust	Use (tons/yr)	Ratio of Abundance to Use (yr)
Fe	5.6%	1,200,000,000	
P	0.1%	153,000,000	
Ni	75 ppm	1,300,000	
Zn	70 ppm	12,500,000	
Cu	55 ppm	15,000,000	
Ag	0.07 ppm	23,000	

If you can see here in terms of it is which one is showing more abundance. As you can see in this particular table, this iron, phosphorus, nickel, zinc, copper and silver for these three there are at different levels, so that is why they have been picked up. So, abundance in crust from that particular first table that we looked at, and then the uses per ton is in the second table.

(Refer Slide Time: 10:16)



Element	Abundance in Crust	Use (tons/yr)	Ratio of Abundance to Use (yr)
Fe	5.6%	1,200,000,000	$1*10^9$
P	0.1%	153,000,000	$1*10^8$
Ni	75 ppm	1,300,000	$1*10^9$
Zn	70 ppm	12,500,000	$1*10^8$
Cu	55 ppm	15,000,000	$7*10^7$
Ag	0.07 ppm	23,000	$6*10^7$

- This presents the scenario if all the material present in the crust can be extracted
- Not all material can be extracted, concentration too low to be extracted cost-effectively
- There is a relationship between the total crustal abundance identified and economically extractable deposits (reserve
- On average, only 1 in 10^7 to 10^9 tons of an element in the crust is an economically viable reserve of the material

So, based on how much we are using, how much it is available, if you do the math, we have around 10 to the power of 9 years of iron left. We have 10 to the power of 8 years of phosphorous more of same, we are on the same for nickel as same as iron zinc and phosphorous as similar copper and gold is at around same like 10 to the power 7 of years. So, that this scenario, stay assuming that whatever is there in the mother earth whatever is present in the mother earth, if we can extract each and every of those material.

So, we have so many years left in terms of the usage of that material. So, all the materials can be extracted which is not always the true, because the concentration becomes too low later on in some of those mining areas. And then they become too costly to extract them so, but there is a relationship between the total crust abundance and economically extractable deposits. So, this is what is the totally extractable deposits like how many years it will go, but there is also a term in terms of the total crust abundance and economically extractable deposits, so that is we call reserves. So, on average only in 1 in 10 to the power 7 into 10 to the power 9 tons of an elements is economically viable reserve of that material. So, that is we although we you see a lot of things it is not that much whatever you see in terms of the years we do not have that many years of all these material.

(Refer Slide Time: 11:46)

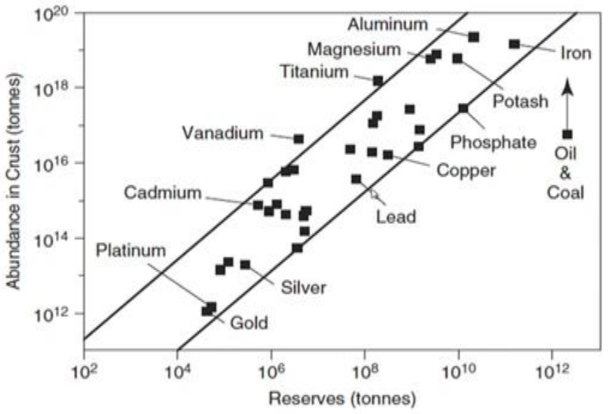


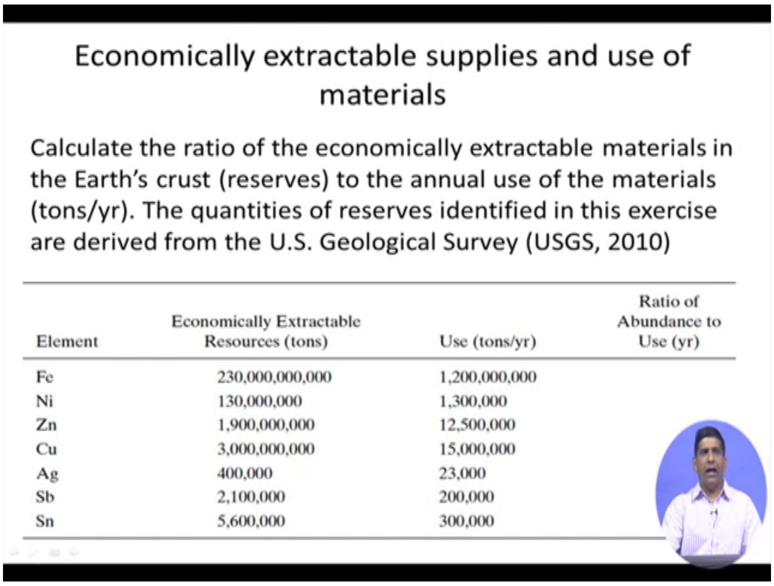
Figure 4-2 Relationship between total crustal abundance and reserves (Kesler, 1994)

And that can be that usually expressed in terms of a graph which has been put together almost two decades ago slightly more than that that is the relationship between the total crust abundance and the reserves. So, as you can see on the x-axis, we have the reserve;

and on the y-axis, we have the abundance in crust. So, how much is really available in terms of different elements we have and out of this what can be extractable, so that is how there. And you see two lines over there and this two lines are based on different technologies which is out there. So, some technologies more efficient we can probably extract more. So, based on the technologies, so this basically give us a range.

So, this with this path is actually a range for us which we can use. So, as you can see for some of these iron and aluminum and other stuff, which we use a lot you see that they have the higher reserves of that something which we were use low we have lower reserves of that and it is very difficult to find out. Oil and coal is also over there which will actually outside of this particular graph, so that is kind of gives you an idea about the total crust abundance as well as the reserves which is present which was put together by (Refer Time: 13:03) in 1994, and we still kind of use that stuff.

(Refer Slide Time: 13:06)



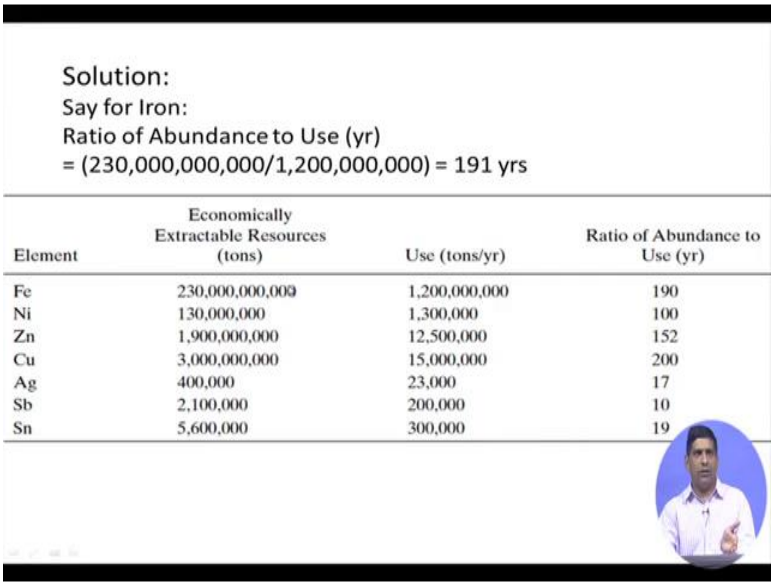
Economically extractable supplies and use of materials

Calculate the ratio of the economically extractable materials in the Earth's crust (reserves) to the annual use of the materials (tons/yr). The quantities of reserves identified in this exercise are derived from the U.S. Geological Survey (USGS, 2010)

Element	Economically Extractable Resources (tons)	Use (tons/yr)	Ratio of Abundance to Use (yr)
Fe	230,000,000,000	1,200,000,000	
Ni	130,000,000	1,300,000	
Zn	1,900,000,000	12,500,000	
Cu	3,000,000,000	15,000,000	
Ag	400,000	23,000	
Sb	2,100,000	200,000	
Sn	5,600,000	300,000	

So, in terms of if you look at ratio of abundance, so you kind of looking at now the same problem, if we start looking at what is the economically extractable resource, and how much use per ton we have for these different elements. So, earlier we were using at the earlier table earlier problem that we looked at we were looking at what if the entire this element present can be extracted. But now we are looking at what is the economically extractable resource not the entire one. And we have putting their usage next to it and then on this third column, if you do the math, so it is very simple math.

(Refer Slide Time: 13:47)



Solution:

Say for Iron:

Ratio of Abundance to Use (yr)

= (230,000,000,000/1,200,000,000) = 191 yrs

Element	Economically Extractable Resources (tons)	Use (tons/yr)	Ratio of Abundance to Use (yr)
Fe	230,000,000,000	1,200,000,000	190
Ni	130,000,000	1,300,000	100
Zn	1,900,000,000	12,500,000	152
Cu	3,000,000,000	15,000,000	200
Ag	400,000	23,000	17
Sb	2,100,000	200,000	10
Sn	5,600,000	300,000	19

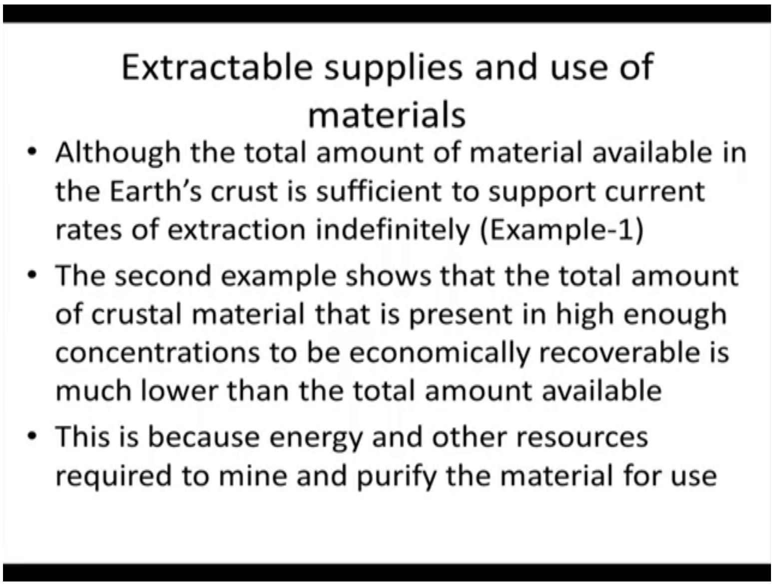
So, as you can see for economically extractable for the first element which is iron over there. And for that I hope you can see it or just make this table little bit smaller. So, you can see that. So, in terms of say for the iron, we have the economically extractable resources 230 million more than million actually 10 to the power of 9 tons that is a extractable resource used per ton years is this much. That means, that we have 190 years of iron left, and this data is based already around 10 years 15 years old. So, we can say around 180 to 185, 175 years of iron, we have left in terms of its abundance. If we keep using iron the way we are using right now, if we do not recycle any of these iron, which is available and if you do not improve our recycling rate, 200 years from now will not have any iron left in with us to use.

So, similarly if you look at the others, silver we have 17 years worth of silver left, copper 200 years, zinc 152 years, nickel 100 years, antimony only 10 years and SN is only 19 which is 10. So, that what is that essentially tells this essentiality tells that we need to start either improving our method improving our process, so that we can make efficient use of these elements that we have. So, that we can increase this years because we whatever if we remember for the very beginning of the class our focus in terms of this sustainability is making use of the resources today and with the plan, so that our future generation can enjoy the same resource.

But as you can see in this table over here that is really not going to happen unless. We change if we keep on working the way we are working in terms of this linear economy where we just make, make, make, things and dump it into the landfills and other places that is not going to happen we have to improve the recycling rate. Many countries Western European countries some of the, I mean North American countries they are working on the recycling rate.

But in the developing countries we are lot of informal recycling is being done, but still we have to improve on our recycling process where we it because its recycling is being done today, but it is not been done in very how it is say it is done in a crude way. So, we there is lot of wastage and there are lots of environmental footprint in those recycling process. So, we need to really look at this recycling in a much better way, to improve this number of years that we can still use these metals. And then of course, we need to look for better technology we are making lots of plastics now and some of these could be iron has been replaced in many of these iron is being replaced by plastic surgery, you can see in your computers laptops, cell phones and other stuffs, so that is why they get lighter as well. So, that was kind of kind of so giving some idea about that.

(Refer Slide Time: 17:04)

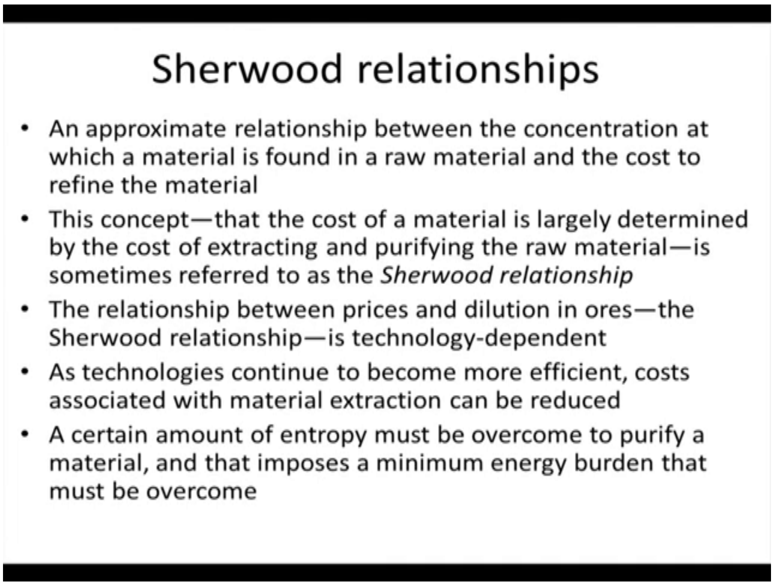


Extractable supplies and use of materials

- Although the total amount of material available in the Earth's crust is sufficient to support current rates of extraction indefinitely (Example-1)
- The second example shows that the total amount of crustal material that is present in high enough concentrations to be economically recoverable is much lower than the total amount available
- This is because energy and other resources required to mine and purify the material for use

So, all though the total amount of material available in earth crust is sufficient to support current rates of extraction in indefinitely as you can see in the example one several number several 10 to the power of 9 years, 10 to the power of 8 years. The second example shows that total amount of actually it is in present in high concentration, which is economically recoverable is much lower. So, this is because the energy and other resources required to mine to purify the material for use.

(Refer Slide Time: 17:32)



Sherwood relationships

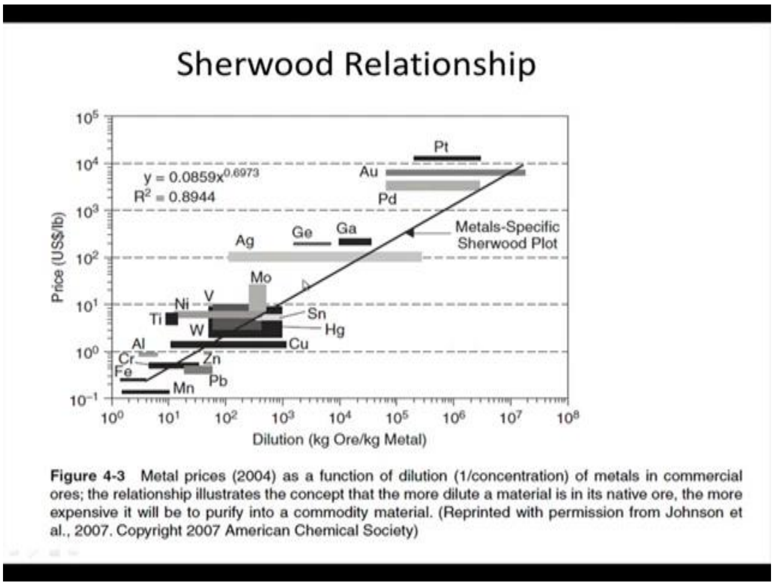
- An approximate relationship between the concentration at which a material is found in a raw material and the cost to refine the material
- This concept—that the cost of a material is largely determined by the cost of extracting and purifying the raw material—is sometimes referred to as the *Sherwood relationship*
- The relationship between prices and dilution in ores—the Sherwood relationship—is technology-dependent
- As technologies continue to become more efficient, costs associated with material extraction can be reduced
- A certain amount of entropy must be overcome to purify a material, and that imposes a minimum energy burden that must be overcome

So, that is where that this concept, the newer, the other concept comes which is known as the Sherwood relationships. The Sherwood relationship that is this concept was what is the cost of the material is largely determined by the cost of extracting and purifying the raw material. So, although it may be there with mother earth, how much cost goes into extracting that material and then to purify and bring it to your table, so that you can go and buy it. So, that is that is the concept of the Sherwood relationship which is kind of goes every step beyond what we have been looked at the example 2. In example 2, we looked at based on the economically recoverable material how much resources we have and so buts that is the. So, there is a relationship and that is in terms of the concentration of the material and the cost to refine the material, so that is our Sherwood relationship, and we will look at that, and that is it is depends on technology.

So, as a technologists, as if you can come up with better technology working with your mining friends, meteorology friends, mechanical friends, again I have been telling you again and again that mother nature does not work in (Refer Time: 18:50), mother nature always works as one entity, we have to look things in a systems perspective. And that is immaterial of whatever you do like whether you are working in whichever field you will work later on in your career, you have to have a tendency to have a systems approach like have the big picture approach of the whole, so that you do not solve problem here, and then create another problem on the other side.

So, if you look at the big picture as a systems approach then we can look at the things in totality. So, save if we can come up with the technology and when we then technology these days cannot be just one discipline whether there is a there will be some automation involved, so computer science has to be there meteorology people has to be there the mining people has to be there mechanical instrumentation, because you are be some instrumentation control. So, lots of things some software. So, it is all the people have to come together. And then if we came up with a better technology and is as the technology becomes more efficient the cost with the material extraction will go down and then the cost can be reduced. So, and then the concept of entropy comes. Remember you heard about entropy you have will take taken a course on chemistry. When you talk about entropy that certain amount of entropy must be overcome to purify the material and that imposes a minimum energy burden that needs to be overcome.

(Refer Slide Time: 20:12)



Sherwood Relationship

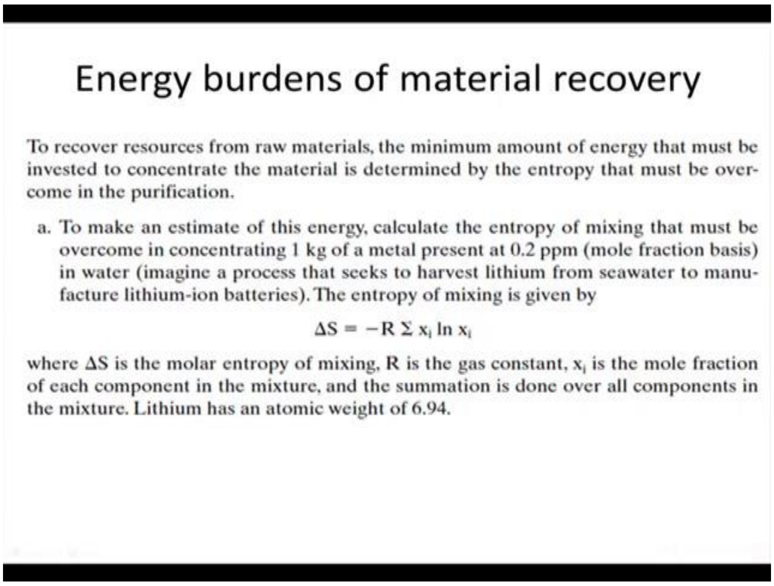
Figure 4-3 Metal prices (2004) as a function of dilution (1/concentration) of metals in commercial ores; the relationship illustrates the concept that the more dilute a material is in its native ore, the more expensive it will be to purify into a commodity material. (Reprinted with permission from Johnson et al., 2007. Copyright 2007 American Chemical Society)

So, if you look at this particular graph, this kind of tells you the metal prices as a function of dilution of the metals in commercial hole. So, this is the dilution the x-axis is dilution that kg of ore per kg of metal how much kg of ore is required to produce 1 kg of metal and then here you see the price. So, a smaller in this particular area we have less number of kgs of ore is required. So, for example, for iron depending again you see a line here because that is depends on different technology. So, for iron you can even start from, so it is from like one point something nearly two here around 3, 4, 5, 6, 7. So, 2 to 7 kg of ore is required to make 1 kg of iron.

And as opposed to if we go to platinum you require almost 10 to the power 6 to the range of 10 to the power of 7, and gold again you have 10 to the power of 5 to 10 to the power of 7 onwards. So, again this line represents different technologies out there, so same thing with the silver different technologies out there. So, based on more and more ores required to produce 1 kg of the metal more will be the price and more it is difficult that is that is what the extractable reserve we have that we talked about earlier. So, that is kind of gives you some idea about how these different kind of material there, in terms of what is available in the mother earth as a total extractable material. And then what is can be economically extracted.

And for any extraction process there is a environmental footprint, there is a water required, there is energy required. So, all those things goes in there, there will be some emissions coming out and then we also have to look at what is economically extractable and then how is the how the price dictates in terms of this Sherwood relationship that you just saw, so that was in the first part.

(Refer Slide Time: 22:18)



Energy burdens of material recovery

To recover resources from raw materials, the minimum amount of energy that must be invested to concentrate the material is determined by the entropy that must be overcome in the purification.

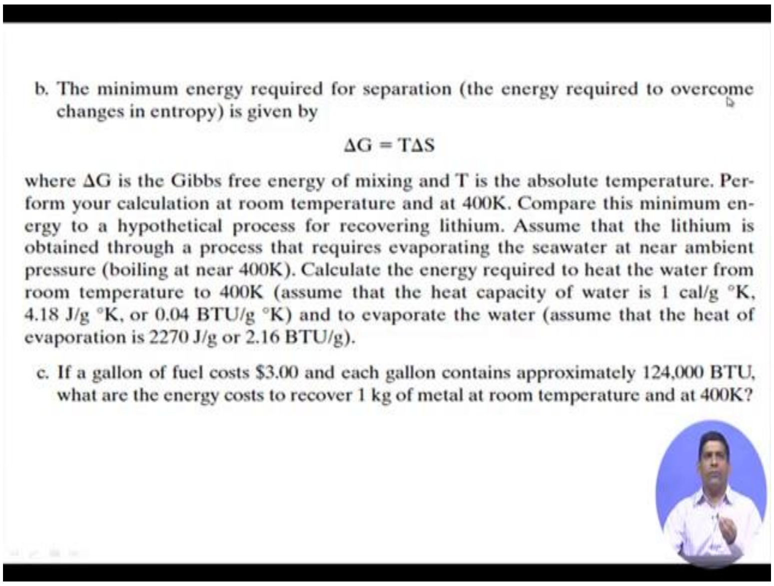
a. To make an estimate of this energy, calculate the entropy of mixing that must be overcome in concentrating 1 kg of a metal present at 0.2 ppm (mole fraction basis) in water (imagine a process that seeks to harvest lithium from seawater to manufacture lithium-ion batteries). The entropy of mixing is given by

$$\Delta S = -R \Sigma x_i \ln x_i$$

where ΔS is the molar entropy of mixing, R is the gas constant, x_i is the mole fraction of each component in the mixture, and the summation is done over all components in the mixture. Lithium has an atomic weight of 6.94.

So, let us kind of look at little bit some of the second part is well in terms of its, so second part is in terms of the material recovery what is the energy burden. Again do not worry too much about this text in the slides it is just for you to read right. Now, I will tell you that just focus on the video part, the audio part, and try to understand what I am trying to explain that it is in terms of the energy burden of the material, we remember that delta s it is we have to look at the estimate of the energy. So, we calculate the entropy, so which entropy has to be overcome is not it? So, if we have 1 kg of metal present at 0.2 ppm mole fraction basis of water. So, we have to harvest this lithium from sea water to make lithium-iron batteries. So, we can calculate delta s which is the entropy with the molar entropy of mixing and then based on your gas constant, mole fraction and atomic weight and all that. So, this is what we have already done as part of some chemistry exercise.

(Refer Slide Time: 23:19)



b. The minimum energy required for separation (the energy required to overcome changes in entropy) is given by

$$\Delta G = T\Delta S$$

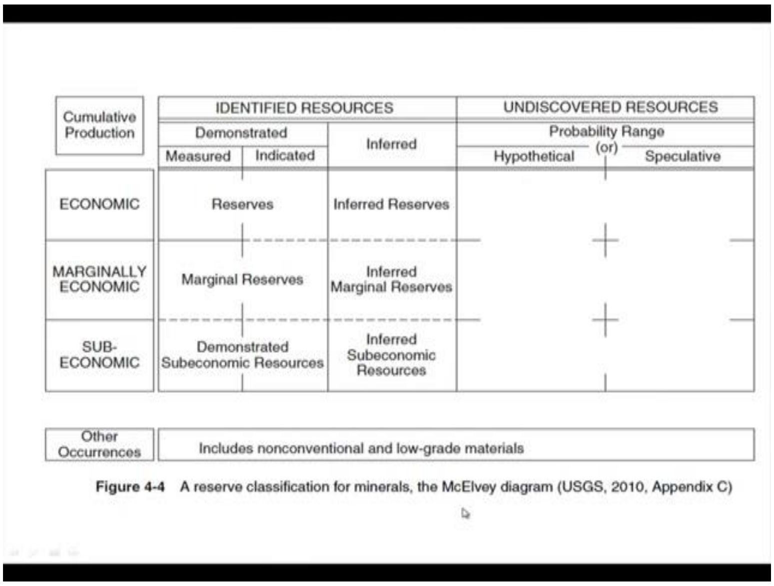
where ΔG is the Gibbs free energy of mixing and T is the absolute temperature. Perform your calculation at room temperature and at 400K. Compare this minimum energy to a hypothetical process for recovering lithium. Assume that the lithium is obtained through a process that requires evaporating the seawater at near ambient pressure (boiling at near 400K). Calculate the energy required to heat the water from room temperature to 400K (assume that the heat capacity of water is 1 cal/g °K, 4.18 J/g °K, or 0.04 BTU/g °K) and to evaporate the water (assume that the heat of evaporation is 2270 J/g or 2.16 BTU/g).

c. If a gallon of fuel costs $3.00 and each gallon contains approximately 124,000 BTU, what are the energy costs to recover 1 kg of metal at room temperature and at 400K?

So, energy burdens of the materials can be calculated and then the minimum energy required is we find we try to get the Gibbs energy. So, that is energy required to overcome the change in entropy that is your delta G, which is the delta G is the Gibbs free energy, T is the temperature and delta S is the entropy, so that you can calculate. And based on that we can find out like what is what are like a with once we know the energy is required we can find out lower the Gibbs free energy more favorable will be the reaction, so based on that we can find out which reaction. Among the different processes out there in terms of elemental recovery elemental refining which one will be more preferable that depends on the Gibbs free energy.

So, that is again whatever I said is already kind of is there on that text that you is there on the slides. So, you can read it and try to understand it again, but it is like do not do not get too much bog down it is not that difficult it is just trying to give you some more detail in terms of these concept. So, if a gallon of fuel like if you have a gallon of fuel costing 3 dollar and each gallon contains around 124,000 BTU which is a energy. What are the energy cost to recover 1 kg of metal at room temperature at 400 Kelvin? So, we can find those kind of information on that particular aspect as well.

(Refer Slide Time: 24:41)

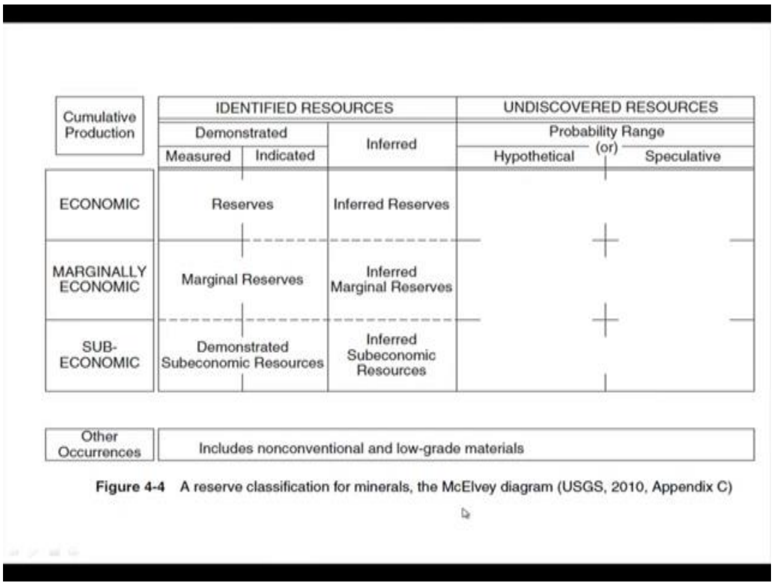


Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		
Other Occurrences	Includes nonconventional and low-grade materials				

Figure 4-4 A reserve classification for minerals, the McElvey diagram (USGS, 2010, Appendix C)

So, that is in terms of the entropy part in terms of how things has to be recovered. Economically recoverable reserve there is a McElvey diagram which is its amount of various elements in the earth crust that is a present in high enough concentration to be recoverable are limited which we saw already. So, the cost of material is not by only physical laws overcoming entropy, but by the technology used technologies are continue into evolve. So, the amount of energy that can be economically recovered today is different may be different than what are to be 10 years from now because the technology may have evolve and we have better technology is we may be able recover some of these metal which we not able to recover it today.

(Refer Slide Time: 25:34)

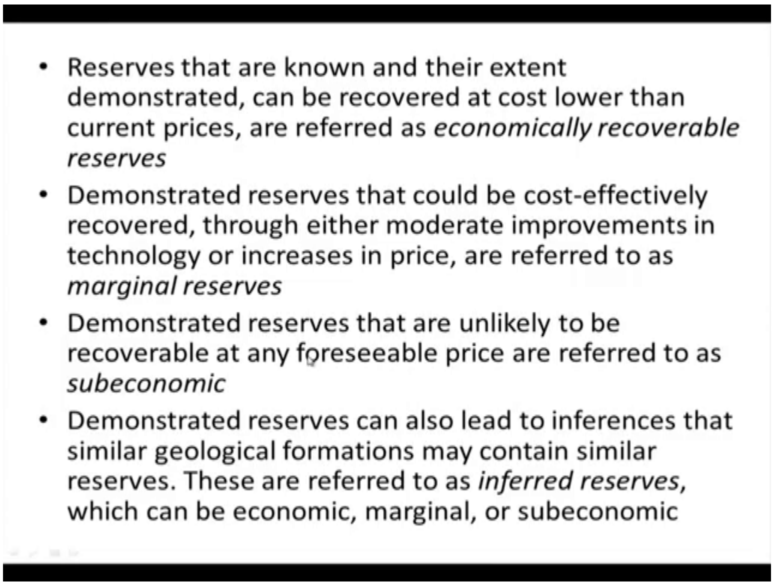


Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		
Other Occurrences	Includes nonconventional and low-grade materials				

Figure 4-4 A reserve classification for minerals, the McElvey diagram (USGS, 2010, Appendix C)

So, and the amount that is economically can be reserved is known as reserve and they are defined in multiple ways. So, if you look at this particular the reserve classification that is the McElvey diagram which is from USGS, 2010 kind of a make a report where they looked at this cumulative production, cumulative production which is like economic, marginally economic, sub economic which and there could be some other occurrences nonconventional a low grade materials. Then what are the identified resource whether demonstrated measured indicated, infrared, undiscovered resources, what is the probability range in terms of hypothetical or speculative. So, they have come up with this diagram, where they looked at ok, this is economic means they will there is reserves available, and there are inferred reserves or we know the reserve is fine. And then marginally, marginal reserves, sub economic means we have demonstrated sub economic resources although it is there, but it is at low concentration, so that may not be a very effective way of doing it.

(Refer Slide Time: 26:32)

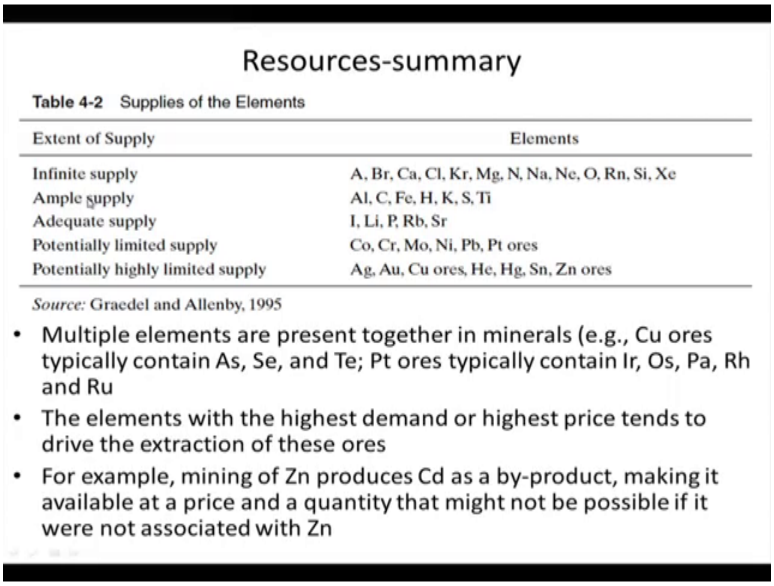


- Reserves that are known and their extent demonstrated, can be recovered at cost lower than current prices, are referred as *economically recoverable reserves*
- Demonstrated reserves that could be cost-effectively recovered, through either moderate improvements in technology or increases in price, are referred to as *marginal reserves*
- Demonstrated reserves that are unlikely to be recoverable at any foreseeable price are referred to as *subeconomic*
- Demonstrated reserves can also lead to inferences that similar geological formations may contain similar reserves. These are referred to as *inferred reserves*, which can be economic, marginal, or subeconomic

So, reserves as we know they are economically recoverable which it can be recovered at cost lower than the current price, so that is your economically recoverable. Reserves that are known and their extent demonstrated. Demonstrated reserves that could be cost effectively recovered through either moderate improvements in technology or increase are known as marginal reserves. So, whatever is the technology today if we improve the technology we can even get this stuff which is there in marginal reserve, although the cost may be little bit high. Demonstrated reserves are unlikely to be recoverable at any foreseeable price are referred to as sub economic; although it is there, but it will be too costly to recover it, so that becomes sub economics. It is not economical to do that and then so the demonstrated reserves that can lead to inferences that similar geological formations may contain similar reserves.

So, that is your inferred reserve and which can be economic marginal sub economic all three. So, because we are not sure that the reserve is there, but it is possible that it since the natural in that natural conditions the mineralogy and other things in this newer side is similar to the previous side where this particular element was very readily found, so those can be used for that.

(Refer Slide Time: 27:55)



Resources-summary

Table 4-2 Supplies of the Elements

Extent of Supply	Elements
Infinite supply	A, Br, Ca, Cl, Kr, Mg, N, Na, Ne, O, Rn, Si, Xe
Ample supply	Al, C, Fe, H, K, S, Ti
Adequate supply	I, Li, P, Rb, Sr
Potentially limited supply	Co, Cr, Mo, Ni, Pb, Pt ores
Potentially highly limited supply	Ag, Au, Cu ores, He, Hg, Sn, Zn ores

Source: Graedel and Allenby, 1995

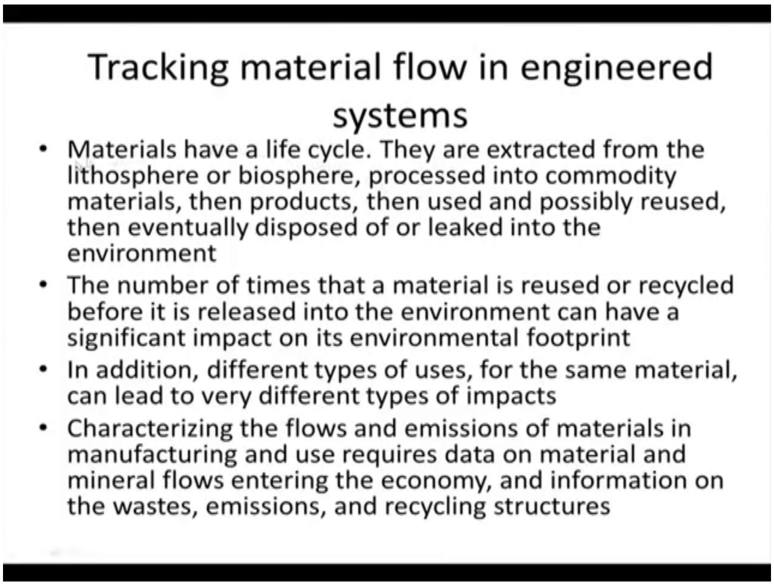
- Multiple elements are present together in minerals (e.g., Cu ores typically contain As, Se, and Te; Pt ores typically contain Ir, Os, Pa, Rh and Ru
- The elements with the highest demand or highest price tends to drive the extraction of these ores
- For example, mining of Zn produces Cd as a by-product, making it available at a price and a quantity that might not be possible if it were not associated with Zn

Some elements in terms of the supply we have based on there is again when we say infinite supply it is not really infinite, but in since for several years it is available. There are some for ample supplies some are potentially limited supply will look at the bottom one, which is the potentially high limited supply. Silver, gold, copper, ores, mercury, tin, zinc, ore, so many of these we use is not it, many of you use for many of the our different usage we have especially for country like India where gold is so much of high demand in for marriages time, and other purposes people love to have buy gold. But the gold we have a limited supply and then we have some we have potentially like highly limited supply then we have potentially limited supply with some other elements and then we have adequate ample and infinite supply.

So, multiple elements are present together in minerals, for example, copper, ores typically contain arsenic, selenium and other things as well. Platinum most typically contains uranium, OS, these rare earth metals. The elements with the highest demand or highest price tends to drive the extraction of this ores. So, if you have a copper ore which contain arsenic, selenium and Te. If the copper is more pricy we you your focus will be on copper the others may get collected may if it becomes as a byproduct fine; if it is not it may just get as part of the mining over the burden. The problem with that is if arsenic goes into the mining over burden not extracted, arsenic will have a leaching issue and those.

So, for example, mining of zinc produces cadmium. So, there is another example here that in terms of the economics when you produce zinc, cadmium is produced as a byproduct. So, although you have not really making any extra effort to get cadmium, since cadmium is available as a byproduct of zinc production, cadmium becomes cheaper because there is no extra effort to recover cadmium, you get it as a buy one get one free that he say in many of this the supermarket sale these days. So, when you go for zinc you get cadmium as well. So, that you can you can have a cheaper price for cadmium because you did not had to pay you did not had to make. So, much of an extra effort, but that is not always the case, but that is if for other elements.

(Refer Slide Time: 30:21)



Tracking material flow in engineered systems

- Materials have a life cycle. They are extracted from the lithosphere or biosphere, processed into commodity materials, then products, then used and possibly reused, then eventually disposed of or leaked into the environment
- The number of times that a material is reused or recycled before it is released into the environment can have a significant impact on its environmental footprint
- In addition, different types of uses, for the same material, can lead to very different types of impacts
- Characterizing the flows and emissions of materials in manufacturing and use requires data on material and mineral flows entering the economy, and information on the wastes, emissions, and recycling structures

So, materials they have a lifecycle, and there are extracted we talked about that material can be reused and recycled. There is the different types of uses the same material, more and more we can recycle reuse we can have a significant impact on this environmental footprint we can reduce this environmental footprint, different types of uses of the same material can have different types of impacts as well. So, we have to look at this flow of emissions of material manufacturing use.

So, in the next module, we will try to look at some of this how to track this materials in the engineer system. So, far we have talked about it terms of its abundance; first of all in the in terms of the abundance how much it is out there what is economically reserved what is non economical whether it is there, but may not be available and then some of these which comes as a comes in a together. So, we looked at all these different aspects in terms of the reserve. Now, once the material has been extracted, how it flows into the engineer system that would be the focus of the next module that will take up after this.

So, thank you and hope that you are enjoying this course, do keep us posted for any questions or anything you have through the discussion forum and we will be very happy to answer you, answer your questions.

Thank you.